Proceedings

NADP Fall Meeting and Scientific Symposium

Monitoring for a Sustainable Future

November 14-18, 2022

Knoxville, TN

Version: 11-11-2022

National Atmospheric Deposition Program

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MEETING INFORMATION

LOCATIONS

November 14-18, 2022 - **Fall Meeting and Scientific Symposium** will be held at the **UT Conference Center**, the address is 600 Henley Street, Knoxville, TN.

Acknowledgements

The NADP Program Office would like to thank the following people for their support of and contributions to the 2022 Fall Meeting and Scientific Symposium:

Dr. Linda Geiser, Scientific Symposium Chair
Dr. Elena Craft, Environmental Defense Fund, Keynote Speaker
NADP Executive Committee

In addition, we thank everyone who submitted abstracts and 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.

Message from the NADP Scientific Symposium Chair

As we emerge from the COVID-19 pandemic and the challenges it has brought to the National Atmospheric Deposition Program and community, there is much for which we can be thankful. The Program Office, site operators, and Wisconsin State Laboratory of Hygiene continue to keep the networks operating smoothly and to deliver outstanding service. Now in its fifth decade, the Program continues to provide the highest quality data to advance the science of atmospheric chemistry and deposition, track trends in atmospheric deposition, respond to emerging environmental issues, and support decision makers in their efforts to protect human and ecosystem health. Every member of the NADP community, from site operator to committee member to data user, contributes to the success and growth of NADP and your commitment is very much appreciated.

As we look to the future, larger environmental crises are already unfolding, acutely affecting tens of millions of people in 2022, and poised to leave no one unaffected. The livability of our planet for current and future generations will be disproportionately affected by our collective actions within the next few years.

What to do and how can the NADP help?

Prioritizing sustainability by choosing actions that maintain or improve resource conditions, and are thus sustainable into the future, provides an overarching strategy for addressing the climate crisis; the pollution of air, water, and soil; the loss of biodiversity, and for equitably meeting the resource needs of unprecedented human populations. Prioritizing sustainability as an overarching strategy will also help the NADP network continue to evolve and contribute to a livable future. For NADP, this means choosing actions that:

- Track depositional substances relevant to informed decision-making;
- Serve the country equitably, including where people live, work, and raise their families;
- Increase inclusivity and participation in monitoring and data use;
- Keep costs affordable; reduce waste of dollars and of material resources and;
- Maintain or improve data quality and accessibility.

Thus, expanding the NADP National Trends Network, mercury, and ammonia networks, particularly to urban areas, will be Program priorities in 2023. Recognizing the impact of inflation and thinning budgets for monitoring among participating agencies, the Program will continue its commitment to financial responsibility by adopting efficiencies and improvements to keep costs affordable to participants. Opportunities for collaboration among NADP and other monitoring programs to enhance network sustainability will be explored. Additionally, NADP will pursue opportunities to venture into new types of measurements, expanding on current monitoring infrastructure and the capabilities of the Wisconsin State Laboratory of Hygiene.

On behalf of the Program, I enthusiastically look forward to your participation in the 2022 NADP Fall Meeting and Scientific Symposium.

Linda H. Geiser, USDA Forest Service

Vice-Chair of the Executive Committee

Agenda

Monitoring for a Sustainable Future

Note all times are in EST

Technical and Science Committee Meetings

Monday, November 14, 2022

8:30 AM – 12:00 PM	Total Deposition (TDep) Meeting Room 406
9:30 AM – 12:30 PM	Mercury in the Environment and Links to Deposition (MELD) Meeting Room 400A
1:30 PM – 5:00 PM	Critical Loads of Atmospheric Deposition (CLAD) Meeting Room 400A
3:10 PM – 3:30 PM	CLAD Break
2:00 PM – 5:30 PM	Network Operations Subcommittee (NOS) Meeting Room 406
3:55 PM – 4:10 PM	NOS Break

Tuesday, November 15, 2022

8:30 AM – 10:30 AM	Aeroallergen Science Monitoring Committee (AMSC) Meeting Room 406
9:00 AM – 10:00 AM	CLAD Critical Load Uncertainty Breakout Group Room 400A
10:00 AM – 11:00 AM	CLAD Ozone Critical Loads Breakout Group Room 400A
10:30 AM – 10:45 AM	Break
11:00 AM – 12:00 PM	CLAD Critical Load Hub: Part 1 Breakout Group Room 400A
10:45 AM – 12:00 PM	Education and Outreach Subcommittee (EOS) Meeting Room 406
1:30 PM – 3:00 PM	Joint Subcommittees Meeting Room 413 A/B/C
3:00 PM – 3:30 PM	Break

3:30 PM – 6:45 PM	Executive Meeting
4:00 PM – 5:00 PM	CLAD Critical Load Hub: Part 2 Breakout Group Room 400A

Scientific Symposium

Wednesday, November 16, 2022

8:00 AM – 8:15 AM	Welcome and logistics; Room 413 A/B/C
	Opening of Symposium, Linda Geiser, USDA Forest Service Welcome, Jamie Schauer, Director Wisconsin State Laboratory of Hygiene
8:15 AM – 8:45 AM	Annual State of the NADP Address, David Gay, Coordinator
8:45 AM – 9:40 AM	Keynote Address: Science in the Service of Community, Elena Craft, Environmental Defense Fund
9:40 AM – 10:00 AM	Break

Session 1: Diversity, equitability, and inclusion in air quality monitoring; serving urban and rural communities; promoting public awareness and access to information and decision-making

Co-Chairs: Sarah Jovan (USDA Forest Service) and Linda Geiser (USDA Forest Service)

10:00 AM – 10:20 AM	S. Douglas Kaylor (U.S. EPA) - *Past, present, and future of adversity and public welfare in the National Ambient Air Quality Standards*
10:20 AM – 10:40 AM (Virtual)	Sarah Jovan (USDA Forest Service) - *Heavy metals in moss guide environmental justice investigation: A case study using community science in Seattle, WA, USA*
10:40 AM – 11:00 AM	Susan Sachs (NPS-GSMNP) - *Monitoring Air Quality Impacts with Students*
11:00 AM – 11:20 AM	Deborah Sauder (University of Maryland Eastern Shore) - *First Measurement of Ambient Air Quality on the Rural Lower Eastern Shore of Maryland*

Session 2: Deposition monitoring for science-based management of air pollution in a changing world; applications of critical loads to sustain biodiversity and ecosystem services

Chairs: Nifer Wilkening (U.S. Fish and Wildlife Service) and Jeremy Ash (USDA Forest Service)

11:20 PM – 11:40 AM	Linda Pardo (USDA Forest Service) - *Re-assessing risk from nitrogen and sulfur deposition to forest ecosystems across the continental US*

11:40 AM – 12:00 PM (Virtual)	Hazel Cathcart (ECCC) - *Mapping critical loads of acidic deposition and exceedances for soils in Canada*
12:00 PM – 1:30 PM	Lunch Break (on your own)

Session 2: Deposition monitoring for science-based management of air pollution in a changing world; applications of critical loads to sustain biodiversity and ecosystem services (Continued)

1:30 PM – 1:50 PM	Meredith G. Lassiter (U.S. EPA) - *Shifts in the Composition of Nitrogen Deposition in the Conterminous United States are Discernable in Stream Chemistry Response*
1:50 PM – 2:10 PM	Christopher Clark (U.S. EPA) - *Updates of Critical Load Research from the EPA, NPS, and USFS*
2:10 PM – 2:30 PM	Michael Bell (National Park Service) - *Standardized application of critical loads and critical load exceedances within Class I areas helps guide decision-making and future research*
2:30 PM – 2:50 PM	Ruth Heindel (Kenyon College) - *Particulate Matter Deposition Along an Urban-Agricultural Gradient in Central Ohio, USA*
2:50 PM – 3:10 PM	Break

Session 3: Deposition monitoring to assess and address chemical contamination of the environment

Chair: Kristi Morris (NPS)

3:10 PM – 3:30 PM	Jana Compton (U.S. EPA) - *Stream nitrogen response to Clean Air Act policies in the US: An application of National Nutrient Inventory and the National Rivers and Streams Assessment*
3:30 PM – 3:50 PM	Maria Antonia Villegas Botero (Syracuse University) - *Patterns of Change in an Adirondack Ecosystem: Monitoring changes in wet deposition, water chemistry, and watershed and lake fluxes as evidence of ecosystem recovery from acid deposition*
3:50 PM – 4:10 PM (Virtual)	Nagdalina Baez (Syracuse University) - *Concentrations of selenium and other trace metals in precipitation at the Hubbard Brook Experimental Forest, NH*
4:10 PM – 4:30 PM	Rodolfo Sosa Echeverría (Universidad Nacional Autónoma de México) - *The experience and perspectives of collaboration in Mexico with the National Atmospheric Deposition Program*

4:30 PM – 4:50 PM (Virtual)	Umesh Chandra Kulshrestha (Jawaharlal Nehru University) - *Wet Deposition of Major Ions at Urban, Rural and Himalayan Sites in India*
4:50 PM – 5:10 PM (Virtual)	Ankita Katoch (Jawaharlal Nehru University) - *Wet Deposition of Non-Essential Heavy Metals and Reactive Nitrogen Species during Monsoon at Delhi (India)*

6:30 PM – 8:30 PM **Poster Session** – Atrium
Chair: Linda Geiser (USDA Forest Service)

Thursday November 17, 2022

Session 4: Tracking emerging pollutants and climate change indicators

Chair: John Offenberg (U.S. EPA)

8:00 AM – 8:20 AM	Christopher Lawrence (University of Albany) - *The Emerging Role of Organic Carbon in Atmospheric Chemistry at Whiteface Mountain*
8:20 AM – 8:40 AM	John Offenberg (U.S. EPA) - *Initial evaluation of cloud water content of per- and polyfluorinated compounds in archived samples from Whiteface Mountain, NY.*
8:40 AM – 9:00 AM	Piyaporn Sricharoenvech (University of Wisconsin - Madison) - *Development and Application of Methods for the Measurement of Black Carbon (BC) Wet Deposition for NADP*
9:00 AM – 9:20 AM	Martin Shafer (University of Wisconsin-Madison/WSLH) - *Atmospheric Processing & Deposition of PFAS: A Synopsis of Recent Studies*

Session 5: Links between reductions in deposition and climate resilience

Chair: Jennie McLaren (The University of Texas at El Paso)

9:20 AM – 9:40 AM	Todd McDonnell (E & S Environmental Chemistry) - *Climate change and air pollution effects on soil and vegetation of the United States*
9:40 AM – 10:00 AM	Shaun Watmough (Ontario Ministry of the Environment and Parks) - *The response of vascular plants in xeric Boreal forests to atmospheric nitrogen deposition depends on precipitation*

10:00 AM – 10:20 AM Break

Session 5: Links between reductions in deposition and climate resilience (continued)

10:20 AM – 10:40 AM	Jennifer Holguin (The University of Texas at El Paso) - The interactive effects of N deposition and drought on plant communities and biogeochemistry in three southwestern Chihuahuan Desert grasslands within Carlsbad Caverns National Park, NM, US
10:40 AM – 11:00 AM	Patrick Levasseur (Trent University) - *The impact of severe pollution from smelter emissions on carbon and metal accumulation in peatlands*

Session 7: Technological advances in deposition measurements and monitoring

Chair: David Gay (WSLH NADP PO)

11:00 AM – 11:20 AM (Virtual)	Wendell Walters (Brown University) - *Nitrate chemistry in the Northeast US: Nitrogen isotope seasonality tracks nitrate formation chemistry*
11:20 AM – 11:40 AM	Colleen Baublitz (U.S. EPA) *Developing a framework for inferential modeling of dry deposition fluxes across the Ammonia Monitoring Network (AMoN)*
11:40 AM – 12:00 PM	Bruce Hicks (Metcorps/University of Tennessee) - *Dry Deposition in NADP: On Rekindling the Flame*
12:00 PM – 1:30 PM	Lunch Break (on your own)

Session 6: Mercury deposition and effects

Chair: Colleen Flanagan-Pritz (NPS)

1:30 PM – 1:50 PM	Lin Wu (SUNY-ESF) - *Improving Simulation of Redox Chemistry and Gas Particle Partitioning of Atmospheric Mercury*
1:50 PM – 2:10 PM (Virtual)	Peter Weiss-Penzias (University of California, Santa Cruz) - *Investigating gaseous oxidized mercury and particulate bound mercury washout in precipitation events*
2:10 PM – 2:30 PM (Virtual)	Guey-Rong Sheu (National Central University) - *Atmospheric mercury deposition to a suburban site in Northern Taiwan*
2:30 PM – 2:50 PM (Virtual)	Connor I. Olson (Syracuse University) - *Changes in Organic Soil Mercury Concentrations Over 20 years at the Hubbard Brook Experimental Forest, New Hampshire*
2:50 PM – 3:10 PM	Collin Eagles-Smith (USGS) - *Linking patterns of atmospheric mercury deposition with bioaccumulation in aquatic ecosystems at a national scale*
3:10 PM – 3:30 PM	Break

Session 8: Advances in atmospheric chemistry and deposition modeling and critical loads

Chair: Colleen Baublitz (U.S. EPA) and Ryan McCammon (BLM)

3:30 PM – 3:50 PM	Nathan R. Pavlovic (Sonoma Technology) - *Empirical Critical Levels of Ozone for U.S. Tree Species and their Uncertainties with Machine Learning*
3:50 PM – 4:10 PM	Kiran Alapaty (U.S. EPA) - *Development and Evaluation of an Advanced Model for Ozone and Aerosol Deposition*
4:10 PM – 4:30 PM	Bret Schichtel (NPS) - *Assessing the Impact of Agricultural Emissions on U.S. National Park Air Quality*
4:30 PM – 4:50 PM (Virtual)	Patrick Campbell (George Mason University /NOAA) - *Pronounced increases in nitrogen emissions and deposition due to the historic 2020 wildfires in the western U.S.*
4:50 PM – 5:10 PM	Jeff Collett (Colorado State University) - *Tracking the Fate of Ammonia During Transport from Urban and Agricultural Source Regions to Rocky Mountain National Park*
5:10 PM – 5:30 PM	Jesse Bash (U.S. EPA) - *Evaluation and optimization of the Surface Tiled Aerosol and Gaseous Exchange (STAGE) resistance model with long term ozone fluxes at multiple sites*
5:30 PM	Symposium Closing Remarks

Keynote Address

Dr. Elena Craft

Science in the Service of Community

Environmental Defense Fund

Wednesday November 16, 2022 8:45 AM

Dr. Elena Craft is Associate Vice President of Climate and Health at Environmental Defense Fund, one of the world's leading environmental organizations. Based in Texas, Dr. Craft has played a central role in bringing together multiple agencies to expand monitoring capabilities and streamline how cities respond to hazardous air pollution and climate-fueled weather disasters, with particular emphasis on identifying vulnerable communities closest to the facilities that most threaten public health and safety. She has helped public officials to identify toxicological exposures from large releases of air pollution, including during climate-fueled disasters, like hurricanes. Her work uncovered a massive leak of cancer-causing benzene in a Houston neighborhood during Hurricane Harvey in 2017. Since then, city, county, and state agencies have purchased additional mobile monitoring instruments to provide rapid and precise information on public health risks for emergency responders and people living near oil refineries, chemical plants, and other potential sources of toxic contamination. She also helped a historically Black neighborhood along the Houston Ship Channel to purchase and install the largest community-owned and -managed network of air quality monitors in the state of Texas.

Dr. Craft serves as an adjunct assistant professor at the University of Texas Health Sciences Center and Texas A&M University, and as a Kinder fellow at Rice University. Through those connections, she has pushed forward research efforts to protect public health, including a leading role in the establishment of the Texas Flood Registry – the first registry after catastrophic flooding – to understand the Hurricane Harvey's toll on people's physical and mental health. Dr. Craft has testified extensively in local, state, and national forums, including testifying three times at Congressional House hearings on national air pollution policy. Dr. Craft holds a B.S. degree in biology from the University of North Carolina-Chapel Hill, a M.S. degree in toxicology from North Carolina State University, and a Ph.D. from Duke University.

2022 NADP Site Operator Awards

35 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
KS07	Dan Mosier	Farlington Fish Hatchery	US Geological Survey	NTN	1987
FL41	April Ammeson	Verna Well Field	US Geological Survey	NTN	1987

30 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
AK03	Andrea Blakesley	Denali National Park	National Park Service	NTN	1992
NY67	Tom Butler	Ithaca	National Oceanic and Atmospheric Administration	NTN/AMoN AIRMoN	1992
MI99	David Toczydlowski	Chassell	US Forest Service	NTN	1991

25 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
MN08	Mary Jo Flack	Hovland	National Oceanic and Atmospheric Administration	NTN	1997
PA42	Kevin Horner	Leading Ridge	Pennsylvania State University-State Agricultural Experiment Station-	NTN	1997

20 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
KY10	Johnathan Jernigan	Mammoth Cave National Park-Houchin Meadow	National Park Service	NTN/MDN	2002
MT97	Tanya Neidhardt	Lost Trail Pass	US Forest Service	NTN	2002
SD04	Marc Ohms	Wind Cave National Park-Elk Mountain	National Park Service	NTN	2002
WI36	Therese Hubacher	Trout Lake	Wisconsin Department of Natural Resources	NTN	2002

15 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
CO13	Derek Day	Fort Collins	Wood-Environmental Protection Agency	AMoN	2007
ID11	Barry Caldwell	Reynolds Creek	US Geological Survey	NTN	2007
KY03	Belinda Warden	Mackville	US Geological Survey / Wood-Environmental Protection Agency	NTN/AMoN	2007
SC06	Herman Keller	Santee National Wildlife Refuge	US Geological Survey	NTN	2007
VI01	Devon Tyson	Virgin Islands National Park-Lind Point	National Park Service	NTN	2007
WI10	Joe Cebe	Potawatomi	Forest County Potawatomi Community	MDN/NTN /MLN	2007
WV05	Heidi Lindsay	Cedar Creek State Park	Wood-Environmental Protection Agency	NTN/AMoN	2007
WY08	John Klaptosky	Yellowstone National Park – Tower Falls	National Park Service	NTN/MDN	2007

10 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
IL46	Adam Beck	Alhambra	Wood-U.S. Environmental Protection Agency	NTN and AMoN	2012
IN20	Karey Davis	Roush Lake	U.S. Geological Survey / Wood-U.S. Environmental Protection Agency	NTN and AMoN	2012

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
MN23	Meg Nygren	Camp Ripley	U.S. Geological Survey/Minnesota Pollution Control Agency	MDN and NTN	2012
NH02	Brenda Minicucci	Hubbard Brook	Wood-U.S. Environmental Protection Agency	AMON	2012
NY28	Erik Cortright	Piseco Lake	New York State Energy Research & Development Authority	NTN	2012
NY52	Dr. Steven Skubis	Bennett Bridge	Wood-U.S. Environmental Protection Agency	NTN	2012
NY94	Ken Eckhardt	Nick's Lake	New York State Energy Research & Development Authority / Wood-U.S. Environmental Protection Agency	NTN and AMoN	2012
NY98	Paul Casson	Whiteface Mountain	U.S. Geological Survey / Wood-U.S. Environmental Protection Agency	NTN and AMoN	2012
OK00	Robert Kildow	Salt Plains National Wildlife Refuge	U.S. Geological Survey	NTN	2012
WV18	Chris Cassidy	Parsons	U.S. Forest Service / Wood-U.S. Environmental Protection Agency	NTN and AMoN	2012

5 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
CO06	Jack McDonnell	CAMP	City of Denver	NTN	2017
CO10	Steve Jennison	Gothic	Wood-U.S. Environmental Protection Agency	NTN and AMoN	2017
CO88	Jim Bromberg	Rocky Mountain National Park - Longs Peak	National Park Service	AMON	2017
GA41	Samuel Wright	Georgia Station	University of Georgia / Wood-U.S. Environmental Protection Agency	NTN and AMoN	2017
ID03	Todd Stefanic	Craters of the Moon National Monument	National Park Service	NTN and AMoN	2017
IL11	Michael Atkinson	Bondville	Wood-U.S. Environmental Protection Agency	NTN and AMoN	2017
MS12	Michael Archer	Grand Bay NERR	National Oceanic and Atmospheric Administration	MDN and NTN	2017

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
NC34	Lane Hartley	Piedmont Research Station	North Carolina State University	NTN	2017
NV05	Jonathan Reynolds	Great Basin National Park-Lehman Caves	National Park Service	NTN	2017
OH16	Rae Grant	Northeast Ohio Regional Sewer District (NEORSD)	Northeast Ohio Regional Sewer District (NEORSD)	MDN	2017
OH32	David Heithaus	Kenyon College	Kenyon College	AMON	2017
OH49	Elaine Stottsberry	Caldwell	U.S. Geological Survey	NTN	2017
OK31	Andrew McCollum	Copan	Oklahoma Department of Environmental Quality	MDN	2017
SK28	Chelsea Hofer	Flat Valley	Environment and Climate Change Canada	AMON	2017
UT09	Nathan Ament	Canyonlands National Park-Island in the Sky	National Park Service	NTN and AMoN	2017
UT95	Ryan Mower	East McKee	U.S. Forest Service	NTN	2017
VA00	Suzanne Maben	Charlottesville	U.S. Geological Survey	NTN	2017
VA13	Erica Jones	Blue Grass Trail	Wood-U.S. Environmental Protection Agency	NTN and AMoN	2017
WI08	Julie Perala	Brule River	Wisconsin Department of Natural Resources	MDN and NTN	2017
WY94	Simeon Caskey	Grand Tetons National Park	Grand Tetons National Park / National Park Service	NTN and AMoN	2017

Happy Retirement! Donna Schwede

A longtime member of the NADP family retired this past summer. Donna Schwede (retired – U.S. EPA) has been a part of the NADP for many years and was Chair of the Executive Committee during the transition of the Program from Illinois to Wisconsin. She has worked closely with a number of us over the years and will surely be missed. As part of her retirement celebration, folks were invited to submit limericks to honor Donna's career.

Donna was a model to admire
Such stature to acquire
Her dedication
Should earn her a vacation
Away from the fire!

—Camille Danielson (NADP)

Re deposition
We now know how much it is
Big thanks to Donna!

—Linda Geiser (NADP)

She models chemistry, precip, and gales
Compares it with ions measured in pails
But it's finally in reach
She is off to the beach
From the NPS, happy trails!

To NADP, Donna is kin
Known for drinking Old Fashions and gin
She helped them move
And we have now proved
All is fine in Wiscon-sin

Donna – a true modeling ace
Explains it simply and always with grace
But a lesson to learn
We should all model her
And the world would be a better place

—Kristi Morris (NADP)

She's a scientist with hair so fair
Who knows all matters of the air
and When a dark force
Changed NADP's course
Her strength proved beyond compare.

—Greg Wetherbee (NADP)

We're having a panic attack
What will we do without CMAQ?
Donna's model runs were brave
Atmospheric deposition behaved
But enjoy your retirement, you are always welcome back!

—Jill Baron (USGS)

Dear scientist, Donna by name
Chem modeling that was your game
You're formidable, kind,
With a cracker jack mind
In the next stage let fun be your aim

—AnneMarie MacDonald (NADP)

An inspiration, mentor, and female powerhouse
Talking deposition in the dark beer Haus
Steadfast support for quality science
And building a CASTNET alliance
Now it's time to enjoy Flagler, Boone, and upstate NY with your spouse!

—Melissa Puchalski (OAR/OAP/CAMD)

We had deposition fluxes at sites we could use
But walk away from that site, no one knew what to do
Well, Donna saw measurements 'N' models used compatibly
It was all a ton of data and no one else could see
Donna stepped up and said, "All you gotta do is fuse!"

—Greg Beachley (OAR/OAP/CAMD)

There was a young Donna from R-T-P
Who said I'll join the jolly folks at NADP
Soon she became a mighty leader
And when U of I said get out we cried "we need her"
To find us a new home to be happy

—Doug Burns (NADP)

Lame Poetry to Donna

Holy smokes, Donna is retiring.
She's a bright star in the NADP firmament, and always inspiring.
Donna is fun to work with, through thick and thin,
with a heart of gold, but thick of skin.
A wide-ranging collaborator to many a scientific endeavor,
In times of duress, she goes way beyond measure.
NADP is losing someone special, but that's OK,
Her legacy will shine on, come what may.
Thanks for all that you have done for the NADP thing,
And may your future be bright on your next big thing.
This poem is lame, but that's not too surprising
When you ask a fool to write verse,
You can expect the worst!

—Tom Butler (NADP)

There once was a scientist named Donna
Who studied air pollution to protect flora and fauna.
She modified Daewon's code
To calculate critical load
But now she no longer wanna.

—Rick Artz (NOAA)

Dear Donna, air modeler divine
Tracking ammonia from farm to alpine
Our budget Nooksack
Really needed CMAQ
Now our inputs and outputs align

—Jana Compton
(CPHEA/PESD/FEB)

Abstracts

Session 1: Diversity, equitability, and inclusion in air quality monitoring; serving urban and rural communities; promoting public awareness and access to information and decision-making

Past, present, and future of adversity and public welfare in the National Ambient Air Quality Standards

S. Douglas Kaylor[1], Jeffrey D. Herrick[2], Rebecca M. Dalton[3], Kristopher Novak[4], Tara Greaver[5], Emma Leath[6], and Caroline E Ridley[7]

Environmental policy is linked to how societies value ecosystems. Individual and societal values are on a spectrum and are multifaceted; ecosystems can be valued intrinsically and/or instrumentally (for the health, economic, cultural, or religious benefits they provide). The Clean Air Act (CAA) states that the National Ambient Air Quality Standards (NAAQS) should protect the public welfare from any known or anticipated adverse effects. The ways in which we value ecosystems affect the definition of adversity to public welfare and are vital to making policy decisions.

Society and science are changing in ways that affect how adversity to public welfare is defined and measured. Government agencies in the United States are being urged to consider historically excluded voices and incorporate a diversity of values in decision-making. Specifically, environmental justice and equity are examples of values that society and, by extension, government have a renewed focus on. Scientific methods are shifting, too. Increased computing power, a long satellite record of free spatial data, and on-the-ground participatory science efforts that generate data with smart phones are all powerful tools which expand the ways we measure and report ecosystem change. Concurrent with these advances, new challenges are arising from climate change. As society and science are affected by and must respond to climate change, a review of the approaches to how societal values are incorporated in science policy are needed to protect ecosystems and public welfare from the adverse effects (however defined) from air pollution now and in the future.

Using the NAAQS process as a case study, we examine the ways in which adversity and public welfare have historically been discussed in rulemakings of the CAA, as well as the ecosystem endpoints previously considered. We discuss current approaches to ecosystem valuation and their potential shortcomings in terms of being translated, incorporated, and/or considered in policy that protects public welfare. Lastly, we provide ideas for the future of scientific assessments meant to inform decision-making, including ways we can incorporate a multiplicity of values and better connect ecological adversity to public welfare.

[1] Center for Public Health and Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC, kaylor.steven@epa.gov
[2] Center for Public Health and Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC, Herrick.Jeffrey@epa.gov
[3] Center for Public Health and Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC, Dalton.Rebecca@epa.gov
[4] Center for Public Health and Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC, Novak.Kristopher@epa.gov
[5] Center for Public Health and Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC, Greaver.Tara@epa.gov
[6] Oak Ridge Associated Universities (ORAU) National Student Services Contract Participant at the US Environmental Protection Agency, Research Triangle Park, NC, Leath.Emma@epa.gov
[7] Center for Public Health and Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC, Ridley.Caroline@epa.gov

Monitoring Air Quality Impacts with Students

Susan Sachs[1]

Educators in Great Smoky Mountains National Park have been monitoring foliar injury from exposure to ground-level ozone in Bio-monitoring Gardens since 2003. Middle and high school students learn how to recognize and estimate the percentages of injury on sensitive plant species. Data is collected on the same leaves of Cut-leaf Coneflower (*Rudbeckia laciniata*) and Crownbeard (*Verbesina occidentalis*) throughout the growing season. Cultural connections are made for students with the Cut-leaf coneflower that is called Sochan by the Cherokee people who live in the region. Sochan is an edible green eaten as a spring tonic. The park has recently begun expanding their partnership with the Eastern Band of the Cherokee to include Sochan monitoring.

The park also has additional projects looking at the impacts of acid deposition on salamanders, snails, terrestrial invertebrates/soils, lichens, tardigrades and aquatic systems. These community science programs allow students to see how often invisible air pollutants impact resources in their community. Data is entered into internet databases hosted by FieldScope so students can ask and answer their own questions of the data. Teachers learn how to use the FieldScope platform during training workshops. Rangers meet with students in live virtual programs to discuss critical issues impacting park resources and to teach students how to analyze data.

[1] Great Smoky Mountains National Park, susan_sachs@nps.gov

Heavy metals in moss guide environmental justice investigation: A case study using community science in Seattle, WA, USA

Sarah Jovan[1]

Heavy metals concentrations often vary at small spatial scales not captured by air monitoring networks, with implications for environmental justice in industrial-adjacent communities. Pollutants measured in moss tissues are commonly used as a screening tool to guide use of more expensive resources, like air monitors. Such studies, however, rarely address environmental justice issues or involve the residents and other decision-makers expected to utilize results. Here, we piloted a community science approach, engaging over 55 people from nine institutions, to map heavy metals using moss in two industrial-adjacent neighborhoods. This area, long known for disproportionately poor air quality, health outcomes, and racial inequities, has only one monitor for heavy metals. Thus, an initial understanding of spatial patterns is critical for gauging whether, where, and how to invest further resources towards investigating heavy metals. Local youth led sampling of the moss *Orthotrichum lyellii* from trees across a 250×250-m sampling grid (n = 79) and generated data comparable to expert-collected samples (n = 19). We mapped 21 chemical elements measured in moss, including 6 toxic 'priority' metals: arsenic, cadmium, chromium, cobalt, lead, and nickel. Compared to other urban *O. lyellii* studies, local moss had substantially higher priority metals, especially arsenic and chromium, encouraging community members to investigate further. Potential hotspots of priority metals varied somewhat but tended to peak near the central industrial core where many possible emissions sources, including legacy contamination, converge. Informed by these findings, community members successfully advocated regulators for a second study phase – a community-directed air monitoring campaign to evaluate residents' exposure to heavy metals – as is needed to connect moss results back to the partnership's core goal of understanding drivers of health disparities. This follow-up campaign will measure metals in the PM_{10} fraction owing to clues in the current study that airborne soil and dust may be locally important carriers of priority metals. Future work will address how our approach combining bioindicators and community science ultimately affects success addressing longstanding environmental justice concerns. For now, we illustrate the potential to co-create new knowledge, to help catalyze and strategize next steps, in a complex air quality investigation.

[1] USDA Forest Service PNW Research Station, sarah.jovan@usda.gov

First Measurement of Ambient Air Quality on the Rural Lower Eastern Shore of Maryland

Deborah Sauder[1], Bernice Bediako[2], Moses Kairo[3], and Ryan Auvil[4]

The Lower Eastern Shore (LES) of Maryland is situated between the Chesapeake Bay and the Atlantic Ocean. A substantially rural area, agriculture is responsible for a significant fraction of the economic activity on the LES. Approximately 500 Concentrated Animal Feeding Operations (CAFO) - raising 30,000-560,000 chickens at a time are located here. We report the first data collected to examine ambient air quality on the LES. Data was collected in Princess Anne, Somerset County and Pocomoke, Worcester County. It is presented in comparison to data from MDE's existing regulatory sites at Horn Point in Cambridge, Dorchester County and in Baltimore City. Ammonia, other nitrogen containing species, PM2.5, PM10 and meteorological conditions were monitored continuously at the LES sites. Data from April 2020-September 2022 will be presented. Correlations between demographic characteristics and air quality will be presented. Somerset County has the highest percentage African American population on the shore and the lowest average household income in the state as of 2020. Within a two-mile radius of the Worcester County sampling site CAFO operations house some 900,000 birds. Horn Point is in a region of low agricultural activity. Baltimore City provides a high population density, high traffic, more industrial intensive urban site for comparison.

[1] University of Maryland Eastern Shore, Department of Natural Sciences, dgsauder@umes.edu
[2] University of Maryland Eastern Shore, Department of Natural Sciences, bbediako@umes.edu
[3] University of Maryland Eastern Shore, Dean, School of Agricultural and Natural Sciences, mkairo@umes.edu
[4] Maryland Department of the Environment, Air Monitoring Program, ryan.auvil@maryland.gov

Session 2: Deposition monitoring for science-based management of air pollution in a changing world; applications of critical loads to sustain biodiversity and ecosystem services

Re-assessing risk from nitrogen and sulfur deposition to forest ecosystems across the continental US

Linda Pardo[1], Chris Clark[2], Jeremy Ash[3], Justin Coughlin[4], Robert Sabo[5]

The consequences of atmospheric nitrogen and sulfur deposition continue to affect the growth and survival of trees in forest ecosystems across the US. We found that the majority of the 94 tree species we evaluated had detrimental responses to N and or S deposition. Based on analysis of US Forest Service Forest Inventory and Analysis (FIA) data and US-EPA TDep model deposition estimates, we set critical loads for N and S deposition for 73 tree species in the conterminous United States. Growth and survival estimates were made from repeated measurements of more than 1.4 million individual trees measured between 2000 and 2016. By including species with fewer than 2000 individual (the threshold in the original analysis), we increased the number of species that were evaluated in the recent re-analysis to 146 tree species. In addition, this re-analyses allowed us to separate the confounding effect of ozone on survival and growth, thus improving our estimates for critical loads and exceedance.

We examine tree CLs and exceedances using the web-based tool, CLAS—Critical Load Assessment by Site. The CLAS tool outputs can be used to demonstrate how resource managers could use this information to assess likely impacts from atmospheric N and S deposition under various management scenarios at areas of concern.

[1] USDA Forest Service, Northern Research Station, linda.pardo@usda.gov
[2] US-EPA ORD, Clark.Christopher@epa.gov
[3] USDA Forest Service, jeremy.ash@usda.gov
[4] US-EPA, coughlin.justin@epa.gov
[5] US-EPA, Sabo.Robert@epa.gov

Mapping critical loads of acidic deposition and exceedances for soils in Canada

Hazel Cathcart[1], Julian Aherne[2], Amanda Cole[3]

The critical loads concept is widely used to assess risk of damage from acidic deposition, and maps showing what regions receiving acidic deposition in excess of their critical loads are important tools for policymakers and scientists. In Canada, provincial maps of critical loads have made comparisons between regions difficult due to differences in resolution and methodology, as coverage for all provinces and territories was not complete. Computational hurdles and availability of high-resolution mapped data have also challenged creation of harmonised Canada-wide critical loads maps. In this study, we mapped critical loads of acidity for the entirety of Canada and estimated exceedance based on 2016 total sulphur and nitrogen deposition maps from the GEM-MACH model. A raster-based approach using high-resolution soil, climate, and landcover maps to parameterize the Simple Mass Balance (SMB) model was undertaken to estimate critical loads for terrestrial mineral soils at 250 m resolution. A site-specific approach for setting the critical base cation to aluminum ratio (Bc/Al_{crit}) based on landcover and dominant species was used to explore two (5% and 20%) growth reduction scenarios. Results highlight low critical loads (below 250 eq ha^{-1} yr^{-1}) in arctic Canada and areas on the Precambrian Shield, as well as exceedance in soils near point sources. This work lays the foundation for Environment and Climate Change Canada's receptor ecosystem project, which aims to monitor the extent of critical loads exceedances using measurement-model fusion (ADAGIO) deposition maps.

[1] Air Quality Measurement and Analysis Research Section, Atmospheric Science and Technology Directorate, hazel.cathcart@ec.gc.ca, amanda.cole@ec.gc.ca
[2] Trent University, jaherne@trentu.ca
[3] Air Quality Measurement and Analysis Research Section, Atmospheric Science and Technology Directorate, amanda.cole@ec.gc.ca

Shifts in the Composition of Nitrogen Deposition in the Conterminous United States are Discernable in Stream Chemistry Response

Meredith G. Lassiter[1], Jiajia Lin[2], Robert Sabo[3], Jana E. Compton[4], Jennifer Phelan[5], John L. Stoddard[6], Steve Mcdow[7], and Tara Greaver[8]

Across the conterminous U.S., the composition of atmospheric nitrogen (N) deposition is changing spatially and temporally. Previously, deposition was dominated by oxidized N, but now reduced N is equivalent to oxidized N when deposition is averaged across the entire nation and, in some areas, reduced N dominates deposition. Characterization of these changing N deposition patterns on stream chemistry is warranted considering that current trends are expected to continue under existing emissions controls. Based on precedent in the literature, we expect the shift in the composition of atmospheric deposition to alter stream chemistry via differences in the biogeochemical cycling of reduced and oxidized forms of N. To evaluate if there are effects of this change at the national scale, estimates of N deposition form (oxidized or reduced) from the National Atmospheric Deposition Program Total Deposition (TDEP) data were coupled with stream measurements from the EPA National Rivers and Streams Assessments (NRSA; three stream surveys between 2000 and 2014). We focus on a subset of NRSA stream watersheds (<1000 km^2) where N deposition was the largest source of N (n=1,906), and used water chemistry data (NH^{4+}, NO_3^-, total N (TN)) to evaluate if atmospheric deposition trends are discernable in the streams. There was a clear temporal shift from a greater proportion of sites dominated by oxidized N deposition to a greater proportion of sites dominated by reduced forms of N deposition. We found a significant positive correlation between oxidized N deposition and stream NO_3^-. Sites dominated by atmospheric inputs of reduced N forms had higher stream total organic N and total N despite lower total N deposition on average. Furthermore, this study compared two approaches to quantifying oxidized N deposition, use of measured-only data (dry nitric acid [HNO_3] + wet and dry nitrate [NO_3^-], 'tno3_dw' deposition estimate from TDEP) and measured plus modeled total oxidized N deposition ('noxi_tw' deposition estimate from TDEP). When additional modeled organic and inorganic N forms were included in total oxidized deposition, estimates increased by an average of 20% across all sites (range 3% to 55%; 95th percentile 33%) and some deposition-stream chemistry relationships were no longer significant, suggesting we need to understand more about how these oxidized forms of N are processed chemically and biologically in the watershed.

The views expressed in this abstract are those of the authors and do not necessarily represent the views or policies of the US EPA.

[1] U.S. EPA, Office of Research and Development (ORD), Center for Public Health and Environmental Assessment (CPHEA), lassiter.meredith@epa.gov
[2] U.S. EPA, ORD, CPHEA, Pacific Ecological Systems Division/ former Oak Ridge Institute for Science and Education, jlin42@outlook.com
[3] US EPA, CPHEA, sabo.robert@epa.gov
[4] US EPA, ORD, CPHEA, Pacific Ecological Systems Division, Compton.jana@epa.gov
[5] RTI International, jenphelan@rti.org
[6] US EPA, ORD, CPHEA, Pacific Ecological Systems Division, stoddard, john@epa.gov
[7] US EPA, ORD, CPHEA, mcdow.stephen@epa.gov
[8] US EPA, ORD, CPHEA, greaver.tara@epa.gov

Updates for 2023 of Critical Load Research from the EPA, NPS, and USFS

Christopher Clark[1], Rebecca Dalton[2], Jesse Miller[3], Tara Greaver[4], Linda Pardo[5], Michael Bell[6], Linda Geisr[7], Jeff Herrick[8], Karen Dillman[9], Nathan Pavlovic[10], Jennifer Phelan[11], Kemen Austin[12], and Todd McDonnell[13]

There are several lines of research ongoing within the EPA, NPS, and USFS to advance critical load science and information in the U.S. This talk will provide an overview of a portion of that body of work and a summary of where we may be headed. Topics covered include: (1) several recent advances to tree critical loads (regional variation, inclusion of ozone and climate change as drivers, and using machine learning to expand our inference), (2) progress from CLAD working groups on characterizing uncertainty in critical loads, (3) recent advances in herb critical loads to use PROPS to examine scenarios of change across protected areas, (4) recent advances in lichen critical loads to support decision making, and (5) new tools and handbooks coming online to support decision making and stakeholder groups.

[1] US Environmental Protection Agency, clark.christopher@epa.gov
[2] US Environmental Protection Agency, dalton.rebecca@epa.gov
[3] US Environmental Protection Agency, miller.jesse.n@epa.gov
[4] US Environmental Protection Agency, greaver.tara@epa.gov
[5] US Forest Service, linda.pardo@usda.gov
[6] National Park Service, mdbell@nps.gov
[7] US Forest Service, linda.geiser@usda.gov
[8] US Environmental Protection Agency, herrick.jeffrey@epa.gov
[9] US Forest Service, karen.dillman@usda.gov
[10] Sonoma Tech, npavlovic@sonomatech.com
[11] RTI International, jenphelan@rti.org
[12] RTI International, kaustin@rti.org
[13] E&S Environmental Chemistry, todd.mcdonnell@esenvironmental.com

Standardized application of critical loads and critical load exceedances within Class I areas helps guide decision -making and future research

Michael D. Bell[1], Jeremy Ash[2], Linda H. Pardo[3], Jason A. Lynch[4], Linda H. Geiser[5], Christopher M. Clark[6], and Emmi Felker-Quinn[7]

The NADP Critical Loads of Atmospheric Deposition (CLAD) science committee has been compiling information on critical loads since 2006 within the National Critical Load Database. Recent research has developed national- and regional-scale critical load (CL) datasets that provide an increase in spatial resolution and species-specific responses for various ecosystem components. In an effort to make the data more accessible to decision-makers, CLAD has developed a standardized application process for each CL and developed a CL Summary Report incorporating all the data within federal boundaries. This analysis summarizes data from seven critical loads of N (alpine, aquatic, epiphytic macrolichen, herbaceous community, herbaceous species, tree species, and soil mycorrhizal) and four critical loads of S (aquatic, epiphytic macrolichen, herbaceous species, tree species) within 151 Class I areas in the conterminous US. Critical loads exceedances, and thus harm to the ecosystem components, were evaluated using Total N and Total S deposition from the 2018-2020 NADP Total Deposition Model.

All Class I areas evaluated have at least 1 critical load of N, but not all have a critical load of S; with and average of 5 and 2 components respectively. 15 Class I areas have CL information for all ecosystem components analyzed. Given its breadth of coverage, the CL of N for a decline in herbaceous species richness is the only CL present in all Class I areas. Critical load exceedances exist for at least one ecosystem component in 147 Class I areas. The CL of N for alpine communities (100%) and the CL of S for a decline in tree species health (97%) have the highest percentages of exceedances across all areas, while CL of S for a decline in lichen community richness (15%) and the CL of N for a decline in herbaceous species richness (23%) have the fewest exceedances. Looking at the critical loads and exceedances holistically across all units helps identify data gaps and how patterns of exceedance can inform which critical loads are used to define regional ecosystem variation. Standardizing the application process across agencies also assists in consistent use and cross-boundary interpretation of ecosystem health.

[1] National Park Service, michael_d_bell@nps.gov
[2] U.S. Forest Service, jeremy.ash@usda.gov
[3] U.S. Forest Service, linda.pardo@usda.gov
[4] U.S. Environmental Protection Agency, lynch.jason@epa.gov
[5] U.S. Forest Service, linda.geiser@usda.gov
[6] U.S. Environmental Protection Agency, clark.christopher@epa.gov
[7] National Park Service, emmi_felker-quinn@nps.gov

Particulate Matter Deposition Along an Urban-Agricultural Gradient in Central Ohio, USA

Ruth Heindel[1], Sean Scott[2], Ansley Grider[3], and Sadie Richards[4]

Atmospheric particulate matter (PM) is often enriched in limiting nutrients and heavy metals, with consequences for human health, water quality, and ecosystem biodiversity. The sources and subsequent transport pathways of PM, which often determine its chemical composition, are difficult to untangle. In and around Columbus, OH, potential sources of PM include road and construction dust, industrial and mobile emissions, coal combustion, and agriculture. Little is known about how PM sources vary along land-use gradients in central OH, a region that is undergoing rapid development as suburbia encroaches into farmland. During June and July of 2021, we collected weekly bulk deposition samples at four sites along an urban-agricultural transect from downtown Columbus to 100 km northeast of the city, where land use is predominantly forest and row crop agriculture. We filtered the bulk deposition samples and analyzed the filters for total mass, stable lead (Pb) isotopes, and trace element composition. In addition, we used the Stochastic Time-Inverted Lagrangian Transport (STILT) Model to generate weekly back-trajectory footprints corresponding to each PM sample.

The mass of PM deposited at the urban site was significantly higher than at the suburban and rural/agricultural sites. Back-trajectory analysis indicated that at the urban site, potential source areas of PM were 23% agricultural and 49% developed, while at the most rural/agricultural site, potential source areas of PM were 42% agricultural and 21% developed. Particulate matter Pb isotopes agree with previous studies of midwestern precipitation, and deviations from the North American Atmospheric Trend Line were more negative with increased development, suggesting that anthropogenic inputs are characterized by lower $^{208}Pb/^{206}Pb$. The trace element data will allow us to test the prediction that urban PM contains higher concentrations of anthropogenically derived metals compared to the rural/agricultural PM. As development and agriculture continue to intensify across the midwestern US, and as drought conditions are exacerbated by climate change, monitoring the quantity and chemical composition of PM should be a priority for urban and rural communities alike. Tools such as monitoring along land-use gradients, back-trajectory modeling, and isotopic and trace element analysis can help untangle the many potential sources of PM that threaten both human and ecosystem health.

[1] Kenyon College, heindel1@kenyon.edu
[2] Wisconsin State Laboratory of Hygiene, srscott4@wisc.edu
[3] University of Maine, ansley.grider@maine.edu
[4] Kenyon College, richards2@kenyon.edu

Session 3: Deposition monitoring to assess and address chemical contamination of the environment

Stream nitrogen response to Clean Air Act policies in the US: An application of National Nutrient Inventory and the National Rivers and Streams Assessment

Jiajia Lin[1], Jana E. Compton[2*], Robert Sabo[3], Alan T. Herlihy[4], Ryan Hill[5], Marc Weber[6], J. Renée Brooks[7], Steve G. Paulsen[8], John L. Stoddard[9]

Air quality regulations have decreased nitrogen (N) and sulfur (S) deposition to the United States (US) landscape over the last several decades. To assess the stream response to declining deposition across the US, we combined the US EPA's National Nutrient Inventory with N chemistry in small streams (watershed areas < 1000 km2) between 2000 and 2014 from the EPA's National Rivers and Streams Assessment. We focus the analysis on watersheds where deposition was the largest N input to the watershed using the inventory data. Weighted change analysis quantified that deposition declined across most of the US watersheds, especially across the Eastern region. However, average growing season stream nitrate concentrations showed only a small and non-significant decline in these areas. This small trend in nitrate was offset by a substantial and significant gain in total organic N (TON) concentrations across most of the US. Instead of a net decline, total N concentrations increased in these small streams where atmospheric deposition is the largest source across all regions. Increases in TON concentration coincided with reductions in atmospheric deposition of N and S, pointing toward a recovery from acidification, and is similar to recent increases in dissolved organic matter or "browning" of streams and lakes across northern latitudes. The water quality benefits of reducing N deposition loads through air quality regulations are masked by increases in organic nitrogen mobilization in small streams across the US.

[1] Pacific Ecological Systems Division, Office of Research and Development, US Environmental Protection Agency/Oak Ridge Institute for Science and Education, jlin42@outlook.com

[2] Pacific Ecological Systems Division, Office of Research and Development, US Environmental Protection Agency, compton.jana@epa.gov

[3] Center for Public Health and Environmental Assessment, Office of Research and Development, US Environmental Protection Agency

[4] Pacific Ecological Systems Division, Office of Research and Development, US Environmental Protection Agency/National Research Council, US National Academy of Sciences

[5] Center for Public Health and Environmental Assessment, Office of Research and Development, US Environmental Protection Agency

[6] Center for Public Health and Environmental Assessment, Office of Research and Development, US Environmental Protection Agency

[7] Center for Public Health and Environmental Assessment, Office of Research and Development, US Environmental Protection Agency

[8] Center for Public Health and Environmental Assessment, Office of Research and Development, US Environmental Protection Agency

[9] Center for Public Health and Environmental Assessment, Office of Research and Development, US Environmental Protection Agency

[*] Corresponding author

Patterns of Change in an Adirondack Ecosystem: Monitoring changes in wet deposition, water chemistry, and watershed and lake fluxes as evidence of ecosystem recovery from acid deposition

Maria Antonia Villegas Botero[1], Nicholas LoRusso[2], Mario Montesdeoca[3], Patrick McHale[4], Colin Beier[5], Kimberley Driscoll[6], and Charles Driscoll[7]

Long-term environmental monitoring is essential for detecting and understanding patterns of change in ecosystem structure and function and possible drivers behind these changes. Long-term monitoring is also vital in determining the ultimate impacts of environmental policy, regulation, and land management, and provides clarity to decision-making processes. Particularly important was the 1990 Clean Air Act Amendments, which aimed to decrease acid deposition through reductions in NO_x and SO_2 emissions. By using the concept of mass balance, which allows for quantification of inputs, accumulation, transformations and losses of materials within ecosystems, we aim to calculate the rates of change of those processes and examine how changes in atmospheric deposition compare to chemical changes in stream water, lake water, and the overall lake-watershed ecosystem. We used Arbutus Lake Watershed as the study site for investigation. Arbutus Lake Watershed is located in the Huntington Wildlife Forest ((43°590'N, 74◦140'W) of the central Adirondack Mountains of New York. The watershed, with an area of 3.52 km^2, a maximum depth of 7.9 m, and a hydraulic residence time of 0.6 yrs. Measurements of wet deposition were obtained using data from the National Atmospheric Deposition Program (NADP) National Trends Network at site NY20 and dry deposition estimates were obtained from the EPA Clean Air Status and Trends Network (CASTNet). Water chemistry data and flow data were collected and measured using standard methods. Mass fluxes were calculated using the Adjusted Maximum Likelihood Estimation method in the LOADEST load estimator, to estimate constituent loads in streams. This study spans the years 1999 to 2020 to provide a long-term record of ecosystem changes in the watershed. Constituents analyzed included Na^+, Mg^{2+}, K^+, Ca^{2+}, total aluminum, Si, dissolved organic carbon (DOC), Cl^-, SO_4^{-2}, and nitrogen constituents NO_3^-, NH_4^+, and total nitrogen. Deposition of sulfate and nitrogen species is particularly important to monitor as they are key drivers of surface water acidification. Results indicate a recovering ecosystem with decreasing SO_4^{2-} and NO_3^- deposition. These results align with decreasing emissions nationally. An SO_4^{2-} mass balance indicates that watershed stream and lake losses coincide with decreases in atmospheric S deposition but with lower loss rates, suggesting a lag in recovery. In-lake retention of SO_4^{2-} has also diminished with decreases in atmospheric deposition. Mass balances for other constituents will be presented.

[1] Department of Civil and Environmental Engineering, Syracuse University, mvillega@syr.edu
[2] Department of Civil and Environmental Engineering, Syracuse University
[3] Department of Civil and Environmental Engineering, Syracuse University
[4] Department of Environmental Biology, College of Environmental Science and Forestry
[5] Department of Sustainable Resources Management, College of Environmental Science and Forestry
[6] Department of Civil and Environmental Engineering, Syracuse University
[7] Department of Civil and Environmental Engineering, Syracuse University

Concentrations of selenium and other trace metals in precipitation at the Hubbard Brook Experimental Forest, NH

Nagdalina Baez[1], Connor Olson[2], Mario Montesdeoca[4], and Charles Driscoll[5]

The atmospheric deposition is potentially an important pathway of selenium inputs to terrestrial ecosystems with implications for ecological and human health . Selenium is an essential element to humans but can be toxic at high exposures. Selenium may also moderate the toxic effects of mercury by binding to its inorganic form, preventing the formation methyl-mercury. The risk of selenium deficiency or over exposure is thus important to evaluate alongside mercury contamination. Precipitation samples were obtained from Hubbard Brook Experimental Forest, NH. The samples preserved with nitric acid and analyzed via Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for total selenium. For very dilute samples, each sample was concentrated by a factor of 10, using a hot plate until the sample completely evaporated. Then, 10 mL of sample was reconstituted using a 1% nitric acid solution. The focus of this project is to develop a method for effectively concentrating precipitation samples to analyze them for selenium, while evaluating changes in concentrations and deposition over time. Ultimately our goal is to use these data to determine selenium and mercury deposition to Hubbard Brook.

[1] Department of Civil and Environmental Engineering, Syracuse University, Syracuse NY, 13244 , nabaez@syr.edu

The experience and perspectives of collaboration in Mexico with the National Atmospheric Deposition Program

Rodolfo Sosa Echeverría[1], Ana Luisa Alarcón Jimenez[2], Monica Jaimes Palomera[3] Gilberto Fuentes García[4], Pablo Sánchez Alvarez[5], Elizabeth Vega[6], David Gay[7], and John Walker[8]

Mexico City Metropolitan Area (MCMA) has a population of more than 20 million inhabitants, thus it has always been a very important place for the study of air pollution and its implications due to the large number of emission sources, both natural and anthropogenic. The study of wet atmospheric deposition in the MCMA began in the 1980s with attention to acid rain, and from 2002 to date a monitoring network has operated in collaboration with the National Autonomous University of Mexico (UNAM) and the Ministry of the Environment (SEDEMA) of the Government of Mexico City, following the protocols of the National Trends Network (NTN) of the National Atmospheric Deposition Program (NADP) as well as the World Meteorological Organization (WMO).

In recent years, the need has emerged to comprehensively evaluate reactive nitrogen (Nr) in the MCMA in its oxidized forms (NO, NO_2 and NOx) in ambient air, and also in wet atmospheric deposition on a in its oxidized and reduced forms, nitrate and ammonium respectively. Among the main findings is the predominance of the reduced form as ammonium, since an NH_4^+/NO_3^- ratio >2 has been found throughout the MCMA.

Due to the need to measure the reduced form of Nr in ambient air, such as ammonia, passive methods are currently being tested to be comparable with the NADP Ammonia Monitoring Network (AMON). Likewise, a measurement campaign with a continuous analyzer is being prepared together with the United States Environmental Protection Agency (USEPA) and NADP.

Collaboration with the NADP Atmospheric Mercury Network (AMNET), is beginning to monitor mercury in MCMA air. Two automatic analyzers will be received initially, which will be installed in two MCMA sites. The first will be installed on the UNAM campus, located in the south of the MCMA, and the second in the northern portion on a SEDEMA monitoring site.

Outside of Mexico City, the determination of the chemical composition of rainfall in the Gulf of Mexico region has been carried out. The measurements enable comparison of results between the sites in Mexico with the NADP sampling sites in Texas, Louisiana, and Florida.

[1] Instituto de Ciencias de la Atmósfera y Cambio Climático (ICAyCC), rodsosa@unam.mx
[2] Universidad Nacional Autónoma de México (UNAM), ana.alarcon@atmosfera.unam.mx
[3] ICAyCC, UNAM , mjaimes@sedema.cdmx.gob.mx
[4] Secretaria de Medioambiente (SEDEMA), Gobierno de la Ciudad de México, fuenbeto@icloud.com
[5] ICAyCC, UNAM , pasa@unam.mx
[6] ICAyCC, UNAM, evega@atmosfera.unam.mx
[7] National Atmospheric Deposition Program (NADP), dgay2@wisc.edu
[8] United States Environmental Protection Agency (USEPA), Walker.Johnt@epa.gov

Wet Deposition of Major Ions at Urban, Rural and Himalayan Sites in India

Umesh Chandra Kulshrestha[1], Sudesh Yadav[2], Yogender Singh[3], Moh Naseem[4], Ankita Katoch[5], Mudita Chaturvedi[6], Sunaina[7], Akanksha Roy[8], Anshu Sharma[9], Manisha Mishra[10], Bablu Kumar[11], and Saumya Singh[12]

Atmospheric deposition plays an important role in nutrient cycling through soils, waterbodies, plants and animals. Acidic deposition affects forests, biodiversity, food chain dynamics, carbon sequestration. Increased levels of nitrogen and phosphorus may lead to eutrophication while the increased levels of oxides of sulphur and nitrogen in air may lead to acid rain. Therefore, it is important to carry out systematic measurements on the chemical characteristics of wet and dry depositions in different environments. This study reports bulk rain chemistry measurements carried out during 2012-2019 under DRSNet-India and GCRF-South Asian Nitrogen Hub programs from 20 sites in India. The NO_3^- was recorded in the range of 6.4-43.3 µeq/l at urban sites while 6.5-18.3 µeq/l at rural sites suggesting higher levels of NOx at urban sites. The Himalayan sites had higher NO_3^- (7.02-22.5 µeq/l) as compared to the rural sites, probably due to increased urbanization and tourist activities which emit precursors of NO_3^-. Similar to NO_3^- pattern, $nssSO_4^{2-}$ was very high at urban sites (42.6-103.2 µeq/l) followed by rural sites (14.7-69.4 µeq/l). Interestingly, a rural site (Meetli) which is influenced by brick kilns emissions had very high NO_3^- and $nssSO_4^{2-}$ having concentrations corresponding to the urban sites. However, the Himalayan sites had the lowest range of $nssSO_4^{2-}$ (12.4-29.0 µeq/l) indicating the least influence of fossil fuel emissions. NH_4^+ concentration was the highest at rural sites ranging from 23.7-237.1 µeq/l due to agricultural activities and biomass burning influence. At urban sites, NH_4^+ concentrations varied from 50.2-223.4 µeq/l and at the Himalayan sites, NH_4^+ concentrations ranged from 18.4 to 112.4 µeq/l. The nss Cl^- calculations indicated very high non-marine chloride at a few rural sites especially in the areas having large number of brick kilns. It is worth mentioning that the measurements are reported with QA/QC including representatives of sites, sample collection procedures, application of thymol to preserve the samples and use of certified reference material in analysis by ion chromatography. Therefore, the results of the study may be helpful for achieving reliable modelling outcome and formulation of relevant policy purposes. However, the study also suggested to carry out long term measurements at a few selected sites in order to find out the effect of oxides of N and S on the acidity of precipitation and a relationship with trends of fossil fuel emissions in the region.

[1] Jawaharlal Nehru University, School of Environmental Sciences, umeshkulshrestha@gmail.com
[2] Jawaharlal Nehru University, School of Environmental Sciences, sudeshyadav1902@gmail.com
[3] Jawaharlal Nehru University, School of Environmental Sciences, yogendersinghdhanda@gmail.com
[4] Jawaharlal Nehru University, School of Environmental Sciences, mohnaseemmalik@gmail.com
[5] Jawaharlal Nehru University, School of Environmental Sciences, ankitakatoch@gmail.com
[6] Jawaharlal Nehru University, School of Environmental Sciences, mudita.chaturvedi@hotmail.com
[7] Jawaharlal Nehru University, School of Environmental Sciences, sunainakanojia1111@gmail.com
[8] University, New York, akanksharoy59@gmail.com
[9] National Taiwan University, Taiwan, anshuu.jnu@gmail.com
[10] Jawaharlal Nehru University, School of Environmental Sciences, manishamishra30j90@gmail.com
[11] Jawaharlal Nehru University, School of Environmental Sciences, bablukumarjnu@gmail.com
[12] University of California, Berkeley, saumya_singh@berkeley.edu

Wet Deposition of Non-Essential Heavy Metals and Reactive Nitrogen Species during Monsoon at Delhi (India)

Ankita Katoch[1], Sudesh[2], Yogender Singh[3] and U.C. Kulshrestha[4]

Non-essential heavy metals such as Cd, Pb and Hg are not required by living organisms even in trace amounts for any biological processes but their occurrence may cause toxicity in the environment. Various studies have highlighted the atmospheric deposition of these non-essential trace metals. Similarly, rising concentrations of Reactive Nitrogen (NH_4^+ and NO_3^-) in rainwater have piqued considerable interest in the scientific community. In this study, we have monitored the concentrations of reactive nitrogen species and non-essential heavy metals along with their their enrichments from anthropogenic sources in the rain water in a heavily polluted metropolitan, Delhi during monsoon season (July-September, 2022). The mean concentrations (µg/l ± SD) for Cd, Pb and Hg were 73.8±25.3, 466.9±343.9 and 18.0±8.4, respectively. The enrichment factors for Cd and Hg were extremely high (EF>10000) bearing significant influence from anthropogenic sources. The mean concentrations for NH_4^+ and NO_3^- (µg/l ± SD) were as high as 942.8±452.4 and 2514.5±452.4, respectively showing high abundance of Reactive Nitrogen in precipitation. Delhi lies in the Indo-Gangetic Plain (IGP) region and the back trajectory clustering and concentration-weighted trajectory (CWT) approach was employed to investigate the origin of reactive nitrogen ions and non-essential metallic constituents in the precipitation in the metropolitan. Our analysis indicated that more than 70% of contributions for Cd, Pb, Hg, NH_4^+ and NO_3^- were by the air masses passing from the IGP which comprised of the states such as Uttar Pradesh, Bihar and West Bengal. In case of Hg and Pb, limited contributions were also made by the air masses travelling from Arabian Sea, Gujarat and Rajasthan areas. This study suggests to carry out comprehensive investigations on the interlinkages of reactive nitrogen species and heavy metals in precipitation, and find out their sources and routes of transport in Indian region.

[1] Jawaharlal Nehru University, School of Environmental Sciences, New Delhi, India, ankitakatoch@gmail.com
[2] Jawaharlal Nehru University, School of Environmental Sciences, New Delhi, India, sudeshyadav1902@gmail.com
[3] Jawaharlal Nehru University, School of Environmental Sciences, New Delhi, India, yogendersinghdhanda@gmail.com
[4] Jawaharlal Nehru University, School of Environmental Sciences, New Delhi, India, umeshkulshrestha@gmail.com

Poster Session

Temporal changes and spatial patterns in the acid-neutralizing capacity of base cations and reduced nitrogen in wet and bulk deposition in Ohio, U.S.

Ansley Grider[1] and Ruth Heindel[2]

Precipitation pH has shifted in recent years and the causes behind these changes warrant further research. Over the past four decades, precipitation acidity has decreased dramatically due to the Clean Air Act Amendment that enacted regulations on NO_x and SO_2 emissions, shifting the dominant control on precipitation pH. Base cations (Ca^{2+} and Mg^{2+}) and reduced nitrogen (N) species (NH_3 and NH_4^+) can have neutralizing effects on precipitation, and both Ca^{2+} and reduced N have increased across the U.S. during the last three decades due to increased dust deposition and agricultural activities. A knowledge gap remains about how the acid-neutralizing capacity of Ca^{2+} and reduced N varies temporally and spatially. To address this, we studied precipitation pH in Ohio, a state with high N deposition and a mix of urban, industrial, and agricultural land. We used data from the NADP to assess temporal changes in the drivers of precipitation pH in Ohio, and we set up four bulk and particulate deposition sites along an agricultural-urban transect in Ohio during the 2021 summer to study spatial patterns.

At the NADP sites, correlations between wet deposition pH and Ca^{2+} and NH_4^+ have increased over the past four decades, with correlations between pH and NH_4^+ having the greatest increase. For the transect sites, Ca^{2+} and NH_4^+ showed strong positive correlations with bulk deposition pH, but Ca^{2+} had the strongest correlations. The urban site had distinctly steeper relationships between bulk deposition pH and Ca^{2+} and NH_4^+ compared to the other sites, which is likely driven by elevated total particulate deposition at the urban site compared to the other sites. This is supported by the strong correlation between total particulate matter and Ca^{2+} at the urban site, suggesting that urban dust plays a role in neutralizing urban precipitation pH. Over time, the acid-neutralizing capacity of Ca^{2+} and NH_4^+ has exerted a greater control on precipitation pH, and landuse can affect the strength of acid neutralization, with urban areas distinct from other landuse areas. This emphasizes the need for more monitoring of precipitation pH, especially as Ca^{2+} and reduced N increase.

[1] University of Maine, ansley.grider@maine.edu
[2] Kenyon College, heindel1@kenyon.edu

Critical loads of reactive nitrogen exceeded by urban wet deposition at the Rocky Flats National Wildlife Refuge, 2017 – 2019

Gregory A. Wetherbee[1]

Wet deposition of inorganic reactive nitrogen (Nr) emitted to the atmosphere as nitrate and ammonium by combustion and agricultural sources[1] can harm ecosystems.[2, 3] The Rocky Flats National Wildlife Refuge (RFNWR) in Colorado is home to increasingly rare xeric tallgrass prairie[4], and it is also located near many sources of Nr air pollution, including urban emissions (e.g. gas-powered vehicles)[3]. In this habitat, excessive deposition of Nr can lead to the increase of exotic plant species and the loss of native prairie species. The amount of air pollution deposition below which ecosystem harm does not occur is called the "critical load."[5] Exceedances of critical loads are often estimated using Total Deposition of Atmospheric Nitrogen (TDep) deposition maps. The TDep maps incorporate National Atmospheric Deposition Program/National Trends Network (NADP/NTN) data for regionally representative Nr deposition but exclude data from sites considered to be influenced by urban emission sources, thus the need to evaluate the impact of urban deposition data on modeled critical load exceedances.[6, 7]

Atmospheric wet-depositions of Nr and other pollutants were measured at RFNWR at NADP/NTN site CO86 as part of the Network for Urban Atmospheric Nitrogen Chemistry, operated during 2017–2019 by the U.S. Geological Survey. A normal amount of precipitation (48.8 centimeters (cm)) was measured in 2017, followed by a drier year in 2018 (42.2 cm) and then a wet year in 2019 (54.5 cm). However, measured Nr deposition increased every year between 2017–2019. The Nr deposition at RFNWR was much higher than at nearby, regionally representative NTN sites. When CO86 data were substituted into the 2017–2019 total Nr deposition maps (CO86 measured wet plus TDep dry), critical load exceedances were indicated, whereas excluding CO86 data indicated no exceedances.[7]

Back trajectory modeling[8] results indicated that the highest Nr deposition events predominantly came from storms that tracked from north and northeast of RFNWR – a region with intense urbanization in the Boulder and Denver Metropolitan areas and agricultural production. Although RFNWR has rural land-surface characteristics, measurements of wet-deposition of air pollutants at CO86 and nearby Denver (CO87) and Boulder (CO85) are similar.[3] Exclusion of NTN data from urban sites in TDep models underestimates the amounts of Nr deposition in urban ecosystems like RFNWR. Therefore, critical load exceedances are underestimated as well. Urban NTN data for this analysis are available at: https://doi.org/10.5066/P9OOIQ0E.

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[1] USGS, Water Mission Area, OSD, HNB, wetherbe@usgs.gov

Assessment of a Novel Method for Collection and Determination of Total Nitrogen and Total Phosphorus in Precipitation using a Modified NADP-NTN Wet-Deposition Collector

Katie Blaydes[1], Abby Carr[2], and Martin Shafer[3]

The National Atmospheric Deposition Program (NADP) currently monitors the two major inorganic nitrogen species, ammonium (NH_4^+) and nitrate (NO_3^-), and an inorganic form of phosphorus, orthophosphate (PO_4^{3-}) in the National Trends Network (NTN) wet deposition samples. However, organic forms of nitrogen and phosphorus 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 contribution of organic nitrogen species to total nitrogen deposition, and the uncertainty in organic phosphorus (org-P) contributions to total phosphorus (TP) deposition is even greater.

Unfortunately, the authorized NAPD-NTN wet-deposition sampler and sampling protocol is not appropriate for collection of samples for quantitative TN and TP measurement due to mineralization & transformation of organic species over the standard one-week NTN collection period. To address this significant issue, we developed a supplemental sampler, the SNiPiT (Sampler for Nitrogen and Phosphorus in Total), which attaches to NADP's existing NCON collector, and which incorporates a collection bottle, charged with a preservative, that stabilizes the org-N and org-P species, thus enabling quantitative TN and TP determinations.

In this study we investigated the application of a duplex total nitrogen and total phosphorus method that utilizes a potassium persulfate digestion (HACH chemistries: 10-107-04-4-C and 10-115-01-4-C), and that can measure both total nitrogen and total phosphorus from a single digest. The digestion is designed to convert all forms of nitrogen into nitrate and all forms of phosphorus into orthophosphate, which are then quantified colorimetrically by NADP's robust dual-channel Flow Injection Analyzer (FIA). The method requires only 6 mL of sample, and a batch of 120 samples can be processed over 3 hours.

To evaluate the efficacy of this approach we assessed the accuracy and precision of the collection method, preservation techniques, and the recovery of specific representative and relevant organic and inorganic nitrogen and phosphorus species from spiked samples. Our presentation will provide a summary of these method evaluation/validation outcomes and will be framed in the context of determining the feasibility of integrating total nitrogen and total phosphorus measurements into the NADP Lab processing of NTN samples.

[1] WSLH - UW Madison, Katie.Blaydes@slh.wisc.edu
[2] WSLH - UW Madison, abigail.carr@slh.wisc.edu
[3] WSLH - UW Madison, mmshafer@wisc.edu

Long-term trends in atmospheric mercury and linkage to concentrations in aquatic biota

Henry Long[1], Connor Olson[2], Steve Jane[3], Peter McIntyre[4], Nina Schoch[5], and Charles Driscoll[6]

Mercury is a neurotoxic pollutant that is released into the environment by both natural processes and human activities. Environmental mercury concentrations have increased markedly since the pre-industrial age. Human activities have resulted in a 300-500% increase in mercury in the atmosphere since 1850. The United States, as well as many other countries, have established policies to limit the release of mercury into the atmosphere and environment over the past 50 years. Due to these measures, mercury emissions have declined 80% since the Mercury and Air Toxics Rule was promulgated in 2011 in the United States. Emissions of mercury are deposited from the atmosphere. Mercury in the environment may then be transformed into methylmercury by microbes. This form of mercury biomagnifies as trophic level increases in the food web, leading to high concentrations in top predators. Wildlife higher up in the food chain can accumulate toxic levels of methylmercury in their tissues, which can cause negative behavioral, and reproductive effects. Monitoring methylmercury levels in fish, birds, and other aquatic predators is essential to better understand the effects of mercury contamination on ecosystems. The common loon *(Gavia immer)* inhabits lakes across the northern region of the United States and Canada. Loons are upper trophic level predators with long life spans, and therefore can accumulate high concentrations of methylmercury, which can cause adverse effects on their health and populations. Our research question is: Have recent emission decreases across the U.S. resulted in decreased mercury concentrations in air, precipitation, and biota in the Adirondack region of New York? To address this question, we analyze trends in concentrations of mercury in the atmosphere (using the Atmospheric Mercury Network; (AMNet)) and wet mercury and litter mercury deposition (using the Mercury Deposition Network (MDN) and the Litterfall Mercury Network (MLN)) at Huntington Forest in the Adirondack region of NY and compare these with trends in mercury concentrations in the muscle tissue of brook trout (*Salvelinus fontinalis*) and eggs from common loon from lakes in the Adirondacks. We find significant decreases in atmospheric concentrations of gaseous elemental mercury and gaseous oxidized mercury, but increasing trends in particulate bound mercury. We also see significant decreases in volume-weighted concentrations of mercury in wet deposition and non-significant decreases in wet mercury deposition. While decreases in air mercury concentrations and wet mercury deposition are generally consistent with decreases in emissions, patterns in brook trout muscle tissue and common loon eggs show less compelling trends. Continued monitoring of these apex predators is important for assessing the impacts of regulations regarding mercury emissions.

[1] Syracuse University CEE, hdlong@syr.edu
[2] Syracuse CEE, connoriolson@gmail.com
[3] Cornell University Department of Natural Resources, sfj24@cornell.edu
[4] Cornell University Department of Natural Resources, pmcintyre777@gmail.com
[5] Adirondack Center for Loon Conservation, nschoch@adkloon.org

Evaluating Mercury Conditions and Trends in National Parks

Katherine Ko[1], Colleen M. Flanagan Pritz[2], Ksienya Taylor[3], Emmi Felker-Quinn [4], Kristi Morris[5], James Willacker[6], and Collin A. Eagles-Smith[7]

Air quality is monitored in national parks across the country. The National Park Service Air Resources Division (NPS-ARD) reports conditions and trends based on pollutant concentrations in air or precipitation and the associated risks to visitor experience, human health, vegetation health, or ecosystem health. In 2022, the NPS-ARD added mercury to the suite of reported air quality parameters (see https://www.nps.gov/subjects/air/park-conditions-trends.htm); park conditions are based on mercury concentrations measured in organisms or tissues and characterized based on potential risk to wildlife. Park mercury trends are based on National Atmospheric Deposition Program/Mercury Deposition Network (MDN) monitors in and near parks. This synthesis of existing mercury data allows parks, scientists, resource managers, and the public to learn how mercury concentrations in park fish, birds, and invertebrates relate to risk benchmarks and how mercury deposition is changing over time in 125 parks.

Park mercury trends are based on annual wet mercury deposition. Mercury trends are reported for parks with representative MDN wet deposition monitors within 16 km of park boundaries. Park mercury conditions are based on potential risks to wildlife using a new tool developed collaboratively by the U.S. Geological Survey and NPS-ARD. The potential risks of mercury exposure to wildlife are quantified by comparing mercury concentrations found in park fish, birds, and/or invertebrates to existing tissue and dietary health benchmarks established for fish and birds (Willacker and Eagles-Smith 2022). The risk sub-scores developed for fish and birds are then integrated into one park-specific condition score: good, fair, or poor. A confidence score (low, medium, or high) is also calculated for each park condition based on the variability in wildlife mercury concentrations, sample sizes, and number of sites sampled. Most wildlife mercury data used to calculate conditions are from NPS-led collections of park fish and dragonfly larvae; conditions also incorporate summary data from published studies conducted in individual parks (Flanagan Pritz et al. 2022).

The NPS-ARD mercury condition and trends tools amass diverse data on mercury in biota and deposition, integrating it in a simple framework for use by resource managers. Not only do these condition and trend assessments link mercury deposition and potential effects, but they also have practical applications for other federal land management agencies assessing current or changing resource condition and evaluating temporal trends of mercury deposition in protected areas.

[1] National Park Service, katherine_ko@nps.gov
[2] National Park Service, colleen_flanagan_pritz@nps.gov
[3] National Park Service, ksienya_taylor@nps.gov
[4] National Park Service, emmi_felker-quinn@nps.gov
[5] National Park Service, kristi_morris@nps.gov
[6] U.S. Geological Survey, jwillacker@usgs.gov
[7] U.S. Geological Survey, ceagles-smith@usgs.gov

Estimating mineral surface area and acid sensitivity of forest soils

Patrick A. Levasseur[1], Shaun A. Watmough[2], Julian Aherne[3], Colin J. Whitfield[4], M. Catherine Eimers[5]

Soil mineral surface area is regarded as a key uncertainty in the estimation of base cation weathering rates yet is rarely measured. Acidification studies rely heavily on pedotransfer functions (PTFs) that use widely available soil data to estimate mineral surface area. This study examined the relationship between soil properties and mineral surface area in soils (n = 25) from Kitimat, British Columbia, an area that is receiving elevated sulphur (S) deposition due to recent modernization of an aluminum (Al) smelter. Mineral surface area was measured on bulk soil samples using BET (Brunaeur, Emmett and Teller) gas-adsorption. Previously published particle size-based PTFs were a poor predictor of surface area in Kitimat soils (R^2 between 0.42 and 0.66). Instead, mineral surface area was best predicted using a regionally-specific PTF (R^2=0.81), which used particle size as well as the concentration of kaolinite, the most abundant clay mineral in the region. Surface area values estimated using the regionally-specific PTF were applied to the PROFILE model to calculate weathering rates for critical load estimates. These estimates predicted that none of the sites received S deposition in exceedance of their critical load for acidity. However, as surface area is largely related to kaolinite content (a mineral that does not largely contribute to weathering rates), the applicability of using surface area functions for weathering rates is questionable. Further, the texture-based PTF developed for Kitimat did not provide accurate estimates of measured surface area for other soils in Canada, particularly at surface area values exceeding 2.5 m^2 g^{-1}.

[1] Environmental and Life Sciences Graduate Program, Trent University, patricklevasseur@trentu.ca
[2] School of the Environment, Trent University
[3] School of the Environment, Trent University
[4] School of Environment and Sustainability, and Global Institute for Water Security, University of Saskatchewan
[5] School of the Environment, Trent University

Applying Established Mycorrhizal Critical Loads of Nitrogen to Class I Areas within the United States

Cody L. Clemens[1], Michael D. Bell[2], and Emmi Felker-Quinn[3]

Anthropogenic Nitrogen (N) deposition harms various ecosystem processes through a combination of eutrophication and acidification. Adding N to the soil changes nutrient availability for plants and for their associated microbial partners. Increasing deposition is correlated with shifts in fungal communities from ectomycorrhizal to arbuscular mycorrhizal species. Critical loads (CLs) for this shift are lower for conifer-associated ectomycorrhizal fungal species (5-6 kg-N ha^{-1} yr^{-1}) than for other ectomycorrhizal fungal species (10-20 kg-N ha^{-1} yr^{-1}). Federal agencies use CLs to assess the risk to natural resources from current levels of deposition. For this project, we apply the CLs of N to prevent a shift in forest mycorrhizal communities. We identify forested area in the conterminous US using the National Land Cover Database (NLCD) and assess exceedance using the NADP Total Deposition model 2018-2020. We then assess the number of Class I National Parks, Tribal lands, USFS, and FWS with forested area in exceedance of the relevant CLs and reveal the areas in which forest ecosystems are at risk due to mycorrhizae CL exceedance.

The NLCD characterizes 38.4% of forest as conifer-dominated where we applied a minimum CL of 5 kg N and a maximum CL of 6 kg N; and 47.6% of forest as broadleaf-dominated, where we applied a minimum CL of 10 kg N, and a maximum CL of 20 kg N. Using the minimum of the range for each forest type, we found that 85 of 146 Class I areas have an exceedance within their boundary, 13 of which were in exceedance throughout the entire area. Using the maximum of the range for each forest type, we found 68 of 146 Class I areas have an exceedance within their boundary, 2 of which were in exceedance throughout the entire area. In the eastern US, 76.3% (29 of 38) of Class I areas with forest cover have a minimum CL exceedance within their boundary, compared to the west, where 51.9% (56 of 108) of areas have a minimum CL exceedance. Although there was a higher percentage of exceedances of mycorrhizal CLs in the east, there were more Class I areas located in the West, and therefore the data is being driven mostly by western areas where conifer species are more dominant. Future research should look at overlap between areas of tree CL exceedance and areas of mycorrhizal CL exceedance to assess whether N deposition triggers aboveground and belowground community shifts in concerted or mismatched responses. The results of this project may be used in future CLAD national mapping efforts for CLs. This analysis will also expand our understanding of the effects of N deposition to Class I areas, as well as direct future management decisions within these areas.

[1] National Park Service - Air Resources Division; University of Colorado, Denver, cody_clemens@partner.nps.gov
[2] National Park Service - Air Resources Division, Michael_D_Bell@nps.gov
[3] National Park Service - Air Resources Division, emmi_felker-quinn@nps.gov

Investigations into agricultural influences on nitrogen and sulfur in the atmosphere

Philip Silva[1]

Focus has been place on nitrogen and sulfur emissions from agriculture and their potential influence on local and regional deposition. Here we describe field and laboratory measurements aimed at understanding the presence and of and interaction between nitrogen and sulfur compounds from agricultural operations to the atmosphere. Measurements at poultry, swine, and dairy operations have been conducted. While ammonia is always high near source (part per million levels) the presence of amines is variable and there are indications that organic nitrogen may vary dependent on animal species. Sulfur concentrations vary dramatically from one operation to another and are strongly related to the waste handling methods, with hydrogen sulfide present in highest concentration but organic sulfides important at times.

In parallel with field work, chamber experiments investigating interactions of nitrogen and sulfur have been conducted. In these experiments gaseous compounds from agriculture are exposed to atmospheric oxidation. Though ammonia is normally thought of as the main agricultural contributor to aerosol formation via reaction with urban and industrial sources of sulfur and nitrogen, our experiments show that the reduced nitrogen and sulfur compounds co-emitted with ammonia have aerosol formation potential. These experiments suggest that modeling of agricultural influences to both particulate matter and deposition should be performed looking at the aggregate whole rather than just focusing on ammonia mixing with other air masses.

Recently, our next five year project plan for research has been approved and includes an aspect of measurements near animal facilities for the purpose of better understanding the deposition of agricultural nitrogen. This plan will be described and potential collaborations with NADP and its users will be discussed.

[1] USDA-ARS, phil.silva@usda.gov

Wildfire Impacts to Ozone and Biomass Measurements at Rocky Mountain National Park, CO, USA

Timothy Sharac[1], Amy Sullivan[2], Gregory Beachley[3], Melissa Puchalski[4], Jason Lynch[5], Barkley Sive[6], Ryan McCammon[7], and Christopher M. Rogers[8]

The Clean Air Status and Trends Network (CASTNET) is a long-term monitoring network designed to measure acidic pollutants and ambient ozone (O_3) concentrations in rural areas across the United States. CASTNET is managed collaboratively by the U.S. Environmental Protection Agency – Clean Air Markets Division (EPA), the National Park Service – Air Resources Division (NPS), and the Bureau of Land Management – Wyoming State Office (BLM-WSO).

The Rocky Mountain National Park – Longs Peak (ROMO/ROM406) is sited within a protected Class I area in the Northern Front Range in Larimer County Colorado. The National Park Service began ozone and meteorological measurements at this site in 1987 as part of the Gaseous Pollutant Monitoring Program, which was later adopted into CASTNET in 1994. Despite being a Class I area, Rocky Mountain National Park is frequently impacted by local and regional air pollution.

Since 2015, Colorado State University has deployed 47 mm nylon filters at Rocky Mountain National Park to assess air quality impacts from wildfires. The nylon filters are analyzed using high-performance anion exchange chromatography with pulsed amperometric detection (HPAEC-PAD) to measure levoglucosan and ion chromatography to measure cations and anions.

In 2020, much of the western United States experienced one of the most active wildfire seasons on record. In Colorado, there were four wildfires greater than 100,000 acres, including the East Troublesome Fire, which entered Rocky Mountain National Park.

In this presentation, we compare the hourly ozone measurements with the filter-based biomass measurements to assess the timing and magnitude of wildfire impacts to ozone levels within Rocky Mountain National Park. We complement this analysis using on-site meteorology, fire incident databases, and back-trajectory analysis to rule out non-wildfire emission sources.

[1] Environmental Protection Agency, Clean Air Markets Division, sharac.timothy@epa.gov
[2] Department of Atmospheric Science, Colorado State University, Amy.Sullivan@ColoState.edu
[3] Environmental Protection Agency, Clean Air Markets Division, Beachley.Gregory@epa.gov
[4] Environmental Protection Agency, Clean Air Markets Division, Puchalski.Melissa@epa.gov
[5] Environmental Protection Agency, Clean Air Markets Division, lynch.jason@epa.gov
[6] National Park Service, Air Resources Division, barkley_sive@nps.gov
[7] Bureau of Land Management – Wyoming State Office, rmccammon@blm.gov
[8] WSP USA, christopher.rogers@wsp.com

Long-Term Trends in Ozone Concentrations Measured by CASTNET

Christopher Rogers[1], Timothy Sharac[2], Melissa Puchalski[3], Nathan McGinnis[4], Kevin Mishoe[5], and Marcus Stewart[6]

The Clean Air Status and Trends Network (CASTNET) is a long-term monitoring network designed to measure acidic pollutants and ambient ozone (O_3) concentrations in rural areas throughout the United States and Canada. CASTNET is managed collaboratively by the Environmental Protection Agency – Clean Air Markets Division (EPA), the National Park Service – Air Resources Division (NPS), and the Bureau of Land Management – Wyoming State Office (BLM-WSO). In addition to EPA, NPS, and BLM-WSO, numerous other participants provide site operator support and grant land access including North American tribes, other federal agencies, States, private landowners, and universities.

Eighty-eight CASTNET sites report hourly O_3 concentrations used to assess regional trends, evaluate climate impacts on air quality, and model exposure effects on vegetation. Additionally, 87 of the O_3 monitors at CASTNET sites meet the requirements of Title 40 of the Code of Federal Regulations (CFR) Part 58 and are used to determine compliance with the O_3 National Ambient Air Quality Standard (NAAQS). One CASTNET site was established as a research site located above a forest canopy at Duke Forest, NC.

Each CASTNET monitor measures ambient O_3 concentrations for the entire year. CASTNET O_3 data are submitted to the AIRNow Tech website for near-real time reporting (www.airnowtech.org) and to EPA's Air Quality System (AQS) database (https://aqs.epa.gov/aqs). Annual performance evaluations (PE) and results from the National Performance Audit Program (NPAP) are also submitted to AQS routinely.

Preliminary 2018-2020 3-year average of the fourth highest daily maximum rolling 8-hour averages calculated using the 2015 ozone NAAQS indicate that four CASTNET sites exceed the 70 ppb O_3 NAAQS including Joshua Tree National Park, CA; Sequoia & Kings Canyon National Parks, CA; Yosemite National Park, CA; and Beltsville, MD. Two additional sites, Rocky Mountain National Park, CO and Washington Crossing, NJ, had a 3-year average of 70 ppb.

Ozone data and additional information about the CASTNET monitoring program can be found on the CASTNET webpage at https://www.epa.gov/castnet.

[1] WSP USA, christopher.rogers@wsp.com
[2] Environmental Protection Agency, Clean Air Markets Division, Sharac.Timothy@epamail.epa.gov
[3] Environmental Protection Agency, Clean Air Markets Division, puchalski.melissa@epa.gov
[4] University of Florida, Herbert Wertheim College of Engineering
[5] WSP USA, kevin.mishoe@wsp.com
[6] WSP USA, marcus.stewart@wsp.com

Water Soluble Organic Nitrogen Characterization Study

Nathaniel Topie[1], Marcus Stewart[2], John Walker[3], Ryan Fulgham[4], Melissa Puchalski[5], Kevin Mishoe[6], and Christopher Rogers[7]

Organic forms of nitrogen (N) are an important component of atmospheric deposition to terrestrial and aquatic ecosystems, which are not routinely measured. As summarized in a recent review by Jickells et al. (2013), global datasets of precipitation chemistry indicate that water soluble organic nitrogen (WSON) contributes ~25% of the total N in wet deposition, on average. In the U.S, annual averages of WSON range from 2.6% to 33% (Beem et al., 2010; Benedict et al., 2013b, 2013a; Keene et al., 2002; Scudlark et al., 1998; Walker et al., 2012; Whitall and Paerl, 2001). Generally, measurements of WSON in precipitation and aerosol are limited in North America due to a lack of routine monitoring, precluding development of a complete picture of the spatial and temporal patterns of the contribution of WSON to WSTN in wet and dry deposition at regional to continental scales.

The Clean Air Status and Trends Network (CASTNET) is a long-term environmental monitoring network of approximately 100 stations that measure changes in ambient air quality and assesses atmospheric deposition over broad geographic regions of the U.S. (https://www.epa.gov/castnet). The Environmental Protection Agency (EPA) coordinates the operation of the network in cooperation with numerous federal, tribal, state, and local partners.

CASTNET sites measure weekly average concentrations of particulate sulfate (SO_4^{2-}), particulate nitrate (NO_3^-), particulate ammonium (NH_4^+), sulfur dioxide (SO_2), nitric acid (HNO_3), chloride (Cl^-) and the base cations (Na^+, K^+, $Mg^{2+}$and Ca^{2+}) using a 3-stage filter pack.
This pilot study assessed the feasibility of determining temporal and spatial patterns of WSTN and WSON in particulate matter (PM) by analyzing the existing Teflon filter extracts collected by CASTNET. Bulk WSON in PM is calculated by measuring the concentration of WSTN and then subtracting the concentrations of the measured inorganic components ($NH_4^+$and NO_3^-). The project consisted of two preliminary phases: 1) an assessment of the stability of nitrogen containing compounds during storage and handling of CASTNET filter samples and 2) measurement of WSTN and WSON at 5 CASTNET sites for a period of 3 months. Results from the initial assessment showed that WSTN and WSON could be determined using the CASTNET Teflon filter. Currently, a 27 site, one-year pilot study is being conducted to assess seasonal and spatial patterns and to estimate the contribution of WSON to the total nitrogen deposition budget. A new SEAL AA500 AutoAnalyzer with a total N channel was procured for the study.

[1] WSP USA, nathaniel.topie@wsp.com
[2] WSP USA, marcus.stewart@ wsp.com
[3] Environmental Protection Agency, Center for Environmental Measurement and Modeling, walker.johnt@epa.gov
[4] Environmental Protection Agency, Center for Environmental Measurement and Modeling, fulgham.ryan@epa.gov
[5] Environmental Protection Agency, Clean Air Markets Division, puchalski.melissa@epa.gov
[6] WSP USA, kevin.mishoe@ wsp.com
[7] WSP USA, christopher.rogers@ wsp.com

Atmospheric Deposition of PFAS via Precipitation: Further Evaluation of the U.S. National Atmospheric Deposition Program (NADP) National Trends Network (NTN) for Assessment of PFAS Wet-Deposition

Emily Sellers[1], Rachel Nelson[2], and Martin M. Shafer[3]

An increasing body of evidence (including our own efforts) document measurable levels of a broad range of PFAS compounds in precipitation, which translate into very significant deposition loads to terrestrial and aquatic resources. We have previously documented in a series of laboratory and field experiments the efficacy of the NADP-NTN for collection of robust PFAS wet-deposition data, and therefore the viability of the 255 site network for a national PFAS wet-deposition sampling network. However, quantitative recovery of selected PFAS compounds required that the NTN collector bucket be rinsed with a small volume of methanol (MeOH), which, while not an onerous burden on the site operators, did require some additional time on-site. Additionally, the NTN has now moved to a bag-in-bucket precipitation collection paradigm and therefore there is a strong incentive to move PFAS collections to this approach and standardize across the NTN.
This poster will report on a succession of experiments designed to evaluate the efficacy of bags as a PFAS collection approach and whether MeOH rinsing will still be necessary; and if so, whether that rinsing could be performed back at the laboratory, instead of in the field. In doing so we hope to further reduce the incremental field effort and eliminate barriers to broader adoption of PFAS deposition monitoring from the NADP-NTN. Dedicated experiments in synthetic matrices with a diverse suite of 33 PFAS compounds addressed both blanks, and stability/losses of the PFAS species in both bucket-only and bag-in-bucket configurations. The recovered aqueous solutions as well as MeOH rinses of the buckets and bags were analyzed for the PFAS compounds by LC/MS/MS using our targeted method based upon ISO 21675. In addition we examined a series of real-world precipitation samples from NTN collectors (configured with bags) across the upper Midwest, quantifying PFAS levels in both the precipitation and MeOH rinse of the bag (performed in the laboratory upon return of the precipitation sample). Preliminary data indicate that PFAS sorption losses to the bag are substantively less than those in bare buckets.

[1] University of Wisconsin-Madison, WI State Lab of Hygiene, Emily.Sellers@slh.wisc.edu
[2] University of Wisconsin-Madison, WI State Lab of Hygiene, Rachel.Nelson@slh.wisc.edu
[3] University of Wisconsin-Madison, WI State Lab of Hygiene, mmshafer@wisc.edu

Contribution of emissions from the oil sands activities to atmospheric concentration and deposition of nitrogen and sulfur species at a downwind site

Yuan You[1], Jason O'Brien[2], Amanda Cole[3], Leiming Zhang[4], Zhuanshi He[5], Samuel Pearson[6], and Jian Feng[6]

Oil and gas activities in the Athabasca Oil Sands Region are large sources of atmospheric nitrogen oxides (NO_x) and sulfur dioxide (SO_2) emissions. Most previous studies on nitrogen and sulfur deposition in this region focused on the area within 50 km of the facilities. This study investigates the atmospheric deposition of nitrogen and sulfur compounds at a downwind site about 350 km away from the oil sands facilities to quantify the impact of emissions from oil sands activities on a wider region. Measurement data in this study are from the Canadian Air and Precipitation Monitoring Network (CAPMoN) from 2015 to 2019. Sector analysis of air mass back trajectories with the Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT) is conducted to distinguish measurements with different air mass origins. Trajectories arriving at half of the boundary layer height are used for ambient concentration and dry deposition analysis; while trajectories arriving at 1 km are used for precipitation samples and wet deposition analysis. Results indicate that the median atmospheric concentrations of nitrate acid (HNO_3), SO_2, particulate nitrate (pNO_3^-), particulate sulfate (pSO_4^{2-}), and particulate ammonium (pNH_4^+) in air masses coming from the oil sands sector are significantly greater than those from the background sector by 72 %, 99 %, 42 %, 46 %, and 34 %, respectively. In precipitation samples, the precipitation-weighted mean concentrations of nitrate (NO_3^-), sulfate (SO_4^{2-}), and ammonium (NH_4^+) on days where air masses came from the oil sands sector are 76 %, 65 % and 81 % greater than those from the background sector, respectively. Estimated contributions of emissions from oil sands activities to wet depositions of NO_3^-, SO_4^{2-}, and NH_4^+ at this site are 12.5 ± 8.9 %, 8.7 ± 4.4 %, and 6.0 ± 3.3 %, respectively. Dry deposition of gases and particles are calculated by the inferential method, and estimated contributions to dry depositions of HNO_3, SO_2, pNO_3^-, pSO_4^{2-} and pNH_4^+ are 11.0 ± 2.8 %, 36.5 ± 18.6 %, 3.7 ± 2.5 %, 5.6 ± 2.2 %, and 3.9 ± 1.6%, respectively. Quantifications of the contribution to dry depositions of NO_2 and NH_3, as well as the contributions to total deposition of nitrogen and sulfur, are still preliminary. Comparison of total deposition of sulfate at this site to the modeled critical loads of lakes in the area is also discussed.

[1] Air Quality Research Division, Environment and Climate Change Canada, yuan.you@ec.gc.ca
[2] Air Quality Research Division, Environment and Climate Change Canada, jason.obrien2@ec.gc.ca
[3] Air Quality Research Division, Environment and Climate Change Canada, amanda.cole@ec.gc.ca
[4] Air Quality Research Division, Environment and Climate Change Canada, leiming.zhang@ec.gc.ca
[5] Air Quality Research Division, Environment and Climate Change Canada, zhuanshi.he@ec.gc.ca
[6] Air Quality Research Division, Environment and Climate Change Canada, Samuel.Pearson@ec.gc.ca
[7] Air Quality Research Division, Environment and Climate Change Canada, jian.feng@ec.gc.ca

Inter-comparison of measurements from NADP and CAPMoN at collocated sites in the U.S. and Canada during 1986-2019

Jian Feng[1], Amanda Cole[2], Gregory A. Wetherbee[3], Kulbir Banwait[4]

Wet deposition monitoring is a critical part of the long-term monitoring of acid deposition, which aims to assess the ecological impact of anthropogenic emissions of SO_2 and NO_x. In North America, long-term wet deposition has been monitored through two national networks: the Canadian Air and Precipitation Monitoring Network (CAPMoN) and the United States National Atmospheric Deposition Program (NADP), for Canada and the U.S., respectively. In order to assess the comparability of measurements from the two networks, collocated measurements have been collected at two sites, one in each country, since 1986 (Sirois et al., 1999; Wetherbee et al., 2009). In this study, we compared the collocated measurements from NADP and CAPMoN instrumentation at the collocated sites located at the Pennsylvania State University (Penn State), U.S., from 1989-2016, and Frelighsburg, Quebec, Canada, for 2011-2019. We also included in the study the collocated daily-*vs*-weekly measurements by the CAPMoN network during 1999-2001 and 2016-2017 in order to evaluate the differences due to sampling frequency alone. The study serves as an extension to two previous ones by Sirois et al. (1999) and Wetherbee et al. (2009).

For the annual deposition measured at the Penn State site during 1986-2019, CAPMoN results were 5%, 16%, and 19% higher for SO_4^{2-}, NO_3^-, and NH_4^+, respectively; 12% higher for H^+; and between 5% and 18% higher for base cations and Cl^-. At the Frelighsburg site, NADP changed the sample collector from the Aerochem Metrics Model 301 (ACM) to the N-CON Systems Inc. Model ADS 00-120 (NCON) in October 2011. For 2002-2011, the inter-network biases were similar to those at the Penn State site. However, after the NADP collector was changed, the annual deposition values from CAPMoN were between 7% and 25% lower than from NADP, except that CAPMoN's annual H^+ deposition was 22% higher during 2012-2019. Understanding the biases in the data for these networks is important for interpretation of continental scale deposition models and transboundary comparison of wet-deposition trends.

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[1] Air Quality Measurement and Analysis Research Section, Atmospheric Science and Technology Directorate, Environment and Climate Change Canada, jian.feng@ec.gc.ca
[2] Air Quality Measurement and Analysis Research Section, Atmospheric Science and Technology Directorate, Environment and Climate Change Canada, amanda.cole@ec.gc.ca
[3] Branch of Quality Systems, US Geological Survey, Denver, CO, wetherbe@usgs.gov
[4] Air Quality Measurement and Analysis Research Section, Atmospheric Science and Technology Directorate, Environment and Climate Change Canada, kulbir.banwait@ec.gc.ca

Equipment Upgrades in the National Atmospheric Deposition Program

Wyatt Sherlock[1], Mark Olson[2], Billy Gates Jr.[3], and Richard Tanabe[4]

The National Atmospheric Deposition Program (NADP) operates 300+ precipitation collectors throughout the United States, Canada, and the Caribbean Islands to measure atmospheric chemical deposition. To ensure the continued longevity of the program, upgrades are being developed for the Aerochem precipitation collectors, which constitute a majority of the collectors within NADP. These upgrades include improvements to the precipitation grid sensor and collector motorbox. Design improvements are needed to increase collector reliability and therefore maximize the production of high-quality, atmospheric deposition data. The current grid sensor design uses out-of-date components that frequently fail in the field. Recent upgrades to the grid sensor printed circuit board (PCB) have increased its reliability and performance while improving network operations by reducing the repair time in the Network Equipment Depot. The sensor PCB upgrades incorporate surface-mounted components, updated electrical connectors and a conformal coating. This sensor design will eventually replace previous generations of sensors that are still deployed across the NADP networks. The precipitation collector motorbox is also being upgraded to improve its reliability in the field. These upgrades include an upgraded PCB that incorporates modern electronic technology, updated electrical connectors and a microcontroller. Furthermore, electrical current sensing circuitry will be used to monitor the current, and therefore torque, exerted by the motor. This would eliminate the need for a clutch, thereby simplifying the motorbox design and improving its reliability. The motor itself is also being upgraded for continuous use at the torque required by the collector (480 oz-in). Field testing of the upgraded motorbox and sensor will take place at the Eagle Heights NADP site in Madison, Wisconsin. These design upgrades, for the grid sensor and motorbox, would enhance the Aerochem collector reliability, help maximize the production of atmospheric deposition data and improve network operations within the NADP.

[1] Wisconsin State Laboratory of Hygiene, wyatt.sherlock@slh.wisc.edu
[2] now with University of Wisconsin, Influenza Research Institute, mark.l.olson@wisc.edu
[3] University of Wisconsin, Physics Electronics Shop, bjgates@wisc.edu
[4] Wisconsin State Laboratory of Hygiene, richard.tanabe@slh.wisc.edu

QA/SAC-Americas Laboratory Intercomparison Study Trends

Evan Rea[1] and Tom Bergerhouse[2]

Quality Assurance/Science Activity Centre – Americas (QA/SAC-Americas), is one of five QA/SACs operates to ensure data quality and support science activities in the World Meteorological Organization Global Atmosphere Watch (GAW). The QA/SAC-Americas seeks to document and help improve the quality of precipitation chemistry measurements from around the world. It conducts semi-annual inter-laboratory comparison studies. The Illinois State Water Survey serves as the Central Calibration Laboratory and manages these studies.

The laboratory intercomparison study (LIS) has been reaching up to 75 laboratories across the world since 1985 with the goal of providing a precipitation-specific quality assurance service for laboratories in the Global Atmosphere Watch program without any cost to participants. The LIS is modeled after a traditional proficiency testing program. Twice each year, samples are shipped to participating laboratories, who then return their results to ISWS. Once the study ends, result submission is closed and participants are scored based on the results of their peers. Unique diagrams visually disseminate the data in addition to tabular data. The QA/SAC- Americas also provides a precipitation chemistry manual and technical advice to participants to help them achieve accurate and unbiased data.

This poster examines trends in the LIS results.

[1] Illinois State Water Survey at the University of Illinois Urbana-Champaign - Health and Environmental Applications Laboratory (HEAL), erea@illinois.edu

[2] Illinois State Water Survey at the University of Illinois Urbana-Champaign - Health and Environmental Applications Laboratory (HEAL), bergerho@illinois.edu

Atmosphere-surface exchange of gaseous elemental mercury (GEM) in a salt marsh estuary in Massachusetts, USA

Ting Wang[1], Inke Forbrich[2], Jun Zhou[3], Joshua Polen[4], and Daniel Obrist[5]

Terrestrial ecosystems serve as important global atmospheric Hg sinks, driven by plant-uptake of atmospheric gaseous elemental mercury (GEM), but the importance of GEM deposition in estuarine ecosystems is largely unknown. The goal of this study is to measure annual atmosphere-surface exchange of GEM in a densely vegetated salt marsh estuary in Massachusetts, USA, using a tower-based micrometeorological flux approach. Our current measurement record spans 258 days from May 3rd of 2021 to January 16th of 2022, at which a catastrophic tower failure occurred due to a major winter storm. We measured highly variable GEM exchange fluxes ranging from -229.3 ng m^{-2} hr^{-1} (i.e., deposition to the ecosystem) to 228.9 ng m^{-2} hr^{-1} (i.e., emissions to the atmosphere), typical of such GEM flux records due to challenge to measure very small GEM fluxes against a large atmospheric GEM background. On average, the marsh experienced a net GEM deposition flux of -0.6 ng m^{-2} hr^{-1} and a cumulative GEM deposition of 3.6 µg m^{-2} over 258 days, which is in contrast to previously reported GEM evasion from aquatic ecosystems attributed to transpiration losses by aquatic macrophytes. Extrapolating GEM flux data to a full year, we estimate an annual GEM deposition of 8.4 µg m^{-2} (range of 5.1 to 11.7 µg m^{-2} yr^{-1}), which is four times larger than gaseous oxidized Hg (GOM) and particulate Hg (PHg) deposition and double that of atmospheric wet deposition (e.g., by rain and snow), so that GEM deposition accounted for 58% (55-59%) of total Hg deposition. GEM deposition in this salt marsh, however, is much smaller than GEM deposition in two nearby forest ecosystems (e.g., 13.4 µg m^{-2} yr^{-1} and 25.1 µg m^{-2} yr^{-1}, respectively). In addition, GEM exchange was not dominated by typical growing-season GEM deposition and showed poor correlation to corresponding CO2 exchanges, suggesting a reduced role of plant uptake of GEM compared to forest ecosystems. In fact, active growing season periods showed variable GEM exchanges, including GEM deposition during early season, emissions during late seasons, and near-neutral fluxes in mid-summer, suggesting high variability of GEM exchange processes. Ongoing work aims to complete an annual GEM flux record and elucidate reasons for highly variable GEM fluxes, including by employing flux footprint analyses to assess surface conditions (e.g., vegetated surfaces, tidal channels, and open water surfaces) impact GEM exchanges in this salt marsh.

[1] Department of Environmental, Earth, and Atmospheric Sciences, University of Massachusetts Lowell, Ting_Wang@student.uml.edu
[2] Marine Biological Laboratory
[3] Department of Environmental, Earth, and Atmospheric Sciences, University of Massachusetts Lowell, Jun_Zhou@uml.edu
[4] Department of Environmental, Earth, and Atmospheric Sciences, University of Massachusetts Lowell
[5] Department of Environmental, Earth, and Atmospheric Sciences, University of Massachusetts Lowell, daniel_obrist@uml.edu

Session 4: Tracking emerging pollutants and climate change indicators

The Emerging Role of Organic Carbon in Atmospheric Chemistry at Whiteface Mountain

Christopher Lawrence[1], Archana Tripathy[2], John Campbell[3], Paul Casson[4], Dan Kelting[5], Elizabeth Yerger[6], Phil Synder[7], and Sara Lance[8]

Whiteface Mountain (WFM) in the Adirondack Mountains in Upstate New York is home to an historic cloud water monitoring program, with the chemical composition of cloud water being measured as far back the 1970s. This site was largely founded to investigate the chemical formation of sulfate (SO_4^{2-}) within cloud droplets and to monitor the progress of the Clean Air Act Amendments of the 1990s. Due to these amendments, there has been a steady decrease in SO_4^{2-} and to a lesser extent, nitrate (NO_3^-) in both WFM precipitation and cloud water. These decreasing trends in SO_4^{2-} and NO_3^- coincide with an increasing trend in organic carbon (OC) in WFM cloud water and increasing OC trend in rainwater at Hubbard Brook, New Hampshire and potentially at Sleepers River, VT. In addition to the increasing OC trend, there is an increasing trend in measured cation/anion ratios, which correlates strongly with OC, indicating a growing but unconstrained role of organic compounds in atmospheric aqueous chemistry. To better constrain this important chemistry and speciate part of the measured OC, organic acids including formic acid, acetic acid, oxalic acid, and pyruvic acid were added to the regular suite of chemical species measured in summertime WFM cloud water. This presentation highlights the growing role of organic compounds in WFM cloud water, as indicated by measurements of OC and organic acids. First, an updated trend analysis of OC from 2009-2021 and organic acids from 2018-2021is reported for cloud water collected at WFM. The potential sources of both organic acids and OC are discussed. We then assess contributions of organic acids to important chemical parameters to the aqueous system, including charge balance and acidity. Possible relationships between organic acids and other measured analytes (in particular, ammonium) are proposed. Lastly, the potential implications of increasing atmospheric aqueous phase OC at WFM and the Northeast U.S. is discussed as it relates to the carbon and nitrogen cycles under rapid environmental changes resulting from both emission reductions and climate change.

[1] University of Albany, celawrence@albany.edu

[2] University of Albany, atripathy@albany.edu

[3] US Forest Service, john.campbell2@usda.gov

[4] University of Albany, pcasson@albany.edu

[5] Adirondack Watershed Institute, dkelting@paulsmiths.edu

[6] Adirondack Watershed Institute, eyerger@paulsmiths.edu

[7] Adirondack Lakes Survey Corp, pksnyder@adirondacklakessurvey.org

[8] University of Albany, smlance@albany.edu

Initial evaluation of cloud water content of per- and polyfluorinated compounds in archived samples from Whiteface Mountain, NY.

John Offenberg[1], Sara Lance[2], Adam Deitsch[3], Christopher Lawrence[4], Paul Casson[5], Melissa Puchalski[6], and Martin Shafer [7]

Per- and polyfluoroalkyl substances (PFAS) are persistent environmental pollutants associated with negative health impacts. Evaluation of atmospheric dynamics, including depositional processes indicate potential importance of atmospheric processes in ecosystem loadings, and as part of potential routes of human exposure. Cloud waters have previously not been a focus of such evaluations of atmospheric dynamics despite PFA having physiochemical properties that indicate potential relevance. Characterizing and understanding the role of cloud waters and corresponding deposition in PFAS dynamics is critical for building an understanding of the impacts of these pollutants on several ecosystem types. These ecosystems may include those for which hydrologic dynamics are influenced or dominated by cloud water inputs, such as high altitude, alpine, or desert, or locations with frequent fog occurrence. To begin to explore cloud waters for PFAS content, targeted isotope dilution LC/MS-MS analysis was performed on archived samples that had been previously collected at Whiteface Mountain, NY during 2018 and 2019. Concentrations of 33 PFAS were measured by isotope dilution LC/MS-MS in fifteen archived cloud water samples (including 1 system rinse), and eight blanks (5 bottle and 3 laboratory). Concentrations, including blank levels, spike recoveries, and performance will be presented, and discussed.

[1] Center for Environmental Measurement and Modeling, United States Environmental Protection Agency, offenberg.john@epa.gov
[2] Atmospheric Sciences Research Center, University at Albany, SUNY-Albany, smlance@albany.edu
[3] Atmospheric Sciences Research Center, University at Albany, SUNY-Albany, adeitsch@albany.edu
[4] Atmospheric Sciences Research Center, University at Albany, SUNY-Albany, celawrence@albany.edu
[5] Atmospheric Sciences Research Center, University at Albany, SUNY-Albany, pcasson@albany.edu
[6] Office of Atmospheric Programs, Clean Air Markets Division, United States Environmental Protection Agency, puchalski.melissa@epa.gov
[7] Wisconsin State Laboratory of Hygiene & University of Wisconsin, mmshafer@wisc.edu

Development and Application of Methods for the Measurement of Black Carbon (BC) Wet Deposition for NADP

Piyaporn Sricharoenvech[1], Ross Edwards[2], Muge Yasar[3], David A. Gay[4], and James J. Schauer[5]

Black carbon (BC) aerosols are light-absorbing particles emitted from incomplete combustion of carbon-containing materials that have a significant impact on the Earth's radiation budget and climate stability. The atmospheric lifetime of these aerosols is primarily controlled by wet deposition, yet the wet deposition of BC aerosols is still poorly understood. The utilization of wet deposition samples collected in long-term and large-scale deposition monitoring networks would better constrain the ability to model and predict the impacts of BC. In this work, we developed methods for measuring BC in wet deposition for the NADP networks. Using weekly wet deposition samples from 196 NADP sites in November 2020, we applied the developed methods to quantify BC concentrations and wet removal rates in North America. The data indicated high BC wet deposition in the Central US, which can be associated with wildfire incidents in the western states. Multiple method validations indicated that the developed methods are capable of long-term and large-scale monitoring of BC in wet deposition while providing practical procedures and high-quality data. Further analysis of the measurements is being used to gain information on relationships between BC and existing NADP wet deposition measurements. The results showed that BC demonstrated strong correlations with NO_3^-, NH_4^+, water-soluble organic carbon (WSOC), SO_4^{2-}, and Ca^{2+}, which is more likely to reveal the association with wildfire incidents in November 2020.

[1] Environmental Chemistry and Technology, University of Wisconsin-Madison, sricharoenve@wisc.edu
[2] Environmental Chemistry and Technology, University of Wisconsin-Madison, pedwards5@wisc.edu
[3] Environmental Chemistry and Technology, University of Wisconsin-Madison, kafadar@wisc.edu
[4] Wisconsin State Laboratory of Hygiene (WSLH), University of Wisconsin-Madison, dgay2@wisc.edu
[5] Environmental Chemistry and Technology/WSLH, University of Wisconsin-Madison, jjschauer@wisc.edu

Atmospheric Processing & Deposition of PFAS: A Synopsis of Recent Studies

Martin M. Shafer[1]

An increasing body of evidence documents measurable levels of a broad range of PFAS compounds in precipitation, which translate into substantial deposition loads to terrestrial and aquatic resources. In many environments these atmospheric deposition fluxes can represent the dominant source of PFAS – as documented in mass-balance studies of lakes and terrestrial ecosystems. However, key gaps in our understanding of atmospheric sources and processing, and deposition fluxes of PFAS remain. This presentation will provide an overview of several recently completed and on-going efforts directed at atmospheric cycling of PFAS; touching on sampling & measurement design, quality assurance aspects, and a synoptic picture of outcomes from the wet-deposition studies. Atmospheric processing that facilitates and enhances wet-deposition of PFAS compounds, e.g. oxidation of precursors will be addressed. The talk will wrap-up with a brief overview of on-going air monitoring (vapor and aerosol phase) efforts for PFAS; a critical complement to the wet-deposition measurements – essential for dry-deposition modeling and furthering our understanding of atmospheric transformations and wash-out of PFAS.

[1] University of Wisconsin-Madison, Wisconsin State Laboratory of Hygiene

Session 5: Links between reductions in deposition and climate resilience

Climate change and air pollution effects on soil and vegetation of the United States

Todd McDonnell[1], Michael Bell[2], Christopher Clark[3], Jack Cosby[4], Charles Driscoll[5], Tara Greaver[6], Brian Knees[7], Jennifer Phelan[8], Timothy Sullivan[9], and Alan Talhelm [10]

Critical loads (CLs) and target loads (TLs) of atmospheric deposition specify the thresholds of air pollution above which damage to ecosystems is expected to occur. Model estimates of CL and TL can vary for a given location and these differences can be important for characterization of ecosystem effects from elevated sulfur (S) and nitrogen (N) deposition and associated timeframes to recovery. Published CLs and TLs based on soil acidity criteria derived from steady-state versus dynamic models for evaluating adverse effects on vegetation communities were compared. Results showed that CLs/TLs from dynamic models generally produce a broader range of values of acid-sensitivity, including lower CLs/TLs, as compared with a steady-state approach. In addition to soil acidification, vegetation communities are often sensitive to changes in climate and fertilization effects from atmospheric N deposition. Individual and combined effects of climate change and N deposition were explored with a case study of the Great Smoky Mountains National Park (GRSM) using the newly developed US-PROPS approach, which is based on species response functions for over 1,500 understory plant species. Efforts are underway to extend the methods developed in this GRSM case study to all National Parks with available mapped vegetation data (n = 192). Similar to understory vegetation species, tree growth and survival depend on a host of environmental conditions in ways that are unique for a given species. Previous efforts have been made to statistically relate tree growth and survival to a limited set of these drivers. Efforts are underway to expand the set of explanatory variables for modeling species-level tree growth and survival to include additional drivers (e.g., light availability; forest disturbances such as fire, disease, and insect infestation; ozone concentrations, etc.).

[1] E&S Environmental Chemistry, todd.mcdonnell@esenvironmental.com
[2] National Park Service, Michael_D_Bell@nps.gov
[3] U.S. Environmental Protection Agency, Clark.Christopher@epa.gov
[4] UK Centre for Hydrology & Ecology, jaccos@ceh.ac.uk
[5] Syracuse University, ctdrisco@syr.edu
[6] U.S. Environmental Protection Agency, Greaver.Tara@epa.gov
[7] E&S Environmental Chemistry, brian.knees@esenvironmental.com
[8] RTI International, jenphelan@rti.org
[9] E&S Environmental Chemistry, tim.sullivan@esenvironmental.com
[10] California Air Resources Board, alan.talhelm@arb.ca.gov

The response of vascular plants in xeric Boreal forests to atmospheric nitrogen deposition depends on precipitation

Andrew M. McDonough[1] and Shaun A. Watmough[2]

Elevated nitrogen (N) deposition in the bituminous sands region of northern Alberta, Canada is localized but expected to increase over time. Here we seek to determine the effects of above canopy N deposition on understory vascular plants in a jack pine (*Pinus banksiana*) stand in a five-year experimental study. Aqueous N (ammonium nitrate) was applied four times annually (May through October) via helicopter above the canopy between 2011 and 2015 across a narrow but environmentally relevant N deposition gradient (0, 5, 10, 15, 20 and 25 kg N ha^{-1} yr^{-1}). Changes in vascular plant species richness, diversity and total vascular cover were best explained by throughfall water flux, but the positive responses to precipitation decreased with increasing N application. *Arctostaphylos uva-ursi* and *Maianthemum canadense* showed positive cover increases in wet years; however, the positive cover expansion at ≥ 5 kg N ha^{-1} yr^{-1} treatments was supressed relative to controls. Total cover expansion was muted in low precipitation years in treatments ≥ 10 kg N ha^{-1} yr^{-1}. In contrast, *Vaccinium vitis-idaea* cover changes ≥ 10 kg N ha^{-1} yr^{-1} were consistently negative. There were no differences in soil net N mineralization rates, plant foliar N or NO_3^- leaching among treatments. We conjecture the extensive moss/lichen layer of the forest floor that accumulates most of incoming N in throughfall allows them to outcompete vascular plants for water during higher precipitation years, effectively reducing vascular cover expansion relative to controls. This work suggests the response of vascular plants in xeric jack pine ecosystems may interact with climate and these interactions should be considered in risk assessment studies.

[1] Ontario Ministry of the Environment and Parks, Andrew.McDonough@ontario.ca
[2] Trent University, swatmough@trentu.ca

The interactive effects of N deposition and drought on plant communities and biogeochemistry in three southwestern Chihuahuan Desert grasslands within Carlsbad Caverns National Park, NM, US

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

Anthropogenic nitrogen (N) deposition has altered the structure and function of many terrestrial ecosystems across the globe. In aridland ecosystems, however, predictions of the effects of N deposition are often challenged due to conflicting responses between aridland N addition studies (i.e., strong, weak, or no response to N). Contrasting responses between these studies may be due to several reasons, such as differences in underlying limiting resources (e.g., water and other nutrients), gaseous N losses, and differences in experimental design (e.g., N loading and duration). In the Southwestern US, Carlsbad Caverns National Park (CAVE) is modeled to be experiencing elevated N deposition levels and is ranked among the most sensitive ecosystems to N enrichment across all US parks. Here, we present findings from a four-year N deposition simulation field experiment, which assessed the effects of realistic N inputs (ambient deposition ~4; low N 6; high N 8 kg N ha^{-1} yr^{-1}) on plant community structure and biogeochemistry in three grasslands within CAVE. Two years into this study, biogeochemical processes (e.g., microbial biomass and function) did not respond to N amendments. However, this lack in response contrasted findings from a complementary N addition laboratory incubation experiment, which showed that microbes from these three grasslands were N limited when given sufficient water. Therefore, to test if this ecosystem may be co-limited by water and N, we supplemented water (+54mm over eight weeks) at a single site during the monsoon season of year three. Still, water and N did not stimulate a response from microbes, but the lack of effect was likely due to a severe record drought that occurred the year we supplemented water. Overall, monsoon season rainfall (a period in which this region receives ~60% of its annual rain) was lower than average. Interannual summer rainfall also varied substantially, ranging from a low of 43mm to a high of 201mm. While uncertain, climate models predict little change in total summer precipitation in this region. However, evidence demonstrates that aridity is increasing, and longer and more intense droughts are occurring in the Southwestern US. Analyses for biogeochemical responses during the final year (i.e., relatively high rainfall year) and all plant community responses are ongoing. Still, responses will likely be complicated by drought and highly variable growing season rainfall between years.

[1] The University of Texas at El Paso, jholguin14@miners.utep.edu
[2] The University of Texas at El Paso, jrmclaren@utep.edu

The impact of severe pollution from smelter emissions on carbon and metal accumulation in peatlands

Jodi E. Newman[1], Patrick A. Levasseur[2], Peter Beckett[3], and Shaun A. Watmough[4]

Peatlands are unique habitats that function as a carbon (C) sink and an archive of atmospheric metal deposition. *Sphagnum* mosses are key components of peatlands but can be adversely impacted by air pollution potentially affecting rates of C and metal accumulation in peat. Here we show that *Sphagnum* cover in peatlands increased with distance from the main copper (Cu) and nickel (Ni) smelter in Sudbury, Ontario. The depth of accumulated peat formed during the 100+ year period of smelter activities also increased with distance from the smelter. Concurrently, peat bulk density decreased with distance from the smelter, which resulted in relatively similar average rates of apparent C accumulation (32 – 46 g m^{-2} y^{-1}). These rates are within the range of published values despite the historically high pollution loadings. Surface peat close to the smelters was greatly enriched in Cu and Ni, and Cu profiles in dated peat cores match known pollution histories much better than Ni that increased well before the beginning of smelter activities likely a result of post-deposition mobility in peat cores.

[1] Environmental and Life Sciences, Trent University, jodinewman@trentu.ca (corresponding author)
[2] Environmental and Life Sciences, Trent University,
[3] School of Natural Sciences and the Vale Living with Lakes Centre, Laurentian University,
[4] School of the Environment, Trent University,

Session 6: Mercury deposition and effects

Investigating gaseous oxidized mercury and particulate bound mercury washout in precipitation events

Peter Weiss-Penzias[1], Gabriel Quevedo, Seth Lyman, Lynne Gratz, Mae Sexauer Gustin

Mercury collected in precipitation (wet deposition of Hg) is mainly from washout of gaseous oxidized mercury (GOM) and particulate bound mercury (PBM), referred together as reactive mercury (RM). Despite there being copious data from the Atmospheric Mercury Network (AMNet) that measures GOM and PBM using Tekran® instruments, there have been few attempts to compare measured RM concentrations from AMNet with Hg in precipitation (Hg_{aq}) measured by the Mercury Deposition Network (MDN). In this study we developed R-code for integrating the raw AMNet (3-hour), the MDN Hg_{aq} (weekly), and the MDN precipitation (1-hour) datasets from 21 shared sites. The goal is to compare RM concentrations from times when it was raining to times when it was dry, to see if there are significant differences, and to determine if RM concentrations are equal to that measured in precipitation. Data analyses are currently ongoing, but preliminary results showed that at one urban-industrial site (NJ30), there was an average of 3.8 pg m^{-3} (91%) increase ($p < 0.0001$) in RM mean concentrations when it was dry compared to when it was raining, looking across 4 years of data. We also examined RM concentrations measured with the Utah State dual channel system at Storm Peak, Colorado, and compared those to MDN Hg_{aq} and hourly precipitation from the nearby MDN site CO97 (using 9 months of data). The Storm Peak data showed that RM concentrations were higher by 30 pg m^{-3} (53% increase) when there was no rain compared to when it was raining ($p = 0.05$). We note that the percent difference between the rain/no-rain categories is smaller than the absolute difference, suggesting that both measurement methods are observing roughly the same relative magnitude of the washout effect, but the KCl denuder is biased low compared to the dual-channel system. If we assume that the RM concentration difference between the rain/no-rain periods represent the RM washout, we can link the washout amount to that observed in precipitation and potentially provide an estimate of a correction factor for the low biased RM at multiple sites.

[1] University of California, Santa Cruz, pweiss@ucsc.edu

Atmospheric mercury deposition to a suburban site in Northern Taiwan

Guey-Rong Sheu[1] and Yu-Hsuan Lin[2]

Concentrations of rainwater and various species of atmospheric mercury (Hg) have been monitored between January 2018 and December 2020 on the campus of National Central University (NCU; 24.9675°N, 121.1856°E, 125 m a.s.l.). NCU is situated in the suburb of Taoyuan City, which is a major industrial city in northern Taiwan. Therefore, although the immediate surroundings of the sampling site are mainly residential and agricultural areas, there are several potential anthropogenic Hg emission sources within the 20 km radius, mostly locating to the north and east of NCU. In this study, we reported the atmospheric Hg deposition at the NCU site in 2018–2020. Dry deposition of speciated Hg was estimated using a bi-directional air-surface flux exchange model for gaseous elemental mercury (GEM) and dry deposition models for gaseous oxidized mercury (GOM) and particulate-bound mercury (PBM). Wet deposition of Hg was calculated as the product of rainwater Hg concentration and rainfall depth. The average concentrations of GEM, GOM, PBM and rainwater Hg in 2018-2020 were 2.32 ng m^{-3}, 7.1 pg m^{-3}, 13.1 pg m^{-3}, and 10.1 ng L^{-1}, respectively. The average annual total dry deposition flux was 36.5 µg m^{-2} yr^{-1}. Among the three forms of atmospheric Hg, GEM was the main contributor to the total dry deposition, contributing about 91.5% to the total, due to vegetation uptake and much higher concentration of GEM than GOM and PBM. The average annual wet deposition flux was 15.2 µg m^{-2} yr^{-1}. The annual dry/wet deposition ratio of 2.4 at NCU indicated that Hg deposition to this area was governed by dry rather than wet deposition.

[1] Department of Atmospheric Sciences, National Central University, grsheu@atm.ncu.edu.tw

[2] Center for Environmental Monitoring and Technology, National Central University, yuna47joy@gmail.com

Changes in Organic Soil Mercury Concentrations Over 20 years at the Hubbard Brook Experimental Forest, New Hampshire

Connor I. Olson[1], Benjamin M. Geyman, Colin P. Thackray, Chris E. Johnson, Elsie M. Sunderland, and Charles T. Driscoll

Over the past half century, air quality management efforts have led to substantial decreases in mercury emission across the United States. Subsequent declines of mercury concentrations in air and precipitation have been well documented, resulting in lower mercury fluxes in wet deposition. The responsiveness of ecosystems to these decreasing inputs is an on-going point of scientific inquiry and for some matrices, considerable uncertainty exists. Organic surface soils are one such example, with relatively little known about how and on what time scale soils react to changes in mercury deposition. Here, we present an analysis of total mercury in organic soils from the Hubbard Brook Experimental Forest (HBEF), spanning over 20 years. Archived soil samples representing the Oie and Oa horizons in the reference watershed (WS6) were oven-dried, milled, and analyzed via direct mercury analyzer. Trends in total mercury concentration varied over time and among organic soil horizons, with overall mercury concentration decreasing. Trends in soil concentration were compared with tree ring analysis and modeled deposition for the experimental area and found to be in agreement. Calculated changes in the organic soil mercury reservoir for the watershed were compared to modeled inputs to estimate the turnover time for organic soils at HBES. Overall, results suggest that organic soils at HBEF are dynamic and responsive to changes in atmospheric emissions.

[1] Syracuse University, connor.i.olson@gmail.com

Linking patterns of atmospheric mercury deposition with bioaccumulation in aquatic ecosystems at a national scale

Collin Eagles-Smith[1], James Willacker[2], Branden Johnson[3], Colleen Flanagan Pritz[4], Sarah Nelson[5], and Colleen Emery[6]

Despite decadal declines in atmospheric mercury emissions and deposition, clear linkages with declines biotic concentrations in the environment remain elusive. We evaluated interannual temporal patterns in biosentinel dragonfly larvae mercury concentrations from more than 100 national park sites across the US, and also assessed the relationships between watershed level atmospheric deposition and dragonfly larvae mercury concentrations from more than 500 paired site-year measurements across the US. Preliminary findings suggested high variability in site-specific temporal trends of dragonfly mercury concentrations, with some sites decreasing, some increasing, and some where there were no directional trends. Additionally, at a site scale there were no relationships between paired atmospheric deposition or concentrations and dragonfly larvae mercury concentrations, suggesting a decoupling between delivery of atmospheric inorganic mercury to a waterbody and the amount of mercury accumulating through the food web. A substantial proportion of this variability can be explained by site-specific biogeochemical characteristics that regulate mercury bioavailability and methylmercury production. However, when accounting for variability associated with individual sampling locations, we found that at a national scale, annual average dragonfly mercury concentrations declined by approximately 16% between 2011 and 2020, and were highly correlated with average annual Hg concentrations in precipitation, which similarly declined by 19% over the same time frame. Collectively our preliminary findings indicate that despite considerable site-level variation in relationships between Hg deposition and bioaccumulation, when integrated at a national scale, temporal patterns in mercury bioaccumulation are consistent with patterns in the amount of mercury delivered in precipitation.

[1] US Geological Survey, ceagles-smith@usgs.gov
[2] US Geological Survey, jwillacker@usgs.gov
[3] US Geological Survey, branden_johnson@usgs.gov
[4] National Park Service, colleen_flanagan_pritz@nps.gov
[5] Appalachian Mountain Club, snelson@outdoors.org
[6] US Geological Survey, cemery@usgs.gov

Improving Simulation of Redox Chemistry and Gas Particle Partitioning of Atmospheric Mercury

Lin Wu[1], Huiting Mao[2], Alfonso Saiz-Lopez[3], Theodore S. Dibble[4], and Zhuyun Ye[5]

It has been a daunting task to reproduce the concentrations and depositions of reactive mercury (RM=gaseous oxidized mercury (GOM) + particulate borne mercury (PBM)) using chemical transport models due in large part to poor representation of the redox chemistry and gas particle partitioning processes. Most three-dimensional chemical transport models neglect the gas particle partitioning process of speciated GOM. We further improved our mercury chemistry mechanism (CMAQ-newHg-Br) by updating the Hg chemical mechanism and implementing an improved gas particle partitioning scheme. Using the modified model with global model output as initial and boundary conditions, we conducted simulations over the northeastern United States for the time period of March-November 2010. The modified model was evaluated through comparison of simulated and observed concentrations and deposition fluxes of gaseous elemental mercury (GEM), GOM, and PBM. The effects of the updated mercury chemistry mechanism and the gas particle partitioning scheme were examined and quantified for spatiotemporal variations in concentrations and wet/dry deposition of mercury in various environments.

[1] Chemistry department, SUNY-ESF, lwu127@syr.edu
[2] Chemistry department, SUNY-ESF, hmao@esf.edu
[3] Institute of Physical Chemistry Rocasolano, CSIC, a.saiz@csic.es
[4] Chemistry department, SUNY-ESF, tsdibble@esf.edu
[5] Department of Environmental Science, Aarhus University, zye@envs.au.dk

Session 7: Technological advances in deposition measurements and monitoring

Nitrate chemistry in the Northeast US: Nitrogen isotope seasonality tracks nitrate formation chemistry

Wendell W. Walters[1], Claire Bekker[2], Lee T. Murray, and Meredith G. Hastings[4]

Despite significant precursor emission reductions in the US over recent decades, atmospheric nitrate deposition remains an important terrestrial stressor. Here we utilized statistical air mass back trajectory analysis and nitrogen stable isotopes (δ15N) to investigate atmospheric nitrate spatiotemporal trends in the northeastern US from samples collected at three US EPA Clean Air Status and Trends Network (CASTNET) sites from December 2016-2018. For the considered sites, similar seasonal patterns in nitric acid (HNO3) and particulate nitrate (pNO3-) concentrations were observed with spatial differences attributed to nitrogen oxide (NOx) emission densities in source contributing regions that were typically ≤1000 km. Significant spatiotemporal δ15N variabilities in HNO3 and pNO3- were observed with higher values during winter relative to summer, similar to previous reports from CASTNET samples collected in the early 2000s for our study region. In the early 2000s, δ15N of atmospheric nitrate in the Northeast US had been suggested to be driven by NOx emissions; however, we did not find significant spatiotemporal changes in modeled NOx emissions by sector and fuel type or δ15N(NOx) for the source regions of the CASTNET sites. Instead, the spatiotemporal trends were driven by δ15N fractionation associated with nitrate formation. Under the field conditions of low NOx relative to O3 concentrations and when δ15N(NOx) emission sources do not have significant variability, we demonstrate that δ15N of atmospheric nitrate can be a robust tracer for diagnosing nitrate formation.

[1] Brown University, wendell_walters@brown.edu
[2] University of California Los Angeles, ckbekker72@g.ucla.edu
[3] Brown University, meredith_hastings@brown.edu

Developing a framework for inferential modeling of dry deposition fluxes across the Ammonia Monitoring Network (AMoN)

Colleen Baublitz[1], Zhiyong Wu[2], John T. Walker[3], and Jesse Bash[4]

The dry deposition of ammonia is an increasingly influential component of the U.S. nitrogen (N) budget. However, its spatiotemporal variability is not well understood because there are few long-term observations of this process. Here we present a new tool that simulates fieldscale dry deposition fluxes across the U.S. Ammonia Monitoring Network (AMoN). This approach employs publicly available, observation-based datasets and the model for Surface Tiled Aerosol and Gaseous Exchange (STAGE). After evaluating this framework using observations at three pilot sites, we use it to investigate the spatiotemporal variability of dry deposition across AMoN in 2018. With additional sensitivity simulations, we also test the influence of individual processes and empirical model parameters on the component (stomatal, cuticular and soil) ammonia fluxes. Preliminary results indicate that the largest total fluxes occur in Colorado, Texas and Utah, generally driven by comparably high measured ammonia concentrations. Ammonia dry deposition is bi-directional, and we find that crop, grass and shrublands become a net source for ammonia in the summer driven by re-emission from stomata for crops and soil for grass and shrublands. The annualized net flux of grass and shrublands is also upward such that AMoN sites with these land cover classes may serve as an under-appreciated source of ammonia. However, the grassland signal is not robust when excluding sites with high concentrations, so that the net dry depositional flux at grasslands over 40 of 44 sites is downward. These results hinge on confident representation of ammonia deposition processes, implying that measurements of ammonia dry depositional fluxes over shrub and grasslands could facilitate improved constraints on the representation of bi-directional ammonia fluxes over the USA. At present, direct measurements of dry deposition remain scarce due to their expense; our framework offers observationally derived, process-based inference for ammonia dry deposition for monitoring sites with low cost, time-integrated concentration measurements.

[1] US Environmental Protection Agency, baublitz.colleen@epa.gov

[2] Research Triangle Institute International, zhiyong319@gmail.com

[3] US Environmental Protection Agency, walker.johnt@epa.gov

[4] US Environmental Protection Agency, bash.jesse@epa.gov

Dry Deposition in NADP: On Rekindling the Flame

Bruce B. Hicks[1]

When NADP requirements for dry deposition quantification became evident in the mid-1970s, a committee was assembled to provide guidance on how to advance from the wet/dry samplers that remained after use in earlier radioactive fallout studies. The committee recognized that routine measurement of dry deposition rates of the key chemical species was not possible using the methods then available, so instead recommended adoption of an inferential approach. This entailed the routine measurement of relevant air concentrations and the archiving of observations of variables known to control the various deposition velocities. A two-level monitoring program was recommended and initiated by NOAA — routine monitoring sites at selected locations (AIRMoN) were supported by more advanced CORE stations where research methods were used to improve the routine operational protocols. The overall activity was implemented as the dry deposition component of NADP. Support for the program was provided by Congress, as part the National Acid Precipitation Assessment Program. The NADP program was a component of NOAA, however the federal funding allotted for it was sent to the EPA. EPA determined that its regulatory activities had no need for the research component, and so a new program arose within NADP – CASTNet. The activities of NADP have since become more closely oriented with the regulatory interests of several of its contributing agencies, and the early scientific focus appears to have suffered.

Current NADP activities will be reviewed in light of the early planning and expectations, with emphasis on the current reliance in NADP on modeling as a substitute for the research products that were originally planned. Uncertainties associated with the estimation of Total Deposition and its related use in the context of Critical Loads will be explored. In all such cases, final products result from model analyses based on determinations made by other models, with only distant guidance from actual observations. It is proposed that a major potential role for NADP is to return to its original scientific focus so that modern advances cab be used to guide the regulatory decisions that now appear to dominate NADP activities. Recent advances in fast-response detection of specific chemical species are particularly exciting. The time is right for NADP to take a giant step forward.

[1] Metcorps/Soil Science, U. of Tennessee, hicks.metcorps@gmail.com

Session 8: Advances in atmospheric chemistry and deposition modeling and critical loads

Empirical Critical Levels of Ozone for U.S. Tree Species and their Uncertainties with Machine Learning

ShihYing Chang[1], Nathan R. Pavlovic[2]*, Joey Huang[3], Kenneth J. Craig[4], Christopher Clark[5], Kevin Horn[6], and Charles T. Driscoll[7]

Exposure to ambient ozone concentrations can impact vegetation through an array of cascading effects. In particular, research has shown that tree species experience biomass loss and increased mortality due to ozone exposure. Recent U.S. Environmental Protection Agency (EPA) analysis (U.S. EPA, 2020) introduced a new causality determination for ecological effects of ozone on tree survival. Robust exposure-response functions have been developed for reduced growth and yield in trees, but the relationship between ozone exposure and tree survival has not been sufficiently investigated. The ozone exposure level at which a harmful effect occurs is referred to as a "critical level." Previously, we used machine learning (ML) to characterize the uncertainty of potential negative impacts on 108 tree species from atmospheric deposition of nitrogen and sulfur. ML modeling allows representation of ecological processes with greater accuracy than other approaches and provides more flexibility in the form of a modeled relationship between deposition and tree growth and survival. In this work, we apply our methodology to understand the impact of ozone exposure on tree growth and survival, and describe the critical levels of individual tree species for ozone. Further, we describe the uncertainty of the critical levels. With increasing interest in ozone impacts on trees, there is a need for additional evidence to understand the relationship (and its uncertainty) between ozone exposure and tree growth and survival. Our work provides a new set of relationships to understand these impacts.

[1] Sonoma Technology, cchang@sonomatech.com
[2] Sonoma Technology, npavlovic@sonomatech.com
[3] Sonoma Technology, jhuang@sonomatech.com
[4] Sonoma Technology, kcraig@sonomatech.com
[5] U.S. Environmental Protection Agency, Clark.Christopher@epa.gov
[6] U.S. Agency for International Development, 3horns@gmail.com
[7] Syracuse University, ctdrisco@syr.edu

* Corresponding author

Development and Evaluation of an Advanced Model for Ozone and Aerosol Deposition

Kiran Alapaty[1], Jesse Bash[2], Bin Cheng[3], Qian Shu[4], Saravanan Arunachalam[5], and J. William Munger[6]

Literature indicates that turbulence strength is under-represented in almost all dry deposition models and the different types of stability functions used are contributing to biases in the estimated dry deposition of ozone and aerosol and are also a source for differences among models' simulations. For aerosol deposition, various formulations have been developed that mostly rely on friction velocity, while some formulations use additional ad hoc factors to represent enhanced impacts of turbulence. However, none were formally linked with the threedimensional (3-D) turbulence.
To alleviate these issues, we developed a 3-D turbulence velocity scale and proposed a set of 3D turbulence-dependent resistance formulations for representing ozone and aerosol dry deposition based on turbulence kinetic energy. New formulations developed are for the aerodynamic and cuticle resistances, and relevant formulations for other resistances were revised to include improved representation of turbulence strength. A revised stomatal resistance includes impacts of dew formation on adaxial surface and particle blockage of abaxial stoma. Further, additional turbulence parameters such as turbulence factor, intensity of turbulence, effective sedimentation velocity, and effective Stokes number are newly introduced into two different aerosol deposition schemes to improve turbulence strength representation.

Decadal measurements (1991-2000) (referred to as **OBS**) available from the Harvard Forest site are used to drive a single-point (box) model and to evaluate O_3 deposition flux estimation by original resistance formulations in Surface Tiled Aerosol and Gaseous Exchange (referred to as **STAGE**) as well as the new version of STAGE that includes above mentioned new/revised resistance formulations (referred to as **TKE-STAGE**). We hypothesized and proved that a new 3D turbulence velocity scale can effectively avoid the usage of stability functions, and that inclusion of an improved estimate of turbulence strength, along with other revisions, leads to a more accurate simulation of O_3 deposition. Decadal averaged monthly & hourly variations of simulated O_3 fluxes by TKE-STAGE are much closer to OBS when compared to STAGE. We found that the bias reduction is attributable to improved representation of processes in the TKE-STAGE formulations. For aerosol deposition, the newly proposed schemes predict stronger diurnal variation of particle dry deposition velocity and are comparable to corresponding short-term measurements while existing formulations indicate large underpredictions. We also find that the incorporation of new turbulence parameters either introduced or added stronger diurnal variability to sedimentation velocity and collection efficiencies values, resulting in higher deposition values during daytime and nighttime predicted by the new schemes when compared to existing schemes. The findings from the research may help improve the ability of dry deposition schemes to better estimate dry deposition fluxes and opens doors for the development of a community dry deposition model for use in regional/global air quality models. The TKE-STAGE formulations will be available as an additional option to choose from in a future release of Box model and Community Multiscale Air Quality (CMAQ) model. Disclaimer: The views expressed in this article are those of the authors and do not necessarily represent the views or policies of US EPA.

[1] U.S. Environmental Protection Agency, Research Triangle Park, alapaty.kiran@epa.gov
[2] U.S. Environmental Protection Agency, Research Triangle Park, bash.jesse@epa.gov
[3] Institute for the Environment, The University of North Carolina at Chapel Hill
[4] U.S. Environmental Protection Agency, Research Triangle Park
[5] Institute for the Environment, The University of North Carolina at Chapel Hill
[6] Harvard School of Engineering and Applied Sciences

Assessing the Impact of Agricultural Emissions on U.S. National Park Air Quality

Bret Schichtel[1], Gustao Cuchiara[2], Michael Barna[3], Jennifer Hand[4], and John Vimont[5]

Agricultural activities are the largest source of ammonia emissions, accounting for about 80% of U.S. emissions, as well as a source of nitrogen oxides (NOx = NO + NO_2) and dust. Together these emissions contribute to excess nitrogen deposition adversely affecting ecosystems; to particulate matter affecting human health, visibility, and climate; to ozone affecting human and plant health; and to dust deposition to snow pack, which can alter the hydrological cycle. In addition, the ammonia emissions partially determine aerosol properties, including acidity and hygroscopicity. Many national parks (NPs) are located in rural lands downwind of intensive agricultural activities and suffer from excess levels of nitrogen deposition, haze, and ozone. With a few notable exceptions, the contribution of agricultural activities to these NP issues is unknown. To address this information gap, the Comprehensive Air Quality Model with Extensions (CAMx) is being used to simulate contributions of agricultural and other sectors to NPs and wilderness areas. Model inputs include the 2016 emissions and meteorology from the Environmental Protection Agency modeling platform. The model results are being evaluated against ambient and wet-deposited air quality data, e.g., from the Interagency Monitoring of Protected Visual Environments (IMPROVE) program, National Atmospheric Deposition Program (NADP), and Ammonia Monitoring Network (AMoN). The model performs similarly to other recent modeling efforts. However, systematic biases in some nitrogen compounds have been identified. The initial source apportionment assessment is focused on the contributions of livestock, fertilizer application, field burning, and other sectors to the total simulated nitrogen deposition. In most NPs, more than half of the total measured nitrogen deposition is composed of reduced nitrogen, i.e., ammonia and ammonium. As expected, the agricultural emissions account for the majority of the modeled reduced nitrogen deposition. Other source sectors such as mobile and wildfires are significant contributors at some NPs.

[1] National Park Service, bret.schichtel@colostate.edu
[2] Cooperative Institute for Research in the Atmosphere, Colorado State University, G.Copstein_Cuchiara@colostate.edu
[3] Cooperative Institute for Research in the Atmosphere, Colorado State University, Mike.Barna@colostate.edu
[4] Cooperative Institute for Research in the Atmosphere, Colorado State University, Jenny.Hand@colostate.edu
[5] National Park Service, john_vimont@nps.gov

Pronounced increases in nitrogen emissions and deposition due to the historic 2020 wildfires in the western U.S.

Patrick Campbell[1]

Wildfire outbreaks can lead to extreme biomass burning (BB) emissions of both oxidized (e.g., nitrogen oxides; NO_x = $NO+NO_2$) and reduced form (e.g., ammonia; NH_3) nitrogen (N) compounds. High N emissions are major concerns for air quality, atmospheric deposition, and consequential human and ecosystem health impacts. In this study, we use both satellite-based observations and modeling results to quantify the contribution of BB to the total emissions, and approximate the impact on total N deposition in the western U.S. Our results show that during the 2020 wildfire season of August–October, BB contributes significantly to the total emissions, with a satellite-derived fraction of NH_3 to the total reactive N emissions (median ~ 40%) in the range of aircraft observations. During the peak of the western August Complex Fires in September, BB contributed to ~55% (for the contiguous U.S.) and ~ 83% (for the western U.S.) of the monthly total NO_x and NH_3 emissions. Overall, there is good model performance of the George Mason University-Wildfire Forecasting System (GMU-WFS) used in this work. The extreme BB emissions lead to significant contributions to the total N deposition for different ecosystems in California, with an average August – October 2020 relative increase of ~78% (from 7.1 to 12.6 kg ha^{-1} $year^{-1}$) in deposition rate to major vegetation types (mixed forests + grasslands/shrublands/savanna) compared to the GMU-WFS simulations without BB emissions. For mixed forest types only, the average N deposition rate increases (from 6.2 to 16.9 kg ha^{-1} $year^{-1}$) are even larger at ~173%. Such large N deposition due to extreme BB emissions are much (~6-12 times) larger than low-end critical load thresholds for major vegetation types (e.g., forests at 1.5-3 kg ha^{-1} $year^{-1}$), and thus may result in adverse N deposition effects across larger areas of lichen communities found in California's mixed conifer forests.

[1] George Mason University/NOAA-Air Resources Laboratory, Patrick.C.Campbell@noaa.gov

Tracking the Fate of Ammonia During Transport from Urban and Agricultural Source Regions to Rocky Mountain National Park

Jeffrey L. Collett, Jr.[1], Da Pan, Lilly Naimie, John T. Walker[2], Amy P. Sullivan[3], Aleksandra Djurkovic[4], and Bret A. Schichtel[5]

Elevated reactive nitrogen (N_r) deposition leads to decreased biological diversity and increased soil acidification in sensitive ecosystems. Ammonia (NH_3) dry deposition is a critical component of N_r deposition, particularly downwind of agricultural areas where high NH_3 concentrations are commonly observed. Rocky Mountain National Park (RMNP) is one such area, where N-sensitive alpine and subalpine ecosystems are impacted by agricultural and urban ammonia sources of the Front Range and northeast Colorado. Upslope flows, driven by synoptic pressure gradients or solar heating of east-facing mountain slopes, transport ammonia emissions from the plains into the park where they can be dry or wet deposited. Our previous studies found a substantial fraction of ammonia and ammonium deposition occurs during these upslope events. Uncertainty remains, however, regarding the efficiency with which ammonia is dry deposited to ecosystems within the park and to land types between the source region and the park. Addressing this uncertainty is complicated by the bidirectional nature of ammonia exchange between the atmosphere and surface. In this study we measured and modeled NH_3 surface-atmosphere exchange to a forest canopy in RMNP (an important ecosystem type within the park) and at a grassland site in the plains (an important ecosystem between the source region and RMNP). Measurements were conducted in summer and fall of 2021 and 2022. Air-surface exchange fluxes of NH_3 and other N_r species (i.e., nitric acid, particulate ammonium, and particulate nitrate) were measured across vertical gradients using URG denuder/filter-pack systems and the modified Bowen ratio method. NH_3 surface-atmosphere exchange models, including multilayer and bi-directional approaches, were also evaluated and optimized using directly measured NH_3 fluxes. Findings from these investigations will be reported as we work toward better understanding the fate of ammonia, including deposition and re-emission, as it travels from urban and agricultural source regions to sensitive Rocky Mountain ecosystems.

[1] Colorado State University, collett@colostate.edu
[2] United States Environmental Protection Agency (USEPA), Walker.Johnt@epa.gov
[3] Colorado State University, Amy.Sullivan@ColoState.edu
[4] United States Environmental Protection Agency (USEPA), djurkovic.aleksandra@epa.gov
[5] National Park Service, bret.schichtel@colostate.edu

Evaluation and optimization of the Surface Tiled Aerosol and Gaseous Exchange (STAGE) resistance model with long term ozone fluxes at multiple sites

Jesse O. Bash[1], Christian Hogrefe[1], Bin Cheng[1], Kiran Alapaty[1], Donna Schwede[1], Mhairi Coyle[2], Erick Fredj[3], Ignacio Goded[4], Orestis Gazetas[5], László Horváth[6], Qian Li[7], Ivan Mammarella[8], Giovanni Manca[4], J. William Munger[9], Ralf Staebler[10], Eran Tas[7], Timo Vesala[11], Tamás Weidinger[12], Zhiyong Wu[1], Leiming Zhang[10], and Olivia Clifton[13]

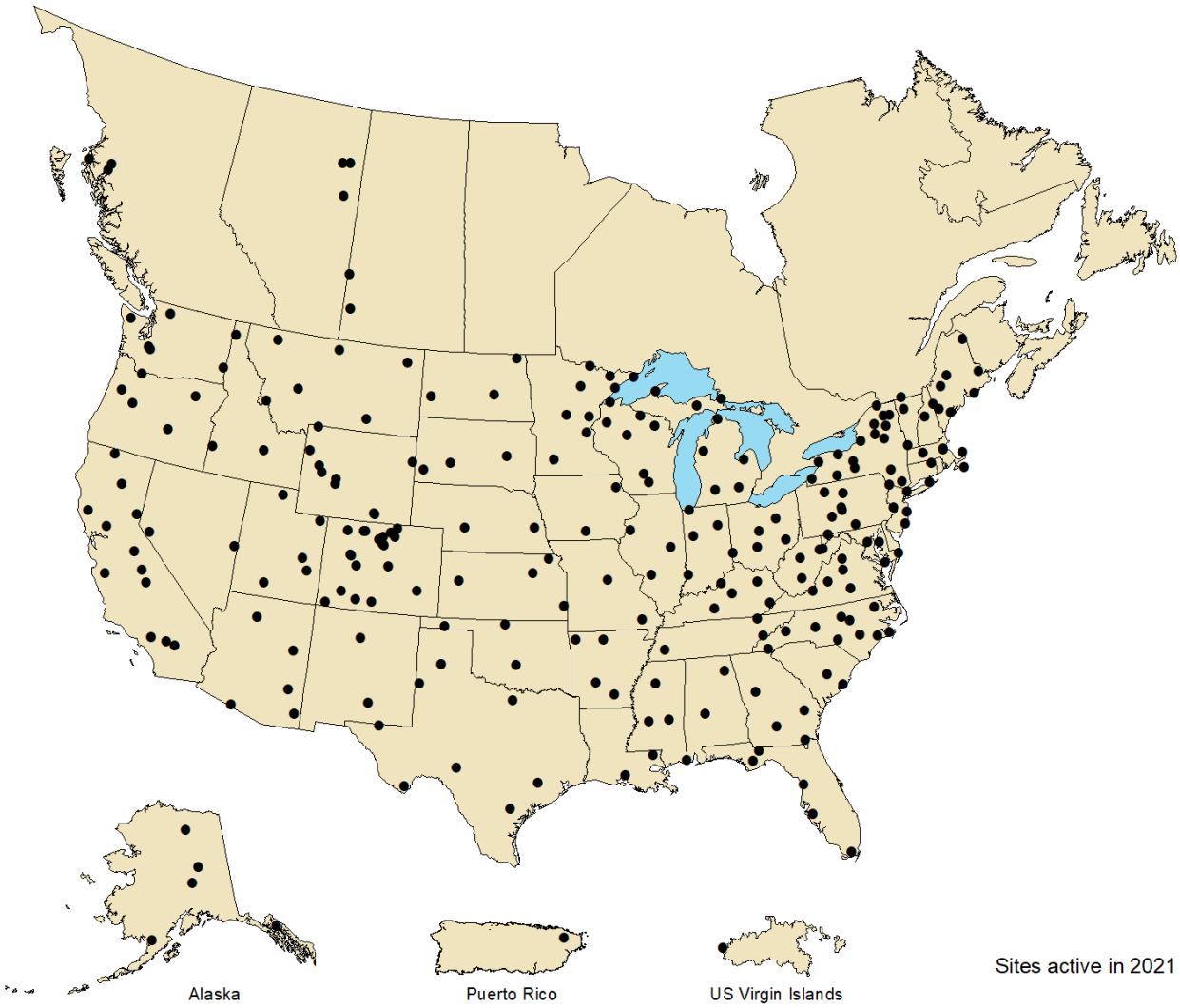
A box model of the Surface Tiled Aerosol and Gaseous Exchange (STAGE) option in CMAQ was applied to meteorological, site, and flux data at seven long term O_3 micrometeorological flux sites. These sites represent evergreen needleleaf, deciduous broadleaf, grass land and shrub biomes/plant functional types. Both estimated fluxes and deposition velocities were evaluated. 2,000 random hourly samples from each site were selected, representing approximately 2.9% to 65.1% of the observed data at the sites, for an aggregate evaluation to prevent the overrepresentation of sites with longer data records. The modeled deposition velocities and fluxes were underestimated in the winter and nighttime conditions and overestimated in the afternoon and summer at most sites. Modeled biases at individual sites using the full record of observations ranged from 43% to -87% and 34% to -85% for fluxes and deposition velocities respectively. The randomly selected data was equally divided into eleven subsets for a ten-fold cross-validation and a validation dataset for the optimization of non-stomatal resistances applied to both deposition velocities and fluxes. Each training sub-set was used to optimize the soil, cuticular, and snow resistance using quasi-Newton and conjugate-gradient algorithms. The cuticular resistance was assumed to be a function of leaf mass per area and relative humidity. Due to a lack of correlation in the observed fluxes and deposition velocities with observed data, soil and snow resistances were assumed to be constant. Optimized model results reduced model biases and errors and increased correlation with observations for both the validation data set and for the range of biases and errors at the modeled sites. Preliminary CMAQ model simulations indicate that this revised parameterization results in substantial improvements in ambient O_3 concentrations when evaluated against network observations.

[1] U.S. EPA, Office of Research and Development, bash.jesse@epa.gov
[2] United Kingdom Centre for Ecology and Hydrology, Bush Estate, Penicuik, Midlothian, EH26 0QB UK, and The James Hutton Institute, Craigiebuckler, Aberdeen
[3] The Jerusalem College of Technology, Israel
[4] Joint Research Center, European Commission, Italy
[5] Scottish Universities Environmental Research Centre (SUERC), East Kilbride
[6] Greengrass - Atmospheric Environment Expert Ltd. fellowship, Hungary
[7] The Institute of Environmental Sciences, The Hebrew University of Jerusalem, Israel
[8] University of Helsinki, Finland
[9] Harvard University, USA
[10] Environment and Climate Change Canada, Canada
[11] University of Helsinki, Helsinki, Finland
[12] Eötvös Loránd University, Hungary
[13] NASA Goddard Institute for Space Studies

2021 Network Site Maps and Listings

National Atmospheric Deposition Program

National Trends Network (NTN)



Site ID	Site Name	Site Sponsor	Start Date
AB32	Fort Mackay	Wood Buffalo Environmental Association	9/13/2016
AB34	Stony Mountain	Wood Buffalo Environmental Association	4/24/2019
AB36	Wapasu	Wood Buffalo Environmental Association	11/5/2019
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

Site ID	Site Name	Site Sponsor	Start Date
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
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
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
CO81	Missile Site Park	Weld County, CO	12/8/2020
CO82	Orchard	Weld County, CO	1/12/2021
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

Site ID	Site Name	Site Sponsor	Start Date
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
FL00	Austin-Cary Forest	U.S. Environmental Protection Agency - Clean Air Markets	3/29/2016
FL05	Chassahowitzka National Wildlife Refuge	U.S. Fish and Wildlife Service	8/27/1996
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	lhambra	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

Site ID	Site Name	Site Sponsor	Start Date
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
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

Site ID	Site Name	Site Sponsor	Start Date
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
MI94	Riverside		11/16/2021
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
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

Site ID	Site Name	Site Sponsor	Start Date
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
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	11/19/1983
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

Site ID	Site Name	Site Sponsor	Start Date
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	Westpoint	U.S. Geological Survey	9/13/1983
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

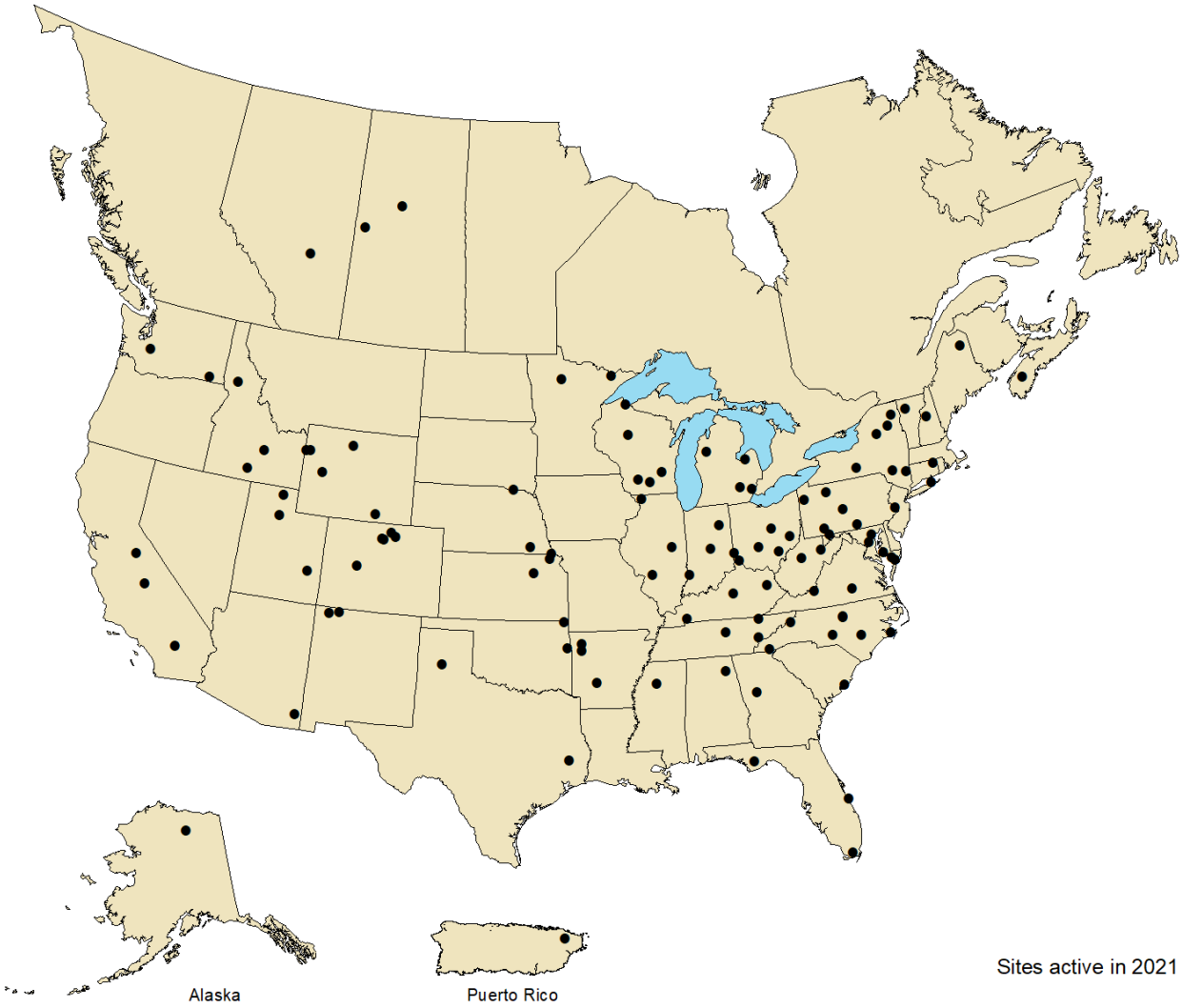
Site ID	Site Name	Site Sponsor	Start Date
OR07	Burns Sagebrush	U.S. Geological Survey	8/3/2021
OR09	Silver Lake Ranger Station	U.S. Geological Survey	8/23/1983
OR10	H. J. Andrews Experimental Forest	USDA - Forest Service	5/13/1980
OR18	Starkey Experimental Forest	U.S. Geological Survey	3/6/1984
OR97	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
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
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

Site ID	Site Name	Site Sponsor	Start Date
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
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
WI06	UW Arboretum	University of Wisconsin - State Laboratory of Hygiene	2/11/2019
WI08	Brule River	Wisconsin Department of Natural Resources	4/22/2014

Site ID	Site Name	Site Sponsor	Start Date
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
WV99	Canaan Valley Institute	National Oceanic and Atmospheric Administration - Air Resources Laboratory	8/27/2019
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

Ammonia Monitoring Network (AMoN)



Site ID	Site Name	Site Sponsor	Start Date
AB35	Elk Island	Alberta Ministry of Environment and Parks	10/15/2019
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

Site ID	Site Name	Site Sponsor	Start Date
IN20	Roush Lake	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
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

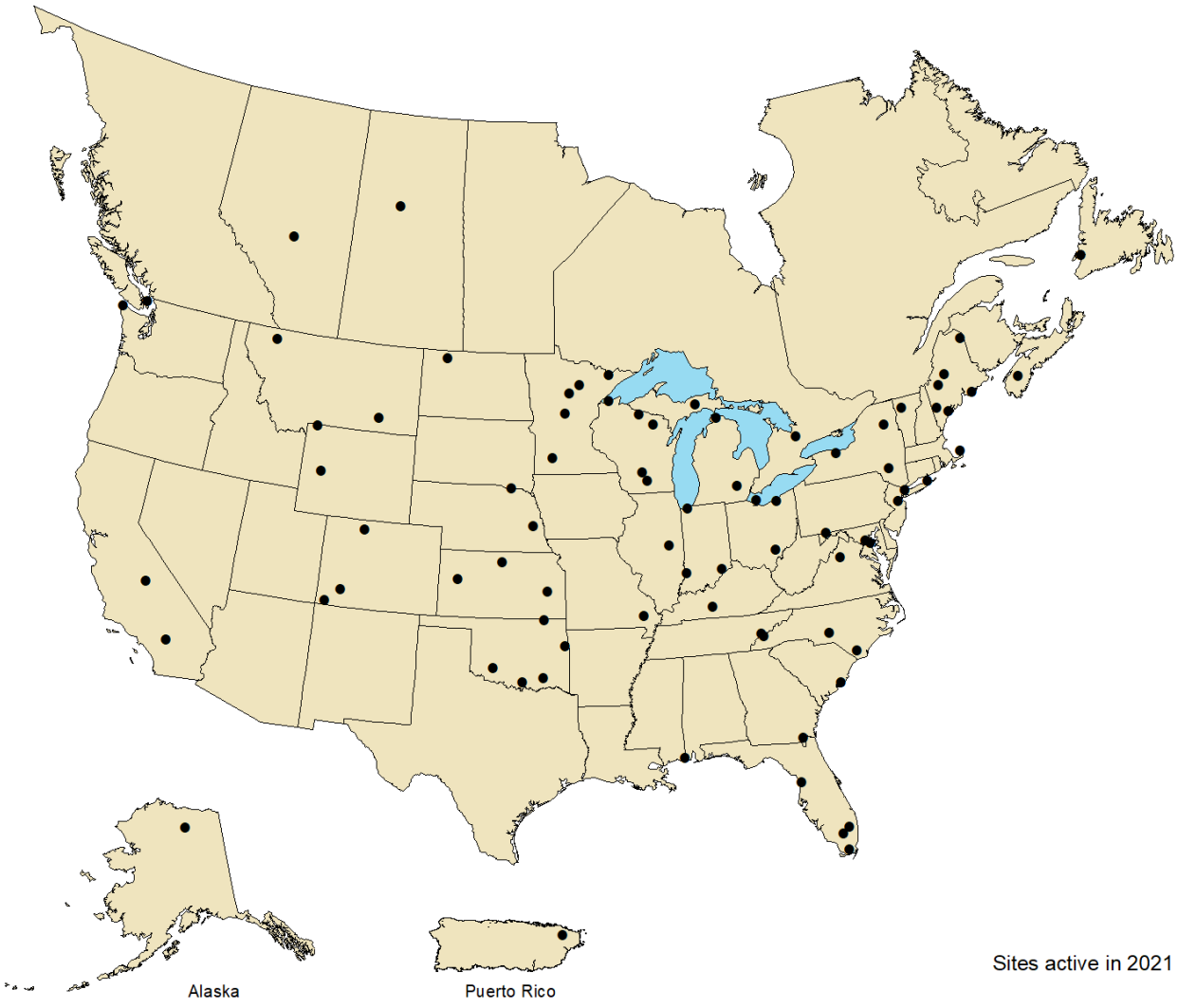
Site ID	Site Name	Site Sponsor	Start Date
NC30	Duke Forest	U.S. Environmental Protection Agency - Clean Air Markets	6/24/2008
NC35	Clinton Crops Research Station	U.S. Environmental Protection Agency - Clean Air Markets	8/5/2008
NC98	Duke Forest Flux Tower	U.S. Environmental Protection Agency - Clean 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

Site ID	Site Name	Site Sponsor	Start Date
OK99	Stilwell	U.S. Environmental Protection Agency - Clean Air Markets	10/30/2007
PA00	Arentsville	U.S. Environmental Protection Agency - Clean Air Markets	10/13/2009
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
WI06	UW Arboretum	University of Wisconsin State Laboratory of Hygiene	2/19/2019
WI07	Horicon Marsh	U.S. Environmental Protection Agency - Clean Air Markets	10/30/2007

Site ID	Site Name	Site Sponsor	Start Date
WI35	Perkinstown	U.S. Environmental Protection Agency - Clean Air Markets	3/29/2011
WI94	Bakken's Pond	Private	8/6/2019
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
WY92	Grand Targhees	USDA - Forest Service	10/1/2019
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)



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
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
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
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
ME00	Caribou	Maine Department of Environmental Protection	5/9/2007

Site ID	Site Name	Site Sponsor	Start Date
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
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

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
OK06	Wichita Mountains NWR	Oklahoma Department of Environmental Quality	11/20/2007
OK31	Copan	Oklahoma Department of Environmental Quality	10/24/2006
OK99	Stilwell	Cherokee Nation Environmental Programs	4/29/2003
ON07	Egbert	Environment and Climate Change Canada	3/7/2000
PA13	Allegheny Portage Railroad National Historic Site	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
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
WA03	Makah National Fish Hatchery	Wisconsin State Laboratory of Hygiene	3/2/2007
WI06	UW Arboretum	University of Wisconsin State Laboratory of Hygiene	3/5/2019
WI08	Brule River	Wisconsin Department of Natural Resources	3/5/1996
WI10	Potawatomi	Forest County Potawatomi Community	6/7/2005

Site ID	Site Name	Site Sponsor	Start Date
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

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Atmospheric Mercury Network (AMNet)

Site ID	Site Name	Site Sponsor	Start Date
AK95	Utqiagvik	National Oceanic and Atmospheric Administration - Air Resources Laboratory	10/8/2021
HI00	Mauna Loa	National Oceanic and Atmospheric Administration - Air Resources Laboratory	12/30/2010
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
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
NY20	Huntington Wildlife	New York State Energy Research and Development Authority	11/21/2007
NY98	Whiteface Mountain	New York State Department of Environmental Conservation	9/30/2020
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

National Atmospheric Deposition Program

Mercury Litterfall Network (MLN)

Sites active in 2021

Site ID	Site Name	Site Sponsor	Start Date
GA09	Okefenokee National Wildlife Refuge	U.S. Fish and Wildlife Service	9/1/2008
IN21	Clifty Falls State Park	Lake Michigan Air Directors Consortium	9/1/2007
IN22	Southwest Purdue Agriculture Center	Lake Michigan Air Directors Consortium	9/1/2015
IN34	Indiana Dunes National Lakeshore	Lake Michigan Air Directors Consortium	9/1/2007
KY10	Mammoth Cave National Park-Houchin Meadow	National Park Service - Air Resources Division	9/8/2021
MD99	Beltsville	National Oceanic and Atmospheric Administration	9/1/2008
MI14	Little Traverse Bay	Little Traverse Bay Bands of Odawa Indians	9/4/2019
MI48	Seney National Wildlife Refuge-Headquarters	U.S. Fish and Wildlife Service	9/1/2008
MN02	Red Lake	Red Lake Nation	9/1/2015
MN16	Marcell Experimental Forest	U.S. Forest Service	9/1/2008
MO46	Mingo National Wildlife Refuge	U.S. Fish and Wildlife Service	9/1/2012
NY20	Huntington Wildlife	State University of New York	9/1/2013
NY67	Ithaca	Penn State	9/1/2017
NY68	Biscuit Brook	NYSERDA	9/1/2008
NY88	Cayuga Nature Center	Penn State	9/11/2017
OH02	Athens Super Site	Lake Michigan Air Directors Consortium	9/1/2007
OH52	South Bass Island	Lake Michigan Air Directors Consortium	9/1/2017
OK99	Stilwell	Cherokee Nation	9/1/2020
SC05	Cape Romain National Wildlife Refuge	U.S. Fish and Wildlife Service	9/1/2008
TN11	Great Smoky Mountains National Park-Elkmont	National Park Service - Air Resources Division	9/1/2007
TX22	Guadalupe Mountains National Park Frijole Ranger Station	National Park Service - Air Resources Division	9/1/2021
WI01	Odanah	Bad River Band of Lake Superior Chippewa	9/1/2012
WI10	Potawatomi	Forest County Potawatomi Community	9/1/2017

NADP Program Office
Wisconsin State Laboratory of Hygiene
University of Wisconsin-Madison
465 Henry Mall
Madison, WI 53706
http://nadp.slh.wisc.edu