Rocky Mountain Research Station

Research Note

United States Department of Agriculture
Forest Service
Rocky Mountain Research Station
Research Note RMRS-RN-65
June 2014

Ozone Monitoring at Remote Sites Using Low-Power Instrumentation

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Introduction

Collection of non-urban ambient ozone data at regional or larger scales (for example, Peake and Fong 1990; Bytnerowicz et al. 2004) is cost- and labor-intensive. Collection efforts are often further complicated by difficulty of access to data collection sites, the need for climate-controlled facilities to house instrumentation, and a requirement for a connection to utility-grade (grid) power. Regional ozone is more often studied via modeling (for example, Kumar et al. 1994). Although nitrite-based passive samplers (Koutrakis et al. 1993; Vardoulakis et al. 2009) may be used to estimate seasonal and longer-term exposure levels and trends, these samplers are easily contaminated, are sometimes inaccurate, and provide an ozone value that represents accumulation over the entire sample period, ignoring the dynamics of the exposure during that time period. Estimates of other ozone metrics used for regulatory compliance (e.g., W126, AOT40, 8-hour averages) are not possible without continuous ozone data. More detailed knowledge of the daily and longer-term patterns of ozone exposure is vital to evaluating the impact of this pollutant on plant tissues (Musselman and Minick 2000).

Continuous ozone data are usually acquired using large EPA equivalency-method instruments such as the ThermoFisher Model 49i. However, due to their delicacy, bulk, weight (>25 kg) and power consumption (150W), these instruments require a climate-controlled building or shelter, grid power (115V AC or equivalent), and proximity to roads for installation. However, a vegetation-based secondary standard

Citation:

Citation: Korfmacher, John L.; Musselman, Robert C. 2014. **Ozone monitoring at remote sites using low-power instrumentation.** Res. Note RMRS-RN-65. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 7 p.

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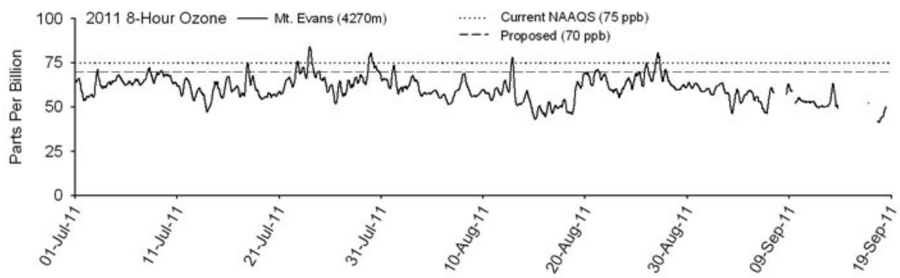

Figure 1—Ambient ozone at a high-elevation site in central Colorado. Note the peaks approaching 100ppb at this remote, well-mixed site.

for atmospheric ozone concentration has been proposed (USEPA 2011) that will result in increased need for data collection at remote sites where standard instrumentation would be difficult to deploy. Although some organizations (for example, U.S. National Park Service) currently conduct remote-site ozone data collection with portable instruments, little information exists on the design and construction of these facilities. Deployment of data collection assets to remote sites will assist in compliance with regulatory mandates, create new opportunities for research, and may generate some surprising results (for example, figure 1).

In 2006, the Air, Water and Aquatic Environments Science Program of the Rocky Mountain Research Station (RMRS), U.S. Forest Service (USFS), began ozone data collection in central and western Colorado in response to requests from other USFS units (Musselman and Korfmacher 2014). Ozone data collection resources in the western United States are sparse and are concentrated in urban or suburban settings that do not adequately represent ozone in rural or remote areas or at high elevation. To address the need for remote-site ozone data, RMRS developed an automated, stand-alone, solar-powered installation for a new type of low-power monitor (Models 202 and 205) from 2B Technologies, Inc., Boulder, Colorado (figure 2).

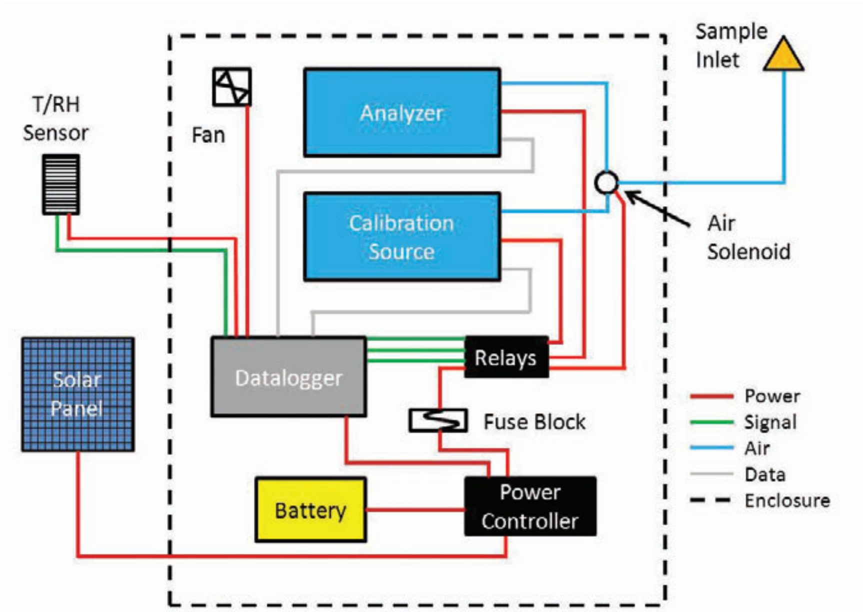

Figure 2—Schematic of the portable ozone analyzer installation (Versions 5.0 and 5.1).

Ozone analyzers were initially deployed at three locations in 2006 and expanded incrementally by 2012 to 17 locations in the southern Rocky Mountains (Musselman and Korfmacher 2014). Additional installations have been deployed at 12 USFS Experimental Forests in the United States and Puerto Rico. Two versions of the installation for "three-season" (spring-summer-autumn) were developed, and an insulated third version was developed to provide year-round data collection capability.

Installation Descriptions

Version 3.1 (figure 3; instrument mounting panel photo, engineering diagram and sample datalogger program available in Korfmacher and Musselman 2014)

This is the smallest, simplest and least expensive version. It consists of an ozone analyzer, power controller, small air circulation fan, 32 A-hr 12V battery, 40W solar panel, and a Campbell Scientific CR800 datalogger. The datalogger records ozone data, environmental variables, analyzer flow rate, and sample cell pressure, and it is programmed to turn off the analyzer if battery power is insufficient or if air temperature drops below freezing. The datalogger also will turn on the circulation fan if the temperature exceeds 30 °C. Version 3.1 is also equipped with a small activated-charcoal canister and air solenoid for the purpose of conducting datalogger-controlled zero checks of the analyzer. Datalogger programming is flexible and can accommodate additional instrumentation and a broad range of custom control and measurement functions. Periodic on-site calibrations with a portable ozone calibration source are necessary with this version of the installation.

Power supply for the installation is managed by a 6-amp Morningstar power controller, a low-cost, off-the-shelf component commonly used for small solar power applications. One 12-volt, 32 amp-hour deep-discharge battery permits operation of the ozone analyzer for about 80 hours without recharging (if, for example, the solar

Figure 3—Version 3.1 installation on the Black Hills National Forest showing inlet support, instrument/battery enclosure and 40W solar panel.

panel is covered with snow). A 40-watt solar panel is necessary to keep the battery at full charge. This wattage has proven adequate for the relatively sunny conditions in the southern Rocky Mountains, but other locations may require higher wattage. For example, the installation at the cloudiest location in the study (Mt. Evans, Colorado, 4300 m) required two 40-watt solar panels for adequate charging.

Total cost of materials for construction of a Version 3.1 installation is approximately $7960 (see parts and price list in Korfmacher and Musselman 2014).

Version 5.0 (figure 4; instrument mounting panel photo, engineering diagram and sample datalogger program available in Korfmacher and Musselman 2014)

Version 5.0 incorporates an ozone calibration source (2B Model 306) in place of the charcoal canister. The calibration source conducts a multi-point calibration check (typically zero, span, and two precisions) of the analyzer at a user-specified interval (typically once per week). In addition, Version 5.0 is equipped with an air temperature and relative humidity sensor (Campbell HMP50), and a thermocouple for recording instrument temperature. A Campbell CR1000 datalogger is used for data storage, power control and calibration check functions. Inclusion of the calibration source permits the Version 5.0 (and 5.1, below) installation to meet standards for EPA equivalency-method data collection when other siting criteria are met.

Total cost of materials for construction of a Version 5.0 installation is approximately $13,770 (see parts and price list in Korfmacher and Musselman 2014).

Figure 4—Version 5.0 installation showing 40W solar panel, instrument/battery enclosure, and sample inlet support (Gunnison National Forest near McClure Pass, Colorado).

Version 5.1 (Figure 5; instrument mounting panel photo, engineering diagram and sample datalogger program available in Korfmacher and Musselman 2014)

Version 5.1 is a cold-weather modification of Version 5.0, built in a larger enclosure to allow for the inclusion of 5 cm (R-13) of insulation around the analyzer and calibration source. Datalogger programming for this version includes code for control of a cold-weather mode of operation. In cold-weather mode, the Version 5.0 installation uses the calibration source's ozonator heater to keep the instruments warm. Although this requires additional battery power (60 A-hr total) and greater solar capacity (75-120W depending on location), it extends the installation's operating range down to about -25 °C and permits year-round data collection in most locations.

Total cost of materials for construction of a Version 5.1 installation is approximately $14,600 (see parts and price list in Korfmacher and Musselman 2014).

All versions of the installation use serial (RS232) communications for datalogger download and data/instruction transmission between the instruments and datalogger. For details, see Korfmacher and Musselman 2014. Power to the air solenoid, analyzer (and ozone calibration source, in Versions 5.0 and 5.1) is controlled by the datalogger via small, PC-board latching relays (see circuit diagram and photo in Korfmacher and Musselman 2014).

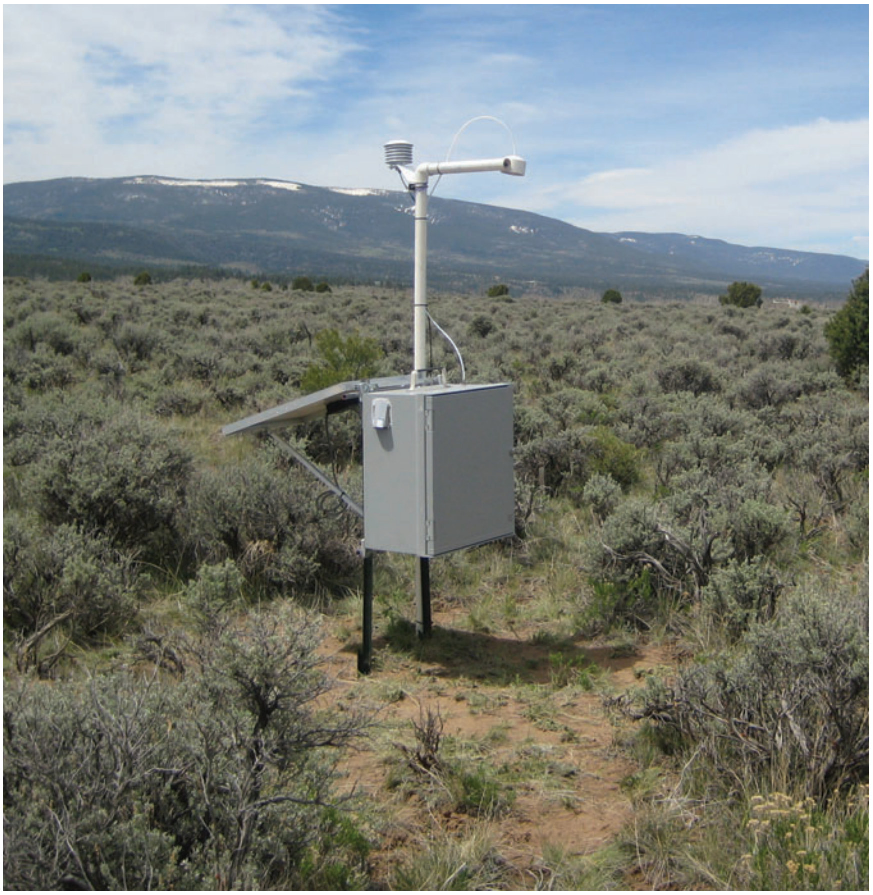

Figure 5—Version 5.1 installation showing 75W solar panel, larger insulated instrument/battery enclosure, and sample inlet support (USFS Helipad, Dutch John, Utah).

Field Use of the Ozone Instrument Installations

It is possible to pack-transport all three versions of the ozone installation. The total weight of a Version 3.1 installation, including battery and solar panel, is about 25 kg, and Version 5.0 (with the addition of the calibration source) is about 27 kg. Version 5.1 is in a larger, bulkier enclosure to make room for the insulation and an additional battery and is considerably heavier (40 kg).

The enclosure is secured by its mounting lugs to two horizontal bars (typically 2.5-cm aluminum square tube) that are fastened with U-bolts to two steel fence posts pounded into the ground about 0.7 m apart. The solar panel is fastened to the back of the steel posts and instrument enclosure. Sample inlets should be at least 2 m above ground level and protected from particulate contamination by a PTFE inlet filter of 0.5-mm (or smaller) pore diameter.

RMRS has installed analyzers at locations ranging in elevation from 1600 to 4300 m. The analyzer's firmware and internal pressure sensor automatically compensate for variations in atmospheric pressure and ambient temperature, although operation of machines without insulation at sub-freezing temperatures is not recommended. Instrument operation at low temperatures is associated with erratic ozone data due to more frequent pump diaphragm failures and/or malfunction of the analyzer's mercury-vapor UV lamp.

In 6 years of data collection, four sites have experienced data loss due to damage from external sources. One high-elevation site was struck by lightning, resulting in the destruction of the analyzer's circuit board. Three other sites were damaged by animals (cattle and elk). Fenced enclosures should be used for the installation on sites where large animals are present.

The analyzer's two standard pumps are rated for 3000 hours of operation each, for a total of about 8.5 months. Failure of the primary pump will automatically activate the backup. This system has occasionally failed, resulting in lost data and damage to the pump power-control components on the circuit board. The manufacturer has recently introduced long-life (15,000-hour) pumps and improved circuitry that largely negate this shortcoming.

The analyzer's mercury-vapor UV lamp has experienced durability problems. A new lamp typically will perform adequately for 6-12 months, after which the lamp's output can become erratic, resulting in large sample-to-sample variation. However, the lamps are easily replaced and may be reconditioned by placing them in an oven at 90°C for 3-4 hours. Lamp performance can be tracked, and quality-control protocols implemented, if the datalogger is programmed to record the standard deviation of sample measurements.

RMRS experience has indicated that UV lamp performance is much less of an issue in the 2B Model 205, which incorporates dual sample cells. Data quality may be significantly enhanced by selecting the Model 205, especially at sites where long-term, continuous data collection is required. The improved performance of the Model 205 may be well worth the additional cost.

RMRS field protocols specify monthly on-site visits at each installation for data download, inlet filter membrane change, instrument calibration (in the case of Version 3.1 installations) and, if necessary, instrument repair. Regular replacement of inlet filter membranes is especially critical if wildfires have occurred near or upwind of the analyzer, or if the analyzer is deployed in a very dusty location. Remote communication with the dataloggers is possible via cellphone or satellite modem, which could potentially reduce the number of site visits, but RMRS did not consider the additional expense and complexity to be justified. However, adding wireless communications to an installation may be desirable for operators of sites that are very remote or have other unique access problems.

Acknowledgments

The equipment, programs and procedures described here and in supplemental materials were developed in part with funding from Region 2, USFS. The authors thank John Birks, Morgan Allers, and Craig Williford of 2B Technologies, Boulder, Colorado; John Frank, RMRS; Andrea Holland, White River National Forest; and Helen Kempenich, Ashley National Forest, for field and technical assistance. We also thank Robert Stencel, University of Denver; Roger Wilson; Aspen Skiing Co.; and Eldora Mountain Resort for accommodation of field sites. Mention of companies, products or trade names does not constitute endorsement by the U.S. Department of Agriculture, US Forest Service, or any other government entity.

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