

Vaisala CARBOCAP Carbon Dioxide Probe GMP343:

In-Soil Carbon Dioxide measurements

This application note gives some basic guidelines on measuring the in-soil CO₂ concentration with a probe-type of instrument. The Vaisala CARBOCAP® Carbon Dioxide Probe GMP343 is designed for ecological measurements and intended to be used in harsh environments in the field. It is a compact and light-weight instrument with a low power consumption and heat emission. Therefore, the probe can be buried below-ground for CO₂ profile measurements.

Why measure CO₂ below ground?

There are different reasons for measuring CO₂ below ground. One of the main reason is to obtain information about the growth conditions for plants and trees in agricultural and forest research. In-soil CO₂ measurements can also be used for measuring the CO₂ flux from the soil. In this type of research, which is often related to studying the carbon cycle, the objective is to clarify how the CO₂ flux from the soil to the atmosphere varies with season, light conditions, geographical location, properties of the soil, etc.

Soil CO₂ efflux is generated by a combination of biotic, chemical and physical processes that take place in the soil. The biotic processes consist of the respiration of roots, micro-organisms and larger fauna living in the soil. Plant roots contribute directly to soil respiration by releasing lots of easily decomposable carbohydrates. The microbiological activity in the soil largely determines the

decomposition rate of organic matter and thus, the contribution of respiration to soil CO₂ efflux. The chemical processes that take place in the soil include the chemical oxidation of minerals. Although this is normally a relatively small source of CO₂ compared to others, it increases at higher temperatures. The physical processes consist of soil CO₂ degassing and the transport of CO₂ through soil to the surface by diffusion and convection.

Factors affecting soil respiration rate

Various factors affect the soil CO₂ respiration rate. These are:

- soil temperature
- soil moisture
- soil type and texture

Soil temperature is the most dominant factor in regulating soil respiration. The temperature varies depending on geographical location, season, time of the day, and weather conditions. Soil respiration increases exponentially with increasing temperature (to a certain extent).

Soil moisture is another important factor influencing soil respiration. Soil CO₂ efflux is usually low under dry conditions due to low root and microbial activity, and increases with soil moisture to a certain limit. At very high moisture conditions, soil CO₂ efflux is reduced due to a limitation of diffusion of oxygen. The understanding of the relationship between soil moisture and soil respiration and the underlying mechanisms is still limited.

Soil respiration usually responds most to whichever of the two factors, temperature or moisture, is the most limiting. If the soil is very dry, the soil respiration is not sensitive to temperature. When the moisture level increases, the level of respiration becomes much more sensitive to temperature. Similarly, at temperatures below 5°C soil respiration is not sensitive to moisture, but becomes increasingly responsive at higher temperatures.

The soil type and its texture have a strong effect on soil respiration because the diffusion of CO₂ is influenced by

the soil porosity. Small pores, for instance, retain water well. Larger interconnecting pores allow water and air to move freely into and out of the soil.

In-Soil CO₂ measurements

The CO₂ flux from the soil indicates the biological activity in the soil. The aim of in-soil CO₂ measurements is typically to measure the CO₂ profile at variable depths in the soil, which can be used to calculate the CO₂ flux from the soil. The most active layer in soil is closest to the surface [2, 3, 4, 5], thus measuring the CO₂ profile close to the surface layer gives information of the CO₂ flux from the soil to the atmosphere. Most measurements, also those with agricultural applications, are made fairly close to the surface layer of the soil.

The CO₂ concentration below-ground increases with the depth and depends largely on the soil type and the environmental conditions. The CO₂ efflux and soil air CO₂ concentration changes rapidly when it rains. After a rain event, the humidity in the soil can be very high for quite some time. Sensor durability and stability are thus key issues in below-ground measurements.

Measurement instrument requirements

In order to clarify the CO₂ profile in the soil, several sensors are buried below ground at different depths [1]. The GMP343 is designed for harsh environments and can be buried below-ground (see *Figure 1*).

As shown in *Figure 1*, the CO₂ profile in the soil can be measured with several sensors installed on exact depths either in vertical or horizontal position. In below-ground CO₂ profile measurements it is important to record the exact depth to maintain the comparability of the measurements to other measurements and to reliably determine the vertical distribution of the CO₂ profile in the soil. A 55 mm saw drill is recommend for making the

holes in to avoid disturbance of the soil profile as much as possible.

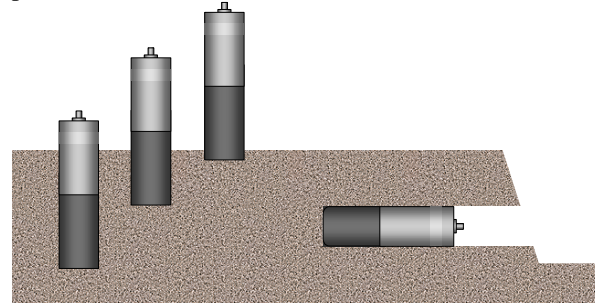


Figure 1. Alternative positions for the GMP343 in below-ground measurements

For vertically installed GMP343 probes, an adapter with an open end is recommended. However, it must be taken care that the cap joints are firmly sealed against the probe body to avoid water from entering the GMP343 sensor optics. In the horizontal installations of the GMP343, an adapter with a diffusion slot on the lower side of the probe is recommended. The diffusion slot enables also condensation water inside the cap to run out from the sensor optics.

For further details, please refer to the in-soil adapter manuals of the GMP343 for vertical and horizontal installations.

The challenge in below-ground CO₂ measurements is to prevent the sensors from changing conditions inside the soil. The main problem is that the soil texture easily changes when the sensors are buried below ground - It is therefore important to acknowledge that it will most probably take months or even years until the situation has recovered. Generally the horizontal installation is recommended, because of its smaller impact on the temperature profile in the soil. However, if the vertical position for some reason is used, it is important to understand that heat conducted along the sensor body might change the conditions in the soil.

Despite these difficulties there is an advantage in using small, diffusion-based CO₂ sensors with a low power consumption. The low power consumption minimizes the heating of soil, and thus, a formation of microclimate around the sensors can be avoided.

The Vaisala CARBOCAP® Carbon Dioxide Probe GMP343 has a variety of measurement ranges up to 5000 ppm. Soil CO₂ concentration may, however, be much higher. For these kinds of installations, the Vaisala CARBOCAP® Carbon Dioxide Transmitter Series GMT220 can be used. The GMT220 Series has measurement ranges of up to 0...20%CO₂.

For a reference of vertical installation of Vaisala CARBOCAP® Carbon Dioxide Transmitter Series GMT220 see *Figure 2*. Reference [1] discusses in detail the measurement setup and the results according to the figure.

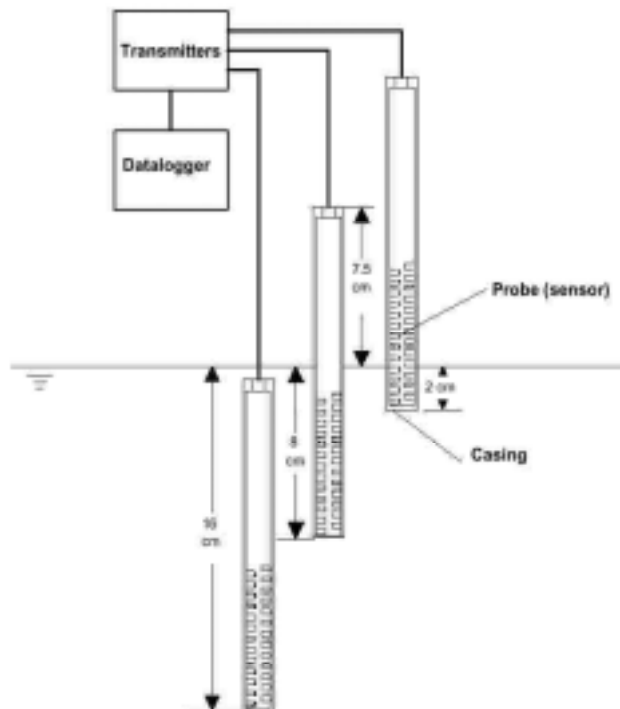


Figure 2. The Vaisala CARBOCAP Carbon Dioxide Transmitter Series GMT220 in below-ground measurements [1]

There are adapters for vertical and horizontal in-soil installations available for the GMP343. In addition, an adapter for vertical in-soil adapter installations of the GMP220 Series Probe is available.

References:

- [1] Tang, J, D.D. Baldocchi, Y. Qi, and L. Xu, 2003. *Assessing soil CO₂ efflux using continuous measurements of CO₂ within the soil profile with small solid-state sensors.* Agricultural and Forest Meteorology, 118, 207-220
- [2] Kähkönen, M.A., C. Wittman, J. Kurola, H. Ilvesniemi, and M.S. Salkinoja-Salonen, 2001. *Microbial activity of boreal forest soil in a cold climate.* Boreal Environment Research 6:19-28
- [3] Kähkönen, M. A., C. Witmann, H. Ilvesniemi, C.J. Wetsman, and M.S. Salkinoja-Salonen, 2002. *Mineralization of detritus and oxidation of methane in acid boreal coniferous forest soils: seasonal and vertical distribution and effects of clear-cut.* Soil Biology & Biochemistry 34 (2002) 1191-1200
- [4] Pumpanen J., H. Ilvesniemi, and P. Hari, 2003. *A process-based model for predicting soil carbon dioxide efflux and concentration.* Soil Science Society of America Journal. 67:402-413
- [5] Billings S.A., D.D. Richter, and J. Yarie, 1998. *Soil carbon dioxide fluxes and profile concentrations in two boreal forests.* Can. J. For. Res. Vol 28, 1998 1773-1783