



# CLEAN AIR STATUS AND TRENDS NETWORK (CASTNET)

## PROGRAM OVERVIEW

CASTNET is a long-term environmental monitoring network with 97 sites located throughout the United States and Canada. CASTNET is managed and operated by the U.S. Environmental Protection Agency (EPA) in cooperation with the National Park Service (NPS); Bureau of Land Management, Wyoming State Office (BLM); and other federal, state, and local partners including six Native American tribes that operate CASTNET sites on tribal lands. The network was established under the 1990 Clean Air Act Amendments to provide accountability for emission reduction programs by reporting trends in pollutant concentrations and acidic deposition. Data from CASTNET also support the assessment of the primary and secondary National Ambient Air Quality Standards (NAAQS) for ozone (O<sub>3</sub>), nitrogen dioxide (NO<sub>2</sub>), and sulfur dioxide (SO<sub>2</sub>). Additionally, the NPS and BLM utilize CASTNET data for assessing critical loads exceedances in sensitive ecosystems (i.e., high elevation and coastal sites) and applications related to permitting.

*CASTNET is a long-term, rural monitoring network used to assess the environmental results due to emission reduction programs and pollutant impacts to sensitive ecosystems and vegetation.*

CASTNET (<https://www.epa.gov/castnet>) measures weekly ambient concentrations of gases and particles including SO<sub>2</sub>, nitric acid (HNO<sub>3</sub>), sulfate (SO<sub>4</sub><sup>2-</sup>), nitrate (NO<sub>3</sub>), ammonium (NH<sub>4</sub><sup>+</sup>), chloride (Cl<sup>-</sup>), and base cations, as well as hourly O<sub>3</sub> concentrations. Measured concentrations from CASTNET provide data to assess long-term trends in air quality and dry and total deposition. CASTNET measurements are combined with modeled, gridded deposition velocities to provide annual dry deposition estimates using the total deposition hybrid method (Schwede and Lear, 2014). Recognizing the increasing importance of reduced nitrogen species, CASTNET also participates in the National Atmospheric Deposition Program's (<http://nadp.slh.wisc.edu>) Ammonia Monitoring Network (NADP/AMoN). AMoN sites measure biweekly concentrations of ambient ammonia (NH<sub>3</sub>) using passive samplers. CASTNET is co-located with AMoN at 69 sites providing a more complete nitrogen budget. Results from the Community Multi-Scale Air Quality (CMAQ) model estimated CASTNET was missing 10 to 40% of the total nitrogen budget before the addition of AMoN. Unlike the downward trends in oxidized nitrogen species, AMoN sites that were installed in 2007–2008 show increasing NH<sub>3</sub> concentrations throughout most of the United States (Butler *et al.*, 2016).

CASTNET complements the NADP's National Trends Network (NTN), which is considered the nation's primary source of wet deposition data and provides weekly wet deposition fluxes at more than 250 sites across the contiguous United States, Canada, Alaska, Puerto Rico, and the U.S. Virgin Islands. Nearly all CASTNET sites are co-located with or near an NTN



site. Together, these two monitoring programs provide data necessary to estimate long-term temporal and spatial trends in total deposition (dry and wet) as well as ecosystem health.

Ozone monitors at 84 of the 85 CASTNET O<sub>3</sub> sites meet the requirements of Title 40 of the Code of Federal Regulations (CFR) Part 58 and are used to determine compliance with the NAAQS for O<sub>3</sub>. Hourly O<sub>3</sub> measurements are submitted to the AIRNow website (<https://www.airnow.gov>) and to EPA's Air Quality System (AQS) database.

CASTNET also features measurements of trace-level gases at select sites. Eight sites measure reactive oxides of nitrogen (NO/NO<sub>y</sub>). NO<sub>y</sub> is a reactive gas that contributes to the formation of O<sub>3</sub> and fine particulate matter (PM<sub>2.5</sub>). One of these sites features an enhanced NO/NO<sub>y</sub> system that permits speciation of reactive nitrogen into its components. One site measures nitric oxide/nitrogen oxides (NO/NO<sub>x</sub>). Three sites measure SO<sub>2</sub> and carbon monoxide (CO) as part of their participation in EPA's National Core (NCore) network.

In 2012, CASTNET developed a small-footprint monitoring station that does not require a walk-in shelter. These sites can be operated using alternative power sources (wind/solar). Currently, there are 12 operating CASTNET small-footprint sites, including 3 alternate power sites.

Since 2013, total deposition estimates have been assessed using NADP's Total Deposition Science Committee (TDep) measurement-model fusion technique. The hybrid approach combines ambient measurements from CASTNET with model output from CMAQ to provide gridded estimates of dry deposition. These grids are combined with wet deposition fluxes from NTN and NADP's Atmospheric Integrated Research Monitoring Network (AIRMoN) to develop total deposition maps. Available products include gridded data sets and maps of the components of total nitrogen and sulfur deposition. The TDep method is described in Schwede and Lear (2014) and in a fact sheet available on the NADP TDEP website at: <http://nadp.slh.wisc.edu/committees/tdep/>.

The use of CMAQ in combination with available ambient atmospheric concentrations permits greater spatial resolution and the inclusion of additional nitrogen compounds that contribute to total dry deposition of nitrogen.

Development of the hybrid method continues as part of the TDep mission to improve estimates of atmospheric deposition. Figure 1 displays the output of the TDep method for 2017 total nitrogen deposition.

### ACCOUNTABILITY & RESULTS

Emission reduction programs such as the Acid Rain Program, the Clean Air Interstate Rule, and most recently the Cross-State Air Pollution Rule (CSAPR) and CSAPR Update Rule have led to significant reductions in ambient sulfur and nitrogen pollutants as well as ambient O<sub>3</sub> concentrations. One of CASTNET's goals is to quantify the environmental results of these emission reduction programs. Results of these programs are summarized in EPA's Clean Air Markets Division's (CAMD's) annual progress reports (<https://www.epa.gov/airmarkets>).

### Atmospheric Concentrations

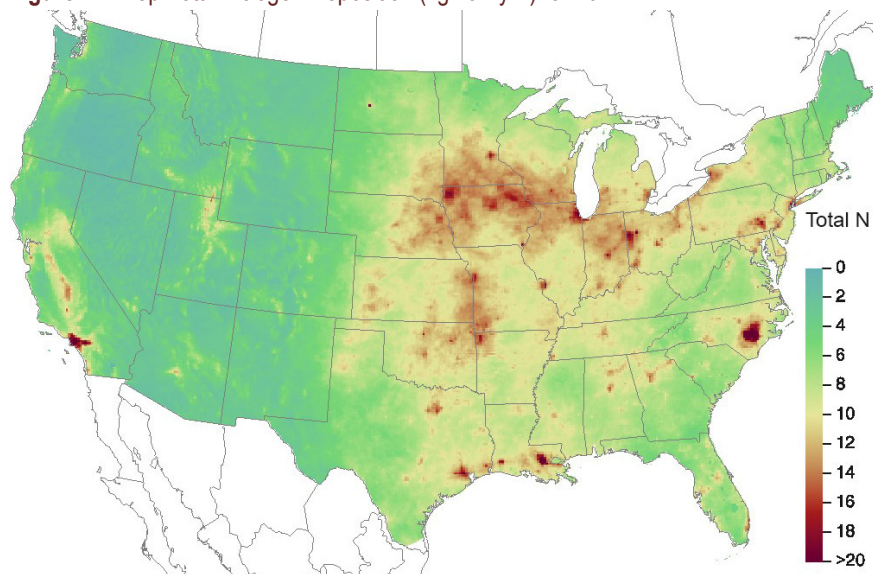
CASTNET reports on the long-term, regional trends of atmospheric pollutants. Figures 2 and 3 show the trends in sulfur dioxide and total nitrate concentrations in the eastern United States between 1990 and 2017. The 3-year mean of sulfur dioxide concentrations decreased by 89% (8.8 to 0.9  $\mu\text{g}/\text{m}^3$ ) between 1990–1992 and 2015–2017 in the eastern United States. Total nitrate (NO<sub>3</sub> + HNO<sub>3</sub>) concentrations decreased by 51% (3.0 to 1.5  $\mu\text{g}/\text{m}^3$ ) over the same period. While concentrations at western CASTNET sites are typically lower, they have not shown the same level of reductions as eastern sites.

### Ozone

CASTNET is the primary network for measuring rural, regionally representative O<sub>3</sub> concentrations and assessing changes in background O<sub>3</sub> contributions. All but one CASTNET ozone site meets 40 CFR Part 58 regulatory monitoring criteria. Two sites are co-located with primary O<sub>3</sub> monitors. These are designated for QA purposes and are, therefore, not used for determining compliance with the NAAQS. As a result, CASTNET data from 82 sites are included in design value calculations to support the NAAQS determinations.

The 3-year average of the fourth highest daily maximum rolling 8-hour average (DM8A) O<sub>3</sub> concentration has decreased 24% (from 85 to 64 ppb) between 1990–1992 and 2015–2017 in the eastern United States. CASTNET sites in the west realized a 10% reduction over the period 1996–1998 to 2015–2017 (74 to 66 ppb). Figure 4 shows the 3-year average fourth highest DM8A for 2015–2017 for CASTNET sites meeting completeness criteria.

Figure 1: TDep Total Nitrogen Deposition ( $\text{kg ha}^{-1} \text{ yr}^{-1}$ ) for 2017



**Dry deposition** is the fraction of atmospheric deposition that is deposited to the earth's surface by settling, impaction, or adsorption.  
**Wet deposition** is the fraction of atmospheric deposition deposited to the earth's surface by precipitation, predominately as rain, snow, or cloud droplets.  
**Dry and wet deposition** are combined to estimate the total deposition of pollutants (gases and particles) to the earth's surface.

Figure 2: CASTNET Trends in Sulfur Dioxide Concentrations (Eastern United States)

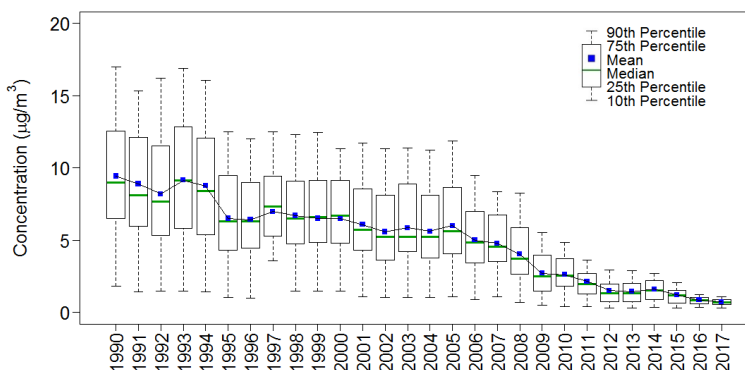
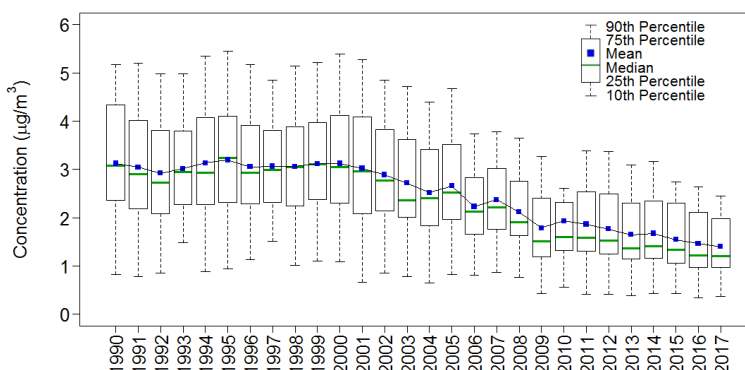
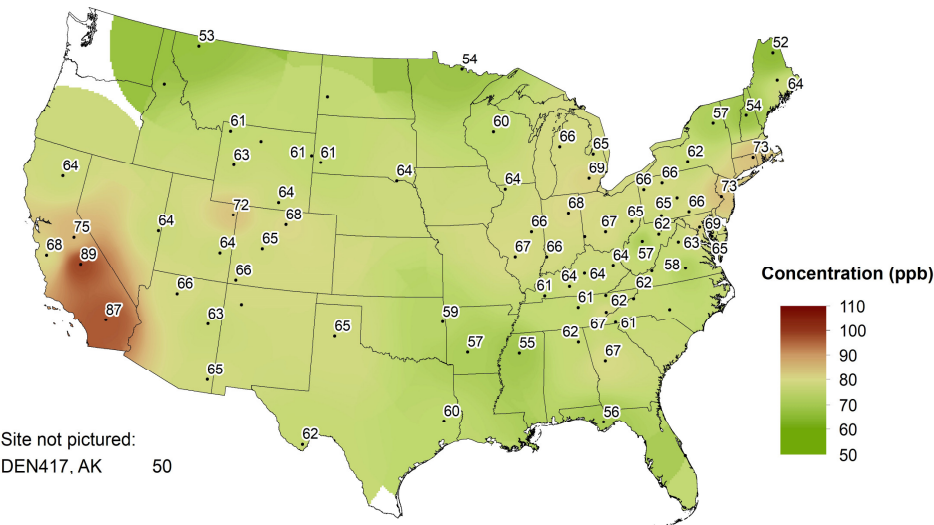


Figure 3: CASTNET Trends in Total Nitrate Concentrations (Eastern United States)





**Figure 4: Three-year Average Fourth Highest DM8A Ozone Concentrations for 2015–2017**

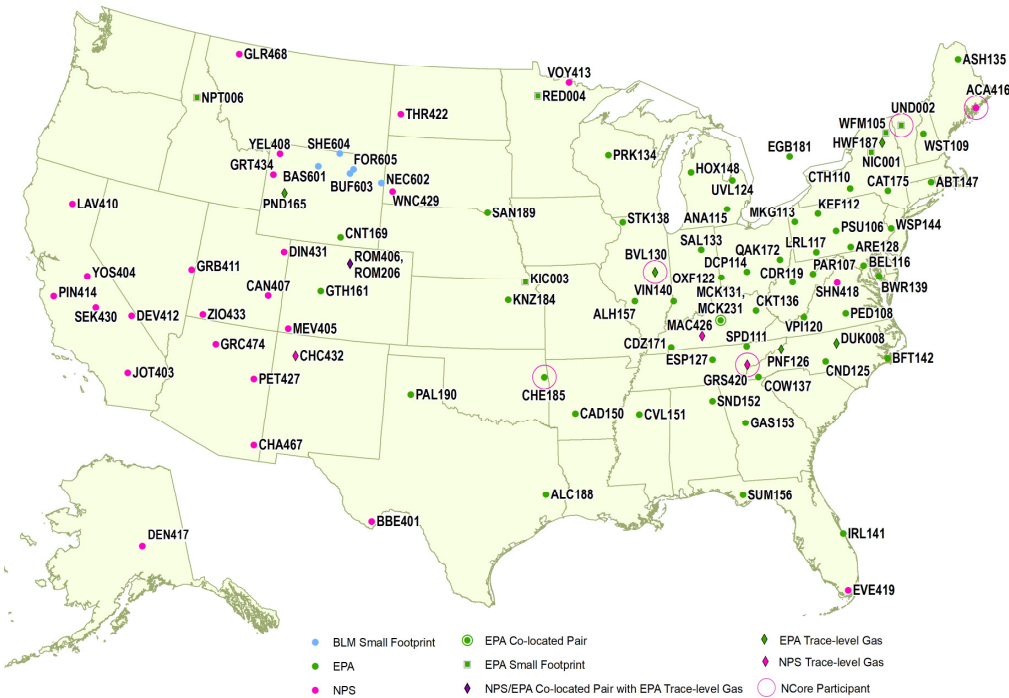


Site not pictured:  
DEN417, AK 50

**CASTNET PARTNERSHIPS**

Figure 5 shows currently operating CASTNET sites. EPA operates 63 sites, NPS operates 29 sites, and BLM operates 5 sites in Wyoming. EPA co-sponsors two of its sites in New York with the New York State Department of Environmental Conservation (NYSDEC) and New York State Energy Research and Development Authority (NYSERDA). EPA co-sponsors a site in Florida with the Indian River Lagoon (IRL) Council. EPA also co-sponsors tribal CASTNET sites with six Native American tribes. Many sites are co-located with other monitoring networks such as NADP's NTN, AMoN, Mercury Deposition Network (MDN), and Atmospheric Mercury Network (AMNet); the Interagency Monitoring of Protected Visual Environments (IMPROVE); and EPA's NCore monitoring network. Together, these complementary networks support regulatory accountability and provide data used by the scientific community to improve and validate air quality models and evaluate changing atmospheric chemical processes.

**Figure 5: CASTNET Site Map**



Network Summary	
<b>Number of Sites</b>	97
<b>Weekly Ambient Measurements</b>	
<b>Gaseous</b>	Sulfur dioxide (SO <sub>2</sub> ) Nitric acid (HNO <sub>3</sub> )
<b>Particulate</b>	Sulfate (SO <sub>4</sub> <sup>2-</sup> ) Nitrate (NO <sub>3</sub> ) Ammonium (NH <sub>4</sub> <sup>+</sup> ) Base cations (Mg <sup>2+</sup> , Ca <sup>2+</sup> , K <sup>+</sup> , Na <sup>+</sup> ) Chloride ion (Cl <sup>-</sup> )
<b>Hourly Measurements</b>	
	Ozone (O <sub>3</sub> ) Trace-level gas* Nitrogen oxide (NO) Reactive oxides of nitrogen (NO <sub>x</sub> ) Sulfur dioxide (SO <sub>2</sub> ) Carbon monoxide (CO) Shelter temperature 9-m temperature
<b>Meteorological Parameters<sup>†</sup></b>	
	2-m temperature Wind speed and direction <b>(1-hour averages)</b> Sigma theta Solar radiation Relative humidity Precipitation Surface wetness

\* At select sites

† Meteorological measurements were discontinued at most EPA-sponsored CASTNET sites in 2010.

**Participating in CASTNET**

By joining a long-term national monitoring program, partners can assess and track regional trends in air quality and deposition. Monitoring data may also improve representation in regional and national policy decisions. While CASTNET will provide technical and logistical guidance in establishing sites, partners are responsible for funding and operations. However, the data validation, training, equipment maintenance and calibration, laboratory analyses, and audits are provided through the established program following site installation.

There are various funding opportunities for air quality monitoring including Science to Achieve Results (STAR) Research Grants, the State and Tribal Grant Program (STAG), various opportunities through EPA's Office of Enforcement and Compliance Assurance, as well as federal, EPA Office of Air and Radiation, tribal, and environmental justice grants available from various EPA offices. Interested in participating in CASTNET? The first step is to reach out to the EPA CASTNET Program Office (puchalski.melissa@epa.gov).

## RESEARCH AREAS

### Enhanced Reactive Nitrogen Measurements

Deposition velocities of species contributing to total reactive nitrogen can vary significantly, leading to large uncertainties in nitrogen flux estimates where individual species are not measured (i.e., NO<sub>y</sub>). EPA's CAMD is currently operating an enhanced reactive nitrogen system at the Duke Forest, NC (DUK008) site. The system uses a traditional NO/NO<sub>y</sub> system with additional converters to speciate reactive nitrogen (i.e., NO<sub>2</sub>, NH<sub>x</sub>) using a single NO detector. Measurements will be compared with other nitrogen monitoring systems deployed at the DUK008 site to evaluate performance of the system and to analyze contributions from the components of reactive nitrogen. Speciated concentrations of reactive nitrogen not only reduce uncertainties in nitrogen deposition but also provide information on precursors for secondary pollutants (O<sub>3</sub>, PM<sub>2.5</sub>), which is useful for understanding NAAQS exceedances.

### Direct Deposition Flux Measurements

Direct measurement of dry deposition fluxes is expensive and labor intensive. However, alternative measurement methods are currently being developed and, once available, will be used to compare estimated dry deposition fluxes from CASTNET to direct deposition measurement results.

EPA's CAMD and Office of Research and Development (ORD) have supported the operation of the Monitor for Aerosols and Gases in Ambient Air (MARGA) at numerous sites. The MARGA produces hourly concentrations of many analytes historically collected by CASTNET plus NH<sub>3</sub>. The MARGA system is being used to measure direct dry deposition fluxes across different ecosystems to improve model parameterizations and characterize the integrated measurements from the CASTNET filter pack. To date, MARGA instruments have been operated at the following locations:

MARGA Operating Group	Location	CASTNET Site ID	Operation Period
CAMD	Beltsville, MD	BEL116	2013–2016
ORD	Duke Forest, NC	DUK008	2011–2018
ORD	Coweeta, NC	COW137	2014–2015
Colorado State University	Theodore Roosevelt National Park, ND	THR422	2015
Colorado State University	Rocky Mountain National Park, CO	ROM406	2015
College of Charleston	Charleston, SC	N/A	2017
Illinois State Water Survey	Bondville, IL	BVL130	2017

In 2019, the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) plans to operate a MARGA in Denton, MD. For more information on collaboration and MARGA use in monitoring intensives, contact the EPA CASTNET Program Office (beachley.gregory@epa.gov).

In 2015, ORD, with support from CAMD and the USDA Forest Service, completed the Southern Appalachian Nitrogen Deposition Study (SANDS), which included dry deposition flux measurements near the COW137, NC site. Equipment included a fast response NO<sub>y</sub> monitor, a MARGA direct deposition system, a Cavity Attenuated Phase Shift (CAPS) monitor for NO<sub>2</sub>, and other advanced equipment. Five subsites within the Coweeta basin monitored concentrations along a transect using passive samplers for NH<sub>3</sub>, SO<sub>2</sub>, and nitric acid. The passive samplers were deployed biweekly in conjunction with CASTNET filter

pack and AMoN sampling. Data from the passive samplers are being used to estimate the spatial variability of sulfur and nitrogen deposition across the Coweeta basin.



### Reduced Nitrogen Measurements

Recognizing the importance of reduced nitrogen in the atmospheric nitrogen budget, its contribution to deposition, and its role in the formation of PM<sub>2.5</sub>, EPA will continue to support reduced nitrogen measurements and deposition model development and parameterizations. EPA's CAMD and ORD are leading the AMoN Site Characterization Study. Soil, leaf, and litterfall samples were collected at three CASTNET sites and analyzed in addition to leaf area index, micrometeorology, and soil temperature and moisture. Data are being processed and used to parameterize the NH<sub>3</sub> bi-directional flux model. The model will be run to calculate NH<sub>3</sub> fluxes at all AMoN sites. The study's goals include improving input parameterizations for an NH<sub>3</sub> bi-directional dry deposition model and increasing understanding of NH<sub>3</sub> compensation points and the factors that most directly affect them.

## DATA AVAILABILITY

**CASTNET Data:** Ambient concentrations, dry and total deposition fluxes, and site information can be downloaded from the CASTNET website (<https://www.epa.gov/castnet>) under "Download Data."

The CASTNET annual report provides long-term trends, regional patterns of pollutants, and network quality assurance results. Recent annual reports can be found on the CASTNET website (<https://www.epa.gov/castnet>) under "Publications."

**NADP Data:** NTN wet deposition data and AMoN ambient NH<sub>3</sub> concentrations can be downloaded from the NADP website (<http://nadp.slh.wisc.edu/data/ntn/>).

**TDep Measurement Model Fusion Estimates:** Data and maps produced using the TDep method can be downloaded from the NADP TDep website (<http://nadp.slh.wisc.edu/committees/tdep/>).

## References

- Butler, T., Vermeylen, F., Lehmann, C.M., Likens, G.E., Puchalski, M. 2016. Increasing Ammonia Concentration Trends in Large Regions of the USA Derived from the NADP/AMoN Network. *Atmos. Environ.* 146:132-140. DOI: 10.1016/j.atmosenv.2016.06.033.
- Schwede, D.B. and Lear, G.G. 2014. A Novel Hybrid Approach for Estimating Total Deposition in the United States. *Atmos. Environ.*, 92:207-220. DOI: 10.1016/j.atmosenv.2014.04.008.