Preparation for the Rocky Mountain National Park Tour

Air Quality Issues in the US National Parks – Applied Science (Part I)

Elk, Cub Lake Trail, RMNP, CO, 29 May 2006 (KG)

Kristi Gebhart, **Mike Bell**

& Bret Schichtel

National Park Service

Air Resources Division

NCAR Advanced Study Program,

Summer Colloquia

29 Jul 2016, Boulder, CO

2016 National Park Service CENTENNIAL

NATIONAL PARK SERVICE

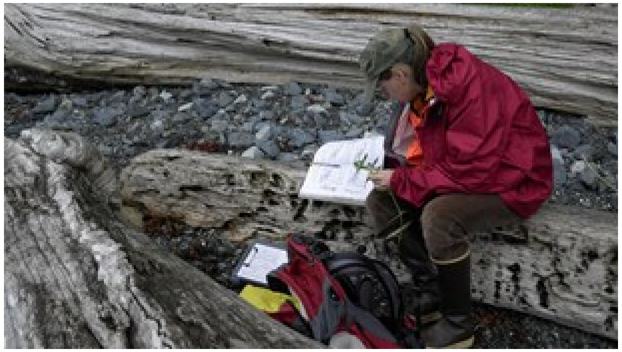
Outline

- Who is the Air Resources Division?
- Pollutants of NPS Concern
- Ecosystem Effects
  - Rocky Mountain Case Study
- Data Driven Assessments
  - Regional Haze
  - Nitrogen Deposition
  - Source Apportionment

Natural Resource Stewardship and Science Directorate (NRSS)

- Provides scientific, technical, and administrative support to national parks for the management of natural resources.

- NRSS develops, utilizes, and distributes the tools of natural and social science to help the National Park Service (NPS) fulfill its core mission: **the protection of park resources and values.**



Air Resources Division

Air Resources Division

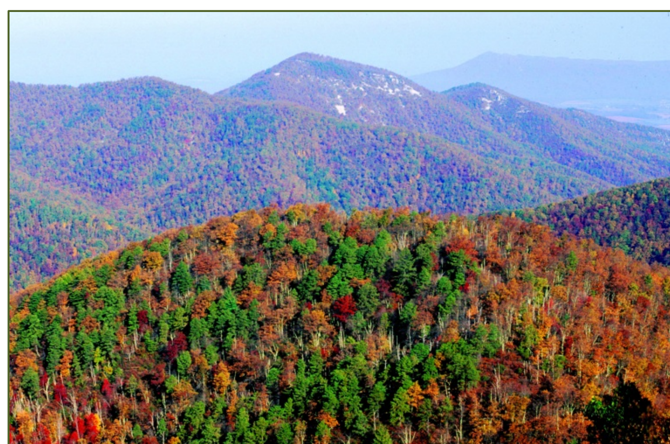
- **Breathe Easy**
  - *Visitor Health*
- **See Far**
  - *Visitor Experience*
- **Let Nature Thrive**
  - *Protect natural systems*

Why do we do research?

- **Understand**
  - What causes poor air quality/visibility?
  - What are the ecosystem responses to air pollution?
- **Share**
  - Transfer the results to other parks
- **Improve**
  - How is this data used to improve air quality?
  - How can this knowledge help us improve management?

Parks as Laboratories

- 270 Inventory and Monitoring Parks
- National Distribution
- Natural Variation
  - Climate
  - EcoRegions
  - Geology

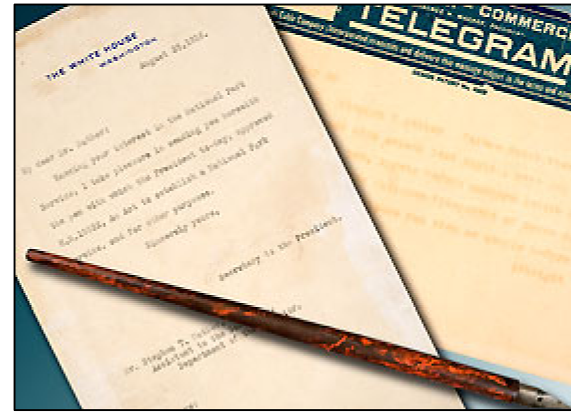


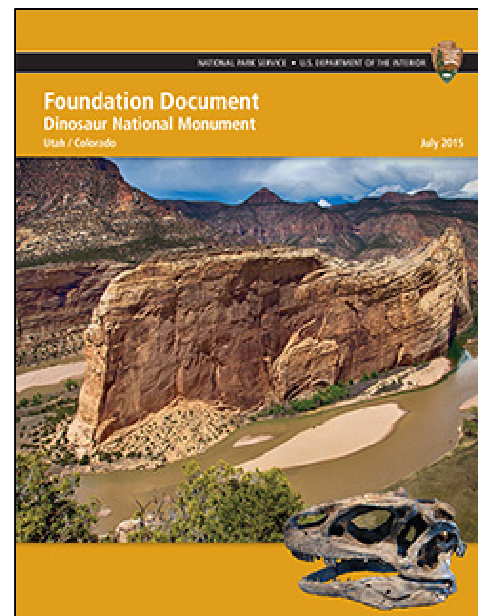
Parks as Icons

- Engage Public interest
- Preserve iconic species and habitats

Enabling legislation

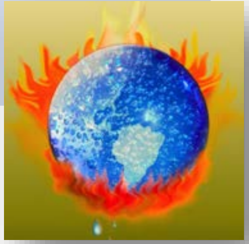
- **Organic Act of 1916**
  - "…will leave them unimpaired for the enjoyment of future generations"
- **Clean Air Act of 1963**
  - Amendments in 1970, 1977 and 1990
- **Foundation Documents**
  - Park specific, why a park was founded
  - What resources are most important





Air Quality Issues in National Parks?

Issue	Major Sources	Major Impacts On
Excess Nitrogen Deposition	Mostly Fossil Fuel Combustion, Agriculture	Ecosystems
Smoke	Intermittent control burns and wild fires	Visibility, human health, (Nitrogen, Ozone, PM)
Dust	Disturbed soils, agriculture, off road vehicles, drought, alternative energy	Visibility, human health
Ozone	Mobile Sources, fossil fuel burning, oil & gas extraction	Ecosystems, human health
Fine Particles	Fossil fuels, mobile sources, fires, oil & gas, agriculture	Visibility
Toxics including Mercury	Coal Combustion, agriculture (pesticides), industrial activities, oil & gas	Ecosystems, human health (fish consumption)
Climate Change	Mostly fossil fuels	Ecosystem stress, emissions (VOCs, biogenics, dust)



Work with regulators

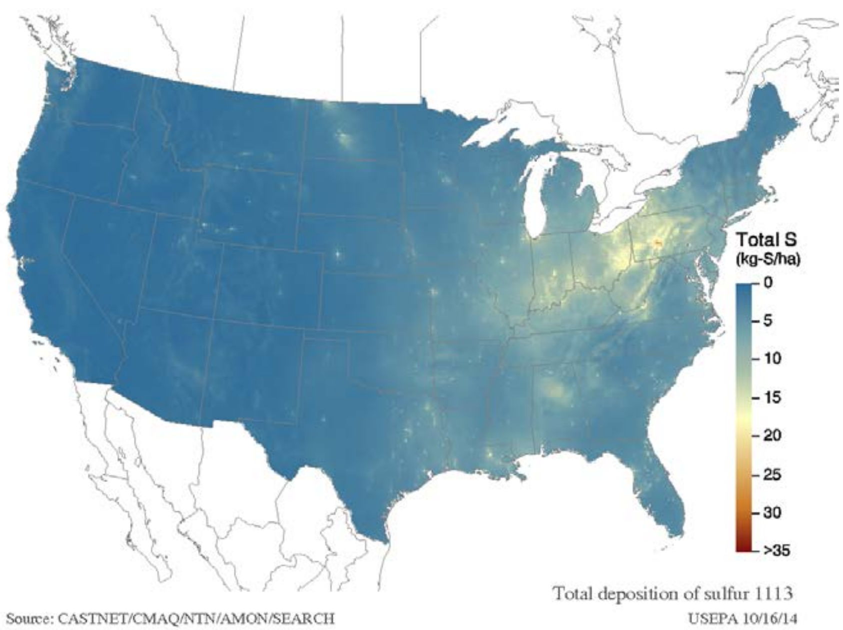
- NAAQS secondary standards
  - Based on human welfare
- Oil and gas regulations
  - Increasing impacts, how to regulate
- Regional haze rule
  - Reduce visibility impairment
- Agricultural impacts
  - Unregulated, but growing concern

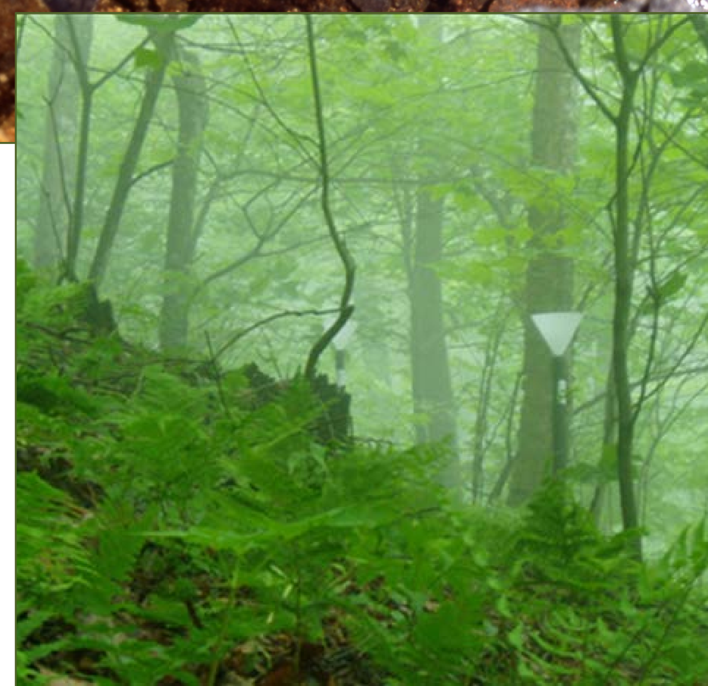
Nitrogen Deposition

- Eutrophication
  - Terrestrial and aquatic
- Direct Species loss
  - Lichen

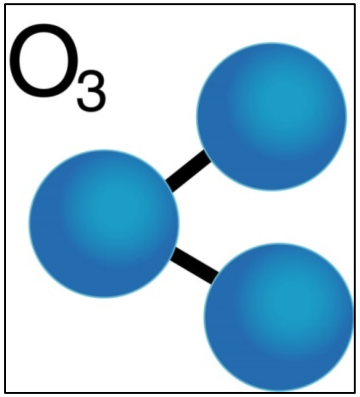
Sulfur Deposition

- Acidification
  - Surface water
  - Soils

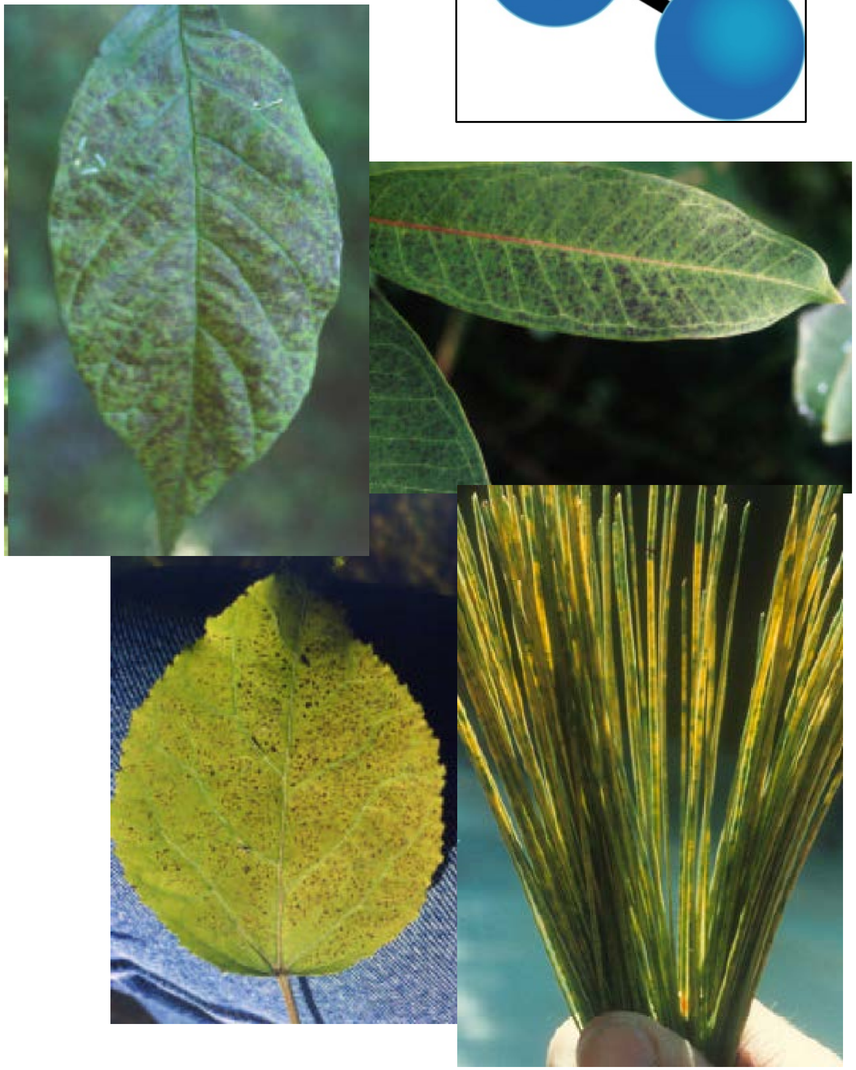




Ozone



- Visitors and employees being outside in high ozone concentrations
- Health of vegetation
  - Triad concept of injury
- Visitor experience and enjoyment

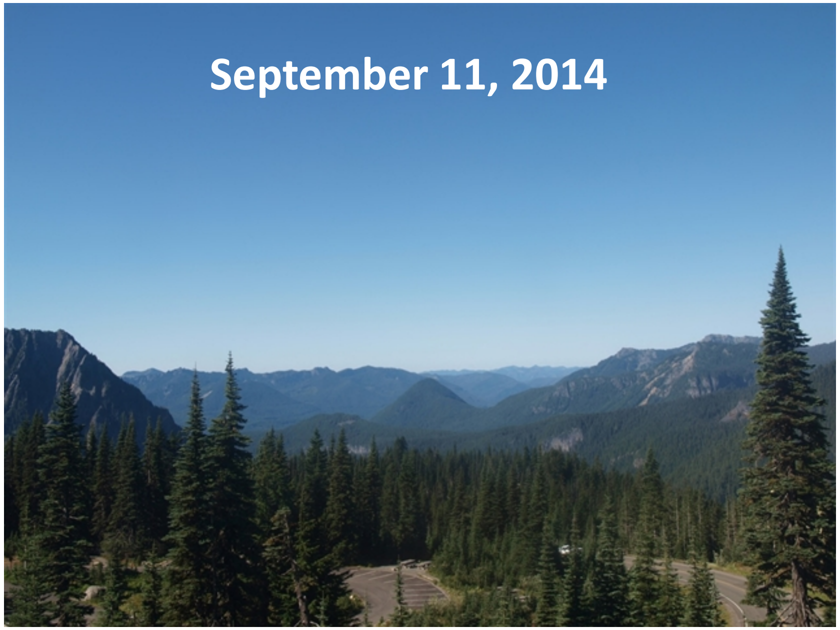


Visibility

- Historically defined as:

  "the farthest distance one can see a large black object against the background sky."

- Also describes how "well" we can see the colors, textures, forms, and detail in distant landscape features.



Mount Rainier Webcam Images

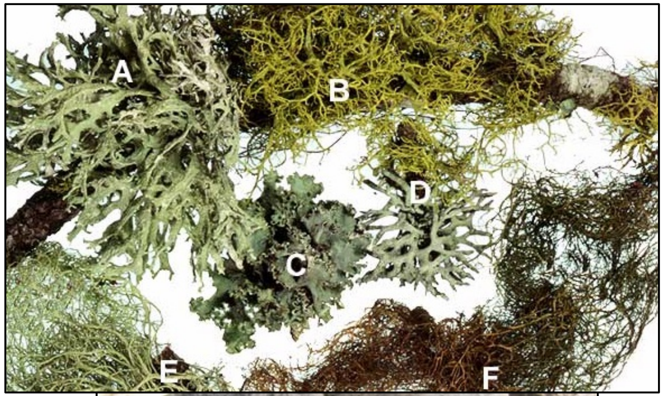
Mercury

- Can impact Human health / faunal health
  - Bioaccumulation up the food chain
  - Use dragonfly larvae as biosentinel

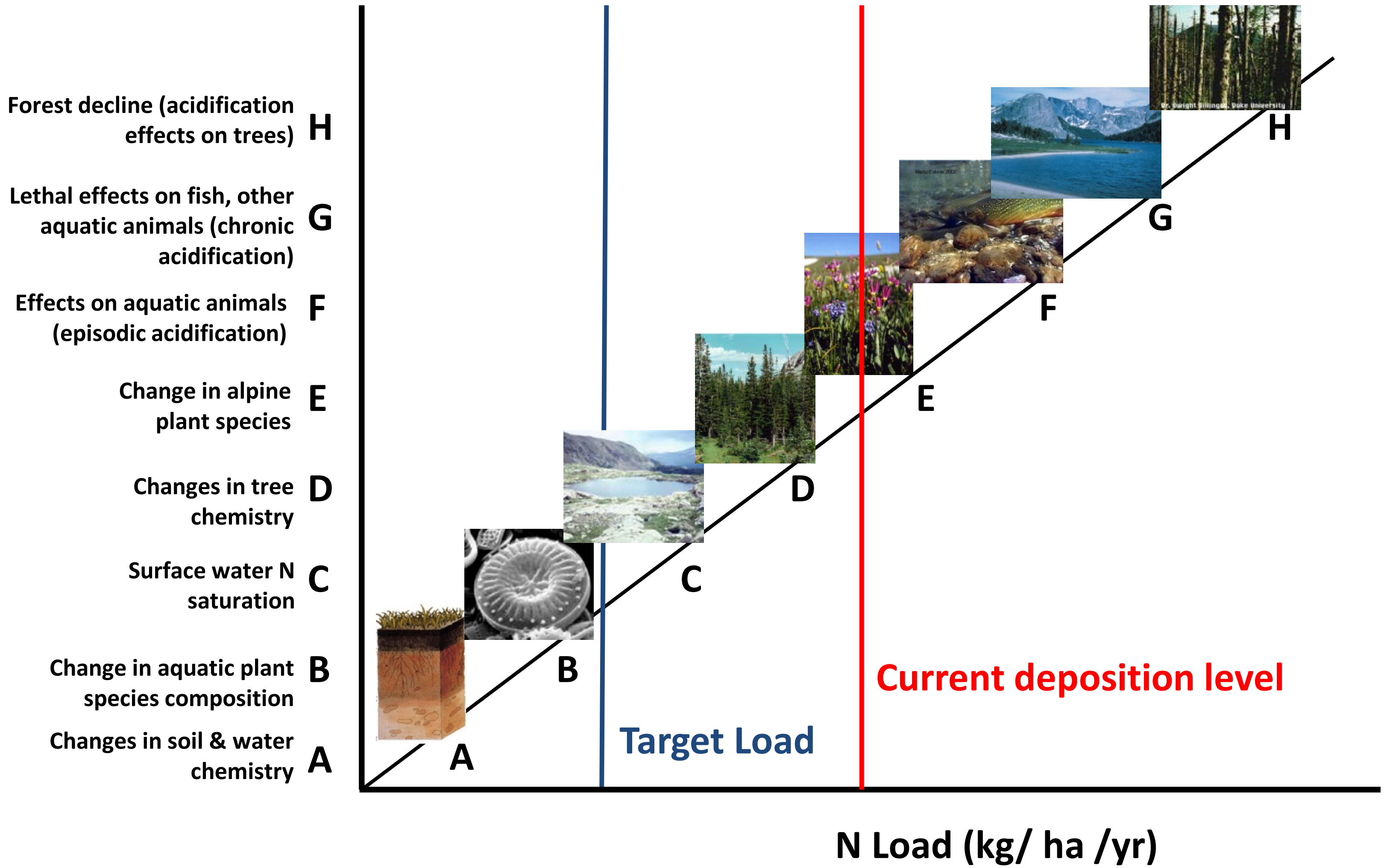
Critical Loads

- *The threshold of deposition below which specified harmful ecological effects do not occur.* (Porter et al. 2005)

Photos: Edith Allen, UC Riverside



Critical Loads



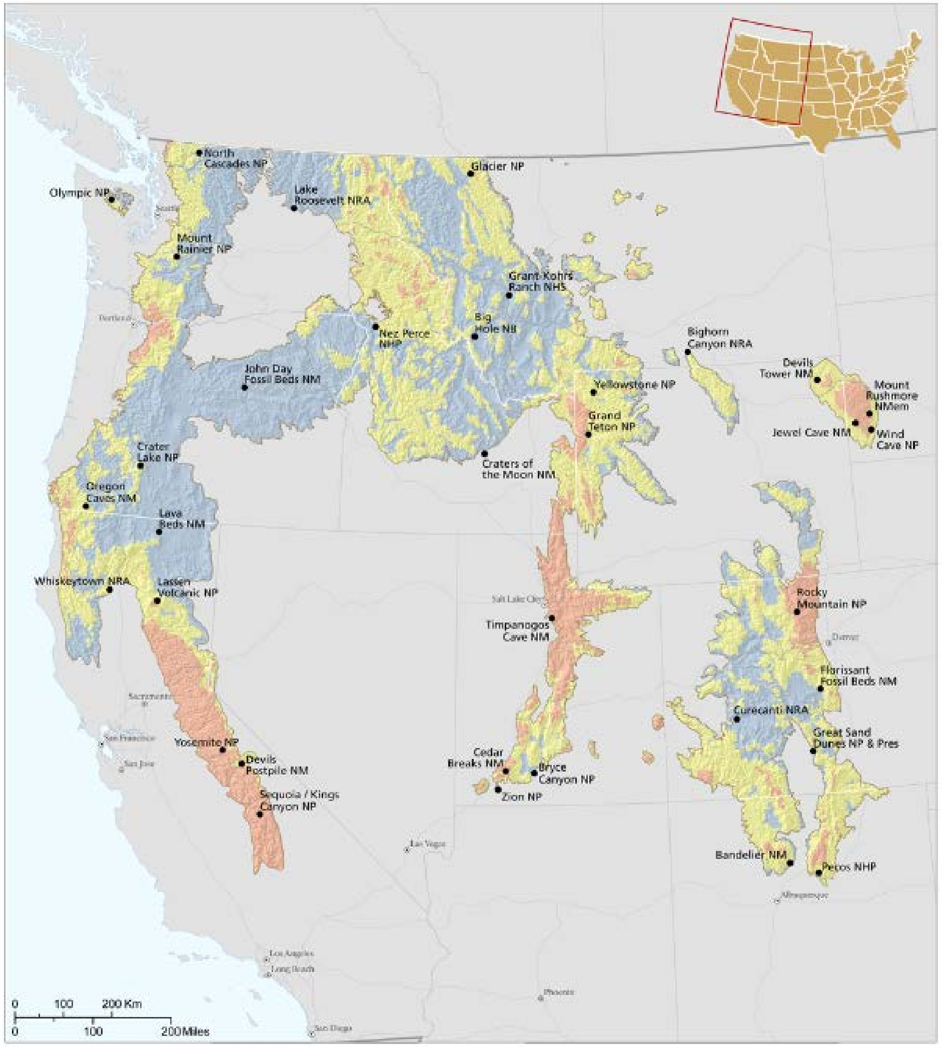
Critical Load

Minimum: **4.0** kg/ha/yr
Maximum: **17.0** kg/ha/yr

Confidence

Rated by Pardo et al. as **"Reliable"**: a number of published papers of various studies show comparable results.

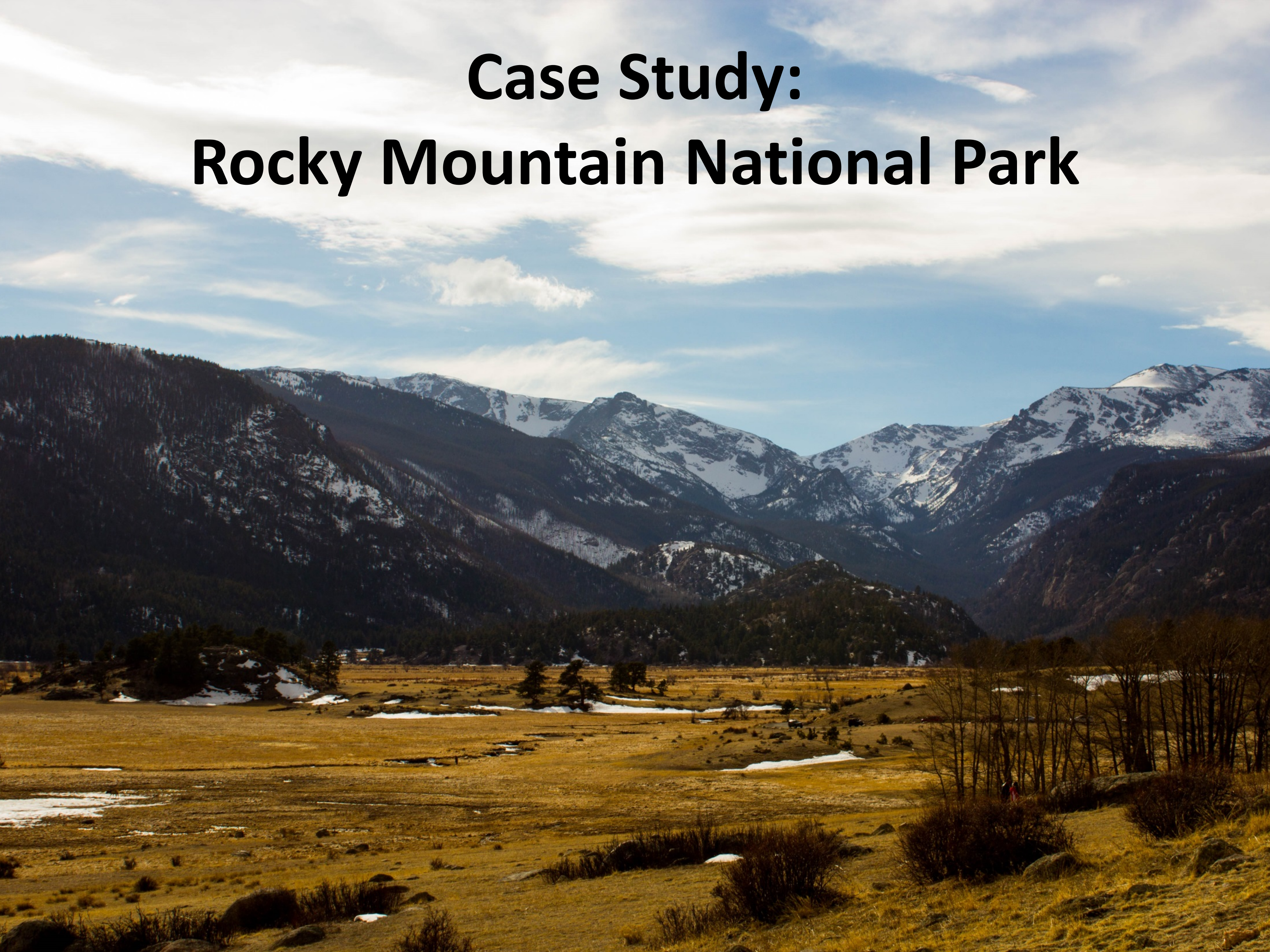
Critical Load Maps



Northwestern Forested Mountains - Forest Critical Load Exceedance (Click map to enlarge)

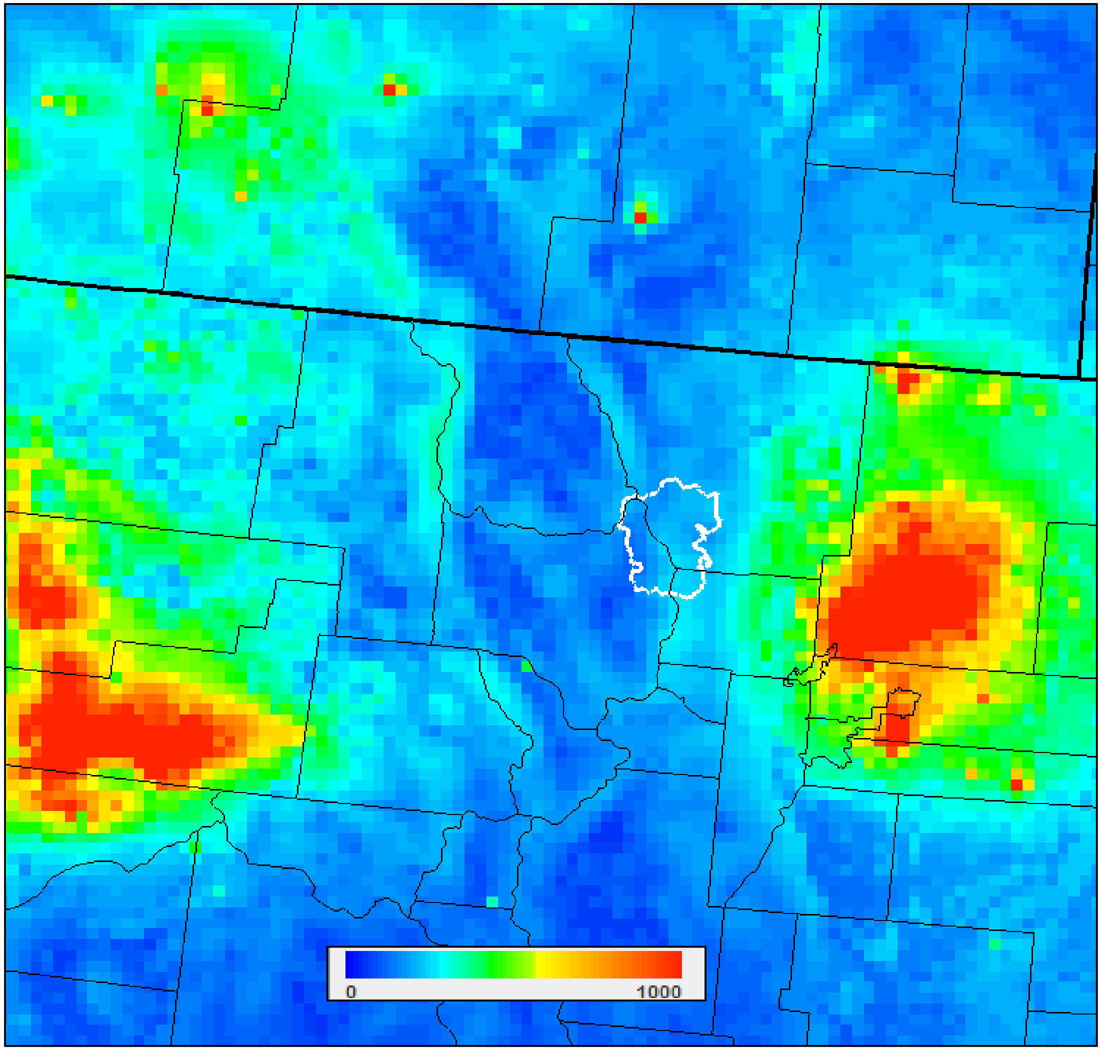
- **Deposition Below Critical Load**
- **Deposition At MinimumCritical Load (± 1.0 kg/ha/yr)**
- **Deposition Between Min. and Max. Critical Load**
- **Deposition Above Maximum Critical Load**

Case Study:
Rocky Mountain National Park



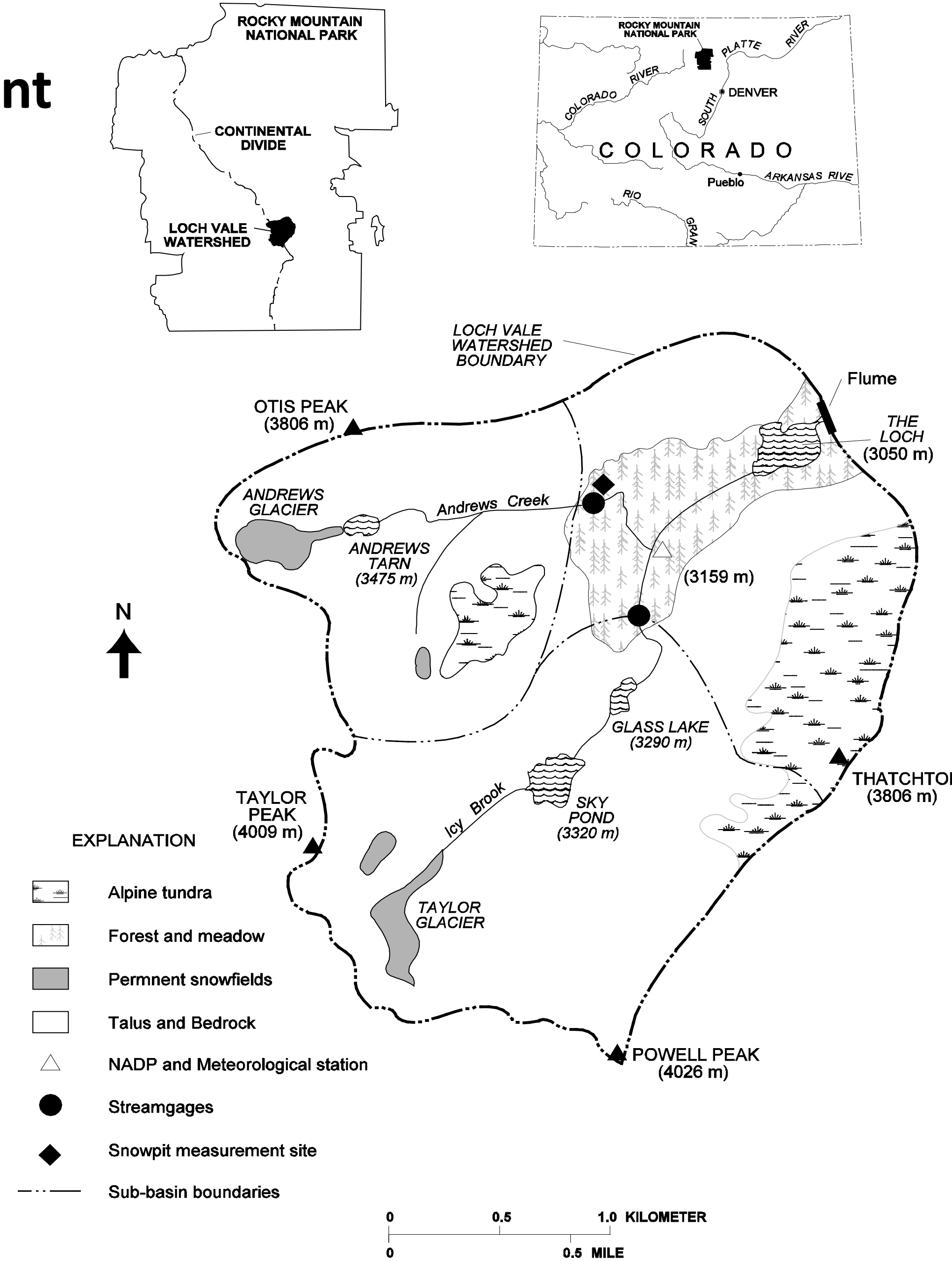
Rocky Mountain NP

- Between the Piceance and Denver-Julesberg O&G basins
- Up to 0.3 kg/ha/yr N



Deposition and Ecosystem Effects of N: Research relevant to Rocky Mountain NP:

- Loch Vale Research **Watershed**
- USGS **Snow** Sampling along Continental Divide (MT to NM)
- USFS, USGS, and NPS **Lake** Sampling in Colorado Parks, Wildernesses and Forests
- UC Boulder Niwot Ridge Studies



Loch Vale

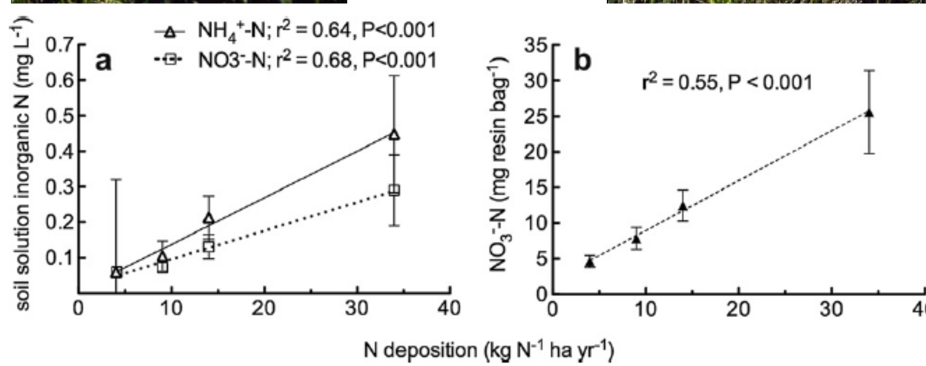
- Monitoring began in 1982 and addresses watershed-scale ecosystem processes, particularly as they respond to atmospheric deposition and climate
- Monitoring:
  - Climate
  - Hydrology
  - precipitation chemistry
  - surface water quality

http://nrel.colostate.edu

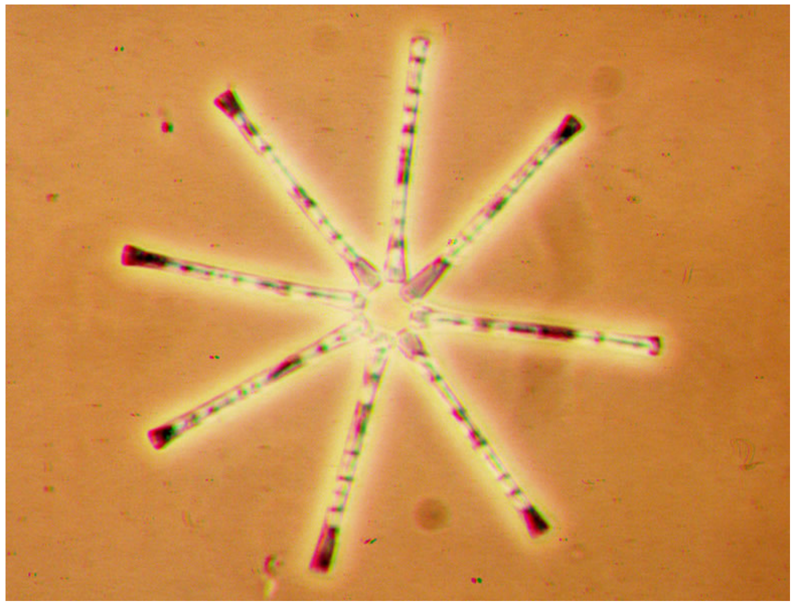
Alpine health

- **3-4 kg/ha/yr** is N critical load for faster growth of alpine grasses

(Bowman et al. 2012)

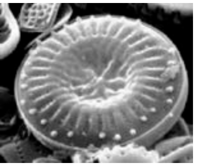


Aquatic plants are first indicators of ecosystem changes from N fertilization



Changes in aquatic plant species on east side of park represent biological evidence that high elevation lakes on the east side of the park have shifted from natural undisturbed systems to disturbed (weedy) systems.

Significance of Ecosystem Changes in Rocky Mountain National Park…



Aquatic Plant Species Shift- Changes in aquatic plant species represent biological evidence that high elevation lakes on the east side of the park have shifted from undisturbed to disturbed (weedy) systems- which are "unnatural" at these sites .

Stage 2 Nitrogen Saturation in soils and streams- Stream nitrate consistently above zero indicates “stage 2+ nitrogen saturation” (in progression of nitrogen effects to ecosystems between stage 0-3). This shows stream conditions are declining and will likely worsen as deposition continues.

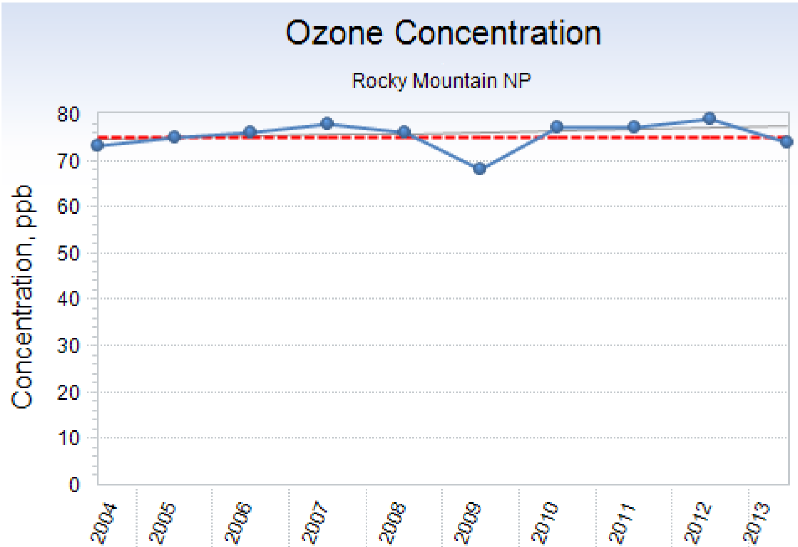
Elevated Soil Microbial Activity- When sufficient N accumulates in forest soils- biological activity cranks up and produces even more N in a feedback loop. This unnatural change has already occurred in Front Range soils on the east side and is an indication of “unhealthy” ecosystems in those areas.

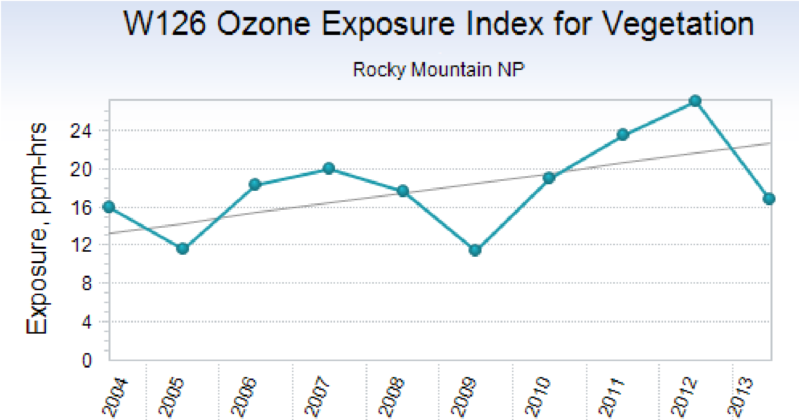
Elevated N in spruce tree needles- Studies in the eastern US show that changes to tree chemistry like those beginning in Rocky Mountain NP can cause increases in insect and disease infestation, reduce health of forests, and cause eventual forest decline (tree death) if soils acidify.

Shift from alpine flowers to grasses- Reduction of wildflowers and increase in grasses in Front Range alpine ecosystems changes food and habitat for animals, is likely to affect visitor enjoyment of alpine areas, and is "unnatural".

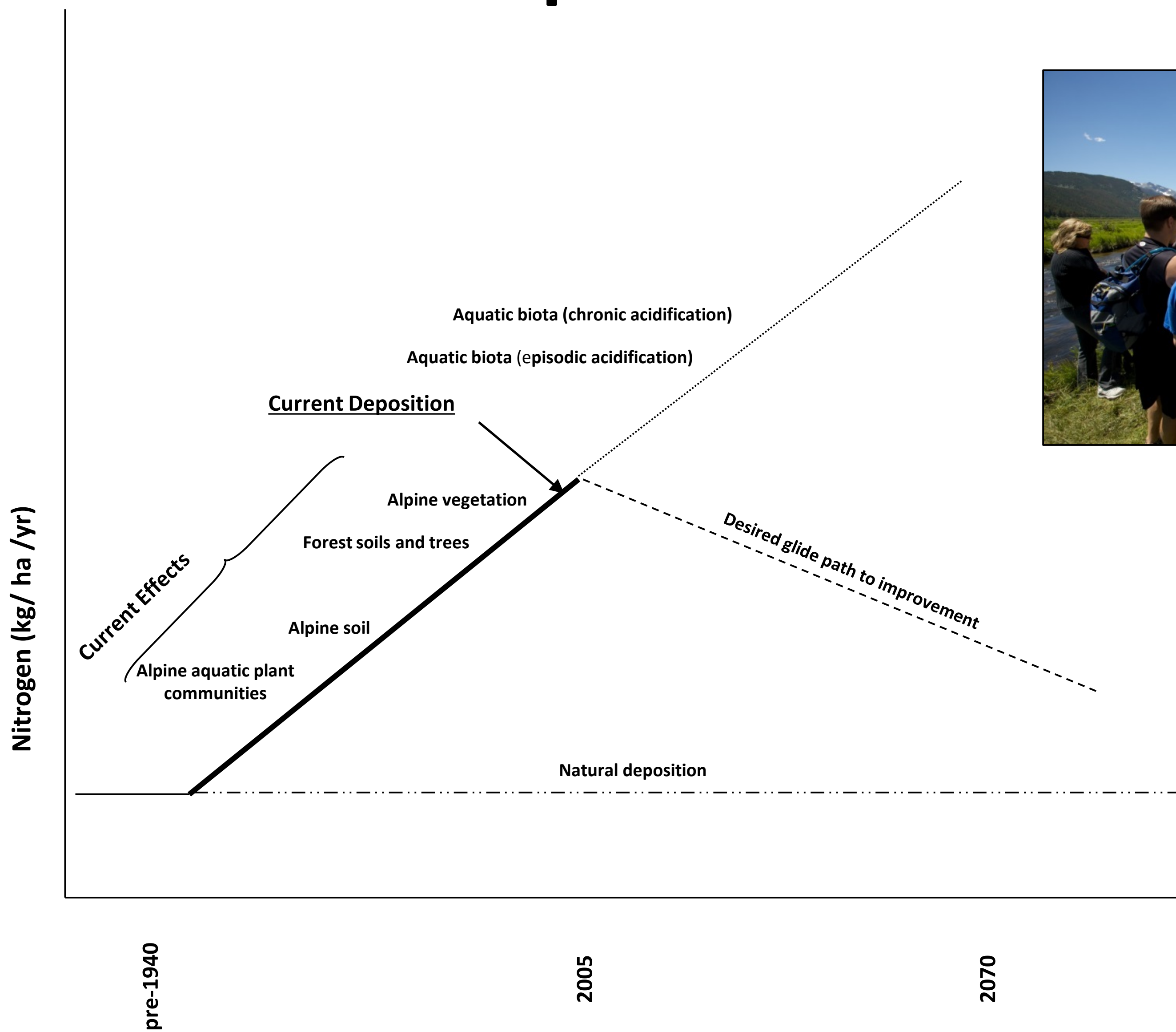
ROMO – Ozone damage

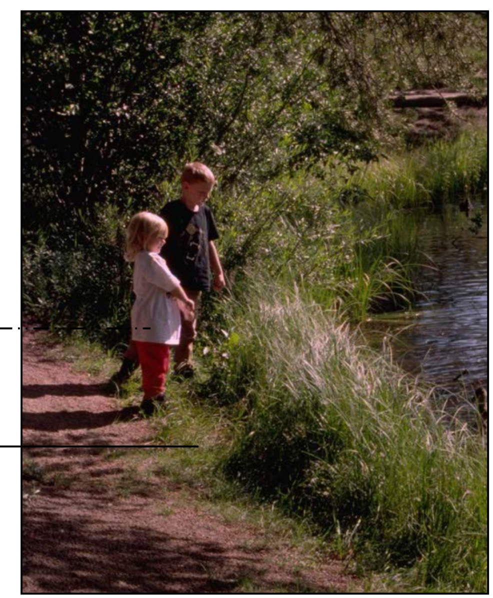
www.slu.edu



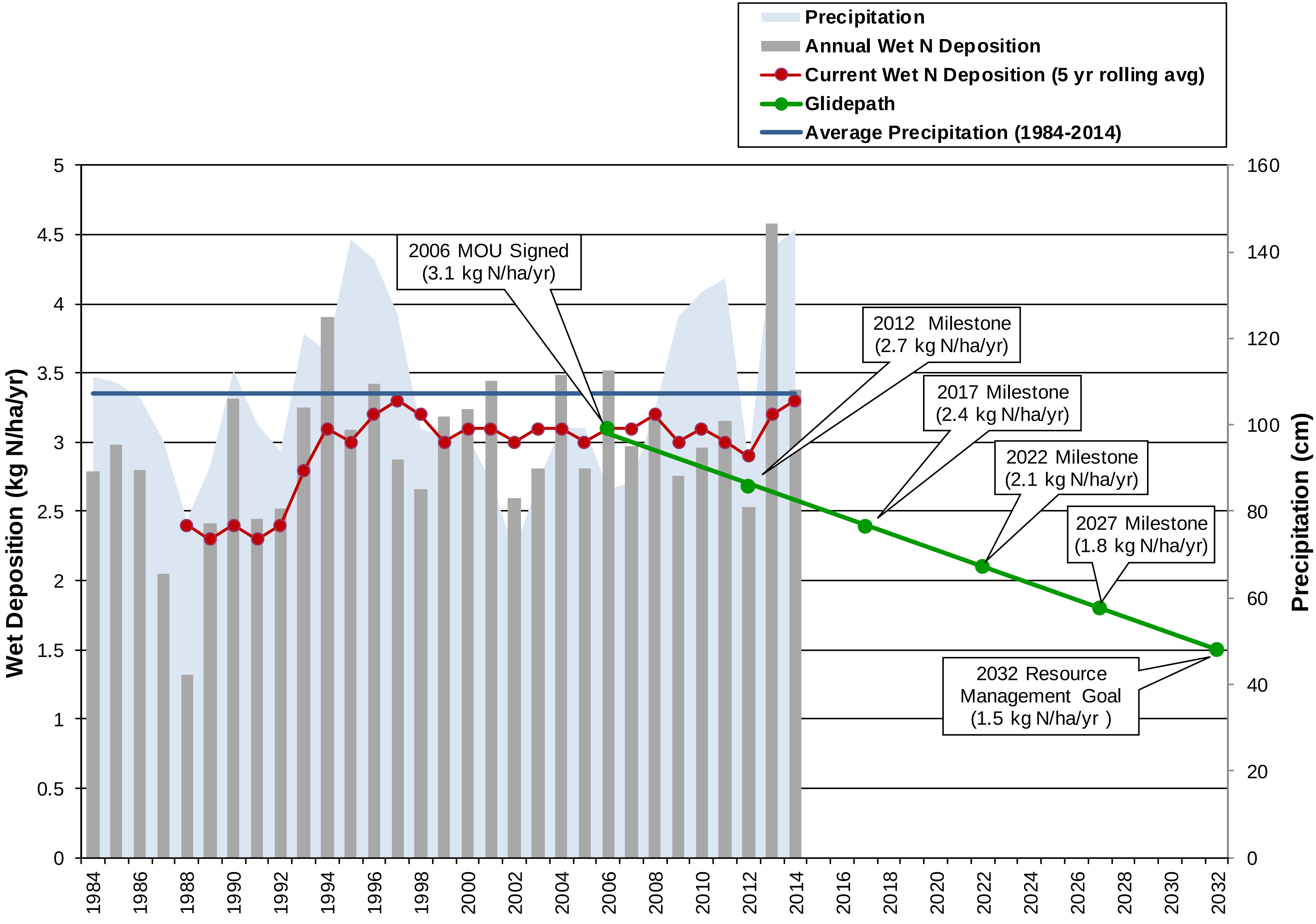


What's in store for "future generations" of park visitors?





RMNP Loch Vale Nitrogen Deposition & NDRP Glidepath



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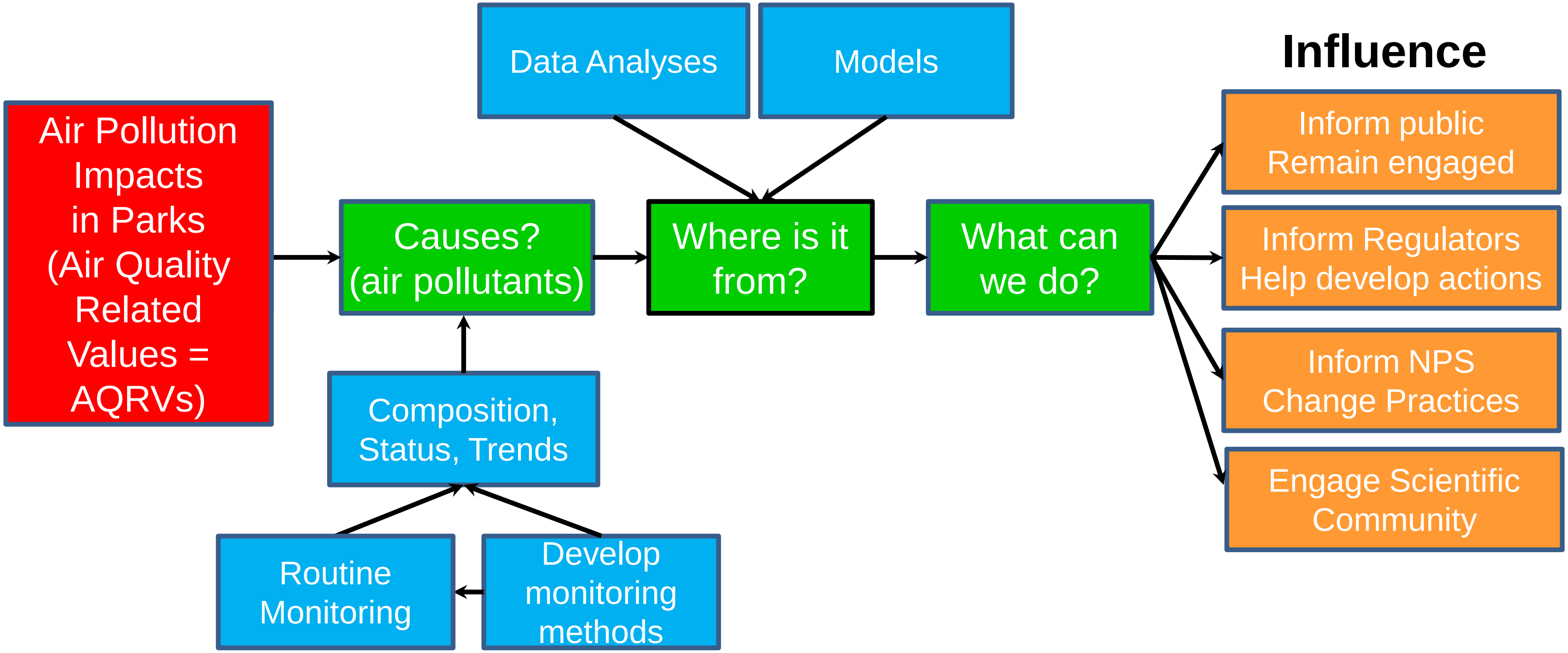
2016 National Park Service Centennial

Data Driven Assessments



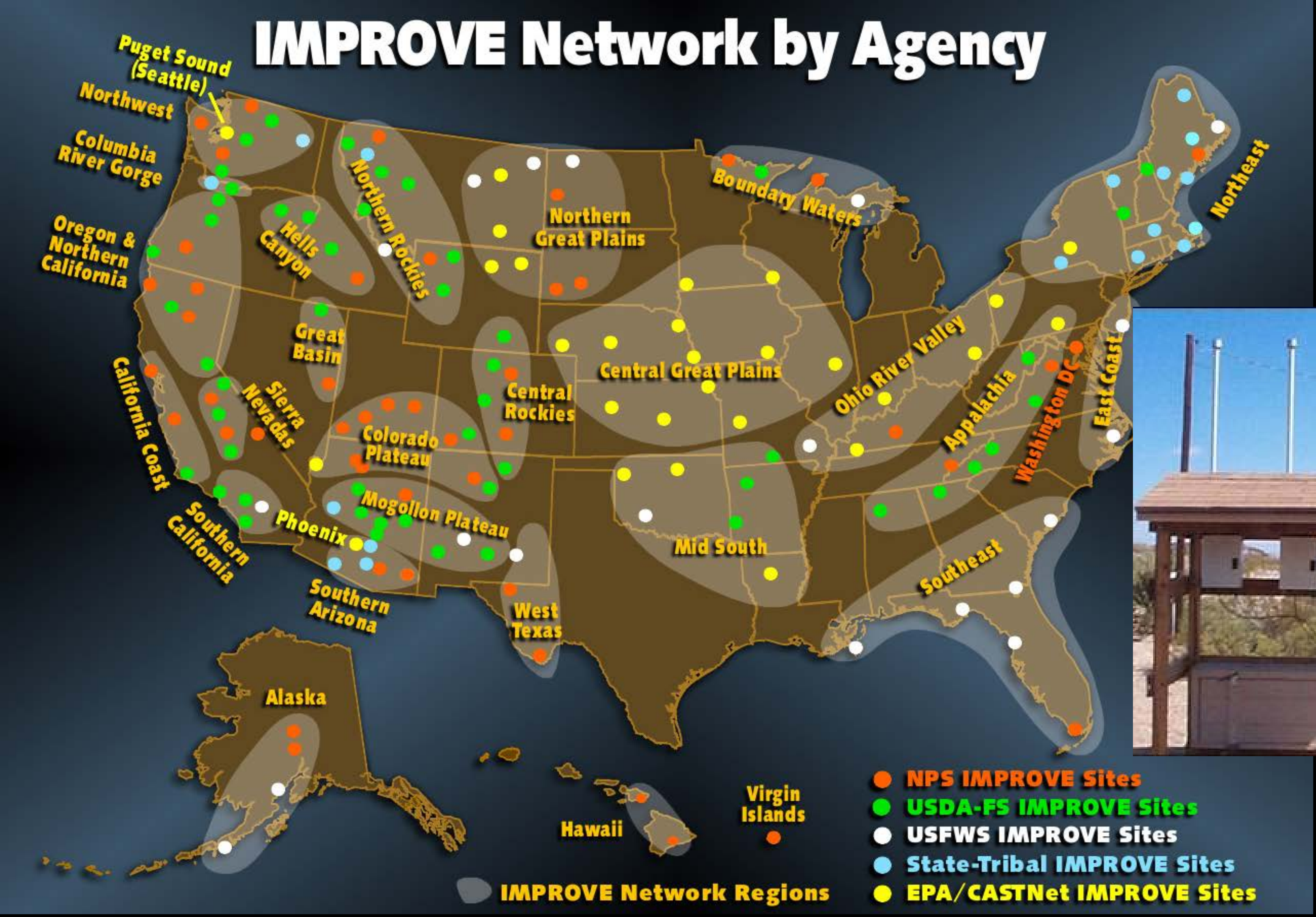
Understanding the causes and origin of air pollutants continues to require the development of new monitoring and data analysis and modeling techniques. We use both routine long-term monitoring and intensive special studies with modeling and monitoring components to hone in on issues.

Some Past Research Topics

- **Source attribution** – source types, source locations, international sources, natural vs anthropogenic
- **Hygroscopicity** – water uptake
- **Smoke** – natural smoke vs anthropogenic, organic chemistry issues, markers
- **Use of Satellites** – fill in spatial patterns, verify models
- **Improving Measurement Techniques** – faster, cheaper, better resolution, more accuracy, better documentation
- **Data & information dissemination** – web sites, databases, software, books, papers, conferences, etc.
- **Tracking trends** – emissions, concentrations, deposition, visibility
- **Natural Background** – what is it and how can we get there?
- **Nitrogen Deposition** – why is it increasing, how can we better measure it, what sources are contributing? How to understand organic nitrogen.
- **Human Perception** – what do people see, value, remember?

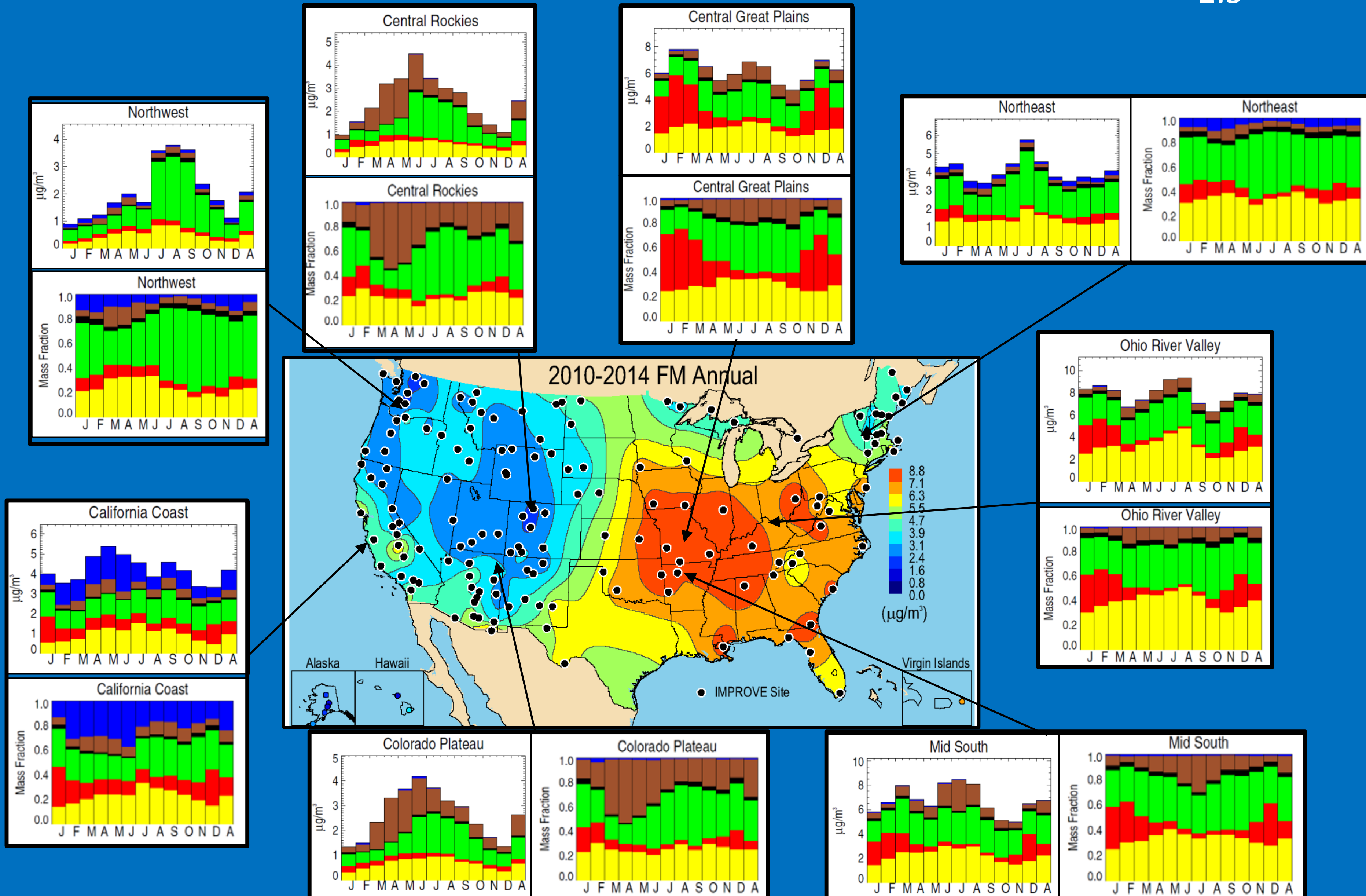
Example 1: Regional Haze

- NPS research started in early 1980’s
- Primary activity: Haze in Parks
  - Basic research into physical/chemical/optical properties of haze
  - Instrument development
  - Human perception studies
  - Determine status and trends of aerosol and haze
  - Haze source apportionment
- 20 years of research/assessment fed into the development of the 1999 Regional Haze Rule



Speciated PM2.5 and PM10 mass monitoring network
Began operating in 1988 with 20 sites
Today has ~160 sites - most with ten or more years of data.

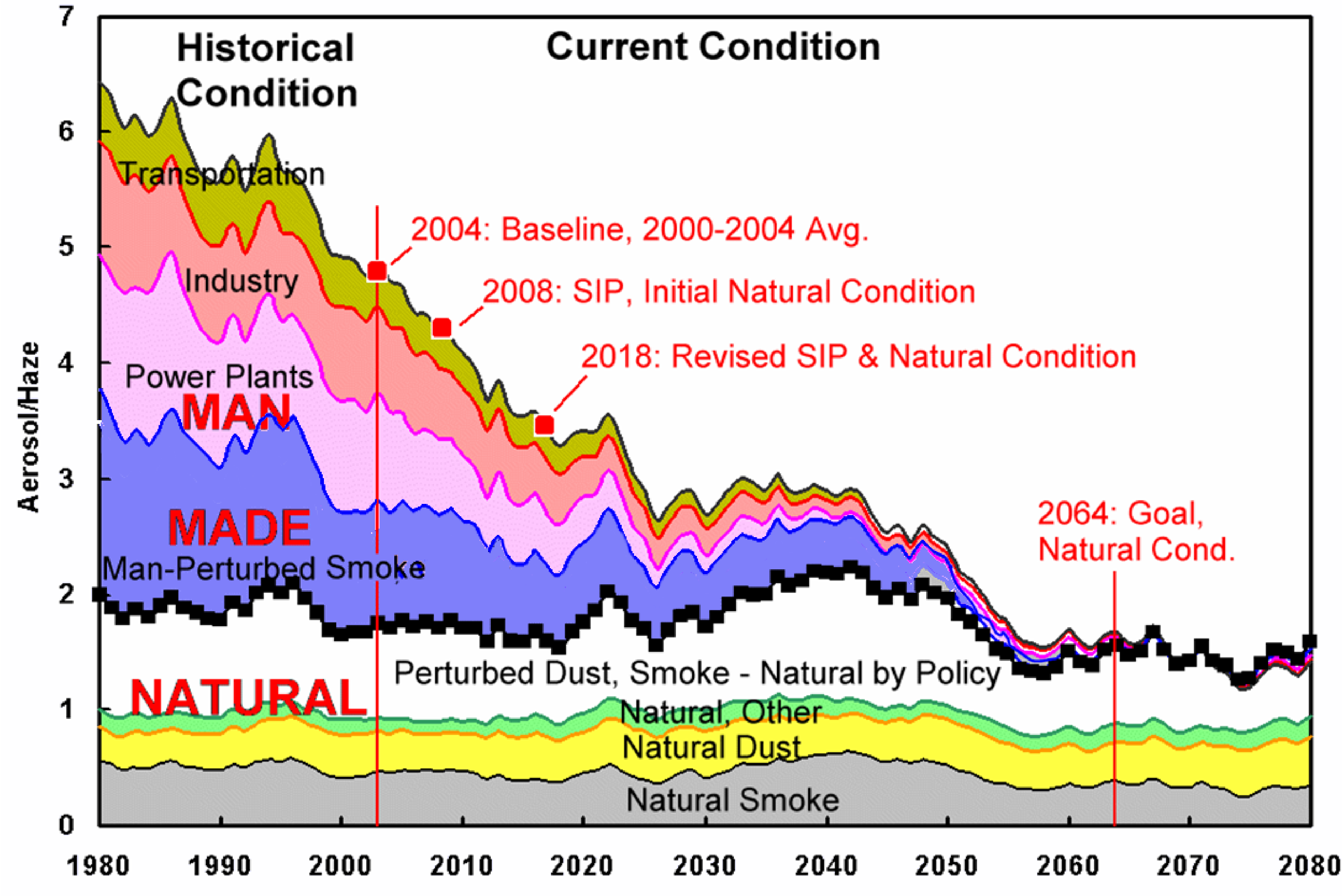
2010-2014 IMPROVE Annual Mean Fine Mass ($PM_{2.5}$)



ammonium sulfate ammonium nitrate particulate organic matter elemental carbon dust sea salt

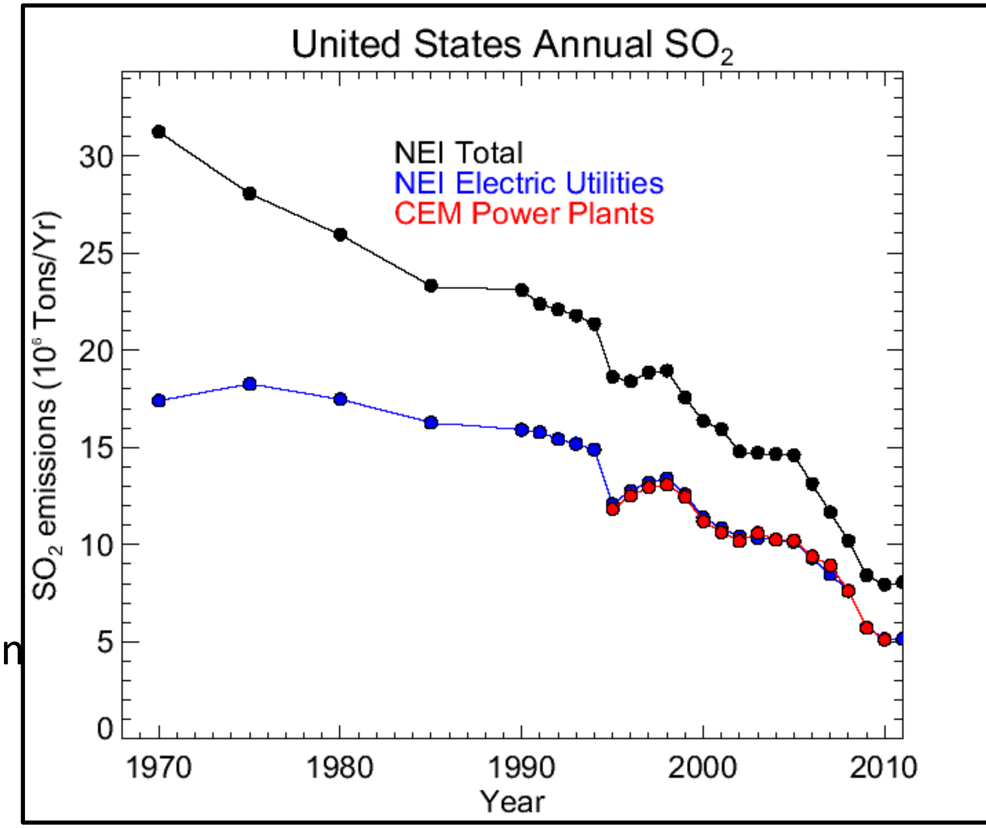
J.L. Hand et al., 2012, JGR

The Regional Haze Rule:



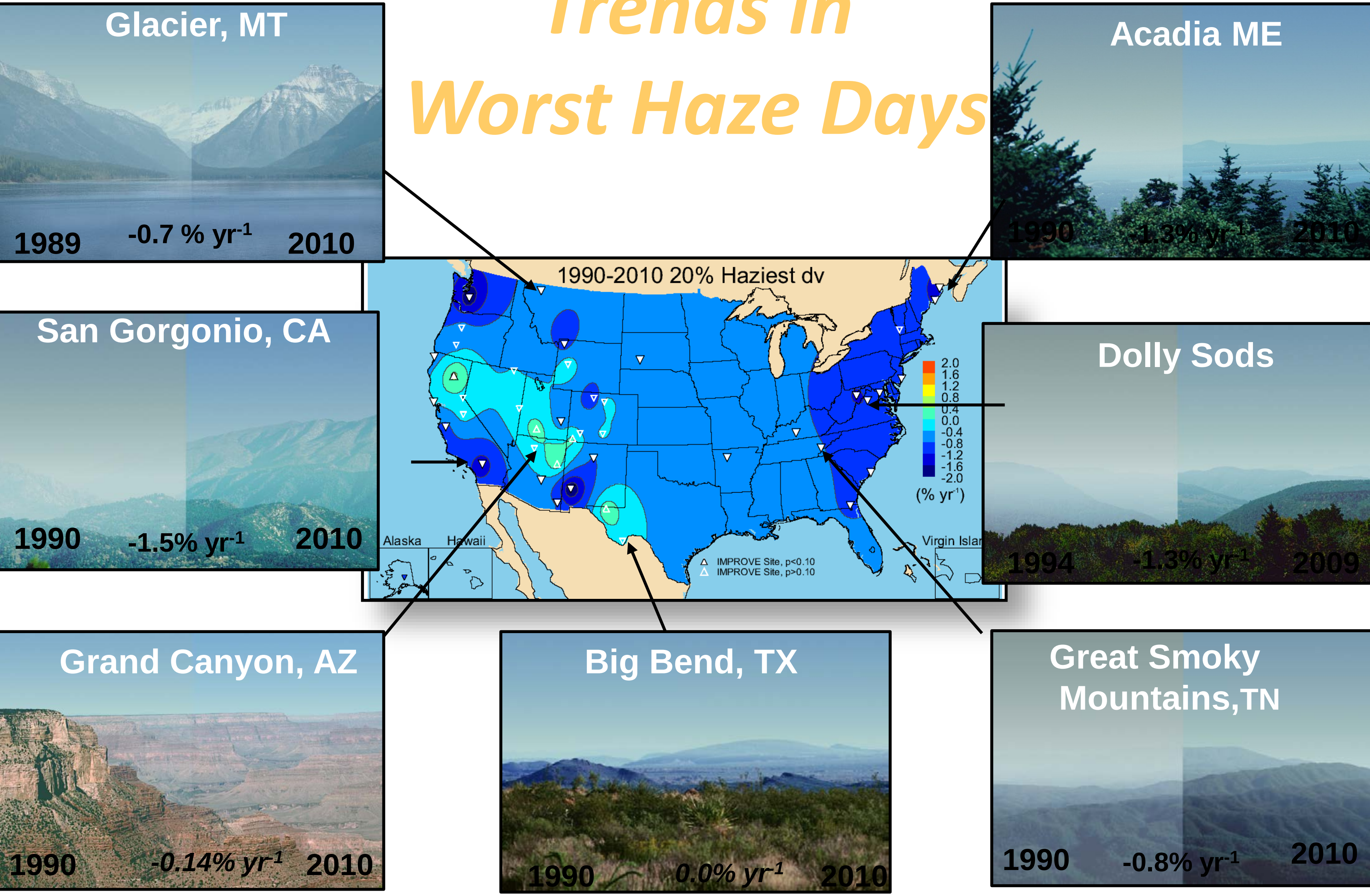
Successful Regulatory Programs

- **1970 Clean Air Act**
  - Established a framework to reduce air pollutants to safeguard health and welfare.
- **1977 the Clean Air Act Amendments**
  - Strengthening the ability to reduce emissions
  - Set the national goal to prevent future impairment and remedy existing impairment in class I areas
- **1990 Clean Air Act Amendments**
  - Acid Rain Program reduce emissions from power plants and mobile sources
- **1999 Regional Haze Rule**
- **2005 Clean Air Interstate Rule (CAIR)**
  - Cap and trade program to reduce SOx and NOx
  - 2008 The D.C. Circuit remanded without vacature CAIR



- In last 40 years
  - U.S. population has grown 50%
  - Electricity production has grown 150%
  - The GDP has tripled in real dollars

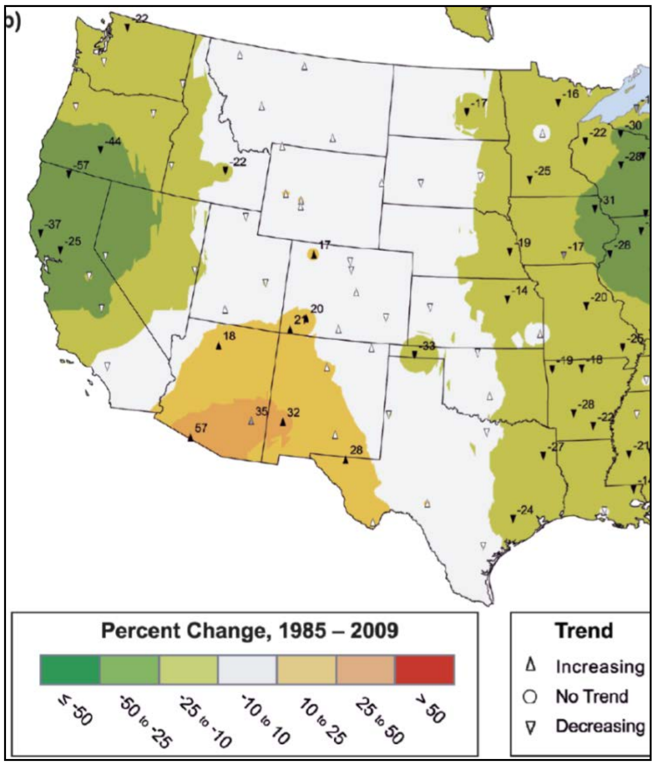
Trends in Worst Haze Days



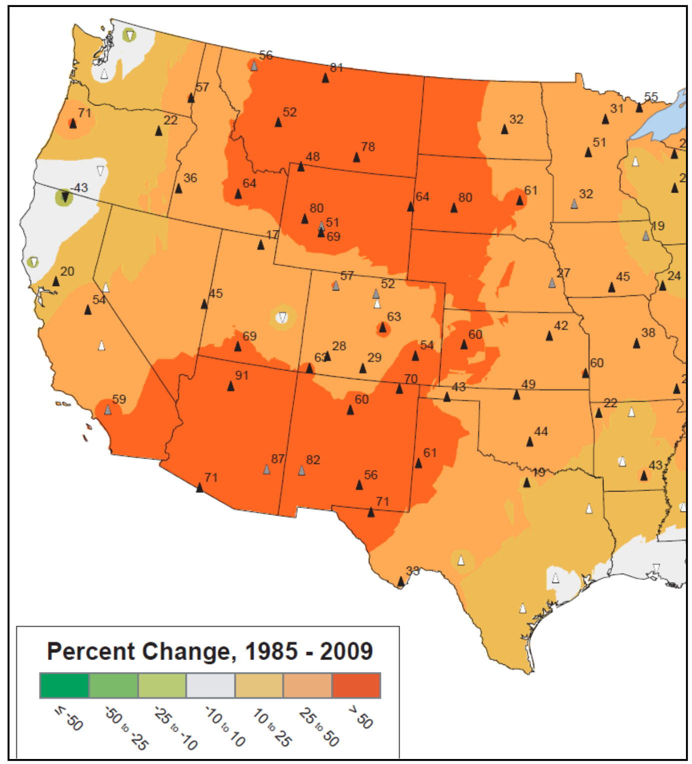
Example 2: Concerns about Nitrogen Deposition

Increasing Wet N Deposition 1985-2009

Lehman et al., 2011



Wet nitrate deposition trends



Wet ammonium deposition trends

Concerns at RMNP

- Alpine lakes have low capacity to sequester atmospheric N deposition
- N enrichment and shifts in diatom communities in alpine lakes
- N enrichment in organic soil layer and Engelmann spruce needles on eastern slope

Rocky Mountain Airborne Nitrogen and Sulfur (RoMANS) Study Objectives

- Characterize the atmospheric concentrations of sulfur and reactive nitrogen species in gaseous, particulate and aqueous phases along the east and west sides of the Continental Divide

- Identify relative contributions to atmospheric sulfur and nitrogen species
  - from within and outside of Colorado.
  - from emission sources along Front Range vs other areas of Colorado.
  - from mobile sources, agricultural activities, large and small point sources within Colorado.

Lake of Glass, RMNP, CO, 12 July 2008 (KG)

Glacier Gorge Trail, RMNP, CO, 12 July 2008 (KG)

Rocky Mountain NP Deposition Special Studies

ROMANS Pilot Study – Summer 2005

RoMANS I: 2006 – April and July

RoMANS II: Nov 2008-Nov 2009

April – September 2010

Summer 2014 FRAPPE'

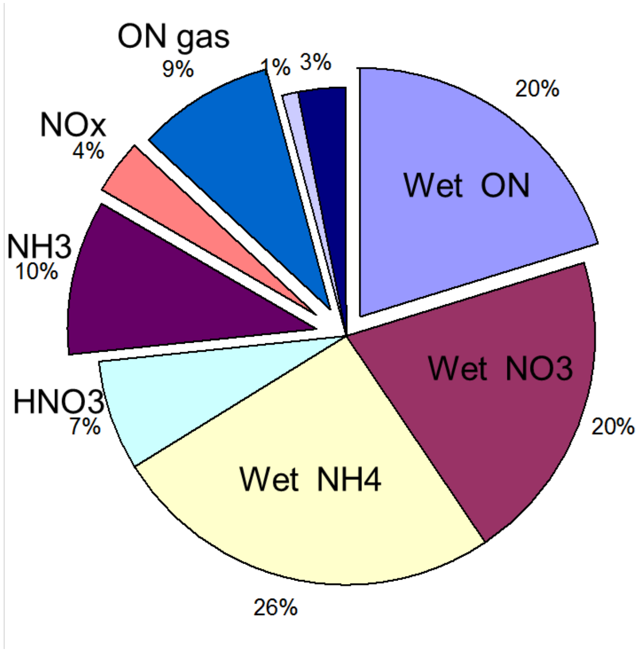
- Particle composition and gases
  - 24 hr $PM_{2.5}$ and composition
  - 15 minute $PM_{2.5}$ ions (PILS)
  - 24 hr SO_2, NH_3 and HNO_3 (URG)
  - Continuous NO_x, NO_y, NH_3, O_3, CO
  - Weekly HiVol – $PM_{2.5}$
- Wet deposition
  - Event and sub-event/hourly
  - Ion chromatography
  - Org N = TN – inorg N
- Other measurements

Core Site: With IMPROVE & CASTNet Highway 7 between Estes Park & Allens Park

Radar Wind Profiler: Estes Park, near power plant at junction of Highways 34 & 36

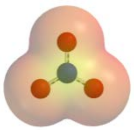
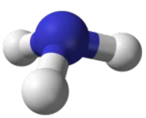
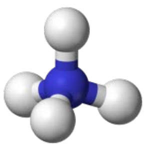
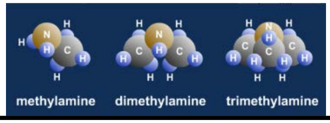
Special Study Field Measurements

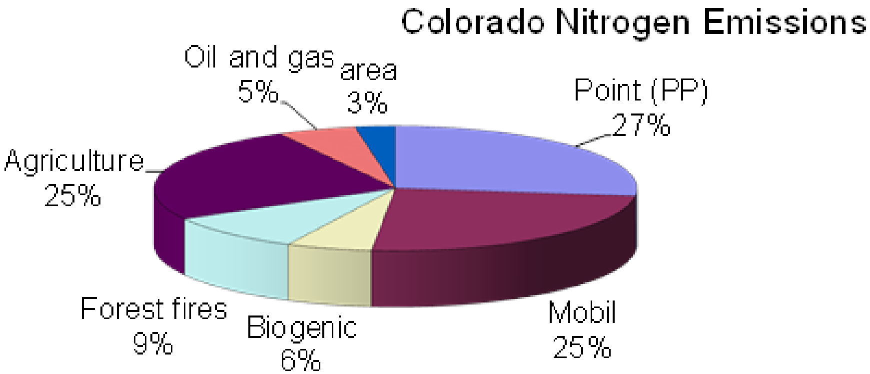
- Detailed measurements not suitable to routine field programs
- Develop more complete concentration/deposition budgets

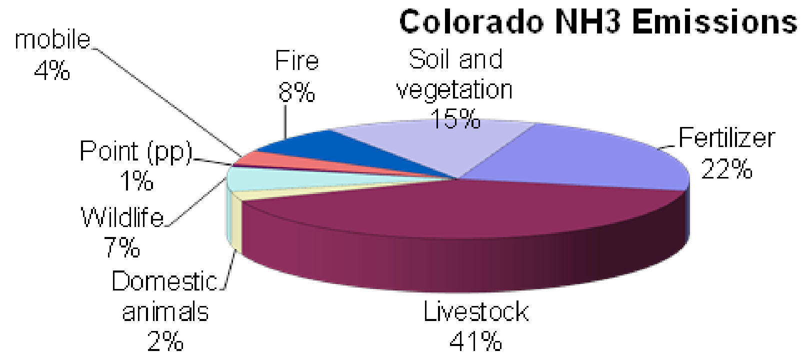


- ~45% of N deposition at RMNP is not routinely measured

Sources of Reduced and Oxidized Gases

Compound	Anthropogenic	Naturally Occurring
$NO_2 \rightarrow NO_3$  	Fossil Fuel Combustion (power plants, mobile, oil and gas) Fertilizer, Prescribed fire	Soil Release; Lightning; Wild fire
$NH_3 \rightarrow NH_4$  	Feedlots; Fertilizer; Mobile Waste water treatment	Wild animals – Ecosystem respiration
Organic N 	Feedlots, Fires	Vegetation; Fires





Deterministic Source Based Models

Meteorology
Emissions
Initial & Boundary Conditions

→

Complex Modeled Interactions

→

Predicted Concentrations
High time and spatial resolution

Challenges: Expense, uncertain inputs, complicated interactions

"Models have truthiness."
---Mike Barna, NPS

Receptor (Backwards) Models

Average Source Attribution

←

Statistical Analysis

←

Measured data
Usually concentrations

(Often) Meteorology or Source Characteristics

Challenges: Assumptions of linearity, average results only, multiple solutions

Apportionment Strategy (Weight of Evidence)

- Multiple approaches from simple to complex
  Reconciliation of differences

Qualitative
  - Concentration gradients.
  - Which way is the wind coming from?
  - Simple back trajectories.
  - Frequency with which the air mass passes over source areas before it arrives at the receptor - residence time analysis.

Quantitative
  - Trajectory receptor models.
  - Other receptor models.
  - Chemical transport models.
  - Hybrid Models.

Trailridge Road, RMNP, CO, Summer 1987 (KG)

Views from RMNP

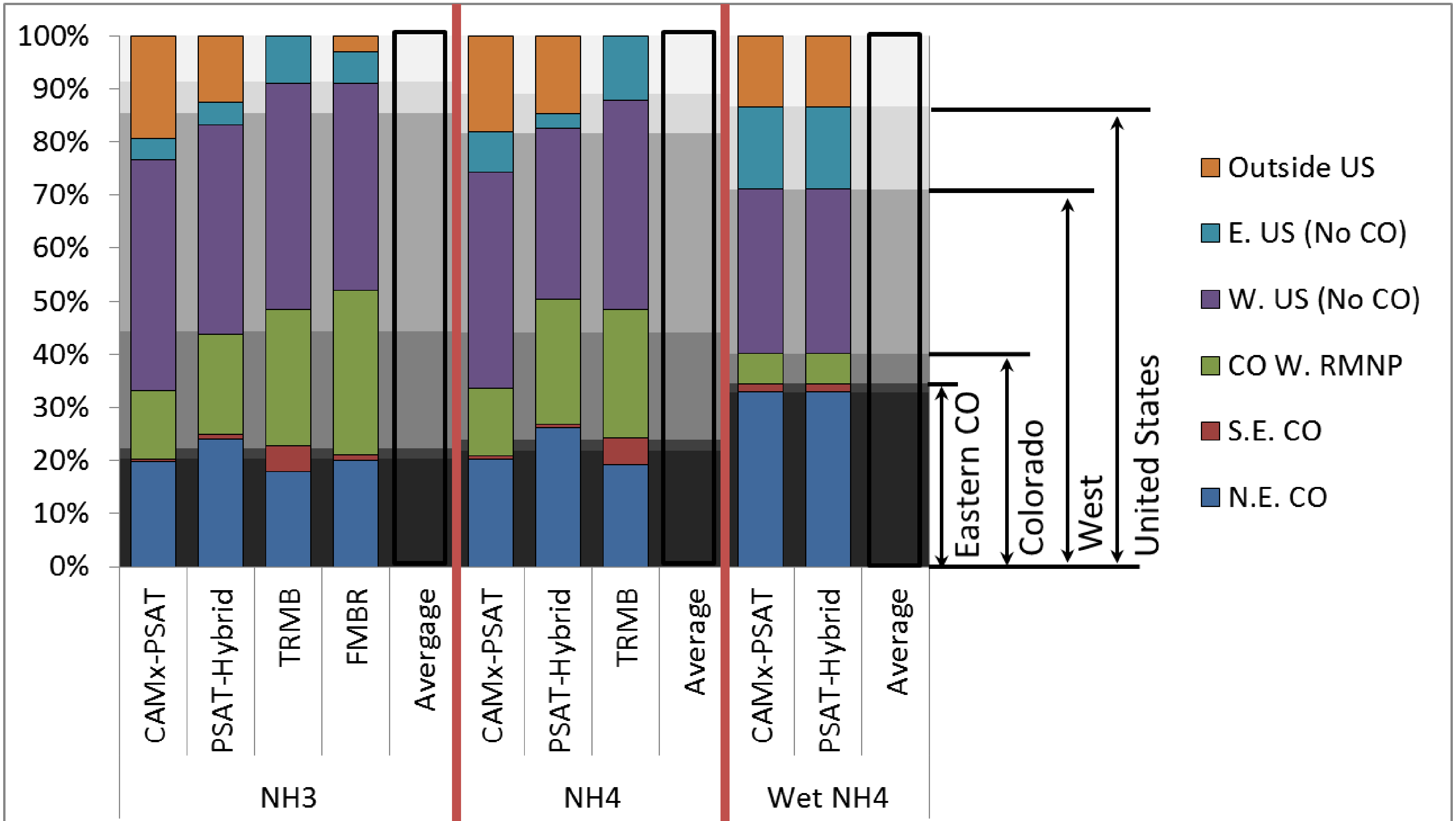
Alpine Visitor Center

Looking West (top)

Looking East (bottom)

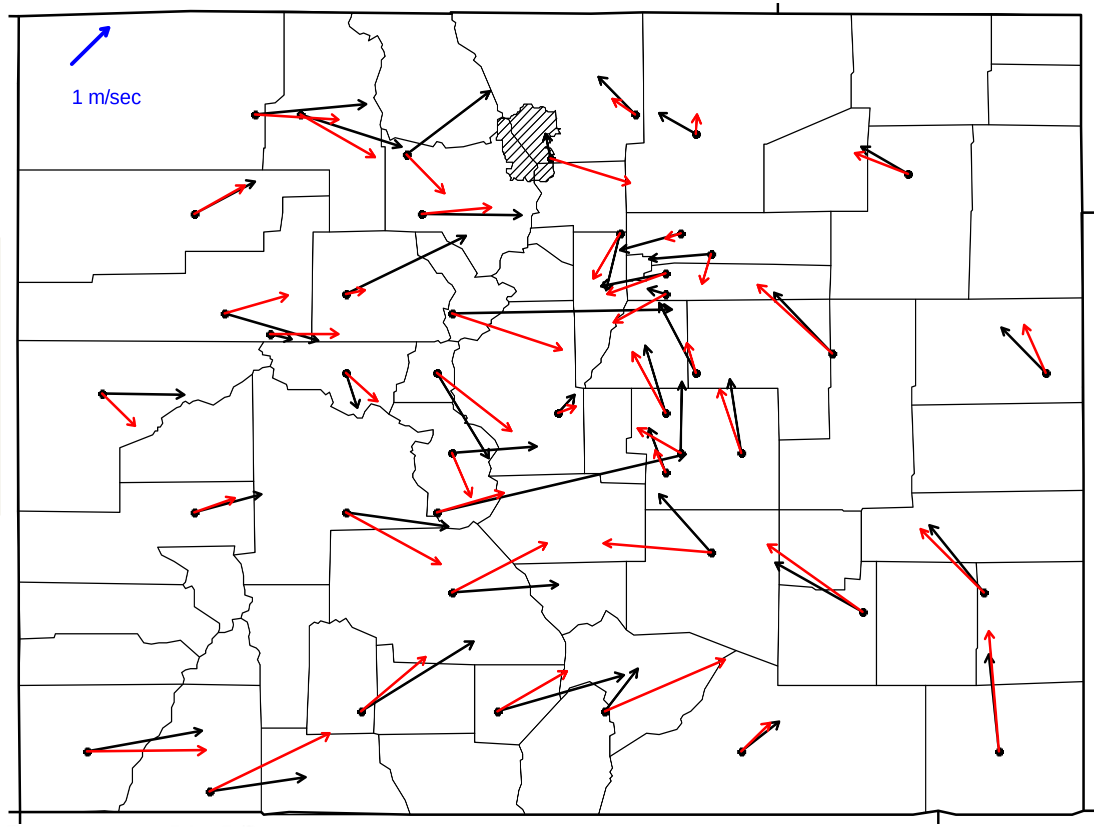
Take a Look Tomorrow!

Comparison of Results
Sources of Reduced Nitrogen

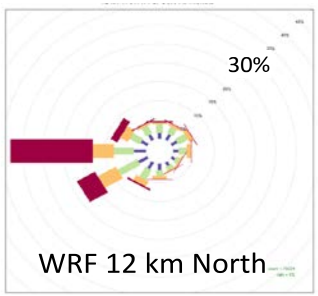


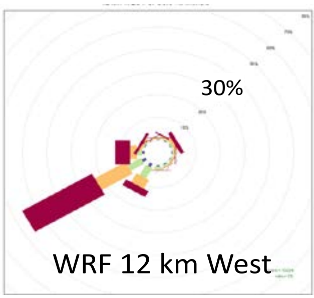
Example: One Ongoing Modeling Challenge

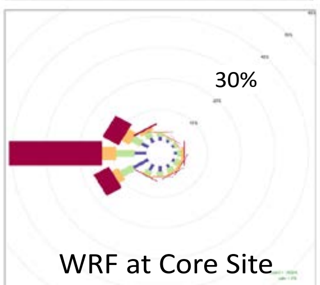
Wind Directions in Complex Terrain – Are we systematically underestimating contributions from sources to the East?

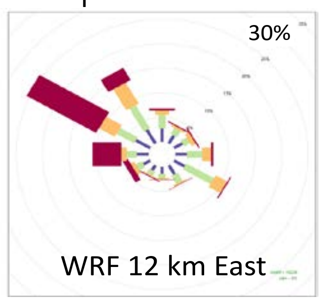


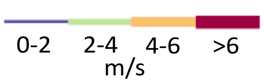
Mean **observed (black)** and **modeled (red)** wind vectors in Colorado, Jun–Aug 2009 at 3:00 pm local time.

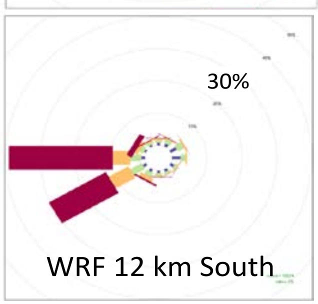


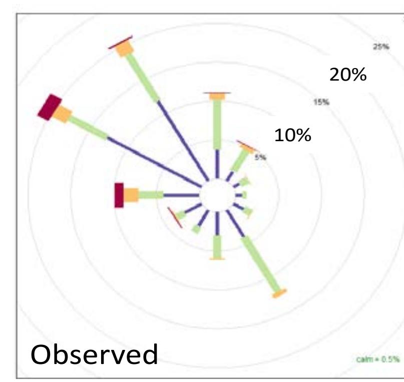




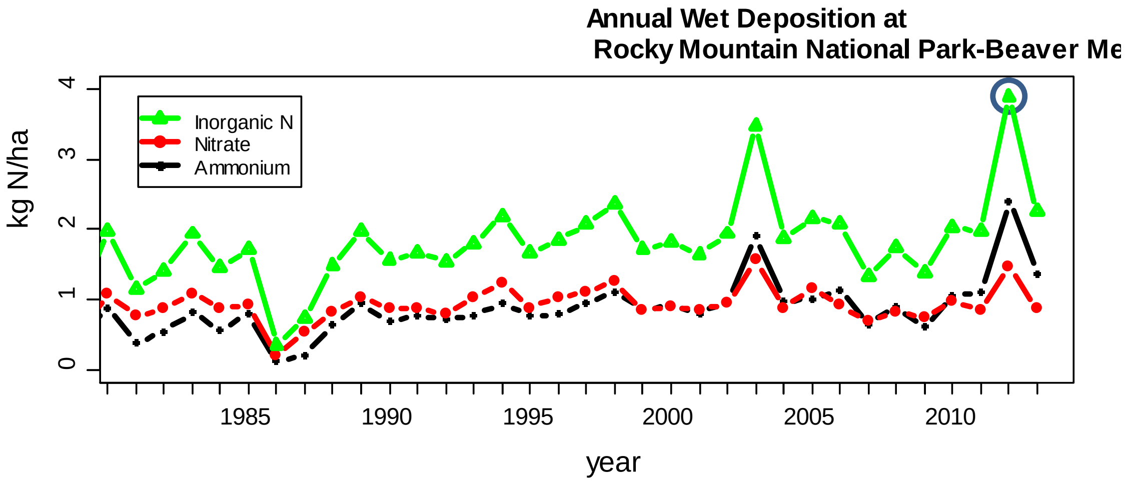


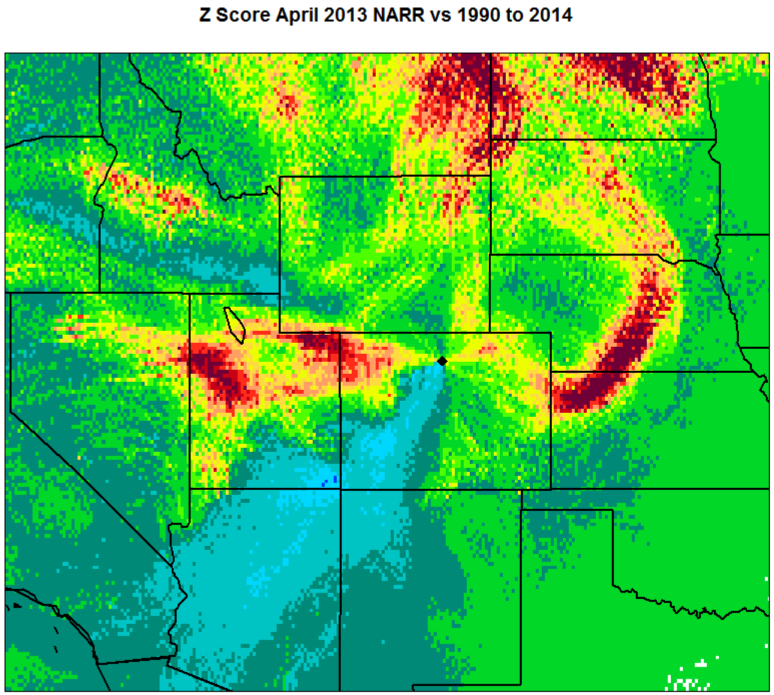


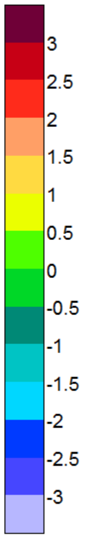


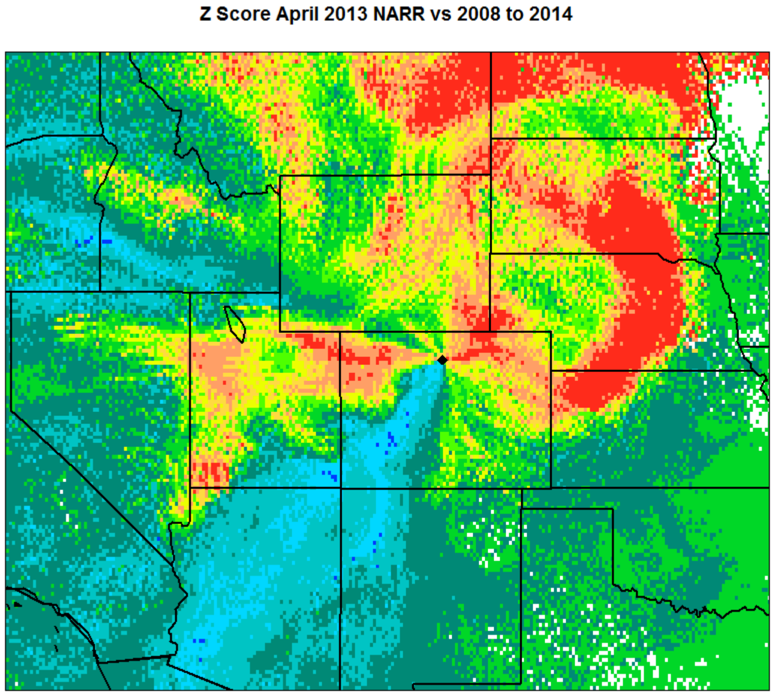


Follow up: Origins of Air Masses During Period of Interest



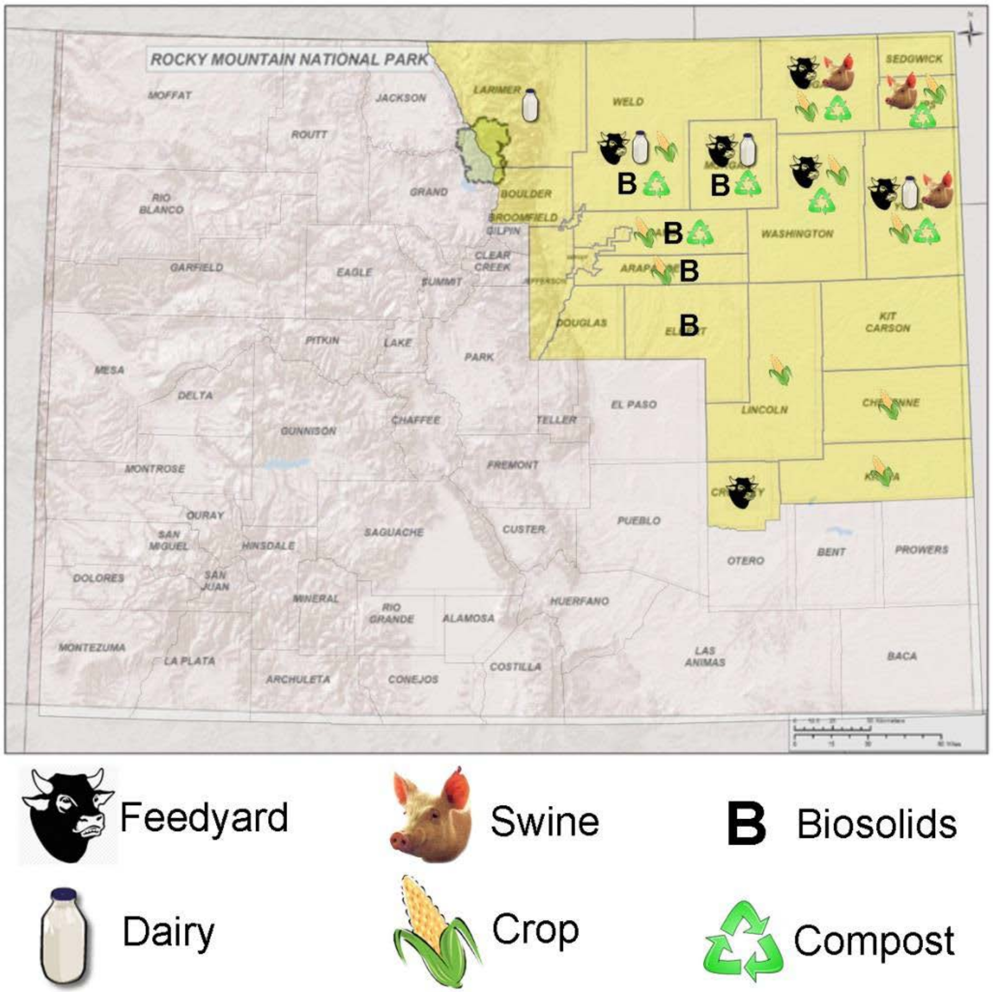




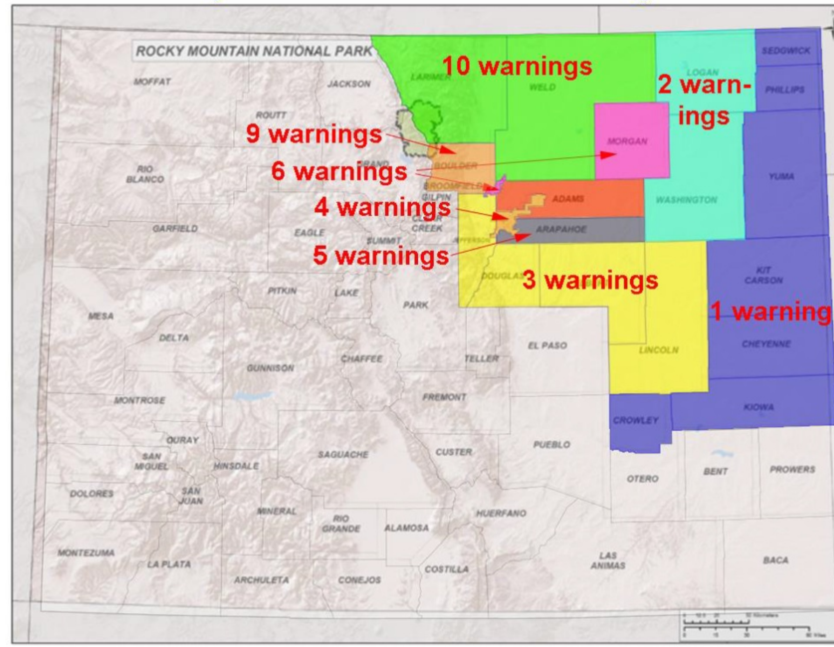


An Experimental Mitigation Strategy: CSU Early Warning System (Voluntary)

Agricultural Producer Participants by Type



Warnings Issued in 2014



Where Are We in 2016?

- Easy
  - Large reductions in emissions have resulted in large reductions in air pollution
- Challenge
  - In a modern industrial society reliant on abundant energy with large concentrated populations, how do we optimize emissions to minimize air pollution and maximize economic benefit while not alienating any portion of the population?

Questions?

Bret is here: East of Angle Pass, Wind Rivers, WY