9.8 Tracer emissions inferred from a backward Lagrangian stochastic dispersion model: a validation study

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1 Introduction

A dispersion model provides a useful tool for estimating gas emissions. Combining predictions of dispersion from a source, and observations of downwind concentration C, one can diagnose source emission rate Q. Compared with other techniques, the dispersion-model-based approach has the benefit of experimental simplicity, flexibility in the type and location of the C measurement, and applicability (in principle) even in disturbed flows.

A "backward" Lagrangian stochastic (bLS) model provides an efficient method for calculating dispersion from area sources (Flesch et al., 1995). An ensemble of random upwind trajectories are calculated from the C measurement location (Fig.1), and Q is calculated from the locations and vertical velocities (w_0) of trajectory "touchdowns" on the ground

$$Q_{bLS} = \frac{C\ N}{\sum 2/w_0} \tag{1}$$

where the summation covers only touchdowns on the source, and N is the total number of trajectories calculated.

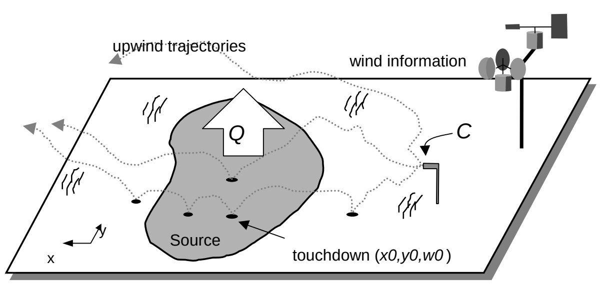

Figure 1: Illustration of bLS approach. Concentration C is measured downwind of the source, and Q is deduced from "touchdowns" inside the source.

2 Field Study and bLS Model

We performed experiments to examine the accuracy of this technique (see also paper **P1.21**). The study site (Ellerslie, Alberta) was flat, with uniform cover of short-grass and alfalfa. We released methane at a known rate from a synthetic 6 x 6 m surface area source. Two

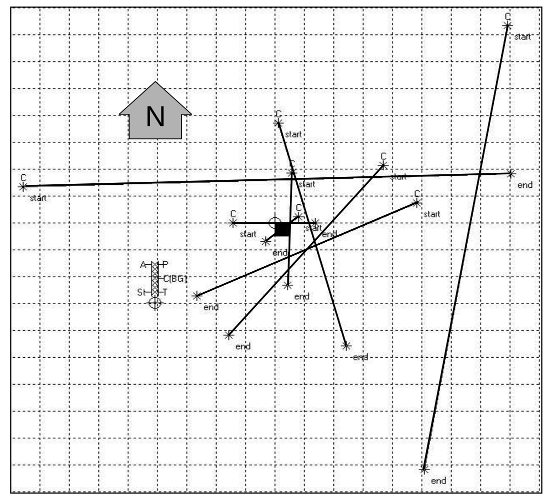

Figure 2: Tracer source is shown by the center square, laser paths (not all used simultaneously) are given by lines. Meteorological tower is indicated by the symbol. Grid spacing is 12 m.

open-path lasers measured line-average methane concentration (C_L) above and (up to 100 m) downwind of the source (Fig.2); beam height $z_b \approx 1m$. Measurements were made over five days in May and June 2001; each day gas was released over two to three hours, C_L being averaged over 15 minute intervals. Data shown here cover four daytime releases, and one nighttime-early morning release.

Our bLS model was based on Thomson's (1987) well-mixed 3d model for Gaussian inhomogeneous turbulence, implemented with standard Monin-Obukhov (MO) formulae for surface layer wind statistics: the profiles of mean windspeed (S), of standard deviations of the velocity fluctuations ($\sigma_u, \sigma_v, \sigma_w$), and of a Lagrangian timescale (T_L). We chose T_L to ensure the turbulent Schmidt number $S_c = 0.6$ (as is implied by Project Prairie Grass; Wilson et al., 2001). To parameterisation of σ_w we used

$$\begin{aligned} \frac{\sigma_w}{u_*} &= b\left(1 + 0.2\frac{z}{L}\right), \quad L > 0 \\ &= b\left(1 - 3.0\frac{z}{L}\right)^{0.33}, L < 0 \end{aligned} \tag{2}$$

where z is the height above ground, L is the Obukhov length, and b is value of σ_w/u_* in neutral stratification.

The bLS model is fully defined with a single measurement of windspeed S and direction β at an arbi-

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trary height; the surface roughness length (z_0); and the atmospheric stability (L). These properties were measured/inferred from windspeed profiles (cup anemometers, corrected for over-speeding), temperature profiles (thermocouples), and turbulence observations (3-d sonic anemometer).

The basis of our Q_{bLS} estimate is the C_L observation. A bLS simulation begins with the release of thousands of "particles" along the laser path. These are followed upwind and Q_{bLS} is calculated via eqn(1). A line-average concentration C_L is advantageous with a dispersion-model-based technique, for it reduces sensitivity to bLS model error; if the laser path completely traverses the tracer plume then an accurate description of lateral dispersion is unimportant.

3 Results

Our first-pass Q_{bLS} predictions used the conventional $b = 1.25$ in eqn(2). Fig.(3) illustrates the resulting ratios of Q_{bLS}/Q, for all 74 observations. On average, $Q_{bLS}/Q = 1.32$; the standard deviation of the individual 15-min ratios was 0.45. Overprediction was slightly worse in stable stratification, and as the source-to-laser distance increased. This error was larger than we had hoped, given that the site was very flat and uniform.

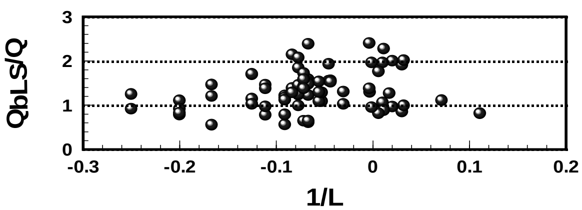

Figure 3: Q_{bLS}/Q versus stratification ($b = 1.25$ in the bLS model).

Measurements from the sonic anemometer suggested a possible reason for inaccuracy of the estimates of Fig.(3). Fig.(4) shows observed σ_w/u_* during our observations, where σ_w is from a $CSAT3$ sonic at $z = 2m$ (after a coordinate rotation setting $\overline{w} = 0$), and u_* is derived from the tower profiles $S(z), T(z)$. These are significantly below the values from eqn(2) with $b = 1.25$. On average our data indicates $b = 0.95$. We adjusted b so that its application in eqn(2) would reproduce observed σ_w/u_* for each interval (values of b in the range $0.8 - 1.10$ were required), and reran the bLS model (Fig.5). The result was a significant improvement in the accuracy of Q_{bLS}. On average, $Q_{bLS}/Q = 1.08$, and the standard deviation of the individual 15-min ratios was 0.27. In addition the error in Q_{bLS} is no longer correlated with stability or source-to-laser distance.

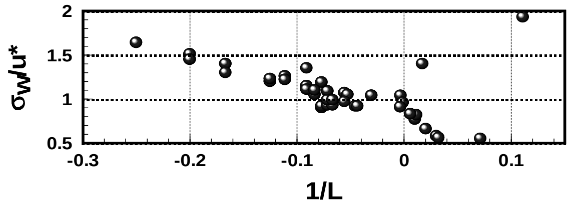

Figure 4: Observed σ_w/u_*.

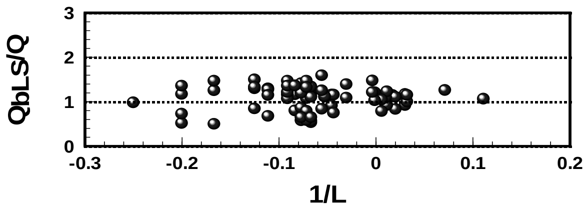

Figure 5: Q_{bLS}/Q versus stratification, using b values which give the observed σ_w/u_*.

4 Conclusion

The bLS dispersion-model-based estimates of surface emissions are "tolerably" accurate, if one is permitted the flexibility to invoke actual values for σ_w/u_*. This begs the question of "realistic expectations", and, what level of uncertainty or error is "tolerable"? One must remember that alternative techniques probably carry no lesser uncertainty - but are more complex.

Our observed values of σ_w/u_* were generally lower than would be expected from published empirical MO formulae. We tentatively accept them, primarily because an intercomparison of two sonics yielded means and standard deviations that were consistent[2] to better than 3%, and secondarily (though less legitimately) since calculated source strengths based on measured σ_w were systematically superior.

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[2]This does not eliminate the possibility of a consistent error in *both* sonics.