Phase I Attribution of Haze Overview

(Geographic Attribution for the Implementation of the Regional Haze Rule)
or
(*an experiment in weight-of evidence*)

National RPO Technical Meeting
Denver
June 9, 2005

Introduction

- **Identified in WRAP Strategic Plan (2003)**
- **Report (http://wrapair.org/forums/aoh/ars1/report.html) is a gateway to the detailed information integrated into Phase I of the Attribution of Haze (AoH) project.**
- **Most of this information resides on the WRAP website and with WRAP data centers. Major report sections include:**
  - **Introduction – AoH project background and goals**
  - **Analytical Approach – data sets and methods.**
  - **Attribution of Haze Web Site Description**
  - **Regional Attribution and Assessment results**
  - **Recommendations for Phase II – future AoH work.**

WRAP Strategic Plan

	Phase I 2003-05	Phase II 2005-07
Purpose:	Dry run for Phase II.	Refine and apply Phase I approaches for SIP/TIP purposes.
Scale:	Regional.	Regional and subregional.
Apportionment:	96/02 source contributions. Areas each plan to address.	2002 source contributions. Reduction obligations.
Strategies:	Identify options, screen.	Cost/benefit, select, design.
Communication:	Public education.	Public acceptance.
Major State/Tribal submittals:	2002 emissions inventory.	Modeling run specifications.

Project Goals

- **Provide WRAP region state and tribal air regulators with an initial, regional assessment of the attribution of haze in their Class I areas;**
- **To provide an initial assessment of the impact of natural and anthropogenic emissions from each state at WRAP region Class I areas; and**
- **Ultimately, to develop tools, methods, and data formats to provide air regulators with the information needed to prepare SIPs and TIPs under the Regional Haze Rule.**

Technical Objectives – what was done

Integrate/synthesize *available* 2002 monitoring, modeling, & emissions data to identify and analyze:

- **IMPROVE data at WRAP region Class I areas**
- **Emissions sources:**
  - **Defined as mass and species by source category/state**
  - **Natural and anthropogenic emissions by species/state**
- **Independent modeling techniques:**
  - **CMAQ regional dispersion model with Tagged Species Source Apportionment (TSSA) tool, use to assess the impact of each state's point and mobile emissions at WRAP region Class I areas**
  - **Trajectory Regression Analysis of air parcel residence times over source regions (defined as states) for sulfate and total light extinction, for each WRAP region IMPROVE site**

Phase I Deliverables

- Prepared 96 regional/state emissions maps
- Prepared data summaries for 85 sites
- Reviewed and analyzed 2002 attribution results for more than 120 federal and tribal Class I areas
- Determined regional groupings of source impacts across the WRAP region
- Developed project web page to support findings
- Reviewed and addressed dozens of comments
- Prepared Phase II recommendations
- Prepared final summary report

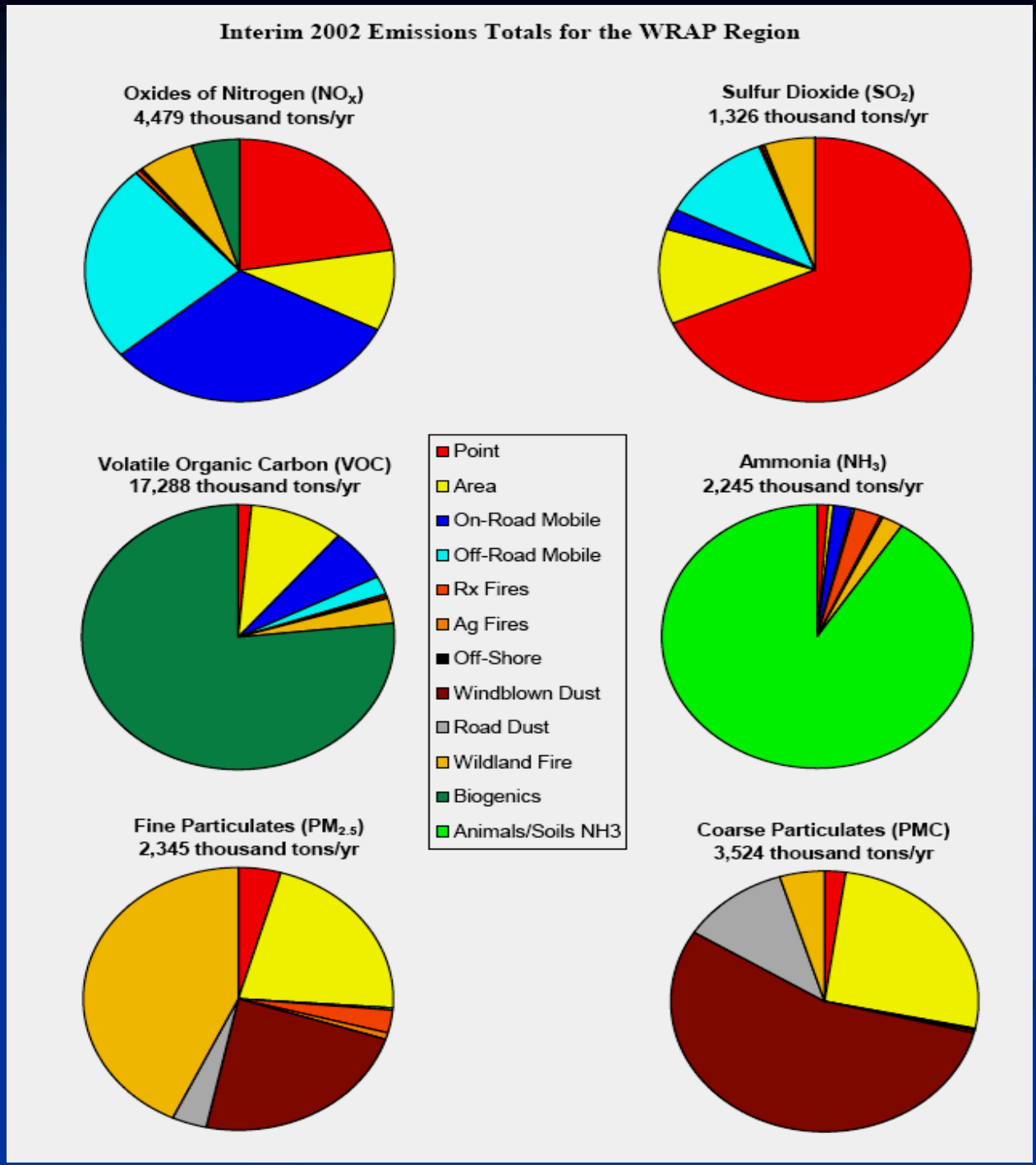
Primary Data Inputs

- **Emissions Inventories**
  - Tracks pollution estimates of source categories and aerosol species
  - Spatial variation and source strength in EIs affects monitoring data and model results
  - Confidence in these data is medium
- **Monitoring Data**
  - Snapshot of aerosol pollution at a given location
  - Confidence in these data is high
- **Modeling**
  - Allows us to estimate the transformation and movement and fate of emissions in the atmosphere
  - Model performance is tested by comparisons to monitoring data

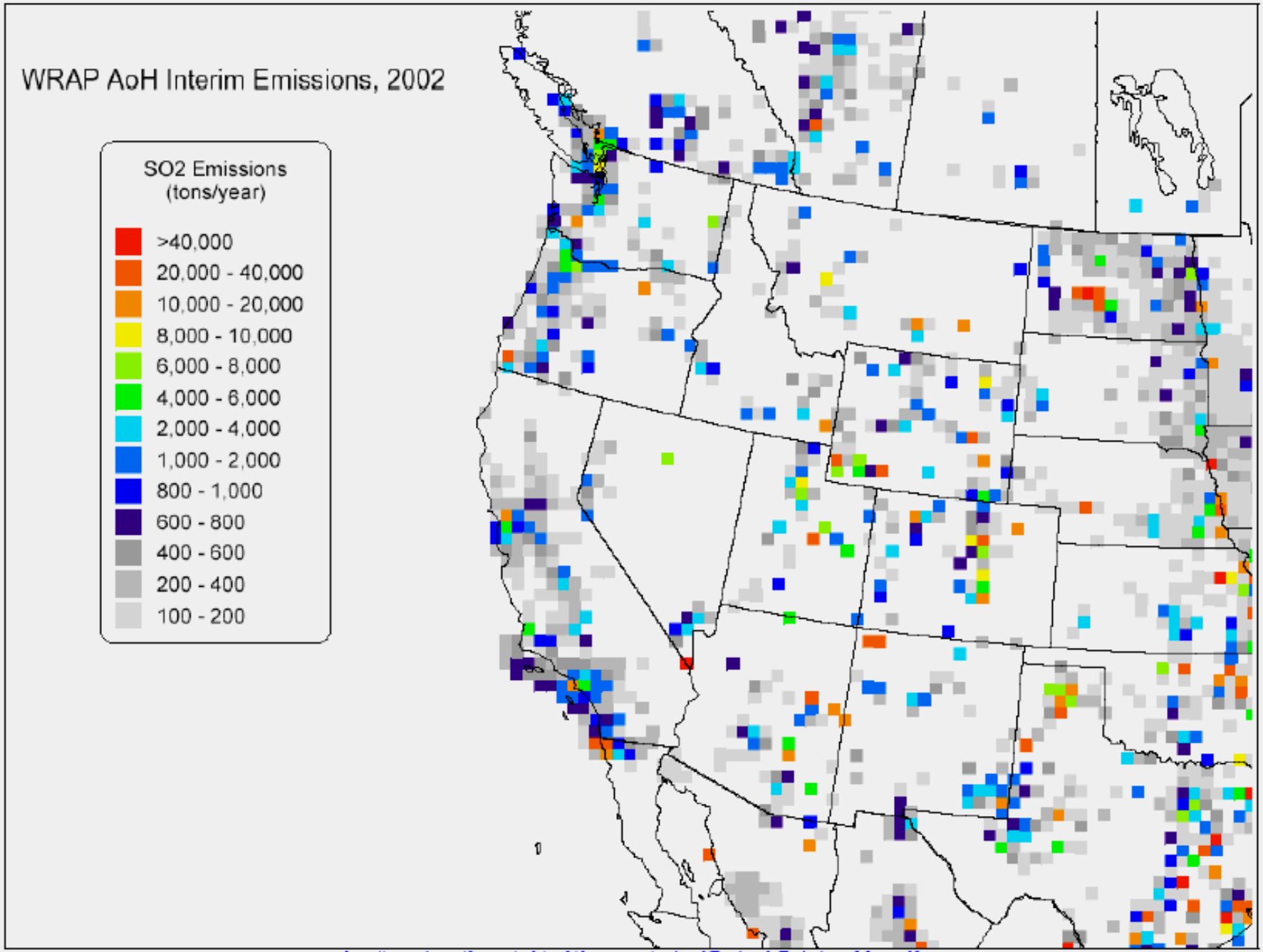
Emissions Data Set

- EPA 2002 NEI not useable for this purpose → WRAP facilitated development of "interim" 2002 emissions
  - Point
  - Area
  - Mobile (On-Road & Non-Road)
  - Road Dust (Paved & Unpaved)
  - Fire
  - Windblown Dust
  - Biogenics
  - Modeling Domain Boundary Conditions

Interim 2002 Emissions Totals for the WRAP Region

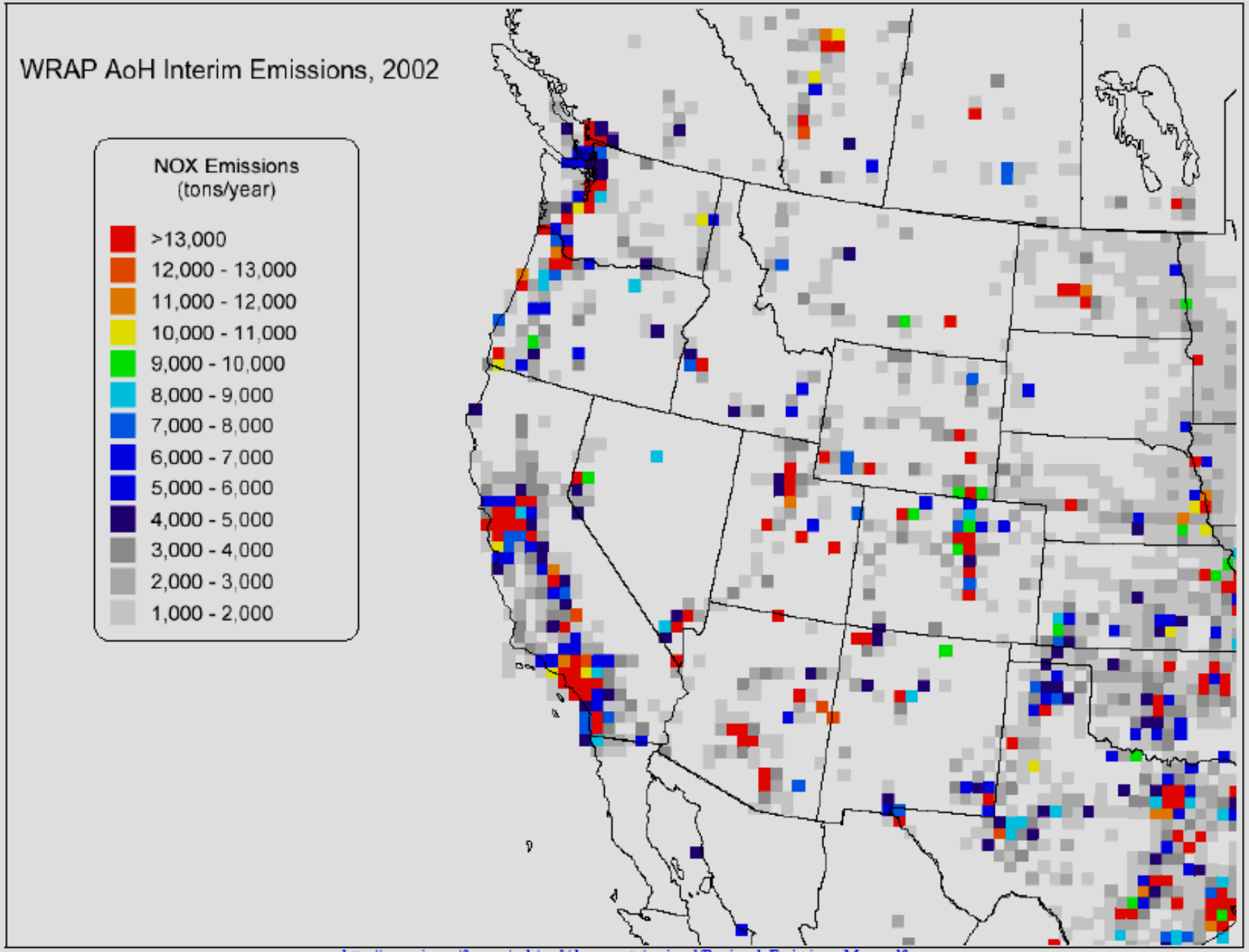


WRAP AoH Interim Emissions, 2002



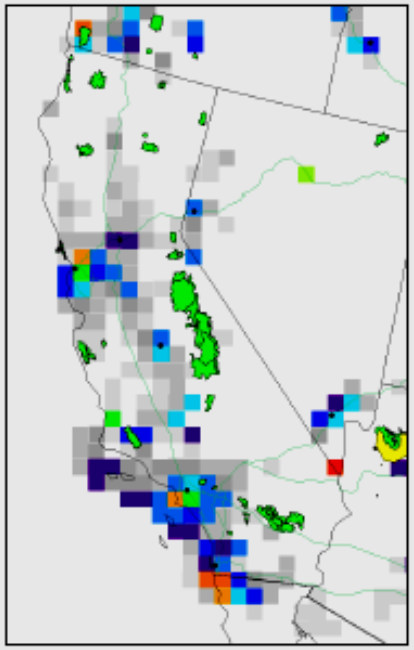
http://wrapair.org/forums/aoh/ars1/documents/regional/Regional_Emissions_Maps.pdf

WRAP AoH Interim Emissions, 2002



http://wrapair.org/forums/aoh/ar21/documents/regional/Regional_Emissions_Maps.pdf

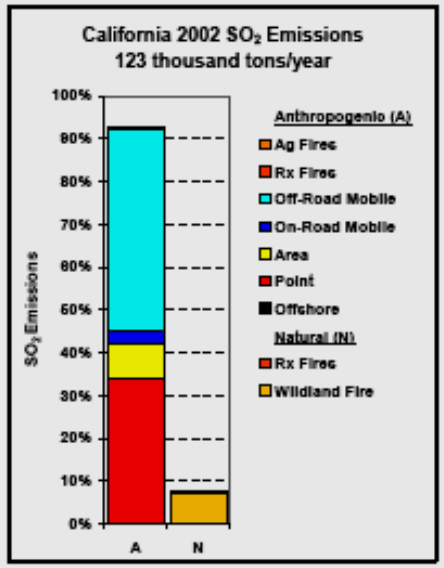
California SO_2 Emissions
WRAP Interim 2002 Inventory



Emissions from all available source categories are indicated according to magnitude in 36x36km squares. Class I Areas are indicated in green, dotted lines indicate interstate highways and black dots indicate major cities.

Sulfur oxide gases (SOx) are formed when sulfur containing fuels, such as oil or coal, are burned, when gasoline is extracted from oil or when metals are extracted from ore. In California, 2002 emissions of SO_2 were dominated by point and off-road sources.

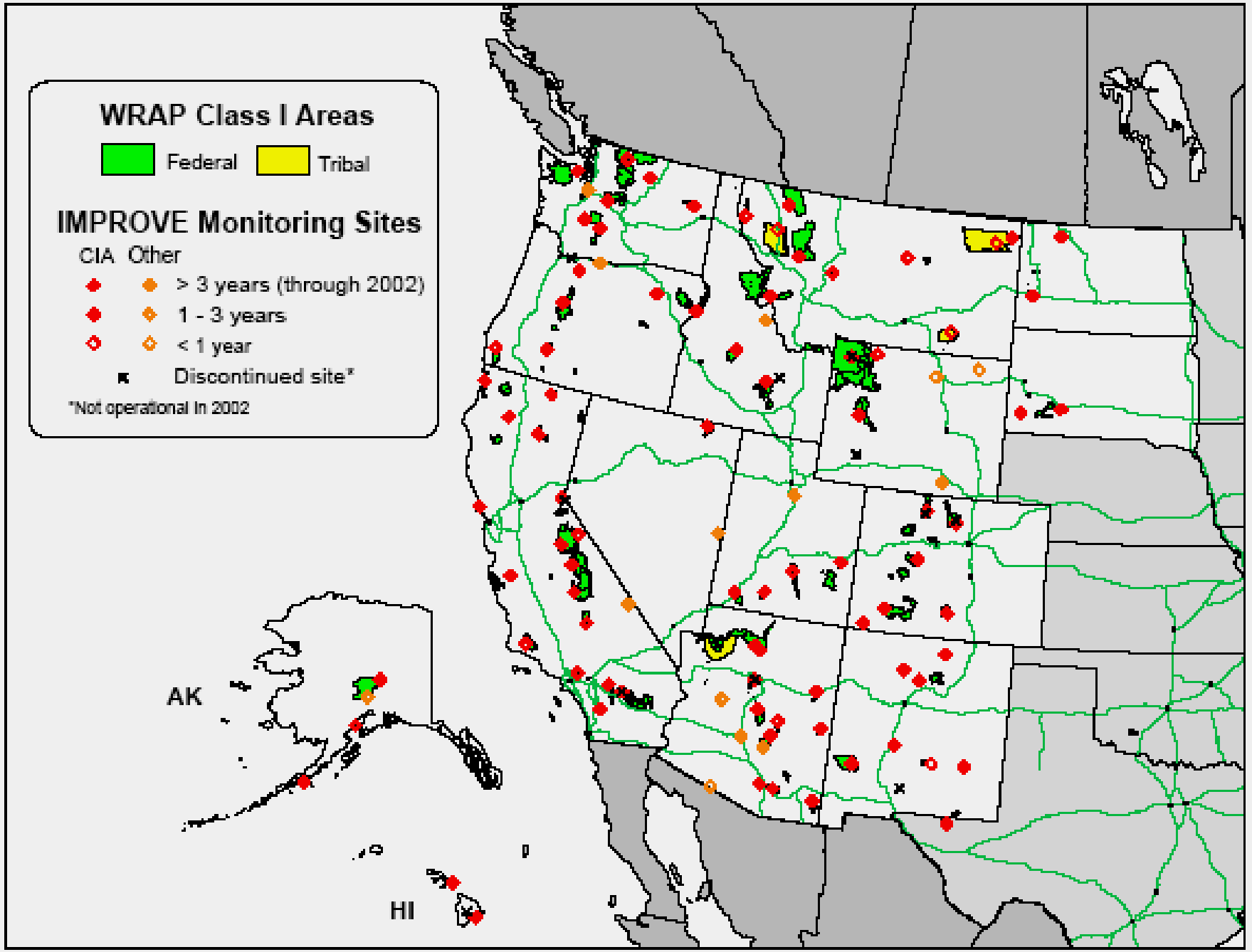
SO_2 dissolves in water vapor to form acid, and contributes to the formation of sulfate compounds (e.g. $(NH_4)_2SO_4$). These compounds can block the transmission of light, contributing to visibility reduction on a regional scale in our Class I Areas.



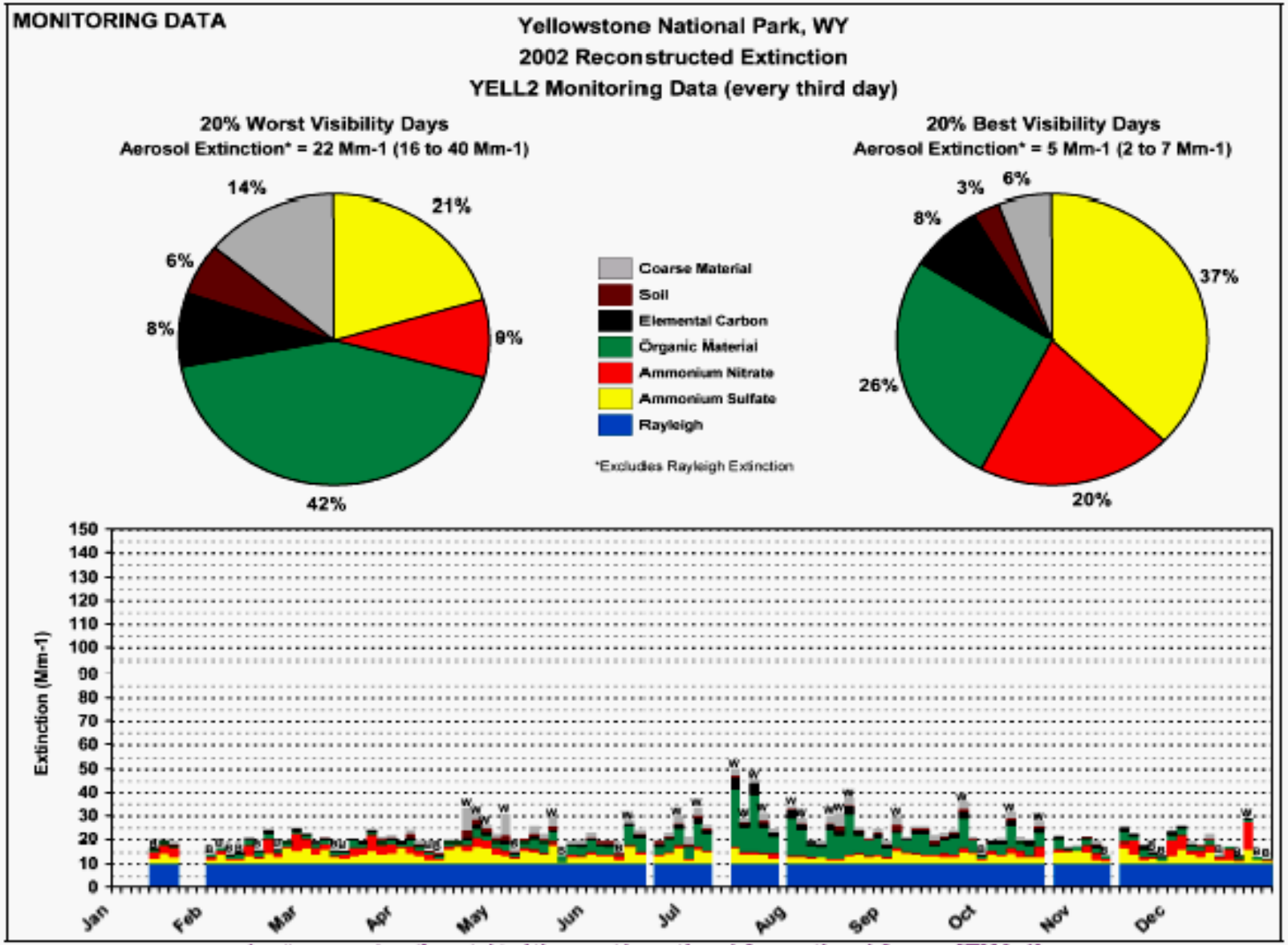
http://www.wrapair.org/forums/aob/art/documents/regional/California_Emissions_Maps.pdf

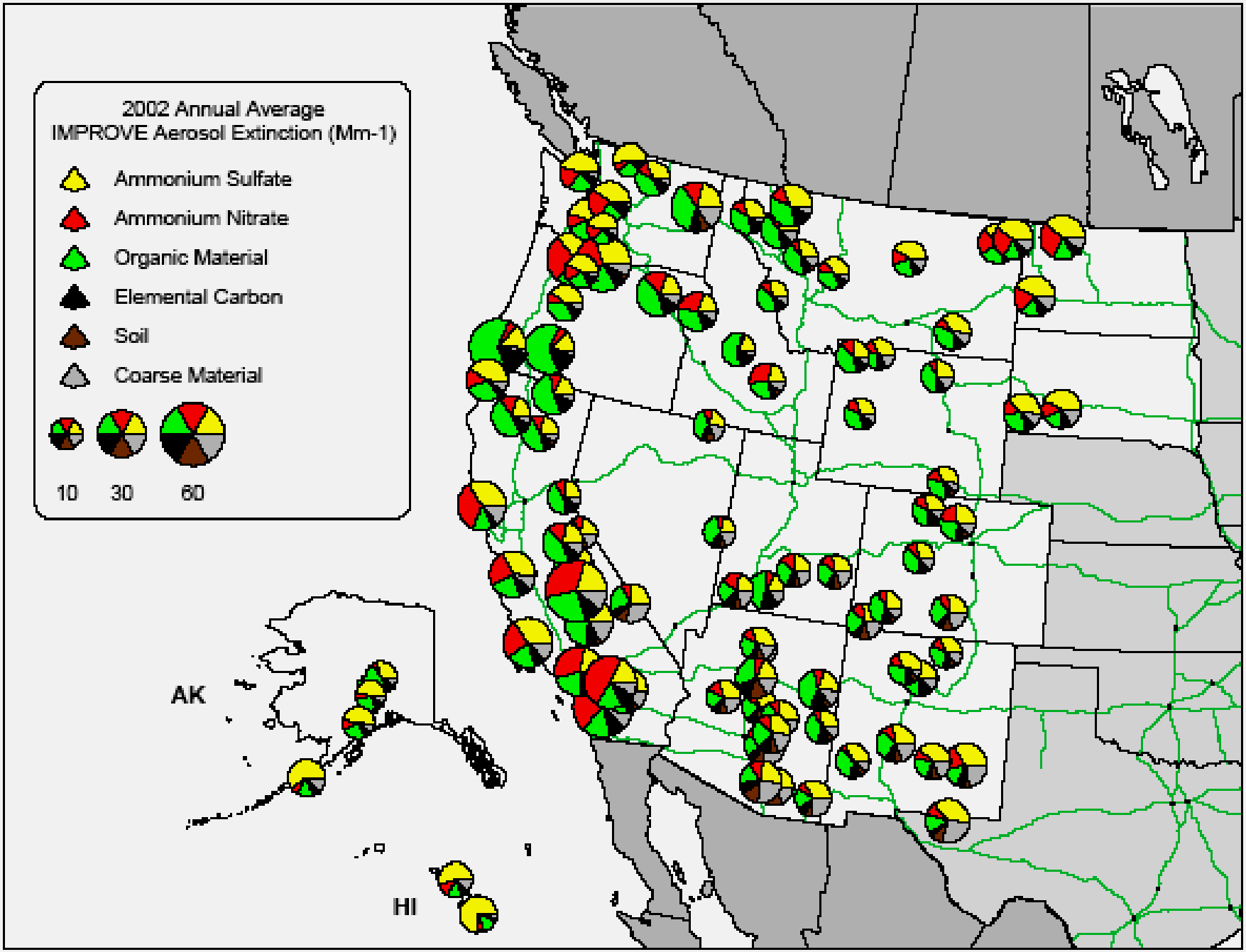
Monitoring

- IMPROVE + protocol sites
- Developed new displays
- Looked at missing and partial sample results

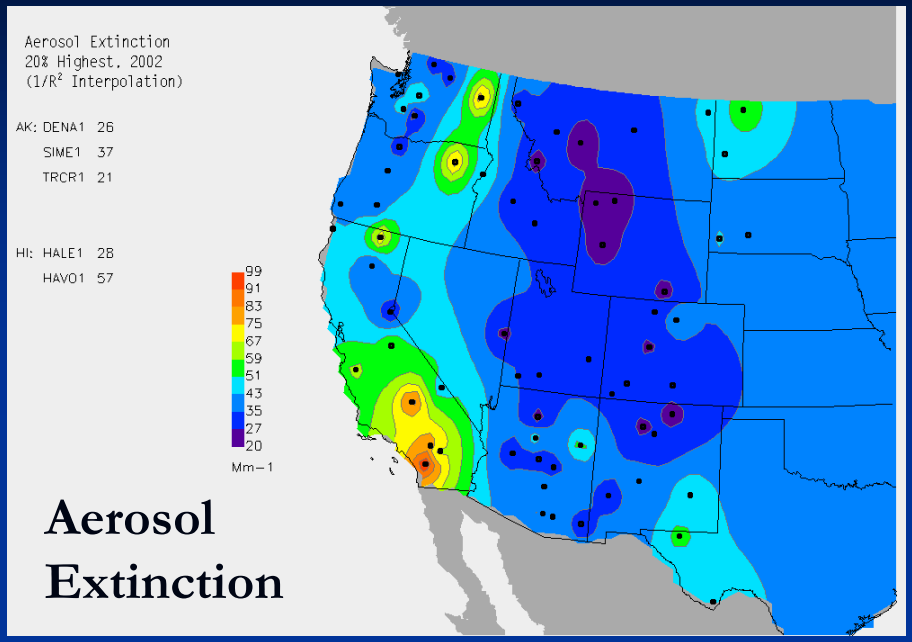

WRAP Class I Areas
Federal
Tribal
IMPROVE Monitoring Sites
CIA Other
> 3 years (through 2002)
1 - 3 years
< 1 year
Discontinued site*
*Not operational In 2002
AK
HI

Example IMPROVE Data Timeline Plot

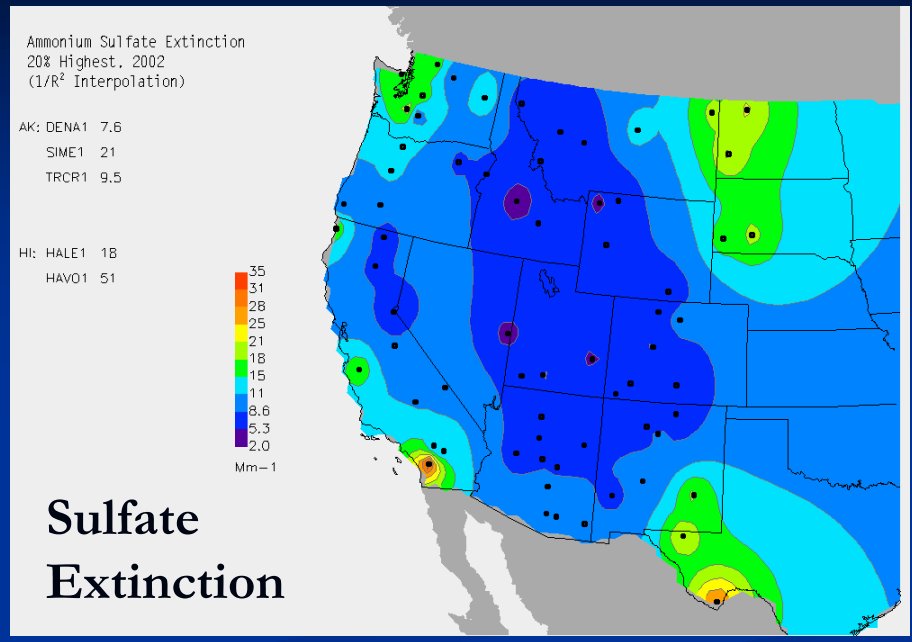



2002 Annual Average
IMPROVE Aerosol Extinction (Mm-1)
Ammonium Sulfate
Ammonium Nitrate
Organic Material
Elemental Carbon
Soil
Coarse Material
10
30
60
AK
HI

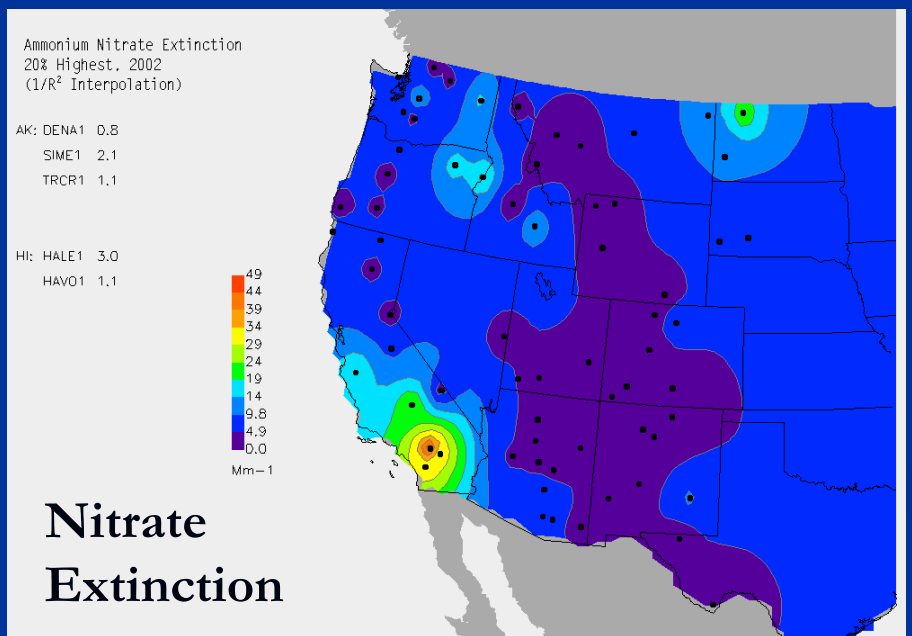
2002 WRAP Aerosol/Species Extinction



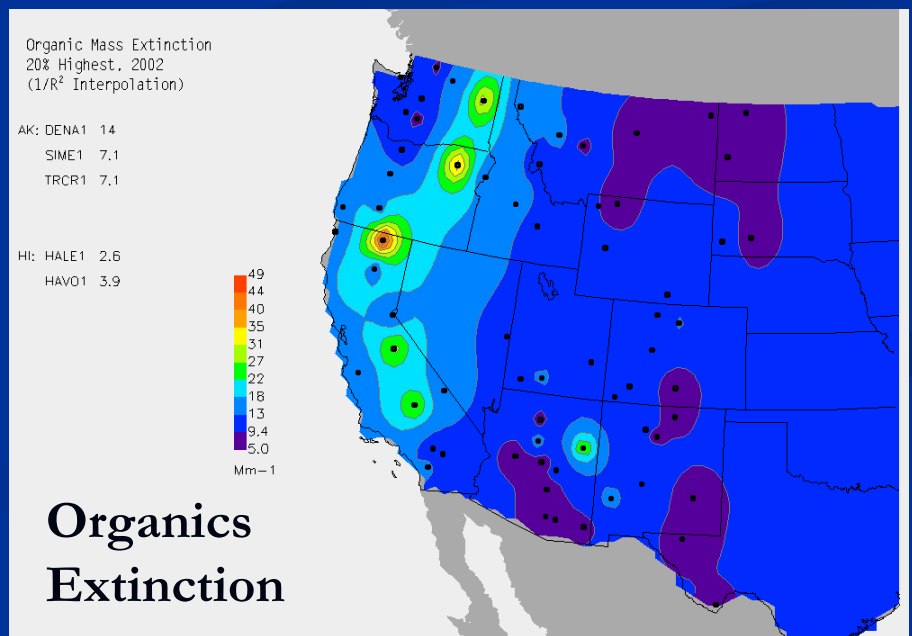
Aerosol Extinction



Sulfate Extinction



Nitrate Extinction



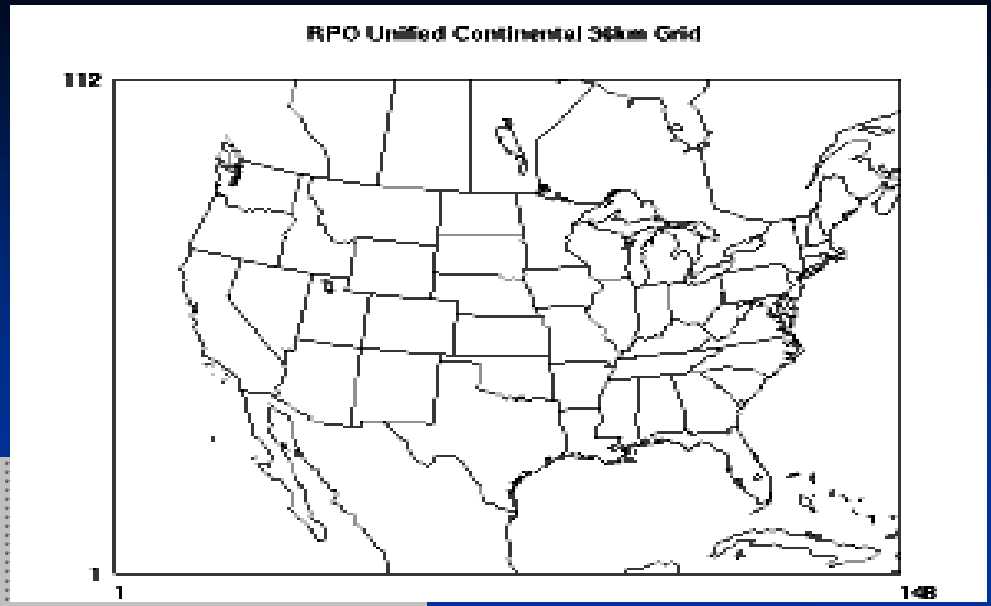
Organics Extinction

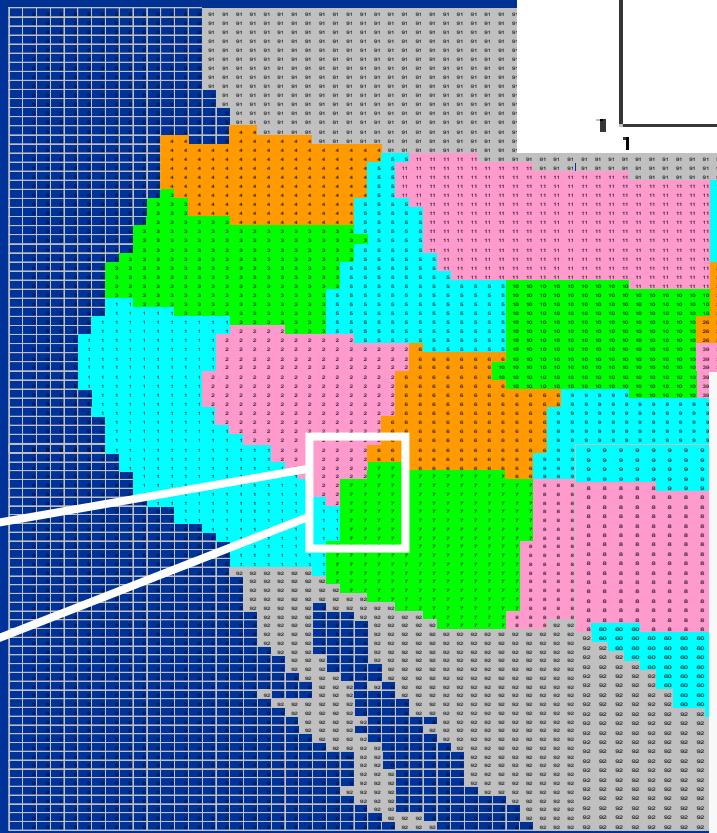
AoH Regional Scale Modeling

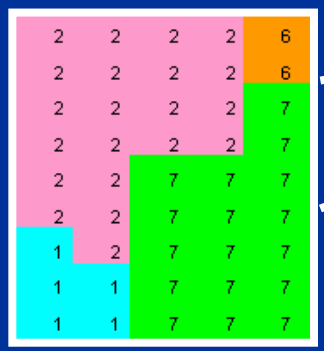
- WRAP Regional Modeling Center
  - http://pah.cert.ucr.edu/aqm/308/
- CMAQ model runs using 2002 "interim" EIs and MM5 data
- CMAQ – EPA-developed model for regional analysis
- Tagged Species Source Apportionment (TSSA)
  - Use "Tagged Species" tracers to track chemical transformations and deposition across domain
  - Add source type tracers for key species and for defined regions and source categories
  - Contribution results at each receptor site – no need for aerosol samplers to be present

Traced Area: WRAP Modeling Domain

Each state is distinguished by a unique number in the source area mapping file







Source Tags Available for Use in the TSSA Simulation

Types	Source Category	Notes
ICON	ICON	Initial Conditions
BCON	BCON	Boundary Conditions
Emissions	MV_*	Mobile sources from any state
	BG_*	Biogenic sources from any state
	RD_*	Paved + unpaved road dust from any state
	NR_*	Non-road dust sources from any state
	PT_*	Point sources from any state
	AR_*	Area sources from any state
	WF_*	Wildland fire from any state
	AG_*	Agricultural fire from any state
	RX_*	Prescribed fire from any state
	ET_*	Total emissions from any state
	*_WRAP	Any type of source category emissions from WRAP domain
Others	OTHER	Any sources other than all of the above

* Asterisks represent unique identifiers for each source region (e.g., AZ represents Arizona).
RED tags are those selected for the AoH work.

CMAQ Summary for Rocky Mountain NP

MODEL RESULTS

Rocky Mountain National Park, CO
2002 Reconstructed Extinction
CMAQ Model Results (every day)

20% Worst Visibility Days			
	Average (Mm-1)	Minimum (Mm-1)	Maximum (Mm-1)
Total Extinction:	39.1 (13.6 dv)	28.8 (10.6 dv)	105.2 (23.5 dv)
Aerosol Extinction*:	29.1	18.8	95.2
	Average (Mm-1)	% of Tot. Extinction	% of Aer. Extinction
Ammonium Sulfate:	7.0	18%	24%
Ammonium Nitrate:	7.7	20%	27%
Organic Material:	9.5	24%	33%
Elemental Carbon:	3.0	8%	10%
Soil:	1.2	3%	4%
Coarse Material:	0.6	2%	2%
Rayleigh:	10.0	26%	N/A
20% Best Visibility Days			
	Average (Mm-1)	Minimum (Mm-1)	Maximum (Mm-1)
Total Extinction:	16.5 (5.0 dv)	11.5 (1.4 dv)	18.6 (6.2 dv)
Aerosol Extinction*:	6.5	1.5	8.6
	Average (Mm-1)	% of Tot. Extinction	% of Aer. Extinction
Ammonium Sulfate:	3.1	19%	47%
Ammonium Nitrate:	1.1	7%	17%
Organic Material:	1.5	9%	23%
Elemental Carbon:	0.4	2%	6%
Soil:	0.2	1%	4%
Coarse Material:	0.2	1%	3%
Rayleigh:	10.0	60%	N/A

*Excludes Rayleigh Extinction

AoH Trajectory Regression Analysis (TRA)

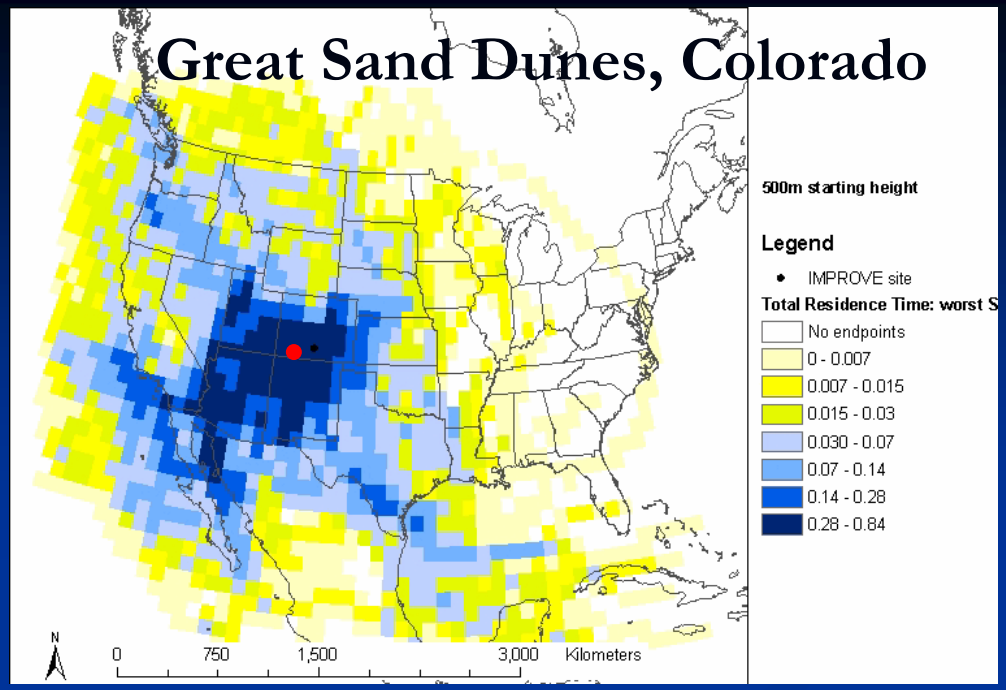
- Desert Research Institute
  - Part of WRAP Causes of Haze Assessment (CoHA)
  - http://coha.dri.edu/index.html
- Meteorological back trajectories run for 2000 – 2002 to determine flow patterns for each IMPROVE site
- TRA finds the best fit between the time air spends over a defined area (source region) and the air quality parameter measured at an IMPROVE site
- Contribution results at each IMPROVE site
  - No results for unmonitored CIAs
  - Monitored locations must have sufficient data

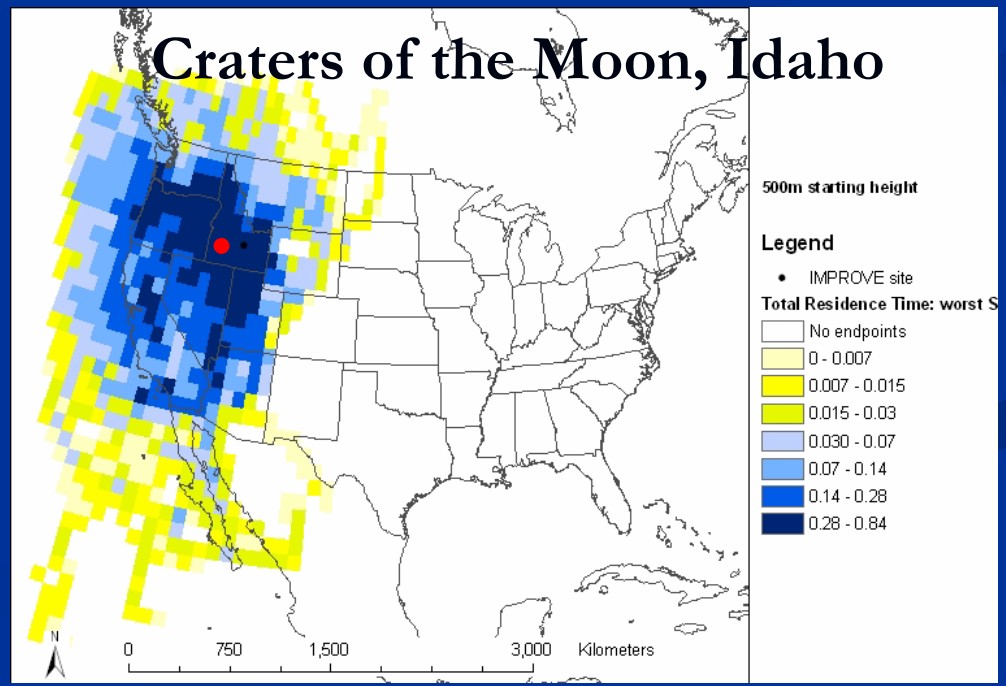
Back Trajectory Residence Time Summaries

- 20% worst sulfate days (2000 – 2002)
- W, SW, SE show highest residence times at Great Sand Dunes
- NW, W, S show highest residence times at Craters of the Moon

Back Trajectory Model Parameters Selected for AoH Analysis

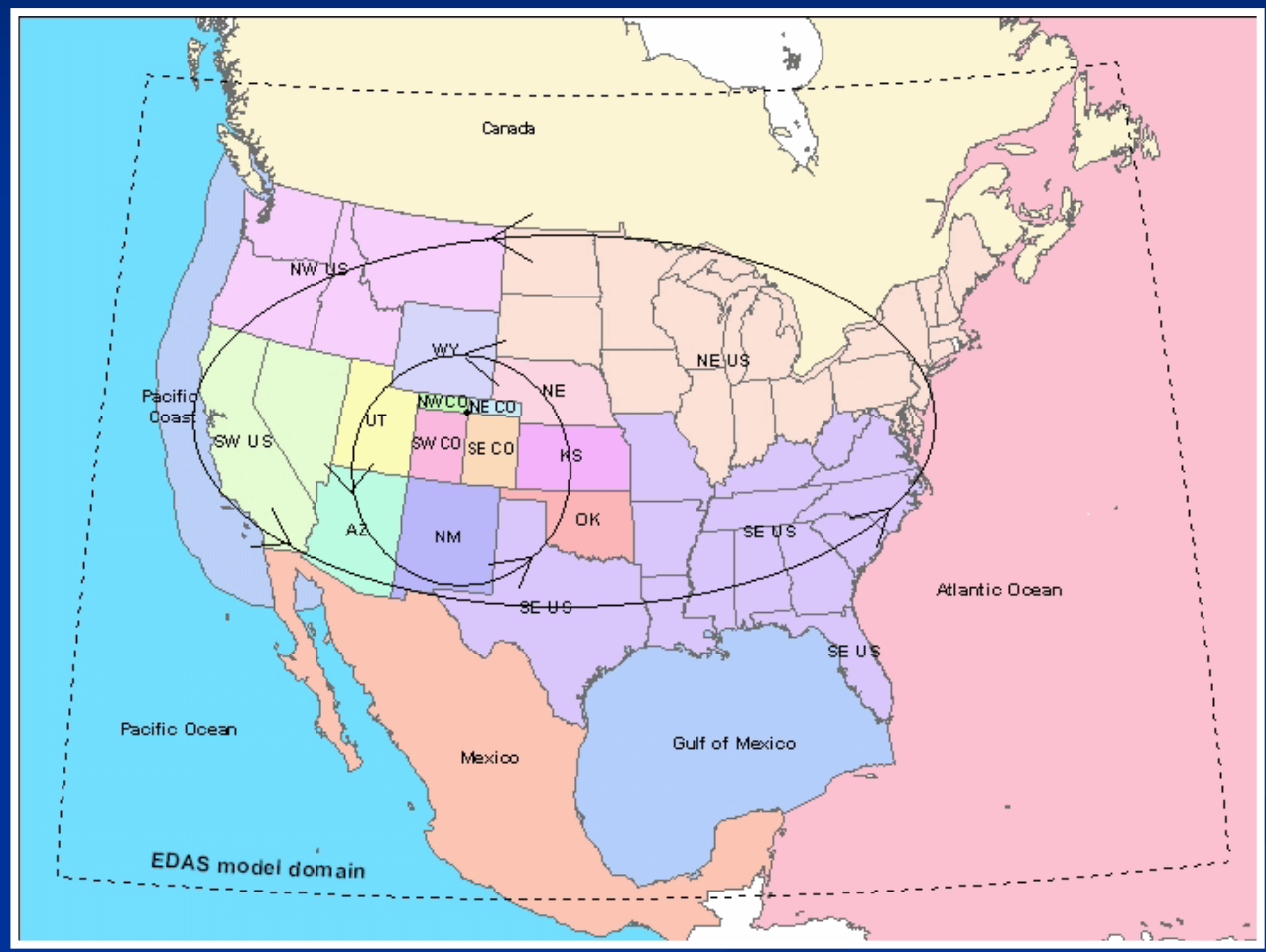
Model Parameter	Value
Trajectory duration	192 hours (8 days) backward in time
Top of model domain	14,000 meters
Vertical motion option	used model data
Receptor height	500 meters
Meteorological Field	EDAS and FNL (location dependent)





Source Region Grouping - Example

- Used for comparison of TSSA and TRA results
- Boundary states (inner circle)
- U.S. regions (outer circle)
- International (Can., Mex.)
- Other (ocean, gulf, boundary conditions, unknown or not able to attribute)



Modeling Uncertainties

- TSSA
  - Errors and uncertainties in gridded meteorological data
  - Emissions inventories uncertain and in some cases incomplete
  - TSSA – new application in CMAQ
  - 36 km grid resolution is too coarse to resolve near field effects
- TRA
  - Statistical technique – has associated uncertainty limits
  - Based on EDAS back trajectories – uncertainty increases as you move away from the end time and date
  - "Edge effect" for CIAs or source regions near the boundary of a state

Integrated Analysis and Results

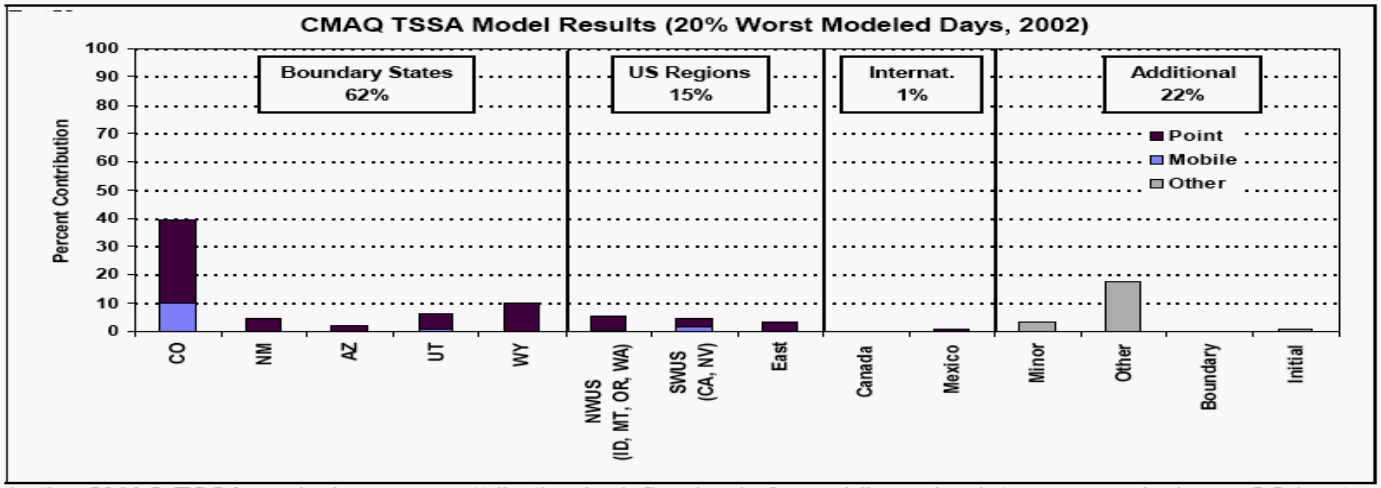
- Weight of evidence approach:
  - Less confident in any single analysis
  - Multiple, independent analyses are necessary to gain more confidence in findings
- Integrated analysis looked at:
  - Accuracy and reliability of EIs, monitoring data, model results
  - Geographic source regions for SO4 and NO3
    - TSSA – Point and Mobile emissions
    - TRA – Did not distinguish between source categories
  - Logical groupings of CIAs exist based on attribution of these pollutants

Weight of Evidence Approach – Considerations

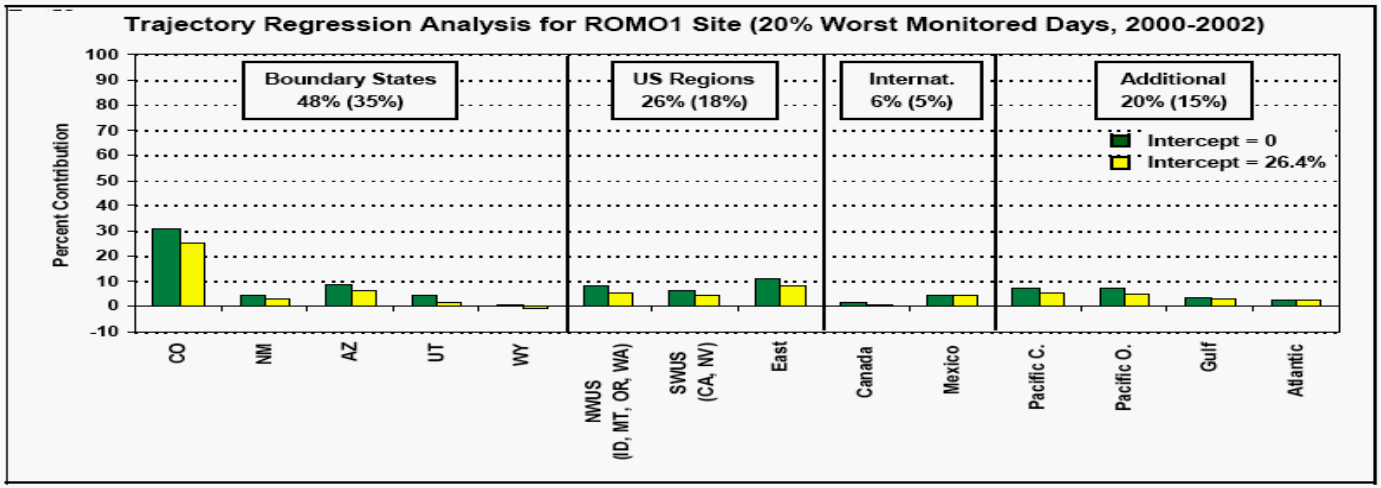
- TSSA Results
  - Supported by other analyses?
  - What if contradicted by other analyses?
- TRA Results
  - Noisy data – statistical interpretation required
  - Farther source regions must be larger to compensate for increasing uncertainties in longer trajectories
  - Do we see possible "edge effects"?
- Monitoring Data
  - Reasonably accurate and certain measurements
  - As a snap shot, can't demonstrate cause and effect
- Emissions
  - EI are estimates, not directly measured
  - Do EI inputs support attribution results?

Rocky Mountain NP – Sulfate Apportionment Results

Rocky Mountain National Park, CO
SO4 Source Apportionment Method Comparison



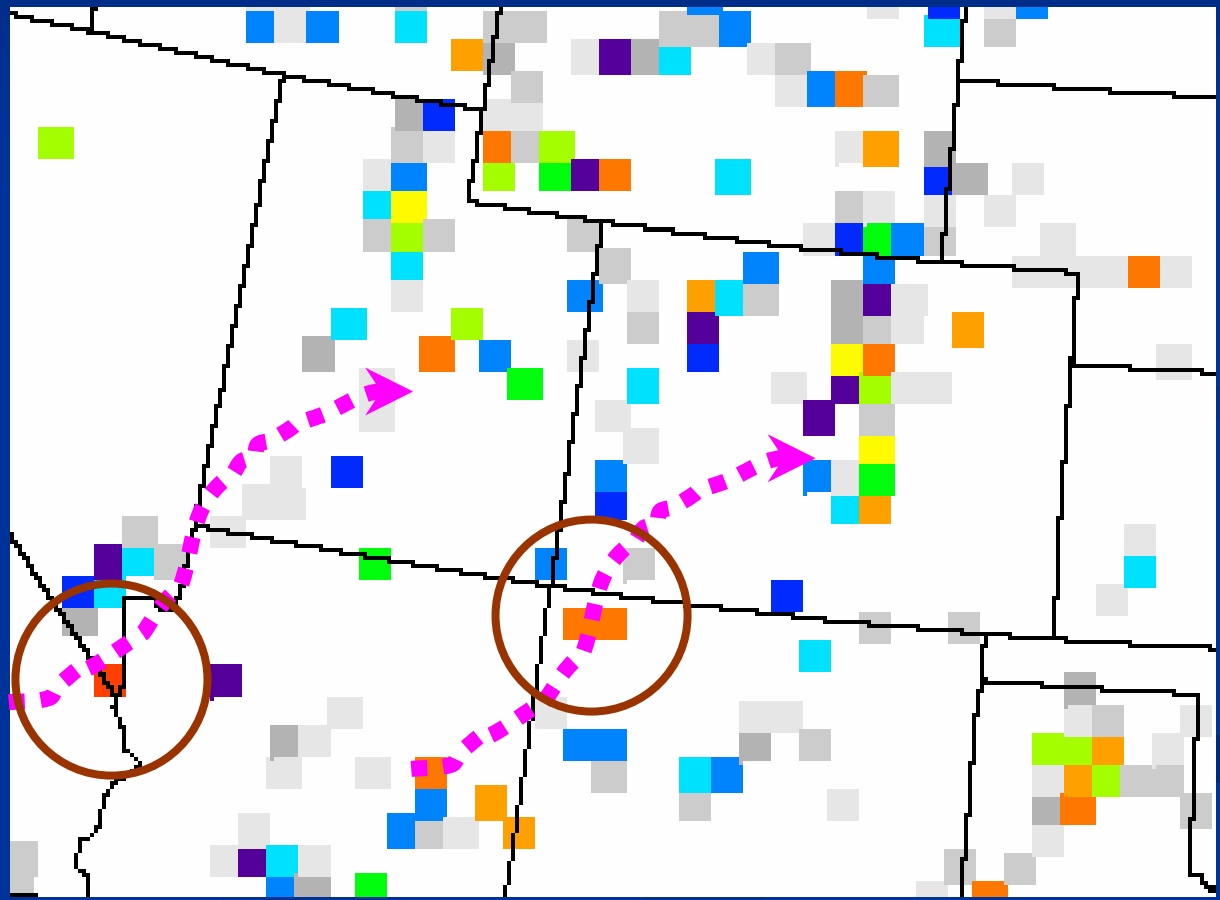
In the CMAQ TSSA analysis, source attribution is defined only for mobile and point source emissions. SO4 not attributed to mobile or points sources is labeled "Other". Emissions not included in the identified categories are grouped as "Minor".



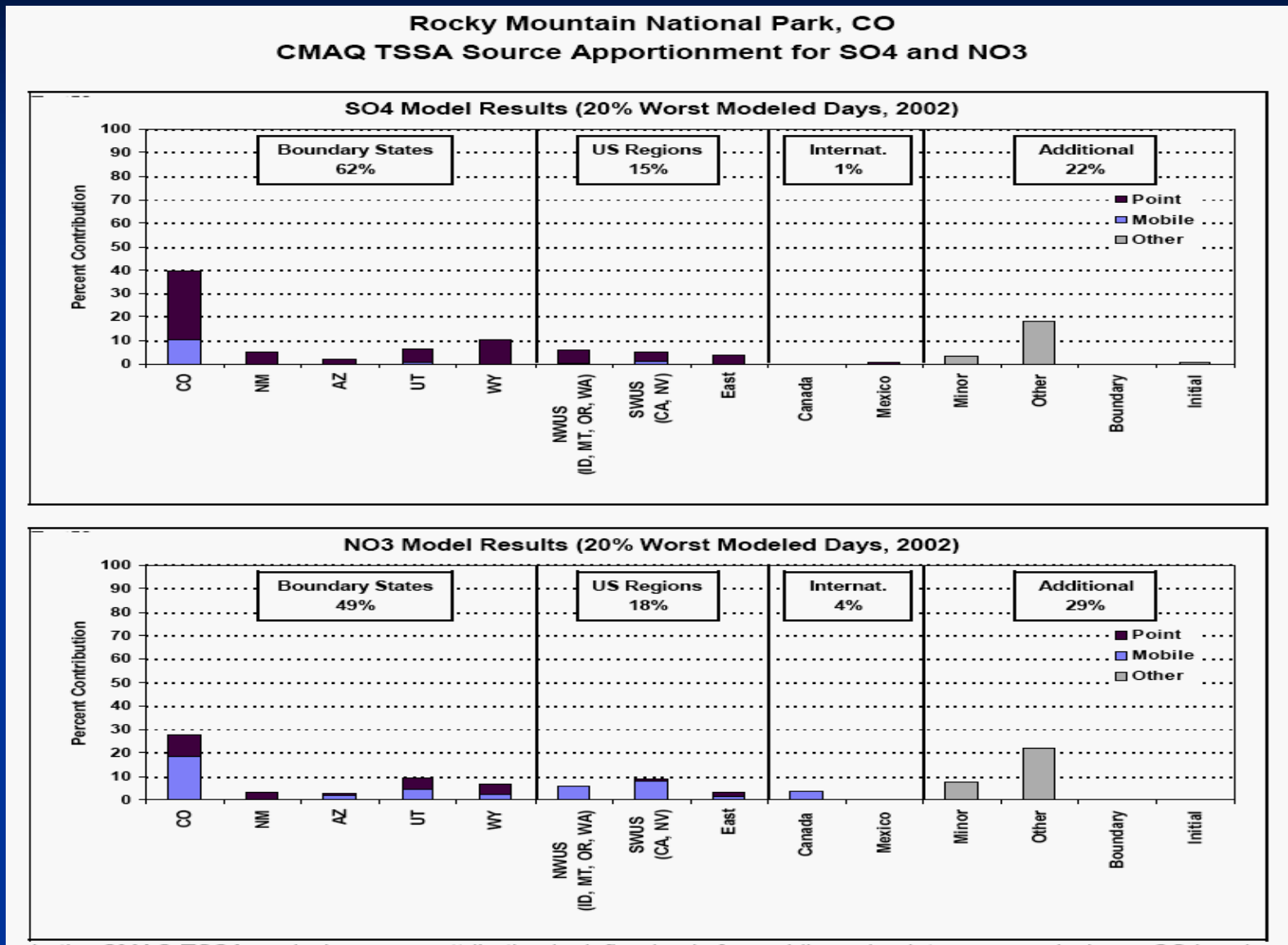
Trajectory regression analysis attributes monitoring results using back trajectory residence times and measured pollutant values. Regional percent sums are indicated with non-zero intercept values in parentheses. Categories in the "Additional" grouping do not directly correspond to categories listed in the CMAQ TSSA

"Edge Effect" Explanation for Sulfate TRA Results

- Trajectory points every 3 hours may not accurately represent high emission source regions near the edges of states
- Therefore, TRA results may miss or underestimate the impact from these regions

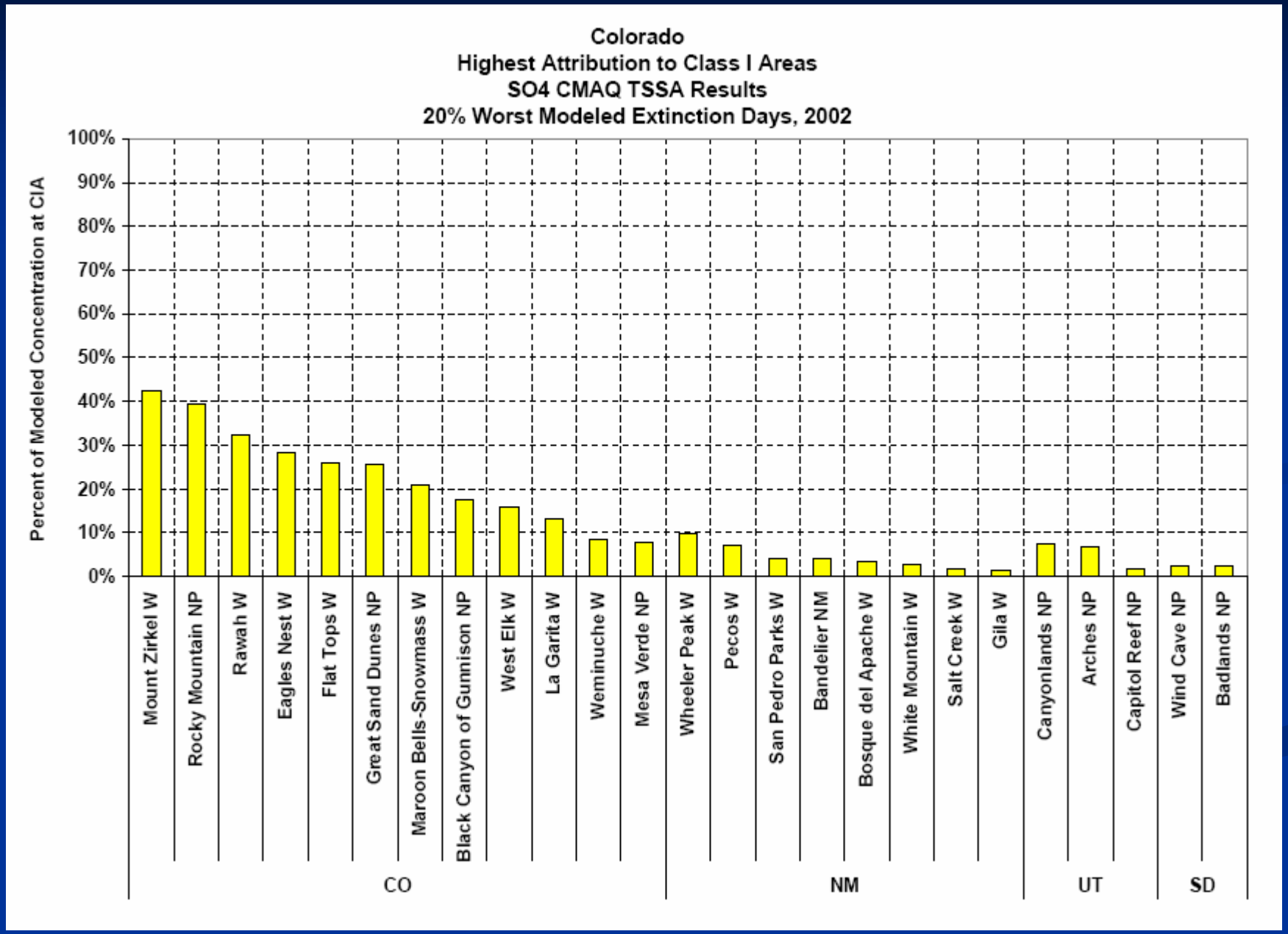


Rocky Mountain NP – TSSA SO4/NO3 Results



In the CMAQ TSSA analysis, source attribution is defined only for mobile and point source emissions. SO4 and NO3 not attributed to mobile or points sources is labeled "Other". Emissions not included in the identified categories are grouped as "Minor".

SO4 Attribution Summary for Colorado



Available Attribution Information

- More information for some species than others
- Credibility of results depend on how well all categories of information agree

Species	Attribution Results		Attribution Support	Other Supporting Data	
	TSSA	Trajectory Regression	Back Trajectory Summaries	Emissions	Monitoring
Sulfate	x	x	x	x	x
Nitrate	x		x	x	x
Org. Carbon			x	x	x
Elem. Carbon			x	x	x
Soil			x	x	x
Coarse Mass			x	x	x
Extinction		x	x		x

Initial Grouping of CIAs by Sulfate and Nitrate Source Attribution

- 20 groupings
- Based on source region attribution and species signal strength and similarity
- Groupings similar for SO4 and NO3

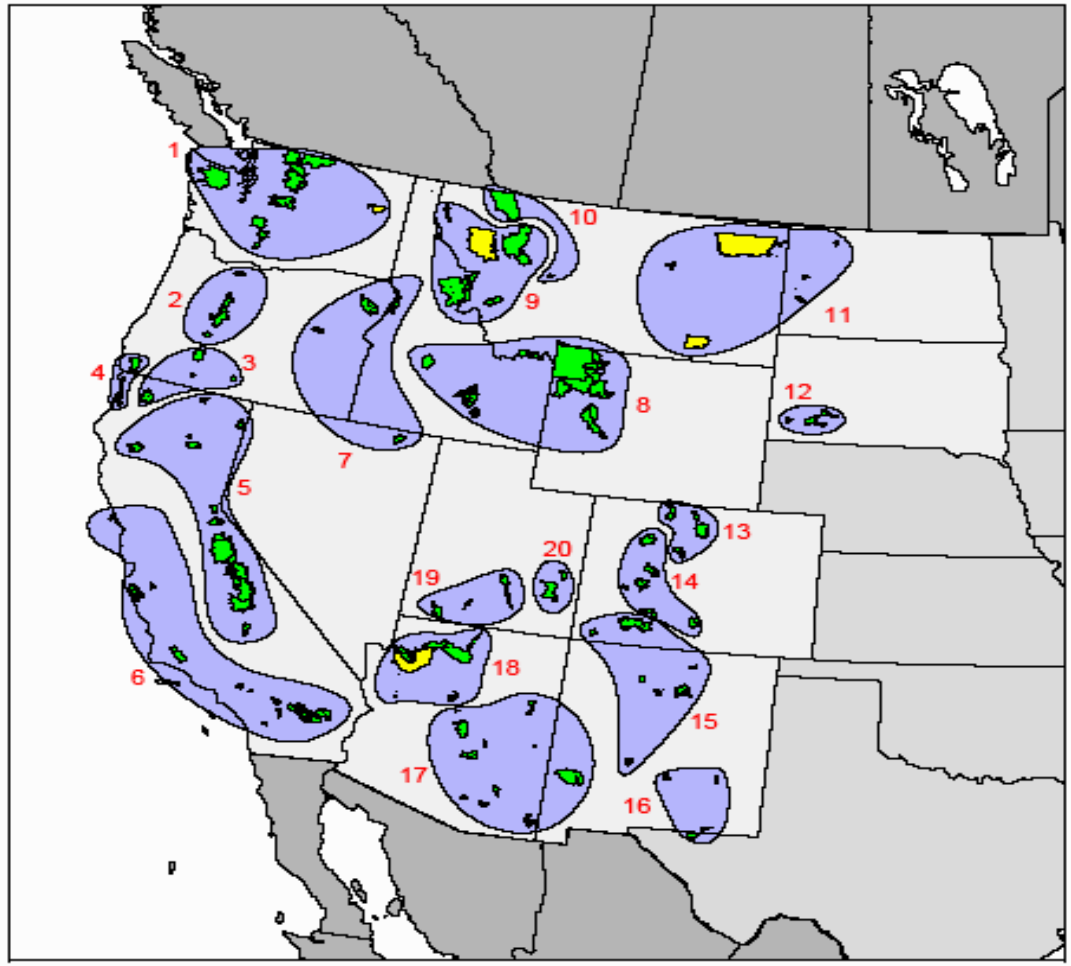


Figure 4-1. Initial grouping of Class I areas by TSSA source region attribution of sulfate and nitrate. No consideration of monitoring data was made to generate these groupings.

CMAQ Results for SO4 and NO3

Class I Area Group Characteristics

Range of TSSA Sulfate and Nitrate Contributions in Percent (Rounded to Nearest 5%)

Group	Species	AZ	CA	CO	ID	MT	NV	NM	ND	OR	SD	UT	WA	WY	Mex	Can	EA US	Other
Group 1	SO4									0-10			30-70					25-65
	NO3									5-10			30-65			5-10		20-30
Group 2	SO4									30-40			15-20					35-45
	NO3		5-25							25-40			15-25					15-20
Group 3	SO4		5-15							15-20			10					55
	NO3		35-40				5-10			5-15								25-45
Group 4	SO4									15			10					65-70
	NO3		5-10							20			5-10					55-65
Group 5	SO4		15-45							0-10								40-55
	NO3		30-65							0-10								25-55
Group 6	SO4		50-85															10-40
	NO3		55-75															15-25
Group 7	SO4				10-20		5-10			10-25			10-15					30-45
	NO3		5-10		15-20					10-15			10					30
Group 8	SO4				10-35	0-20				0-10		0-10	0-10	0-20				25-40
	NO3		5-10		10-20	0-10				0-10		10-20	5-10			0-10		25-30
Group 9	SO4				5-10	10-35				5-10			10-30					30-35
	NO3				5-15	5-20				5-10		0-10	10-25			5-10		25-30
Group 10	SO4					65							5-10					15-20
	NO3					15-20							10-15			10		25-30
Group 11	SO4					5-35			10-40					0-10				25-45
	NO3					5-15			5-10				5-10			15-25		30-35
Group 12	SO4								10-20					20			10	30-40
	NO3													10		10	10	30
Group 13	SO4			30-45				5-10				5-10		10-15				20
	NO3		5-10	20-30								10-15		5-10				20-25
Group 14	SO4	5-10		15-25				10-20				5-15		5-10			0-10	15-25
	NO3		10	10-15				5-10				10-20						15-25
Group 15	SO4	5-20		0-10				20-50				0-15					0-15	10-20
	NO3	10	10-15	10-15				15-30				10-15					0-10	10-25
Group 16	SO4							15-25							5-15		35-50	10-20
	NO3							10-15									20-25	25-30
Group 17	SO4	30-50	0-15					0-15							0-10		0-15	20-30
	NO3	20-40	15-20												0-10			25-35
Group 18	SO4	15-20	15-20				10-20					5-10						25-30
	NO3	20-30	30-35									5-15						20-25
Group 19	SO4		10-15				10-20					15-25						25-30
	NO3	5-10	15-20				5-10					25-35						15-20
Group 20	SO4							10-15				30		10				20-25
	NO3			10				10				30-35						15

BLUE text indicates ranges ~10 – 25% **RED** text indicates ranges exceeding 25%

Major Findings

- Compiled attributions for 120+ Class I areas
- Independent apportionment methods generally consistent in identifying source regions
- AoH weight of evidence method generally applicable to haze attribution
- Emissions from mobile and point source categories:
  - SO_2 and NO_x are regional pollutants, comprising a significant percentage of each state's emissions
  - Both are important contributors to light extinction
  - Modeled emissions from each WRAP region state impact Class I areas of one or more other states and tribes