2020

Clean Air Status and Trends Network Five Year Network Assessment

Clean Air Markets Division

Office of Atmospheric Programs

US Environmental Protection Agency

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Five Year Network Assessment

1. Introduction

A. Purpose

Monitoring agencies that submit data to the U.S. Environmental Protection Agency (EPA) for regulatory purposes are required to conduct an assessment of their air quality surveillance system once every five years. This network assessment was performed to ensure the Clean Air Status and Trends Network (CASTNET) meets the requirements in 40 CFR Part 58.10(d). The purpose of the assessment is to determine, at a minimum, whether the network meets the monitoring agencies' objectives. The focus of this assessment is on the CASTNET monitoring program from 2015 to 2019. The assessment includes a review of the network's effectiveness in reporting trends and regional concentrations of O_3, SO_2, CO, and oxides of nitrogen and recommendations to improve network performance as CASTNET adapts to meet agency objectives.

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 Environmental Protection Agency – Clean Air Markets Division (EPA), the National Park Service – Air Resources Division (NPS), and the Bureau of Land Management – Wyoming State Office (BLM-WSO) 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 provide network support. CASTNET monitors provide critically important, regionally representative data used to provide 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; 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. 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 98 monitoring stations throughout the contiguous United States, Alaska, and Canada. EPA operates 63 CASTNET monitoring stations, NPS operates 30 CASTNET stations, and BLM-WSO operates five CASTNET stations. Thirty 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 three, eight, and three CASTNET sites, respectively.

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

- monitor the status and trends in regional air quality and atmospheric deposition;
- provide information on the contribution of atmospheric pollution to 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 critical component of the CAAA required the EPA to conduct research, monitoring, and analysis of air pollutant trends and their effects on terrestrial and aquatic ecosystems. CASTNET data support this legislative requirement.

The NPS uses CASTNET monitoring data to assess environmental conditions and trends in O_3, sulfur, and nitrogen deposition, and also 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.

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 future outlook for the program.

From the CASTNET QAPP version 9.3:

Project Objective	Required Data	DQO
Estimate dry deposition fluxes	Ambient concentration data for sulfur species, nitrogen species and O_3 along with meteorological parameters and information on vegetation and land use. CMAQ calculations of unmeasured nitrogen species, including nitrous acid (HONO), nitrogen pentoxide (N_2O_5), nitric oxide (NO), nitrogen dioxide (NO_2), organic nitrate (NTR), peroxyacyl nitrate (PAN), aromatic PANs (OPAN), and C3 and higher PANs (PANX)	No standards or standard methods are available to determine the accuracy of the CMAQ deposition model. However, model evaluation and intercomparison studies indicate that TDep/CMAQ model simulates higher dry deposition rates than MLM calculations. However, year-by-year changes in aggregated deposition rates were comparable for both modeling systems and changes in SO_2 and NOx-related pollutants were comparable to changes in SO_2 and NOx emissions. In order to better assess model performance, the model output will have to be compared to independent, multi-year flux measurements.
Detect and quantify seasonal and annual trends in concentrations and dry deposition fluxes for sulfur species, nitrogen species, and O_3	10-year record of ambient concentration and deposition data	To detect a minimum annual trend of 1.0 percent in the concentration of selected measured and/or modeled chemical species with 10 years of data at a given site in the United States region with a statistical confidence of 95 percent.
Define the spatial distribution of pollutants	Ambient concentration data for sulfur species, nitrogen species and O_3 collected over a large number of sites that constitute sufficient geographic coverage. Gridded CMAQ-modeled concentrations of sulfur species, nitrogen species, O_3 and other pollutants.	Spatial distributions of nationwide SO_2, SO_4^{-2}, total nitrate, NH_4^+ and other pollutant concentrations are produced by combining CMAQ simulations with measured concentrations over a specified (e.g., 12 km) grid system.

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, with additional monitoring coverage provided 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. CASTNET has historically used the Multi-Layer Model (MLM) to estimate dry deposition fluxes using measured concentrations, on-site meteorology and site characteristics, including land use and vegetation, as input.

In 2011, EPA-sponsored CASTNET sites discontinued on-site meteorological measurements at all except five sites. Beginning with 2014 measurements the new total deposition (TDep) hybrid approach (Schwede and Lear, 2014), which incorporates CMAQ output with air quality monitoring data, was used for spatial analyses of dry and total deposition. The TDep approach is documented on EPA's total deposition TDep FTP site (ftp://newftp.epa.gov/castnet/tdep/Total_Deposition_Documentation_current.pdf). In summary, dry deposition is determined as the product of the atmospheric concentration and the deposition velocity. The deposition velocity is modeled in CMAQ using the electrical resistance paradigm where resistances are defined along pathways from the atmosphere to the vegetation or surface and act in series and parallel. Beginning in 2015, the TDep approach became the primary method to produce deposition gridded surfaces. The CASTNET filterpack measurements provide weekly concentrations of gaseous sulfur dioxide (SO_2) and nitric acid (HNO_3), and particulate sulfate (SO_4^{2-}), nitrate (NO_3^-), ammonium (NH_4^+), base cations (Ca^{2+}, K^+, Mg^{2+}, Na^+), and chloride (Cl^-). A single laboratory, operated under contract to the EPA, analyzes the filterpack samples for all CASTNET sites.

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 86 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), Cherokee Nation, OK (CHE185), and Underhill, VT (UND002) are NCore sites with trace gas NO/NOy, SO_2, and CO. Additionally, there are ten sites that operate without a walk-in shelter, represented by a triangle on the map in Figure 1 (e.g., Small Footprint sites). Forty CASTNET sites measure hourly meteorological parameters including all 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.

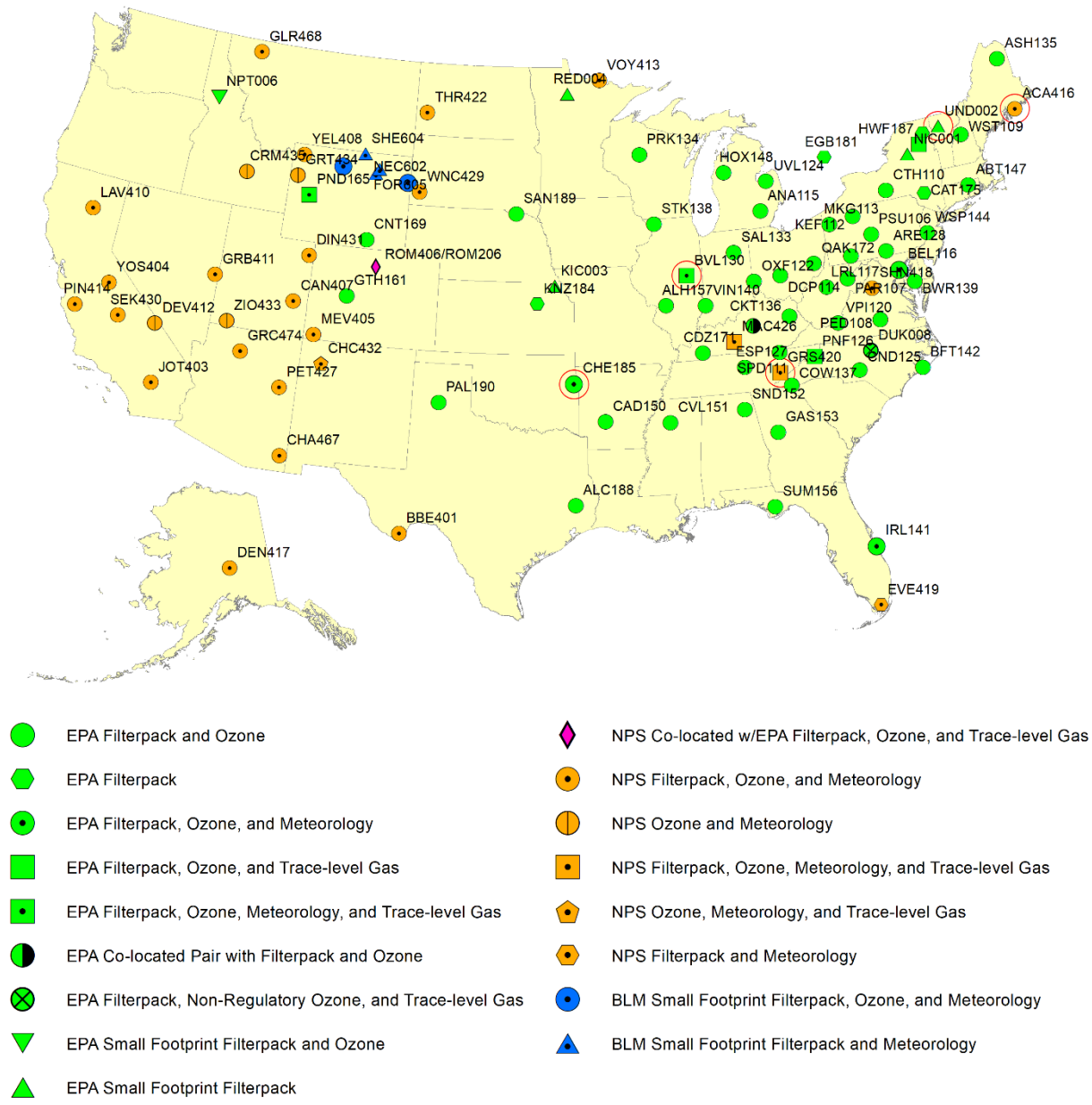


Figure 1. Map of CASTNET sites (May 2020). Green shapes represent EPA-sponsored sites. Orange shapes represent NPS-sponsored sites. The purple diamond represents a co-located pair of NPS-sponsored ozone and filterpack monitoring and EPA-sponsored ozone, filterpack, and trace-level gas monitoring. Blue shapes represent BLM-Wyoming State Office-sponsored sites. National Core network (NCore) sites are identified with a large red circle.

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, Wood Environment & Infrastructure Solutions, Inc. (Wood), 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**
Allegheny National Forest (NF) Apalachicola NF Environment Canada Gunnison NF Holly Springs NF Hubbard Brook Experimental Forest Medicine Bow-Routt NF Monongahela NF Nantahala NF National Park Service (NPS) United States Army Engineering District/Louisville US Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) USDA Agricultural Research Center (ARS) USDA Southern Research Station Coweeta Hydrological Lab US Fish & Wildlife Service USDA- Forest Service (FS) Timber & Watershed Lab USDA-FS Forestry Sciences Laboratory USDA-FS Rocky Mountain Research Station USDA-FS Toecane District US Department of Interior (DOI)-Bureau of Land Management White Mountain NF	Alabama-Coushatta Tribe of Texas Cedar Creek State Park WV Division of Natural Resources Cherokee Nation Cumberland St. Forest VA Department of Forestry Deer Creek State Park OH Dept. of Natural Resources (DNR) Edgar Evans State Park TN Dept. of Environmental Conservation (DEC) Laurel Hill State Park PA Dept. of Conservation & Natural Resources (DCNR) ME Dept. of Environmental Protection (ME DEP) Maurice K. Goddard State Park (PA DCNR) New York DEC ND Department of Health NYS Energy Research & Development Authority Rocky Mountain Biological Laboratory Santee Sioux Tribe of Nebraska St. Johns River Water Management District SD Dept. of Environmental & Natural Resources (SD DENR) Vermont DEC Washington Crossing State Park (NJ DEP)	Auburn University Alabama Agricultural Experiment Station Cornell University, Ecology & Evolutionary Biology KS State University (KSU) Division of Biology/Konza Prairie Long-term ecological research (LTER) Miami University Institute for the Environment & Sustainability Ouachita Baptist University School of Natural Sciences Pennsylvania State University (PSU) Fruit Research & Extension Center PSU Department of Meteorology Proctor Maple Research Center (UVM) Purdue University Department of Agronomy State University of NY (SUNY) ESF Adirondack Ecology Center Texas A&M Agrilife Research & Extension Center University of GA, College of Agriculture & Environmental Science University of IL, Illinois State Water Survey University of Maine Plant, Soil & Environmental Science University of MD Department of Atmospheric & Oceanic Science University of Michigan School of Natural Resources University of NC Institute of Marine Sciences VA Tech Department of Plant Pathology, Physiology & Weed Science

E. CASTNET Ozone Monitoring Program

CASTNET operates 98 monitoring sites throughout the US and Canada and 86 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. Four CASTNET O_3 sites are located on Tribal Lands including Santee Sioux, NE (SAN189), Cherokee Nation, OK (CHE185), Alabama-Coushatta, TX (ALC188), and Nez Perce, ID (NPT006).

Eighty-six CASTNET sites collect ambient O_3 concentrations, reported as hourly averages, using a dual cell, ultraviolet photometric analyzer. Eighty-five of the eighty-six CASTNET O_3 monitoring analyzers meet the ambient monitoring and quality assurance requirements of Title 40, Code of Federal Regulations (CFR) Part 58 Appendices A, C, D and E. 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 9.3 at http://java.epa.gov/castnet/documents.do (Wood, 2019).

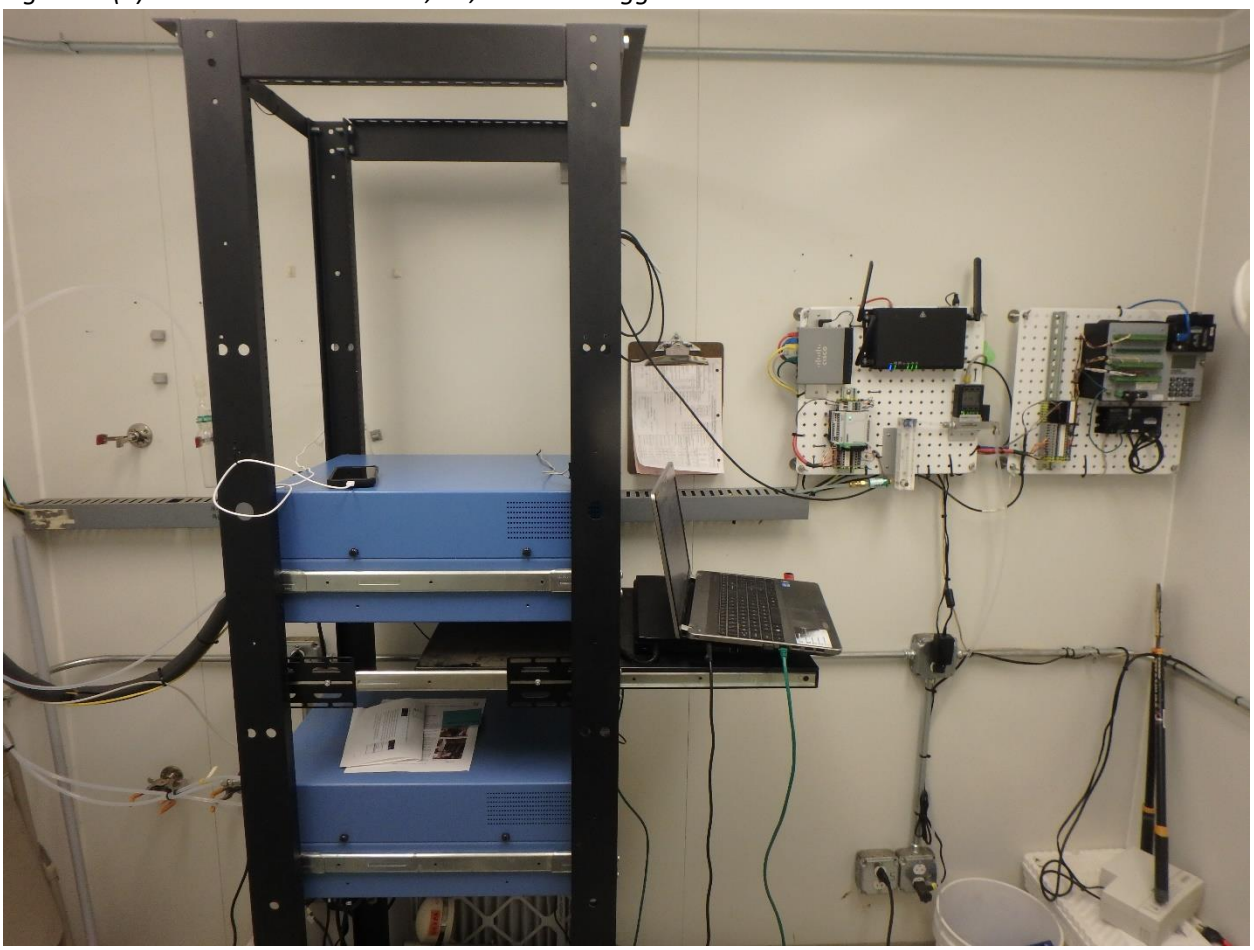
Figure 2 shows images of the typical configuration of a CASTNET site with the full suite of monitoring equipment including the temperature-controlled shelter and a 10-m tipping tower. The O_3 inlet is located within the rain shield at the top of the 10-m tipping tower which also houses the CASTNET filter pack. Two NPS-sponsored CASTNET sites, Wind Cave National Park, SD (WNC429) and Theodore Roosevelt National Monument, ND (THR422), have O_3 inlet heights at 3.35 m and 12.2 meters, respectively. The O_3 monitors at WNC429 and THR422 are managed by the respective state agencies. 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. Network Modifications for Regulatory Ozone Monitoring

The National Park Service established their regulatory O_3 monitoring program prior to 1990. While the NPS-sponsored O_3 monitoring program was designed to meet O_3 monitoring regulations from the beginning, the EPA-sponsored O_3 monitoring program was not. All EPA-sponsored O_3 monitors were upgraded by 2011 to comply with the requirements in 40 CFR Part 58. EPA replaced the existing O_3 analyzers with a pair of Thermo Scientific™ Model 49i analyzers, where one analyzer has an onboard O_3-generator for use as an on-site transfer standard. 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. The upgrade of the EPA-sponsored O_3 analyzers resulted in an improved ability to evaluate the quality of the ambient data. 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).

Prior to being used for regulatory monitoring, zero, span, and precision (ZSP) checks of the O_3 analyzer at EPA-sponsored sites were performed every week; now all sites perform ZSP checks daily. 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 validated hourly O_3 concentrations are submitted monthly to AQS by the sponsoring agency's contractor. Additionally, the daily 1-point precision checks are submitted quarterly to AQS for each site. PE results are submitted to AQS routinely by the designated independent auditor. 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, Wind Cave National Park, SD (WNC429) submitted by South Dakota Department of Environment and Natural Resources, Cherokee Nation, OK (CHE185) submitted by Cherokee Nation Clean Air Program, and Theodore Roosevelt National Monument, ND (THR422) submitted by North Dakota Department of Health.

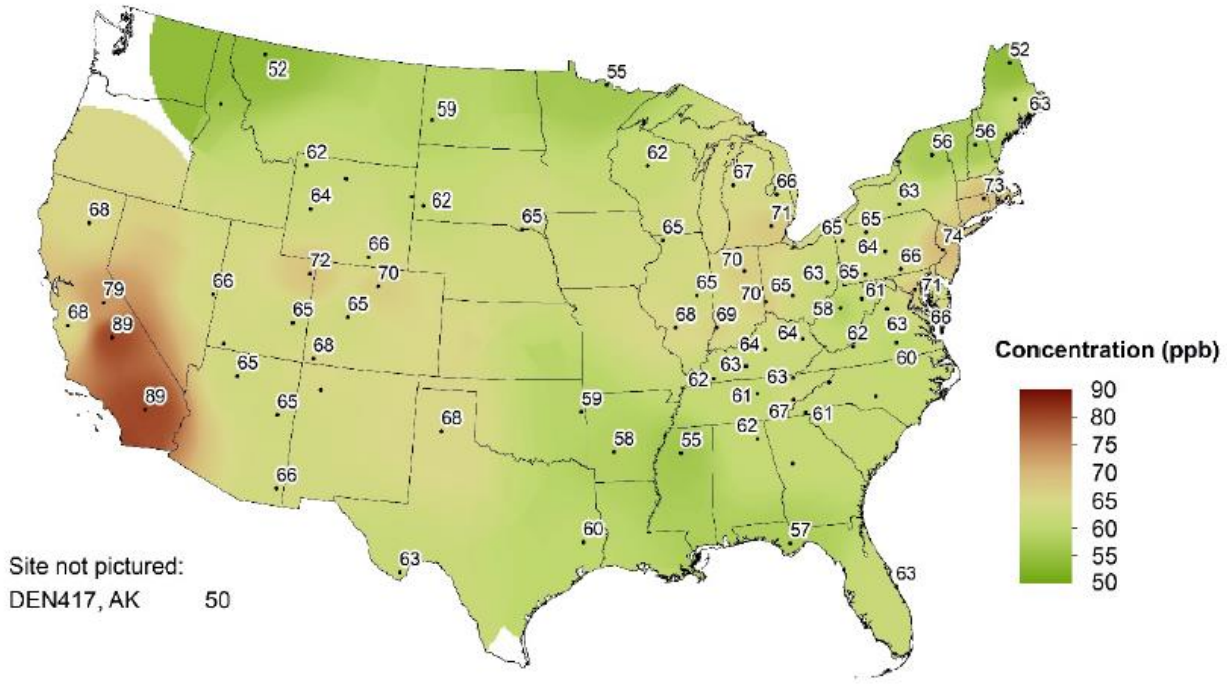
2. Monitoring Results

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 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 2016-2018 fourth highest daily maximum 8-hour O_3 average for all sites that met the completeness criteria (40 CFR Part 50, Appendix I). 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 2016-2018, eight sites exceeded the primary O_3 standard of 70 ppb.

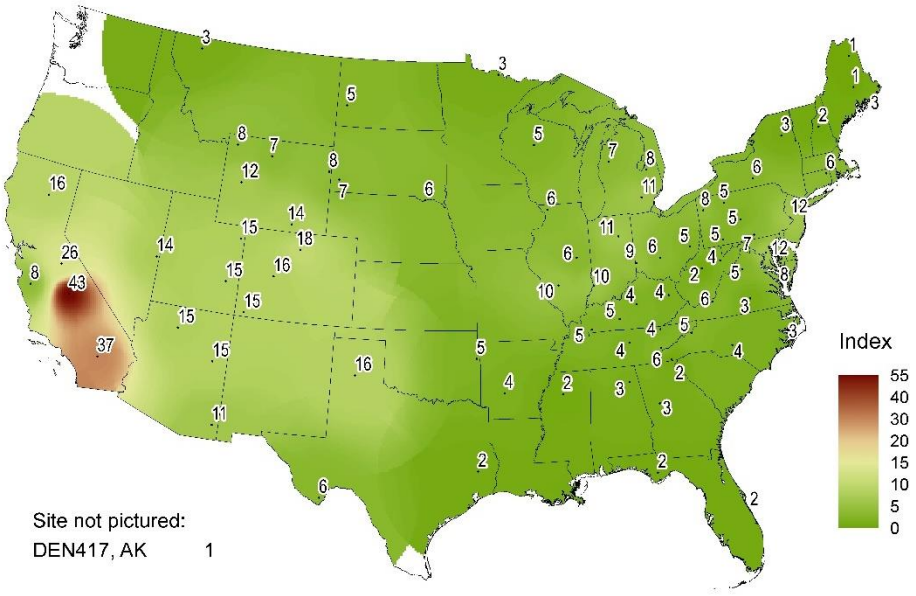
Figure 4. Map of 2016-2018 fourth highest daily maximum 8-hour ozone average



B. 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 losses, 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 in rural areas and often in sensitive ecosystems where vegetation related effects are significant. Figure 5 shows the W126 values from CASTNET sites in 2018.

Figure 5. Maximum W126 value for 2018



C. Ozone Trends

For the purpose of 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 6). Eastern long-term sites have been operating since at least 1990, while Western long-term sites have been operating since at least 1996.

Figure 6. CASTNET Western and Eastern Reference Sites

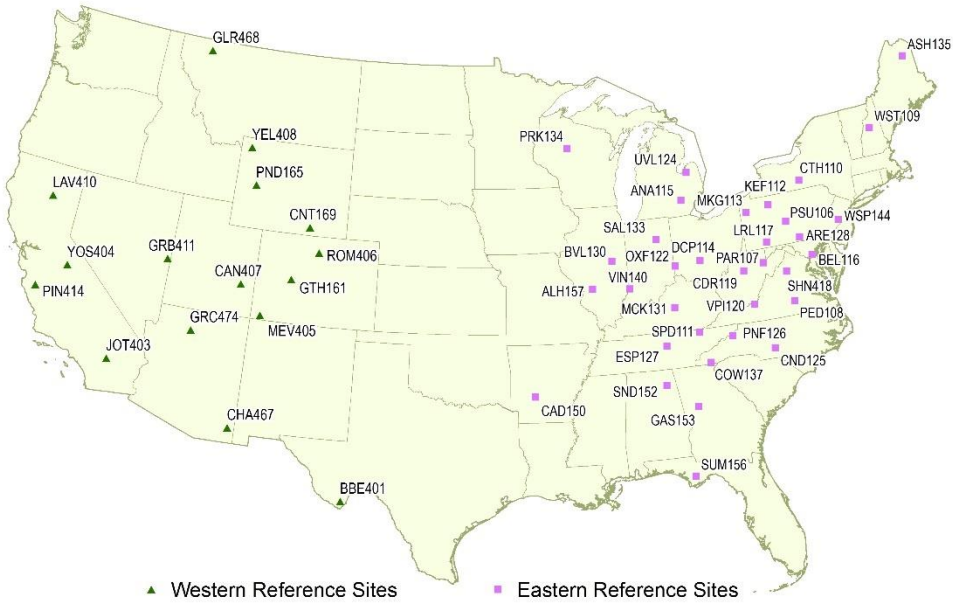
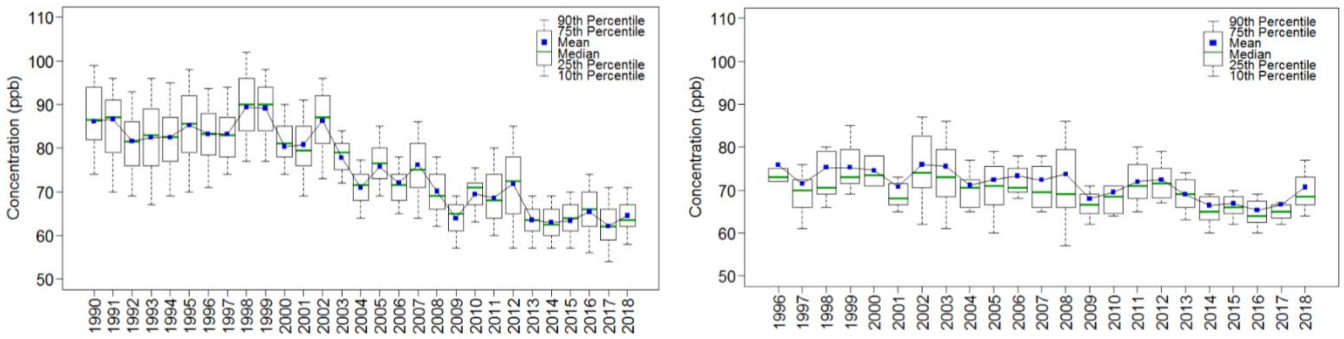


Figure 7 shows the trends in ambient fourth highest eight hour daily maximum O_3 concentrations from 1990-2018 (eastern sites) and 1996-2018 (western sites). The fourth highest eight hour daily maximum O_3 data from the 34 Eastern reference sites show substantial reductions in concentrations since 2002. The Eastern reference sites realized a 25% reduction between 2000-2002 and 2016-2018. In 2018, the median fourth highest daily maximum 8-hour average for the Eastern reference sites was 64 ppb. The western reference sites do not show the same dramatic reductions in O_3 concentrations. There was a 9% reduction in O_3 concentrations as measured by the Western reference sites between 2000-2002 and 2016-2018. In 2018, the median fourth highest daily maximum 8-hour average was 69 ppb at the 16 western reference sites.

Figure 7. Annual trends in fourth highest eight hour daily maximum ozone concentrations from the eastern (left) and western (right) 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 in order 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 9.3 (Wood, 2019) 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 (http://java.epa.gov/castnet/documents.do).

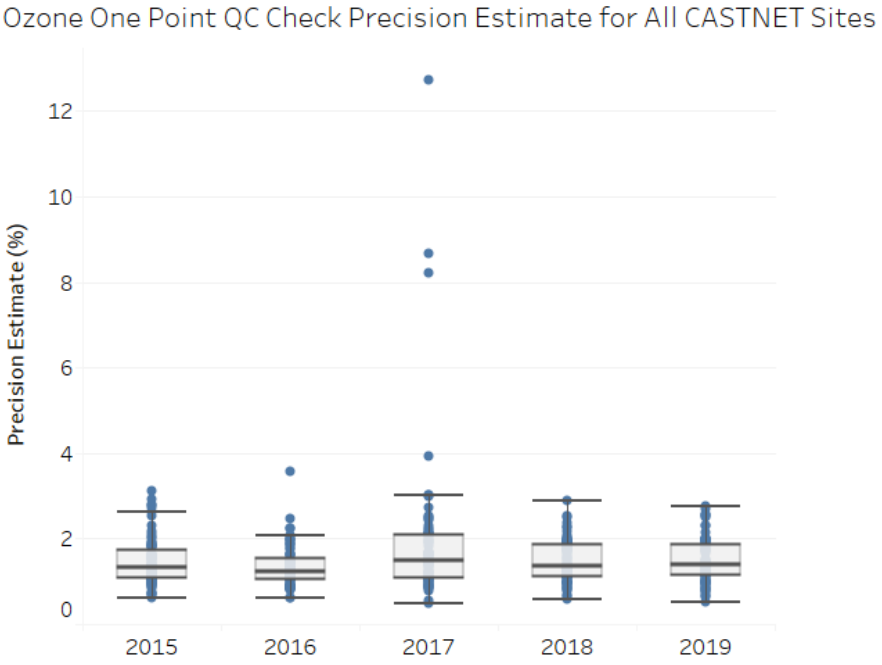
CASTNET data quality indicators including precision, accuracy, bias, and completeness are reported by the AMP256 QA Data Quality Indicator Report made available from the U.S. EPA Office of Air Quality Planning and Standards' (OAQPS) Air Quality System (AQS). The AMP256 report provides annual summaries 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

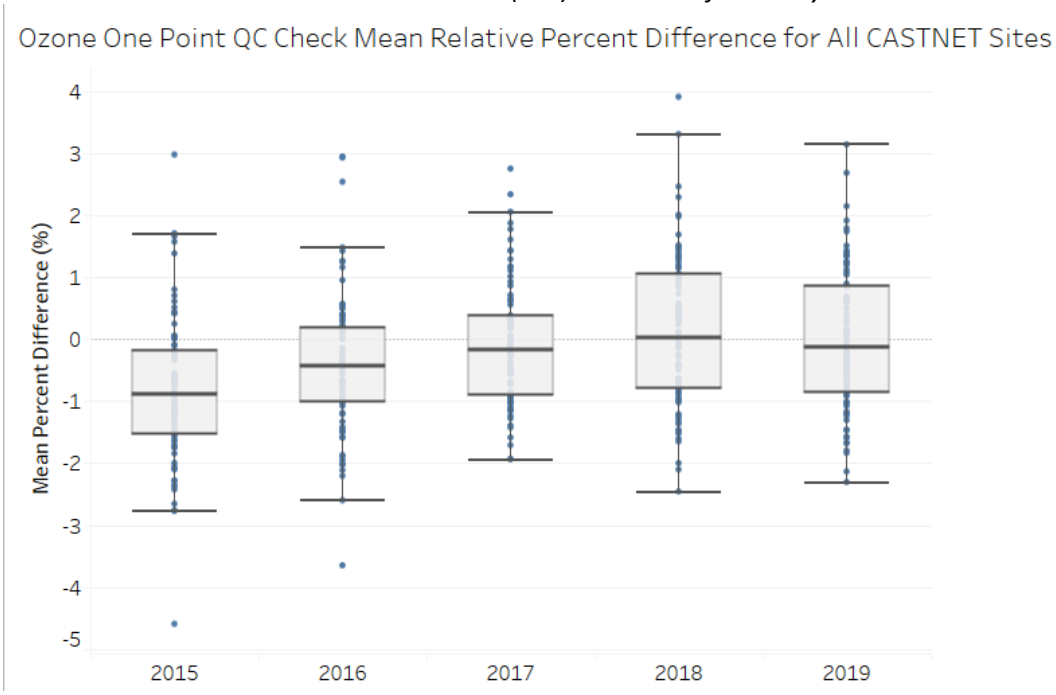
quarterly. Additional data review is required for sites that do not meet the 7.1% criterion. Figure 9 reports the precision estimates for all CASTNET sites from 2015 to 2019 in the form of box plots from the AMP256 report. In 2015, 2016, 2018, and 2019 all sites met the 7.1% acceptance criterion. In 2017, all sites except Rocky Mountain National Park (ROM406, CO, 8.67%), Canyonlands National Park (CAN407, UT, 12.72%), and Sequoia and Kings Canyon National Park (SEK430, CA, 8.20%) met the acceptance criteria.

Figure 9. Box Plot showing all CASTNET ozone precision estimates for 2015-2019. 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 10 shows the annual RPD for all CASTNET sites using the 1-point QC checks from the AMP256 report. The median RPD values for 2015, 2016, 2017, 2018, and 2019 were -0.89, -0.42, -0.18, 0.04, and -0.28 ppb, respectively.

Figure 10. 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 25th and 75th 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 2015 through 2019 are shown in Table 2. 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 2015 through 2019. Table 2 reports 1-point QC check bias results evaluated from the AMP256 report.

Table 2. The bias estimate calculated from one-point QC checks for 2015 through 2019.

Ozone One Point QC Bias for Each CASTNET Site

Site ID	2015	2016	2017	2018	2019	Site ID	2015	2016	2017	2018	2019
ABT147	1.571	1.172	0.720	1.384	1.335	IRL141	1.600	1.082	1.453	0.981	1.037
ALC188	1.185	1.577	1.314	1.360	1.838	JOT403	2.282	1.810	0.858	0.943	0.802
ALH157	1.366	0.839	1.284	1.378	1.595	KEF112	1.104	1.253	1.525	1.775	1.752
ANA115	0.853	0.977	1.948	2.466	1.158	LAV410	0.959	1.459	1.339	1.556	1.169
ARE128	1.060	1.183	1.137	1.731	1.940	LRL117	0.751	0.742	0.923	1.051	1.035
ASH135	1.614	0.758	1.786	1.844	1.539	MAC426	1.851	1.568	1.075	1.681	1.975
BAS601	1.249	1.550	1.467	1.526	2.025	MCK131	2.222	0.814	1.016	1.764	1.071
BBE401	2.044	1.793	1.073	1.057	2.144	MCK231	2.554	1.347	0.822	1.893	1.140
BEL116	4.869	1.024	1.175	1.152	1.145	MEV405	1.053	3.088	1.612	1.300	1.529
BFT142	1.604	1.514	1.230	0.953	2.364	MKG113	0.929	0.721	1.029	1.615	1.190
BVL130	2.993	1.657	1.110	1.602	1.888	NEC602	0.953	0.755	2.207	2.841	1.741
BWR139	3.230	2.154	2.630	2.102	1.529	NPT006			0.590	0.925	1.038
CAD150	1.076	1.206	1.274	1.481	1.614	OXF122	2.995	2.352	2.469	1.628	1.605
CAN407	2.489	1.374	3.254	0.572	1.479	PAL190	2.495	1.200	1.358	1.610	1.422
CDR119	2.840	2.143	1.390	1.383	1.401	PAR107	1.692	1.374	1.272	0.910	1.109
CDZ171	0.754	0.618	1.140	1.574	1.664	PED108	3.066	2.137	1.392	0.843	0.768
CHA467	1.018	2.419	0.927	1.944	2.797	PET427	1.990	2.679	0.882	0.659	0.728
CHC432			3.304	2.608	3.331	PIN414	1.279	1.745	0.868	1.915	1.763
CKT136	1.538	0.734	0.677	0.649	0.576	PND165	2.755	2.633	2.173	1.552	1.711
CND125	1.045	2.076	1.282	2.202	1.362	PNF126	2.613	2.021	1.867	1.353	0.807
CNT169	2.611	1.312	2.144	0.775	0.804	PRK134	1.856	2.128	1.410	1.773	1.315
COW137	2.093	1.735	1.583	1.105	1.407	PSU106	2.128	0.611	0.612	1.713	1.434
CRM435					1.218	QAK172	1.220	1.340	2.511	2.889	2.624
CTH110	2.223	1.103	1.408	1.587	1.551	ROM206	1.863	0.856	1.746	1.977	2.554
CVL151	0.667	0.662	2.003	1.656	1.193	ROM406	2.503	1.170	3.161	1.000	1.086
DCP114	1.687	1.247	1.597	1.893	2.203	SAL133	1.381	1.040	1.700	4.024	1.950
DEN417	1.628	1.224	1.626	1.344	1.651	SAN189	0.744	0.951	1.955	1.648	2.747
DEV412					0.749	SEK430	1.274	0.830	2.621	1.562	1.334
DIN431	2.419	3.788	1.381	1.725	1.568	SHN418	1.781	1.723	1.851	1.138	2.067
ESP127	1.399	0.969	1.249	1.888	1.991	SND152	2.085	1.267	2.978	2.669	2.493
GAS153	0.557	0.511	2.129	2.319	1.989	SPD111	1.772	0.922	0.821	0.961	0.907
GLR468	1.523	1.628	1.159	0.757	0.888	STK138	0.821	0.882	1.307	1.702	1.147
GRB411	2.083	1.717	1.350	2.017	0.917	SUM156	1.373	1.194	2.232	0.956	0.819
GRC474	1.128	2.144	2.311	0.797	1.324	UVL124	0.816	0.854	1.579	1.063	1.075
GRS420	2.388	1.256	0.473	0.967	1.194	VIN140	1.130	3.154	1.473	1.435	2.053
GRT434					2.292	VOY413	0.833	0.967	0.579	0.800	1.727
GTH161	1.069	3.229	2.480	1.994	1.915	VPI120	1.015	0.970	0.813	1.591	1.689
HOX148	0.884	1.307	1.483	1.554	1.645	WSP144	1.455	1.728	1.733	2.146	2.442
HWF187	1.018	0.981	0.906	1.698	0.921	WST109	1.208	1.013	0.605	0.939	1.341

Bias Sign
- -
- +
- +/-

D. Accuracy

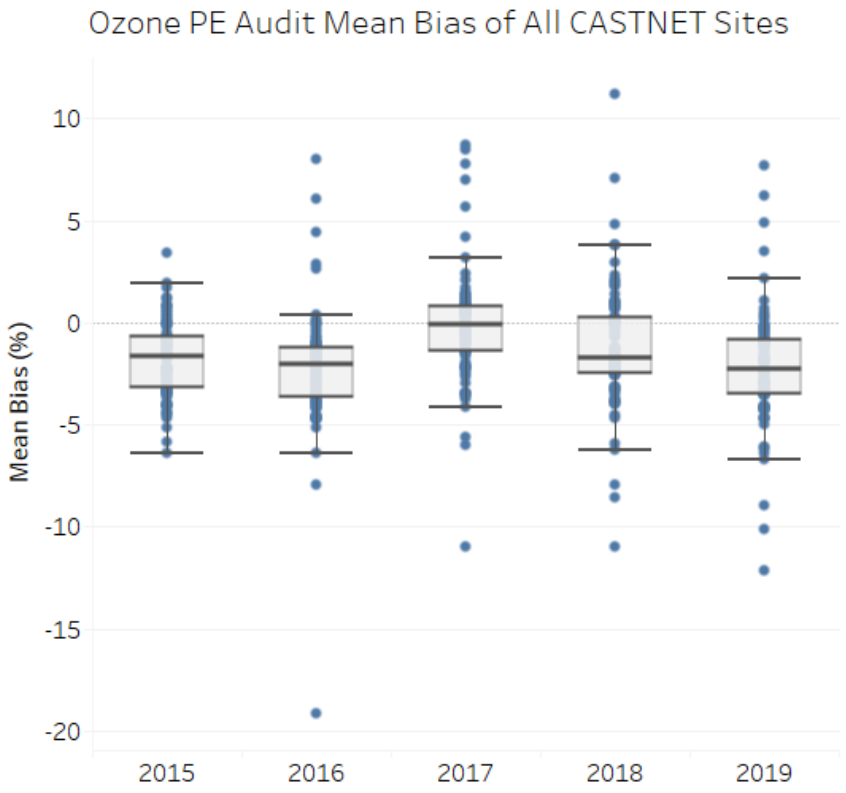
1. Semi-Annual Site Visits

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 11.

Figure 11. Estimated Bias in O_3 concentrations from PE Audit Results for All CASTNET Sites for years 2015 through 2019



The bias is estimated from the PE values for the years 2015 through 2019 and displayed in Figure 11. The median for all sites are within ±2.5% 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 2017-2019 time period, 74 out of 82 (90 percent) CASTNET O_3 sites met both completeness criteria.

4. Precursor Measurements and Meteorology

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 eight 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 Duke Forest, NC (DUK008) NO_y analyzer has been converted to an "enhanced" NO_y analyzer which includes 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.).

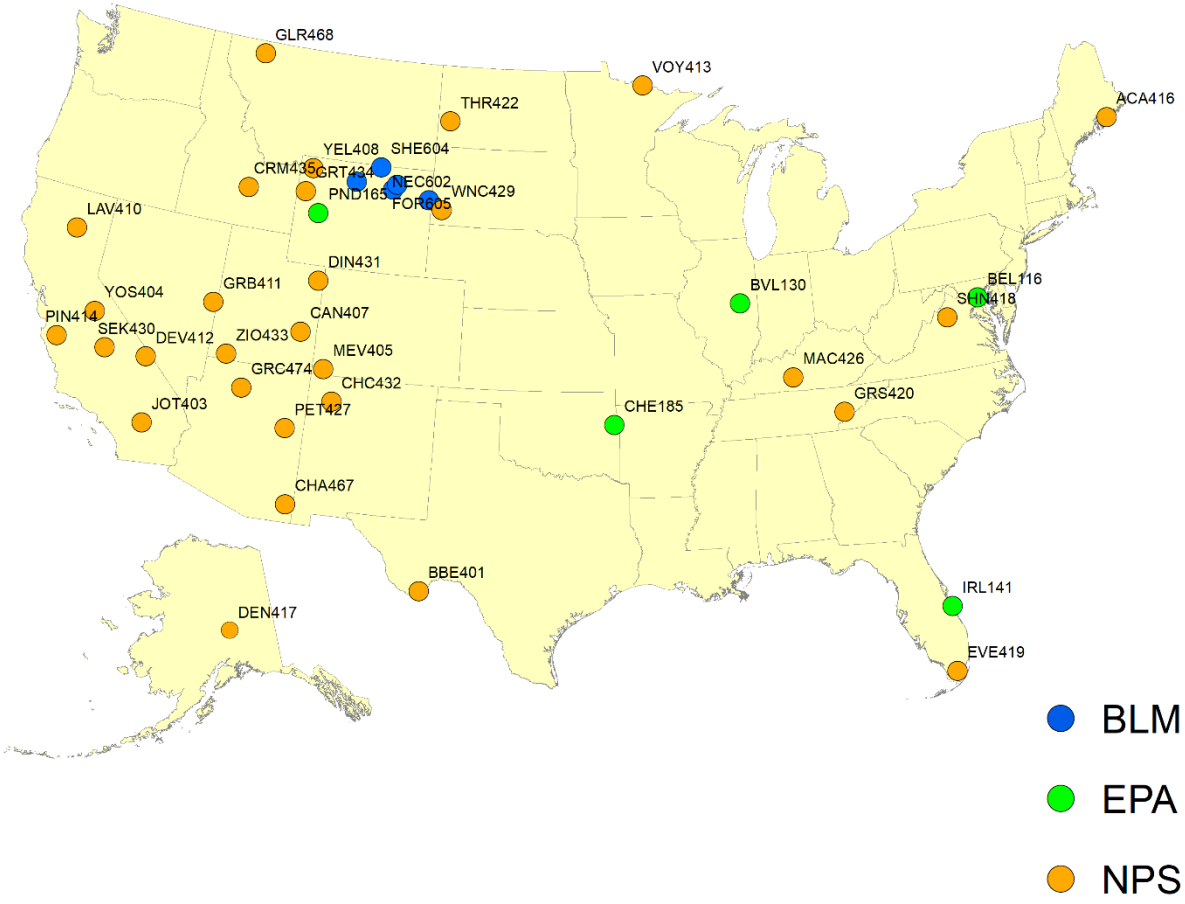
Trace NO_y is audited twice per year by the CASTNET contractor and audited once every other year by an independent 3rd party. The ambient data are submitted to AQS monthly and the QC results are submitted quarterly. Trace-level precision is verified against the acceptance criteria in 40 CFR Part 58 Appendix 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 CAMD, OAQPS, the EPA Regions, the manufacturer, and contractors.

B. CASTNET 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 40 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. Sites with on-site meteorology and regulatory O_3 measured by CASTNET (May 2020)



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 sensitive areas and other federal lands. Other stakeholders and participants include Tribes, States, other federal agencies, and universities who use CASTNET data to evaluate air quality models and determine human health and environmental risks in their areas.

With thirty 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.

Data quality indicators indicate that most CASTNET sites are meeting the network quality assurance criteria for accuracy, bias, and precision for 2017-2019, the most recent 3-year period available. While 90 percent of CASTNET sites met the completeness criteria for NAAQS attainment decisions for 2017-2019, many of the sites that did not meet the criteria were 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 back plane replacements.

CASTNET remains committed to improving our understanding of reactive nitrogen and other O_3 and $PM_{2.5}$ precursors in the ambient environment. Eight monitoring sites already provide continuous NO_y data, and several of these sites also measure continuous SO_2 and CO. In addition, an enhanced NO/NO_y analyzer has been developed and was deployed at Duke Forest, North Carolina in May 2017 where it continues to provide hourly measurements of reactive nitrogen concentrations. 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 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.

References

Brown-Steiner, B. and Selin, N. E. and Prinn, R. G. and Monier, E. and Tilmes, S. and Emmons, L. and Garcia-Menendez, F. (2018). "Maximizing ozone signals among chemical, meteorological, and climatological Variability." Atmospheric Chemistry and Physics. 18: 8373—8388. https://doi.org/10.5194/acp-18-8373-2018

Hogrefe, C. and Liu, P. and Pouliot, G. and Mathur, R. and Roselle, S. and Flemming, J. and Lin, M. and Park, R. J. (2018). "Impacts of different characterizations of large-scale background on simulated regional-scale ozone over the continental United States." Atmospheric Chemistry and Physics. 18: 3839--3864. https://doi.org/10.5194/acp-18-3839-2018

Itahashi, S., Mathur, R., Hogrefe, C., and Zhang, Y. (2020). "Modeling stratospheric intrusion and trans-Pacific transport on tropospheric ozone using hemispheric CMAQ during April 2010 -- Part 1: Model evaluation and air mass characterization for stratosphere--troposphere transport." Atmospheric Chemistry and Physics. 20: 3373—3396. https://doi.org/10.5194/acp-20-3373-2020

Kaldunski, Ben and Pierce, Brad and Holloway, Tracey. (2017). "When Stratospheric Ozone Hits Ground-level Regulation: Exceptional Events in Wyoming". Bulletin of the American Meteorological Society. 98: 889-892. https://doi.org/10.1175/BAMS-D-14-00133.1

Kerr, G. H., Waugh, D. W., Sarah, S. A., Steenrod, S. D., Oman, L. D., & Strahan, S. E. (2019). "Disentangling the drivers of the summertime ozone-temperature relationship over the United States." Journal of Geophysical Research: Atmospheres. 124: 10503-10524. https://doi.org/10.1029/2019JD030572

Lin, Meiyun., Fiore, Andrea., Horowitz, Larry W., Langford, Andrew O., Oltmans, Samuel J., Tarasick, David and Rieder, Harald E. (2015). "Climate variability modulates western US ozone air quality in spring via deep stratospheric intrusions." Nature Communications. 6**:** 7105 (2015). https://doi.org/10.1038/ncomms8105

Rieder, Harald E., Fiore, Arlene M., Clifton, Olivia E., Correa, Gustavo, Horowitz, Larry W., and Naik, Vaishali. (2018). "Combining model projections with site-level observations to estimate changes in distributions and seasonality of ozone in surface air over the U.S.A." Atmospheric Environment. 193: 302-315. https://doi.org/10.1016/j.atmosenv.2018.07.042

Travis, K. R. and Jacob, D. J. (2019). "Systematic bias in evaluating chemical transport models with maximum daily 8h average (MDA8) surface ozone for air quality applications: a case study with GEOS-Chem v9.02". Geoscientific Model Development. 12: 3641—3648. https://doi.org/10.5194/gmd-12-3641-2019

U.S. Environmental Protection Agency (2017). "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II, Ambient Air Quality Monitoring Program." EPA-454/B-17-001.

https://www3.epa.gov/ttn/amtic/files/ambient/pm25/qa/Final%20Handbook%20Document%201_17.pdf
Accessed May 2020.

Wood Inc. (2019) “CASTNET Quality Assurance Project Plan 9.3”
https://www3.epa.gov/castnet/docs/CASTNET_QAPP_v9-3_Main_Body.pdf
Accessed May 2020.