NEON SOIL SENSOR DEPTH SELECTION

PREPARED BY	ORGANIZATION	DATE
Ed Ayres	FIU	02/26/2013

APPROVALS	ORGANIZATION	APPROVAL DATE
Kate Thibault	SCI	05/26/2022

RELEASED BY	ORGANIZATION	RELEASE DATE
Tanisha Waters	CM	05/26/2022

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Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A	09/01/2015	ECO-03218	Initial Release
B	05/26/2022	ECO-06832	• Revised NEON logo and fine print

TABLE OF CONTENTS

1 DESCRIPTION

1.1 Purpose

The purpose of this document is to describe the methodology for choosing soil sensor depths at NEON sites in an objective and repeatable manner.

1.2 Scope

This document describes the approach that will be used to select soil sensor depth placements, however, it does not define site-specific sensor depths for each soil plot, which will be documented elsewhere. The scope is limited to soil sensors that will be installed at different depths across NEON sites, *i.e.*, soil temperature sensor, soil water content/soil water ion content sensor, and soil CO_2 concentration sensor. The depths are based in part on the soil profile identified at the TIS Soil Pit measured at each NEON site, which is usually located a few hundred meters from the NEON TIS soil plots. As a result, the sensor depths may need to be modified at the time of installation if the sensor borehole depth differs from the depth achieved at the soil pit.

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

Applicable documents contain information that shall be applied in the current document. Examples are higher level requirements documents, standards, rules and regulations.

AD [01]	NEON.DOC.000291	NEON Configured Sensor List

2.2 Reference Documents

Reference documents contain information complementing, explaining, detailing, or otherwise supporting the information included in the current document.

RD [01]	NEON.DOC.000008	NEON Acronym List
RD [02]	NEON.DOC.000243	NEON Glossary of Terms

2.3 Acronyms

N/A

2.4 Verb Convention

"Shall" is used whenever a statement expresses a convention that is binding. The verbs "should" and "may" express non-mandatory provisions. "Will" is used to express a declaration of purpose on the part of the design activity.

3 RULES FOR SELECTING SOIL SENSOR INSTALLATION DEPTHS

3.1 Soil Water Content/Soil Water Ion Content Sensor

Soil water content/soil water ion content sensors will be installed in a single vertical profile in each of the five soil plots within the TIS Soil Array. According to the manufacturer the soil water content/soil water ion content sensors have a 10 cm vertical measurement zone (i.e., 5 cm above and below the mid-point of the sensor) (Sentek 2011). In addition, the sensors can only be installed at 10 cm increments starting at 6 cm below the soil surface (i.e., the mid-point of the sensors can only be placed at 6, 16, 26, 36 … cm below the soil surface). Currently each profile will consist of 8 sensors, however, this number will be reduced if the bottom of the soil C horizon is shallower than 80 cm at some soil plots.

The installation depth refers to the depth of the vertical mid-point of the sensor. The selection of installation depths to place soil water content/soil water ion content sensors shall comply with the following rules applied sequentially in the order shown:

1. The three highest sensors in the profile shall be installed 6 cm, 16 cm, and 26 cm below soil surface since this is where soil moisture will be most dynamic. Note that an existing NEON requirement, based on a USDA definition, specifies how the soil surface is determined.
2. The lowest sensor in the profile shall be installed at 196 cm at non-permafrost sites, 5-14 cm (based on sensor mounting position) above the permafrost layer at permafrost sites if that is ≤296 cm, 296 cm at permafrost sites if the top of the permafrost is deeper than 300 cm, or 5-14 cm (based on sensor mounting position) above the bottom of the C horizon if this is shallower than 200 cm at non-permafrost sites or 300 cm at permafrost sites. This ensures that the profile extends over the maximum possible depths within NEON's design constraints.
3. At least 4 sensors in the profile shall be installed at depths of ≤56 cm if the bottom of the C horizon is ≥50 cm, and at least 5 sensors shall be installed at depths of ≤106 cm if the bottom of the C horizon is ≥120 cm. The sensor installation depths are at a higher density near the soil surface since that is where soil moisture is most dynamic.
4. One sensor shall be installed in each soil horizon (based on the soil horizon depths identified in the TIS Soil Pit) to ensure that horizon-specific dynamics are captured.
    a. If there are more soil horizons than available sensors, then the sensors shall be installed in:
        i. each master horizon (e.g., O, A, E, B, C, AB, BC, E/B, B/E, or B/C) starting from the top horizon;
        ii. then each subhorizon (e.g., Bt, Bw, etc) starting from the top subhorizon; and
        iii. then each subdivision within a horizon or subhorizon (e.g., C1, C2, C3, Bt1, Bt2) starting from the top subdivision until no more sensors are available.
    b. If there are two or more potential installation depths within a soil horizon the installation depth shall be at least 5 cm above the bottom of the horizon and at least 5 cm below the top of the horizon.

i. If there are no installation depths that are least 5 cm above the bottom of the horizon and at least 5 cm below the top of the horizon, the installation depth that results in the greatest amount of the target soil horizon in the 10 cm vertical measurement zone shall be selected.

ii. If there are two or more potential installation depths within a soil horizon that are at least 5 cm above the bottom of the horizon and at least 5 cm below the top of the horizon, then the installation depth closest to the middle of the soil horizon shall be selected to increase the likelihood that the sensor is installed in the target horizon (since horizon depths will vary spatially).

5. If there are fewer soil horizons than sensors then each horizon with a thickness of ≥50 cm shall have two sensors installed starting with the uppermost horizon and getting progressively deeper until no more sensors are available. If sensors are still available after this, then each horizon with a thickness of ≥40 cm shall have two sensors installed starting with the uppermost horizon and getting progressively deeper until no more sensors are available.
   a. When two sensors are installed in a horizon they shall be installed at least 5 cm above the bottom of the horizon and at least 5 cm below the top of the horizon; and they shall be installed at depths that are as close to one-third and two-thirds of the horizon thickness as possible.
      i. If sensors are still available after this, then each horizon with a thickness of ≥50 cm shall have three sensors installed starting with the uppermost horizon and getting progressively deeper until no more sensors are available. If sensors are still available after this, then each horizon with a thickness of ≥40 cm shall have three sensors installed starting with the uppermost horizon and getting progressively deeper until no more sensors are available.
         1. When three sensors are installed in a horizon they shall be installed at least 5 cm above the bottom of the horizon and at least 5 cm below the top of the horizon; and they shall be installed at depths that are as close to one-quarter, one-half, and three-quarters of the horizon thickness as possible.

3.2 Soil Temperature Sensor

Soil temperature sensors will be installed in a single vertical profile in each of the five soil plots within the TIS Soil Array. The number of sensors in a single profile is one-fifth of the number of soil temperature sensors specified for the sites in AD[01] (currently there will be 9 sensors in a single profile depending on the site). However, this number will be reduced if the bottom of the soil C horizon is shallower than 80 cm at some soil plots.

The selection of depths to place soil temperature sensors shall comply with the following rules applied sequentially in the order shown:

1. The two highest sensors in the profile shall be installed at 2 cm and 6 cm below soil surface. This is because soil temperature is most dynamic near the surface and because two temperature sensors must be installed at or above the soil heat flux plate (8 cm below the surface) to calculate heat storage above the heat flux plate. Note that an existing NEON requirement, based on a USDA definition, specifies how the soil surface is determined.
2. The lowest sensor in the soil temperature profile shall be installed at 196 cm at non-permafrost sites, 296 cm at permafrost sites, or 5-14 cm above the bottom of the C horizon (to match the soil water content/ion content sensor installation depth) if this is shallow than 200 cm at non-permafrost sites or 300 cm at permafrost sites. This ensures that the profile extends over the maximum possible depths within NEON's design constraints.
3. Of the remaining soil temperature sensors, one shall be installed each soil horizon that contains a soil water content/soil water ion content sensor. The soil temperature sensors shall be installed at the same depths as the soil water content/soil water ion content sensors starting with the soil water content/soil water ion content sensor at 16 cm and getting progressively deeper until no more temperature sensors are available.
    a. If there are temperature sensors still remaining, temperature sensors shall be installed at the same depth as each soil water content/soil water ion content ≥16 cm.
    b. If more temperature sensors are available than soil water content sensors that are installed at depths of ≥16cm, then the additional temperature sensors shall be installed in:
        i. each master horizon (e.g., O, A, E, B, C, AB, BC, E/B, B/E, or B/C) starting from the top horizon;
        ii. then each subhorizon (e.g., Bt, Bw, etc) starting from the top subhorizon; and
        iii. then each subdivision within a horizon or subhorizon (e.g., C1, C2, C3, Bt1, Bt2) starting from the top subdivision until no more sensors are available.
6. If sensors are still available, then a second sensor shall be installed in the thickest horizon with only one sensor, followed by the next thickest horizon with only one sensor, until all horizons with a thickness of ≥10 cm have two sensors.
    a. The additional sensor shall be placed above or below the sensor that is already in the horizon based on whichever side has the greatest distance to the next sensor. The additional sensor shall be placed equidistant between its two neighboring sensors, unless that would be outside of the target horizon, in which case it shall be placed at the interface between the two horizons.
7. If sensors are still available, then a third sensor shall be installed in the thickest horizon with only two sensors, followed by the next thickest horizon with only two sensor, until all horizons with a thickness of ≥10 cm have three sensors.
    a. The additional sensor shall be placed above, below, or in-between the sensors already in the horizon based on whichever side has the greatest distance to the next sensor. The additional sensor shall be placed equidistant between its two neighboring sensors,

unless that would be outside of the target horizon, in which case it shall be placed at the interface between the two horizons.

3.3 Soil CO_2 Concentration Sensor

The following rules shall be applied to select the installation depths for the soil CO_2 concentration sensors at each NEON site. The soil CO_2 concentration profile shall be measured using at least 3 CO_2 concentration sensors (installed at different depths) in each of the 5 soil plots at a NEON site. The CO_2 profile will be used in conjunction with estimates of soil CO_2 diffusivity to calculate soil CO_2 efflux.

The installation depth corresponds to the depth of the inlets to the sensor assembly relative to the soil surface. The inlets to the assembly allow the sensor measurement headspace to be connected to soil air, with the movement of gases between the headspace and soil air driven primarily by diffusion. The inlets will have a height of ≤1 cm (i.e., only soil air from within a depth increment of ≤1 cm will be able to diffuse into the sensor's measurement headspace).

1. The shallowest soil CO_2 sensor shall be installed at 2 cm below the soil surface.
    a. Justification: To estimate soil CO_2 efflux accurately a CO_2 concentration measurement is needed near the soil surface. Several previous studies that have used the gradient method to successfully calculate soil CO_2 efflux have made the shallowest measurement at 2 cm below the soil surface (Tang et al. 2005, Baldocchi et al. 2006, Vargas and Allen 2008a, b).
2. The minimum vertical distance between sensor depths is 2 cm.
    a. Justification: To ensure gradient in CO_2 concentration is apparent between neighboring sensors.
3. The depth of the second shallowest sensor must not exceed 80% of the depth where the CO_2 concentrations are >20,000 ppm (under mean soil moisture and temp) for any month of the year.
    a. Justification: To avoid exceeding the sensor's maximum range (20,000 ppm) at almost any time. At least two soil CO_2 concentration measurements are needed to estimate soil CO_2 efflux.
        i. Assumption: Soil CO_2 concentration at different depths can be accurately modelled using soil moisture/temp data from the nearest USDA Soil Climate Analysis Network site, bulk density from the NEON soil pit, soil respiration data from Community Land Model, and linking soil CO_2 efflux to soil CO_2 concentration using approach described by Tang et al. (2003).
4. The deepest sensor must not exceed 100% of the depth where CO_2 concentrations are >20,000 ppm (under mean soil moisture and temp) for any month of the year.
    a. Justification: To avoid exceeding the sensor's maximum range (20,000 ppm) most of the time. At least two soil CO_2 concentration measurements are needed to estimate soil CO_2 efflux.

        i. Assumption: CO_2 concentration at different depths can be accurately modelled using soil moisture/temp data from the nearest SCAN site, bulk density from the NEON soil pit, soil respiration data from Land Surface Model, and linking soil CO_2 efflux to soil CO_2 concentration using approach described by Tang et al. (2003).
5. The depth increment between two neighboring CO_2 sensors must correspond to a change in root biomass of ≤25% at the installation depths.
    a. Justification: To ensure the assumption that CO_2 production is uniform across a depth increment is not drastically violated.
        i. Assumption: Root biomass distribution with depth is a proxy for the CO_2 production distribution with depth.
        ii. Assumption: Root biomass distribution can be modelled using the approach and data reported by Jackson et al. (1996).
6. Whenever possible (i.e., without violating the installation requirements listed above), the installation depth of each soil CO_2 concentration sensor below 2 cm shall match the depth of the interface between the next two adjacent soil horizons below the soil CO_2 sensor above it.
    a. Justification: Soil CO_2 production is assumed to be more similar across a given depth increment within a soil horizon, than across the same depth increment spanning more than 1 soil horizon.
    b. Horizon depths are based on soil profile description from TIS Soil Pit.
        i. Assumption: The soil profile described at the TIS Soil Pit is representative of the profile at the installation locations. The soil pit is usually within the same soil type (according to USDA NRCS Web Soil Survey), topographic position, and within a few hundred meters of the locations where the soil CO_2 concentration measurements will be made.
7. When the deepest CO_2 sensor cannot be installed at an interface between soil horizons (e.g., because the soil horizon is too thick) the sensor shall be installed at the deepest depth that does not violate any of the installation requirements listed above.
8. Whenever possible (i.e., without violating the installation requirements listed above), when 3 or more sensors are installed within, or at the interface of, a single soil horizon the middle sensor(s) shall be installed at a depth that minimizes the difference in root biomass between any two adjacent sensors.
    a. Justification: To ensure the assumption that CO_2 production is uniform across a depth increment is not drastically violated.
        i. Assumption: Root biomass distribution with depth is a proxy for the CO_2 production distribution with depth.
        ii. Assumption: Root biomass distribution can be modelled using the approach and data reported by Jackson et al. (1996).

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