

Clean Air Status and Trends Network (CASTNET)

2004 Annual Report

Prepared for:

U. S. Environmental Protection Agency
Office of Air and Radiation
Clean Air Markets Division
Washington, DC

November 2005



Clean Air Status and Trends Network (CASTNET)

2004 Annual Report

Prepared by:



Prepared for:

U.S. Environmental Protection Agency
Office of Air and Radiation
Clean Air Markets Division
Washington, DC

November 2005

Table of Contents

Chapter 1	CASTNET Program Introduction.....	1
	Monitoring Network	3
	CASTNET Measurements	4
	Modeling and Data Management.....	5
	Quality Assurance.....	6
	Instrument Comparison Project	7
	Significant Events During 2004.....	9
	SO ₂ and NO _x Emissions	10
Chapter 2	Atmospheric Concentrations	11
	Sulfur Dioxide.....	11
	Particulate Sulfate	13
	Total Nitrate	15
	Particulate Ammonium	16
	Bias in NO ₃ and HNO ₃ Measurements.....	18
Chapter 3	Deposition of Sulfur and Nitrogen.....	19
	Sulfur Deposition	20
	Contributors to Atmospheric Deposition Measured at CASTNET	
	Eastern Reference Sites.....	24
	Nitrogen Deposition.....	25
	African Saharan Aerosols (Dust) in CASTNET	29
Chapter 4	Ozone Concentrations	31
	Design Values for Ozone Concentrations for 2002 through 2004.....	31
	Eight-Hour Ozone Concentrations.....	33
	Fifteen-Year Trends	34
	CASTNET Ozone Measurements.....	37
Chapter 5	Data Quality	39
	Precision.....	40
	Accuracy	44
	CASTNET Sample Handling.....	46
	Completeness	47
	Conclusion	48
References	R-1
Appendix A	Locational and Operational Characteristics of CASTNET Sites.....	A-1

List of Tables and Figures

Chapter 1 CASTNET Program Introduction

- Figure 1-1** CASTNET Sites as of December 2004
- Figure 1-2** Three-Stage Filter Pack
- Figure 1-3** Multi-Layer Model
- Figure 1-4** Monitoring Instrument for Aerosols and Gases (MARGA)
- Figure 1-5** Trends in SO₂ and NO_x Emissions
- Figure 1-6** Annual Utility SO₂ Emissions (Phase I and Phase II Plants, only) for 2004
- Figure 1-7** Annual Utility NO_x Emissions (Phase I and Phase II Plants, only) for 2004
- Table 1-1** Instrument Specifications for Semi-Continuous Monitoring

Chapter 2 Atmospheric Concentrations

- Figure 2-1** CASTNET Reference Sites
- Figure 2-2** Annual Mean SO₂ Concentrations (µg/m³) for 2004
- Figure 2-3** Trend in Annual Mean SO₂ Concentrations (µg/m³) – Eastern United States
- Figure 2-4** Annual Mean SO₄²⁻ Concentrations (µg/m³) for 2004
- Figure 2-5** Trend in Annual Mean SO₄²⁻ Concentrations (µg/m³) – Eastern United States
- Figure 2-6** Annual Mean Total Nitrate (NO₃⁻ + HNO₃) Concentrations (µg/m³) for 2004
- Figure 2-7** Trend in Annual Mean Total Nitrate (NO₃⁻ + HNO₃) Concentrations (µg/m³) – Eastern United States
- Figure 2-8** Annual Mean NH₄⁺ Concentrations (µg/m³) for 2004
- Figure 2-9** Trend in Annual Mean NH₄⁺ Concentrations (µg/m³) – Eastern United States

Chapter 3 Deposition of Sulfur and Nitrogen

- Figure 3-1** Dry Sulfur (SO₂ + SO₄²⁻) Deposition (as S) (kg/ha/yr) for 2004
- Figure 3-2** Total (Dry + Wet) Sulfur Deposition (kg/ha/yr) for 2004
- Figure 3-3** Trend in Dry Sulfur Deposition (kg/ha/yr) – Eastern United States
- Figure 3-4** Trend in Total (Dry + Wet) Sulfur Deposition (kg/ha/yr) – Eastern United States
- Figure 3-5** Trend in Dry, Wet, and Total Sulfur Deposition (as S) (kg/ha/yr) with Precipitation-Weighted Mean Concentrations in Precipitation (mg/L) – Eastern United States
- Figure 3-6** Dry Nitrogen (HNO₃ + NO₃⁻ + NH₄⁺) Deposition (as N) (kg/ha/yr) for 2004
- Figure 3-7** Total (Dry + Wet) Nitrogen Deposition (as N) (kg/ha/yr) for 2004
- Figure 3-8** Trend in Dry Nitrogen Deposition (kg/ha/yr) – Eastern United States
- Figure 3-9** Trend in Total (Dry + Wet) Nitrogen Deposition (kg/ha/yr) – Eastern United States
- Figure 3-10** Trend in Dry, Wet, and Total Nitrogen Deposition (as N) (kg/ha/yr) with Precipitation-Weighted Mean Concentrations in Precipitation (mg/L) – Eastern United States
- Figure 3-11** Sand Storm

List of Tables and Figures (continued)

Chapter 3 Deposition of Sulfur and Nitrogen (continued)

Figure 3-12 Dust Transport

Figure 3-13 Summer and Winter Dust Transport

Figure 3-14 TOMS Aerosol Index for June 23, 2004

Figure 3-15 Time Series of Weekly Ca^{2+} Concentrations ($\mu\text{g}/\text{m}^3$)

Figure 3-16 Time Series of Weekly Ca^{2+} Deposition (grams/ha/week)

Chapter 4 Ozone Concentrations

Figure 4-1 CASTNET Sites Above 1-Hour NAAQS

Figure 4-2 Three-Year Averages of the Fourth Highest Daily Maximum 8-Hour O_3 Concentrations (ppb) for 2002-2004

Figure 4-3 Fourth Highest Daily Maximum 8-Hour O_3 Concentrations (ppb) for 2004

Figure 4-4 Trend in Fourth Highest Daily Maximum 8-Hour O_3 Concentrations (ppb) – Eastern United States

Figure 4-5 Trend in Mean Seasonal Temperature ($^{\circ}\text{C}$) (May through September) – Eastern United States

Figure 4-6 Trend in Mean Seasonal Solar Radiation (W/m^2) (May through September) – Eastern United States

Figure 4-7 Trend in Total Precipitation (mm) (May through September) – Eastern United States

Chapter 5 Data Quality

Figure 5-1 Historical and 2004 Precision Data for Atmospheric Concentrations

Figure 5-2 Precision Data for Cation and Cl^- Concentrations

Figure 5-3 Precision Results for Laboratory Replicate Samples (2004)

Figure 5-4 Historical and 2004 Precision Data by Quarter for Ozone Concentrations

Figure 5-5 Historical (1990-2003) and 2004 Percent Completeness of Measurements and Modeled Estimates

Table 5-1 Data Quality Indicators for CASTNET Laboratory Measurements

Table 5-2 Collocated Precision Results for 2004 by Quarter (MARPD)

Table 5-3 Data Quality Indicators for CASTNET Field Measurements

Table 5-4 Filter Pack QC Summary for 2004

Table 5-5 Accuracy Results for 2004 Field Measurements

List of Acronyms and Abbreviations

°C	degrees Celsius
Ca ²⁺	particulate calcium ion
CAAA	Clean Air Act Amendments
CAPMoN	Canadian Air and Precipitation Monitoring Network
CASTNET	Clean Air Status and Trends Network
CFR	Code of Federal Regulations
Cl ⁻	particulate chloride ion
COC	chain-of-custody
CVS	continuing verification samples
DQI	data quality indicator
EPA	U.S. Environmental Protection Agency
grams/ha/week	grams per hectare per week
H ₂ SO ₄	sulfuric acid
HNO ₃	nitric acid
Hz	hertz
IC	ion chromatography
K ⁺	particulate potassium ion
kg/ha/yr	kilograms per hectare per year
LAI	leaf area index
LiBr	lithium bromide
m	meters
MACTEC	MACTEC Engineering and Consulting, Inc.
MARCH	Maryland Aerosol Research and Characterization
MARGA	monitoring instrument for aerosols and gases
MARPD	aggregated mean of the absolute value of relative percent difference
Mg ²⁺	particulate magnesium ion
mg/L	milligrams per liter
MLM	Multi-Layer Model
mm	millimeter
Na ⁺	particulate sodium ion
NAAQS	National Ambient Air Quality Standards
NADP/NTN	National Atmospheric Deposition Program/National Trends Network
NAPAP	National Acid Precipitation Assessment Program
NCORE	National Core Network

List of Acronyms and Abbreviations (continued)

NDDN	National Dry Deposition Network
NH ₃	ammonia
NH ₄ ⁺	particulate ammonium
NH ₄ NO ₃	ammonium nitrate
(NH ₄) ₂ SO ₄	ammonium sulfate
NIST	National Institute of Standards and Technology
NO	nitric oxide
NO ₃ ⁻	particulate nitrate
NO _x	nitrogen oxides
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
O ₃	ozone
PM _{2.5}	mass of particles with a mean diameter of less than 2.5 μm
ppb	parts per billion
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
RH	relative humidity
RPD	relative percent difference
Sigma theta	standard deviation of horizontal wind direction within one hour
SLAMS	State and Local Monitoring Stations
SO ₂	sulfur dioxide
SO ₄ ²⁻	particulate sulfate
SOP	standard operating procedures
SR	solar radiation
TOMS	Total Ozone Mapping Spectrometer
μg/m ³	micrograms per cubic meter
μm	micrometer
UPS	uninterruptible power supply
UV	ultraviolet
V _d	deposition velocity
VAC	volts alternating current
W/m ²	watts per square meter

Chapter 1: CASTNET Program Introduction

CASTNET began operation in 1991 to provide long-term monitoring of air quality in rural areas. The network, as of December 2004, features 85 site locations throughout the continental United States and Alaska.



Rocky Mountain National Park, CO (ROM406/206)

The 1990 Clean Air Act Amendments (CAAA) mandated significant reductions in sulfur dioxide (SO₂) and nitrogen oxides (NO_x) emissions from electric utility plants. In addition, the CAAA directed that a national air monitoring network be established to track real-world environmental results as the reductions were implemented. The Clean Air Status and Trends Network (CASTNET) was established by the U.S. Environmental Protection Agency (EPA) in 1991. At that time the National Dry Deposition Network (NDDN), EPA's forerunner to CASTNET, was merged into CASTNET and the approximately 50 NDDN sites became the core CASTNET sites.

CASTNET is a national air monitoring network that provides data for determining relationships between emissions, air quality, deposition, and ecological effects. CASTNET measures atmospheric sulfur and nitrogen pollutants that result from precursor emissions of SO₂ and NO_x together with measurements of ozone (O₃) concentrations and meteorological conditions at 10 meters (m). This report summarizes CASTNET monitoring activities and the resulting concentration and deposition data for 2004.

CASTNET is sponsored by EPA and the National Park Service (NPS). NPS began its participation in CASTNET in 1994 under an agreement with EPA. NPS is responsible for the protection and enhancement of air quality and related values in national parks and wilderness areas. Over the years, the number of NPS-sponsored CASTNET sites has grown to 29 sites as of the end of 2004. EPA, together with partners such as NPS, has added many sites to the network, which now comprises more than 80 sites across the United States.

In addition to EPA and NPS, the principal sponsors, CASTNET operates in partnership with other rural long-term monitoring networks such as the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). NADP/NTN operates monitoring stations with wet deposition samplers to measure the concentrations and deposition rates of air pollutants that are removed from the atmosphere by precipitation. NADP/NTN operates wet deposition samplers at or near virtually every CASTNET site. The Canadian Air and Precipitation Monitoring Network (CAPMoN) operates 25 measurement sites throughout Canada and one in the United States. CASTNET and CAPMoN both operate samplers at monitoring stations in Ontario, Canada and at monitoring stations located at Pennsylvania State University, pictured below. Together, CASTNET, NADP/NTN, and CAPMoN allow for a regional assessment of total (dry + wet) deposition throughout the United States and Canada.

EPA relies on CASTNET and other long-term monitoring networks to generate the data and information used to assess the effectiveness of national air pollution control efforts under several different mandates, including Title IX of the CAAA, the National Acid Precipitation Assessment Program (NAPAP), the Government Performance and Results Act, and the United States – Canada Air Quality Agreement.

Additional information, previous annual reports and other CASTNET documents can be found on the EPA web site, www.epa.gov.castnet.

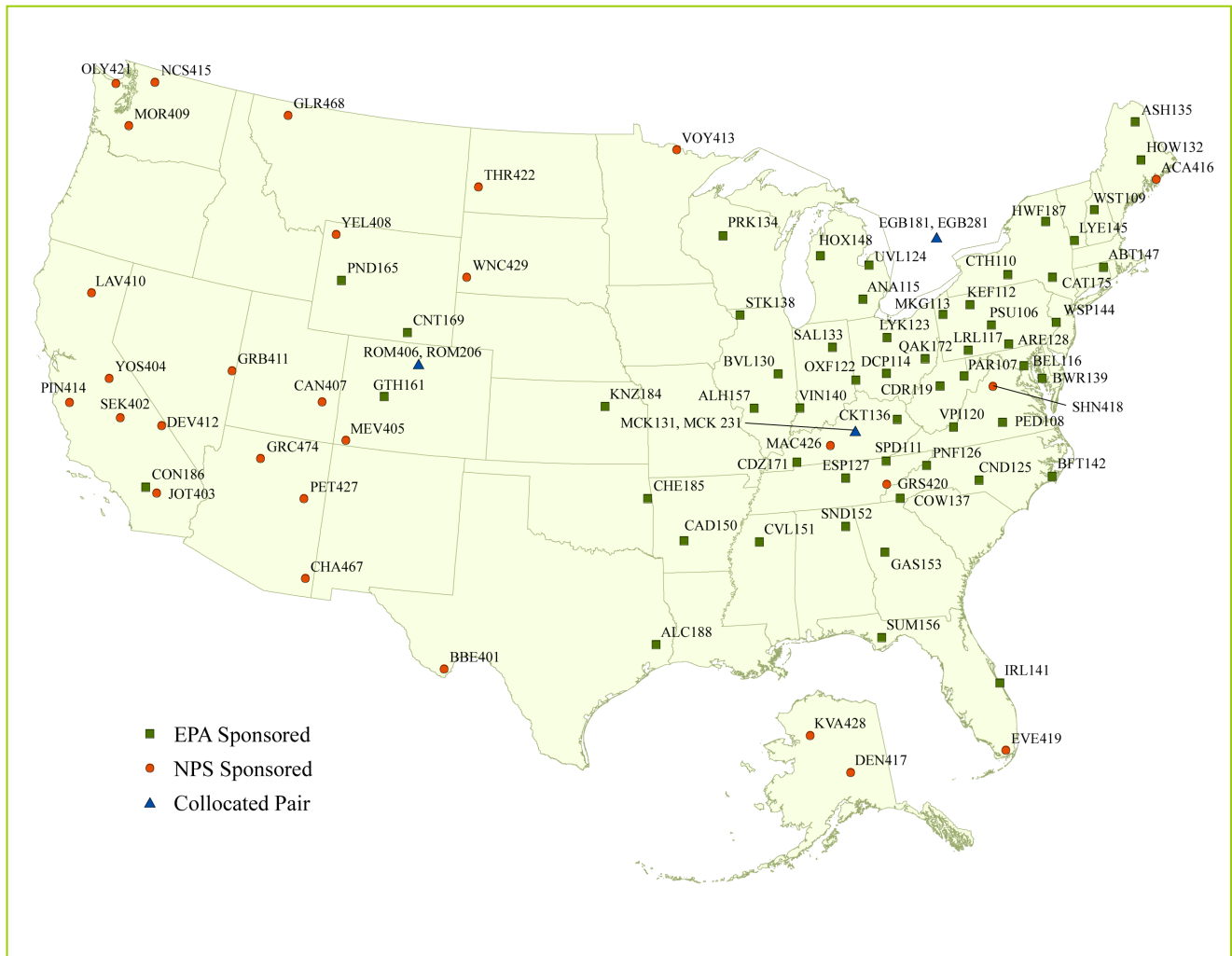


Pennsylvania State University, PA (PSU106)

Monitoring Network

Figure 1-1 shows the locations of CASTNET monitoring sites as of December 2004. Eighty-eight sites were operational at 85 distinct locations. Most CASTNET sites are located in rural or remote locations away from pollution emission sources and heavily populated areas. Appendix A provides the location and operational characteristics of each site by state, including information on start date, latitude, longitude, elevation, and the types of measurements taken at each site. For the purposes of this report, CASTNET sites are called “western” or “eastern” depending on whether they are west or east of 100 degrees west longitude. The dividing line runs north to south across the states of North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas. As a result, THR422, ND; WNC429, SD; and BBE401, TX are western sites while KNZ184, KS; CHE185, OK; and ALC188, TX are eastern sites.

Figure 1-1 CASTNET Sites as of December 2004



CASTNET Measurements

CASTNET sampling stations collect a variety of air pollutant concentrations and meteorological measurements on a weekly basis. Over the course of the week, air is drawn through a three-stage filter pack (Figure 1-2) at a controlled flow rate to collect air pollutants in the form of gases and particles. The filter pack is changed out each Tuesday and shipped to the analytical chemistry laboratory for analysis.

CASTNET measures concentrations of sulfur in the form of sulfur dioxide and sulfate and nitrogen as nitrate, nitric acid, and ammonium. In addition, it measures concentrations of chloride, calcium, sodium, magnesium, and potassium. CASTNET also measures ozone, one of the major components of smog. In addition to the air pollutants, CASTNET sites record meteorological measurements of temperature, solar radiation, relative humidity, precipitation, wind speed and direction, and surface wetness. These meteorological measurements are used to study the interaction of the pollutants with ecosystems in the atmospheric boundary layer and as part of the mathematical model (the Multi-Layer Model or MLM) used for estimating dry deposition to the environment. The ozone and meteorological measurements are recorded continuously and archived as hourly averages.

CASTNET Ambient Measurements

- Sulfur dioxide (SO_2)
- Particulate sulfate (SO_4^{2-})
- Particulate nitrate (NO_3^-)
- Nitric acid (HNO_3)
- Particulate ammonium (NH_4^+)
- Particulate calcium (Ca^{2+})
- Particulate sodium (Na^+)
- Particulate magnesium (Mg^{2+})
- Particulate potassium (K^+)
- Particulate chloride (Cl^-)
- Ozone (O_3)
- Meteorological variables and information on land use and vegetation

Figure 1-2 Three-Stage Filter Pack



Modeling and Data Management

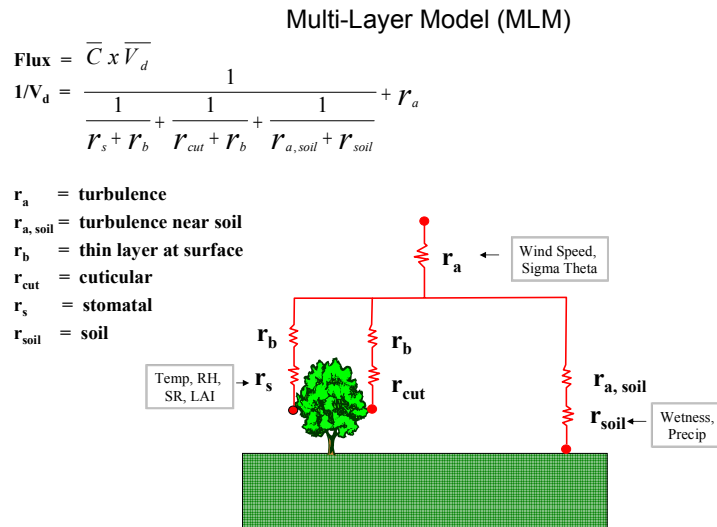
The original network design was based on the assumption that dry deposition or flux could be estimated as the linear product of measured pollutant concentration (C) and modeled deposition velocity (V_d):

$$Flux = C \times V_d$$

Measured atmospheric concentrations are calculated based on the mass of each analyte in each filter extract and the volume of air sampled. The rate of deposition of a pollutant, also known as deposition velocity, is influenced by meteorological conditions, vegetation, and chemistry. Dry deposition processes are modeled as resistances to deposition. The deposition velocity values are calculated for each hour of each year using the mathematical computer model, the Multi-Layer Model (MLM). The data used in the MLM to estimate dry deposition are derived from meteorological measurements and pollutant concentrations taken at the site together with an estimation of the vegetation leaf-out and leaf area index (LAI). The schematic of the MLM in Figure 1-3 shows the relationships among the various resistances and illustrates the meteorological and other data that are required as model input.

The CASTNET database is available to the public via EPA's CASTNET data web page: www.epa.gov/castnet/data. The web site provides archives of the concentration and deposition data. Fully validated data are generally available approximately ten months following collection. Other documentation for the network, including information on all CASTNET sites, can be found at the CASTNET home page: www.epa.gov/castnet.

Figure 1-3 Multi-Layer Model



Quality Assurance

The CASTNET quality assurance (QA) program was designed to ensure that all reported data are of known and documented quality in order to meet CASTNET objectives and to be reproducible and comparable with data from other monitoring networks and laboratories. The QA program elements are documented in the CASTNET Quality Assurance Project Plan (QAPP) (MACTEC, 2003b). The QAPP is comprehensive and includes standards and policies for all components of project operation from site selection through final data reporting. It can be downloaded from www.epa.gov/castnet/library.html.

Data quality indicators (DQI) have been formulated to gauge achievement of CASTNET objectives. DQI are quantitative and qualitative descriptors used to interpret the degree of acceptability and utility of the data collected. The DQI for CASTNET are precision, accuracy, completeness, bias, representativeness, and comparability. Quantitative DQI are assessed by calculating statistical estimates of the precision, accuracy, and completeness of CASTNET measurements for both discrete and continuous data. Continual verification that the data obtained from both field and laboratory measurements meet specific criteria ensures that the data reliably present a true picture of the quantity of those pollutants in the air sampled and of the meteorological conditions used in the MLM. The historical statistics have demonstrated that the QA program is adequate and followed strictly. The results show that the selected DQI parameters are within set limits, or boundaries, and that the long-term database satisfies CASTNET objectives. The CASTNET QA program is discussed in Chapter 5 of this report.



Cranberry, NC (PNF126)

Instrument Comparison Project

CASTNET filter data have provided reliable information on 15-year trends in gaseous and aerosol pollutants. However, with improved measurement technology, data could be accessed in near real-time and available within 24 hours providing a much more timely data stream with improved capability for air quality assessment, including increased specificity and precision of reliable and highly resolved measurements of aerosols and atmospheric gases. Commercially available instrumentation is now capable of providing measurements on a semi-continuous basis for analytical cycles or time intervals ranging from 1 to 60 minutes.

In order to consider deployment of semi-continuous monitoring systems in a long-term monitoring network such as CASTNET, EPA needs to critically evaluate any proposed instrumentation through intensive field testing and intercomparison with current CASTNET filter pack measurements. A joint project between EPA's Emissions Monitoring and Analysis Division of the Office of Air Quality Planning and Standards and the Clean Air Market Programs, a division of the Office of Atmospheric Programs, was initiated to evaluate enhancements to rural multi-pollutant monitoring.

CASTNET has been proposed as a platform for the expansion and enhancement of regional monitoring networks as part of the national CORE Network (NCORE) strategy, which includes multi-pollutant and toxics monitoring. An objective of NCORE is to improve rural air quality assessment and modeling. In addition to standard CASTNET measurements, inclusion of measurements of low-concentration carbon monoxide; total reactive oxides of nitrogen (which include oxides of nitrogen, composed of nitric oxide + nitrogen dioxide, and other reactive nitrogen oxide species); sulfur dioxide; and ammonia have been proposed to support NCORE's objectives.

Figure 1-4 Monitoring Instrument for Aerosols and Gases (MARGA)

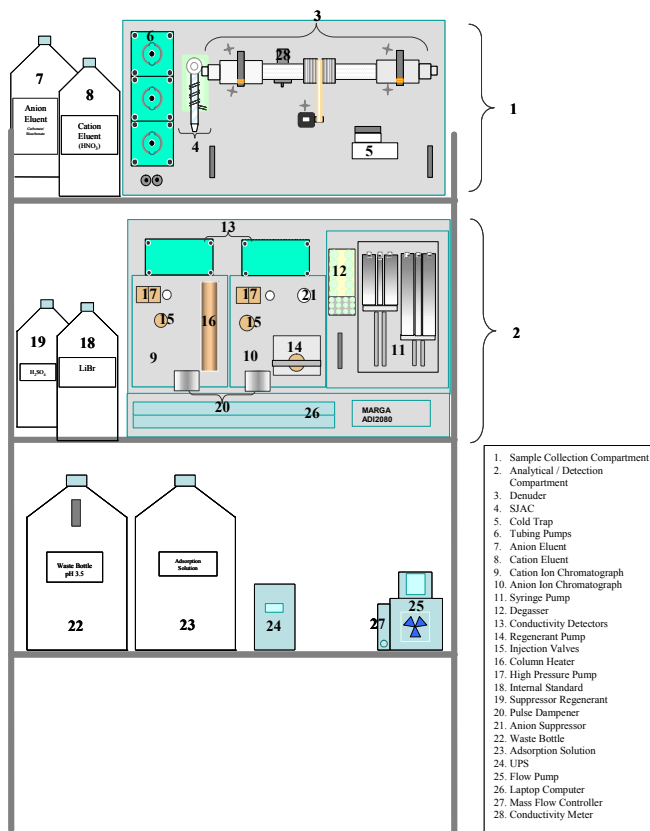


Table 1-1 Instrument Comparison Project: Instrument Specifications for Semi-Continuous Monitoring

Species to Measure:	<ul style="list-style-type: none"> Particle Phase: Sulfate, nitrate, and ammonium, (chloride, sodium, potassium, calcium, and magnesium - desirable). Gas Phase: Sulfur dioxide, nitric acid, and ammonia (nitrous acid and hydrochloric acid - desirable).
Detection limit:	Less than 0.1 µg/m ³ for each species.
Detection method:	Ion chromatography (IC) with conductivity detection.
Resolution:	One hour (sample accumulated for a one-hour period).
Sample collection height:	Four meters.
Sample flow:	Sufficient to achieve detection limit.
Flow control:	Active instrument to log flow rate and sample volume. Concentrations to be based on actual sample volume.
Size selective inlet:	PM _{2.5} optional.
One week unattended operation (7 consecutive days routinely):	Instrument fault detection and catastrophic failure protection.
Consumables and Routine Maintenance:	<ul style="list-style-type: none"> Reservoir size and fluid consumption reasonable for weekly attendance at remote location; incorporate fluid recycle if practicable. Designed to minimize consumables and maintenance (pump design, columns, filters, etc.). Designed for minimal maintenance on a weekly basis. Manufacturer to specify quarterly and annual maintenance requirements.
Operational Environment:	<ul style="list-style-type: none"> Shelter temperature: 25 ±5 °C; Outside temperatures: -30 to 40 °C
Quality Assurance (QC checks):	<ul style="list-style-type: none"> Sample flow rate; Ion concentrations; Other critical parameters (temperature, pressure, etc.)
Instrument Operation:	<ul style="list-style-type: none"> Designed for operators with little/no IC experience. Manufacturer to provide training on operation & maintenance documentation.
Display of current results:	48 hour graphical display and instrument operational parameters.
Storage:	Store hourly concentrations, average flow rate, sample volume, and other instrument parameters.
Format:	Data stored in CSV format.
Remote access:	Via modem or internet; instrument parameters and data available remotely.
Instrument must fit into existing CASTNET shelter with existing equipment.	Footprint less than 8 square feet; Height less than 36 inches.
110 VAC, 60 Hz, 20 amps.	

The purpose of this project is to implement a program to evaluate emerging technically and scientifically advanced measurement techniques and to ultimately determine the feasibility of enhancing the monitoring capacity of CASTNET through use of this instrumentation. The intent of this project is to replicate existing CASTNET measurements by utilizing different instruments and techniques as well as to expand the range of measured analytes at selected CASTNET project sites. The information obtained from this effort will help to further define regional atmospheric chemistry and decrease time required for resolution of atmospheric air quality measurements. By selecting one eastern, one western, and one central U. S. test site, the project will also improve understanding of the acidity of eastern aerosols versus those from western and central locations and the variability of the relative accuracy of CASTNET measurements of nitrate and nitric acid. The three evaluation site locations are Beltsville, MD (BEL116); Converse Station, CA (CON186); and Bondville, IL (BVL130).

Significant Events During 2004

January

Instrument Comparison Project initiated.

NPS-sponsored site VII423, VI stopped sampling as of January 27.

CASTNET Quality Assurance Project Plan, Revision 2.0, was completed.

February

NPS-sponsored site POF425, AK stopped sampling as of February 3.

Automated colorimetry analysis of particulate ammonium was switched to the new Bran+Luebbe AutoAnalyzer 3TM.

April

EPA-sponsored site ALC188, TX became operational.

An automated daily screening procedure for screening continuous data from the sites was deployed.

May

NPS-sponsored site KVA428, AK became operational.

H2NS Environmental's DataLinkTM polling system replaced ENVICOM as the primary polling system.

June

CASTNET Quality Assurance Project Plan, Revision 2.1, completed.

July

NPS-sponsored site HVT424, HI stopped sampling as of July 17.

The recommendation for the Monitoring Instrument for Aerosols and Gases (MARGA) submitted to EPA (Instrument Comparison Project).

August

The annual "floor-to-ceiling" audit of CASTNET property conducted by EPA and the Defense Contract Management Agency at MACTEC's Gainesville, FL location. Property management system approved by audit.

September

Instrument recommendation for trace gas instruments submitted to EPA (Instrument Comparison Project).

NPS-sponsored site KVA428, AK stopped sampling in late September.

October

IRL141, FL reinstalled. The site had been dismantled in September prior to the arrival of Hurricanes Frances and Jeanne.

SO₂ and NO_x Emissions

Title IV of the 1990 Clean Air Act established the Acid Rain Program, which was designed to reduce emissions of sulfur dioxide (SO₂) and nitrogen oxides (NO_x) in two phases. Phase I ran from 1995 through 1999 and required substantive emission reductions from 435 large electric generating plants involving approximately 2,000 individual units (DOE, 1997). Phase II began in 2000 and includes more than 2,000 generating stations.

Figure 1-5 presents information on trends in SO₂ and NO_x emissions. The bars on the chart represent emissions from Phase I and II generating stations over the period 1990 through 2004. The sharp decline in SO₂ emissions in 1995 was a result of utility compliance with Phase I of the Acid Rain Program.

Figure 1-6 presents information on state-by-state total annual Phase I and Phase II utility sulfur dioxide emissions for 2004.

Figure 1-7 presents the same information for emissions of nitrogen oxides. CASTNET's 34 reference sites (see Figure 2-1) are located in the eastern half of the United States where the heaviest emissions occur.

Figure 1-5 Trends in SO₂ and NO_x Emissions

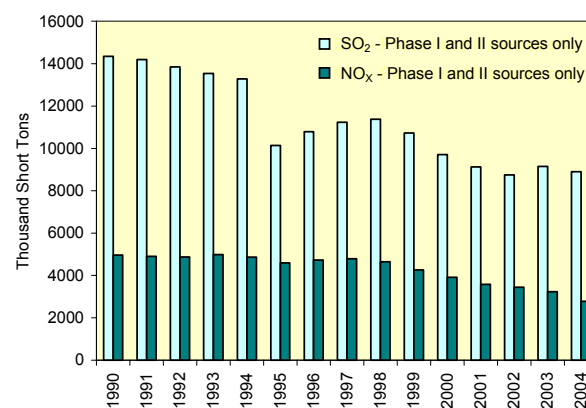


Figure 1-6 Annual Utility SO₂ Emissions (Phase I and Phase II Plants, only) for 2004

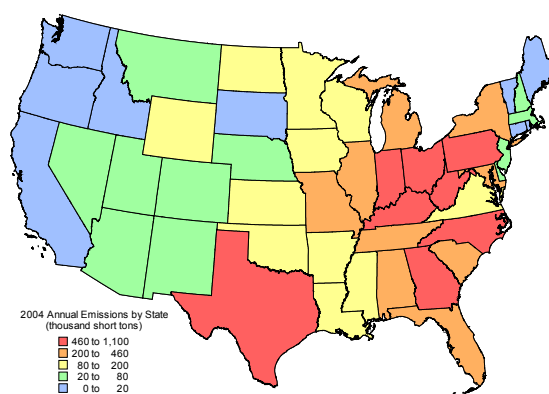
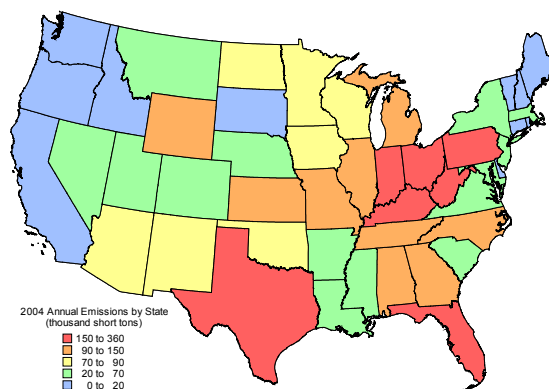


Figure 1-7 Annual Utility NO_x Emissions (Phase I and Phase II Plants, only) for 2004



Chapter 2: Atmospheric Concentrations

Species measured by CASTNET include sulfur dioxide (SO_2), sulfate (SO_4^{2-}), nitric acid (HNO_3), nitrate (NO_3^-), ammonium (NH_4^+), several earth metals, and chloride (Cl^-). Since 1990, measured concentrations of sulfur species have decreased. Concentrations of nitrogen species remained relatively steady until 2000 when they began showing a slow decline.



Bondville, IL (BVL130)

This section presents maps illustrating the magnitude of concentrations across the United States. In addition, measurements from the 34 CASTNET reference sites (Figure 2-1) were analyzed for each pollutant in order to determine any trends in concentrations. These 34 sites have been reporting CASTNET measurements since 1990 and are used for determining long-term trends.

The reference sites were selected using criteria similar to those used by EPA in its *National Air Quality and Emission Trends Report (2000)*. EPA's procedures to interpolate and extrapolate quarterly mean data were also used. The data from the 34 reference sites are presented using box plots for each year for the period 1990 through 2004.

Figure 2-1 CASTNET Reference Sites



Sulfur Dioxide

Mean sulfur dioxide (SO_2) concentrations for 2004 are shown in Figure 2-2. The map shows a region of concentrations greater than 5.0 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) of air centered in the Ohio River Valley and extending to the East Coast. The Ohio River Valley is the major SO_2 emission source region for the United States. Four sites measured concentrations greater than 10.0 $\mu\text{g}/\text{m}^3$. The single highest annual mean concentration (17.0 $\mu\text{g}/\text{m}^3$)

observed at CASTNET sites in the continental United States was measured in eastern Ohio at Quaker City (QAK172). Only three western sites (i.e., sites west of 100 degrees west longitude), Olympic National Park, WA (OLY421); Petrified Forest National Park, AZ (PET427); and Theodore Roosevelt National Park, ND (THR422), measured an annual mean SO₂ level above 1.0 µg/m³.

Figure 2-3 provides box plots that show the trend in annual mean SO₂ concentrations aggregated over the 34 reference sites for the period 1990 through 2004. Comparison of 3-year means from the beginning of the period (1990-1992) to the end of the period (2002-2004) demonstrates a substantial 36 percent reduction in SO₂ concentrations.

Figure 2-2 Annual Mean SO₂ Concentrations (µg/m³) for 2004

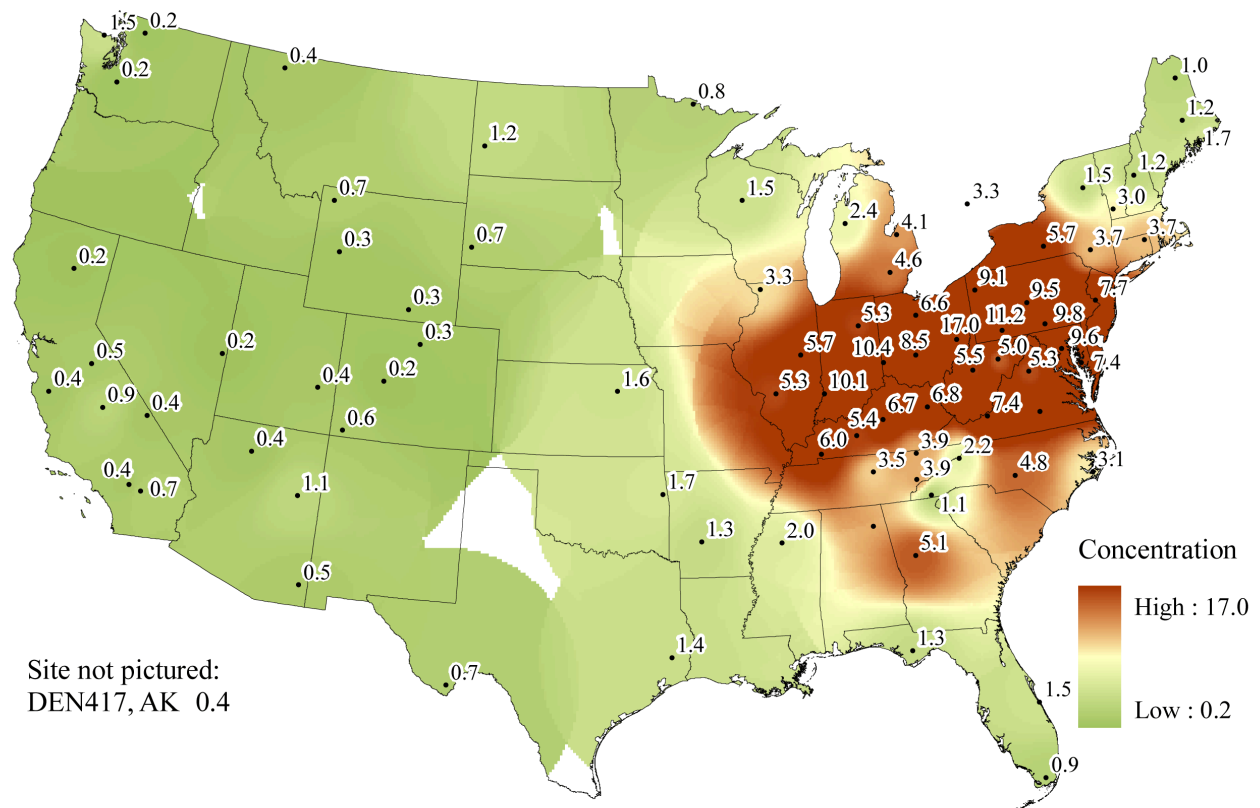
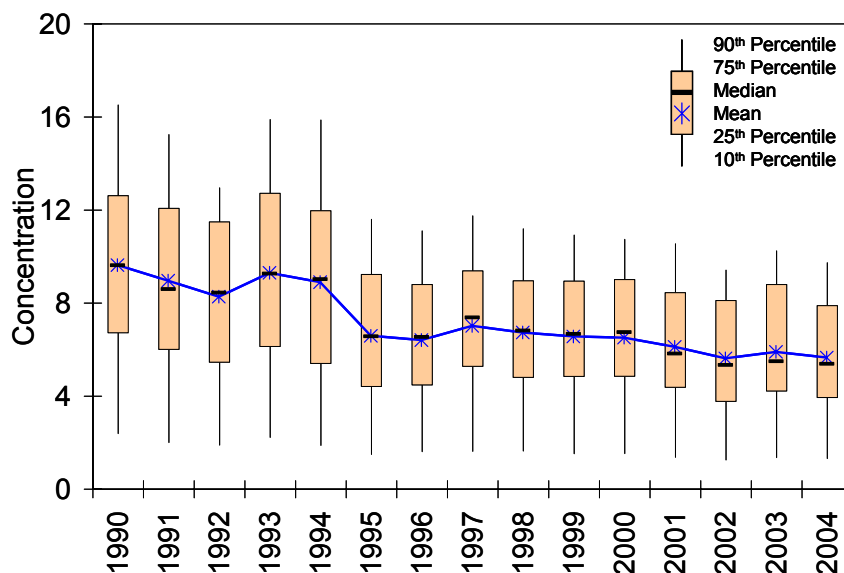


Figure 2-3 Trend in Annual Mean SO₂ Concentrations (µg/m³) – Eastern United States



Particulate Sulfate

Figure 2-4 shows a map of annual mean particulate sulfate (SO₄²⁻) concentrations measured during 2004. The map shows a relatively uniform distribution of atmospheric SO₄²⁻ in the center of the eastern monitoring network with values typically ranging from 3.0 to 5.0 µg/m³. QAK172, OH, with a value of 5.4 µg/m³, was the only site that measured a concentration greater than 5.0 µg/m³. Downward concentration gradients were observed from the center to the periphery of the network. The western monitoring sites measured relatively low annual mean concentrations with values ranging from 0.4 to 2.1 µg/m³. Big Bend National Park (BBE401) in Texas measured the highest mean SO₄²⁻ concentration among the western sites.

The trend in annual mean particulate sulfate concentrations is illustrated by the box plots in Figure 2-5. The diagram shows a significant reduction in SO₄²⁻ over the last 15 years. The difference between 3-year means at the beginning and end of the period is 24 percent.



One of CASTNET's two solar-powered monitoring sites, CAT175, NY is located in a remote area in the Catskills Mountains.

Figure 2-4 Annual Mean SO₄²⁻ Concentrations (µg/m³) for 2004

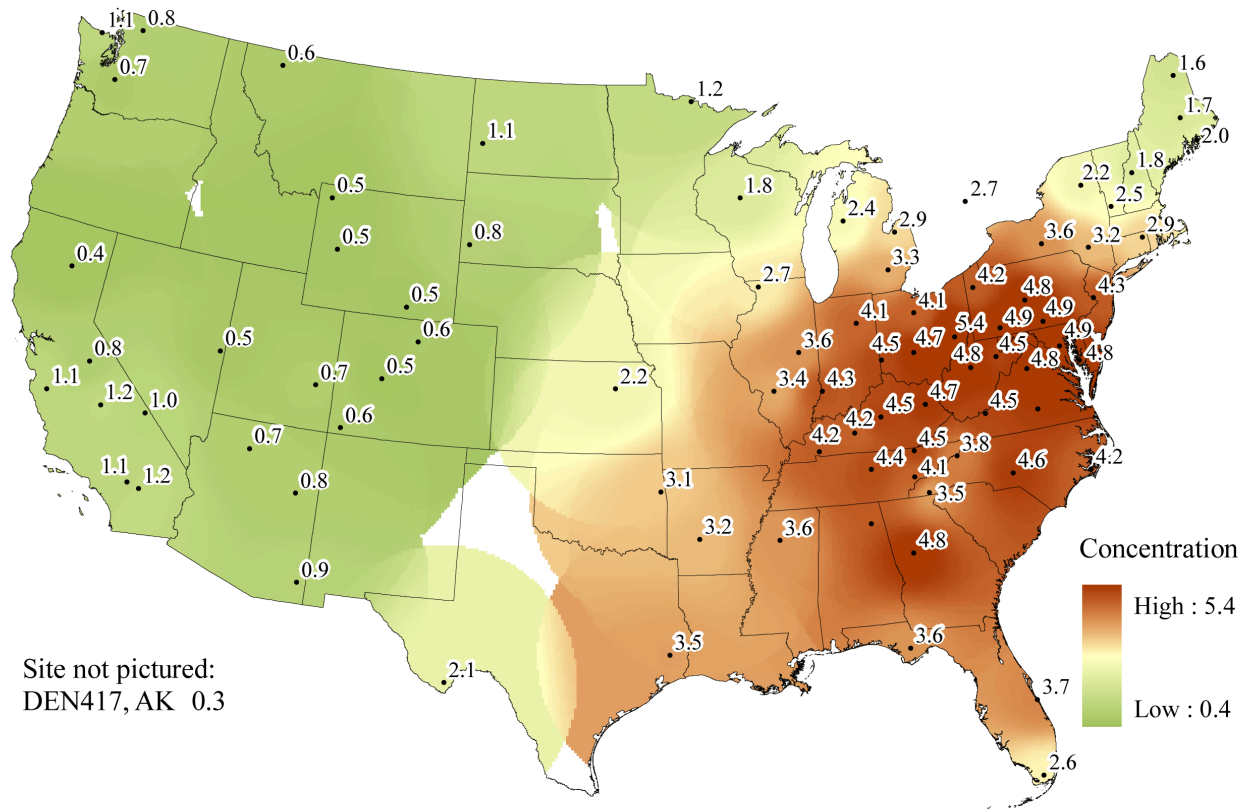
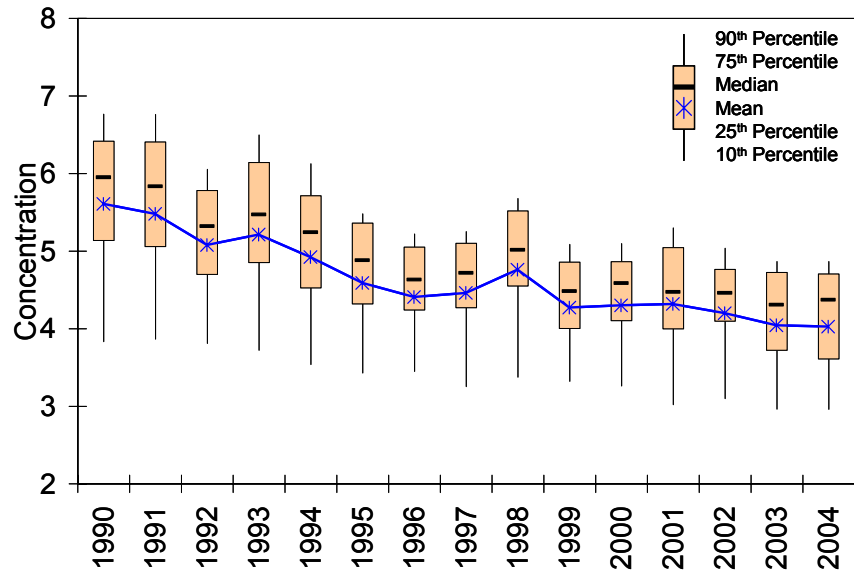


Figure 2-5 Trend in Annual Mean SO₄²⁻ Concentrations (µg/m³) – Eastern United States



Total Nitrate

Annual mean concentrations of total nitrate for 2004 are presented in Figure 2-6. Total nitrate is comprised of particulate nitrate (NO_3^-) plus gaseous nitric acid (HNO_3). Total nitrate concentrations respond to changes in nitrogen oxides (NO_x) emissions and are more representative of ambient conditions caused by NO_x emissions than either of its constituents alone. The uncertainty of measured concentrations of NO_3^- and HNO_3 is discussed in the callout box later in this chapter.

The map in Figure 2-6 shows that concentrations above $4.0 \mu\text{g}/\text{m}^3$ were measured at four sites in the three contiguous states of Illinois, Indiana, and Ohio. Total nitrate levels vary significantly from Georgia to Pennsylvania with a range of concentrations from 0.8 to $3.9 \mu\text{g}/\text{m}^3$. Differences in deposition velocities, atmospheric scavenging rates, fresh nitric oxide (NO) emissions, and inversion heights influence the pattern of nitrate concentrations. Four CASTNET sites in southern California measured total nitrate levels greater than or equal to $2.0 \mu\text{g}/\text{m}^3$.

Box plots of annual total nitrate values are provided in Figure 2-7. The diagram shows an approximate 10 percent decline in total nitrate over the last 5 years. The mean concentration ($3.2 \mu\text{g}/\text{m}^3$) in 2000 declined to $2.6 \mu\text{g}/\text{m}^3$ in 2004.

Figure 2-6 Annual Mean Total Nitrate ($\text{NO}_3^- + \text{HNO}_3$) Concentrations ($\mu\text{g}/\text{m}^3$) for 2004

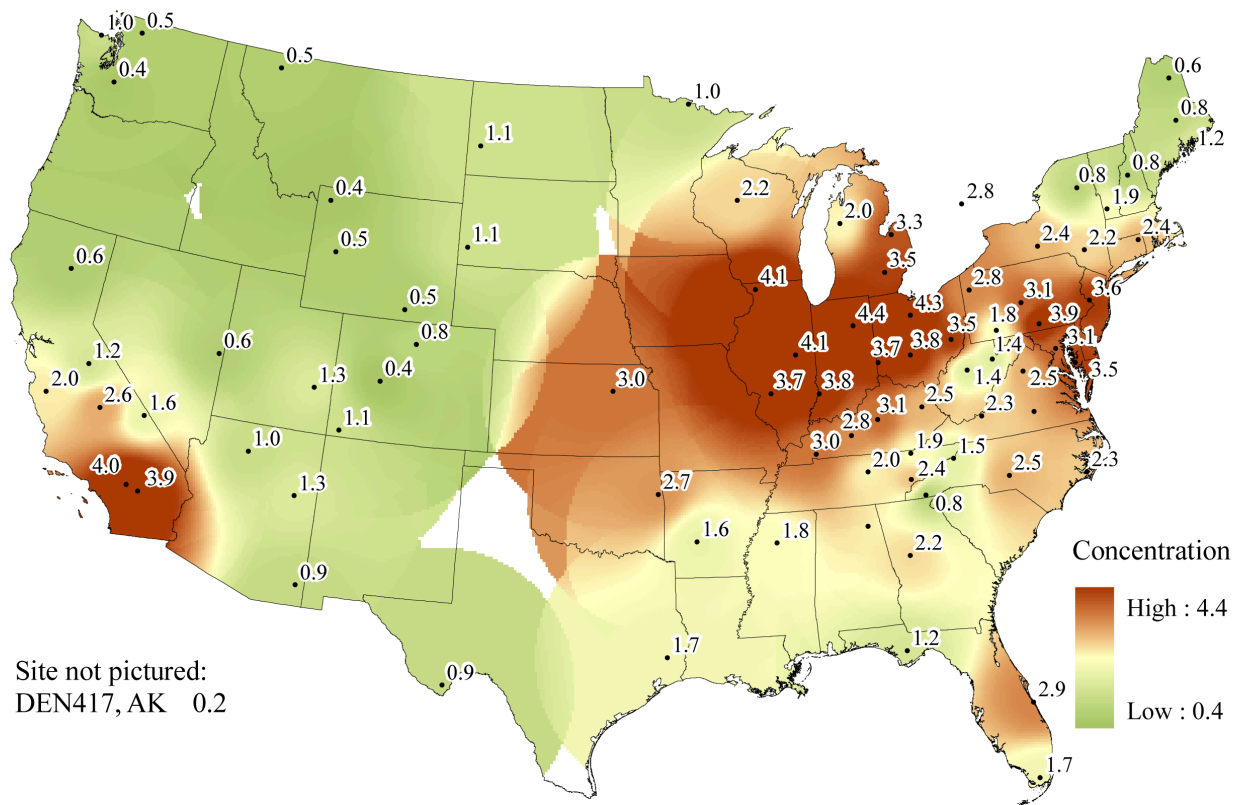
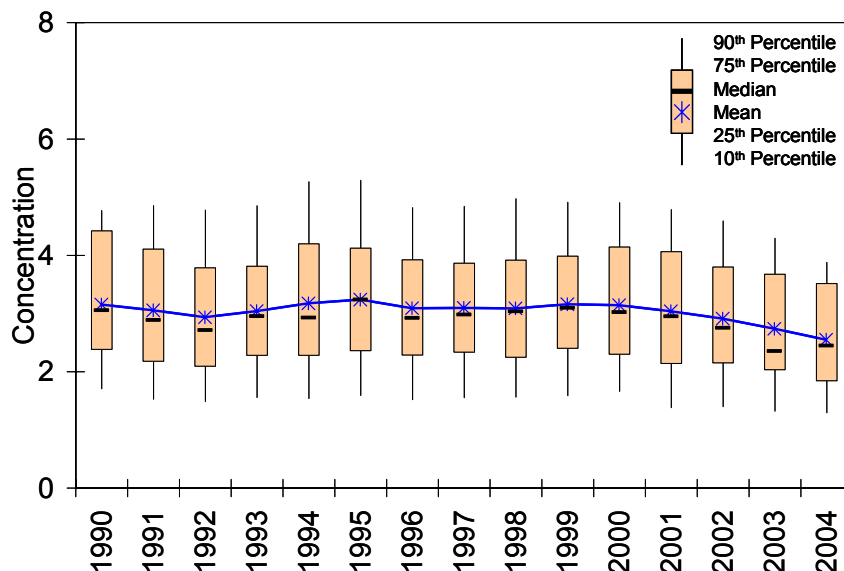


Figure 2-7 Trend in Annual Mean Total Nitrate ($\text{NO}_3^- + \text{HNO}_3$) Concentrations ($\mu\text{g}/\text{m}^3$) – Eastern United States



Particulate Ammonium

A map of 2004 annual mean particulate ammonium (NH_4^+) concentrations is provided in Figure 2-8. Lower concentrations were measured along the periphery of the network – northern New England, Minnesota, and Florida. The NH_4^+ concentrations measured at western sites were relatively low with all but four western sites having annual mean NH_4^+ concentrations below $0.5 \mu\text{g}/\text{m}^3$.

Figure 2-9 presents box plots of annual mean NH_4^+ concentrations. The measurements show a 17 percent decline in mean NH_4^+ concentrations between 3-year means at the beginning and end of the 15-year period. This decrease is believed to be due to the decrease in SO_2 emissions and the concomitant lower production of ammonium sulfate [$(\text{NH}_4)_2\text{SO}_4$].



Cedar Creek State Park, WV (CDR119)

Figure 2-8 Annual Mean NH_4^+ Concentrations ($\mu\text{g}/\text{m}^3$) for 2004

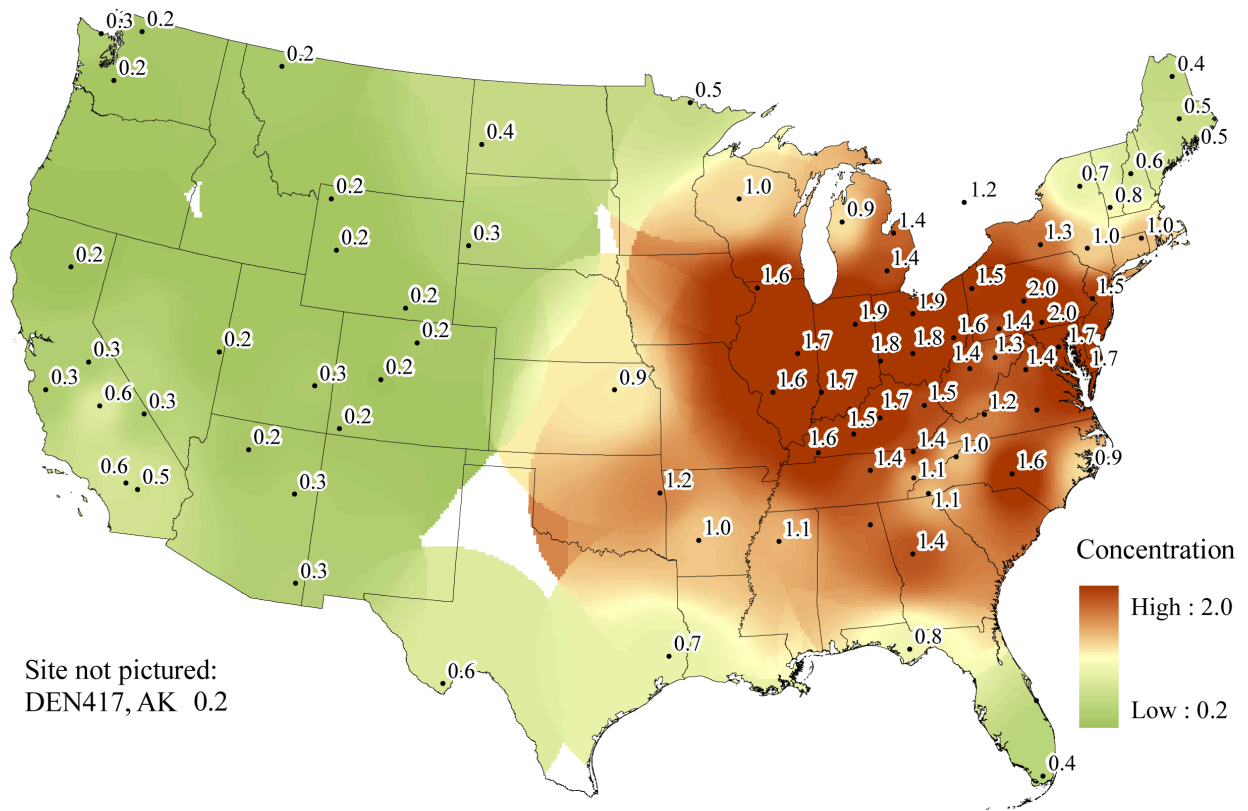
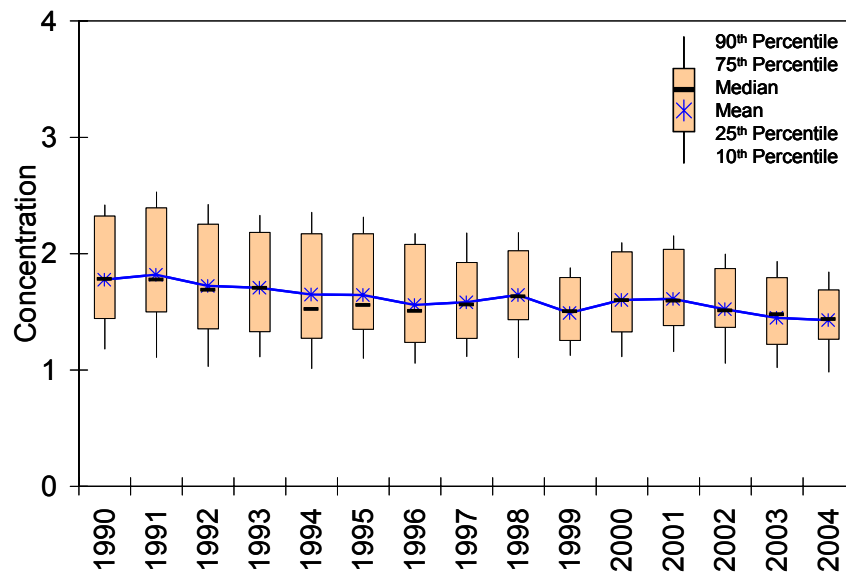


Figure 2-9 Trend in Annual Mean NH_4^+ Concentrations ($\mu\text{g}/\text{m}^3$) – Eastern United States



Bias in NO₃⁻ and HNO₃ Measurements

CASTNET utilizes a filter pack system to measure concentrations of atmospheric sulfur and nitrogen species. The filter pack contains four filters in sequence. The Teflon[®] filter samples particle sulfate (SO₄²⁻), nitrate (NO₃⁻), chloride (Cl⁻), ammonium (NH₄⁺), and other cations. The nylon filter collects nitric acid (HNO₃) and some sulfur dioxide (SO₂). The two cellulose filters collect the remaining SO₂.

Recent studies suggest that typically a fraction of the ammonium nitrate (NH₄NO₃) collected on the Teflon[®] filter dissociates into HNO₃ and ammonia (NH₃). Also, NH₄NO₃ can react with acid SO₄²⁻ particles on the Teflon[®] filter to produce HNO₃. These reactions could result in an overestimate of HNO₃ and an underestimate of particulate NO₃⁻ and NH₄⁺. CASTNET data are being compared to data from other measurement programs to estimate uncertainties in CASTNET filter pack measurements of HNO₃, NO₃⁻, and NH₄⁺ on a seasonal, annual, and geographic basis and the resulting uncertainties in seasonal and annual dry deposition fluxes.

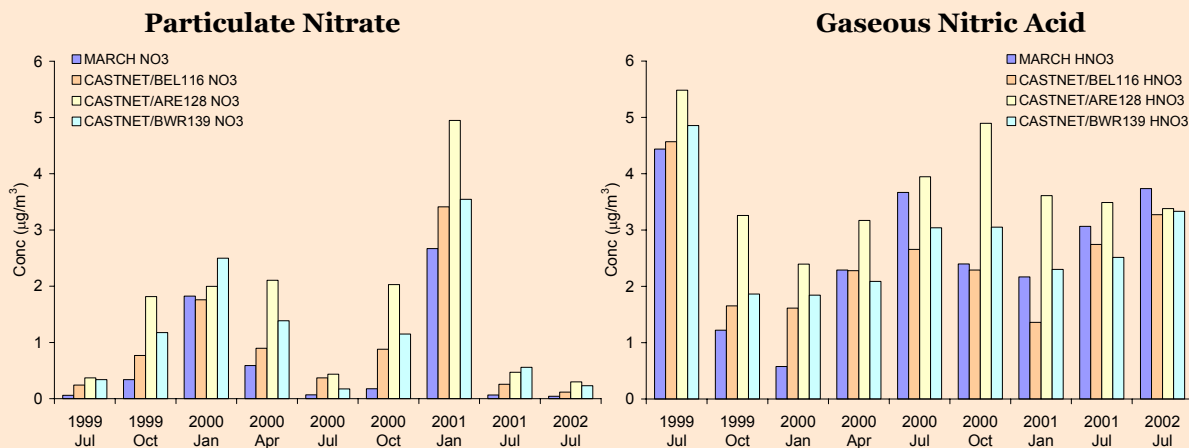
The Maryland Aerosol Research and Characterization (MARCH) database is one of the data sets being compared to CASTNET data. MARCH employed two sequential filter samplers and two sequential gas samplers (Chow *et al.*, 1996) to collect 24-hour samples every third day. Each sampler had two channels, each of which contained a

filter pack with one or two sampling filters. The two gas samplers also used diffusion denuders and appropriate filters to measure gas phase NH₃ and HNO₃. MARCH data collected from the monitoring site at Ford Meade, MD were compared with CASTNET data from the sites at Beltsville, MD (BEL116); Blackwater, MD (BWR139); and Arendtsville, PA (ARE128). Fort Meade is located about 15 kilometers from BEL116.

Results indicate that CASTNET measures higher particulate NO₃⁻ and lower gaseous HNO₃ concentrations than the other measurement systems. These results are somewhat counterintuitive in that opposite results were expected, i.e., lower NO₃⁻ on the Teflon[®] filter and higher HNO₃ on the nylon filter. An explanation is that the CASTNET filter pack collects larger NO₃⁻ particles because the instrument does not include a size selection inlet (e.g., cyclone).

EPA will further investigate the effect of collecting nitrate particles without a size selection inlet by sponsoring additional measurements at the three CASTNET sites (BEL116, MD; BWR139, MD; and ARE128, PA). Weekly nitrate concentrations will be measured with and without cyclones. Several sized inlets will be utilized at BEL116. A 2.5 micrometer (µm) cut-off will be used at BWR139 and ARE128 and compared to concentration measurements collected without a cyclone.

Comparison of MARCH and CASTNET Data



Chapter 3: Deposition of Sulfur and Nitrogen

CASTNET was designed to estimate dry deposition using measured atmospheric pollutant concentrations and deposition velocities. Dry deposition is responsible for approximately 20 to 80 percent of total atmospheric deposition depending on location and climate. Typical percentages are about 40 percent for dry sulfur deposition and 30 percent for dry nitrogen deposition.



Clingmans Dome, TN (CLD303)
Great Smoky Mountains National Park

Gaseous and aerosol sulfur and nitrogen pollutants are deposited into ecosystems through dry and wet atmospheric processes. One of the unique components of CASTNET involves estimation of the rate of dry deposition from measured environmental conditions. Measured concentration data were combined with modeled dry deposition velocities to develop the flux estimates. Wet deposition measurements were obtained from NADP/NTN and combined with CASTNET's dry deposition data to estimate total deposition. Total sulfur and nitrogen deposition rates decreased during 2004. Also, precipitation-weighted mean concentrations in precipitation of total atmospheric sulfur estimated for 2004 continued the downward trend that began in 1995 with implementation of Phase I of the Acid Rain Program. Nitrogen deposition rates show no significant trend. However, nitrogen concentrations in precipitation have declined since 1998.

Dry deposition processes were simulated using the MLM (Figure 1-3) as described by Meyers *et al.* (1998) and Finkelstein *et al.* (2000). The MLM was run using CASTNET meteorological measurements and information on land use, vegetation, and surface conditions to calculate deposition velocities for sulfur dioxide (SO_2), nitric acid (HNO_3), ozone (O_3), and the particles, sulfate (SO_4^{2-}), nitrate (NO_3^-), and ammonium (NH_4^+). The deposition velocities were assumed to be identical for all particle species and were calculated for each hour with valid meteorological data for each CASTNET site for the entire period 1990 through 2004. The MLM has been evaluated for a limited number of vegetation types, terrain settings, and time periods (summarized by Baumgardner *et al.*, 2002).

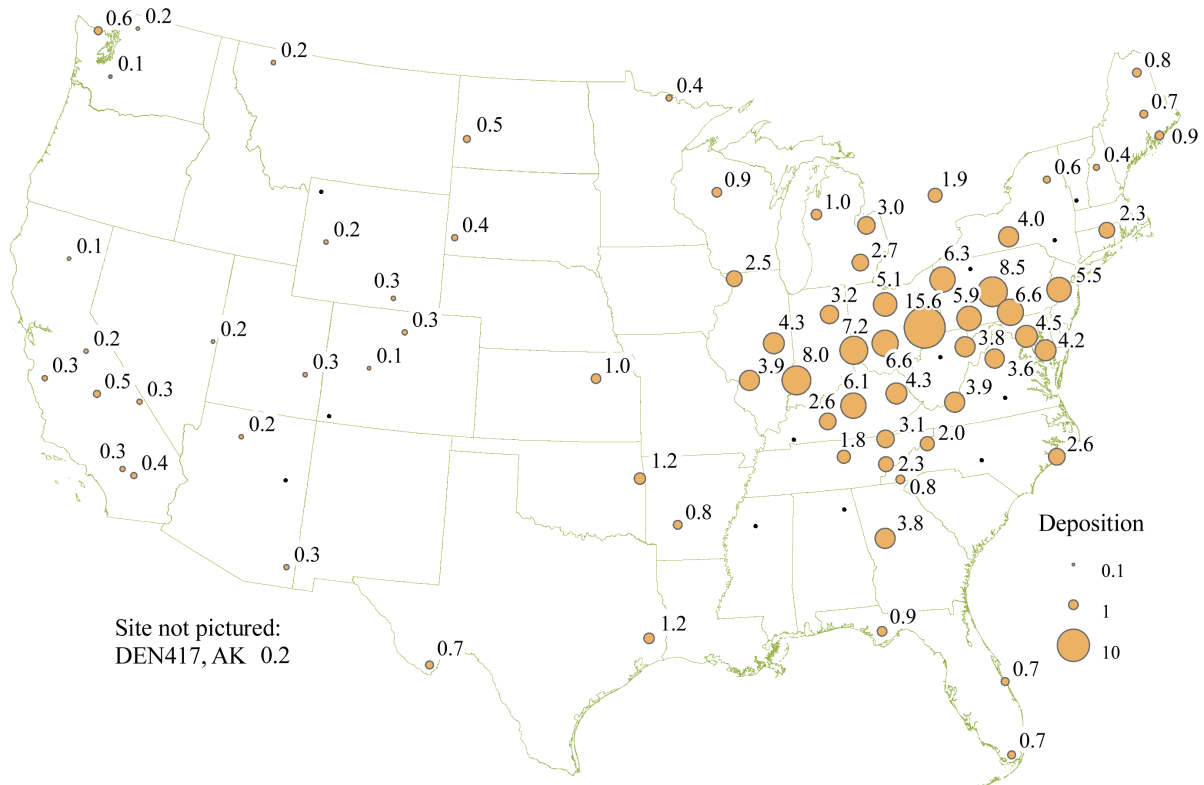


Kodachrome Park, UT

Sulfur Deposition

MLM simulations were done separately for sulfur dioxide (SO_2) and sulfate (SO_4^{2-}). The model calculations were summed to obtain estimates of dry sulfur deposition [as sulfur (S)] for 2004, which are shown in Figure 3-1. The magnitude of a deposition rate is illustrated by the size of the circle. The map shows a narrow region with fluxes greater than 5.0 kilograms per hectare per year (kg/ha/yr) centered around and downwind of the Ohio River Valley from southern Indiana to New Jersey. The highest deposition rate was estimated for Quaker City, OH (QAK172) with a flux of 15.6 kg/ha/yr. The flux data show sharply declining gradients from the Ohio Valley northward into New England and also into Wisconsin and Minnesota. The highest dry sulfur deposition rates were coincidental to the major SO_2 source region (Figure 1-6) and decline sharply with distance.

Figure 3-1 Dry Sulfur ($\text{SO}_2 + \text{SO}_4^{2-}$) Deposition (as S) (kg/ha/yr) for 2004

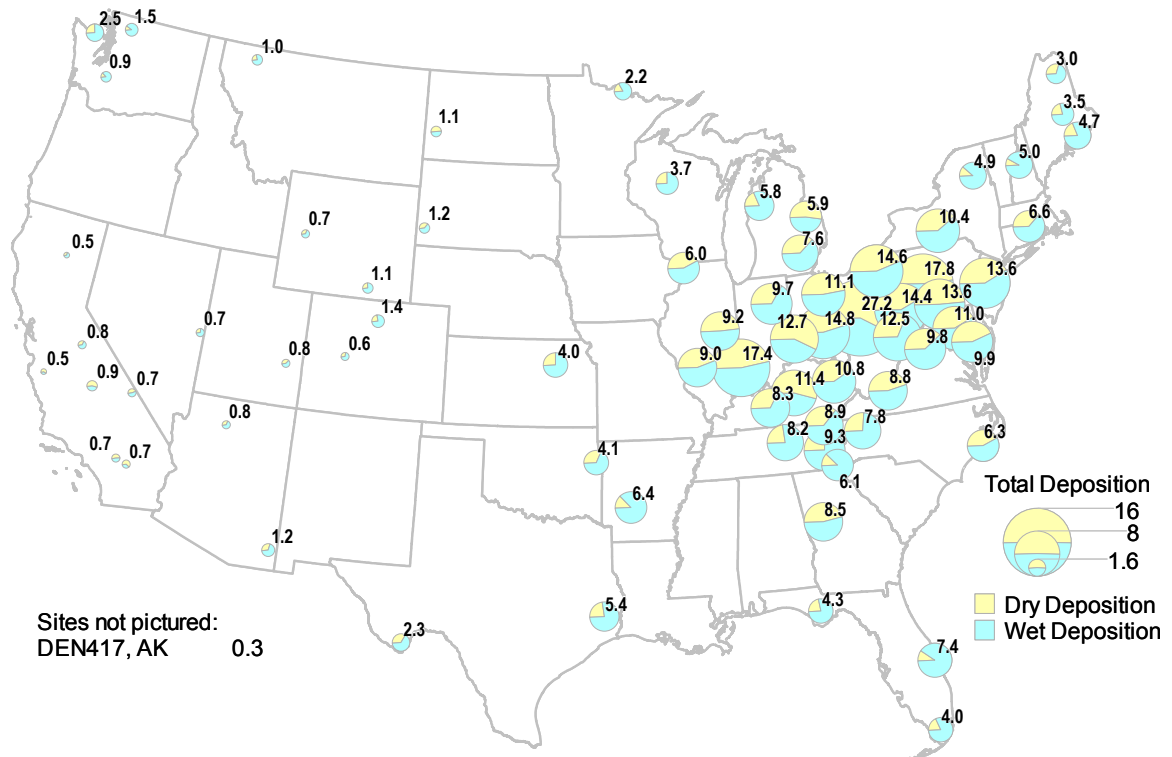


The dry deposition rates for the western sites were all less than 1.0 kg/ha/yr and generally less than 0.5 kg/ha/yr. The MLM was not run for those sites in Figure 3-1 having no numerical value adjacent to the site location because of incomplete data.

Wet deposition values used in trends analyses represent a combination of historical CASTNET wet deposition data with NADP/NTN wet deposition data. For CASTNET sites where wet concentrations were measured prior to January 1999 (when responsibility for wet deposition monitoring activities at CASTNET sites was transferred to NADP/NTN), those values were used in the data set. For sites where no wet concentrations were measured and for all sites after January 1999, values were obtained from a grid of concentration estimates derived from available NADP/NTN sites by using an inverse distance weighting function. Estimated concentrations were multiplied by the precipitation measured at the CASTNET sites to obtain estimates of wet deposition.

Figure 3-2 provides a map of estimates of total sulfur deposition. The map was constructed by adding dry and wet deposition. The circles in the figure illustrate the magnitude of total sulfur deposition and also the relative contributions from wet and dry deposition. The dark shading (blue) signifies wet deposition and the light shading (yellow) shows dry deposition. A region with

Figure 3-2 Total (Dry + Wet) Sulfur Deposition (kg/ha/yr) for 2004



sulfur deposition greater than 10.0 kg/ha/yr extends from southwestern Indiana, central Kentucky, and northern Tennessee, along the Ohio River into Pennsylvania, West Virginia, southwestern New York, Maryland, and New Jersey. Sulfur deposition at western sites was generally less than 2.0 kg/ha/yr with the exception of Olympic National Park, WA (OLY421), which had an estimate of 2.5 kg/ha/yr, and Big Bend National Park, TX (BBE401) with a value of 2.3 kg/ha/yr.

Figure 3-3 presents box plots that show the trend in dry sulfur deposition (as S), and Figure 3-4 shows the trend in annual total (dry + wet) sulfur deposition (as S) over the 15 years, 1990 through 2004. The box plots were based on data obtained from the 34 eastern CASTNET reference sites (Figure 2-1). Sulfur deposition at these sites declined significantly over the 15 years, although the dry and total fluxes were relatively constant over the last four years. Figure 3-5 presents estimates of trends in dry, wet, and total deposition of sulfur (as S) on the same diagram. The trend line for mean sulfur concentrations in precipitation shows a continuing decrease in sulfur concentration over the last few years.

Figure 3-3 Trend in Dry Sulfur Deposition (kg/ha/yr) – Eastern United States

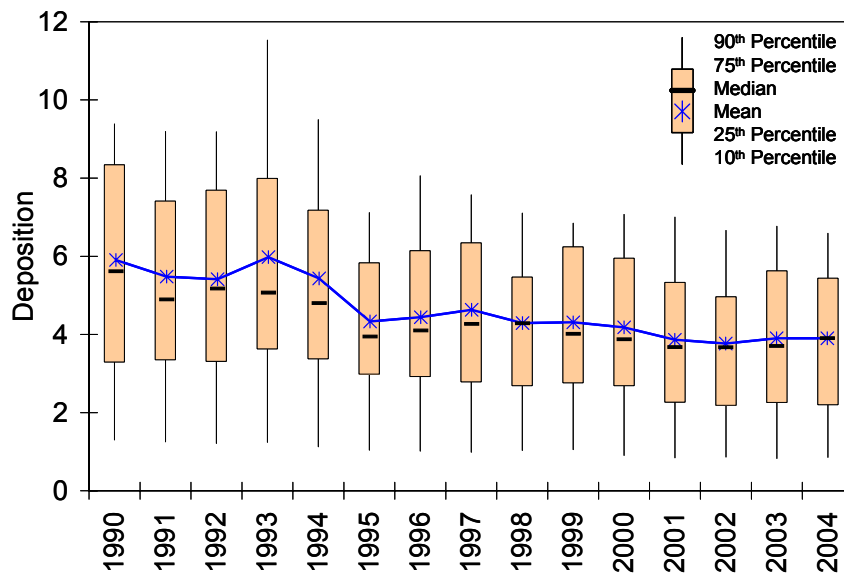


Figure 3-4 Trend in Total (Dry + Wet) Sulfur Deposition (kg/ha/yr) – Eastern United States

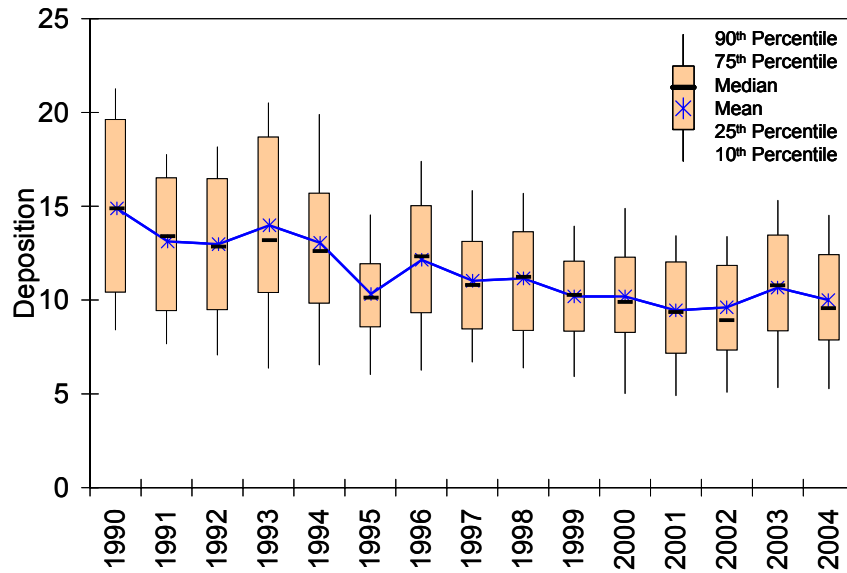
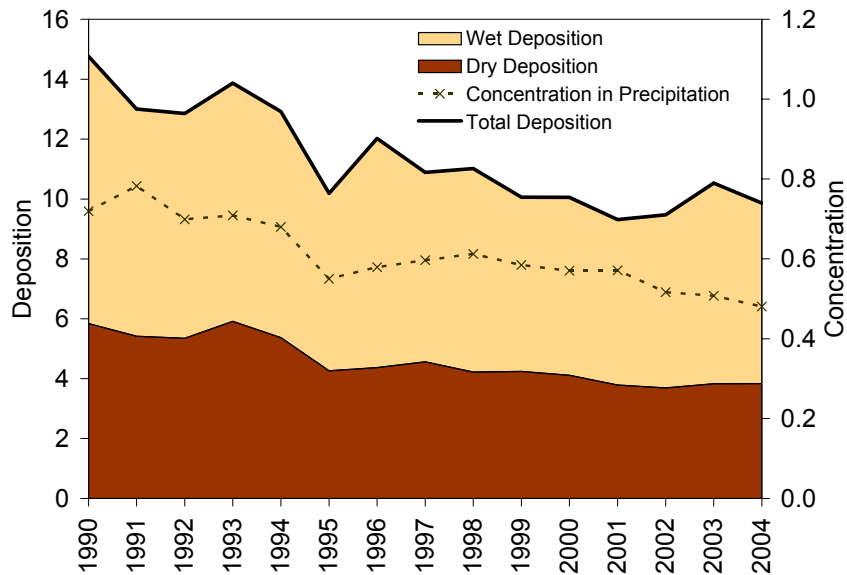
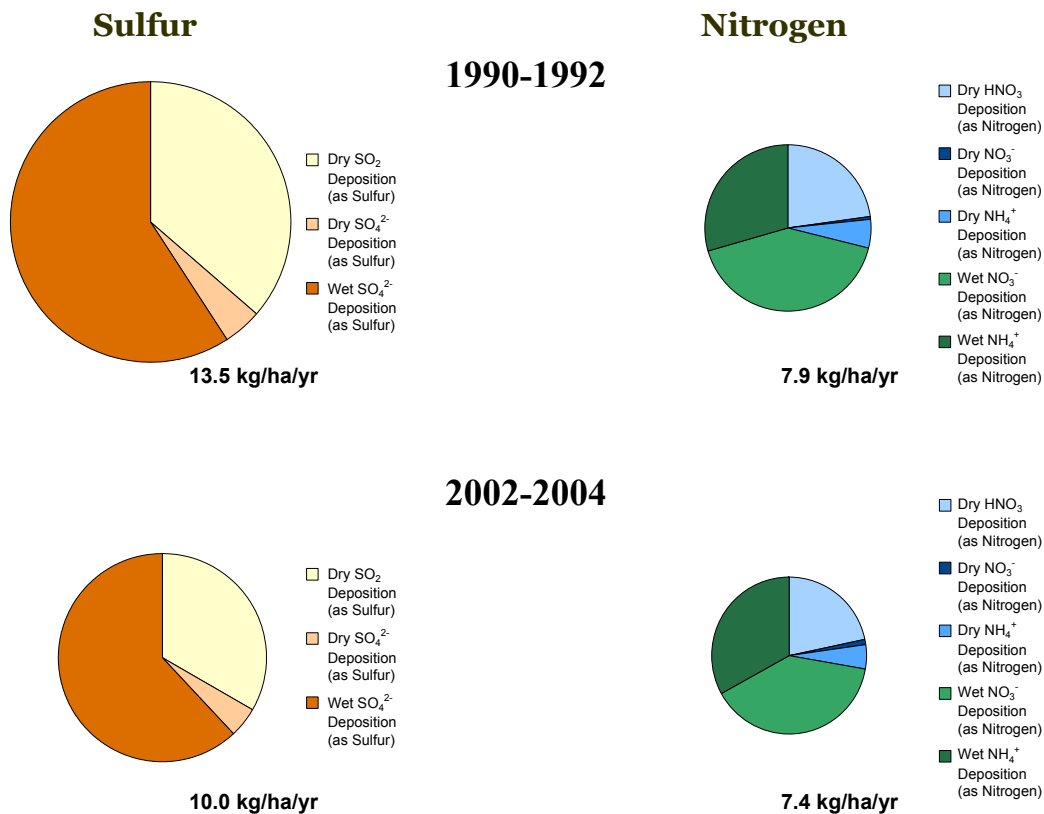


Figure 3-5 Trend in Dry, Wet, and Total Sulfur Deposition (as S) (kg/ha/yr) with Precipitation-Weighted Mean Concentrations in Precipitation (mg/L) – Eastern United States



Contributors to Atmospheric Deposition Measured at CASTNET Eastern Reference Sites



The four pie charts illustrate mean total (wet + dry) sulfur and nitrogen deposition rates for two 3-year periods, 1990 to 1992 and 2002 to 2004. The mean values were obtained for the 34 reference sites. The pie charts show a significant decline in mean total sulfur deposition from about 13.5 to 10.0 kg/ha/yr from the beginning to the ending three years. The charts show a relatively small decline in total nitrogen deposition, from 7.9 to 7.4 kg/ha/yr from the beginning three years to the final three years of the 15-year period.

The data show that wet SO₄²⁻ deposition was the major contributor to total sulfur deposition, followed by dry SO₂ and a much smaller contribution from dry SO₄²⁻. The percentage of dry deposition in total deposition changed from 41 percent to 38 percent over the 15 years.

Wet NO₃⁻ deposition was the major contributor to total nitrogen deposition followed by wet NH₄⁺, dry HNO₃, dry NH₄⁺, and dry NO₃⁻. The percentage of dry nitrogen deposition changed slightly from 29 percent to 28 percent over the 15 years.

For both sulfur and nitrogen, dry deposition contributed from about 20 to 80 percent of total deposition at individual CASTNET sites, depending on location and climate.

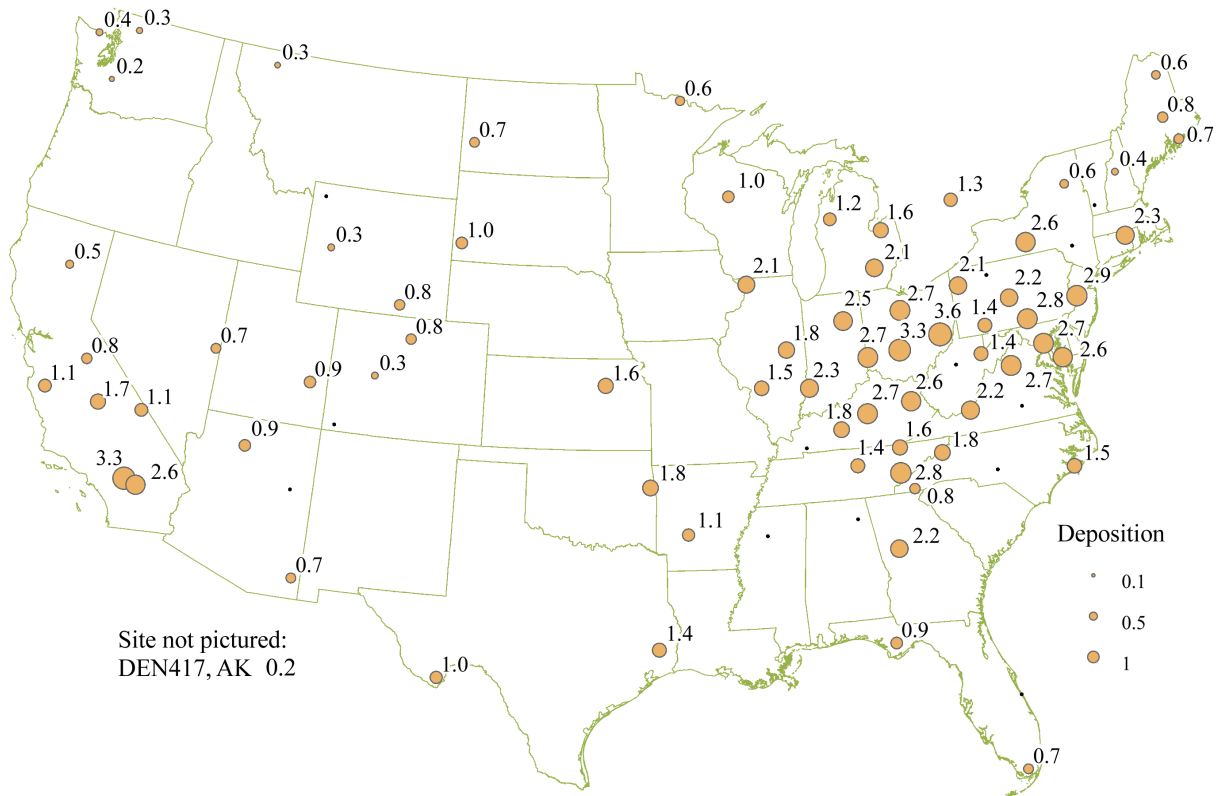


Colorado River, AZ

Nitrogen Deposition

Figure 3-6 presents a map of dry fluxes of nitrogen for 2004. Nitrogen fluxes are comprised of nitric acid (HNO_3) + nitrate (NO_3^-) + ammonium (NH_4^+). This map was constructed by summing the individual MLM simulations for the three species. Almost all of the CASTNET sites in the eastern United States had estimated dry nitrogen deposition rates greater than 1.0 kg/ha/yr, although the geographic pattern is complex. The values range from 0.4 kg/ha/yr in New Hampshire to 3.6 kg/ha/yr in eastern Ohio. Lower fluxes were observed along the periphery of the network. The values at the western sites ranged from 0.2 kg/ha/yr at Mount Rainier National Park, WA (MOR409) to 3.3 kg/ha/yr at Converse Station, CA (CON186).

Figure 3-6 Dry Nitrogen ($\text{HNO}_3 + \text{NO}_3^- + \text{NH}_4^+$) Deposition (as N) (kg/ha/yr) for 2004



A map (Figure 3-7) of total nitrogen deposition (as N) for 2004 was constructed by summing the estimates of dry (light shading) and wet (dark shading) deposition. The figure shows that a large majority of the eastern sites recorded deposition rates greater than 5.0 kg/ha/yr. Values above 10.0 kg/ha/yr were observed in eastern Ohio and eastern Pennsylvania. Lower fluxes were recorded along the periphery of the network (e.g., in New England and Florida and throughout the West). The values at the western sites ranged from 1.1 kg/ha/yr at MOR409, WA to 4.4 kg/ha/yr at CON186, CA.

Figure 3-7 Total (Dry + Wet) Nitrogen Deposition (as N) (kg/ha/yr) for 2004

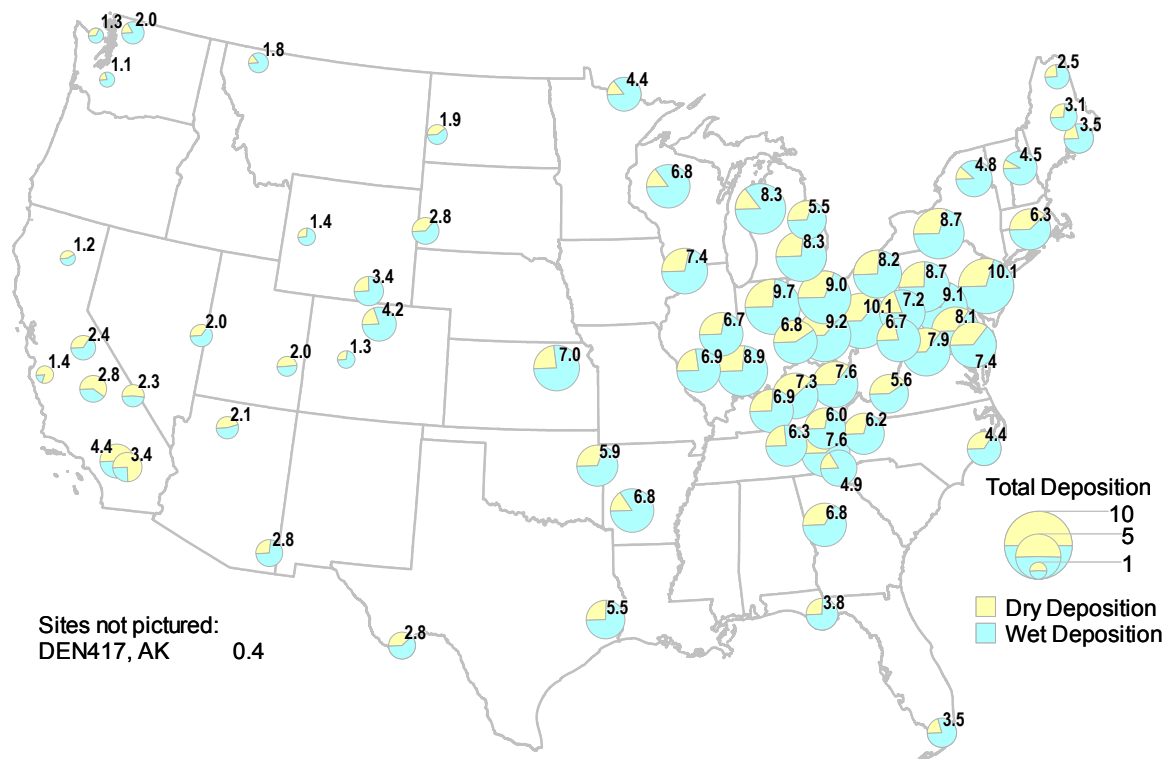


Figure 3-8 presents box plots that show the trend in dry nitrogen deposition, and Figure 3-9 shows the trend in total nitrogen deposition over the 15 years, 1990 through 2004. The box plots show no significant trend although the data suggest a decline in dry nitrogen deposition since 1999.

Figure 3-8 Trend in Dry Nitrogen Deposition (kg/ha/yr) – Eastern United States

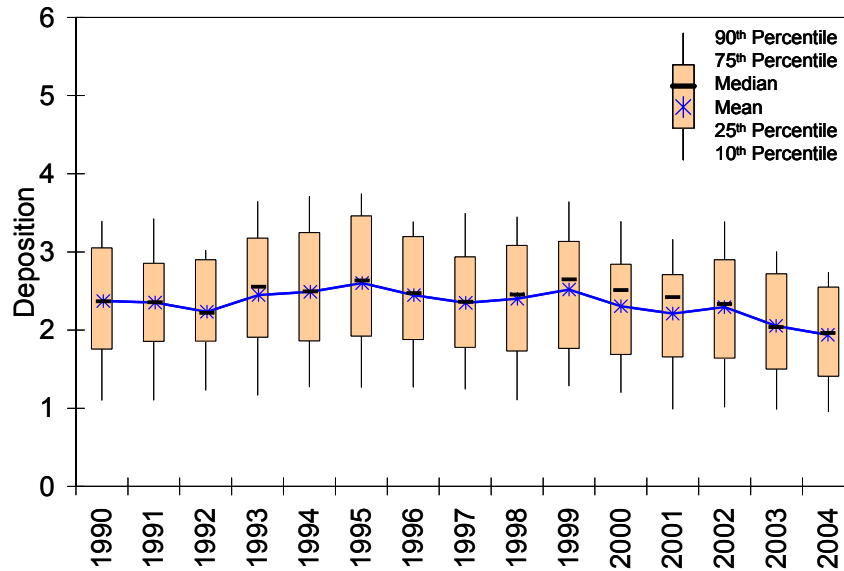
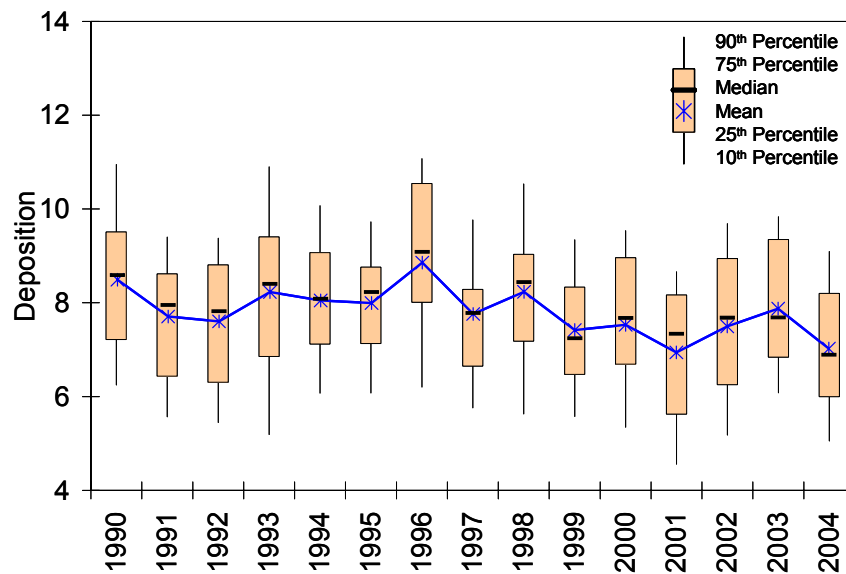
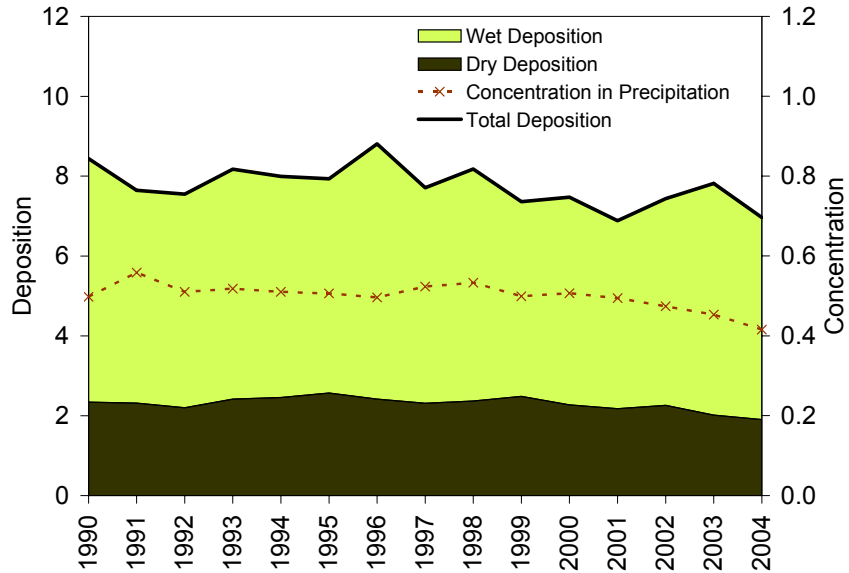


Figure 3-9 Trend in Total (Dry + Wet) Nitrogen Deposition (kg/ha/yr) – Eastern United States



Estimates of trends in wet, dry, and total deposition of atmospheric nitrogen (as N) are presented in Figure 3-10. The trend in precipitation-weighted mean nitrogen concentrations in precipitation is also provided on the same figure. The trend line for precipitation-weighted mean nitrogen concentrations in precipitation shows a slight downward trend over the last several years.

Figure 3-10 Trend in Dry, Wet, and Total Nitrogen Deposition (as N) (kg/ha/yr) with Precipitation-Weighted Mean Concentrations in Precipitation (mg/L) – Eastern United States



African Saharan Aerosols (Dust) in CASTNET

Figure 3-11 Sand Storm



Dust clouds from the Sahara Desert are produced throughout the year but most frequently in the summer. Dust clouds are produced when tropical waves pick up dust from the desert in North Africa and transport the dust through convection to heights of a few miles into the atmosphere. The dust clouds drift west in the easterly trade winds. Figure 3-11 illustrates a sand storm over the African Sahel, the narrow border, or lightly vegetated “greenbelt,” between the Sahara and the agricultural areas to the south. Figure 3-12 shows a satellite photo of a dust cloud blowing off the African coast.

Figure 3-12 Dust Transport

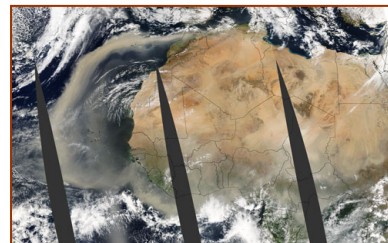
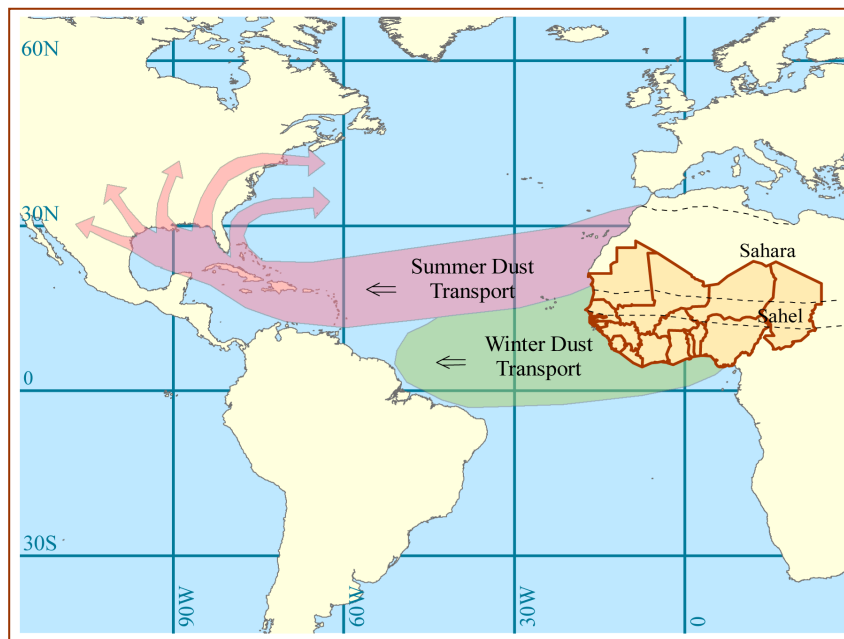
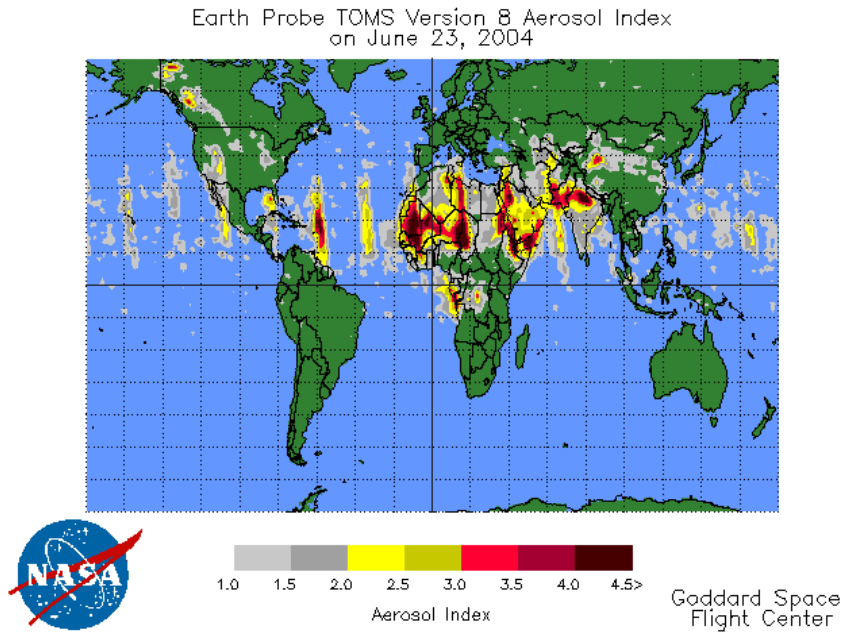


Figure 3-13 Summer and Winter Dust Transport



Summer and winter dust transport patterns are illustrated in Figure 3-13. Summer patterns suggest the transport of the Saharan dust to the Caribbean and then veering northward around the Bermuda High to the United States. Satellite data from the Earth Probe Total Ozone Mapping Spectrometer (TOMS) aerosol index (Herman *et al.*, 1997) detected Saharan dust events during several days of June and July 2004. Figure 3-14 shows the transport pattern on June 23, 2004.

Figure 3-14 TOMS Aerosol Index for June 23, 2004



CASTNET cation measurements document the appearance and transport of Saharan dust across the southeastern United States. Time series of weekly Ca^{2+} concentrations and depositions for three Florida sites are shown in Figures 3-15 and 3-16 for the period June 8 through July 13, 2004. The dates represent the beginning of the sampling periods. The peak concentrations and deposition rates that were measured during the sampling weeks beginning June 22 and July 7 indicate Saharan dust. The June event is illustrated by the TOMS data shown in Figure 3-14. The peak concentrations were approximately double annual mean values.

Figure 3-15 Time Series of Weekly Ca^{2+} Concentrations ($\mu\text{g}/\text{m}^3$)

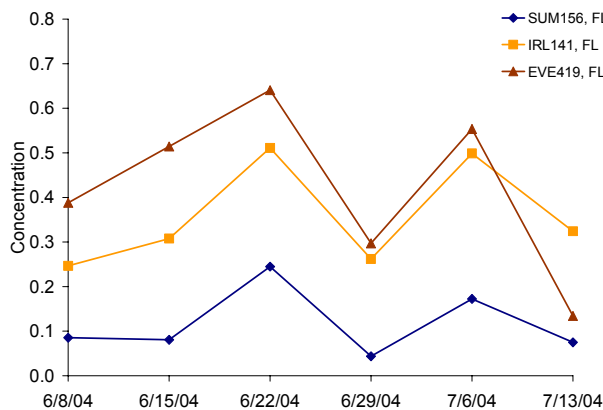
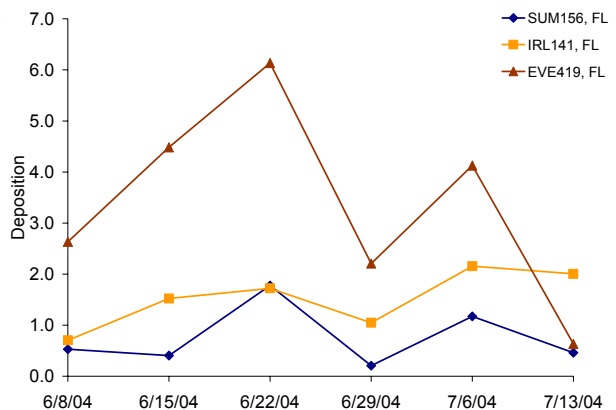


Figure 3-16 Time Series of Weekly Ca^{2+} Deposition (grams/ha/week)



Chapter 4: Ozone Concentrations

CASTNET provides the primary vehicle for measuring rural ozone (O₃) concentrations in the United States.

Ozone concentration measurements during 2004 at the CASTNET reference sites were the lowest in the history of the network.



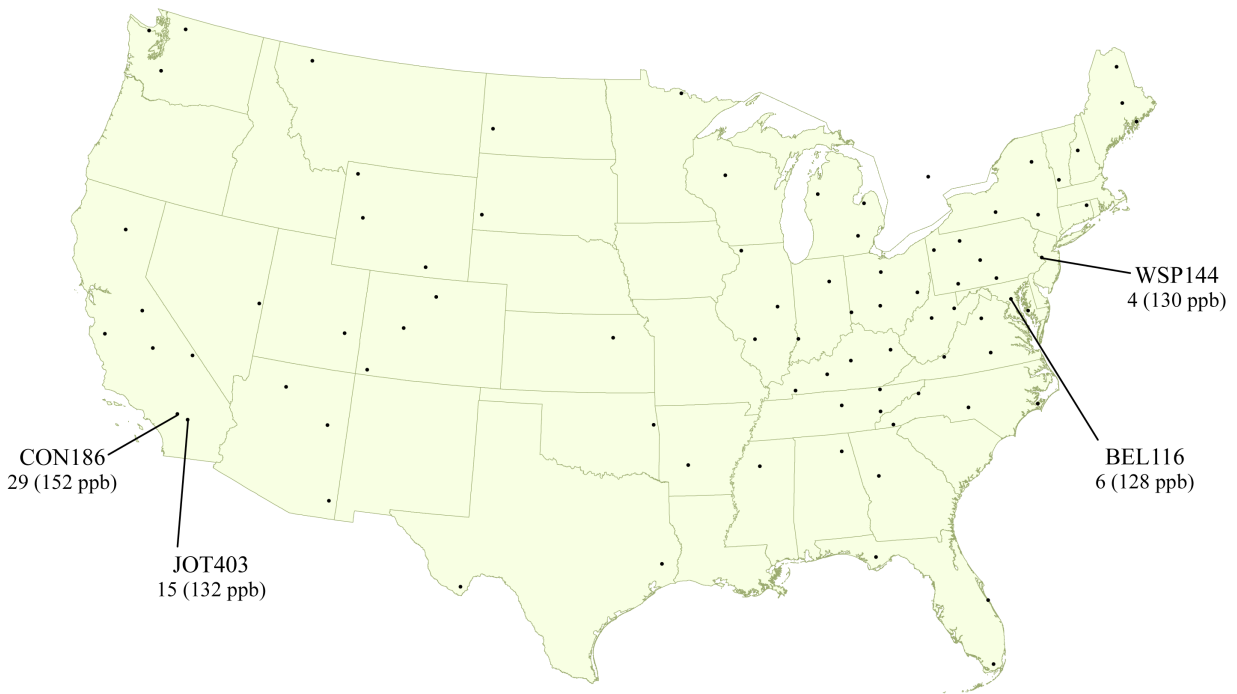
Converse Station, CA (CON186)

CASTNET ozone (O₃) data provide information on geographic patterns in regional O₃ and on the extent to which rural areas potentially exceed concentration values mandated by the National Ambient Air Quality Standards (NAAQS). Fourth highest 1-hour ozone concentrations above 125 parts per billion (ppb) were measured at four sites over the period 2002-2004. These sites are located in the northeastern United States along the East Coast and in southern California. During the same period, 3-year averages of the fourth highest daily maximum 8-hour O₃ concentrations were greater than or equal to 85 ppb at 11 sites. Measurements of 1-hour and 8-hour concentrations during 2004 were considerably lower than previous years and are the lowest O₃ concentrations in CASTNET history.

Design Values for Ozone Concentrations for 2002-2004

Figure 4-1 provides the locations of the sites measuring daily maximum 1-hour O₃ concentrations greater than or equal to 125 ppb for the period 2002-2004. The number of days with measurements equaling or exceeding 125 ppb is listed with the fourth highest 1-hour value for the same time period included in parentheses. Four sites measured elevated concentrations – two on the East Coast and two in southern California. The fourth highest value constitutes the design value for achieving the 1-hour NAAQS. In other words, the value of 128 ppb measured at Beltsville, MD (BEL116) would have to be reduced to 125 ppb to meet the standard.

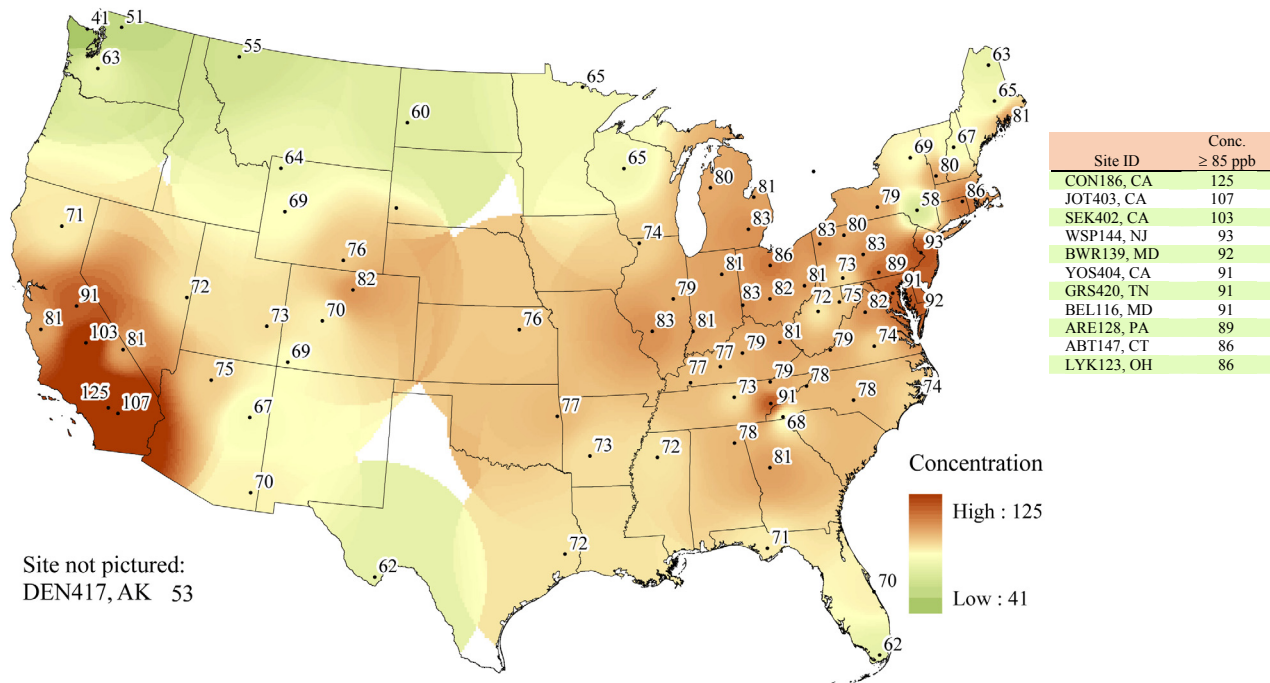
Figure 4-1 CASTNET Sites Above 1-Hour NAAQS



Gothic, CO (GTH161)

Three-year averages of the fourth highest daily maximum 8-hour O₃ concentrations for 2002-2004 are presented in Figure 4-2. These 3-year averages constitute design values for achieving the 8-hour NAAQS. Seven eastern sites and four sites in California observed a 3-year average concentration greater than or equal to 85 ppb. The sites and concentration values are listed in the table next to the map in Figure 4-2. The regions with elevated concentrations were located along the East Coast from Maryland to Connecticut and in Pennsylvania and Ohio. A value of 91 ppb was measured at Great Smoky Mountains National Park, TN (GRS420). Four sites in California observed elevated 8-hour O₃ concentrations.

Figure 4-2 Three-Year Averages of the Fourth Highest Daily Maximum 8-Hour O₃ Concentrations (ppb) for 2002-2004



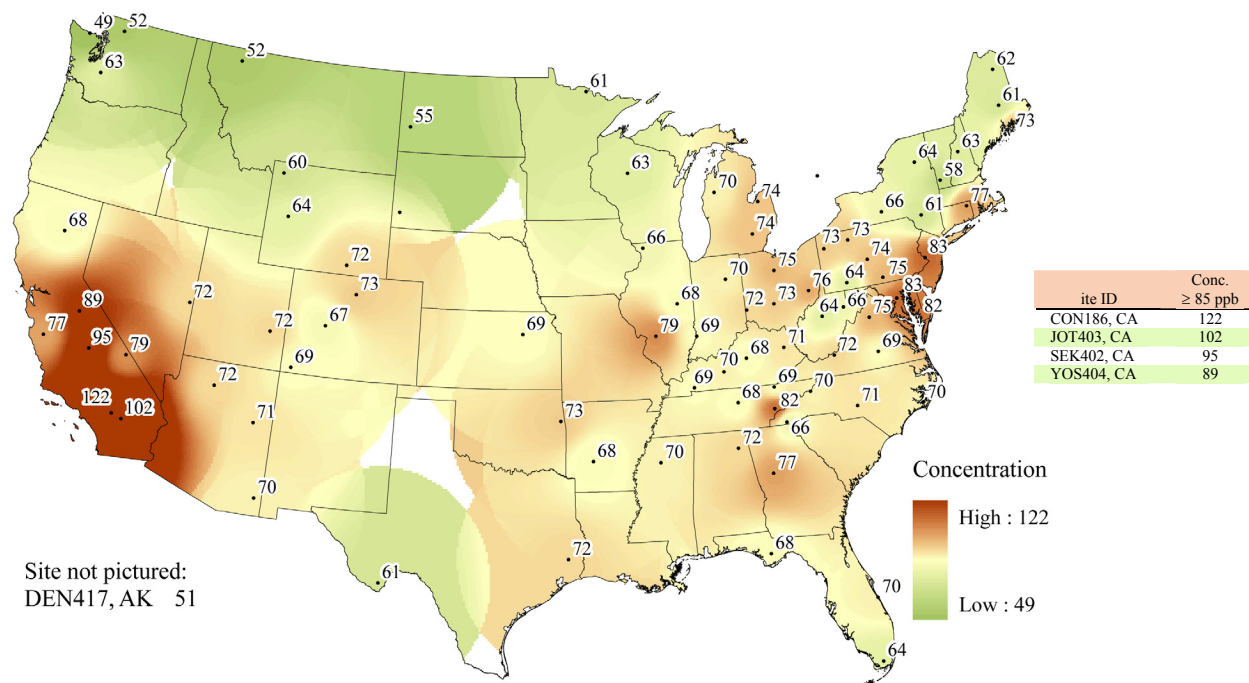
Eight-Hour Ozone Concentrations

Figure 4-3 provides a map of the fourth highest daily maximum 8-hour O₃ concentrations measured during 2004. The sites with concentration values greater than or equal to 85 ppb are listed in the table next to the map in Figure 4-3. No eastern sites measured values greater than or equal to 85 ppb. Four California sites measured high 8-hour concentrations in 2004. The highest concentration (122 ppb) was measured at CON186, CA. The National Oceanic and Atmospheric Administration (NOAA) reported that much of the 2004 O₃ season was dominated by a cool summer, the sixteenth coolest on record. Nationwide, June-August was the tenth wettest summer with Texas, Louisiana, Mississippi, Arkansas, Oklahoma, and Kansas recording their wettest summer and Pennsylvania its fourth wettest summer (NOAA, 2004).



Indian River Lagoon, FL (IRL141)

Figure 4-3 Fourth Highest Daily Maximum 8-Hour O₃ Concentrations (ppb) for 2004



Fifteen-Year Trends

CASTNET measurements at the 34 eastern reference sites show a surprising and remarkable decline in O₃ concentrations from 2002 to 2004. During 2002, 24 sites measured fourth highest 8-hour O₃ levels over 85 ppb, and 50 sites experienced at least one day with an 8-hour O₃ level greater than or equal to 85 ppb. Very high concentrations were measured along the East Coast from Maryland to Maine. During 2003, only six sites observed fourth highest 8-hour concentrations above 85 ppb. During 2004, no eastern sites observed O₃ concentrations that were higher than 85 ppb.

Trends in 8-hour concentrations aggregated over the 34-station subset of reference sites show a significant decline from 2002 to 2003 and a further decline to 2004 (Figure 4-4). Median values decreased from 86 ppb in 2002 to 77 ppb in 2003 to 71 ppb in 2004. The decrease from 2002 to 2003 is explained by unusually cool, cloudy, and wet weather during the 2003 ozone season (Figures 4-5 through 4-7). The additional, significant decrease from 2003 to 2004 is also associated with relatively cloudy and wet weather during the 2004 ozone season. However, trends in total nitrate – nitric acid plus particulate nitrate – also show a decline over the last few years, as shown in Figure 2-7. Figure 1-5 depicts a reduction in utility nitrogen oxides (NO_x) emissions since 1997. Evidently, both weather and a decline in atmospheric nitrogen species contributed to the recent decline in ozone levels. This is the first evidence that a reduction in NO_x emissions is contributing to a decline in tropospheric ozone.

Figure 4-4 Trend in Fourth Highest Daily Maximum 8-Hour O₃ Concentrations (ppb) – Eastern United States

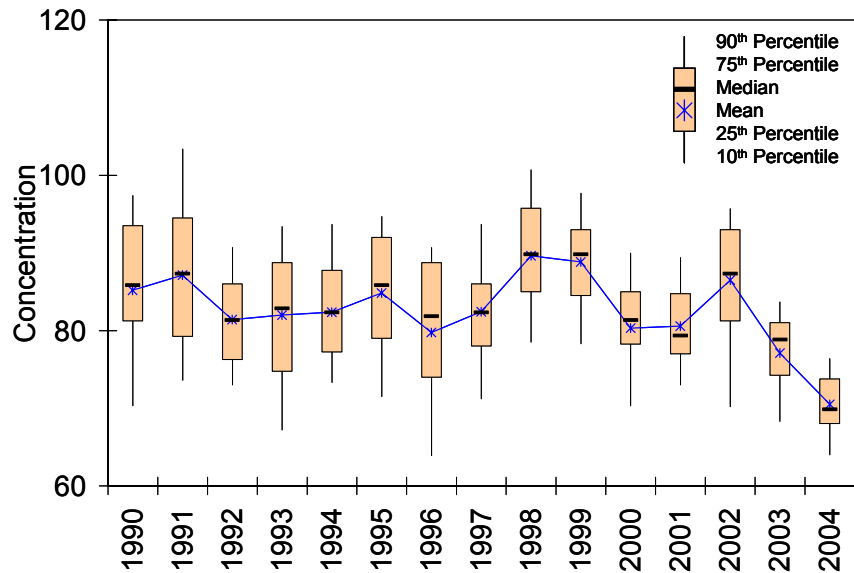


Figure 4-5 Trend in Mean Seasonal Temperature (°C) (May through September) – Eastern United States

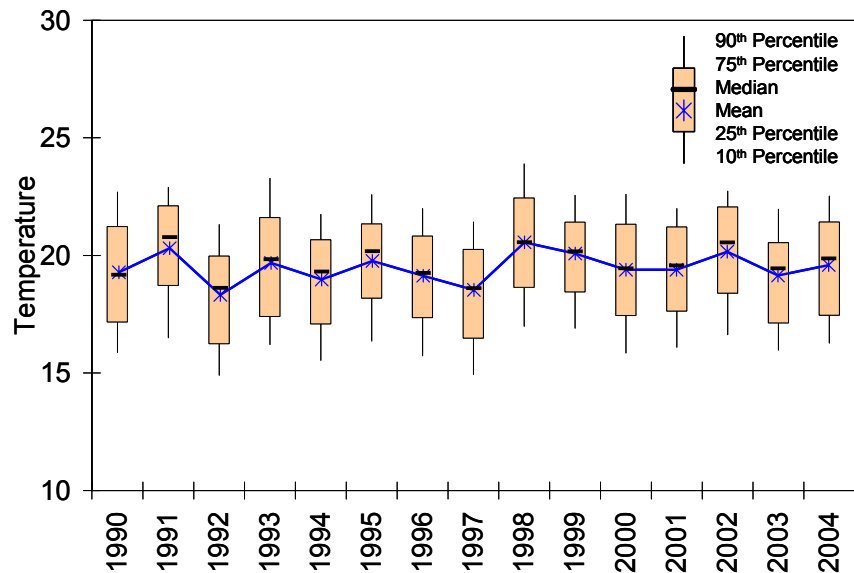


Figure 4-6 Trend in Mean Seasonal Solar Radiation (W/m^2) (May through September) – Eastern United States

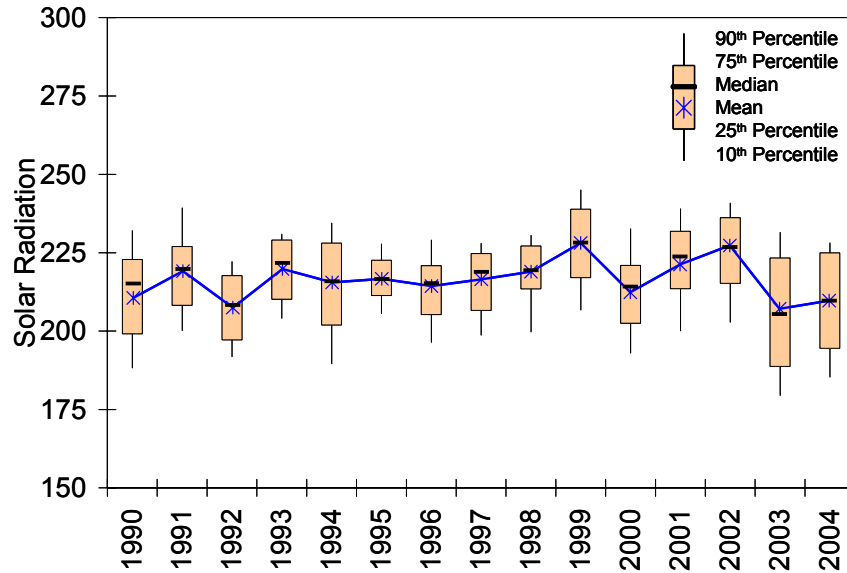
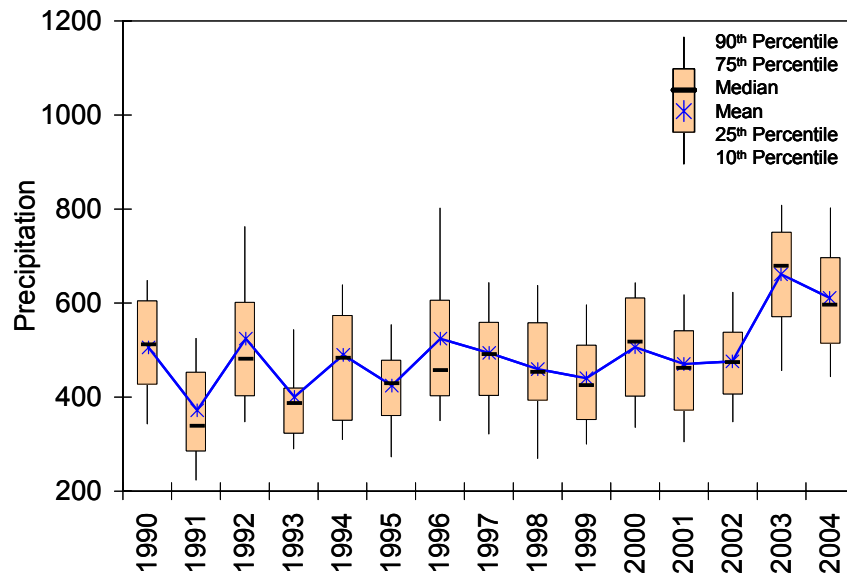


Figure 4-7 Trend in Total Precipitation (mm) (May through September) – Eastern United States



CASTNET Ozone Measurements

Although not a regulatory network, CASTNET O₃ data provide information on measured concentrations in rural areas. To understand how these measurements compare to those measured by the regulatory monitoring stations used for determination of NAAQS compliance, it is necessary to understand how well CASTNET data compare with data collected using regulatory methods.

CASTNET evolved from the NDDN, a research network rather than a compliance monitoring network. As such, requirements established in the Code of Federal Regulations (CFR) to govern and uniformly standardize state and local ozone monitoring stations were not followed.

The essential difference between CASTNET O₃ monitoring and regulatory monitoring is the regulatory requirement that an independent verification check of a test atmosphere be performed with a second in-station photometer at least once every two weeks. At regulatory monitoring stations, test concentrations for O₃ must be obtained in accordance with the ultraviolet (UV) photometric calibration procedure specified in 40 CFR part 50, Appendix D, or by means of a certified O₃ transfer standard. CASTNET O₃ analyzers perform weekly verification checks using a calibrated, internal O₃ generator. The exceptions to this are the CASTNET sites sponsored by NPS and the Cherokee Nation site in Stilwell, OK (CHE185). The NPS sites are tasked with regulatory assessment of non-attainment areas in national parks, and therefore, conform to the regulatory methodology. All aspects of ambient O₃ monitoring at CHE185 are the responsibility of the Cherokee Nation.

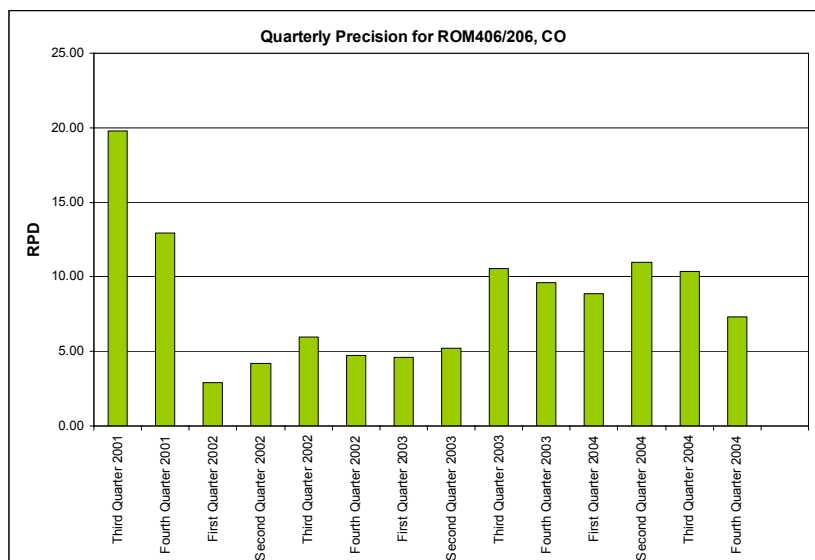
Over time CASTNET has implemented changes to improve the accuracy and precision of O₃ monitoring. In 1998 all systems at EPA-sponsored sites were modified to route the test gases through the O₃ inlet on the sampling tower. In this manner, the integrity of the entire sampling system can be verified during the checks.

Previously, the test gases were introduced at the back of the analyzer and were not routed

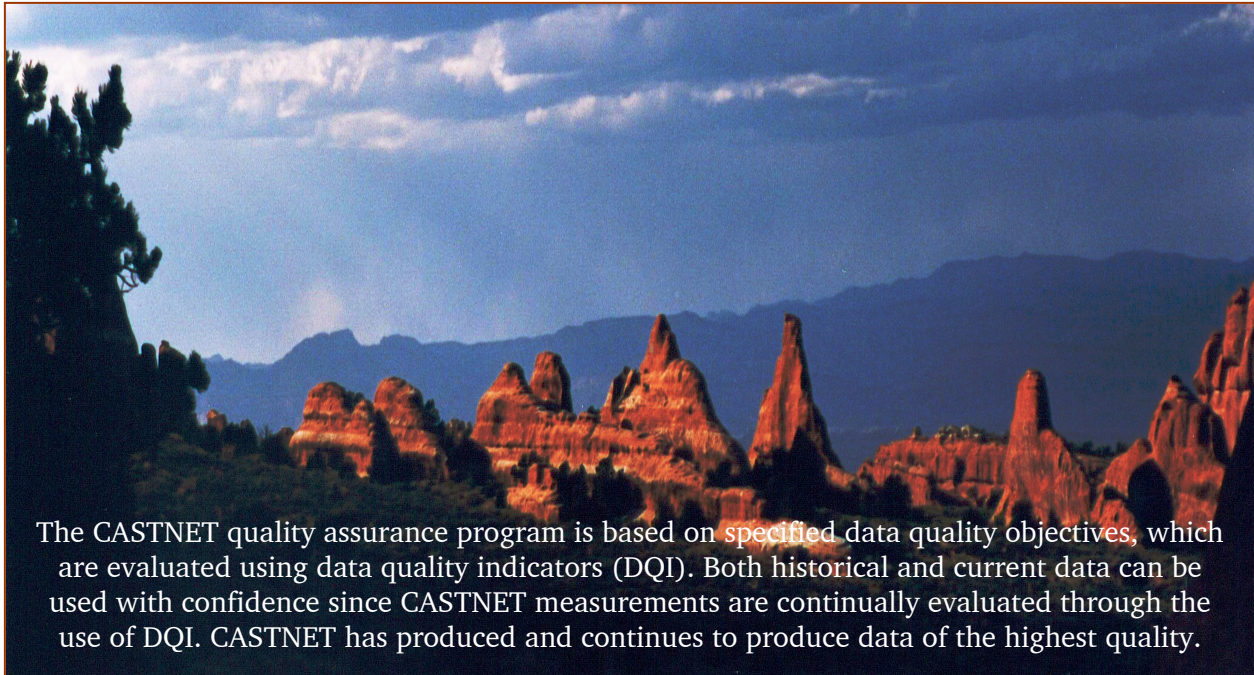
through the sampling system. Beginning in 2000, the calibration of each CASTNET O₃ analyzer was independently verified using a transfer standard every six months. Prior to 2000, O₃ analyzer calibrations were independently verified once per calendar quarter.

In 2001, the NPS-sponsored site at Rocky Mountain National Park, CO (ROM406), a regulatory site, was collocated with an EPA-sponsored site (ROM206). ROM406 conforms to regulatory requirements while ROM206 is operated according to CASTNET protocol. Therefore, data collected from these sites provide an excellent opportunity to compare the method results.

The figure above shows that the data compare very well. The precision goal for CASTNET O₃ measurements is 10 percent. The results obtained when both systems are operating properly indicate that CASTNET O₃ data can be used with confidence. The results for the third and fourth quarters of 2001, third quarter 2003, and second and third quarters of 2004 were affected by various operating problems. Therefore, results for these quarters should be disregarded.



Chapter 5: Data Quality



Bryce Canyon National Park, UT

The CASTNET QA program was designed to ensure that all reported data are of known and documented quality in order to meet CASTNET objectives and to be reproducible and comparable with data from other monitoring networks and laboratories. The QA program elements are documented in the Quality Assurance Project Plan (QAPP) (MACTEC, 2003b). The QAPP is comprehensive and includes standards and policies for all components of project operation from site selection through final data reporting.

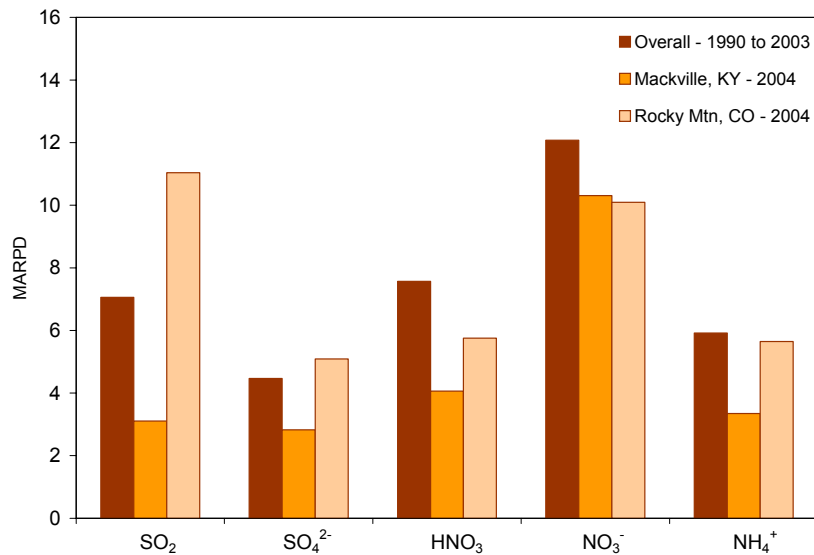
DQI have been established to gauge achievement of CASTNET objectives. DQI are quantitative and qualitative descriptors used in interpreting the degree of acceptability and utility of the data collected. The DQI for CASTNET are precision, accuracy, completeness, bias, representativeness, and comparability. Precision, accuracy, and completeness for CASTNET 2004 data were analyzed and compared with historical data collected during the period 1990–2003. The information in this report is supplemented by analyses that are discussed in quarterly CASTNET Quality Assurance Reports (e.g., MACTEC, 2005). These QA reports are produced four times per year with the fourth quarter report including an annual summary. Both historical and current data can be used with confidence since CASTNET data are always verified and validated through the use of the DQI. CASTNET has produced and continues to produce data of the highest quality.

Precision

Exposed Filter Concentrations

Figure 5-1 provides a bar chart in which the bars represent precision statistics for each CASTNET analyte in terms of mean absolute relative percent difference (MARPD) for both the historical (1990–2003) and the 2004 data for the collocated sites at Mackville, KY (MCK131/231) and Rocky Mountain National Park, CO (ROM406/206). Trace cations and chloride are excluded from this figure but are shown later in Figure 5-2. The historical results vary from about 5 percent for particulate sulfate (SO_4^{2-}) to about 12 percent for particulate nitrate (NO_3^-). The historical MARPD for SO_4^{2-} and ammonium (NH_4^+) each met the criterion, or DQI, for the CASTNET laboratory measurements shown in Table 5-1. The results for sulfur dioxide (SO_2) and nitric acid (HNO_3) were above the 5 percent criterion but were considered reasonable. The results for NO_3^- were significantly above the 5 percent goal. Historically, the precision of NO_3^- measurements has been consistently worse than for the other analytes, possibly because NO_3^- concentrations are the lowest of all the pollutants, and nitrate species include sampling artifacts (MACTEC, 2003a).

Figure 5-1 Historical and 2004 Precision Data for Atmospheric Concentrations



The 2004 precision results shown in Figure 5-1 indicate that the results for MCK131/231 were below historical results for all five parameters. Four parameters (SO_2 , SO_4^{2-} , HNO_3 , and NH_4^+) met DQI precision criteria. The precision results for ROM406/206 were below historical results for two parameters, above for two, and about the same for one. Only the results for NH_4^+ met the DQI criterion.

Table 5-1 Data Quality Indicators for CASTNET Laboratory Measurements

Analyte	Method	Precision (MARPD)	Accuracy (%)	Nominal Reporting Limits
Ammonium (NH ₄ ⁺)	Automated colorimetry	10	90 - 110	0.020 mg-N/L
Sodium (Na ⁺)	ICP-AES	5	95 - 105	0.005 mg/L
Potassium (K ⁺)	ICP-AES	5	95 - 105	0.005 mg/L
Magnesium (Mg ²⁺)	ICP-AES	5	95 - 105	0.003 mg/L
Calcium (Ca ²⁺)	ICP-AES	5	95 - 105	0.003 mg/L
Chloride (Cl ⁻)	Ion chromatography	5	95 - 105	0.020 mg/L
Nitrate (NO ₃ ⁻)	Ion chromatography	5	95 - 105	0.008 mg-N/L
Sulfate (SO ₄ ²⁻)	Ion chromatography	5	95 - 105	0.040 mg/L

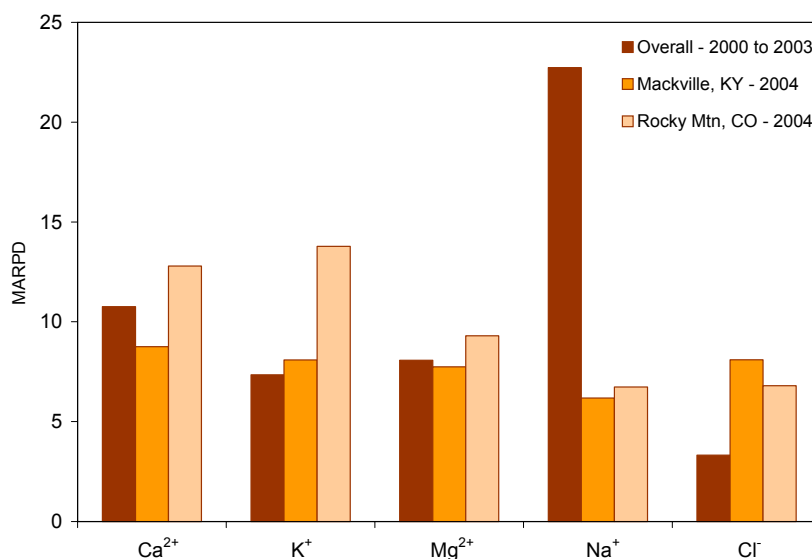
Note:

- ICP-AES = inductively coupled plasma-atomic emission spectrometry
- MARPD = mean absolute relative percent difference
- N = nitrogen

For more information on analytical methods and associated precision and accuracy criteria, see the CASTNET Quality Assurance Project Plan – Revision 2.0 (MACTEC, 2003b).

Precision statistics for 2004 for four cations and chloride (Cl⁻), based on collocated ambient concentrations, are summarized in Figure 5-2. The historical MARPD statistics for both MCK131/231 and ROM406/206 did not meet the DQI criterion of 5 percent, except for Cl⁻, which had a MARPD of 3.3 percent. As discussed in the CASTNET 2002 Annual Report (MACTEC, 2003a), the very high historical MARPD for sodium (Na⁺) was the result of sample bottle contamination. These bottles are no longer purchased. Also, to limit the possibility of future contamination, acceptance testing was instituted for Na⁺, potassium (K⁺), magnesium (Mg²⁺), calcium (Ca²⁺), and Cl⁻. The 2004 precision results for cations and Cl⁻ show that no parameter met the precision criterion.

Figure 5-2 Precision Data for Cation and Cl⁻ Concentrations



The 2004 analytical precision results for five analytes and the three filter types are presented in Figure 5-3. The results were based on analysis of five percent of the samples that were randomly selected for replication in each batch. The results of in-run replicate analyses were compared to the results of the original concentrations. The laboratory precision data met the 5 percent measurement criterion listed in Table 5-1 with the exception of the Whatman filter SO_4^{2-} analyses. A few samples with low values had very high relative percent difference (RPD) values. Table 5-2 summarizes precision results by quarter for the two sets of collocated sites. The results indicate a slight improvement in 2004 precision versus 2003 values for MCK131/231 and a slight decline in precision for ROM406/206 2004 values versus 2003.

Figure 5-3 Precision Results for Laboratory Replicate Samples (2004)

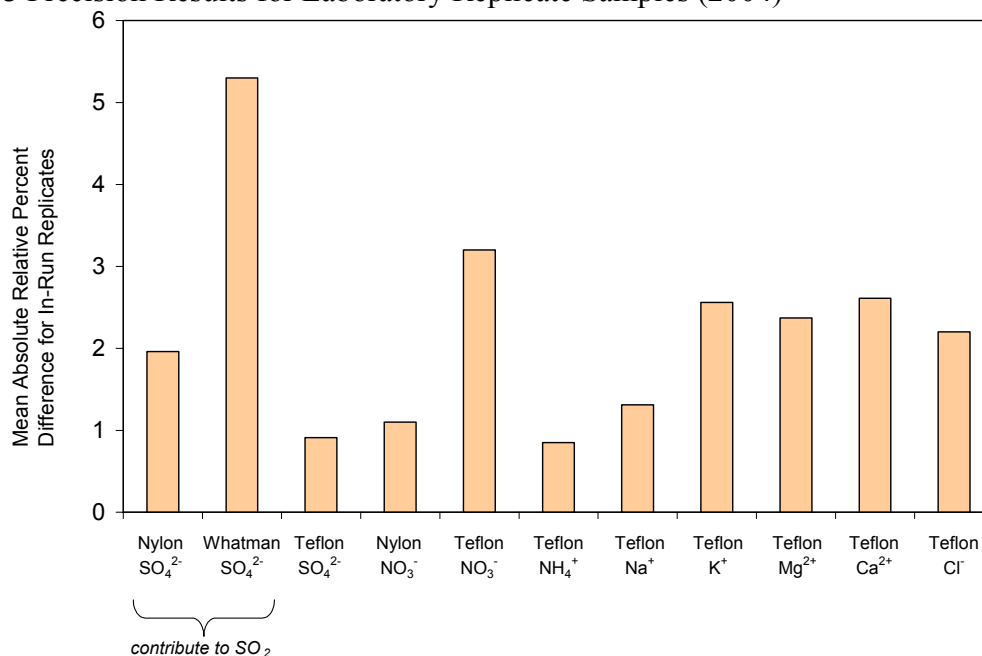


Table 5-2 Collocated Precision Results for 2004 by Quarter (MARPD)

Site Pairs	SO_4^{2-}	NO_3^-	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	HNO_3	SO_2	Total NO_3^-	Cl^-
MCK 131/231, KY											
Quarter 1	3.61	3.83	4.27	7.38	4.03	4.53	8.55	9.87	10.80	9.69	17.03
Quarter 2	2.65	2.67	1.92	9.04	3.54	3.11	4.25	6.22	6.54	7.86	6.99
Quarter 3	3.57	2.39	5.07	17.46	4.16	2.37	7.69	3.61	4.84	5.94	2.50
Quarter 4	2.60	2.41	4.98	7.36	4.62	3.38	4.26	12.68	8.80	11.54	5.90
2004	3.11	2.82	4.06	10.31	4.09	3.35	6.19	8.09	7.74	8.76	8.10
ROM 406/206, CO											
Quarter 1	9.39	6.54	8.21	10.27	5.78	6.61	6.48	13.03	7.50	20.05	16.12
Quarter 2	13.56	4.91	4.44	6.95	4.27	4.85	5.56	9.17	9.53	7.37	3.74
Quarter 3	9.56	4.28	5.66	10.34	4.08	4.03	6.55	9.90	6.34	6.24	2.62
Quarter 4	11.65	4.63	4.70	12.80	4.99	7.10	8.36	23.02	13.86	17.50	4.75
2004	11.04	5.09	5.75	10.09	4.78	5.65	6.74	13.78	9.31	12.79	6.81

Ozone Concentrations

CASTNET QA procedures for the EPA-sponsored ozone (O₃) analyzers are different from the EPA QA requirements for State and Local Monitoring Stations (SLAMS) monitoring (EPA, 1998). However, the QA procedures for the O₃ analyzers at the NPS-sponsored sites do meet the SLAMS QA requirements. The operation of the collocated O₃ analyzers at ROM406/206, CO provides an opportunity to evaluate the precision of the independent systems. Table 5-3 provides the DQI criteria for the CASTNET continuous measurements. The precision criterion for O₃ is 10 percent.

Table 5-3 Data Quality Indicators for CASTNET Field Measurements

Parameter	Measurement		Criteria*	
	Method		Precision	Accuracy
Wind Speed	Anemometer		± 0.5 m/s	The greater of ± 0.5 m/s for winds < 5 m/s or ± 5% for winds ≥ 5 m/s
Wind Direction	Wind Vane		± 5°	± 5°
Sigma Theta	Wind Vane		Undefined	Undefined
Relative Humidity	Thin Film Capacitor		± 10% (of full scale)	± 5%, relative humidity > 85% ± 20%, relative humidity ≤ 85%
Solar Radiation	Pyranometer		± 10% (of reading taken at local noon)	± 10%
Precipitation	Tipping Bucket Rain Gauge		± 10% (of reading)	± 0.05 inch†
Ambient Temperature	Platinum RTD		± 1.0°C	± 0.5°C
Delta Temperature	Platinum RTD		± 0.5°C	± 0.5°C
Surface Wetness	Conductivity Bridge		Undefined	Undefined
Ozone	UV Absorbance		± 10% (of reading)	± 10%
Filter Pack Flow	Mass Flow Controller		± 10%	± 5%

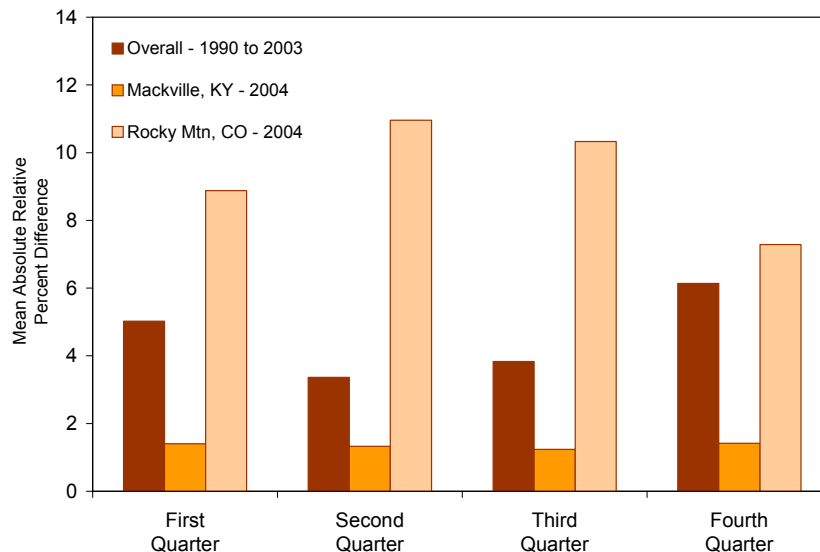
Note:

- °C = degrees Celsius
- m/s = meters per second
- RTD = resistance-temperature device
- UV = ultraviolet
- * Precision criteria apply to collocated instruments, and accuracy criteria apply to calibration of instruments.
- † For target value of 0.50 inch.

MARPD statistics were calculated from hourly O₃ measurements obtained from the collocated sites MCK131/231, KY and ROM406/206, CO during 2004. In addition, quarterly historical precision statistics were compiled for all collocated sites. Quarterly precision results are summarized in Figure 5-4. The data show the historical results met the 10 percent criterion. The precision data show the results for all four quarters for MCK131/231 and for the first and last quarters for ROM406/206 met the 10 percent criterion. The results for ROM406/206 for the second and third quarters were unacceptable because the O₃ analyzer at ROM206 experienced several intermittent problems from February through August 2004. The uninterruptible power supply was replaced in February and the O₃ analyzer itself in March. A loose ground wire was found during April, and a loose card was discovered in August. However, the annual MARPD

for ROM406/206 was approximately 9.4 percent, indicating that the two independently operated O₃ analyzers with different QA/quality control (QC) procedures produce nearly identical results.

Figure 5-4 Historical and 2004 Precision Data by Quarter for Ozone Concentrations



Accuracy

Laboratory Filter Concentrations

Accuracy of laboratory measurements is assessed through the analysis of reference samples and continuing verification samples (CVS). Reference samples and CVS are procured from independent suppliers and are National Institute of Standards and Technology (NIST) traceable. Reference samples are analyzed at the beginning and end of each analytical batch to verify the accuracy and stability of the calibration curve. The target value of the CVS solution is set to the midrange of the calibration curve. The CVS in 2004 were analyzed every tenth sample to verify no drift in the calibration curve. Table 5-4 presents the percent recoveries and standard deviations for reference samples and CVS relative to target concentrations. The table shows that the DQI goals (see Table 5-1) were met in 2004 with the exception of the mean RPD (5.3 percent) for the Whatman SO₄²⁻ in-run replicates. Table 5-4 also lists the precision results that were shown in Figure 5-3.

Table 5-4 Filter Pack QC Summary for 2004

Filter Type	Parameter	Reference Sample ¹ Recovery (%R)			Continuing Verification Samples (%R)			In-Run Replicate ² (RPD)		
		Mean	Std. Dev.	Count ³	Mean	Std. Dev.	Count ³	Mean	Std. Dev.	Count ³
Teflon [®]	SO ₄ ²⁻	99.32	1.53	170	100.16	0.98	871	0.91	1.34	283
	NO ₃ ⁻	102.23	0.95	170	100.03	1.27	872	3.20	3.70	283
	NH ₄ ⁺	100.36	2.63	176	100.04	1.94	853	0.85	1.36	249
	Ca ²⁺	103.23	2.07	209	100.50	1.00	735	2.61	3.86	262
	Mg ²⁺	100.18	1.59	209	99.86	0.76	735	2.37	3.97	265
	Na ⁺	94.65	1.42	209	99.84	0.91	735	1.31	1.44	265
	K ⁺	101.68	3.16	209	100.06	0.89	735	2.56	2.98	265
	Cl ⁻	101.63	1.37	168	99.95	1.20	862	2.20	4.91	283
Nylon	SO ₄ ²⁻	98.40	1.49	141	99.95	0.72	694	1.96	3.17	293
	NO ₃ ⁻	100.53	0.85	141	99.79	1.12	694	1.10	1.12	293
Whatman	SO ₄ ²⁻	100.64	0.66	188	99.10	0.63	708	5.30	7.98	260

Note: % R = percent recovery
RPD = relative percent difference

- ¹ Results of reference sample analyses provide accuracy estimates
- ² Results of replicate analyses provide precision estimates
- ³ Number of QC Samples



Petrified Forest National Park, AZ (PET427)

CASTNET Sample Handling

Objectives

The sample handling system supporting CASTNET is intended to ensure the data collection rate and data quality objectives are met. CASTNET sample handling procedures include these operational goals:

- Maintain a clear chain-of-custody (COC);
- Safeguard sample integrity;
- Recognize, document, and correct operational problems; and
- Maximize the data capture rate.

Positive Controls

CASTNET utilizes an open-face, three-stage filter pack to measure sulfur and nitrogen species. Filter pack handling procedures are designed to minimize handling and transfers (i.e., opportunities for contamination and misdirection). Sample integrity is maintained by ensuring that materials in contact with samples do not affect the analytes of interest in a way that could bias results. These materials must be traceable to a point to enable documentation of their contact with the sample. These goals are supported via documented COC and by incorporating filter acceptance tests, laboratory blanks, and field (trip) blanks.

Filter Acceptance Testing

Maintenance of sample integrity begins prior to preparation of the filter packs. Filters are purchased in lot quantities and subjected to acceptance testing. Filters that are found to be acceptable are then provided to the filter pack technicians. Filter lot numbers and the results of the acceptance testing are documented. Positive control of all filters prior to acceptance testing and of acceptable filters after testing is important in supporting the sample integrity goal.

Chain of Custody

COC begins when the filter pack is prepared and labeled. Filter packing is performed in a dedicated clean area to minimize the contamination potential. Once the filter pack is prepared and loaded in accordance with standard operating procedures (SOP), a filter pack label is applied. A COC form, which includes the filter pack lot number, site number, and employee number of the employee who assembled the filter pack, is included in the shipping container, which is sealed and labeled for shipment.

Quality Control Blanks

Two laboratory blanks are prepared each week during the same time the filter packs are being prepared for the field. Each blank contains a filter from the same lot as the filters used in preparation of the field filter packs. The filters selected for the laboratory blanks are placed directly into the extraction bottles, bypassing the handling involved in loading and unloading the filter packs. This is intended to provide an indication of the effects of filter handling within the laboratory.

Field blanks are prepared once each quarter for each sampling site. The filter packs used for the field blanks contain a nonstandard connection that cannot be installed in the sampling system. The filter pack is prepared and loaded according to SOP. The field blanks are clearly identified and labeled to prohibit their removal from the resealable plastic bag they are packed in. When the field blank is returned from the site, it is unpacked and analyzed following the standard analytical procedures. These samples elucidate the potential for contamination from the filter pack loading and unloading process.

Reagents used in laboratory analyses are analytical reagent grade, traceable to a commercial supplier. Method blanks, containing each reagent used in the analysis, are run with each analytical batch to assess reagent integrity. Method blanks containing detectable levels of analytes of interest and/or interfering analytes indicate possible contamination of the reagent or contamination from other sources (i.e., glassware, carryover). These occurrences are investigated. Once identified, the source of the contamination is quarantined or eliminated.

Future Direction

MACTEC is evaluating the introduction of a routine spiked reagent blank for laboratory analyses. A volume of deionized water identical to the routine aqueous volume used in the extraction of field samples would be spiked with a known concentration of target analytes and carried through the extraction and analysis process. The resulting concentration would elucidate potential gains or losses from the preparation process.

Continuous Measurements

CASTNET sites were calibrated every six months with NIST-traceable standards during 2004. Table 5-5 shows that all continuous parameters were within DQI criteria (Table 5-3) more than 90 percent of the time, except for relative humidity > 85 percent. This parameter met established criteria 78 percent of the time. According to CASTNET project protocols, the associated data are still considered valid if the calibration criterion is not exceeded by more than its magnitude (i.e., if within 2x the criterion). The percent within 2x criterion for relative humidity > 85 percent was 97 percent. Therefore, the completeness value for this parameter was not adversely affected.

Table 5-5 Accuracy Results for 2004 Field Measurements

Parameter	Percent Within Criterion
Temperature (0°C)	97 percent
Temperature (ambient)	97 percent
Delta Temperature (0°C)	94 percent
Delta Temperature (ambient)	97 percent
*Relative Humidity > 85%	78 percent
Relative Humidity ≤ 50%	97 percent
Solar Radiation	91 percent
Wind Direction North	96 percent
Wind Direction South	97 percent
Wind Speed < 5 m/s	98 percent
Wind Speed ≥ 5 m/s	98 percent
Precipitation	99 percent
Wetness (w/in 0.5 volts)	100 percent
Ozone Slope	96 percent
Ozone Intercept	99 percent
Flow Rate	93 percent

Note:

°C = degrees Celsius.

m/s = meters per second.

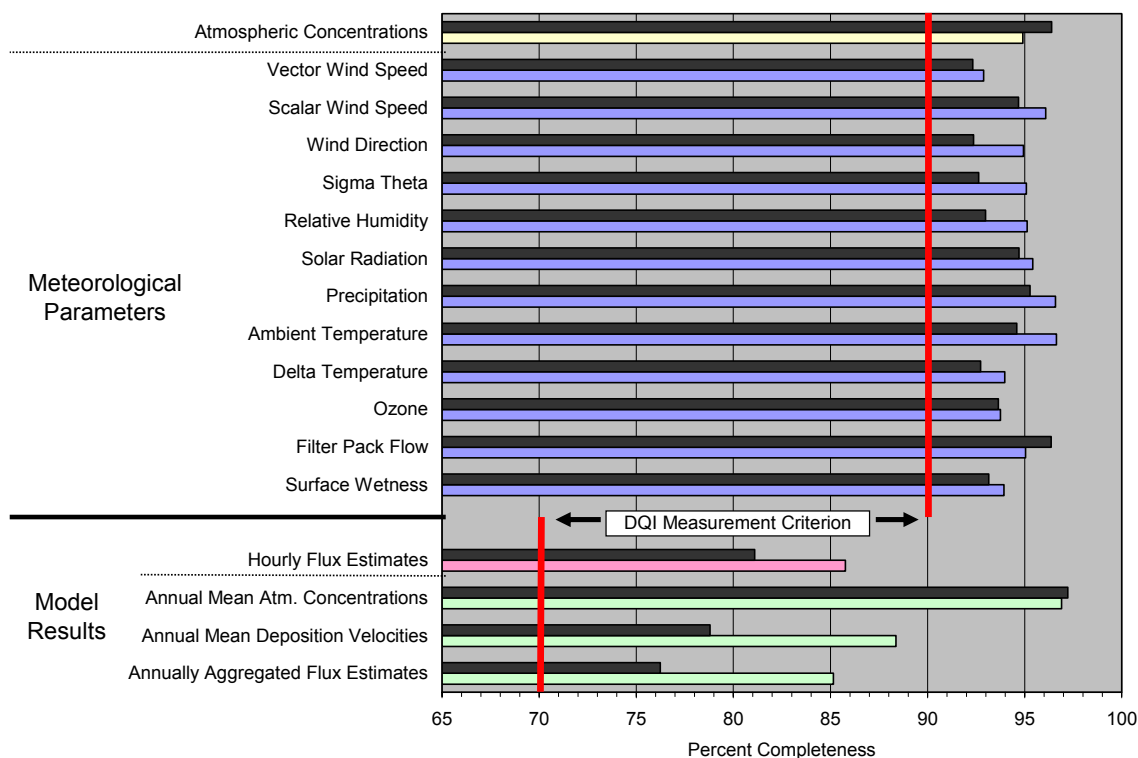
* = Per CASTNET project protocols, data are flagged as “suspect” (S) but still considered valid if the calibration criterion is not exceeded by more than its magnitude (i.e., if within 2x the criterion). The percent within 2x criterion for this parameter was 97 percent.

Completeness

Completeness is defined as the percentage of valid data points obtained from a measurement system relative to total possible data points expected to be obtained. The CASTNET DQI for completeness requires a minimum completeness of 90 percent for every measurement for each quarter. In addition, data aggregation procedures require approximately 70 percent completeness for hourly fluxes and weekly concentrations/fluxes. Figure 5-5 presents historical and 2004 completeness data for all sites for measured filter concentrations, continuous measurements, and calculated parameters. The figure shows that the 2004 direct measurements met the 90 percent goal. The 2004 results show that atmospheric concentrations, filter pack flow values, and ozone

(O₃) data completeness exceeded 95 percent. The four parameters derived from MLM results exceeded 85 percent completeness for 2004. The results for 2004 were better than historical completeness statistics with the exception of atmospheric concentrations, which were about one percentage point worse than the historical results.

Figure 5-5 Historical (1990-2003)* and 2004 Percent Completeness of Measurements and Modeled Estimates



Note:
* Black bars represent 1990-2003 data

Conclusion

DQI results demonstrate that field and laboratory processes were adequately monitored through QA/QC procedures and generally free of systematic bias during 2004. Accuracy data met the established criteria for field and laboratory parameters with the exception of relative humidity > 85 percent. However, since the criterion was exceeded by a value less than its own magnitude, the associated continuous data collected are considered valid. Precision data for sulfur constituents and ammonia are considered acceptable. Precision data for nitrate analyses of collocated field samples have not met the established criterion due, most likely, to the low concentrations generally measured and the unpredictable nature of the gas-particle equilibrium of the nitrate species. Completeness criteria were met for all parameters in 2004.

References

- Baumgardner Jr., R.E., Lavery, T.F., Rogers, C.M., and Isil, S.S. 2002. Estimates of the Atmospheric Deposition of Sulfur and Nitrogen Species: Clean Air Status and Trends Network, 1990-2000. *Environmental Science and Technology*. 36(12):2,614-2,629.
- Chow, J.C., Watson, J.G., Zhiqlang, L., Lowenthal, D.H., Frazier, C.A., Soloman, P.A., Thuillier, R.H., Magliano, K. 1996. Descriptive Analysis of PM_{2.5} and PM_{1.0} at Regionally Representative Locations during SJVAQS/AUSPEX. *Atmos. Environ.* 30, 2079-2112.
- Finkelstein, P.L., Ellestad, T.G., Clarke, J.F., Meyers, T.P., Schwede, D.B., Hebert, E.O., and Neal, J.A. 2000. Ozone and Sulfur Dioxide Dry Deposition to Forests: Observations and Model Evaluation. *J. Geophys. Res.* 105:D12:15,365-15,377.
- Herman, J. R., Bhartia, P. K., Torres, O., Hsu, C., Seftor, C., and Celarier, E. 1997. Global Distribution of UV-Absorbing Aerosols From Nimbus 7/TOMS Data. *J. Geophys. Res.* 102:16,911-16,922.
- MACTEC Engineering and Consulting, Inc. (MACTEC). 2005. *Clean Air Status and Trends Network (CASTNET) Quality Assurance Report: Fourth Quarter 2004 (October-December) with 2004 Annual Summary*. Prepared for U.S. Environmental Protection Agency (EPA), Office of Air and Radiation, Clean Air Markets Division, Washington, D.C. Contract No. 68-D-03-052., Gainesville, FL.
- MACTEC Engineering and Consulting, Inc. (MACTEC). 2003a. *Clean Air Status and Trends Network (CASTNET) 2002 Annual Report*. Prepared for U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, Contract No. 68-D-03-052. Gainesville, FL.
- MACTEC Engineering and Consulting, Inc. (MACTEC). 2003b. *Clean Air Status and Trends Network (CASTNET) Quality Assurance Project Plan (QAPP), Revision 2.0*. Prepared for U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, Contract No. 68-D-98-112. Gainesville, FL.
- Meyers, T. P., Finkelstein, P., Clarke, J., Ellestad, T.G., and Sims, P.F. 1998. A Multilayer Model for Inferring Dry Deposition Using Standard Meteorological Measurements. *J. Geophys. Res.* 103D17:22,645-22,661.

References (continued)

- National Oceanic and Atmospheric Administration (NOAA). 2004. *NOAA Reports Cool Summer, Seventh Coldest August on Record Across the Lower 48 States; Record Number of Named Atlantic Tropical Cyclones for August*. NOAA News Online (Story 2319) <http://www.noaanews.noaa.gov/stories2004/s2319.htm>. October 26.
- U.S. Department of Energy (DOE). 1997. *The Effects of Title IV of the Clean Air Act Amendments of 1990 on Electric Utilities: An Update*. Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, U.S. Department of Energy, Washington, DC. DOE/EIA-0582(97).
- U.S. Environmental Protection Agency (EPA). 2000. *National Air Quality and Emissions Trends Report, 1998*. EPA-454-R-00-003. OAQPS, Research Triangle Park, NC 27711.
- U.S. Environmental Protection Agency (EPA). 1998. *Quality Assurance Requirements for State and Local Air Monitoring Stations (SLAMS)*. 40 CFR 50, Appendix L.

Appendix A

Locational and Operational Characteristics of CASTNET Sites

Table A-1. Locational and Operational Characteristics of CASTNET Sites

Site ID	Site Name	Start date	Latitude (°N)	Longitude (°W)	Elevation (m)	Deposition Filter Pack ¹	Ozone and Meteorology ²	Wet Deposition	Primary Land Use	Terrain	Representative to the MLM ³	Sponsor
Alabama												
SND152	Sand Mountain	12/27/88	34.2894	85.9704	352	•	•		Agri.	Rolling	Y	EPA
Alaska												
DEN417	Denali National Park	10/06/98	63.7258	148.9633	661	•	•		Forested	Complex	N	NPS
KVA428	Kobuk Valley National Park [®]	05/27/04	67.0931	157.8689	88	•	•		Forested	Complex	M	NPS
Arizona												
CHA467	Chiricahua National Monument	04/25/89	32.0092	109.3892	1570	•	•	◇	Range	Complex	N	NPS
GRC474	Grand Canyon National Park	05/16/89	36.0597	112.1822	2073	•	•		Forested	Complex	M	NPS
PET427	Petrified Forest National Park	09/24/02	34.8225	109.8919	1723	•	•		Desert	Flat	Y	NPS
Arkansas												
CAD150	Caddo Valley	10/04/88	34.1792	93.0989	71	•	•		Forested	Rolling	N	EPA
California												
CON186	Converse Station	06/17/03	34.1941	116.9130	1837	•	•		Agri./Forested	Complex	N	EPA
DEV412	Death Valley National Monument	02/21/95	36.5092	116.8481	125	•	•		Desert	Complex	Y	NPS
JOT403	Joshua Tree National Monument	02/16/95	34.0714	116.3906	1244	•	•		Desert	Complex	M	NPS
LAV410	Lassen Volcanic National Park	07/25/95	40.5403	121.5764	1756	•	•		Forested	Complex	M	NPS
PIN414	Pinnacles National Monument	05/16/95	36.4850	121.1556	335	•	•		Forested	Complex	M	NPS
SEK402	Sequoia National Park	02/04/97	36.4292	118.7625	1225	•	•		Forested	Mountaintop	N	NPS
YOS404	Yosemite National Park	09/25/95	37.7133	119.7061	1605	•	•		Forested	Complex	N	NPS

Table A-1. Locational and Operational Characteristics of CASTNET Sites

Site ID	Site Name	Start date	Latitude (°N)	Longitude (°W)	Elevation (m)	Deposition Filter Pack ¹	Ozone and Meteorology ²	Wet Deposition	Primary Land Use	Terrain	Representative to the MLM ³	Sponsor
Colorado												
GTH161	Gothic	05/16/89	38.9573	106.9854	2926	•	•	◇	Range	Complex	N	EPA
MEV405	Mesa Verde National Park	01/10/95	37.1983	108.4903	2165	•	•		Forested	Complex	M	NPS
ROM206	Rocky Mountain National Park	07/03/01	40.2778	105.5453	2743	•	•		Forested	Complex	M	EPA
ROM406	Rocky Mountain National Park	12/20/94	40.2778	105.5453	2743	•	•		Forested	Complex	M	NPS
Connecticut												
ABT147	Abington	12/28/93	41.8402	72.0111	209	•	•	◇	Urban-Agri.	Rolling	M	EPA
Florida												
EVE419	Everglades National Park	10/06/98	25.3911	80.6806	2	•	•		Swamp	Flat	Y	NPS
IRL141	Indian River Lagoon	07/09/01	30.1065	80.4554	2	•	•		Beach	Flat	Y	SJRWMD
SUM156	Sumatra	12/28/88	30.1065	84.9938	14	•	•	◇	Forested	Flat	Y	EPA
Georgia												
GAS153	Georgia Station	06/28/88	33.1812	84.4100	270	•	•		Agri.	Rolling	M	EPA
Illinois												
ALH157	Alhambra	06/28/88	38.8690	89.6229	164	•	•	◇	Agri.	Flat	Y	EPA
BVL130	Bondville	02/09/88	40.0520	88.3725	212	•	•		Agri.	Flat	Y	EPA
STK138	Stockton	12/28/93	42.2872	89.9998	274	•	•		Agri.	Rolling	M	EPA

Table A-1. Locational and Operational Characteristics of CASTNET Sites

Site ID	Site Name	Start date	Latitude (°N)	Longitude (°W)	Elevation (m)	Deposition Filter Pack ¹	Ozone and Meteorology ²	Wet Deposition	Primary Land Use	Terrain	Representative to the MLM ³	Sponsor
Indiana												
SAL133	Salamonie Reservoir	06/28/88	40.8164	85.6608	250	•	•		Agri.	Flat	Y	EPA
VIN140	Vincennes	08/04/87	38.7406	87.4844	134	•	•		Agri.	Rolling	M	EPA
Kansas												
KNZ184	Konza Prairie	03/26/02	39.1021	96.6096	348	•	•		Prairie	Flat	Y	EPA
Kentucky												
CDZ171	Cadiz	10/01/93	36.7841	87.8500	189	•	•		Agri.	Rolling	M	EPA
CKT136	Crockett	08/24/93	37.9211	83.0658	455	•	•		Agri.	Rolling	Y	EPA
MAC426	Mammoth Cave National Park	07/24/02	37.1319	86.1478	243	•	•		Agri./Forested	Rolling	M	NPS
MCK131	Mackville	07/31/90	37.7044	85.0483	353	•	•		Agri.	Rolling	M	EPA
Maine												
ACA416	Acadia National Park	12/01/98	44.3769	68.2608	158	•	•		Forested	Complex	M	NPS
ASH135	Ashland	12/20/88	46.6039	68.4142	235	•	•		Agri.	Flat	Y	EPA
HOW132	Howland	11/24/92	45.2158	68.7085	69	•	•		Forested	Rolling	Y	EPA
Maryland												
BEL116	Beltsville	11/01/88	39.0283	76.8175	46	•	•		Urban-Agri.	Flat	N	EPA
BWR139	Blackwater National Wildlife Refuge	07/04/95	38.4448	76.1115	4	•	•		Forest-Marsh	Coastal	M	EPA

Table A-1. Locational and Operational Characteristics of CASTNET Sites

Site ID	Site Name	Start date	Latitude (°N)	Longitude (°W)	Elevation (m)	Deposition Filter Pack ¹	Ozone and Meteorology ²	Wet Deposition	Primary Land Use	Terrain	Representative to the MLM ³	Sponsor
Michigan												
ANA115	Ann Arbor	06/28/88	42.4164	83.9019	267	•	•	◇	Forested	Flat	M	EPA
HOX148	Hoxeyville	10/31/00	44.1809	85.7390	298	•	•		Forested	Flat	Y	EPA
UVL124	Unionville	06/28/88	43.6139	83.3597	201	•	•	◇	Agri.	Flat	Y	EPA
Minnesota												
VOY413	Voyageurs National Park	06/13/96	48.4128	92.8292	429	•	•		Forested	Rolling	M	NPS
Mississippi												
CVL151	Coffeeville	12/27/88	34.0028	89.7989	134	•	•		Forested	Rolling	M	EPA
Montana												
GLR468	Glacier National Park	12/27/88	48.5103	113.9956	976	•	•		Forested	Complex	N	NPS
Nevada												
GRB411	Great Basin National Park	05/16/95	39.0053	114.2158	2060	•	•		Forested	Complex	M	NPS
New Hampshire												
WST109	Woodstock	12/27/88	43.9446	71.7008	258	•	•		Forested	Complex	N	EPA
New Jersey												
WSP144	Washington's Crossing	12/27/88	40.3133	74.8726	61	•	•		Urban-Agri.	Rolling	M	EPA

Table A-1. Locational and Operational Characteristics of CASTNET Sites

Site ID	Site Name	Start date	Latitude (°N)	Longitude (°W)	Elevation (m)	Deposition Filter Pack ¹	Ozone and Meteorology ²	Wet Deposition	Primary Land Use	Terrain	Representative to the MLM ³	Sponsor
New York												
CAT175	Claryville	05/10/94	41.9423	74.5519	765	•	•5		Forested	Complex	N	EPA
CTH110	Connecticut Hill	09/28/87	42.4010	76.6535	515	•	•	◇	Forested	Rolling	N	EPA
HWF187	Huntington Wildlife Forest	05/28/02	43.9732	74.2232	502	•	•		Forested	Complex	N	EPA
North Carolina												
BFT142	Beaufort	12/28/93	34.8843	76.6213	2	•	•	◇	Agri.	Flat	Y	EPA
CND125	Candor	09/25/90	35.2643	79.8382	198	•	•	◇	Forested	Rolling	M	EPA
COW137	Coweeta	11/04/87	35.0605	83.4302	686	•	•		Forested	Complex	N	EPA
PNF126	Cranberry	12/27/88	36.1040	82.0448	1250	•	•	◇	Forested	Mountaintop	M	EPA
North Dakota												
THR422	Theodore Roosevelt National Park	10/06/98	46.8947	103.3778	850	•	•		Range	Rolling	Y	NPS
Ohio												
DCP114	Deer Creek State Park	09/28/88	39.6358	83.2600	267	•	•	◇	Agri.	Rolling	Y	EPA
LYK123	Lykens	01/10/89	40.9169	82.9981	303	•	•	◇	Agri.	Flat	M	EPA
OXF122	Oxford	08/18/87	39.5314	84.7231	284	•	•		Agri.	Rolling	N	EPA
QAK172	Quaker City	09/28/93	39.9431	81.3378	372	•	•		Agri.	Rolling	M	EPA
Oklahoma												
CHE185	Cherokee Nation	04/02/02	35.7507	94.6700	299	•	•		Agri.	Rolling	Y	EPA
Ontario												
EGB181	Egbert, Ontario	12/27/94	44.2317	79.7840	251	•6	•4		Agri.	Rolling	Y	EPA

Table A-1. Locational and Operational Characteristics of CASTNET Sites

Site ID	Site Name	Start date	Latitude (°N)	Longitude (°W)	Elevation (m)	Deposition Filter Pack ¹	Ozone and Meteorology ²	Wet Deposition	Primary Land Use	Terrain	Representative to the MLM ³	Sponsor
Pennsylvania												
ARE128	Arendtsville	06/28/88	39.9231	77.3078	269	•	•	◇	Agri.	Rolling	M	EPA
KEF112	Kane Experimental Forest	01/03/89	41.5981	78.7683	622	•	•		Forested	Rolling	Y	EPA
LRL117	Laurel Hill State Park	12/15/87	39.9883	79.2522	615	•	•		Forested	Complex	N	EPA
MKG113	M.K. Goddard State Park	01/12/88	41.4250	80.1447	384	•	•		Forested	Rolling	N	EPA
PSU106	Penn. State University	01/06/87	40.7209	77.9316	376	•	•		Agri.	Rolling	M	EPA
South Dakota												
WNC429	Wind Cave National Park	11/18/03	43.5578	103.4839	1292	•	•		Prairie	Rolling	M	NPS
Tennessee												
ESP127	Edgar Evins State Park	03/22/88	36.0389	85.7330	302	•	•		Forested	Rolling	N	EPA
GRS420	Great Smoky Mountains National Park	10/06/98	35.6331	83.9422	793	•	•		Forested	Complex	N	NPS
SPD111	Speedwell	06/12/89	36.4698	83.8265	361	•	•	◇	Agri.	Rolling	Y	EPA
Texas												
ALC188	Alabama-Coushatta	04/02/04	30.4210	94.4045	101	•	•		Forested	Rolling	Y	EPA
BBE401	Big Bend National Park	07/18/95	29.3022	103.1772	1052	•	•		Forested	Complex	M	NPS
Utah												
CAN407	Canyonlands National Park	01/24/95	38.4586	109.8211	1809	•	•		Desert	Complex	M	NPS
Vermont												
LYE145	Lye Brook	03/30/94	43.0510	73.0613	730	•	•5	◇	Forested	Mountaintop	N	EPA

Table A-1. Locational and Operational Characteristics of CASTNET Sites

Site ID	Site Name	Start date	Latitude (°N)	Longitude (°W)	Elevation (m)	Deposition Filter Pack ¹	Ozone and Meteorology ²	Wet Deposition	Primary Land Use	Terrain	Representative to the MLM ³	Sponsor
Virginia												
PED108	Prince Edward	11/03/87	37.1653	78.3070	150	•	•	◇	Forested	Rolling	M	EPA
SHN418	Shenandoah National Park	06/28/88	38.5231	78.4347	1073	•	•		Forested	Mountaintop	M	NPS
VPI120	Horton Station	06/02/87	37.3300	80.5573	920	•	•		Forested	Mountaintop	N	EPA
Washington												
MOR409	Mount Rainier National Park	08/29/95	46.7583	122.1244	415	•	•		Forested	Complex	N	NPS
NCS415	North Cascades National Park	02/14/96	48.5397	121.4472	109	•	•		Forested	Complex	M	NPS
OLY421	Olympic National Park	10/06/98	48.0975	123.4256	125	•	•		Forested	Complex	N	NPS
West Virginia												
CDR119	Cedar Creek State Park	11/10/87	38.8794	80.8478	234	•	•	◇	Forested	Complex	N	EPA
PAR107	Parsons	01/19/88	39.0906	79.6614	510	•	•		Forested	Complex	N	EPA
Wisconsin												
PRK134	Perkinstown	09/27/88	45.2066	90.5972	472	•	•	◇	Agri.	Rolling	M	EPA
Wyoming												
CNT169	Centennial	08/19/91	41.3722	106.2422	3178	•	•		Range	Complex	M	EPA
PND165	Pinedale	12/27/88	42.9214	109.7900	2388	•	•		Range	Rolling	M	EPA
YEL408	Yellowstone National Park	06/26/96	44.5597	110.4006	2400	•	•		Forested	Rolling	N	NPS

-
1. The dry deposition filters are analyzed for the following constituents:

Teflon® = SO₄²⁻, NO₃⁻, NH₄⁺, Cl⁻, K⁺, Na⁺, Mg²⁺, Ca²⁺

Nylon = SO₄²⁻, NO₃⁻ (reported as HNO₃)

Whatman = SO₄²⁻ (reported as SO₂)

2. Meteorological sensors: temperature, delta temperature, relative humidity, solar radiation, vector wind speed, scalar wind speed, wind direction, sigma theta, surface wetness, and precipitation via tipping bucket rain gauge.

3. N = No; Y = Yes; M = Marginal; N/A = Not Applicable.

4. O₃ not measured.

5. Solar-powered sites.

6. Composite filter pack, day filter pack, and night filter pack.

- Indicates current monitoring.

- ◉ Site ran from late May through September, only

- ◇ Indicates discontinued monitoring.

Measurements were discontinued at the various sites because of several reasons including:

- (1) rotate limited number of instruments;
- (2) redundant measurements (e.g., with IMPROVE and NADP/NTN); and
- (3) funding limitations.

100 and 200 series = EPA – Operated Sites

400 series = NPS – Operated Sites

141 site = St. Johns River Water Management District (SJRWMD)

Denotes Sites Sponsored by EPA

Denotes Sites New in 2004 Sponsored by EPA

Denotes Sites Sponsored by NPS

Denotes Sites New in 2004 Sponsored by NPS

For more Information

U.S. Environmental Protection Agency

**Office of Air and Radiation
Clean Air Markets Division
Washington, D.C.**

On the Web:

CASTNET Home Page:

**Clean Air Markets
Division Home Page:**

EPA Home Page:

www.epa.gov/castnet

www.epa.gov/airmarkets

www.epa.gov

