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# Clean Air Status and Trends Network Five Year Network Assessment

Clean Air and Power Division

Office of Atmospheric Protection

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## 1. Introduction

### A. Purpose

This network assessment is required by 40 CFR Part 58.10(d) to ensure the Clean Air Status and Trends Network (CASTNET) program's air quality data meet the conditions for submittal to the U.S. Environmental Protection Agency (EPA) Air Quality System (AQS), EPA's repositor of ambient air quality data. Monitoring agencies that submit data to the EPA for regulatory purposes are required to conduct an assessment of their air quality surveillance system once every five years. The purpose of the assessment is to determine, at a minimum, whether the network meets the monitoring objectives of the EPA, National Park Service, and the Bureau of Land Management – Wyoming State Office. The focus of this assessment is on the CASTNET monitoring program from 2020 to 2025. The assessment includes a review of the network's effectiveness in reporting trends and regional concentrations of $O_3$, $SO_2$, CO, oxides of nitrogen, and recommendations to improve network performance as CASTNET adapts to meet agency objectives.

This CASTNET 5-year network assessment includes network modernization activities that began in 2024. The investments and cost-saving efforts comply with the recommendations from a recent CASTNET scientific review with input from internal and external stakeholders. In 2022, EPA requested that the Science Advisory Board (SAB) convene a panel of experts that would advise the Agency on how to modernize the network, achieve cost-savings, and ensure it continues to provide data for regulatory assessments, policy development, and to support the scientific community. The panel and members of the public who offered comments during the deliberations were overwhelmingly supportive of the program, noting that CASTNET is the Agency's premier network for rural and background measurements, providing information on regional pollutant transport, validating chemical transport models, and reporting atmospheric deposition.

The background material including the charge questions, list of panel members, individual panelist and public comments, and the final report can be found on the CASTNET SAB review panel website[1]. The SAB submitted its final report and recommendations to the Agency in April 2024. Based on the recommendations, EPA developed a modernization plan. Implementation of the network modernization activities began in 2024 and will result in a more efficient, sustainable network that serves the American public.

Below are the key recommendations and status of activities:

- **Maintain as many long-term multipollutant (gases and particles) measurements as possible, recognizing the importance of long-term consistent measurements over adding new pollutants**
  - **Prioritize sites using the evaluation criteria and metrics that align with Agency's monitoring objectives** to evaluate the value of each individual site. Individual sites were ranked using criteria that aligned with network goals. Sites that provide highest value continue to operate while sites with lower scores were or will be decommissioned.

[1] Material from the SAB panel review of the CASTNET program can be accessed at this link: sab.epa.gov/ords/sab/r/sab_apex/sab/advisoryactivitydetail?p18_id=2626&clear=RP,18&session=4785883196892

- **Replace ozone analyzers.** Evaluation of new ozone analyzers is ongoing. Replacement will occur in 2025/2026 to meet updated requirements in the revised ozone technical assistance document (U.S. EPA, 2023).
- **Upgrade site infrastructure.** This is ongoing with new roof, floors, and IT systems for remote access.

- **Evaluate changes to the frequency of filter pack measurements** (e.g., consider bi-weekly)
  - **Consider hourly measurements and lower-cost methods** as instruments/sensors become available to replace the weekly measurements. Evaluating co-located measurements at ASCENT sites.
- **Add $PM_{2.5}$ sensors to create a more robust multipollutant monitoring network** for health and environmental assessments. Low cost PM2.5 sensors deployed at all EPA-sponsored CASTNET sites.
- **Address spatial gaps in the Nation's air quality monitoring network in the Central US, with emphasis on nitrogen measurements.**
  - The Haskell Indian Nations University (HAS012, KS) site was added in 2024 to fill a spatial gap within CASTNET and provide training to students and tribal environmental professionals that can operate air quality monitoring sites on tribal lands.

B. CASTNET Objectives

CASTNET is a long-term monitoring network designed to measure trends in regional measurements of acidic pollutants, base cations, chloride, and ambient $O_3$. The program is authorized under Section 103 (c) of the Clean Air Act which directs the Agency to establish a national network to monitor, collect, and compile data with quantification of certainty in the status and trends of air emissions, deposition, air quality, surface water quality, forest condition, and visibility impairment, and to ensure the comparability of air quality data collected in different States and obtained from different nations. The Environmental Protection Agency – Clean Air and Power Division (EPA), the National Park Service – Air Resources Division (NPS), and the Bureau of Land Management – Wyoming State Office (BLM-WSO) collaboratively manage and operate CASTNET. In addition to EPA, NPS, and BLM-WSO, numerous other participants including Tribes, other federal agencies, states, private landowners, and universities operate sites or provide network support. CASTNET monitors provide critically important, regionally representative data used to report air quality trends, estimate background $O_3$ concentrations, and evaluate air quality models largely in the absence of local emissions (Brown-Steiner et al., 2018; Kerr et al., 2019; Reider et al., 2018; Schwantes et al., 2020; Travis and Jacob, 2019). Additionally, CASTNET $O_3$ data are used to evaluate the effectiveness of national and regional emission reduction control programs, gauge compliance with National Ambient Air Quality Standards (NAAQS), and provide input into regional air quality and total deposition models (U.S. EPA, 2020). Lastly, CASTNET $O_3$ data are also used to assess impacts from stratospheric intrusions and wildfires (Hogrefe et al., 2018; Itahashi et al., 2020; and Lin et al., 2015).

CASTNET currently operates 93 monitoring stations throughout the contiguous United States, Alaska, and Canada. EPA operates 59 CASTNET monitoring stations, NPS operates 29 CASTNET stations, and BLM-WSO operates five CASTNET stations. Thirty-five years of consistent, long-term measurements reported by CASTNET demonstrate reductions in $O_3$, nitrogen, and sulfur concentrations throughout the United States. Additionally, continuous trace-level gas monitoring for sulfur dioxide* ($SO_2$), nitrogen oxide/total reactive oxides of nitrogen ($NO/NO_y$), and carbon monoxide (CO) is ongoing at two, six, and two CASTNET sites, respectively.

* Filter pack sulfur dioxide measurements were discontinued at all NPS and most EPA monitoring sites.

CASTNET's three operating agencies, EPA, NPS, and BLM-WSO coordinate their resources to fulfill the following goals:

- Provide air quality data to assess compliance with the NAAQS;
- deliver near real-time air pollution levels to allow the public to make decisions about health risks;
- monitor the status and trends in regional air quality and atmospheric deposition;
- evaluate the relationships between atmospheric pollution and ecosystem conditions; and
- provide measurements for validating and improving atmospheric models.

Each operating agency also utilizes CASTNET to fulfill their own monitoring objectives. Specific examples are described below.

CASTNET data are used by EPA to evaluate the effectiveness of national and regional emission reduction programs and to determine compliance with the $O_3$ NAAQS. EPA uses these consistent, long-term measurements for determining relationships between changes in emissions and subsequent changes in air quality, atmospheric deposition, and ecological effects. Under Title IV of the Clean Air Act Amendments (CAAA), the Acid Rain Program (ARP) was promulgated to reduce emissions of sulfur dioxide ($SO_2$) and nitrogen oxides ($NO_x$) from electric generating units (EGUs). A unique and critical component of CASTNET is the multipollutant, rural monitoring sites that provide data on the chemical composition and transformation of air pollutants from upwind sources. The ozone and PM precursor measurements are used to provide accountability for regulated sources and determine compliance with the NAAQS in rural areas. The EPA CASTNET program works with several Tribal, state, and local monitoring agencies to collaboratively monitor air quality for the American public.

The NPS uses CASTNET monitoring data to assess environmental conditions and trends in ozone, nitrogen deposition, and to assess compliance with the $O_3$ NAAQS. Coupled with special studies data, this information allows the NPS to understand how air pollutants are currently impacting park air quality and air quality related values (AQRVs). These data help the NPS and the public understand which parks are at highest risk for impacts and where conditions of park air quality and AQRVs are declining or improving. Specifically, ambient measurements of $O_3$, $NO_x$, and $SO_2$ concentrations, deposition, and effects on visibility, soils, waters, and plants are critical components of periodic assessments. For example, $O_3$ and vegetation data from Sequoia and Yosemite National Parks have been used to document the concentrations at which $O_3$ pollution causes damage to Ponderosa pine trees (Bytnerowicz et al., 2008).

The BLM-WSO uses CASTNET data to identify air quality concerns and evaluate air strategy effectiveness. These data also fulfill air monitoring commitments in Resource Management Plans (RMPs) and Records of Decisions (RODs). Lastly, CASTNET data provide necessary information to assess existing conditions, impacts of federal actions, and long-term trends in air quality and deposition on BLM land.

While these CASTNET monitoring objectives go beyond the scope of this assessment, they are provided here in brief to illustrate the utility and breadth of the data generated by CASTNET. In this assessment we provide an overview of the CASTNET monitoring program, the sponsoring agencies' objectives for the regulatory monitoring program, trends and annual results, quality assurance metrics, and the outlook for the program.

C. Network Overview

CASTNET was established under the 1990 Clean Air Act Amendments, expanding the National Dry Deposition Network (NDDN), which began in 1987. NPS began its participation with CASTNET in 1994 under an agreement with EPA. With the involvement of NPS, the network became a national, rather than a primarily eastern, network. BLM-WSO began participation in CASTNET in late 2012, provided additional monitoring coverage in Wyoming. CASTNET was designed to provide accountability for emission reduction programs by reporting trends in pollutant concentrations and acidic deposition. To meet those goals, CASTNET site locations were selected in rural areas to provide regionally representative concentrations and estimates of dry deposition fluxes.

Figure 1 shows the locations of all CASTNET monitoring sites. Circles represent sites operating a filterpack and a continuous $O_3$ monitor. Continuous $O_3$ concentrations are measured at 80 sites. Squares represent sites with trace gas monitors operated by EPA or NPS. Sites at Bondville, IL (BVL130), Acadia National Park, ME (ACA416), Great Smoky Mountains National Park – Look Rock, TN (GRS420), and Cherokee Nation, OK (CHE185) are NCore sites with trace gas NO/NOy, $SO_2$, and CO. Additionally, there are twelve sites that operate without a walk-in shelter, represented by a triangle or triangle over a circle on the map in Figure 1 (e.g., small footprint sites). Thirty-seven CASTNET sites measure hourly meteorological parameters including 28 NPS sites, all BLM-WSO sites, and five EPA sites. Additional information and data from the CASTNET monitoring program can be found on the CASTNET website at https://www.epa.gov/castnet.

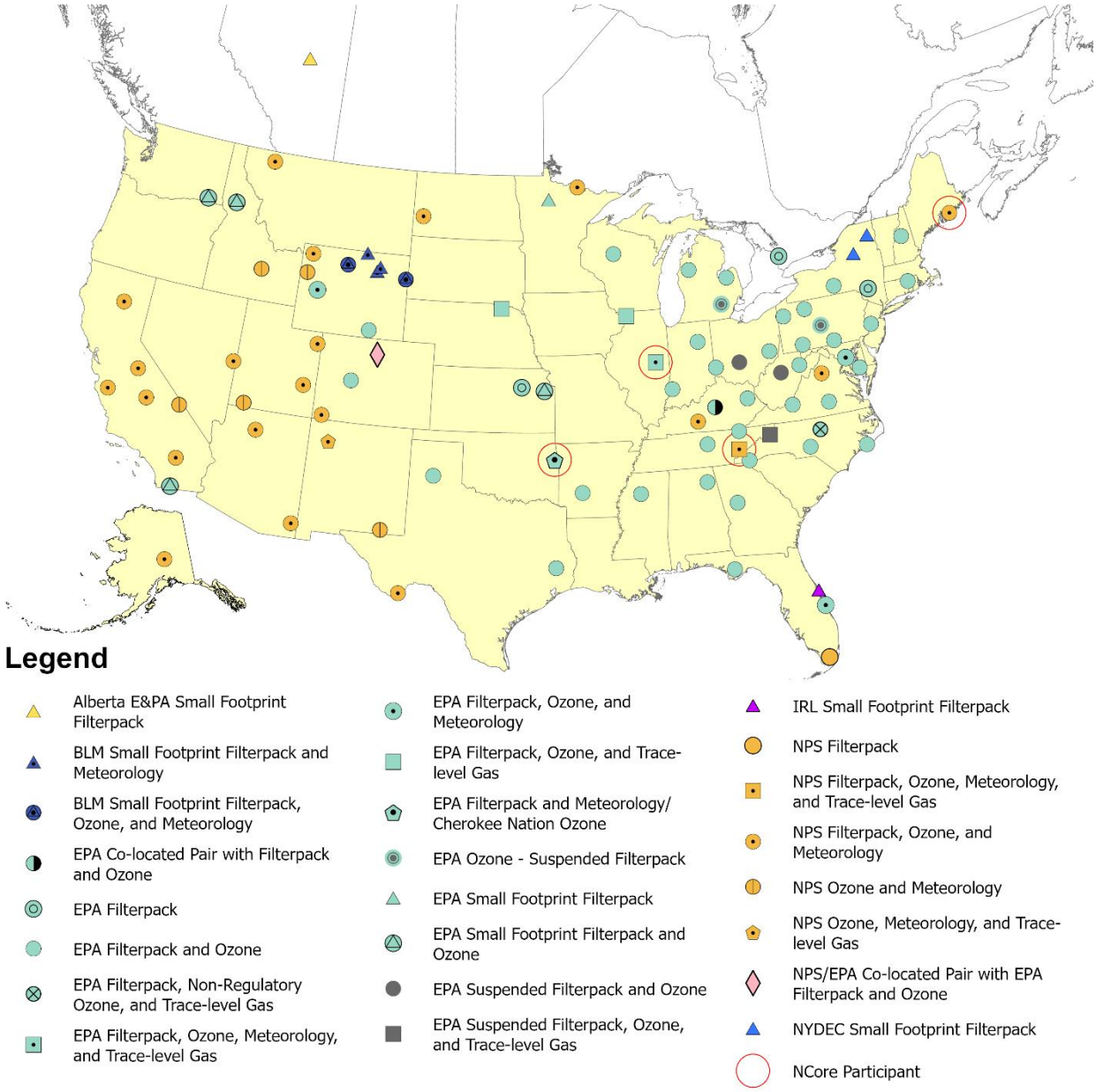



*Figure 1. Map of CASTNET sites. Teal shapes represent EPA-sponsored sites. Dark gray shapes indicate EPA-sponsored sites that suspended some or all monitoring activities in May 2022 due to budget constraints. Orange shapes represent NPS-sponsored sites. The pink diamond represents a co-located pair of NPS-sponsored ozone and filterpack monitoring and EPA-sponsored ozone, filterpack, and trace-level gas monitoring. Navy blue shapes represent BLM-Wyoming State Office-sponsored sites. National Core network (NCore) sites are identified with a large red circle. The yellow triangle indicates the site sponsored by Alberta Environment and Protected Areas. Medium blue triangles represent sites sponsored by New York Department of Conservation.*

D. CASTNET Partners

In addition to EPA, NPS, and BLM-WSO, numerous other participants including Tribes, other federal agencies, states, private landowners, and universities provide network support (Table 1). CASTNET partners may provide local operational support, space for shelters and equipment, or scientific expertise. The EPA contractor, WSP, Inc. (WSP), manages the day-to-day operations for the EPA-

sponsored sites while the NPS and BLM contractor, Air Resource Specialists, Inc. (ARS), manages the operations for the remaining sites.

*Table 1. CASTNET Program Partners*

| Program Partners | | |
|---|---|---|
| **Federal** | **State/Local/Tribal** | **University** |
| Agricultural Research Center (USDA/ARS)<br>Allegheny National Forest<br>Apalachicola National Forest (USFS)<br>Bureau of Land Management (DOI)<br>Environment & Climate Change Canada - CAPMoN<br>Gunnison National Forest<br>Holly Springs National Forest<br>Hubbard Brook Exp. Forest<br>Medicine Bow-Routt National Forest<br>Monongahela National Forest<br>Nantahala National Forest<br>National Park Service<br>United States Army Engineering District/Louisville<br>US Fish & Wildlife Service<br>USDA Natural Res. Conservation Service (NRCS)<br>USDA South. Res. Station Coweeta Hydrological Lab<br>USDA-FS Forestry Sciences Laboratory<br>USDA-FS Rocky Mountain Research Station<br>USDA-FS Timber & Watershed Lab<br>USDA-FS Toecane District<br>White Mountain National Forest | Rocky Mountain Biological Laboratory<br>Cedar Creek SP (WV Division of Nat. Resources)<br>Cumberland St. Forest VA Department of Forestry<br>Deer Creek SP (OH Dept of Nat. Resources)<br>Edgar Evans SP (TN Dept. Of Envir. Conservation)<br>Laurel Hill SP (PA Dept. of Cons. & NR)<br>Maurice K. Goddard SP (PA Dept. of Cons. & NR)<br>New York Department of Environmental Conservation<br>NYS Energy Research & Development Authority<br>St. Johns River Water Management District<br>Washington Crossing SP (NJ DEP)<br>Alabama-Coushatta Tribe of Texas<br>Cherokee Nation<br>Confederated Tribes of the Umatilla Indian Reservation<br>Haskell Indian Nations University<br>La Posta Band of Diegueno Mission Indians<br>Nez Perce Tribe<br>Red Lake Nation<br>Santee Sioux Tribe of Nebraska | Auburn Univ. Alabama Agricultural Experiment St.<br>Cornell University, Ecology & Evolutionary Biology<br>KSU Division of Biology/Konza Prairie LTER<br>Miami Univ. Inst. for the Envir. & Sustainability<br>Ouachita Baptist Univ. School of Natural Sciences<br>Penn State Fruit Research & Extension Center<br>Penn State Univ. Dept. of Meteorology<br>Proctor Maple Research Center (UVM)<br>Purdue Univ. Dept of Agronomy<br>SUNY ESF Adirondack Ecology Center<br>Texas A&M Agrilife Research & Extension Center<br>UNC Institute of Marine Sciences<br>Univ. of GA, College of Agriculture & Envir. Scien<br>University of IL, Illinois State Water Survey<br>University of Maine Plant, Soil & Environ. Science<br>University of MD Dept. of Atmos. & Oceanic Sci.<br>University of Michigan School of Natural Resources |

E. CASTNET Ozone Monitoring Program

CASTNET operates 93 monitoring sites throughout the US and Canada and 80 of those sites measure ground-level, continuous $O_3$ following the regulations in the 40 Code of Federal Regulations (CFR) Part 58 and EPA's Quality Assurance Handbook for Air Pollution Measurement Systems: "Volume II: Ambient Air Quality Monitoring Program" (US EPA, 2017). CASTNET $O_3$ monitors are located in 38 states with at least one CASTNET $O_3$ monitor in each of the ten EPA Regions. Five CASTNET $O_3$ sites are located on Tribal Lands including Santee Sioux, NE (SAN192), Cherokee Nation, OK (CHE185), Alabama-Coushatta, TX (ALC188), Nez Perce, ID (NPT006), and La Posta Band of Indians, CA (LPO010). A new site at Haskell Indian Nations University, KS (HAS012) serves Native American students from more than 140 federally recognized tribes. The HAS012 site is operated as a traditional CASTNET site but will also provide hands-on training experience for students, faculty, and tribal monitoring professionals.

Eighty CASTNET sites collect ambient $O_3$ concentrations, reported as hourly averages, using a dual cell, ultraviolet photometric analyzer. Seventy-nine of the eighty CASTNET $O_3$ monitoring analyzers meet the ambient monitoring and quality assurance requirements in Appendices A, C, D and E of Title 40, Code of

Federal Regulations (CFR) Part 58. The ozone analyzer at Duke Forest, NC (DUK008) does not meet the siting criteria requirements from Appendix E of Part 58 because it has an inlet height of 44 meters. Additional information about CASTNET siting criteria can be found in the Quality Assurance Project Plan version 10.2 at https://www.epa.gov/castnet/documents-reports#QualityAssuranceProjectPlan (WSP, 2025).

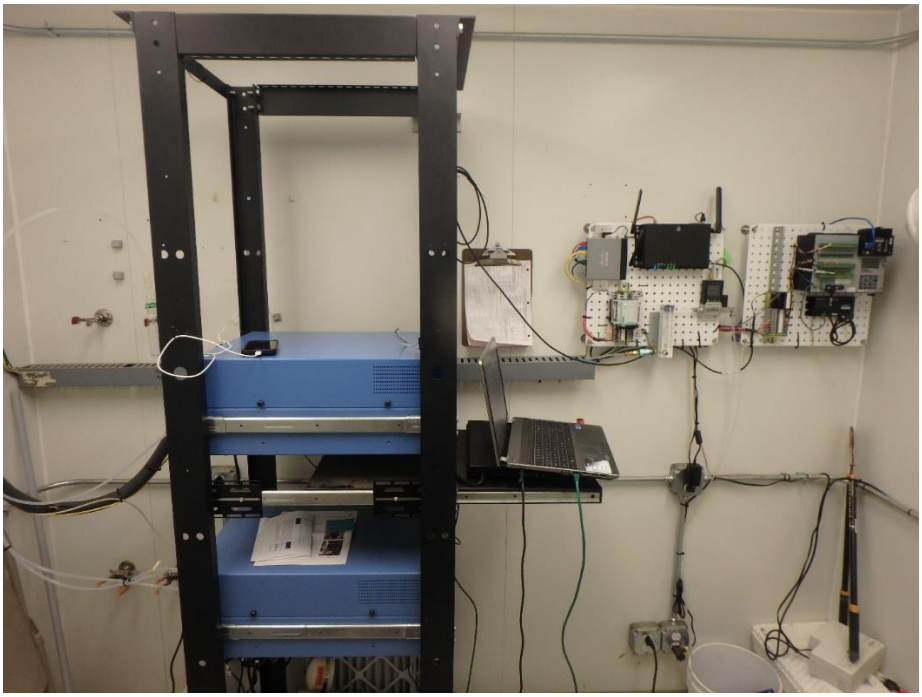
Figure 2 shows images of the typical configuration of a CASTNET site with the full suite of monitoring equipment including the temperature-controlled shelter and a 10-m tipping tower. The $O_3$ inlet is located within the rain shield at the top of the 10-m tipping tower which also houses the CASTNET filter pack. Ambient temperature is measured at every CASTNET site.

CASTNET $O_3$ analyzers, site transfer standards, data loggers, and computers are located within a temperature-controlled shelter. The datalogger can be operated remotely to run manual quality assurance (QC) checks, review status flags, or recover missing data. Each on-site transfer standard has been verified against a National Institute of Standards and Technology (NIST)-traceable Level II transfer standard.

*Figure 2. (a) CASTNET monitoring site*

*Pinedale, WY (PND165)*

*Figure 2. (b) Ozone instrumentation, PC, and data logger inside a CASTNET shelter*



*Palo Duro, TX (PAL190)*

F. Upgrading Ozone Monitoring Equipment

Most of the EPA-sponsored and many of the NPS-sponsored ozone analyzers CASTNET ozone analyzers (model: Thermo 49i) were purchased in 2010 or prior. The Thermo 49i ozone analyzers will no longer be supported by the manufacturer after 2026, therefore EPA is in the process of replacing the CASTNET ozone systems. Several Federal Reference Method (FRM)/Federal Equivalency Method (FEM) analyzers are commercially available. The EPA purchased two new commercially available FEM analyzers for testing within the ozone laboratory. EPA plans to procure new ozone analyzers for the EPA-sponsored sites by the end of FY2025 to replace the 49i analyzers and transfer standards. It is expected that all EPA-sponsored sites will be operating new analyzers by July 2026. EPA is working closely with the other CASTNET federal partners during the evaluation to try to maintain consistent ozone measurements across the network. The CASTNET program faces unique challenges including remote, high elevation sites, longer sample tubing to accommodate inlets at a height of 10 meters, and varying meteorological conditions.

CASTNET uses the monitoring quality objectives from the Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II, Appendix D (US EPA, 2017) to ensure that the highest quality data are being submitted to EPA's Air Quality System (AQS) database. On-going improvements to site equipment and infrastructure are posted to the individual CASTNET site information pages (https://www.epa.gov/castnet/castnet-site-locations).

Zero, span, and precision (ZSP) checks of the $O_3$ analyzer are performed daily. The precision check results are submitted to AQS quarterly by the CASTNET contractor(s). In addition to the daily ZSP QC checks, technicians perform semi-annual audits at each CASTNET site. During these semi-annual visits, technicians audit the on-site analyzer, reverify the on-site transfer standard, calibrate the on-site analyzer to the traveling transfer standard (Level 2) as needed, and verify the responses of the data logger and shelter temperature probe with NIST-traceable standards. All on-site $O_3$ transfer standards at CASTNET sites are NIST-traceable at Level 3. Audit results are used to perform the final validation on the hourly $O_3$ data and validated data are submitted to the sponsoring agency. As required by 40 CFR Part 58 Appendix A, an annual Performance Evaluation (PE) is conducted at each CASTNET $O_3$ site by an independent auditor. For most CASTNET sites the independent auditor is Environmental Engineering & Measurement Services (EE&MS); however, some states act as an independent auditor and perform PEs at CASTNET sites. The PE results are submitted to the CASTNET program and uploaded to AQS to comply with the regulations.

The validated hourly $O_3$ concentrations are submitted monthly to AQS by the sponsoring agency's contractor. Beyond the EPA, the NPS, and the Bureau of Land Management – Wyoming State Office, a subset of the CASTNET partners act as the principal quality assurance organizations (PQAOs) – a unique role where states and Tribes collect and own $O_3$ data at CASTNET sites. This subset includes Acadia National Park, ME (ACA416) submitted by Maine Department of Environmental Protection, Cherokee Nation, OK (CHE185) submitted by Cherokee Nation Clean Air Program, and Theodore Roosevelt National Monument, ND (THR422) submitted by North Dakota Department of Environmental Quality.

G. Network-Wide Changes

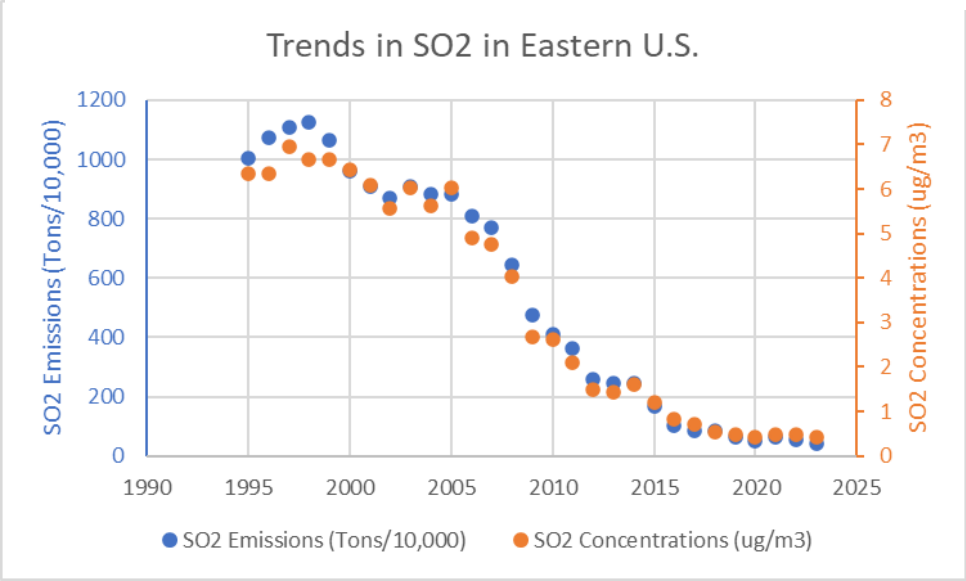
EPA is in the process of implementing network-wide changes to achieve cost-savings while reinvesting in the program to address the current data needs. Discontinuing the measurement and reporting of pollutants that are near the detection limit (e.g., filter pack measurements of $SO_2$) or can be retrieved from other networks (e.g., NCore) will allow the CASTNET program to add foster new partnerships to fill

spatial data gaps and add new measurements that align with current policy questions (e.g., adding $PM_{2.5}$ measurements).

1. Adjustments to the Pollutants Reported

EPA suspended $SO_2$ concentration measurements in July 2024 at most CASTNET sites. Currently, CASTNET sites on Tribal lands, sites sponsored by NY Department of Environmental Conservation, and the Indian River Lagoon Council continue to monitor $SO_2$ concentrations. While $SO_2$ continues to be an important component of dry deposition and acidification of sensitive ecosystems, the concentrations are < 1 µg/m$^3$, a decrease of 95% since 1990 (Figure 3). Maintaining $SO_2$ measurements at select sites will provide spatial coverage for model validation and trends. The cost-savings achieved by discontinuing $SO_2$ measurements will be re-invested to maintain existing sites. The NPS-sponsored CASTNET sites discontinued $SO_2$ measurements in August 2022 as a cost-savings effort to prevent site closures. Currently, 19 CASTNET sites continue to measure filter pack $SO_2$.

*Figure 3 Trends in EGU $SO_2$ emissions and $SO_2$ concentrations as measured by Eastern U.S. CASTNET sites from 1995 - 2023.*




In May 2022, EPA discontinued NOy measurements at four sites: Pinedale, WY (PND165), Huntington Wildlife Forest, NY (HWF187), Pisgah National Forest, NC (PNF126), and Rocky Mountain National Park, CO (ROM206). Trace gas measurements, including NOy continue at the Bondville, IL (BVL130) CASTNET site, which is also part of the EPA's NCore ("National Core") multipollutant monitoring network. The NOy analyzers from the four CASTNET sites will be or were repurposed for research studies targeting specific air quality issues. For example, an NO/NOy system was installed at Santee Sioux, NE (SAN192) and Stockton, IN (STK138) to evaluate ozone and PM pollution transport into the Great Lakes area. The $NO_y$ analyzers at Stockton, IN (STK138) and Duke Forest, NC (DUK008) have been converted to an "enhanced" $NO_y$ analyzer which includes a heated stainless steel converter ($TN_x$), Light Emitting Diode (LED) converter ($NO_2$) and molybdenum converter ($NO_y$) followed by a sodium chloride denuder (NOy - NOyMinus = $HNO_3$). The sample stream switches between each converter (or no converter for NO) to measure or calculate speciated reactive nitrogen, including $NO_y$, $NO_2$, $TN_x$, $NH_x$, NO, $HNO_3$ and $NO_z$.

EPA also discontinued filter pack measurements at Ann Arbor, MI (ANA115) and Penn State Fruit Research and Extension Station, PA (PSU106) in May 2022. EPA intends to keep these two sites as ozone/$PM_{2.5}$ sensor sites unless external resources are provided to resume filter pack sampling.

Most CASTNET sites are co-located with National Atmospheric Deposition Program (NADP) monitoring locations. The NADP provides data on air concentrations of ammonia and other toxics (e.g., mercury) and precipitation chemistry. NADP is evaluating a lower cost option for the passive samplers of ammonia measurements at NADP/Ammonia Monitoring Network (AMoN) sites which would allow the sponsoring agencies, including EPA, to add or sustain sites. The value of the ammonia concentrations provided by AMoN remains significant for evaluating trends, satellite validation, and source contributions to PM formation.

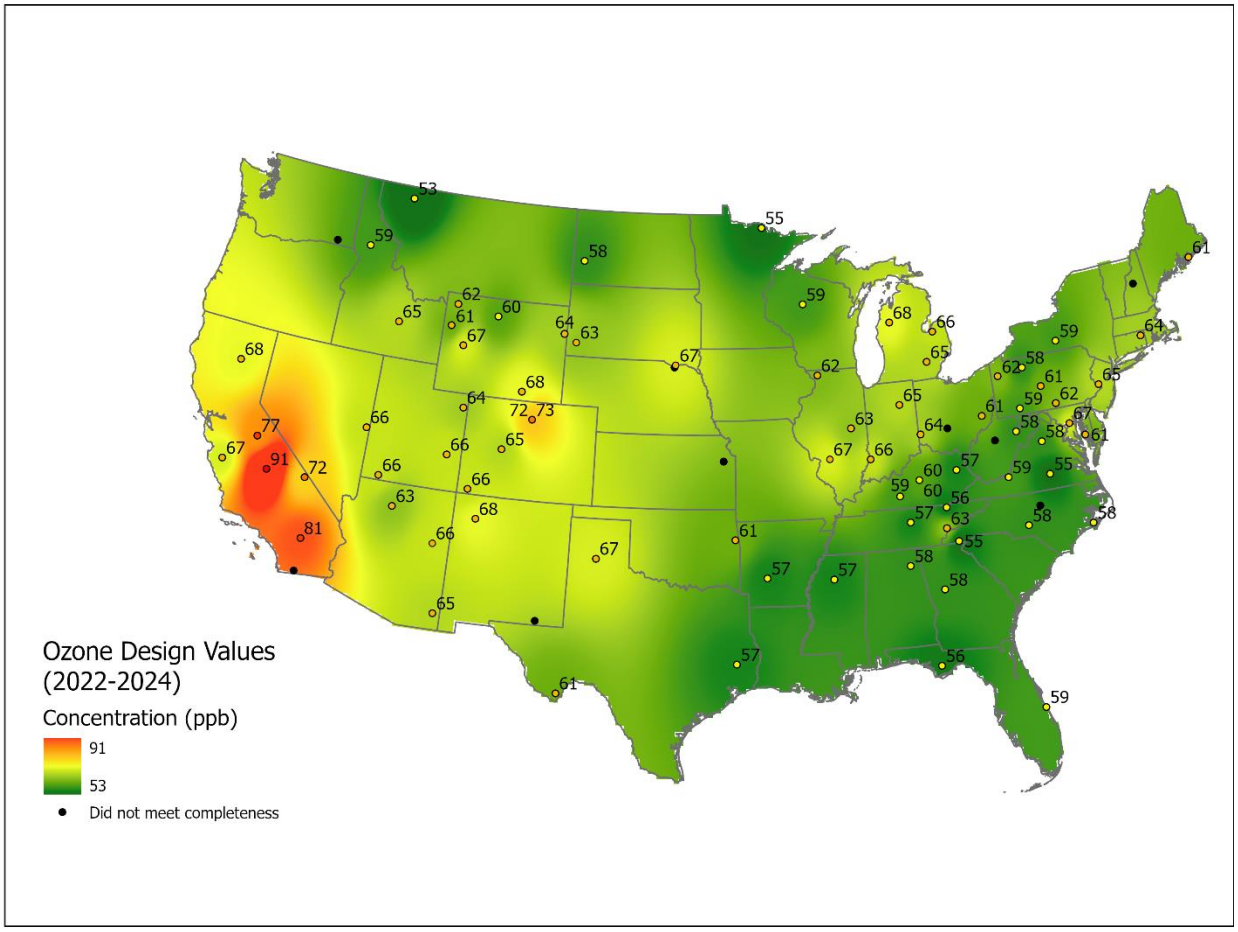
## 2. Monitoring Results

### A. Ambient Ozone Concentrations

CASTNET data provide an assessment tool for quantifying the improvements in air quality due to regional and national emission reduction programs (e.g., the NOx Budget Trading Program, Clean Air Interstate Rule, Cross State Air Pollution Rule, and the Cross State Air Pollution Rule Update).

CASTNET sites measure ambient $O_3$ concentrations for the entire year, which extends beyond the required $O_3$ season for many states. Ozone concentrations from CASTNET are used to gauge compliance with the primary ozone NAAQS. Design values are used to designate and classify nonattainment areas, as well as to assess progress towards meeting the NAAQS. The design values are based on the 3-year average of the fourth highest daily maximum 8-hour average. Figure 4 depicts the 2022-2024 fourth highest daily maximum 8-hour $O_3$ average for all sites that met the completeness criteria (40 CFR Part 50, Appendix U). Ozone concentrations are not included (shown as dots with no value) if the 3-year average was not available because of incomplete data. In this map, exceptional event-impacted data are not excluded. In 2022-2024, five sites exceeded the primary $O_3$ standard of 70 ppb.

*Figure 4. Map of 2022-2024 fourth highest daily maximum 8-hour ozone average*




B. <u>CASTNET and Non-CASTNET Ozone Monitors</u>

CASTNET ozone monitors are often located in rural locations away from large stationary emission sources (e.g., power plants, industry) providing information on interstate and international transport of pollution. To better understand the distribution of CASTNET ozone monitors among themselves and among the national ozone monitoring program, Voronoi polygons were constructed to determine the area served by each monitor. The Voronoi polygons are drawn for each CASTNET ozone monitor (Figure 5) and around each CASTNET ozone and non-CASTNET ozone monitor within the United States (Figure 6). Figure 5 illustrates the polygons defined only by CASTNET sites to represent the extent that each CASTNET monitor represents. Figure 6 displays the Voronoi polygons for each ozone monitor within the United States. In both Figures 5 and 6, the CASTNET monitors are color-coded by respective agency with the non-CASTNET ozone monitors displayed as gray open circles.

*Figure 5. Voronoi polygon areas defined by CASTNET ozone sites*

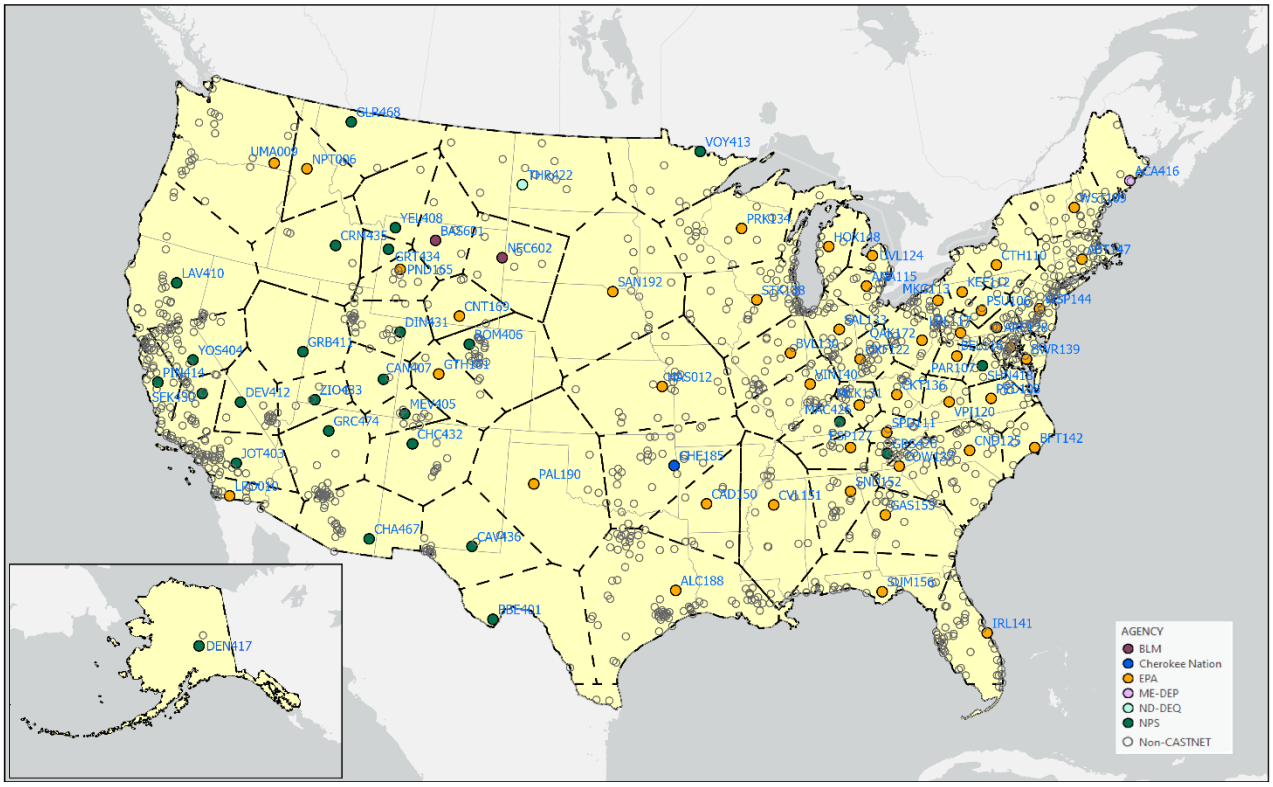
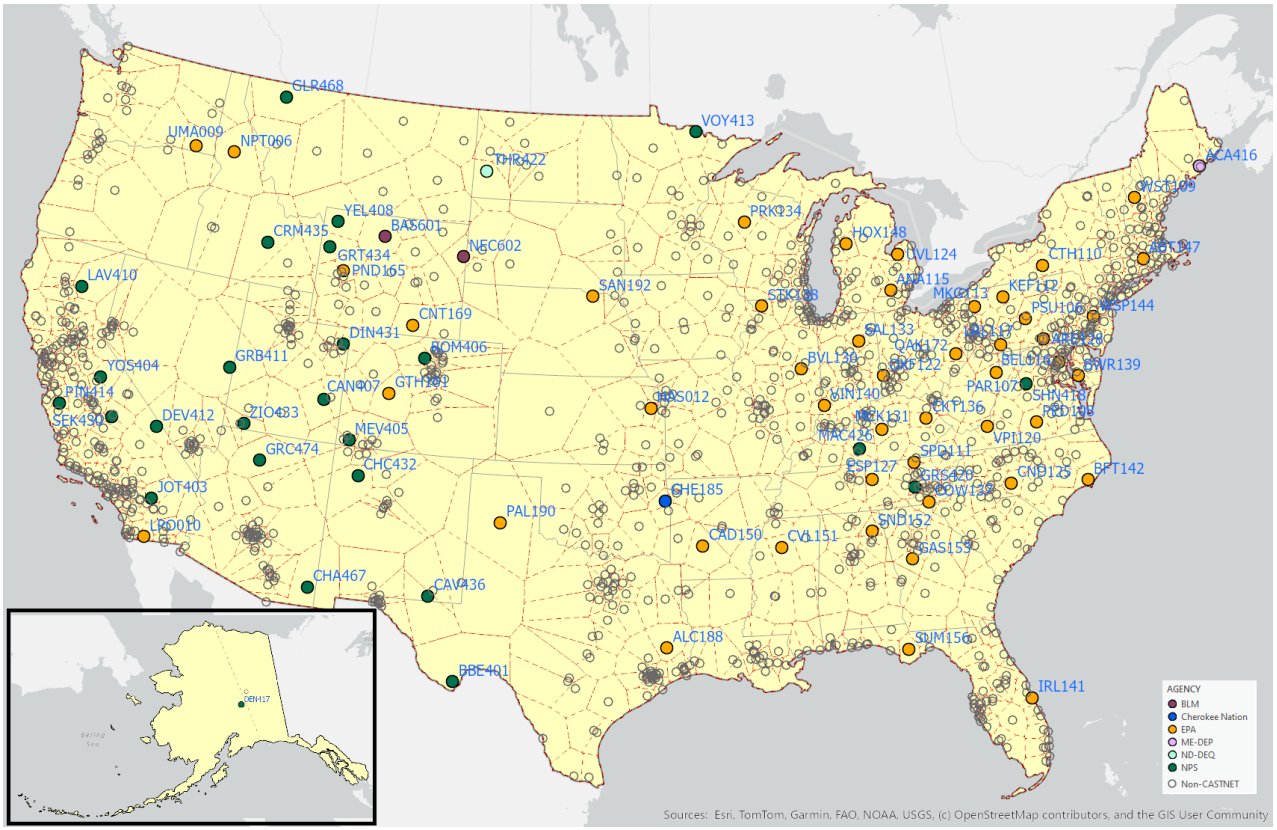



*Figure 6. Voronoi polygon areas defined by all ozone sites*



In Table 2 the geostatistical information, including polygon area in square kilometers and site rank from the Voronoi polygon maps shown in Figures 5 and 6 are displayed. The CASTNET area rank, site area rank, and area per site in CASTNET rank are ordered so that the largest polygons are ranked as first. The site quantity rank is ordered so that the CASTNET polygon containing the fewest non-CASTNET sites are ranked as first. Both rankings highlight the CASTNET's unique position to fill in large spatial monitoring gaps within the United States. Conversely, sites with higher numerical rankings, while located in relatively rural settings, are often used to encompass air quality control regions consistent with 40 CFR Part 81, section 12 of the Clean Air Act.

*Table 2. Voronoi Polygon Geostatistical Information*

| Site ID | EPA Region | Agency | AQS ID | POC | Site Area (km2) | Site Area Rank | CASTNET Area (km2) | CASTNET Area Rank | Site Qty | Site Qty Rank | Area Per Site in CASTNET Area (km2) | Area Per Site in CASTNET Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ABT147 | 1 | EPA | 090159991 | 1 | 1,671 | 73 | 55,299 | 49 | 40 | 73 | 1,383 | 73 |
| ACA416 | 1 | ME-DEP | 230090103 | 1 | 2,266 | 69 | 69,534 | 43 | 9 | 31 | 7,726 | 32 |
| WST109 | 1 | EPA | 330099991 | 1 | 4,064 | 57 | 86,648 | 37 | 20 | 55 | 4,332 | 51 |
| WSP144 | 2 | EPA | 340219991 | 1 | 748 | 77 | 48,806 | 56 | 44 | 76 | 1,109 | 76 |
| CTH110 | 2 | EPA | 361099991 | 1 | 7,791 | 40 | 81,078 | 40 | 12 | 38 | 6,757 | 38 |
| BWR139 | 3 | EPA | 240199991 | 1 | 3,776 | 60 | 24,528 | 71 | 6 | 24 | 4,088 | 54 |
| BEL116 | 3 | EPA | 240339991 | 1 | 379 | 78 | 16,159 | 78 | 22 | 58 | 735 | 77 |
| ARE128 | 3 | EPA | 420019991 | 1 | 883 | 76 | 20,983 | 75 | 12 | 38 | 1,749 | 72 |
| PSU106 | 3 | EPA | 420279991 | 1 | 2,570 | 67 | 21,368 | 74 | 3 | 11 | 7,123 | 35 |
| KEF112 | 3 | EPA | 420479991 | 1 | 10,281 | 30 | 27,939 | 67 | 2 | 9 | 13,970 | 23 |
| MKG113 | 3 | EPA | 420859991 | 1 | 4,542 | 55 | 26,862 | 70 | 22 | 58 | 1,221 | 75 |
| LRL117 | 3 | EPA | 421119991 | 1 | 1,954 | 71 | 20,666 | 76 | 11 | 37 | 1,879 | 71 |
| VPI120 | 3 | EPA | 510719992 | 1 | 6,042 | 45 | 50,377 | 53 | 4 | 14 | 12,594 | 24 |
| SHN418 | 3 | NPS | 511130003 | 1 | 3,467 | 62 | 23,678 | 73 | 5 | 21 | 4,736 | 49 |
| PED108 | 3 | EPA | 511479991 | 1 | 10,267 | 31 | 48,933 | 55 | 9 | 31 | 5,437 | 45 |
| PAR107 | 3 | EPA | 540939991 | 1 | 11,511 | 28 | 24,248 | 72 | 1 | 2 | 24,248 | 14 |
| SND152 | 4 | EPA | 010499991 | 1 | 3,752 | 61 | 77,663 | 41 | 15 | 47 | 5,178 | 47 |
| IRL141 | 4 | EPA | 120619991 | 1 | 1,777 | 72 | 90,639 | 33 | 43 | 75 | 2,108 | 69 |
| SUM156 | 4 | EPA | 120779991 | 1 | 6,875 | 43 | 125,452 | 24 | 17 | 50 | 7,380 | 33 |
| GAS153 | 4 | EPA | 132319991 | 1 | 5,849 | 46 | 119,593 | 26 | 17 | 50 | 7,035 | 36 |
| MAC426 | 4 | NPS | 210610501 | 1 | 5,079 | 49 | 46,010 | 59 | 5 | 21 | 9,202 | 30 |
| CKT136 | 4 | EPA | 211759991 | 1 | 5,292 | 47 | 44,644 | 62 | 9 | 31 | 4,960 | 48 |
| MCK131 | 4 | EPA | 212299991 | 1 | 4,686 | 54 | 28,313 | 66 | 12 | 38 | 2,359 | 66 |
| CVL151 | 4 | EPA | 281619991 | 1 | 13,726 | 25 | 214,570 | 9 | 14 | 43 | 15,326 | 21 |
| BFT142 | 4 | EPA | 370319991 | 1 | 9,114 | 33 | 43,680 | 63 | 4 | 14 | 10,920 | 26 |
| COW137 | 4 | EPA | 371139991 | 1 | 4,006 | 58 | 54,563 | 50 | 17 | 50 | 3,210 | 61 |
| CND125 | 4 | EPA | 371239991 | 1 | 6,078 | 44 | 107,668 | 27 | 28 | 66 | 3,845 | 55 |
| GRS420 | 4 | NPS | 470090101 | 1 | 1,301 | 75 | 17,055 | 77 | 6 | 24 | 2,843 | 63 |
| SPD111 | 4 | EPA | 470259991 | 1 | 2,872 | 65 | 29,678 | 65 | 5 | 21 | 5,936 | 41 |
| ESP127 | 4 | EPA | 470419991 | 1 | 10,196 | 32 | 40,786 | 64 | 7 | 27 | 5,827 | 42 |
| BVL130 | 5 | EPA | 170191001 | 1 | 3,886 | 59 | 96,410 | 30 | 32 | 70 | 3,013 | 62 |

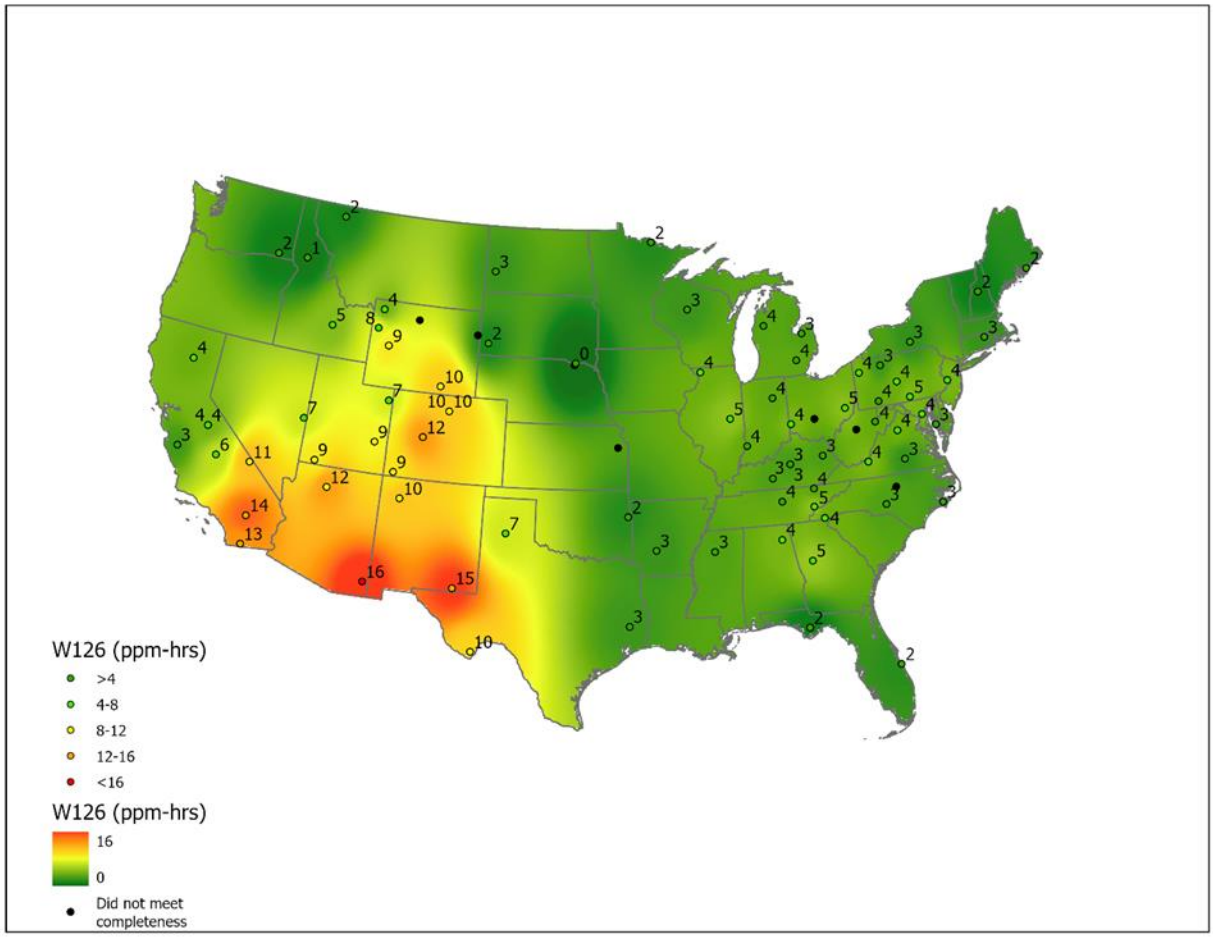
| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STK138 | 5 | EPA | 170859991 | 1 | 8,535 | 37 | 155,349 | 15 | 46 | 77 | 3,377 | 58 |
| VIN140 | 5 | EPA | 180839991 | 1 | 4,968 | 50 | 90,860 | 32 | 22 | 58 | 4,130 | 53 |
| SAL133 | 5 | EPA | 181699991 | 1 | 4,701 | 52 | 53,577 | 51 | 26 | 64 | 2,061 | 70 |
| UVL124 | 5 | EPA | 261579991 | 1 | 7,019 | 42 | 27,084 | 69 | 4 | 14 | 6,771 | 37 |
| ANA115 | 5 | EPA | 261619991 | 1 | 3,062 | 63 | 45,390 | 60 | 14 | 43 | 3,242 | 60 |
| HOX148 | 5 | EPA | 261659991 | 1 | 4,698 | 53 | 75,930 | 42 | 18 | 54 | 4,218 | 52 |
| VOY413 | 5 | NPS | 271370034 | 1 | 13,068 | 26 | 152,990 | 16 | 8 | 28 | 19,124 | 17 |
| OXF122 | 5 | EPA | 390179991 | 1 | 2,110 | 70 | 48,321 | 57 | 20 | 55 | 2,416 | 65 |
| QAK172 | 5 | EPA | 391219991 | 1 | 5,263 | 48 | 52,493 | 52 | 16 | 49 | 3,281 | 59 |
| PRK134 | 5 | EPA | 551199991 | 1 | 12,573 | 27 | 177,388 | 11 | 17 | 50 | 10,435 | 27 |
| CAD150 | 6 | EPA | 050199991 | 1 | 19,621 | 22 | 125,982 | 23 | 8 | 28 | 15,748 | 20 |
| CAV436 | 6 | NPS | 350150010 | 1 | 34,020 | 11 | 162,593 | 13 | 13 | 42 | 12,507 | 25 |
| CHC432 | 6 | NPS | 350450020 | 1 | 31,889 | 12 | 143,628 | 21 | 8 | 28 | 17,954 | 18 |
| CHE185 | 6 | Cherokee Nation | 400019009 | 1 | 4,740 | 51 | 195,679 | 10 | 30 | 69 | 6,523 | 39 |
| BBE401 | 6 | NPS | 480430101 | 1 | 55,005 | 6 | 148,751 | 19 | 1 | 2 | 148,751 | 3 |
| ALC188 | 6 | EPA | 483739991 | 1 | 17,676 | 23 | 330,135 | 3 | 75 | 78 | 4,402 | 50 |
| PAL190 | 6 | EPA | 483819991 | 1 | 105,608 | 2 | 342,123 | 2 | 4 | 14 | 85,531 | 7 |
| HAS012 | 7 | EPA | 200459991 | 1 | 4,134 | 56 | 269,332 | 8 | 29 | 68 | 9,287 | 29 |
| SAN192 | 7 | EPA | 311079992 | 1 | 66,312 | 4 | 330,076 | 4 | 14 | 43 | 23,577 | 15 |
| GTH161 | 8 | EPA | 080519991 | 1 | 22,467 | 18 | 86,954 | 36 | 3 | 11 | 28,985 | 10 |
| ROM406 | 8 | NPS | 080690007 | 1 | 9,099 | 34 | 150,800 | 17 | 21 | 57 | 7,181 | 34 |
| MEV405 | 8 | NPS | 080830101 | 1 | 1,499 | 74 | 47,621 | 58 | 9 | 31 | 5,291 | 46 |
| GLR468 | 8 | NPS | 300298001 | 1 | 42,411 | 8 | 127,522 | 22 | 1 | 2 | 127,522 | 4 |
| THR422 | 8 | ND-DEQ | 380070002 | 1 | 28,174 | 15 | 280,639 | 6 | 10 | 36 | 28,064 | 11 |
| CAN407 | 8 | NPS | 490370101 | 1 | 16,386 | 24 | 65,433 | 45 | 2 | 9 | 32,717 | 9 |
| DIN431 | 8 | NPS | 490471002 | 1 | 8,573 | 36 | 83,788 | 38 | 23 | 62 | 3,643 | 57 |
| ZIO433 | 8 | NPS | 490530130 | 1 | 7,948 | 39 | 63,111 | 46 | 4 | 14 | 15,778 | 19 |
| CNT169 | 8 | EPA | 560019991 | 1 | 22,671 | 17 | 69,483 | 44 | 3 | 11 | 23,161 | 16 |
| BAS601 | 8 | BLM | 560030002 | 1 | 21,312 | 19 | 99,738 | 29 | 4 | 14 | 24,935 | 12 |
| PND165 | 8 | EPA | 560359991 | 1 | 8,070 | 38 | 57,423 | 48 | 9 | 31 | 6,380 | 40 |
| GRT434 | 8 | NPS | 560390008 | 1 | 19,934 | 21 | 27,515 | 68 | 0 | 1 | | |
| YEL408 | 8 | NPS | 560391011 | 1 | 40,796 | 10 | 99,840 | 28 | 1 | 2 | 99,840 | 5 |
| NEC602 | 8 | BLM | 560450003 | 1 | 11,379 | 29 | 149,049 | 18 | 6 | 24 | 24,842 | 13 |
| CHA467 | 9 | NPS | 040038001 | 1 | 42,037 | 9 | 143,642 | 20 | 26 | 64 | 5,525 | 44 |
| GRC474 | 9 | NPS | 040058001 | 1 | 30,188 | 14 | 122,714 | 25 | 15 | 47 | 8,181 | 31 |
| DEV412 | 9 | NPS | 060270101 | 1 | 20,466 | 20 | 81,196 | 39 | 14 | 43 | 5,800 | 43 |
| YOS404 | 9 | NPS | 060430003 | 1 | 8,726 | 35 | 91,307 | 31 | 34 | 71 | 2,686 | 64 |
| PIN414 | 9 | NPS | 060690003 | 1 | 2,384 | 68 | 50,222 | 54 | 37 | 72 | 1,357 | 74 |
| JOT403 | 9 | NPS | 060719002 | 1 | 7,779 | 41 | 90,630 | 34 | 41 | 74 | 2,211 | 68 |
| LPO010 | 9 | EPA | 060739991 | 1 | 3,032 | 64 | 44,654 | 61 | 12 | 38 | 3,721 | 56 |
| LAV410 | 9 | NPS | 060893003 | 1 | 31,798 | 13 | 277,051 | 7 | 28 | 66 | 9,895 | 28 |
| SEK430 | 9 | NPS | 061070009 | 1 | 2,863 | 66 | 58,427 | 47 | 25 | 63 | 2,337 | 67 |
| GRB411 | 9 | NPS | 320330101 | 1 | 82,378 | 3 | 160,920 | 14 | 1 | 2 | 160,920 | 2 |
| DEN417 | 10 | NPS | 020680003 | 1 | 1,087,445 | 1 | 1,723,337 | 1 | 1 | 2 | 1,723,337 | 1 |
| CRM435 | 10 | NPS | 160230101 | 1 | 55,807 | 5 | 169,859 | 12 | 4 | 14 | 42,465 | 8 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NPT006 | 10 | EPA | 160499991 | 1 | 42,516 | 7 | 90,198 | 35 | 1 | 2 | 90,198 | 6 |
| UMA009 | 10 | EPA | 530139991 | 1 | 24,845 | 16 | 320,339 | 5 | 22 | 58 | 14,561 | 22 |

C. W126

CASTNET also provides a unique dataset for evaluating the secondary NAAQS, which protect against vegetation-related effects and other deleterious impacts to public welfare. The secondary $O_3$ NAAQS is currently set equal to the primary NAAQS. While the secondary NAAQS is currently set equal to the primary NAAQS, the W126 index is often used to relate vegetation loses, such as reduced crop yield, foliar injury, and decreased biomass accumulation, with $O_3$ exposure. The W126 index is a cumulative metric that sums weighted hourly $O_3$ concentrations during the $O_3$ season. The W126 is reported as the maximum weighted monthly average during three consecutive months in the growing season when daytime $O_3$ concentrations are the highest and plant growth is most likely to be affected. CASTNET sites are located in rural areas and often in sensitive ecosystems where vegetation related effects are significant. Figure 7 shows the W126 values from CASTNET sites in 2024.

*Figure 7. Maximum W126 value for 2024*



D. Ozone Trends

For reporting long-term regional trends, CASTNET sites are labeled as “western” or “eastern” depending on whether they are west or east of 100 degrees west longitude (Figure 8). Eastern long-term sites have been operating since at least 1990, while Western long-term sites have been operating since at least 1996.

*Figure 8. CASTNET Western and Eastern Reference Sites*

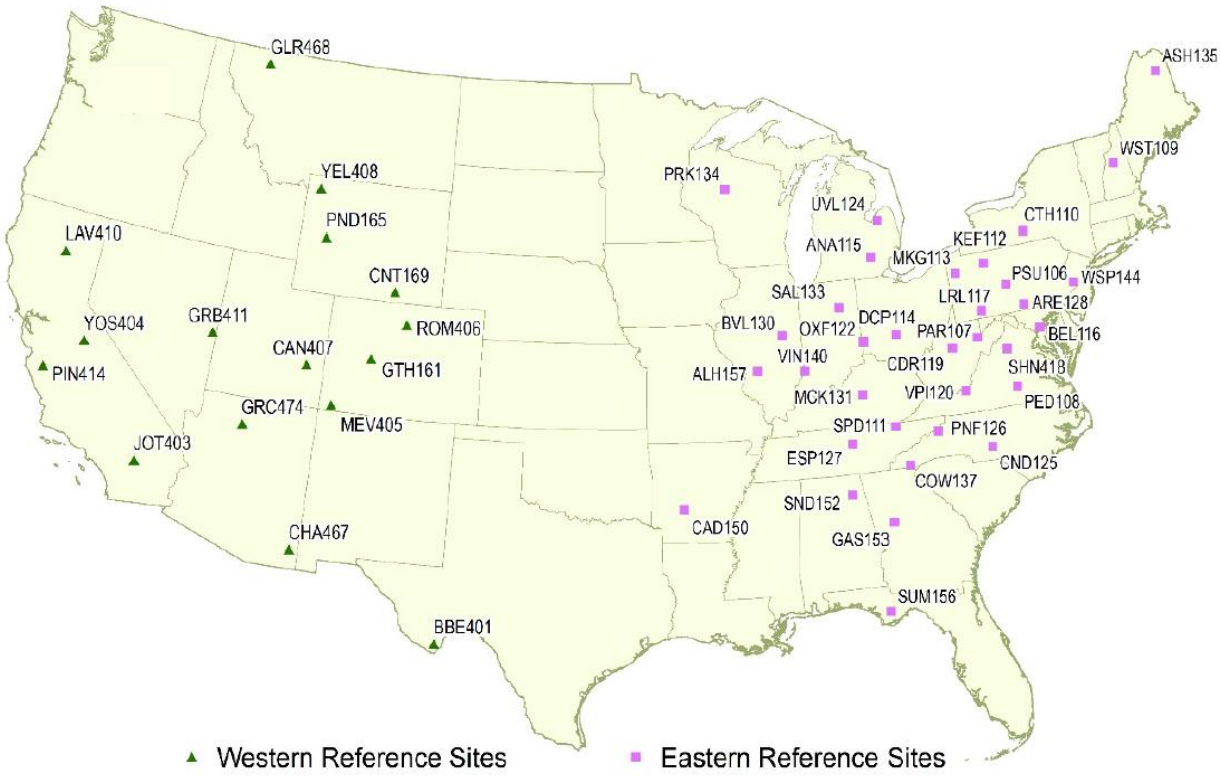
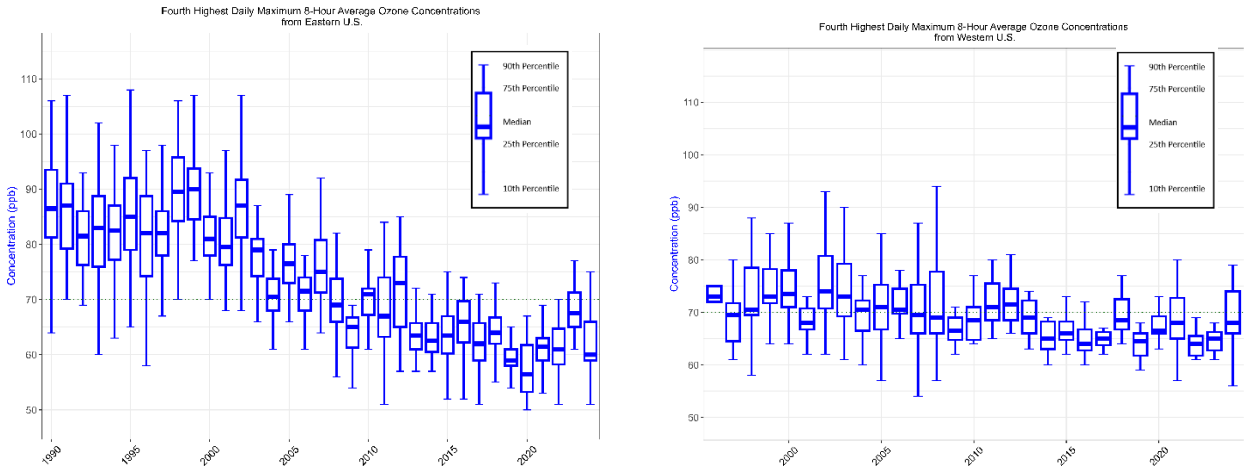



Figure 9 shows the trends in ambient fourth highest eight hour daily maximum $O_3$ concentrations from 1990-2024 (eastern sites) and 1996-2024 (western sites). The fourth highest eight hour daily maximum $O_3$ data from the 34 Eastern reference sites show substantial reductions in concentrations since 2002. The Eastern reference sites realized a 23% reduction between 2000-2002 and 2022-2024. The median fourth highest daily maximum 8-hour average between 2022–2024 for the Eastern reference sites was 63 ppb. The western reference sites do not show the same dramatic reductions in $O_3$ concentrations. There was a 10% reduction in $O_3$ concentrations as measured by the Western reference sites between 2000-2002 and 2022-2024. During the most recent 3-year period (2022–2024), the median fourth highest daily maximum 8-hour average was 65 ppb at the 16 western reference sites.

*Figure 9. Annual trends in fourth highest eight hour daily maximum ozone concentrations from the eastern (right) and western (left) CASTNET sites.*




## 3. Quality assurance

### A. Overview

The purpose of the CASTNET quality assurance (QA) program is to ensure that all reported data are of known and documented quality to meet the CASTNET objectives and to be reproducible and comparable with data from other monitoring networks. The CASTNET QA program is managed by an independent QA Manager and Project QA Supervisor. The QA manager routinely performs internal systems audits, reviews concentration and audit data, and prepares QA reports to management.

The CASTNET QAPP revision 10.2 (WSP, 2025) is comprehensive and covers all aspects of the monitoring program. The QAPP is reviewed and updated by the contractor annually. Details on field, data, and laboratory operations, training, SOPs, system audits, and reporting are examples of information that can be found in the QAPP (Documents & Reports | US EPA).

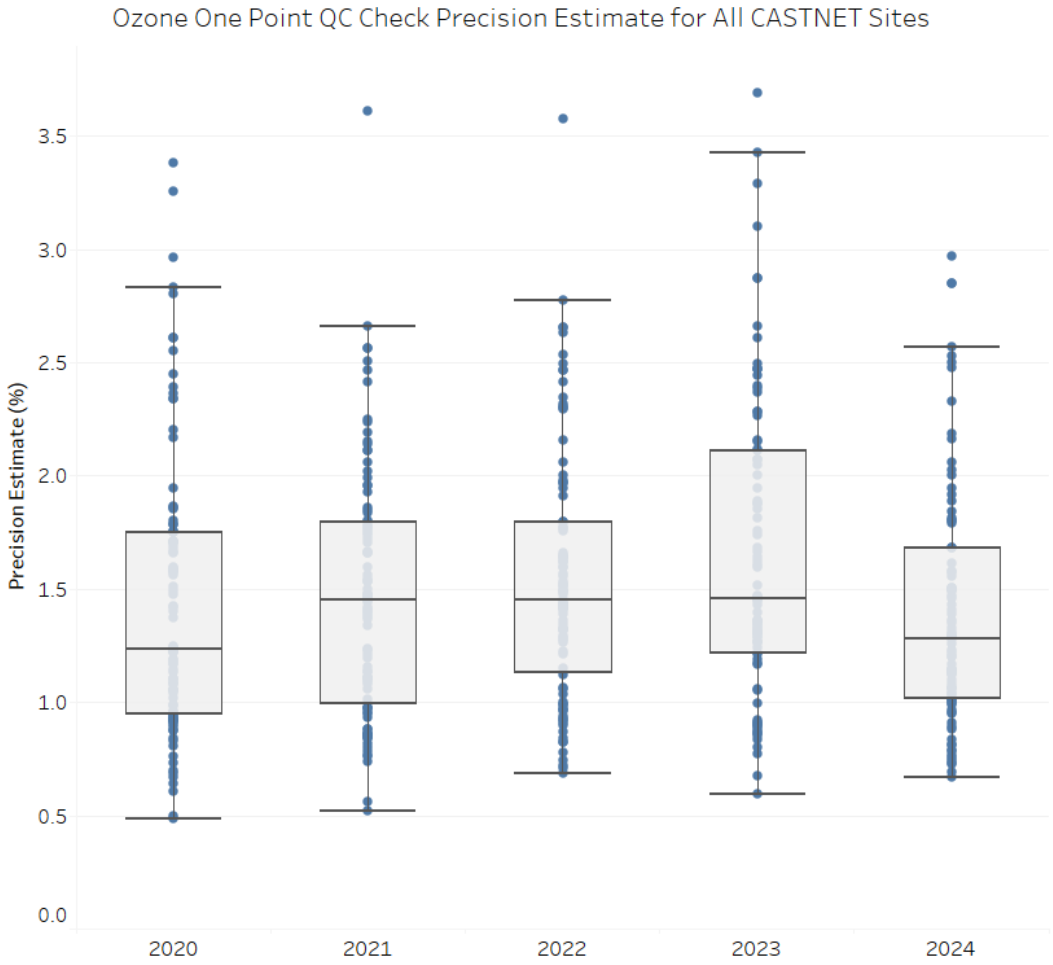
CASTNET data quality indicators including precision, accuracy, bias, and completeness are reported by the AMP256 QA Data Quality Indicator Report made available from the U.S. EPA Office of Air Quality Planning and Standards' (OAQPS) Air Quality System (AQS). The AMP256 report provides annual summaries of 1-point QC check and PE audit results to determine whether each analyzer being used for comparison against the NAAQS meets the precision, accuracy, bias, and completeness requirements from 40 CFR Part 58 Appendix A.

### B. Precision

Ozone precision is reported as the 90 percent confidence limit (CL) of the coefficient of variation (CV) as measured by the 1-point QC checks (40 CFR Part 58, Appendix A 4.1.2). The 1-pt QC check is the difference between a known $O_3$ concentration and the response of the $O_3$ analyzer. For a site to meet the acceptance criterion, the 90% CL of the CV must be ≤ 7.1%. The analyzer is challenged with 60 ppb of $O_3$ during the daily 1-point QC check, which is considered representative of the ambient concentrations measured within the network. Results from the 1-point QC checks are loaded into AQS quarterly. Additional data review is required for sites that do not meet the 7.1% criterion. Figure 10

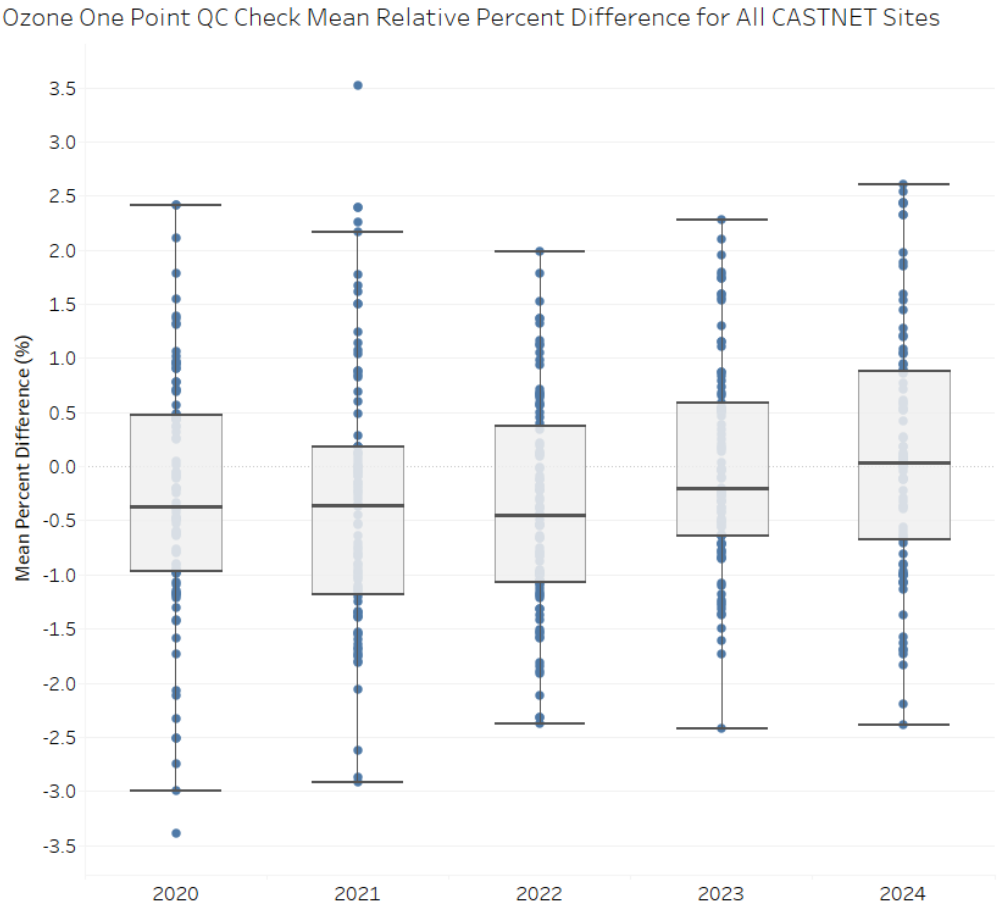
reports the precision estimates for all CASTNET sites from 2020 to 2024 in the form of box plots from the AMP256 report. In 2020 to 2024 all sites met the 7.1% acceptance criterion. The annual medians of the mean precision estimate values for 2020, 2021, 2022, 2023, and 2024 were +1.236, +1.451, +1.455, +1.458, and +1.282 ppb, respectively.

*Figure 10. Box Plot showing all CASTNET ozone precision estimates for 2020-2024. The median values (line) are shown for each year.*




Precision may also be estimated as the relative percent difference (RPD) between the expected concentration and the analyzer response. Figure 11 shows the annual RPD for all CASTNET sites using the 1-point QC checks from the AMP256 report. The annual medians of the mean RPD values for 2020, 2021, 2022, 2023, and 2024 were -0.372, -0.359, -0.447, -0.200, and +0.038 ppb, respectively.

*Figure 11. Relative percent difference between expected response and analyzer response for the 1-point QC checks at all CASTNET sites. The median values (line) are shown for each year.*




C. Bias

The bias estimate is also calculated using results from the 1-point QC checks. A site is required to meet a 95 percent CL of the absolute bias estimate (40 CFR Part 58 App A sec 4.1.3). A site meets the acceptance criterion if the absolute bias is ≤ 7.1%.

A positive or negative direction is assigned to the bias estimate when the signs of both the 25$^{th}$ and 75$^{th}$ percentiles of the percent differences for each site are in the same direction. No direction is assigned if the percentiles are of different signs. Signed bias results, by site, for 2020 through 2024 are shown in Table 3. Sites have orange font if the bias estimate was positive, blue font if the bias estimate was negative, and black font if the bias estimate had no sign. Each site met the 7.1% acceptance criterion for 2020 through 2024. Table 3 reports 1-point QC check bias results evaluated from the AMP256 report.

*Table 3. The bias estimate calculated from one-point QC checks for 2020 through 2024.*

## Ozone One Point QC Bias for Each CASTNET Site

| AQS Site POC | Site ID | YEAR 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|
| 09-015-9991-1 | ABT147 | 1.701 | 0.626 | 1.276 | 3.224 | 1.079 |
| 23-009-0103-1 | ACA416 | 2.170 | 1.575 | 1.532 | 1.148 | 1.011 |
| 48-373-9991-1 | ALC188 | 1.507 | 2.520 | 2.119 | 1.100 | 2.139 |
| 17-119-9991-1 | ALH157 | 1.302 | 1.342 | 1.517 | | |
| 26-161-9991-1 | ANA115 | 1.461 | 1.929 | 2.691 | 2.383 | 2.216 |
| 42-001-9991-1 | ARE128 | 2.113 | 1.412 | 1.545 | 1.818 | 1.126 |
| 23-003-9991-1 | ASH135 | 0.790 | 1.594 | 2.036 | | |
| 56-003-0002-1 | BAS601 | 1.058 | 0.671 | 0.778 | 0.674 | 0.591 |
| 48-043-0101-1 | BBE401 | 0.971 | 0.982 | 1.629 | 1.904 | 2.042 |
| 24-033-9991-1 | BEL116 | 1.329 | 1.334 | 1.160 | 0.699 | 1.490 |
| 37-031-9991-1 | BFT142 | 1.207 | 1.356 | 1.951 | 3.556 | 1.472 |
| 17-019-1001-1 | BVL130 | 1.698 | 2.786 | 2.165 | 2.032 | 1.369 |
| 24-019-9991-1 | BWR139 | 1.387 | 1.550 | 1.861 | 1.486 | 1.255 |
| 05-019-9991-1 | CAD150 | 2.039 | 2.126 | 2.461 | 3.177 | 1.171 |
| 49-037-0101-1 | CAN407 | 0.992 | 1.699 | 2.194 | 1.319 | 1.186 |
| 35-015-0010-1 | CAV436 | | 0.695 | 1.138 | 0.957 | 1.029 |
| 54-021-9991-1 | CDR119 | 1.663 | 1.694 | 1.259 | | |
| 21-221-9991-1 | CDZ171 | 1.129 | 1.058 | 0.906 | | |
| 04-003-8001-1 | CHA467 | 1.445 | 1.292 | 1.277 | 1.883 | 2.595 |
| 35-045-0020-1 | CHC432 | 1.492 | 1.444 | 2.059 | 1.874 | 0.733 |
| 40-001-9009-1 | CHE185 | 3.229 | 1.824 | 1.562 | 2.088 | 1.627 |
| 21-175-9991-1 | CKT136 | 0.736 | 0.546 | 0.779 | 0.944 | 0.976 |
| 37-123-9991-1 | CND125 | 1.218 | 1.471 | 2.207 | 2.276 | 1.358 |
| 56-001-9991-1 | CNT169 | 0.674 | 0.652 | 1.106 | 1.634 | 1.065 |
| 37-113-9991-1 | COW137 | 1.609 | 1.156 | 1.066 | 1.239 | 1.495 |
| 16-023-0101-1 | CRM435 | 1.707 | 0.895 | 1.121 | 1.264 | 2.198 |
| 36-109-9991-1 | CTH110 | 2.180 | 3.603 | 1.311 | 1.151 | 1.217 |
| 28-161-9991-1 | CVL151 | 1.147 | 0.779 | 1.785 | 1.792 | 2.081 |
| 39-047-9991-1 | DCP114 | 1.757 | 2.079 | 1.489 | | |
| 02-068-0003-1 | DEN417 | 1.180 | 1.678 | 2.024 | 0.982 | 0.734 |
| 06-027-0101-1 | DEV412 | 1.475 | 0.693 | 0.728 | 1.495 | 0.616 |
| 49-047-1002-1 | DIN431 | 2.212 | 2.895 | 1.908 | 1.715 | 0.950 |
| 47-041-9991-1 | ESP127 | 1.573 | 0.856 | 1.548 | 2.050 | 1.442 |
| 13-231-9991-1 | GAS153 | 2.749 | 3.406 | 3.114 | 1.660 | 1.517 |
| 30-029-8001-1 | GLR468 | 0.969 | 1.425 | 1.350 | 1.115 | 1.252 |
| 32-033-0101-1 | GRB411 | 1.601 | 2.079 | 2.209 | 0.731 | 1.041 |
| 04-005-8001-1 | GRC474 | 2.820 | 1.771 | 1.316 | 0.735 | 0.805 |
| 47-009-0101-1 | GRS420 | 0.504 | 0.918 | 1.480 | 1.843 | 1.616 |
| 56-039-0008-1 | GRT434 | 2.379 | 1.568 | 1.758 | 1.207 | 1.522 |
| 08-051-9991-1 | GTH161 | 1.602 | 1.413 | 1.492 | 2.011 | 2.362 |
| 26-165-9991-1 | HOX148 | 1.089 | 1.371 | 2.039 | 3.278 | 0.769 |
| 36-031-9991-1 | HWF187 | 1.589 | 2.486 | 2.149 | | |
| 12-061-9991-1 | IRL141 | 1.425 | 2.124 | 1.488 | 1.905 | 2.160 |
| 06-071-9002-1 | JOT403 | 0.564 | 0.801 | 1.289 | 0.546 | 0.582 |
| 42-047-9991-1 | KEF112 | 1.424 | 0.965 | 0.708 | 1.119 | 2.053 |

| AQS Site POC | Site ID | YEAR 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|
| 06-089-3003-1 | LAV410 | 1.976 | 1.721 | 1.533 | 0.703 | 0.605 |
| 06-073-9991-1 | LPO010 | | | | 1.469 | 0.855 |
| 42-111-9991-1 | LRL117 | 0.945 | 1.437 | 1.273 | 0.997 | 1.172 |
| 21-061-0501-1 | MAC426 | 0.793 | 1.313 | 0.751 | 1.632 | 0.550 |
| 21-229-9991-1 | MCK131 | 1.163 | 1.625 | 1.191 | 0.685 | 2.279 |
| 21-229-9991-2 | MCK231 | 0.798 | 0.573 | 0.722 | 1.535 | 1.241 |
| 08-083-0101-1 | MEV405 | 3.178 | 1.503 | 1.467 | 1.813 | 1.196 |
| 42-085-9991-1 | MKG113 | 1.341 | 2.329 | 1.215 | 1.661 | 1.562 |
| 56-045-0003-1 | NEC602 | 1.653 | 0.732 | 1.955 | 1.455 | 1.811 |
| 16-049-9991-1 | NPT006 | 2.767 | 2.044 | 1.209 | 1.575 | 1.536 |
| 39-017-9991-1 | OXF122 | 1.188 | 1.919 | 2.022 | 1.497 | 3.082 |
| 48-381-9991-1 | PAL190 | 0.903 | 1.581 | 1.675 | 1.737 | 1.034 |
| 54-093-9991-1 | PAR107 | 0.915 | 1.505 | 1.091 | 0.962 | 1.148 |
| 51-147-9991-1 | PED108 | 1.363 | 1.563 | 1.036 | 2.032 | 1.439 |
| 04-017-0119-1 | PET427 | 0.799 | 2.009 | 1.680 | 0.956 | |
| 06-069-0003-1 | PIN414 | 1.389 | 1.328 | 0.997 | 1.383 | 1.745 |
| 56-035-9991-1 | PND165 | 1.157 | 1.030 | 1.193 | 2.010 | 1.202 |
| 37-011-9991-1 | PNF126 | 1.008 | 0.870 | 0.756 | | |
| 55-119-9991-1 | PRK134 | 1.004 | 1.151 | 1.931 | 1.541 | 1.446 |
| 42-027-9991-1 | PSU106 | 0.544 | 1.990 | 1.415 | 1.650 | 2.943 |
| 39-121-9991-1 | QAK172 | 2.199 | 2.164 | 1.769 | 2.187 | 1.348 |
| 08-069-0007-3 | ROM206 | 1.657 | 2.052 | 1.528 | 2.130 | 1.300 |
| 08-069-0007-1 | ROM406 | 1.074 | 3.018 | 1.780 | 1.497 | 2.165 |
| 18-169-9991-1 | SAL133 | 1.211 | 0.551 | 0.586 | 0.715 | 0.726 |
| 31-107-9991-1 | SAN189 | 1.884 | 2.323 | 2.679 | 2.380 | 2.527 |
| 31-107-9992-1 | SAN192 | | | | | 1.894 |
| 06-107-0009-1 | SEK430 | 3.103 | 1.197 | 1.579 | 1.673 | 0.837 |
| 51-113-0003-1 | SHN418 | 3.533 | 2.986 | 1.607 | 0.938 | 0.538 |
| 01-049-9991-1 | SND152 | 0.927 | 0.924 | 3.393 | 1.484 | 1.633 |
| 47-025-9991-1 | SPD111 | 0.935 | 1.126 | 2.795 | 1.606 | 1.873 |
| 17-085-9991-1 | STK138 | 1.112 | 1.396 | 1.682 | 2.040 | 1.155 |
| 12-077-9991-1 | SUM156 | 2.265 | 2.242 | 1.286 | 1.907 | 2.452 |
| 38-007-0002-1 | THR422 | 2.882 | 2.812 | 2.269 | 2.209 | 2.719 |
| 53-013-9991-1 | UMA009 | 1.522 | 1.628 | 1.229 | 0.805 | 0.956 |
| 26-157-9991-1 | UVL124 | 1.621 | 1.260 | 1.140 | 1.380 | 1.460 |
| 18-083-9991-1 | VIN140 | 0.958 | 1.951 | 1.578 | 1.078 | 1.141 |
| 27-137-0034-1 | VOY413 | 0.706 | 1.342 | 0.906 | 2.314 | 1.330 |
| 51-071-9992-1 | VPI120 | 2.302 | 2.194 | 1.060 | 1.564 | 2.075 |
| 46-033-0132-3 | WNC429 | 0.436 | 0.851 | 1.746 | 2.171 | 3.307 |
| 34-021-9991-1 | WSP144 | 2.287 | 1.391 | 1.286 | 1.251 | 1.654 |
| 33-009-9991-1 | WST109 | 0.823 | 1.942 | 0.549 | 2.063 | 1.612 |
| 56-039-1011-1 | YEL408 | 1.815 | 1.534 | 1.002 | 1.781 | 1.539 |
| 06-043-0003-1 | YOS404 | 1.183 | 1.790 | 1.075 | 1.173 | 0.916 |
| 49-053-0130-1 | ZIO433 | 0.900 | 1.894 | 1.092 | 1.458 | 2.339 |

## D. Accuracy

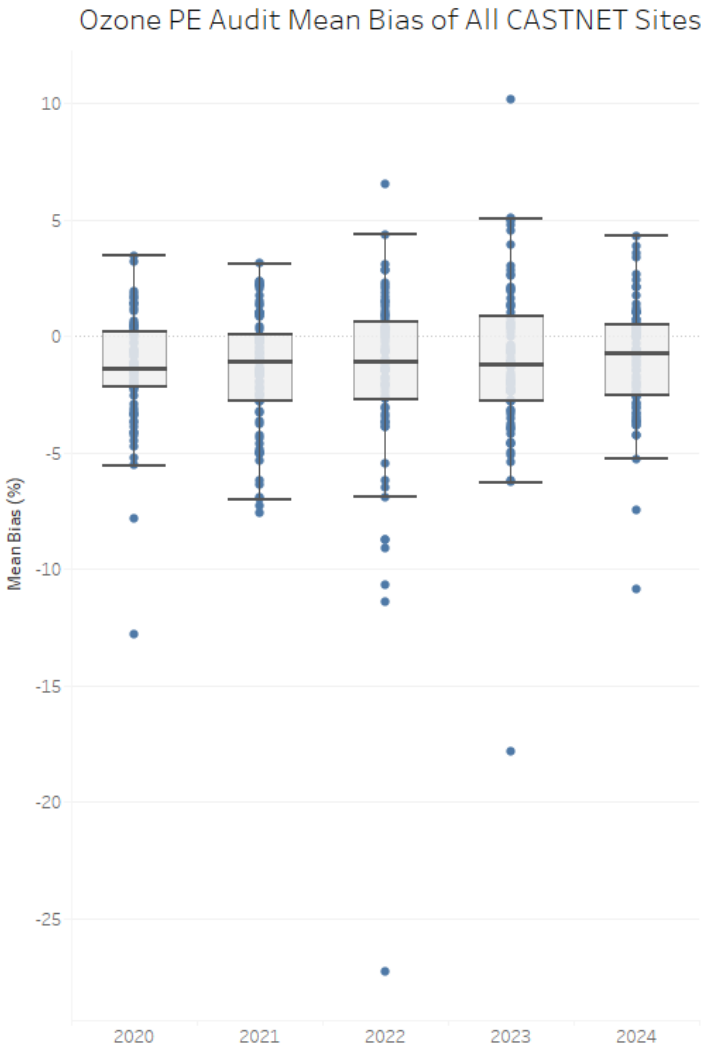
### 1. Semi-Annual Site Visits

Approximately every six months, technicians managed by the Field Operations Manager perform semi-annual performance checks to the on-site analyzer and reverify the on-site transfer standard, calibrate the on-site analyzer to the traveling transfer standard (Level 2) as needed, and verify the data logger and the shelter temperature probe using NIST traceable standards. These results are used to perform final validation on the hourly $O_3$ data.

2. Independent PE Results

The Audit Agency performs annual PEs in accordance with 40 CFR Part 58 Appendix A Section 3.2.2 and EPA's Quality Assurance Handbook for Air Pollution Measurement Systems: Volume II and submits these results to AQS on a quarterly basis (US EPA, 2017). The auditor is required to select audit levels that bracket 80 percent of the ambient data; however, the audit levels do not need to be consecutive. For levels 1 and 2 (which includes the range of 4 to 19 ppb), the acceptance criteria are ±1.5 ppb difference or ± 15.1 percent difference, whichever is greater. The acceptance criteria for levels 3 – 10 are ±15.1 percent difference. PE audit mean bias estimates from the AMP256 report are displayed in the box plots shown in Figure 12.

*Figure 12. Estimated Bias in $O_3$ concentrations from PE Audit Results for All CASTNET Sites for years 2020 through 2024*




The bias is estimated from the PE values for the years 2020 through 2024 and displayed in Figure 12 shows a consistent median low bias of approximately 1 ppb each year. The annual median values for all sites are within ±1.5% for all years.

### E. Completeness

Completeness is a measure of the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained under correct, normal conditions. For comparison with the NAAQS for a given 3-year period, a site must meet two completeness criteria: having at least 75 percent valid data for each of the three ozone seasons comprising the 3-year period and having at least 90 percent valid data for all three ozone seasons combined. For the 2022-2024 time period, 72 out of 77 (94 percent) CASTNET $O_3$ sites met both completeness criteria.

## 4. Precursor Measurements, Meteorology, and $PM_{2.5}$ Sensors

### A. $NO_y$ Monitoring

Reactive nitrogen compounds are precursors for both $O_3$ and $PM_{2.5}$ formation. Total reactive oxidized nitrogen ($NO_y$) is defined as $NO_x$ ($NO + NO_2$) plus $NO_z$ (PAN, $HNO_3$, $HNO_2$, PPN, other organic nitrates, and $NO_2^-$). EPA and NPS operate five trace-level continuous $NO_y$ analyzers at CASTNET sites (Figure 1). Great Smokies National Park, TN (GRS420) operated by NPS and Bondville, IL (BVL130) operated by EPA are also NCore stations. GRS420, TN and BVL130, IL also measure trace $SO_2$ and CO as part of the NCore suite of measurements. The $NO_y$ analyzers at Duke Forest, NC (DUK008) and Stockton, IL (STK138) have been converted to "enhanced" $NO_y$ analyzers which include a heated stainless steel converter ($TN_x$), Light Emitting Diode (LED) converter ($NO_x$) and molybdenum converter ($NO_x$) followed by a sodium chloride denuder. The sample stream switches between each converter (or no converter for NO) to measure or calculate speciated reactive nitrogen, including $NO_y$, $NO_2$, $NO_x$, $TN_x$, $NH_x$, NO, $HNO_3$ and $NO_z$.

Total reactive oxidized nitrogen ($NO_y$) is measured using a thermal molybdenum converter at the inlet to convert reactive nitrogen species to NO followed by the detection of NO by chemiluminescence. The EPA-sponsored CASTNET sites with trace $NO_y$ each have a Teledyne (API) T200U chemiluminescence analyzer, 701H zero air system, and a T700U multi-gas calibrator in addition to the typical suite of CASTNET equipment (e.g., data logger, ozone analyzer, etc.).

Trace $NO_y$ is audited twice per year by the CASTNET contractor and audited once every other year by an independent 3rd party. The ambient data are submitted to AQS monthly and the QC results are submitted quarterly. Trace-level precision is verified against the acceptance criteria in 40 CFR Part 58 Appendix A. The acceptance criterion is an upper 90 CL for the CV of 10%. The $NO_y$ analyzer is challenged with 15 ppb NO every other day. Efforts to better understand the trace gas methods and quality control procedures are on-going between CAPD, OAQPS, the EPA Regions, the manufacturer, and contractors.

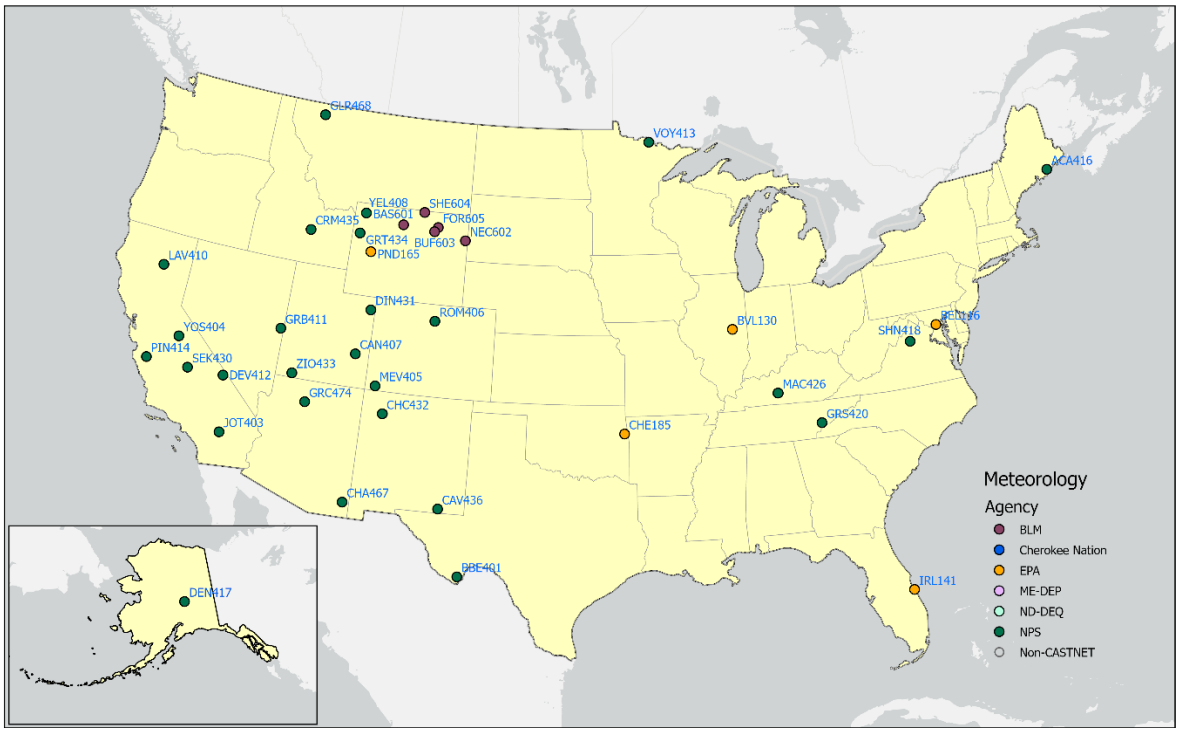
### B. Meteorology

All NPS-sponsored and all BLM-WSO-sponsored CASTNET sites include meteorological measurements. Five EPA-sponsored CASTNET sites: Beltsville, MD (BEL116); Bondville, IL (BVL130); Cherokee Nation Stilwell, OK (CHE185); Indian River Lagoon, FL (IRL141); and Pinedale, WY (PND165) also collect meteorological data. The locations of the 37 CASTNET sites reporting meteorological measurements with regulatory $O_3$ are displayed in Figure 13.

On-site meteorology at a CASTNET site includes measurements of temperature (9m at EPA-sponsored sites and 2m at most NPS-sponsored sites), relative humidity, solar radiation, precipitation, wind speed,

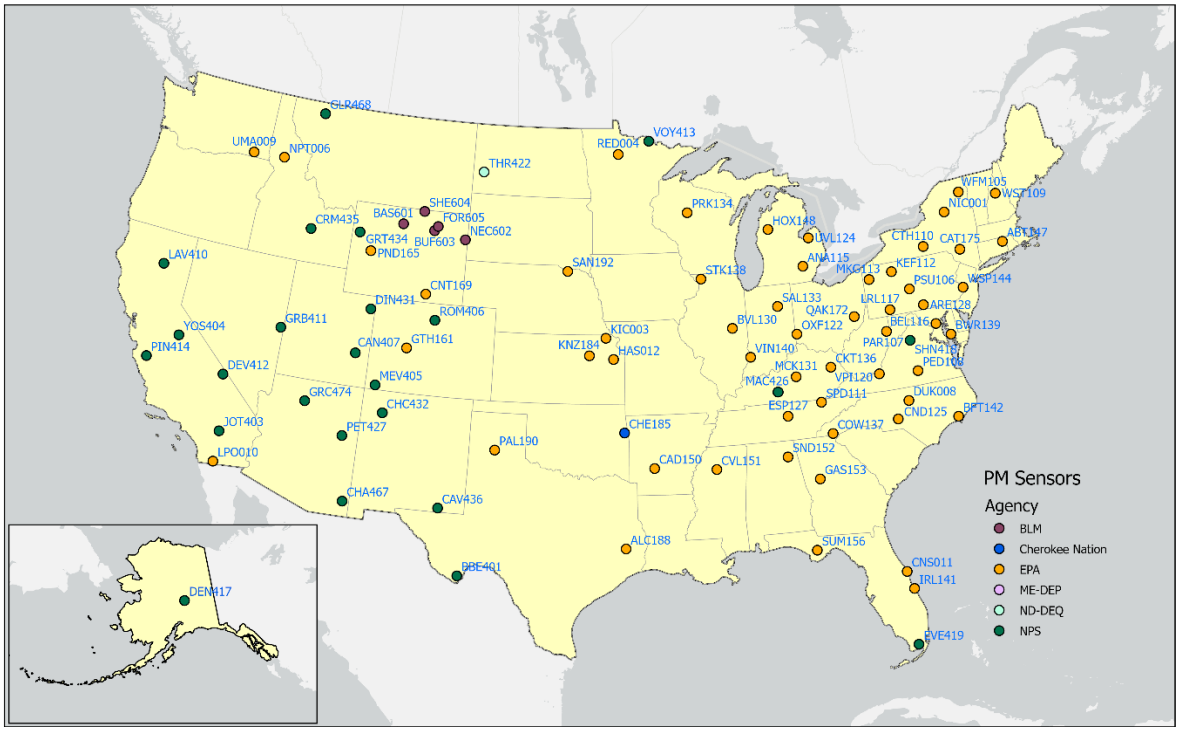
wind direction, sigma theta (standard deviation of the wind direction), and wetness reported as hourly averages.

*Figure 13. CASTNET Sites with on-site meteorology and regulatory $O_3$*




## C. $PM_{2.5}$ Sensors

*Figure 14. CASTNET sites with $PM_{2.5}$ sensors*



Nearly all CASTNET sites now include low-cost, non-regulatory $PM_{2.5}$ sensors to evaluate rural levels of PM to compare concentrations against the PM NAAQS and characterize relationships between PM and CASTNET measurements during wildfire smoke events. The locations of the 87 CASTNET sites reporting $PM_{2.5}$ measurements across CASTNET are displayed in Figure 14. While CASTNET measures the major components of $PM_{2.5}$ (e.g., $SO_4$, $NO_3$, $NH_4$), the network has not traditionally reported $PM_{2.5}$ mass concentrations, one of the six criteria air pollutants the Clean Air Act requires EPA to control. The EPA-sponsored CASTNET sites have each received a Purple Air sensor as of June 2025. The EPA also plans to deploy Modulair QuantAQ PM sensors, a more robust estimate of PM1, PM2.5, PM10. The measurements will provide a first look at ambient PM concentrations in areas that often lack other sources of ambient air quality measurements. While data provided by low-cost sensors are not used for regulatory purposes such as determining attainment of the National Ambient Air Quality Standards (NAAQS), the concentrations reported will be compared to the recently revised $PM_{2.5}$ NAAQS, which was lowered to 9 $\mu g/m^3$ in February 2024. The data from the Purple Air sensors will also be included in the AIRNow Fire & Smoke Map (https://fire.airnow.gov/) for near real-time reporting to the public.

The $PM_{2.5}$ concentrations and existing CASTNET PM precursor data will be leveraged to explore pollutant relationships during smoke and non-smoke impacted events to evaluate how trends may change over time. The analysis may be expanded using existing samples to detect wildfire tracers (e.g., black carbon, levoglucosan, organic nitrogen).

## 5. Summary

The CASTNET ozone monitoring program provides critical information to stakeholders and has met its primary monitoring objectives through consistent, long-term measurements since 1987. The rural ozone monitors detect regional air quality signals, provide a unique data set for evaluating the effects of $O_3$ on vegetation and ecosystems, are used to evaluate the primary and secondary $O_3$ NAAQS, and used to evaluate the impacts to $O_3$ formation from wildfire and stratospheric ozone intrusions. Federal land managers use CASTNET data to assess environmental conditions and risk of air quality impacts on nationally-recognized protected areas. Other stakeholders and participants include Tribes, States, other federal agencies, local air agencies, and universities who use CASTNET data to evaluate air quality models and determine human health and environmental risks in their areas.

With thirty five years of data from many of its sites, CASTNET has measured a significant reduction in regional $O_3$ concentrations in the Eastern US in response to emission control programs, allowing policy makers to assess the effectiveness of these programs for improving air quality. In the coming years, CASTNET data will allow stakeholders to evaluate the effectiveness of current policies and ongoing emission reduction programs such as the Cross-State Air Pollution Rule and Cross-State Air Pollution Update Rule.

Most CASTNET sites are meeting the network quality assurance criteria for accuracy, bias, and precision for 2022-2024, the most recent 3-year period available. Ninety-four percent of CASTNET sites met the completeness criteria for NAAQS attainment decisions for 2022-2024. Most of those sites that did not meet the criteria was due to infrastructure damage from hurricanes, power failures at the monitoring stations, and analyzer pump failures. Recent efforts to improve the data capture efficiency throughout the network include ozone analyzer replacements.

CASTNET remains committed to improving our understanding of $O_3$ and $PM_{2.5}$ precursors in the ambient environment. Ninety one CASTNET sites operate $PM_{2.5}$ sensors and five monitoring sites already provide continuous $NO_y$ data, and several of these sites also measure continuous $SO_2$ and CO. Expanded use of

these and other continuous monitors will enhance the utility of CASTNET data in model evaluation and development.

CASTNET has been a stable platform for regional air monitoring for thirty-five years and the program continues to evolve within the constraints of budgets, regulatory demands, and agency priorities. Developing long-term solutions to improve the cost-effectiveness of routine measurements and leveraging existing and new partnerships has been crucial for the continuity of CASTNET, and these attributes will continue to be important over the next five years as CASTNET strives to improve data capture, enhance the types of measurements collected, and expand into areas with limited air quality monitoring.

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