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Atmospheric monitoring of a perfluorocarbon tracer at the 2009 ZERT Center experiment

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ABSTRACT

Field experiments at Montana State University are conducted for the U.S. Department of Energy as part of the Zero Emissions Research and Technology Center (ZERT) to test and verify monitoring techniques for carbon capture and storage (CCS). A controlled release of CO_2 with an added perfluorocarbon tracer was conducted in July 2009 in a multi-laboratory study of atmospheric transport and detection technologies. Tracer plume dispersion was measured with various meteorological conditions using a tethered balloon system with Multi-Tube Remote Samplers (MTRS) at elevations of 10 m, 20 m, and 40 m above ground level (AGL), as well as a ground-based portable tower with monitors containing sorbent material to collect the tracer at 1 m, 2 m, 3 m, and 4 m AGL. Researchers designed a horizontal grid of sampling locations centered at the tracer plume source, with the tower positioned at 10 m and 30 m in both upwind and downwind directions, and the MTRS spaced at 50 m and 90 m downwind and 90 m upwind. Tracer was consistently detected at elevated concentrations at downwind sampling locations. With very few exceptions, higher tracer concentrations correlated with lower elevations. Researchers observed no statistical difference between sampling at 50 m and 90 m downwind at the same elevation. The US EPA AERMOD model applied using site-specific information predicted transport and dispersion of the tracer. Model results are compared to experimental data from the 2009 ZERT experiment. Successful characterization of the tracer plume simulated by the ZERT experiment is considered a step toward demonstrating the feasibility of remote sampling with unmanned aerial systems (UAS's) at future sequestration sites.

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1. Introduction

The combustion of fossil fuels accounts for more than 90% of greenhouse gas emissions in the United States (US EPA, 2000). Carbon capture and storage (CCS) technology is being developed as a promising approach to stabilizing and eventually decreasing concentrations of CO_2 in the atmosphere. CCS is the process by which CO_2 emissions are captured from large point sources, such as fossil fuel-fired electric power generating facilities, compressed, and injected into geologic formations for permanent storage. Current research addresses concerns about the reliability of storage reservoirs and the potential for migration that could result in the release of CO_2 to the atmosphere (Klara et al., 2003).

The Zero Emissions Research and Technology Center (ZERT) exists as a collaborative effort between several national laboratories and universities to fill critical needs of the U.S. Department of Energy's Carbon Sequestration Program by exploring the basic science of geologic carbon sequestration (Spangler et al., 2009). The National Energy Technology Laboratory (NETL) has participated in ZERT experiments at a test site in Bozeman, Montana since 2006 (Strazisar et al., 2009). NETL's research goals for ZERT include investigating geologic sequestration in coal seams; studying the fundamentals of CO_2 flow through porous media; and building measurement, monitoring, and verification (MMV) strategies.

To develop measurement techniques that verify safe storage by detecting leakage of CO_2 to the surface, NETL has been investigating the feasibility of using perfluorocarbon tracers (PFTs) injected with the CO_2 for leak detection. The Carbon Sequestration Program goal of demonstrating 99% storage permanence by geologic sequestration requires the ability of geologic sequestration site operators to detect

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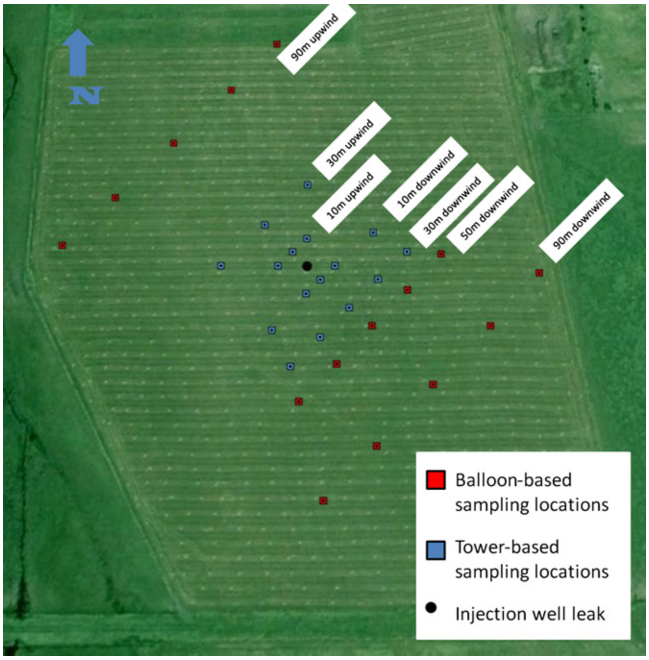

Fig. 1. Balloon-based and tower-based sampling locations for the July 17, 19, and 20, 2009 experiments.

leakage of CO_2 into the atmosphere at a level of one percent of the stored amount of CO_2 (NETL, 2007). The sensitivity of the atmospheric measurements must therefore achieve detection at low levels. Small increases in atmospheric CO_2 concentration due to seepage from the storage reservoir are difficult to distinguish from the natural variability of atmospheric CO_2 concentrations. Loh et al. (2009) report that during well mixed meteorological conditions in daytime, an increase of 4 ppm ($\sim$1%) over background concentration is necessary for accurate quantification of CO_2 flux. A tracer chemical can be detected and distinguished from background concentrations more readily than slight changes in CO_2 concentrations. PFTs have been used in other atmospheric studies for meteorological and environmental monitoring applications (Schichtel et al., 2005; Pitchford et al., 2000; Archer et al., 1997; Draxler et al., 1991). At the ZERT site, researchers conducted an experiment with controlled flux rates of CO_2 with co-injected PFT released to the surface from a well-defined location. In the summer of 2009, arrays of ground-based and aerial monitors measured PFT concentrations before and after injection experiments. The PFT was actively or passively collected on a sorbent material that was analyzed in the laboratory. Tethered balloons allowed collection of the aerial samples. These experiments serve as a basis for planning future experiments using unmanned aerial systems (UAS's) rather than the balloons. Ultimately, NETL aims to demonstrate the usefulness of PFT monitoring using UAS's and a ground-based array of monitors to monitor leakage events via simulations, field and laboratory studies. The experiments conducted by NETL in 2009 established a framework for detection of the PFTs and a protocol for sampling with incorporation of atmospheric dispersion models into the sampling plan.

2. Materials and methods

2.1. Site description

The ZERT field test site in Bozeman, Montana consists of an agricultural plot at the edge of Montana State University's Bozeman campus. According to the U.S. Environmental Protection Agency's Toxics Release Inventory Program (TRI), there are no large sources of air pollution near the site (U.S. EPA, 2008). The site is flat and covered with grasses, alfalfa, clover, dandelion, and thistle. During the summer, wind typically comes from the northwest during the day, changing to southeast at night with speeds usually between 1–3 m s^{-1}. A 98 m horizontal well oriented southwest-to-northeast was installed approximately 2 m below the ground surface. The horizontal well is slotted to allow the release of CO_2, and is divided into six packer sections. During the summer 2009 experiments, the surface leak of CO_2 from the fourth packer section was in a known location about one meter in diameter and near the center of the site. A meteorological station was maintained at the ZERT site with

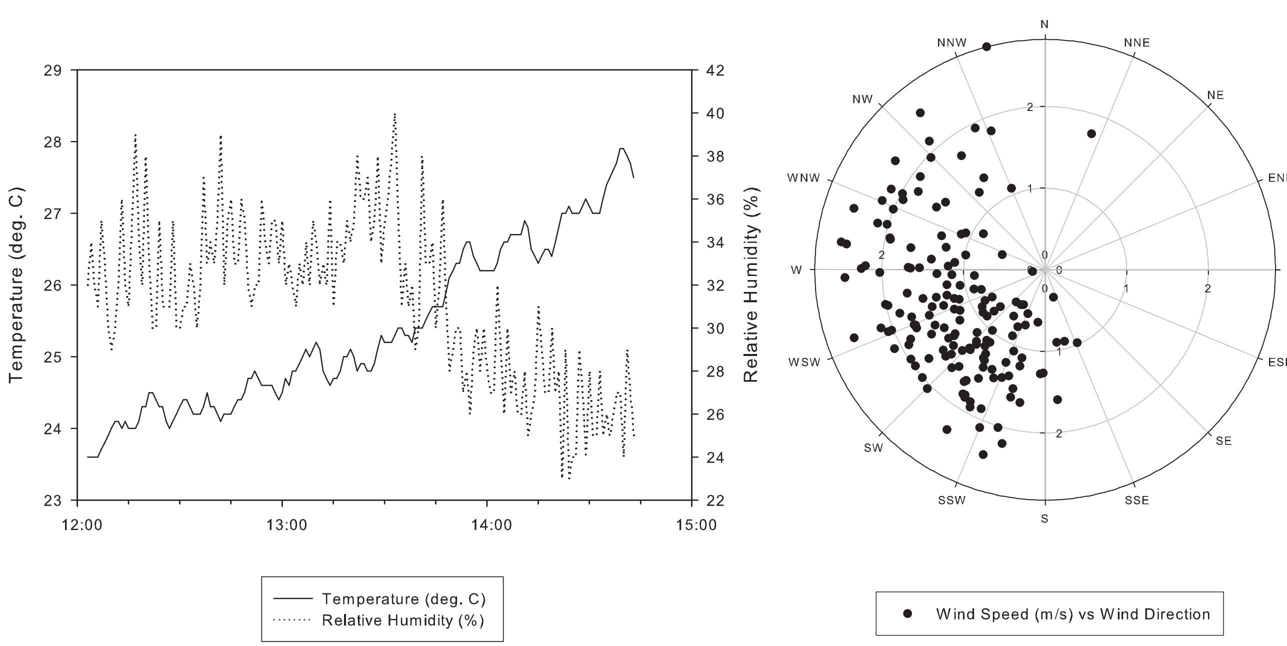

Fig. 2. Temperature, relative humidity, wind speed and wind direction for the experiment conducted on July 17, 2009.