BluBird Instrument Responses to Controlled Natural Gas Release

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1. Experiment Overview

As part of Earthview's continuous efforts to improve the performance of the BluBird Platform, a series of controlled release experiments were carried out in late July 2021. This test is part of ongoing work by Earthview intended to:

- Verify the gas detection capability of the BluBird system
- Test the consistency of modeled vs. measured gas concentration
- Demonstrate the ability to quantify a leak rate given measured concentrations and wind conditions.

Six BluBird version 1.0 instruments in field-ready configuration were positioned at fixed distances ranging from 12m to 40m downwind of a standard CGA cylinder containing compressed natural gas with the gas released at a fixed rate of **1.1 kg/hr** for varying time intervals. Each BluBird sampled the ambient air at a typical interval of 55 seconds, with data (including wind speed and direction) uploaded autonomously to the Earthview cloud database and real-time dashboards.

Earthview-derived algorithms were applied to the BluBird sensor readings to convert sensor-level measurements into estimated methane concentrations. Predicted concentrations, calculated using a Gaussian plume dispersion model, were compared to the BluBird-estimated concentrations. Finally, the inverse of this modeling was done to calculate a likely emission rate given the BluBird-measured gas concentration.

Preliminary Results

Supporting details are provided throughout, but the key takeaways are:

- BluBird instruments were able to detect the emission at the maximum distance tested (38 m / 124 ft).

- The BluBird-estimated gas concentrations were within the range of concentrations predicted using the plume model run in "forward" mode (i.e., to predict concentrations given a known emission rate) using three different atmospheric stability assumptions.
- Estimating potential leak rates using the plume model in inverse mode (i.e., to calculate the emission rate that would yield an observed concentration) with the BluBird concentrations as input, yielded emission rates from 0.4 kg/hr to 2.7 kg/hr; compared to the 1.1 kg/hr rate measured by the flowmeter on the gas cylinder.

2. Experiment Conditions and Set-up

2.1 Location and Time

The experiment was performed outside Earthview's production facility near Longmont, Colorado. on 27 July 2021 at 10:25 - 12:24 hrs. Mountain Time. There were three main periods ("Periods 1, 2 and 3") of gas release, lasting 29 minutes, 30 minutes and 4 minutes respectively.

Location

For this experiment, the gas tank and 6 BluBird units were aligned in a row, arranged between two one-story, single-structure, continuous garage-type buildings spaced about 18m apart, with no openings along the row but with a slight overhang at the building roof line. (This arrangement proved suitable since winds during the test were aligned parallel to the buildings.) The units were set about 2m from this overhang edge, with the BluBird air intakes (at a height of about 3.7m) extending slightly above the roof edge height. The nearest obstruction upwind of the BluBirds was about 70m when winds were from the north at the start of the experiment, to 120m wind winds shifted to the south. The buildings and the BluBird units were aligned due

north and south. The ground surface was dark asphalt. There were no known additional emission sources in the area at the time. Vehicles parked nearby were stationary with engines off.

2.2 Conditions

Winds

Winds were light, interspersed by some calm periods. Wind direction shifted from due north initially, to due south. (As noted above, this aligned the winds so that they passed along the open area between the two rows of buildings.) The gas cylinder was repositioned to keep the source upwind of the BluBird units. Average and maximum wind speeds during the three gas release periods were

Period	Average Wind Speed (m/s)	Max Wind Speed (m/s)
1	0.8	1.6
2	1.1	2.0
3	0.9	1.7

At the start of Period 1, additional air flow was generated temporarily using a hand-held electric blower, which increased the initial wind speed at the BluBirds to 2.6 to 2.8 m/s at BluBird Primary #51 for about 3 minutes. The blower was not used after that time. During portions of the experiment, additional wind speed measurements were obtained using a hand-held Kestrel anemometer. Those data were consistent with the BluBird anomemeter data (for example, the Kestrel measurement during the hand-held blower use was around 3.5 m/s).

Sky conditions

Sky conditions were clear with strong solar insolation, although the gas tank and BluBird units were shaded by nearby buildings for the entire period.

2.3 Gas release

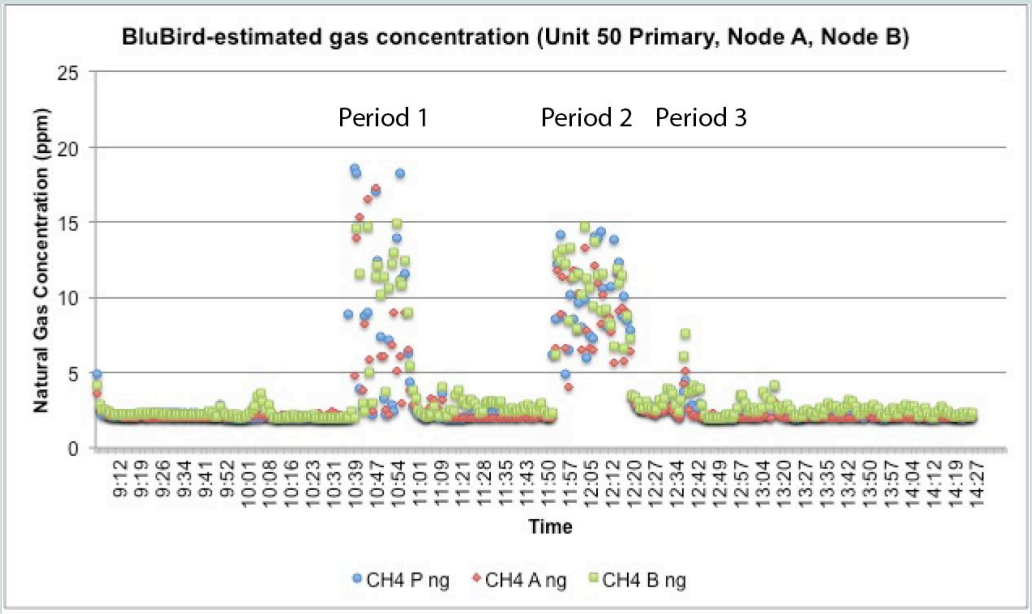
Gas was released from the cylinder at a fixed rate of 1.1 kg/hr, controlled using a combination of a Harris Specialty regulator and Matheson FM-1050 rotameter. The outlet of the rotameter was at a height of 1.5 m, with the outlet pointing in the direction of the BluBird units.

3. Results

Figure 1 shows the time series of estimated concentrations for each of the nodes for Units 50 and 51 (three nodes each). The three gas release periods (lasting

29, 30, and 4 minutes) are noted. For Period 1, the center of the aligned 6 BluBirds was about 13m from the gas cylinder source. The distances increased to about 20m for Period 2 and to 38m for Period 3.

Figure 1



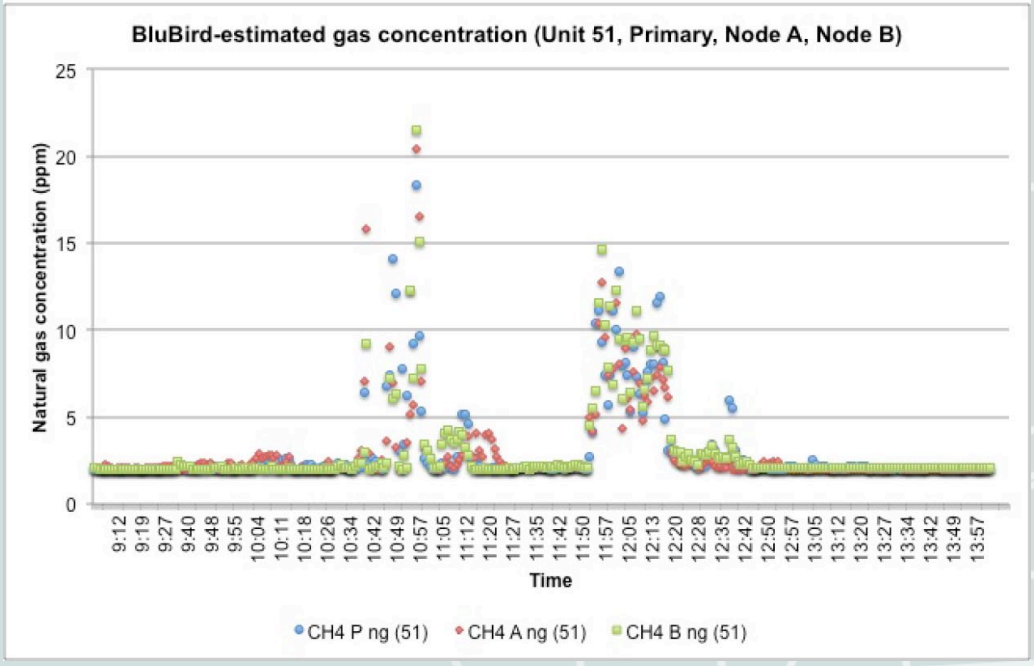


Figure 1. Methane concentrations estimated at each of the 6 BluBird nodes. The time periods when gas was being actively released are indicated by the "Period 1", etc. labels in the top figure.

3.1 Estimated concentrations during the experiment

As seen in Figure 1, all of the BluBird units show responses coincident with the gas emissions, with the exception of small to negligible signals at Unit 51, Nodes A and B during the short Period 3 release event. These units were the furthest from the gas source at that time. Overall, the concentration magnitudes are all consistent between different BluBird units.

In general, the variability in the estimated concentrations over time and between units is less at the 20m distance during Period 2 than when the units are closer to the source at Period 1. This may reflect the greater dispersion of the gas plume over the longer travel distance.

3.2 Comparisons to concentrations predicted using Gaussian plume dispersion modeling

To help place some bounds on how realistic the BluBird results are, we used a version of the standard Gaussian plume dispersion model to calculate predicted gas concentrations at different downwind distances from a 1.1 kg/hr emissions source, using different assumptions about atmospheric stability (and thus different degrees of mixing and spreading of the gas plume; a significant variable in this calculation). The mean wind speeds for each of the gas release periods were used. For the simulations, the BluBird units were assumed to be aligned with the center axis of the plume and at the same height as the source.

Figure 2 shows Gaussian model results along with the maximum observed concentrations by the 6 BluBird units during the three periods noted in Figure 1. The BluBird-estimated versus model-predicted concentrations are within the range of uncertainties associated with the Gaussian plume dispersion assumptions used here, bearing in mind the relatively short plume travel distances as well as the low wind speeds. Given the conditions of light winds but considerable solar heating, offset by some possible constraint on plume mixing in the y (lateral) direction, it is reasonable to think that surface-layer stability fell within the moderately- to extremely-unstable range. Given that, the BluBird-derived concentrations are higher than the model estimates for these conditions, but still within the range of modeling uncertainty, including some uncertainty in the wind speed measurements at the low speeds that were present.

Figure 2

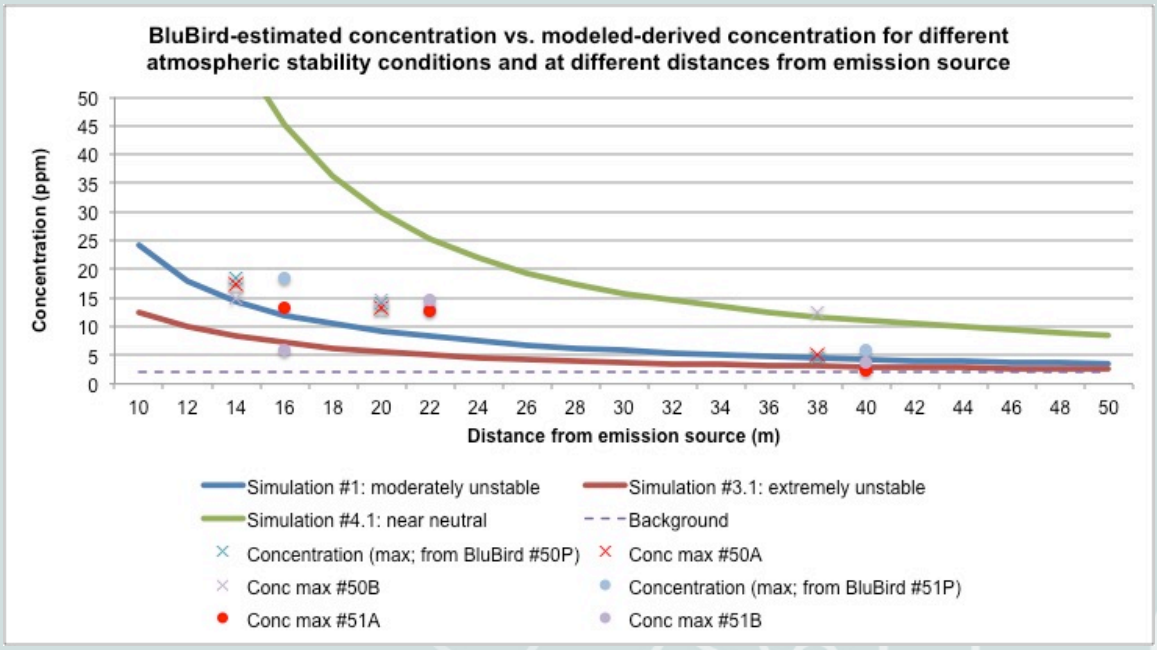


Figure 2. Comparison of model-predicted gas concentrations for different surface-layer stability conditions versus BluBird measurements (maxima for each unit during the gas-release periods). Note that the gas cylinder was moved from north of the BluBirds to south after the Period 1 gas release.

3.3 Estimation of gas emission rate from BluBird measurements

A key question for the BluBird approach is how well emission rates can be quantified, given BluBird-measured concentrations and wind conditions, along with knowledge of distances to likely emitters. To test this, an inversion of the Gaussian plume model was used to calculate likely emission rates (Figure 3) given the observed concentrations and the other assumptions listed in Section 3.2. As expected from the results in Section 3.2, the emission rates calculated

from the BluBird observations lie within the range bracketed by the different model runs. Values range from 0.4 kg/hr at for near neutral conditions and a 14 m distance to 6.1 kg/hr at for extremely unstable conditions at 40 m. Here, the differences between the BluBird-estimated values (in green, blue and red) and the flowmeter-measured, continuous 1.1 kg/hr rate ("x" symbols) amount to an uncertainty range for these conditions. If we assume that atmospheric mixing conditions were indeed fairly active given the local heating and possible turbulence from structures, then the BluBird-derived emission rates are biased on the high side in this case (for example, at about 2 kg/hr using the measurements at 20m vs. the measured 1.1 kg/hr).

Figure 3

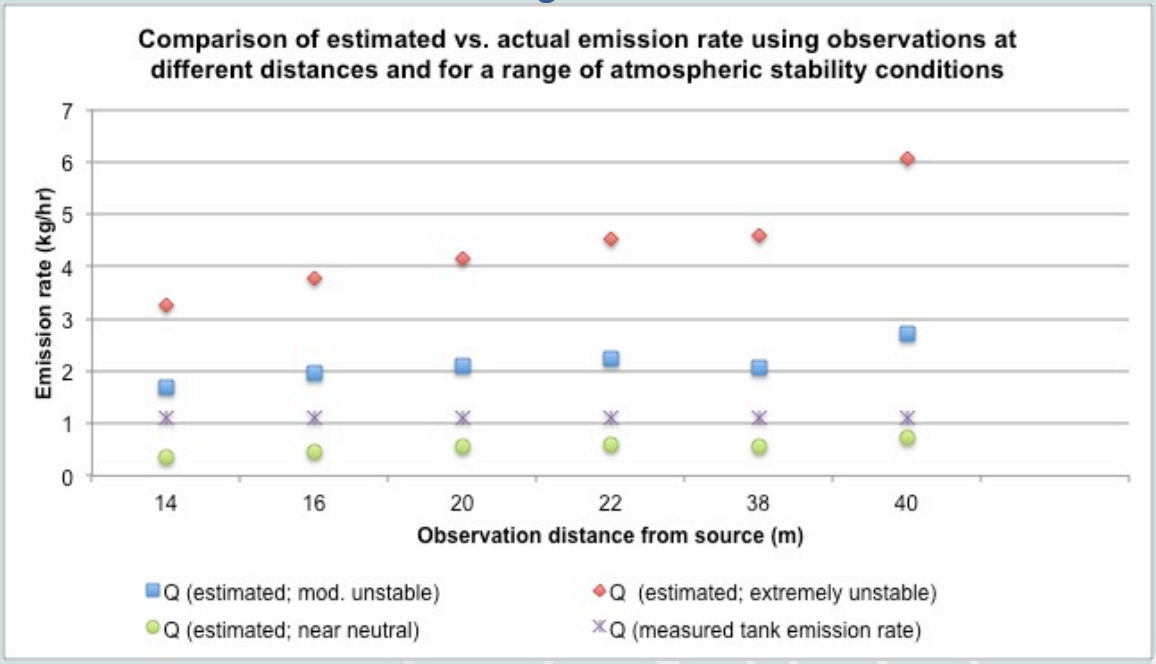


Figure 3. Cylinder emission rate (assumed to be a constant flowmeter-regulated 1.1 kg/hr) compared to emission rates estimated using the BluBird (Unit 50) measured gas concentrations, calculated using inverse Gaussian plume dispersion modeling for three different atmospheric stability conditions and using the BluBird-measured wind speed and distances from the gas-tank source.

4. Conclusions

In this experiment, the BluBird system proved to be able to detect the 1.1 kg/hr emission of natural gas under light winds and at distances of 38m (the longest distance tested) and closer. The derived concentrations are reasonable as compared to expected concentrations for these conditions, and the measurements are relatively consistent between the 6 units. When the results

are used to estimate a likely emission rate that would yield the BluBird-measured concentrations, the derived rates fall within the range of model uncertainty.

Earthview is continuing to conduct these types of tests under a variety of conditions and settings, with planning underway for single-blind tests.