An objective approach to select soil CO_2 concentration measurement depths when using the gradient method to measure soil respiration

Edward Ayres[1], Natchaya Pingintha-Durden[1], Jim Tang[2], Andy Fox[1], Rommel Zulueta[1]

[1]National Ecological Observatory Network, Boulder, CO; [2]The Ecosystem Center, Marine Biological Laboratory, Woods Hole, MA

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Introduction

The gradient method has been increasingly used to calculate soil CO_2 fluxes based on measurements of the soil CO_2 concentration profile and soil CO_2 diffusivity rates. Soil CO_2 concentration measurement depths should be chosen to meet the assumptions of the gradient method and remain within the sensors' measurement range, but at most sites relevant information is not available, which makes selecting depths challenging. Here, we present the approach used by the National Ecological Observatory Network (NEON) to select three site-specific measurement depths at locations throughout the US.

The approach was designed to fulfil four requirements of the gradient method:

1) the shallowest depth should be close to the soil surface so that the entire soil-atmosphere CO_2 flux can be determined;
2) the depths should correspond to CO_2 concentrations that do not exceed the sensors' range (Vaisala GMP343: 0-20,000 ppm range);
3) that CO_2 production rates are similar between any two measurement depths; and
4) the depths maximize the extent of the soil CO_2 profile, since this allows CO_2 production rates at different depths to be determined over a larger range of depths.

The approach requires modeling soil CO_2 concentration profiles (Box 1) and CO_2 production profiles (Box 2), as well as measuring soil horizon depths (Box 3). This information was then used in the measurement depth selection criteria (Box 4).

What is NEON?

NEON is a 30-year National Science Foundation-funded facility for understanding and forecasting the impacts of climate change, land use change, and invasive species on aspects of continental-scale ecology such as biodiversity, biogeochemistry, infectious diseases, and ecohydrology. NEON will measure a wide range of properties at 60 terrestrial and 36 aquatic sites throughout the US using in situ sensors, sample collection/lab analysis, and remote sensing, and all data will be made freely available.

The Observatory is currently under construction and will be fully operational by 2017, however, limited data collection and release began in 2013.

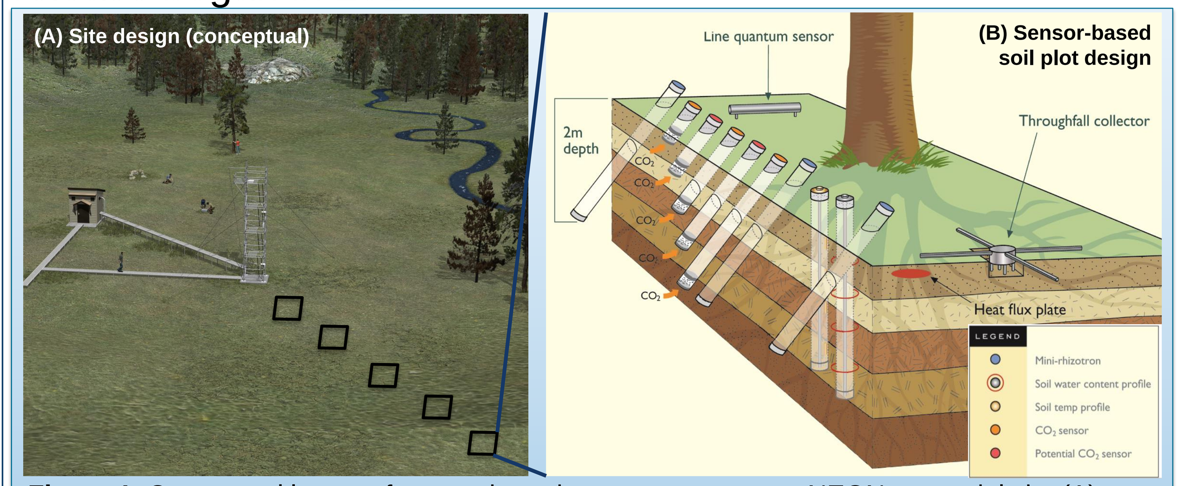

Figure 1. Conceptual layout of sensor-based measurements at a NEON terrestrial site (A) consisting of an instrumented tower and 5 soil plots (B). Soil sensor measurements include temperatures profiles, soil moisture and salinity profiles, CO_2 concentration profiles, root turnover rates from minirhizotrons, and soil heat flux.

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Contact Information: eayres@neoninc.org

USDA NRCS United States Department of Agriculture Natural Resources Conservation Service

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Box 1: Modeled soil CO_2 concentration profile

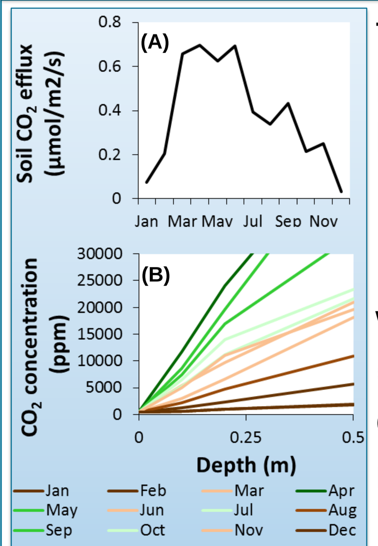


Figure 2. Monthly soil respiration (A) and CO_2 concentrations (B) at CPER site, Colorado.

The CO_2 concentration at 0.1, 0.2 and 0.5 m at each NEON site was calculated for each month using Fick's law:

$$C_z = \frac{C_{flux} \times z}{D} + C_0$$

where, C_z and C_0 is CO_2 concentration at z and 0 m; C_{flux} is mean monthly soil respiration rate from the Community Land Model; and D is soil CO_2 diffusivity rate.

Site-specific inputs required to calculate D using the Millington-Quirk model (Millington and Quirk 1961) were soil bulk density, elevation, and mean monthly soil moisture and temperature. Bulk density and elevation were measured at a soil pit excavated at each NEON site (Box 3), and soil moisture and temperature data were collected from the nearest USDA NRCS Soil Climate Analysis Network site.

The monthly CO_2 concentration profile was constructed by linearly interpolating between concentrations at 0, 0.1, 0.2, and 0.5 m (Figure 2).

Box 2: Soil CO_2 production profile

We used fine root biomass profiles as a proxy for CO_2 production because the relationship between CO_2 production and soil depth was unknown at most sites. We assumed that biomass and respiration were positively and linearly correlated.

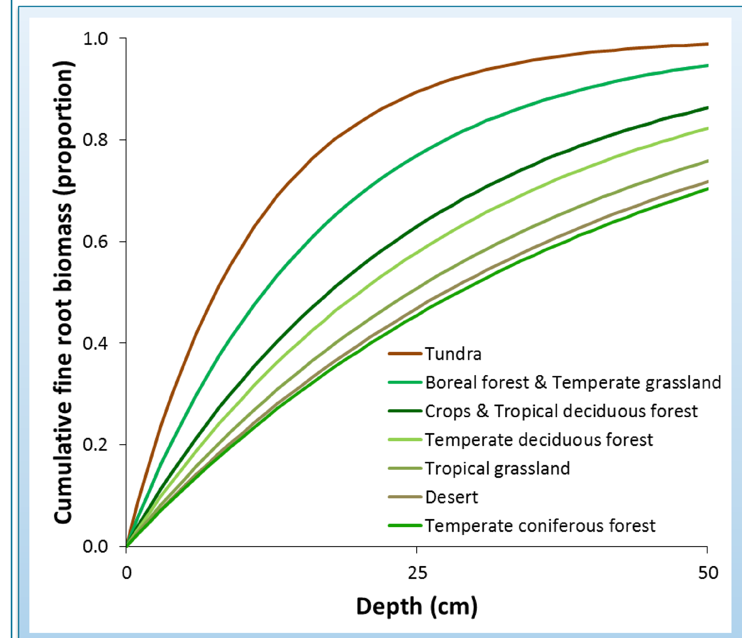


Figure 3. Modeled fine root biomass distribution with soil depth for different biomes from Jackson et al. (1996).

Fine root biomass distributions for different biomes were determined from Jackson et al. (1996; Figure 3) and the ecosystem at each NEON site was assigned to one of these biomes.

Box 3: Soil horizon depths

Soil horizon depths were identified from a single soil pit dug at each NEON site (Figure 4). NRCS soil maps and site visits were used to ensure the soil pit location was representative of the soil plots where the soil CO_2 sensors would be installed. The pit was usually within a few hundred meters of the soil plots. Soil horizons were identified by a local soil scientist, usually from NRCS.

Besides measuring soil horizon depths, soil samples were also collected from each horizon for lab analyses and archiving.

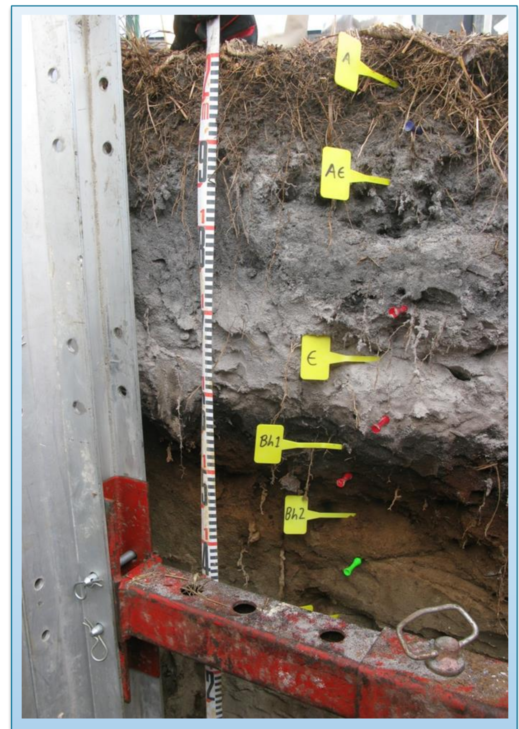


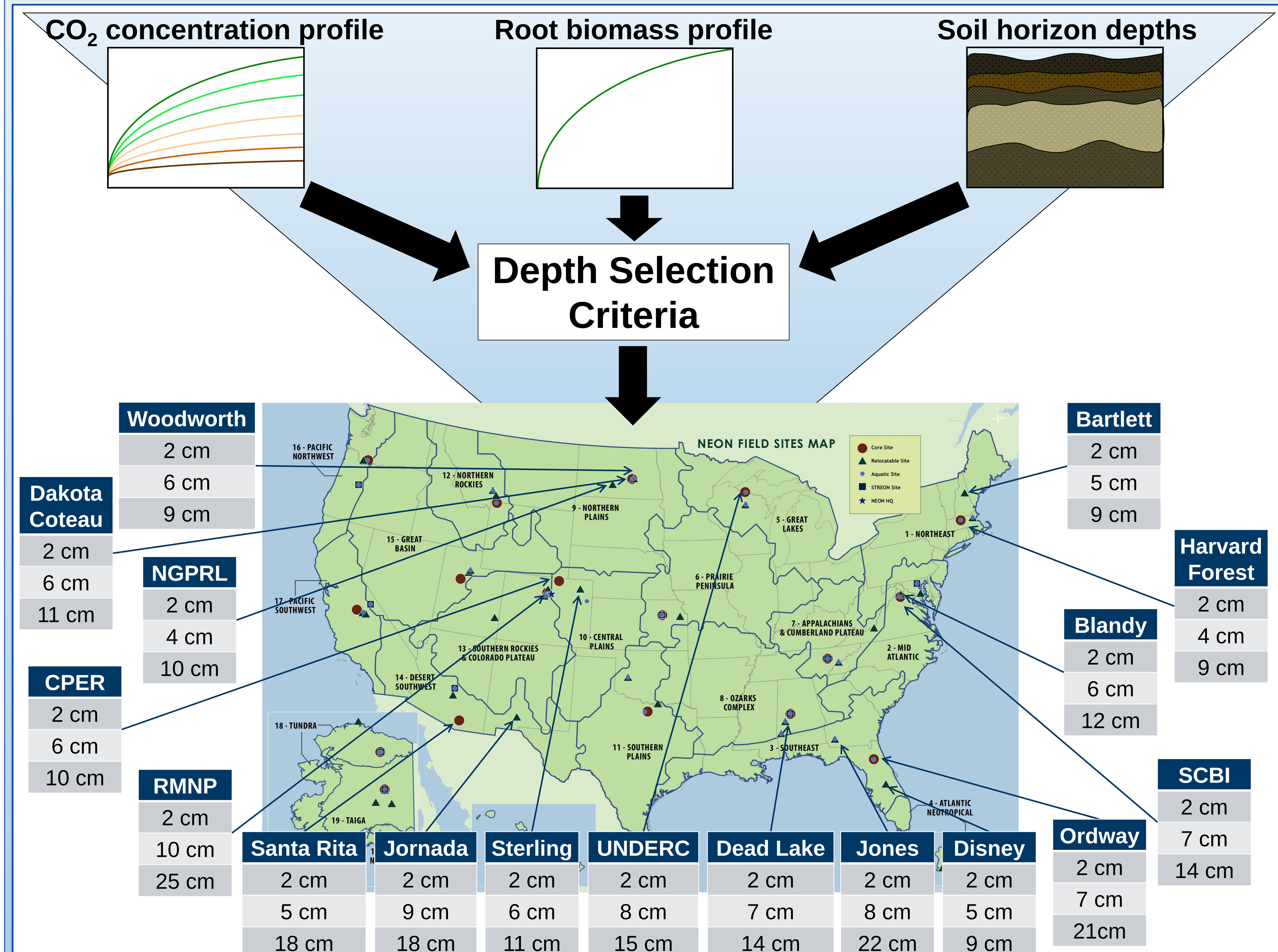
Figure 4. Soil horizons identified at a soil pit excavated at the Disney Wilderness Preserve, Florida.

References:

Jackson RB, Canadell J, Ehleringer JR, Mooney HA, Sala OE, Schulze ED. 1996. A global analysis of root distributions for terrestrial biomes. Oecologia 108:389-411.

Millington R, Quirk JP. 1961. Permeability of porous solids. Trans. Faraday Soc. 57:1200-1207.

Box 4: Depth Selection Criteria



Site	Shallowest	Middle	Deepest
Woodworth	2 cm	6 cm	9 cm
Dakota Coteau	2 cm	6 cm	11 cm
NGPRL	2 cm	4 cm	10 cm
CPER	2 cm	6 cm	10 cm
RMNP	2 cm	10 cm	25 cm
Santa Rita	2 cm	5 cm	18 cm
Jornada	2 cm	9 cm	18 cm
Sterling	2 cm	6 cm	11 cm
UNDERC	2 cm	8 cm	15 cm
Dead Lake	2 cm	7 cm	14 cm
Jones	2 cm	8 cm	22 cm
Disney	2 cm	5 cm	9 cm
Ordway	2 cm	7 cm	21cm
SCBI	2 cm	7 cm	14 cm
Blandy	2 cm	6 cm	12 cm
Harvard Forest	2 cm	4 cm	9 cm
Bartlett	2 cm	5 cm	9 cm

Figure 5. Procedure for selecting soil CO_2 concentration measurement depths. The tables show the measurement depths selected for 17 sites where this approach has been implemented to date.

Depth Selection Criteria

1. The shallowest soil CO_2 sensor shall be installed at 2 cm below the soil surface.
2. The depth of the second shallowest sensor must not exceed 80% of the depth where the CO_2 concentrations are >20,000 ppm for any month of the year.
3. The deepest sensor must not exceed 100% of the depth where CO_2 concentrations are >20,000 ppm for any month of the year.
4. The minimum vertical distance between sensors is 2 cm.
5. The depth increment between two neighboring CO_2 sensors must correspond to a change in root biomass of ≤25%.
6. When possible, and without violating the requirements above, the depth of each soil CO_2 concentration sensor below 2 cm shall match the depth of the interface between the next two soil horizons.
7. If the deepest CO_2 sensor cannot be installed at an interface between soil horizons (e.g., because the horizon is too thick) the sensor shall be installed at the deepest depth that does not violate any of the requirements above.
8. Without violating the requirements above, if 3 sensors are installed within, or at the interfaces of, a single soil horizon the middle sensor shall be installed at a depth that minimizes the difference in root biomass between the sensors.

Results and Discussion

To date this depth selection approach has been implemented at 17 sites (Figure 5), and resulted in CO_2 measurement depths of 2 cm, 4-10 cm, and 9-25 cm for the shallowest, middle, and deepest depths, respectively. This is similar to depths used successfully by other researchers using the gradient method.

A large number of assumptions were made to generate the site-specific data needed for the depth selection criteria. As a result, future research will involve validating this approach once the soil CO_2 concentration sensors have been installed at NEON sites.