



CLEAN AIR STATUS AND TRENDS NETWORK (CASTNET)

PROGRAM OVERVIEW

CASTNET is a long-term environmental monitoring network with 95 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 (www.epa.gov/castnet) including six Native American tribes that operate CASTNET sites on tribal lands. The network was established under the 1991 Clean Air Act Amendments to assess the trends in acidic deposition due to emission reduction programs such as the Acid Rain Program (ARP), NO_x Budget Trading Program (NBP), the Clean Air Interstate Rule (CAIR), and the Cross-state Air Pollution Rule (CSAPR).

CASTNET measures ambient concentrations of sulfur and nitrogen species as well as rural ozone concentrations. Results from CASTNET are used to report on geographic patterns and temporal trends in acidic pollutants and deposition. CASTNET is the only network in the United States that provides a consistent, long-term data record of acidic dry deposition fluxes.

CASTNET complements the National Atmospheric Deposition Program's (NADP's) National Trends Network (NTN). The NTN 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 collocated 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 CASTNET sites meet the requirements of Title 40 of the Code of Federal Regulations (CFR) Part 58 and are used to determine compliance with the National Ambient Air Quality Standard (NAAQS) for ozone. Hourly ozone measurements are submitted to the AIRNow website (www.airnow.gov) and to EPA's Air Quality System (AQS) database.

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.

RECENT CHANGES TO CASTNET

- In 2012, CASTNET developed a small-footprint monitoring station that does not require a temperature-controlled shelter. These filter pack-only sites can be operated using alternative power sources (wind/solar).
- During 2015, 11 CASTNET small-footprint sites, including 4 off-grid, alternate power sites, were operated.
- Trace-level gas analyzers were operated at eight CASTNET sites

during 2015. All eight sites measured reactive oxides of nitrogen (NO/NO_y). NO_y is a reactive gas and is a precursor for ozone and fine particulate matter. Four of these

CASTNET sites measured sulfur dioxide (SO₂), and three of the sites also measured carbon monoxide (CO).

Between 2007 and 2015, EPA, NPS, and BLM deployed more than 65 NADP Ammonia Monitoring Network (AMoN) sites at CASTNET sites. AMoN sites measure biweekly concentrations of ambient ammonia (NH₃). 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.

In 2012, the EPA and NADP began using the Parameter-elevation Regression Independent Slopes Model (PRISM) to supplement NTN precipitation measurements to create interpolated wet deposition fluxes. Previously, the NADP only used precipitation data from NTN measurements to create the annual precipitation surfaces; however, sparse monitoring locations in the western United States with variable terrain caused known biases in the results. PRISM uses point observations, elevation, and climatic factors to estimate precipitation.

Beginning with the initial release of NADP's Total Deposition (TDEP) hybrid



method in 2013, CASTNET and its sponsors have played an integral role in the development of TDEP, which is used to estimate the relative contributions of the components of total deposition. The hybrid approach combines measurements from CASTNET; NADP's NTN, Atmospheric Integrated Research Monitoring Network (AIRMoN), and AMoN networks; and the Southeastern Aerosol Research and Characterization (SEARCH) network with model output from CMAQ. The method is described in Schwede and Lear (2013) and in a fact sheet available on the NADP TDEP web site at:

nadp.isws.illinois.edu/committees/tdep/. Products available include gridded data sets and maps detailing the components of total nitrogen and sulfur deposition.

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.

CASTNET PARTNERSHIPS

CASTNET sites operating during 2015 are shown in Figure 1. EPA operates 65 sites, NPS sponsors 25 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 also co-sponsors tribal CASTNET sites with six Native American tribes. Many sites are collocated with other monitoring networks such as NADP's NTN, AIRMoN, AMoN, MDN, and AMNet; EPA's NCore monitoring network; and the Interagency Monitoring of Protected Visual Environments (IMPROVE). Five CASTNET sites are collocated with EPA National Core (NCore) monitoring sites.

MEASUREMENTS

Each CASTNET site measures weekly concentrations of acidic pollutants, base cations, and chloride using a 3-stage filter pack with a controlled flow rate. Most CASTNET sites also include a temperature-controlled shelter and continuous ozone monitoring system operated according to 40 CFR Part 58

quality assurance (QA) criteria. The ozone inlet and filter pack are located atop a 10-meter tower. Eight sites measure trace-level concentrations of NO/NO_y with four sites also measuring trace-level SO₂ and three sites measuring trace-level CO.

Data are polled remotely from each CASTNET site and updated daily on the CASTNET website. Data are quality assured using automated screening techniques, semiannual calibration results, site operator comments, and manual data review. EPA operates a collocated site at Mackville, KY. EPA and NPS each operate independent, collocated sites at Rocky Mountain National Park, CO.

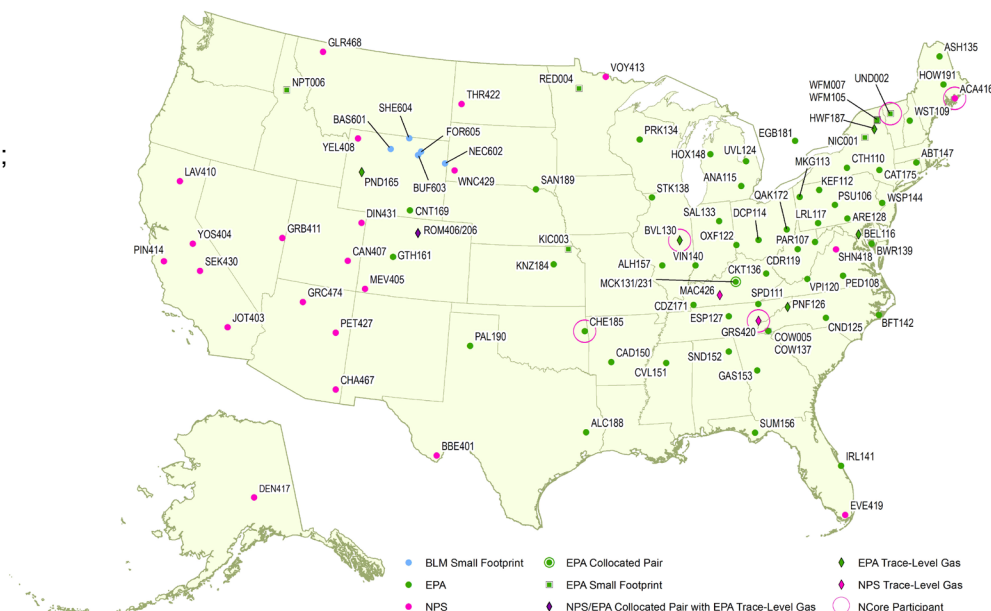
Near real-time ozone data are uploaded to EPA's AIRNow website. The data in AIRNow have only undergone automated screening. Final hourly ozone and trace-level gas concentrations are reported to AQS monthly. CASTNET ozone data reported to AQS are used to calculate ozone design values for comparison with the NAAQS.

ESTIMATES OF DEPOSITION

CASTNET's principal goals include estimating the rate of dry deposition from the atmosphere to sensitive ecosystems and monitoring trends in deposition over time. Since the beginning of CASTNET, hourly meteorological data were used as input to the Multi-Layer Model (MLM) to estimate dry deposition velocities (Meyers *et al.*, 1998). The deposition velocity estimates were then combined with measured atmospheric concentrations to yield dry deposition fluxes. In 2010, meteorological measurements were

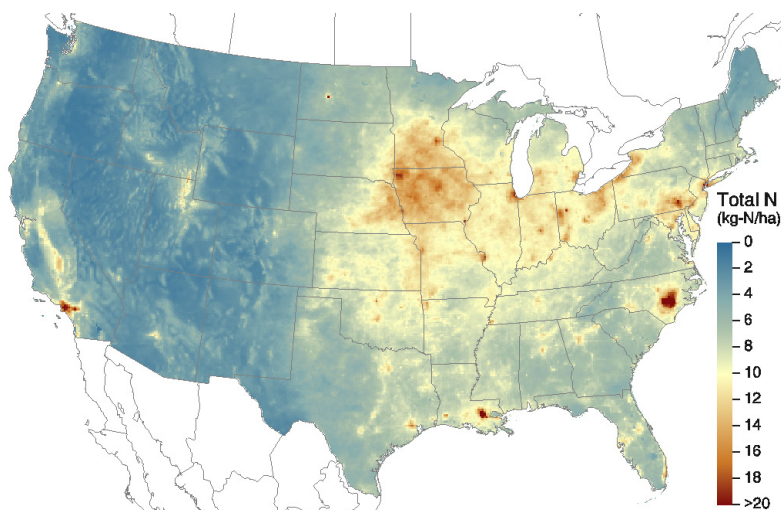
discontinued at most EPA-sponsored CASTNET sites due to changing priorities, which evolved based on input from policymakers and the research community. As a result, EPA developed a method to substitute historical average deposition velocities for missing MLM simulations (Bowker *et al.*, 2011). This method is still in use and provides estimates of trends in deposition. MLM-derived dry deposition values are combined with NADP wet deposition measurements to estimate annual total deposition.

Figure 1: CASTNET Site Map



Total deposition is also assessed using NADP's TDEP hybrid method, which was described previously. The use of CMAQ in combination with available ambient atmospheric concentrations permits greater spatial resolution and the inclusion of many additional nitrogen compounds that contribute to total nitrogen dry deposition. Development of the hybrid method continues as part of the NADP Total Deposition Science Committee's mission to improve estimates of atmospheric deposition. Figure 2 displays the output of the hybrid method for total nitrogen deposition for 2014.

Figure 2: TDEP Total Nitrogen Deposition ($\text{kg ha}^{-1} \text{ yr}^{-1}$) for 2014



ACCOUNTABILITY & RESULTS

Emission reduction programs such as the ARP, NBP, CAIR, and CSAPR have led to significant reductions in sulfur and nitrogen pollutants as well as ambient ozone concentrations. The purpose of CASTNET 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 reports (www.epa.gov/airmarkets).

Atmospheric Concentrations

CASTNET reports on the long-term, regional trends of atmospheric pollutants. Figures 3 and 4 show the trends in sulfur dioxide and total nitrate concentrations in the eastern United States between 1990 and 2014. The 3-year mean of sulfur dioxide concentrations decreased by 82% (8.8 to $1.5 \mu\text{g}/\text{m}^3$) between 1990–1992 and 2012–2014 in the eastern United States. Total nitrate concentrations decreased by 44% (3.0 to $1.7 \mu\text{g}/\text{m}^3$) over the same time 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 ozone concentrations and assessing changes in background ozone concentrations, an indicator of climate change (Bloomer *et al.*, 2010). Nearly every CASTNET ozone site meets 40 CFR Part 58 regulatory monitoring criteria. As a result, CASTNET ozone data that meet the 3-year completeness criterion are used to gauge compliance with the ozone NAAQS.

The 3-year average of the fourth highest daily maximum rolling 8-hour average (DM8A) ozone concentration has decreased 22% (from 84 to 66 ppb) between 1990–1992 and 2012–2014 in the eastern United States. CASTNET sites in the West realized a 6% reduction over the period 1996–1998 to 2012–2014 (74 to 69 ppb). Figure 5 shows the 3-year fourth highest DM8A for 2012–2014 from CASTNET sites meeting completeness criteria.

Network Summary	
Number of Sites	95
Weekly Ambient Measurements	
Gaseous	Sulfur dioxide (SO_2) Nitric acid (HNO_3)
Particulate	Sulfate (SO_4^{2-}) Nitrate (NO_3^-) Ammonium (NH_4^+) Base cations (Mg^{2+} , Ca^{2+} , K^+ , Na^+) Chloride ion (Cl^-)
Hourly Measurements	
	Ozone (O_3) Trace-level gas* Nitrogen oxide (NO) Reactive oxides of nitrogen (NO_y) Sulfur dioxide (SO_2) Carbon monoxide (CO) Shelter temperature 9-m temperature
Meteorological Parameters† (1-hour averages)	
	2-m temperature Wind speed and direction Sigma theta Solar radiation Relative humidity Precipitation Surface wetness

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

Figure 3: CASTNET Trends in Sulfur Dioxide Concentrations (Eastern United States)

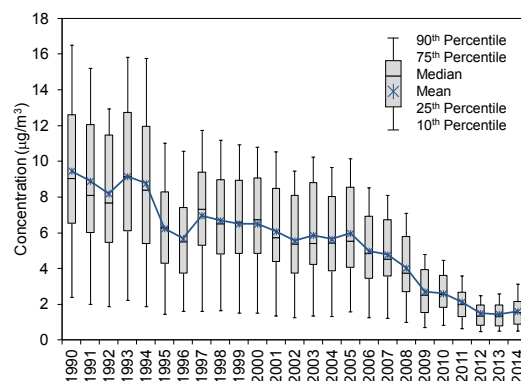


Figure 4: CASTNET Trends in Total Nitrate Concentrations (Eastern United States)

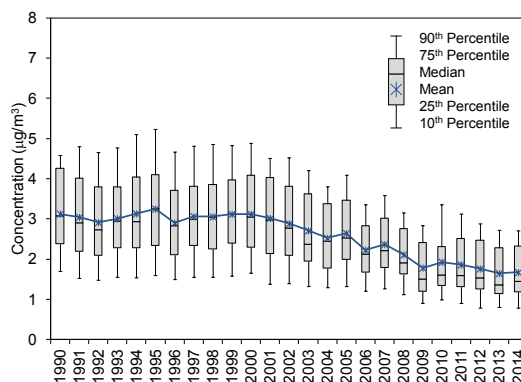
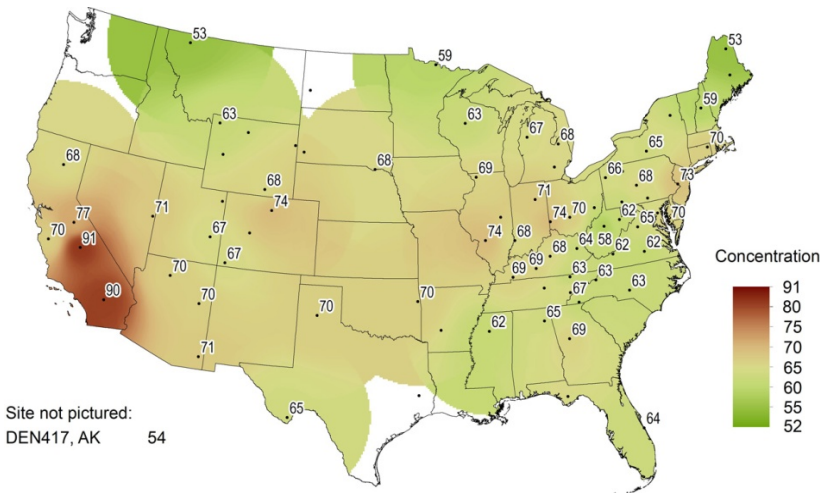


Figure 5: Three-year Fourth Highest DM8A Ozone Concentrations (ppb) for 2012–2014



monitoring intensive at Theodore Roosevelt National Park (THR422) in North Dakota and as part of the Front Range Air Pollution and Photochemistry Experiment (FRAPPE) in Colorado. In 2016, the College of Charleston will be operating a MARGA in South Carolina.

ORD, with support from CAMD, is evaluating methods for dry deposition flux measurements near the COW137, NC site. Equipment includes a fast response NO_y monitor, a MARGA, a Cavity Attenuated Phase Shift (CAPS) monitor for NO_2 , and other advanced equipment. Five subsites in the Coweeta area are monitoring concentrations along an Appalachian valley using passive samplers for NH_3 , SO_2 , and nitric acid. The passive samplers are deployed biweekly in conjunction with CASTNET filter pack and AMoN sampling.

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. EPA's CAMD has deployed an enhanced reactive nitrogen system at the Beltsville, MD (BEL116) site. The system includes additional converters to speciate reactive nitrogen (i.e., NO_2 , NH_x) using a single detector. Measurements will be compared with other nitrogen monitoring systems to evaluate contributions from the components of total reactive nitrogen.

Direct Deposition Flux Measurements

Direct measurement of dry deposition flux is expensive and time-consuming. 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. Two such initiatives are detailed as follows.

EPA's CAMD and Office of Research and Development (ORD) are supporting 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_3 . To date, MARGA instruments have been operated by CAMD at BEL116, MD; by ORD at Duke Forest and at the Coweeta Hydrologic Laboratory (COW137) in North Carolina; and by Colorado State University as part of a

DATA AVAILABILITY

CASTNET Data: Ambient concentrations, dry and total deposition fluxes, and site information can be downloaded from the CASTNET website (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 under "Documents & Reports."

NADP Data: NTN wet deposition data and AMoN ambient NH_3 concentrations can be downloaded from the NADP website (nadp.isws.illinois.edu).

TDEP Hybrid Method Estimates: Data and maps produced using the hybrid method can be downloaded at nadp.isws.illinois.edu/committees/tdep/tdepmaps/.



References

- Bloomer, B.J., Vinnikov, K.Y., and Dickerson, R.R.. 2010. Changes in Seasonal and Diurnal Cycles of Ozone and Temperature in the Eastern U.S. *Atmos. Environ.*, 44:2543-2551. DOI: 10.1016/j.atmosenv.2010.04.031.
- Bowker, G.E., Schwede, D.B., Lear, G.G., Warren-Hicks, W.J., and Finkelstein, P.L. 2011. Quality Assurance Decisions with Air Models: A Case Study of Imputation of Missing Input Data Using EPA's Multi-Layer Model. *Water, Air, & Soil Pollution*, 223:391-402. DOI: 10.1007/s11270-011-0832-7.
- Meyers, T. P., Finkelstein, P., Clarke, J., Ellestad, T.G., and Sims, P.F. 1998. A Multilayer Model for Inferring Dry Deposition Using Standard Meteorological Measurements. *J. Geophys. Res.*, 103(D17):22,645-22,661, DOI: 10.1029/98jd01564.
- 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.