P1.21

USE OF THE NOCTURNAL BOUNDARY LAYER BUDGET METHOD IN ESTIMATING FARM-SCALE GREENHOUSE GAS EMISSIONS

Laura A. Wittebol[1], Ian B. Strachan[1], and Elizabeth Pattey[2]
[1]Department of Natural Resource Sciences, McGill University, Ste. Anne de Bellevue, Quebec, Canada
[2]Eastern Cereal and Oilseed Research Centre, Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada

1. INTRODUCTION

Canada's greenhouse gas inventory is based primarily on estimates derived from a combination of national statistics, measured emission factors, and scientific or engineering models, leading to high uncertainties (Neitzert *et al.*, 1999). Overall uncertainty associated with methane emissions in Canada is 30% and for N_2O is 40% (McCann *et al.,* 1994) and it is highly desirable for this to be reduced. A certain portion of the uncertainty in emissions estimates from the agriculture sector comes from the scaling-up of emissions determined from small-scale plot studies (*e.g.,* tens of square meters) to obtain estimates of emissions at national levels. Emissions need to be studied at larger scales, therefore, to reduce uncertainties and produce a more accurate inventory. The approach being used here to achieve this goal is the nocturnal boundary layer (NBL) budgeting approach (Denmead *et al.,* 1996).

While previous studies have looked at the potential of the NBL budget method and have inspired others to use it to obtain landscape-scale fluxes, no studies have discussed in detail the various sources of uncertainty in the technique, nor have they looked at ascertaining that fluxes obtained are actually reliable and representative of the landscape being studied. The purpose of this study, therefore, was to describe the technique in more detail, referring to sources of uncertainty in fluxes measured using the NBL budget method, and to recommend ways to ensure reliable and representative landscape-scale greenhouse gas fluxes. Given the high uncertainty in current GHG emissions estimates in the agriculture sector in Canada, and the resultant desire to obtain much-needed farm-scale data, the landscape type chosen for the application of the NBL method in this study was the typical eastern Canadian agricultural farm.

2. MATERIALS AND METHODS

In the NBL budget method, tethered balloon soundings in the NBL are conducted with several soundings made in one night, thus following the development of the NBL (Denmead *et al.*, 1996). Successive nocturnal boundary layer profile measurements of the concentration of the desired scalars (trace gases) are integrated over time with respect to height as:

$$F_S = \int_0^z \left(\partial s / \partial t\right) \partial z + A$$

where F_s is the average surface flux of the desired scalar, s is the scalar concentration, z is the height of

---

Corresponding author address: Ian B. Strachan, McGill University (Macdonald Campus), Natural Resource Sciences, 21111 Lakeshore Road, Ste. Anne de Bellevue, Quebec, Canada, H9X 3V9
e-mail: ian.strachan@mcgill.ca

the NBL, and *t* is the average time between successive profile measurements (Denmead *et al.,* 1996). F_s is an average surface flux which incorporates all contributions, horizontal and vertical flux, as well as any advective contribution (*A*) from outside the source area (Eugster and Siegrist, 2000).

Field work for this study was conducted during the summers of 2002 and 2003 at two agricultural farms in eastern Canada. The first, located southwest of Ottawa, Ontario, Canada (45°23'N, 75°43'W) and the second at a private farm near Coteau-du-Lac, QC (45°19' N, 74°10' W), some 20 km southwest of Montreal, QC. In 2002, the experimental site (24 ha), planted with corn, was located within a mix of residential land with public roads and farmland. The topography of the farmland in the area varied less than 2 m for the most part. The field site in 2003 was located 2-2.5 km to the north and northwest of the St. Lawrence River. Otherwise, the field site (20 ha, planted with peas) was surrounded by agricultural land for several km. Land elevation was within 1-2 m for several km around the site. In each year, continuous N_2O concentration gradients were measured at two locations in the field using a tunable diode laser trace gas analyzer (TDLTGA; Edwards *et al.,* 2003). CO_2 fluxes were measured using the eddy covariance technique. Standard meteorological variables were measured on site as were soil moisture and temperature profiles.

Results from the NBL budget method are available for a total of three nights in June and July of 2002 and twelve nights from late May to early September 2003.

2.1 *Sample Collection and Analysis*

Profile measurements of the nocturnal boundary layer were taken multiple times throughout the nights of measurement, using a tethered blimp from the launch site in each study field. The blimp, to which a tethersonde (Model 5A, A.I.R.), CO_2 analyzer (CIRAS-SC, PP Systems), and air sampling equipment (mini-pump and teflon bag) were attached, was raised vertically from the surface up to between 100 to 130 m height, with the goal being to encompass the top of the NBL. The tethersonde measured temperature, pressure, relative humidity, horizontal wind speed, and direction.

Subsamples of the gas sampling bags were taken for analysis of N_2O and CH_4 using gas chromatography (GC). The bulk air samples were also used to measure N_2O and CH_4 on dual lab-based TDLTGA's at Agriculture and Agri-Food Canada. Samples were analyzed within 24-48 hours after collection.

In order to better understand the spatial distribution of gases around the field and aid in the interpretation of fluxes measured using vertical profiles with the tethered balloon, measurements of gases were occasionally made along the perimeter of the field while vertical profiles were being conducted. Equipment for gas sampling and a GPS were installed on an electric golf cart which was driven around the perimeter of the field, stopping at geo-referenced locations. Air was pumped through an IRGA (CO_2) and samples for N_2O and CH_4 analysis on GC were taken by syringe through a sampling port near the bottom of the tubing.

3. RESULTS AND DISCUSSION

3.1 *Uncertainty Associated with Vertical Profiles*

On strongly stable nights where a low-level nocturnal jet or any horizontal wind speed maximum is present, a “turbulent barrier” prevents the escape of gas beyond this height and it is relatively straightforward to calculate an NBL flux; the area between gas concentration curves is closed off and well-defined (*e.g.* Figure 1). As long as the integration height chosen includes the minimum height of convergence, we estimate that the error in the flux calculation will be within, on average, about 10%.

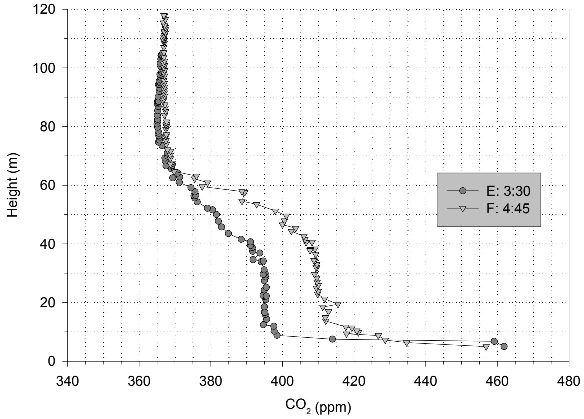

Figure 1. CO_2 profiles (EST) from night of June 28-29, 2002, Ottawa, ON.

However, a problem occurs on weakly stable nights where no (or very few) wind speed maxima are seen and thus most or all profiles never converge at a given concentration at any particular near-surface height (*e.g.,* Figure 2). It is therefore more difficult to accurately estimate the gas flux, because there is no way of knowing the integration height with any certainty. The use of the NBL budget method on nights of weak stability, where there is no clear ‘capping’ of gas emitted from the surface, will lead to fluxes with greater uncertainty. In this case the error in the flux calculation can be as high as, on average, about 40%.

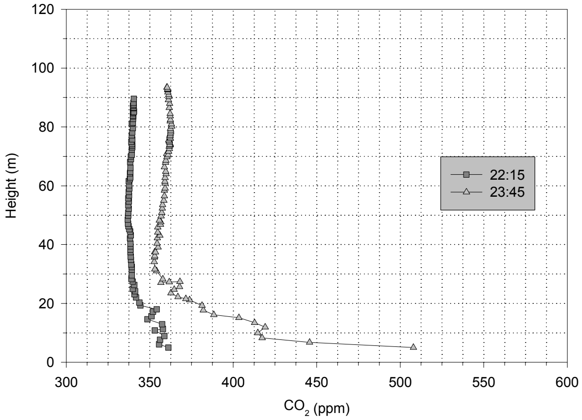

Figure 2. CO_2 profiles (EST) from night of July 17-18, 2002, Ottawa, ON.

On those nights where atmospheric conditions are optimum for the NBL budget method there may still be reason to separate different portions of the night into ‘flux groups’. This is because the NBL may, on a particular night, undergo changes which may destroy any local accumulation of gases at the surface during a particular time period, rendering a so-called “flux” during this time period invalid.

3.2 *Uncertainty Associated with Spatial Variation*

While one of the great advantages of the NBL method is that it incorporates spatial inhomogeneities due to the great size of the NBL chamber, in practice, profiles near the surface are measuring concentrations quite local to the launch site. The spatial sampling of CO_2 conducted at the two field sites indicated that generally, there was not much spatial variability in CO_2

with %CV between sampling locations ranging from 1 to 7%. This lends confidence to measurements at the bottom of the CO_2 vertical profile, despite their limited area of origin near to the balloon launch site.

Results from both sites show that overall spatial variability for N_2O was quite low (1 to 6%, with one instance at 18%). In contrast, studies using chamber methods have shown spatial variability of N_2O ranging from 37 to 90% (*e.g.,* Hénault *et al.,* 1998; Laville *et al.,* 1999) demonstrating the integrating effect of larger-scale micrometeorological methods. Methane variability was higher at the Ottawa site due to the presence of a manure pile and cattle feedlot on one side of the field.

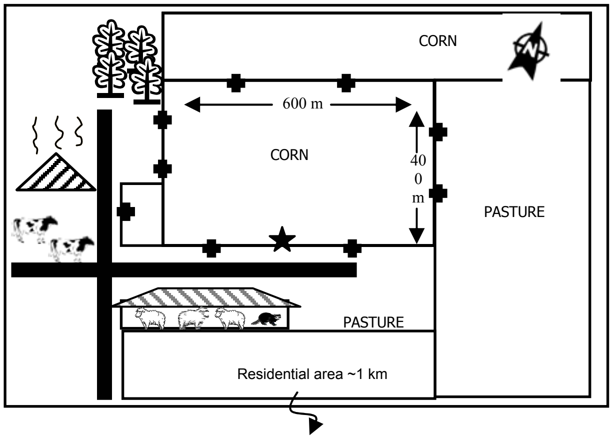

Figure 3. Diagram of Ottawa field site with spatial sampling points (crosses).

Our data set of concurrent spatial and vertical measurements suggests that when gases have low spatial variability and the spatial mean concentration corresponds to the near-surface launch site concentration, we may be confident in the flux value obtained from vertical profile concentrations. For a gas with high spatial variability, it is clear that the location of the launch site will reflect the local gas concentrations. It is recommended that the near-surface spatial average be taken into consideration and used to replace concentrations in the corresponding near-surface height interval of the vertical profile to reflect the homogenizing aim of the NBL budget method.

5. ACKNOWLEDGEMENTS

The authors would like to thank Nathalie Mathieu for field and analytical support throughout the project, Dave Dow for technical assistance and Lynda Blackburn, Matthew Hinther, Melissa Valiquette, Diane Poon, Yao Hua Law, and Melissa Hairabedian for help with summer field work, lab analysis, and data processing at various stages of the project. Thanks to Mr. Guy Vincent for allowing access to his farm as our experimental field site in 2003. Primary funding for this project was provided through a grant to IBS by the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS). IBS wishes to also thank the Canadian Agri-Food Research Council for support through their Climate Change Funding Initiative in Agriculture. LAW acknowledges the support of the Fonds québécois de la recherche sur la nature et les technologies (FQRNT) in the form of a graduate fellowship.

6. REFERENCES

Denmead, O.T., Raupach, M.R., Dunin, F.X., Cleugh, H.A., and Leuning, R., 1996. Boundary-layer budgets for regional estimates of scalar fluxes. Global Change Biol. 2, 255-264.

Edwards, G.C., Thurtell, G.W., Kidd, G.E., Dias, G.M., and Wagner-Riddle, C., 2003: A diode laser based gas monitor suitable for measurement of trace gas exchange using micrometeorological techniques. *Agric. For. Meteorol.*,**115**, 71–89.

Eugster, W., and Siegrist, F., 2000. The influence of nocturnal CO_2 advection on CO_2 flux measurements. Basic and Applied Ecol. 1(2), 177-188.

Hénault. C., Devis, X., Lucas, J.L., and Germon, J.C. 1998. Influence of different agricultural practices (type of crop, form of N-fertilizer) on soil nitrous oxide emissions. Biol. Fertil. Soils 27, 299–306.

Laville, P., Jambert, C., Cellier, P., Delmas, R. 1999. Nitrous oxide fluxes from a fertilised maize crop using micrometeorological and chamber methods. Agr. For. Meteorol. 96, 19-38.

McCann, T.J., and Associates, 1994. Uncertainties in Canada's 1990 Greenhouse Gas Emission Estimates. Independent consultant's report prepared for Environment Canada, Pollution Data Branch, Hull.

Neitzert, F., Olsen, K., and Collas, P., 1999. Canada's Greenhouse Gas Inventory: 1997 Emissions and Removals with Trends. Environment Canada: Greenhouse Gas Division, Pollution Data Branch, Air Pollution Prevention Directorate, Ottawa