Soil Respiration in Eddy Covariance Footprints using Forced Diffusion

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Field Site & Equipment
- Howland Forest is a mature boreal transition forest located in central Maine
- Range of drainage conditions from well to poorly drained (swamp)
- Mean annual temperature is +6°C, and precipitation is 1063 mm
- Soil respiration is measured using opaque, vented chambers (Savage et al., 2013)
- eosFD chambers installed in June 2016. Flux measurements logged every 10 minutes.

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.

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. Measurement of soil respiration (Rs) requires researchers to reconcile nocturnal EC flux data, or provide a means to inform gap-filling models. However, Rs 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 Rs 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 EC footprint.

Within this study, forced diffusion can be characterized as the continuous measurement of soil respiration using a diffusive membrane and eddy covariance techniques. The eosFD device is designed to provide a scalable method to estimate soil respiration that is easy to use, lightweight, and suitable for remote deployments.

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.

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.

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 the spatial and site variability. 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.

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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.

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 moisture. 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.

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 flux values 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.

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 differenting the CO2 concentration in the soil and atmospheric cavities which are in equili- brium with each other via a carefully characterized diffusive membrane. Right - The current generation of eosFD chambers manufactured at Eosense.