AUTONOMOUS LOW-COST OZONE SENSORS: DEVELOPMENT, CALIBRATION, AND APPLICATION TO STUDY URBAN-RURAL GRADIENTS

COLORADO STATE UNIVERSITY EXTENSION

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PROJECT INTRODUCTION

Numerous studies have correlated short term ozone (O_3) pollution with respiratory irritation. O_3 is a strong oxidizer, damaging respiratory tissue and causing the apoptosis of respiratory cells. Short term O_3 exposure can cause irritation and worsen preexisting conditions such as asthma in immunocompromised individuals. Long term O_3 exposure has been correlated with premature death due to respiratory failure and respiratory cancer. Urban O_3 pollution is highly monitored with EPA standardized reference monitors, while rural O_3 pollution is rarely monitored despite the pollutant posing a health risk to rural populations and livestock.

Low-cost gas analyzers have potential as a cost-effective solution for monitoring O_3 pollution in remote locations and studying spatial O_3 gradients. During the summer of 2020, we worked with dairies to understand the impact of O_3 pollution on several bovine health markers while also evaluating a candidate low-cost O_3 sensor, the Aeroqual SM50. While the Aeroqual SM50 demonstrated promise as a stand-alone monitoring solution for ozone exposure, an additional summer of testing was needed to better assess the performance of the sensor and develop solutions to fix sensor overheating and fouling. In this study, Aeroqual SM50 sensors were deployed at five sites across Eastern Colorado alongside reference monitors. These sensors were evaluated over a 2-month rooftop deployment and 1-month field deployment. The efficacy of these low-cost sensors as stand-alone monitoring solutions was established using a range of 1 day test-train interval calibrations.

STUDY GOALS

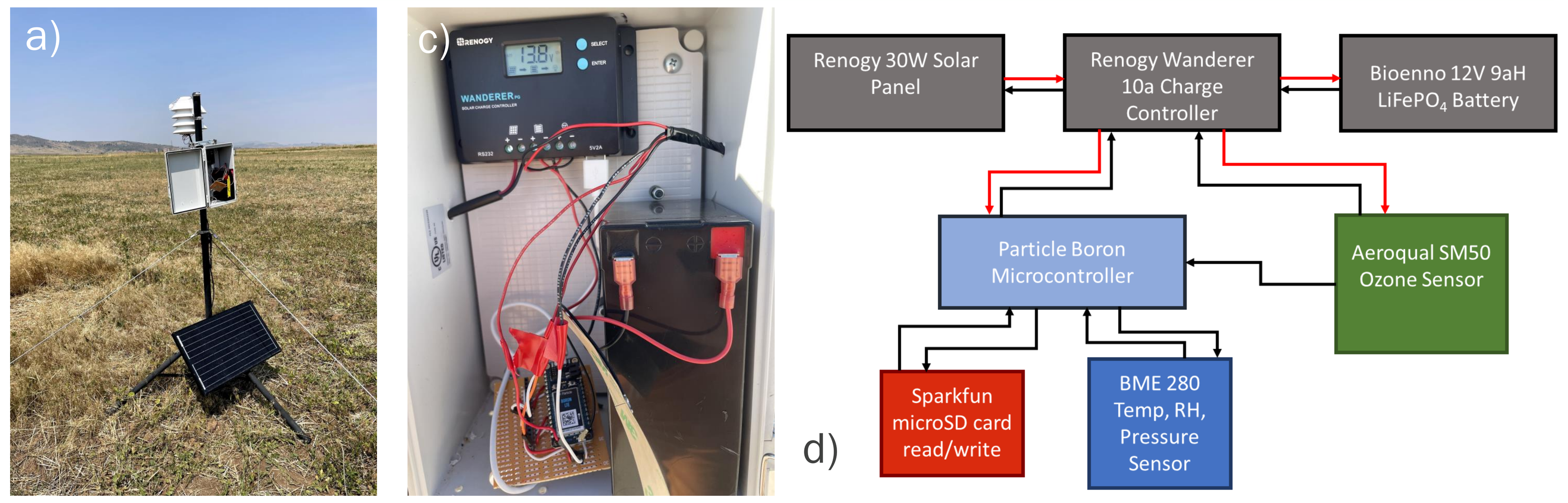
1) Develop and test a radiation shield to reduce the impacts of temperature on the Aeroqual SM50 O_3 sensor.
2) Establish the efficacy of the Aeroqual SM50 sensor as a stand-alone monitoring solution for studying rural O_3 pollution.
3) Examine O_3 pollution gradients across Eastern Colorado using reference monitors and see if our low-cost sensor network can capture this gradient.

HOW DOES THIS APPLY TO YOUR EDUCATION

Product development and testing:
- Developing the radiation shield used in this study required me to learn 3D printing and improve my computer aided design skills.
- I had to iterate, test, and evaluate several prototypes in order to make a fully functioning radiation shield.

Experimental design and collaboration:
- When designing this study, I worked with Extension office and Colorado Department of Health and Environment personnel to coordinate deployments.
- I worked to organize the equipment needed to deploy 8 instruments in the field.
- I gained significant experience in data post-processing, organization, analysis, and presentation.

MOOS SENSOR DESIGN



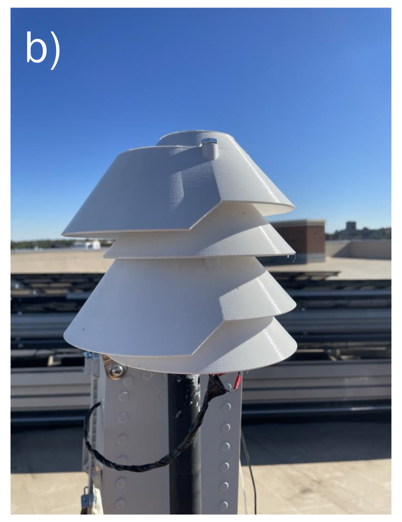
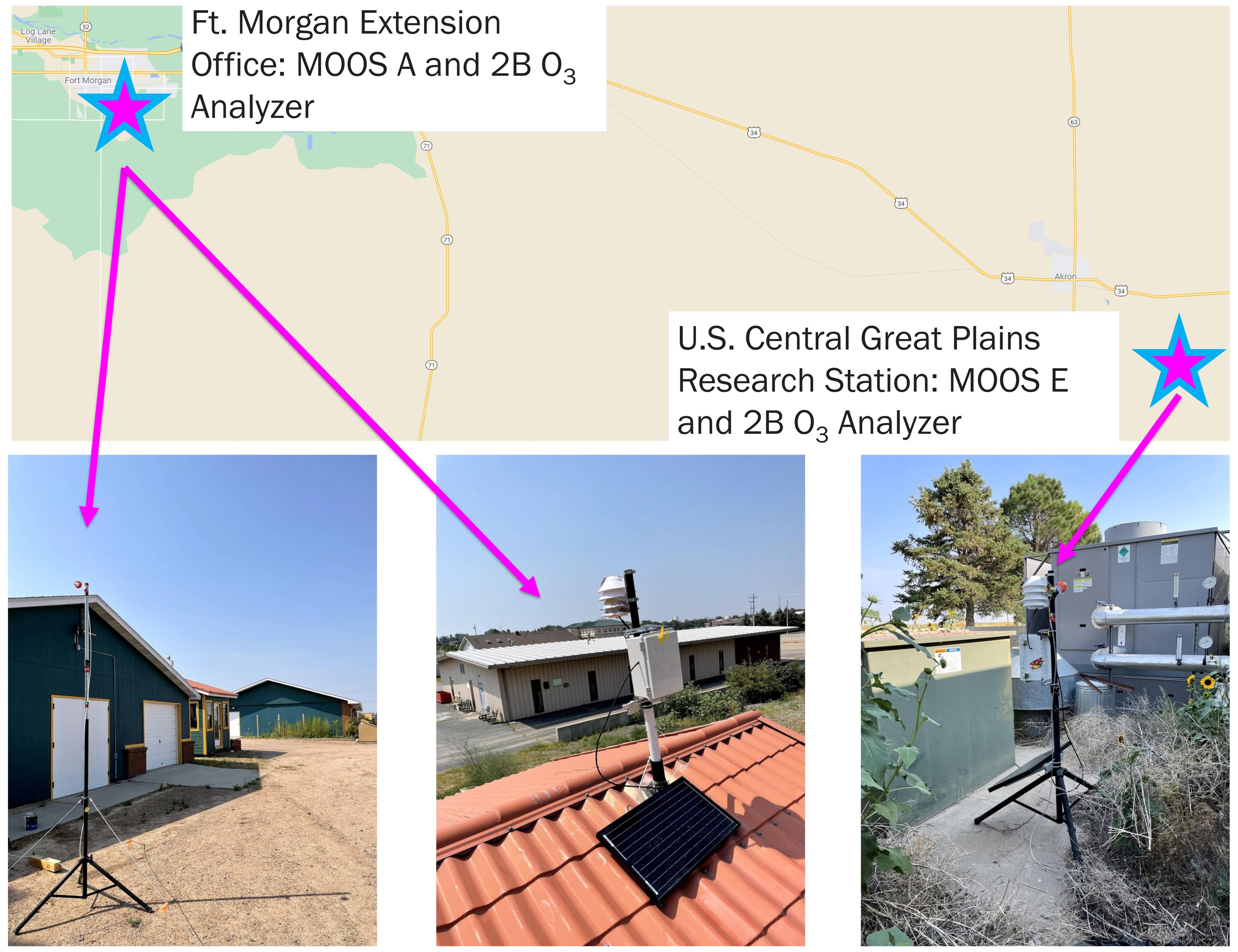


Figure 1: (a) A fully assembled tripod and guy wire setup, sensor radiation shield, and electronics enclosure named "MOOS." (b) An actively cooled radiation shield was developed to protect the sensor inlet from direct ambient air exposure and minimize the temperature of the sensor. This radiation shield used a fan to push air over the sensor while simultaneously venting the sensor housing. (c) The electronics system for the MOOS. (d) A schematic of all the electronic parts.

OVERVIEW OF EXTENSION DEPLOYMENTS



STUDY RESULTS

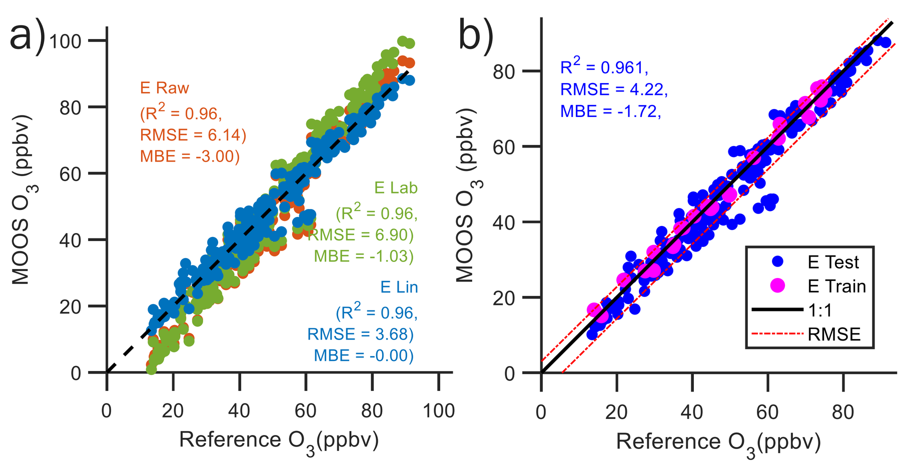


Figure 2: Pre-field comparison of MOOS E and collocated reference monitor O_3 measurements. Raw, laboratory corrected, and full linear corrected MOOS data is shown in (a) and the 2nd worst 1-day linear correction compared is shown in (b).

- Uncorrected measurements from the MOOS tended to underestimate lower O_3 concentrations and overestimate higher O_3 concentrations (Fig. 2a).
- Applying a laboratory calibration developed using a 2B O_3 generator resulted in a higher measurement error than the raw signal ($RMSE_{lab}$ = 6.90 ppbv)(Fig. 2a).
- A linear correction applied to the raw MOOS signal significantly reduced measurement error across all O_3 concentrations ($RMSE_{lin}$ = 3.68 ppbv)(Fig. 2a).
- If we break the entire data set into nine 24-hour intervals and use one interval to develop a linear correction, the 2nd worst interval linear correction increased measurement error by less than 1 ppbv (RMSE = 4.2 ppbv)(Fig. 2b).

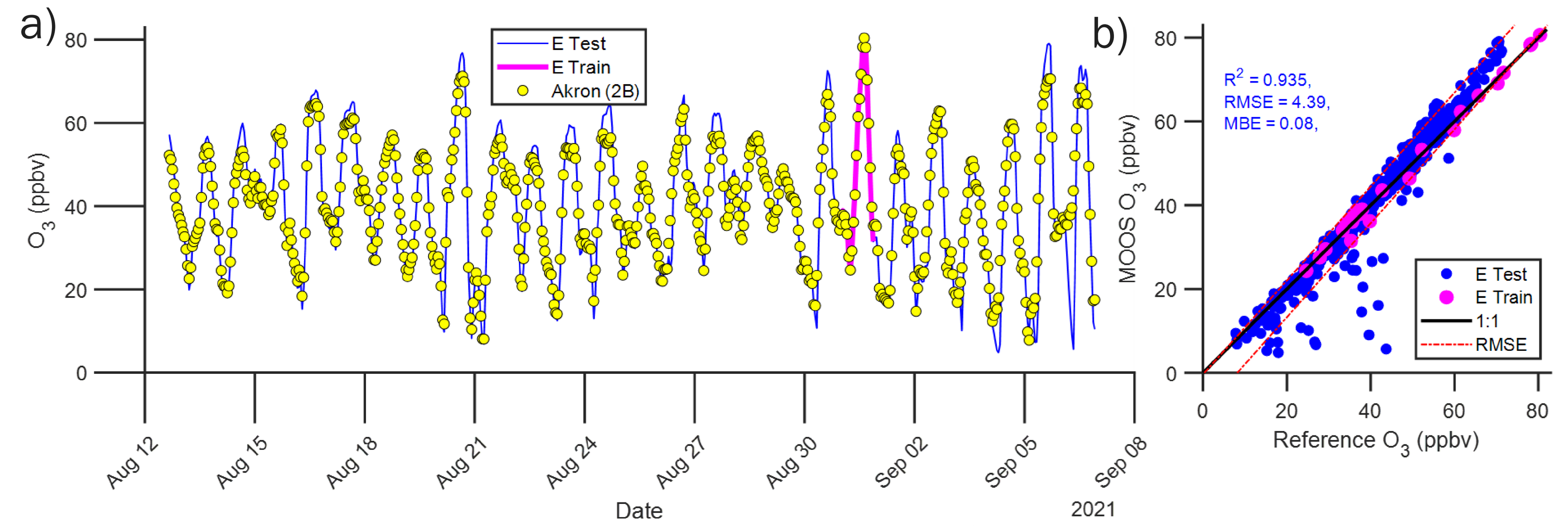


Figure 3: Time series and scatterplot comparison of MOOS E and collocated reference monitor O_3 measurements for the 3rd worst 1-day linear correction.

- When we used twenty-five 24-hour intervals to develop linear corrections in the field, the 3rd worst interval linear correction estimated O_3 concentrations within 4.39 ppbv (Fig. 3b).
- The Aeroqual SM50 has potential as a standalone solution for rural O_3 pollution monitoring, and the radiation shield appears to improve sensor performance.

NEXT STEPS

I am working to further study the performance of these sensors and present my findings as part of my master's thesis. I plan to include a more detailed discussion of sensor drift, O_3 spatial gradients, and sensor sensitivity to variables such as temperature in this analysis.