Soil Respiration in Eddy Covariance Footprints using Forced Diffusion

Nick Nickerson[1], Carrie-Ellen Gabriel[1,2] and Chance Creelman[1]

(1) Eosense Inc., Dartmouth, Canada. (2) St. Francis Xavier University, Antigonish, Canada.

Abstract

Eddy covariance (EC) has been widely used across the globe for more than 20 years, offering researchers invaluable measurements including Net Ecosystem Exchange and ecosystem respiration. Measurements of soil respiration (R_S) may allow researchers to reconcile nocturnal EC flux data, or provide a means to inform gap-filling models. However, R_S measurements have been used sparingly because of the large cost required to scale chamber systems, and data integration and processing burdens. Here we propose the Forced Diffusion (FD) method for the measurement of R_S at EC sites. FD allows for inexpensive and autonomous measurements, providing a scalable approach for matching the EC footprint.

A pilot study at the Howland Forest AmeriFlux site (Maine) was carried out from July 15, 2016 using EC, custom-made automated chambers, and FD chambers in tandem. This study aims to reproduce previous findings from Howland using the FD approach, and demonstrate that the measurements taken using the eosFD correlate well with the existing chamber systems and can be used with equal efficacy. We will discuss the technical and logistical considerations, including chamber placement, chamber sampling frequency, and power consumption, that allow the FD technique to scale to the EC footprint, and data QA/QC procedures that lessen the burden of maintenance and processing.

What is Forced Diffusion (FD)

Forced Diffusion (FD) is a novel method for continuous measurement of soil respiration (Risk *et al.*, 2011). The FD technique is functionally similar to dynamic steady-state chamber systems but uses a diffusive membrane to regulate the flow of gases rather than a pump (Figure 1). Measurement of soil respiration using this diffusive regulation approach offers several benefits created by the lack of external moving parts, including reduced power consumption and the ability to function in harsh environments including under snow pack.

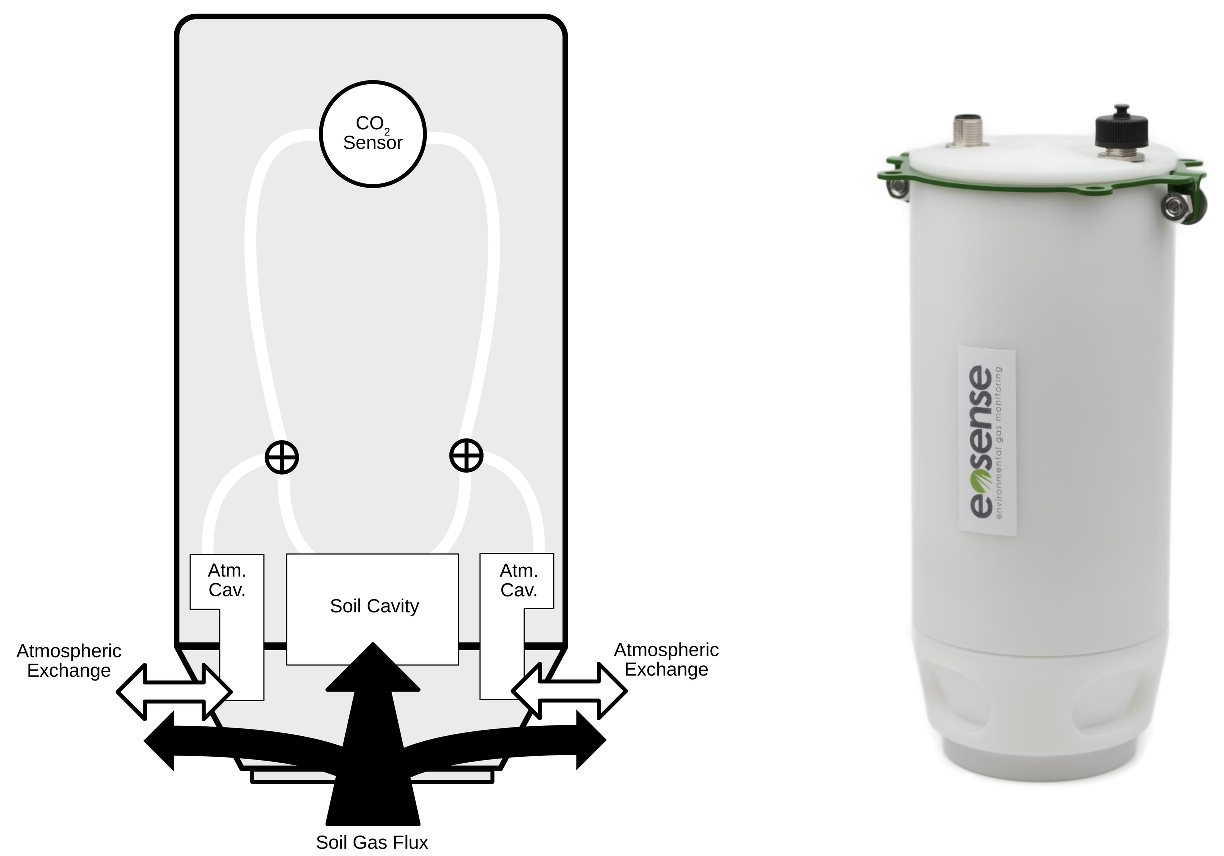


Figure 1: Left - View of the eosFD Chamber flow paths showing the exchange of atmospheric gases with the chamber as well as the interaction of soil flux with the chamber sampling cavities. The FD technique measures flux by differencing the CO_2 concentration in the soil and atmospheric cavities which are in equilibrium with each other via a carefully characterized diffusive membrane. Right - The current generation of eosFD chambers manufactured at Eosense.

Field Site & Equipment

- Howland Forest is a mature boreal transition forest located in central Maine
- Dominated by >160-year-old red spruce and eastern hemlock stands
- Range of drainage conditions from well to poorly drained (swamp)
- Mean annual temperature is +6 C, and precipitation is 1063 mm.
- Within the footprint of a tower measuring NEE by eddy covariance (Hollinger *et al.*, 2000).
- Soil respiration is measured using opaque, vented chambers (Savage *et al.*, 2013).
- eosFD chambers installed in June 2016. Flux measurements logged every 10 minutes.

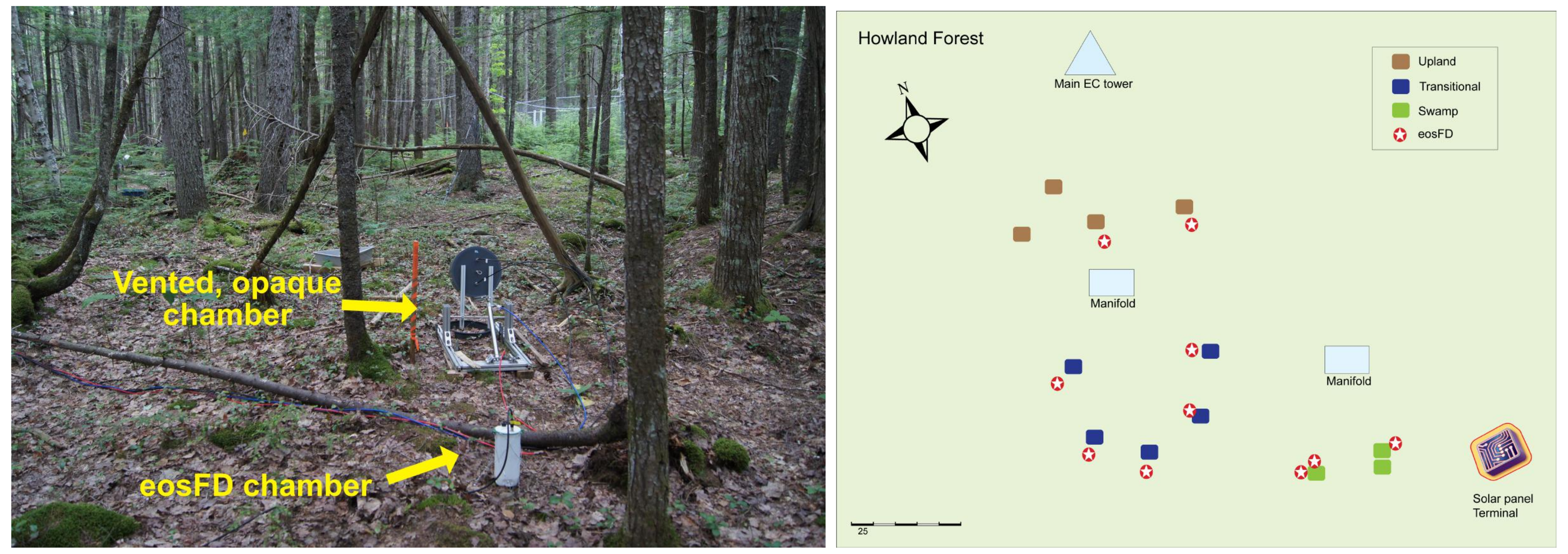


Figure 2: Left - eosFD chamber co-installed at Howland forest alongside an existing automated soil respiration chamber. Right - schematic of the layout of infrastructure at Howland Forest.

eosFD and Automated Chamber Comparison

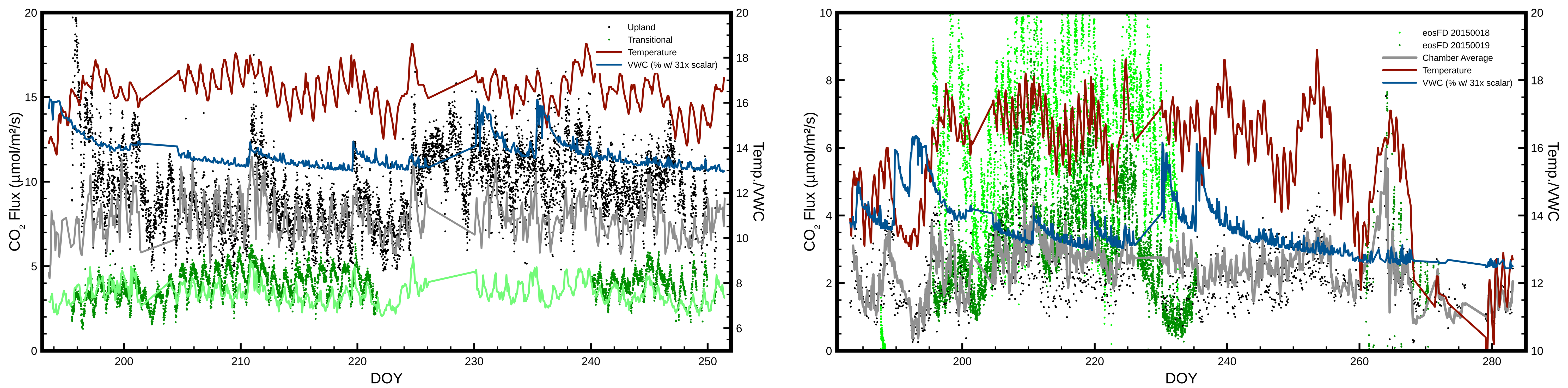


Figure 3: Left - Comparison time series for eosFD (dots) and automated chambers (lines) located at the upland and transitional sites showing a close correspondence and clear responses to both site temperature and moistures. Right - Two co-located eosFD and automated chamber pairs at the wetland site. The grey line shows the average wetland respiration as measured by the automated chamber systems, and black dots show measurements from individual automated chambers. Higher variability at the wetland site for the eosFD chambers compared to the automated system may be caused by the long soil collars that were used to hold the eosFD units in place in the sphagnum and/or the gradual death of the sphagnum below the eosFD chamber during the course of the experiment.

Field Logistics

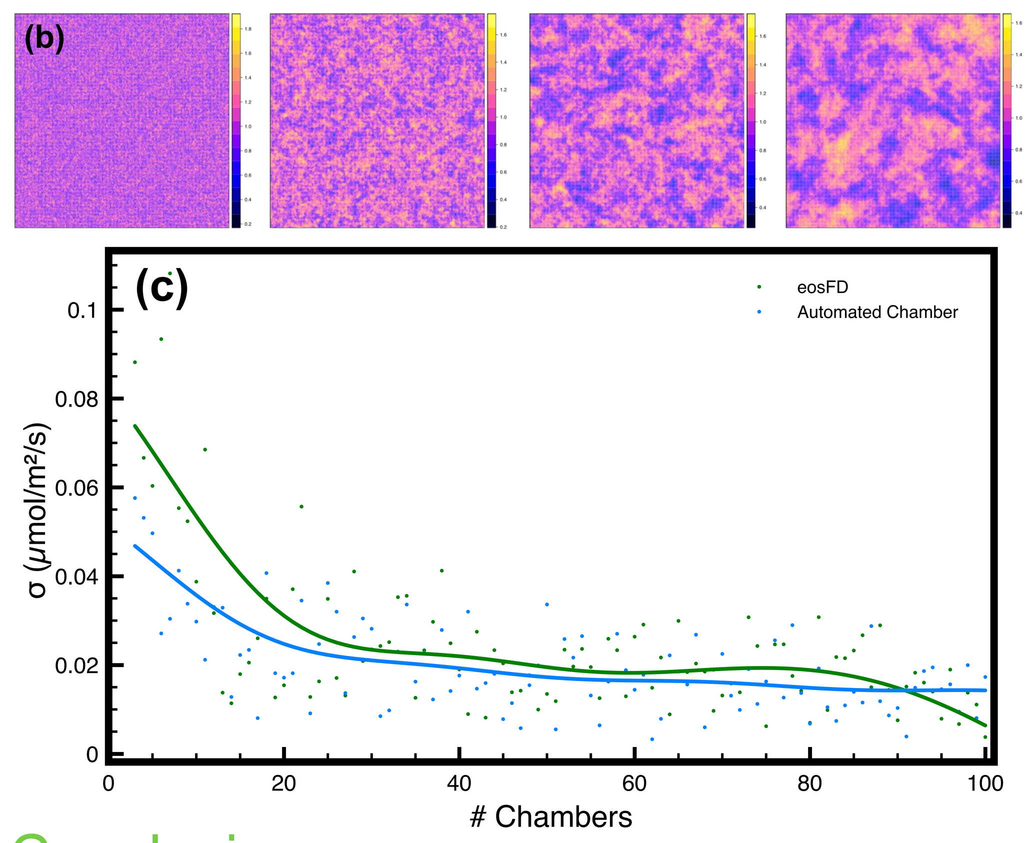
Summarized below are the approximate logistical requirements to continuously operate similar eosFD (example in Figure 4a) and Automated chamber systems during the summer solstice (peak sun) in Nova Scotia, Canada.

System	eosFD (x 12)	Automated Chamber (x 12)
Power	12-18 W	50-350 W
Solar	100 W	150 - 1000 W
Battery	100 Ah	200 - 1250 Ah
Battery Mass	30 kg	55 - 340 kg

Scaling Fluxes & Spatial Variability

One important aspect of scaling soil fluxes to the canopy scale is spatial representativeness and the ability to both capture the mean flux as well as the spatial variability. While the eosFD chamber has a small footprint, simulations using spatially autocorrelated data (Figure 4b) show that the eosFD method is equivalent to using the same number of 20 cm diameter chambers, so long as more than 10 eosFD units are deployed at the site (Figure 4c, below this number the automated chambers win by a slight margin). Important to also consider is that the eosFD devices are not spatially constrained by the central analyzer unit and tubing, and therefore are able to be truly randomly distributed about the field site.

Figure 4: *(a)* - 100 W solar panel used to power the 10 eosFD setup at Howland forest. *(b)* - Simulations of fluxes at spatially autocorrelated field sites (increasing correlation from left to right). *(c)* - Standard deviation from the true efflux mean for varying numbers of randomly deployed chambers showing that, after about 10 units, the small footprint of the eosFD chamber has little impact on the estimated mean.



Conclusions

Our field experiment at Howland forest confirms that the eosFD chambers can be used with similar success to automated chambers systems to estimate soil respiration rates and corroborate and extend data gathered by the Eddy Covariance tower.

eosFD chambers offer benefits over automated chamber systems including less cumbersome power (and other logistical) requirements and improved ability to estimate site means and site variability.

Thanks to Kathleen Savage, Holly Hughes, David Hollinger and the rest of the crew at Howland who made this deployment a success and to Lisa Kellman and Stephanie MacIntyre from StFX who provided invaluable field and logistics help to the project.

Contact: nick@eosense.com

Eosense: Booth 846

twitter.com/eosense