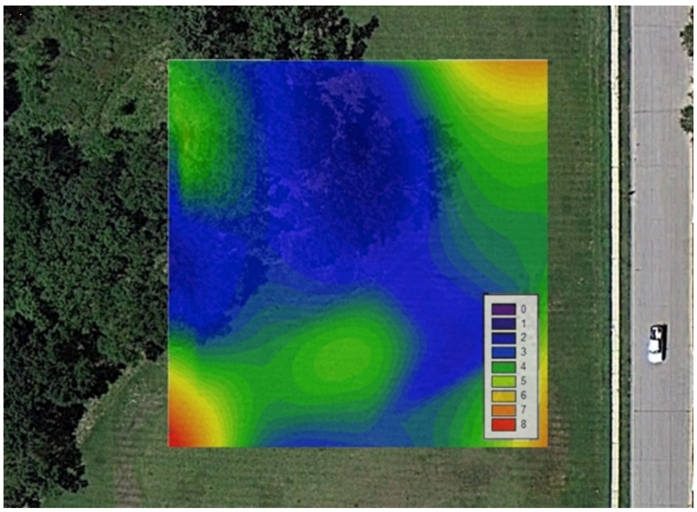
# Addressing Spatial Variability: Determining the Number of Readings Required

Application Note

Soils can be highly variable in terms of gas flux values. Even at a seemingly uniform site, $CO_2$ gas fluxes, for example, may range from 0 µmol $m^{-2}$ $s^{-1}$ to over 8 µmol $m^{-2}$ $s^{-1}$ just a few meters away, as is shown in the following visualization.




Soil $CO_2$ flux data were collected at a site in Lincoln, NE, USA with an LI-8100A Automated Soil Gas Flux System and were analyzed with SoilFluxPro™ Software. The data were then overlaid on a satellite image of the measurement site.

To obtain reliable site-wide mean flux values, it is important to determine how many readings might be required so that time and resources can be properly allocated before starting an investigation.

In addition to spatial heterogeneity, soils also exhibit both diurnal and seasonal patterns of variation in gas evolution due to changes in soil water content, temperature, soil organic carbon resources, and other factors. To accurately characterize site gas fluxes, it is often necessary to take readings with adequate spatial as well as temporal resolution.

## Survey, Long-term, and Multiplexed Measurements

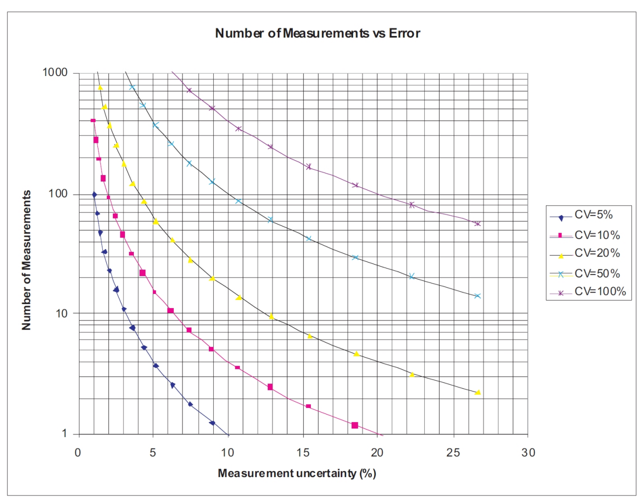
LI-COR soil gas flux solutions are designed to satisfy both the temporal and spatial resolution requirements of soil gas flux monitoring. The new Smart Chamber survey chamber or LI-8100A with a 10 cm or 20 cm survey chamber can be used to rapidly obtain flux readings at many different collar locations to assess spatial variability in soil gas fluxes. After being placed on a collar, the Smart Chamber automatically closes over the collar to begin taking a measurement. After the measurement is complete, the chamber opens, flushes the system of residual high-concentration gas, and is then ready to move on to a new collar.

When connected to 8100-104 or 8100-104C Long-term Chambers, the LI-8100 system can take frequent gas flux readings automatically at user-defined intervals to characterize diurnal and temporal variations in soil gas fluxes. When not taking a reading, the chamber moves away from the measurement collar, allowing ambient gas concentrations to prevail between measurement intervals, also exposing the soil within the collar to wind, rain, sunlight, and other natural elements.

When equipped with the LI-8150 Multiplexer, the LI-8100 is able to control and obtain flux data from up to 16 Long-term Chambers at once, allowing you to assess both spatial and temporal variability in soil gas fluxes.

## Determining Number of Measurements

The graph below shows the number of samples averaged against the uncertainty of the mean for sites with coefficients of variation (CV) ranging from 5% to 100%. These uncertainties were calculated using standard statistical theory, which is described at the end of this note.



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Even for a relatively uniform site with a CV of 10% (e.g., a uniform plot suitable for agronomic experiments), as many as 15 flux readings may be required to obtain a mean value with an uncertainty of about 5%. For sites with greater variability, an even larger number of measurements would be required.

It is evident from the data shown in the figure above that for some investigations, even 16 Long-term Chambers by themselves will not provide an adequate number of readings to obtain a reliable site mean flux value. To avoid the cost of deploying multiple systems, researchers have suggested augmenting the high temporal resolution of long-term automated chamber readings with survey chamber readings (e.g., Savage and Davidson, 2003; Arnold, et.al, 2006)

It has been observed that for collar locations where soil temperature, soil moisture, etc., track each other during the day, their $CO_2$ fluxes will also show similar diurnal patterns, so that infrequent survey chamber measurements can be used to infer the diurnal $CO_2$ fluxes. This approach enables the investigators to model the effects of rapidly varying environmental factors (solar radiation, air temperature, rainfall, etc.), as well as to obtain reliable whole site mean fluxes.

## Determining Sample Size

The standard error, $\sigma \bar{y}$ (the standard deviation of a mean) is related to the total population standard deviation, $\sigma$, by:

$$\sigma_{\bar{y}} = \frac{\sigma}{\sqrt{n}} \qquad 1$$

where $n$ is the number of measurements in a sample.

For a population with normal distribution, there is a 95% probability that the true mean $\mu$, the arithmetic mean of the entire population, lies within the range:

$$\bar{y} \pm \frac{2\sigma}{\sqrt{n}} \qquad 2$$

where $\bar{y}$ is the sample mean.

Generally, we wish to keep $\frac{2\sigma}{\sqrt{n}} \leq$ acceptable error. In other words,

$$\frac{2\sigma}{\sqrt{n}} \leq \mu \times fractional\ error\ acceptable \qquad 3$$

Therefore,

$$\sqrt{n} \geq \frac{2\sigma}{\mu \times fractional\ error\ acceptable} \qquad 4$$

The coefficient of variation (CV) is defined as $\frac{\sigma}{\mu}$. Therefore,

$$n \geq \left(\frac{2.CV}{fractional\ error\ acceptable}\right)^2 \qquad 5$$

## References


Savage, K. and Davidson, E. A., 2003. A comparison of manual and automated systems for soil $CO_2$ flux measurements: trade-offs between spatial and temporal resolution. Journal of Experimental Botany, 54(384): 891-899.

Arnold, Kira, Jay Ham, Clenton Owensby and Patrick Coyne, 2006. Temporal stability of soil respiration in tallgrass prairie: towards watershed-scale estimates of carbon fluxes. Abstract, ASA-CSSA-SSSA 2006 International Meeting, 231-14.


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