Measuring the climate of soils for the next 30 years

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Introduction

Soils can both mitigate and exacerbate the effects of climate change, but our current understanding of the role of soils in influencing climate is limited by a paucity of long term data from a range of ecosystems. To date, experimental studies have demonstrated many different mechanisms that link climate and soils; however, the artificial nature of these experiments limits their applicability to "real" ecosystems. Soil data from long-term observational studies of ecosystems are needed to complement findings from experimental studies in order to assess impacts of, and feedbacks to, climate in the real world. Moreover, since soil properties vary locally and at larger spatial scales (Figure 1), soil data is needed at a range of scales.

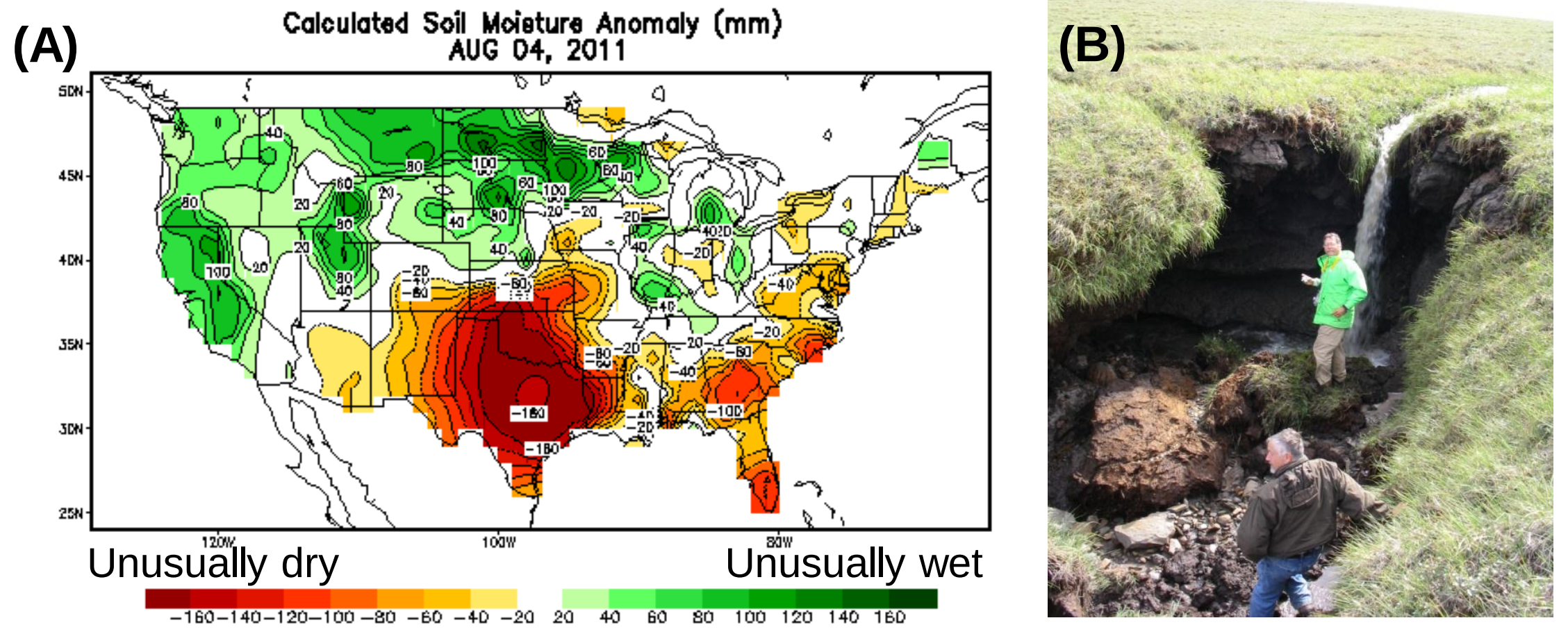

Figure 1. The soil climate varies at different spatial scales, including regional (A) and local (B) scales. Regional soil moisture anomaly (A) showing the recent drought in Texas and Oklahoma (Source: NOAA). Local scale permafrost melting can cause large structural changes to soils, *e.g.*, thermokarsts (B), in tundra ecosystems (Courtesy of M. Gooseff).

Here, we present an overview of the sensor-based soils data that will be collected, and made freely available, across the US for the next 30 years as part of the National Ecological Observatory Network (NEON) (Box 1). In addition, we present case studies of how this data could be used to address current uncertainties in climate-soil interactions in relation to warming, rising atmospheric CO_2 concentrations, and altered precipitation patterns (Boxes 2-4).

NEON overview

NEON is a NSF-funded facility to monitor the impacts of climate change, land use change, and invasive species on biodiversity and ecosystem function. The Observatory is designed to detect and enable forecasting of ecological changes at continental scales over 30 years.

NEON will measure physical, chemical, and ecological properties and processes at >60 sites throughout the US (Fig 2A). A wide range of atmospheric, terrestrial, and fresh water measurements will be made using consistent methodology. Measurements will span a wide range of temporal- (seconds to years) and spatial-scales (cm^2 to 10's km^2) to allow extrapolation to region and continent.

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Box 1: Sensor-based soil measurement strategy

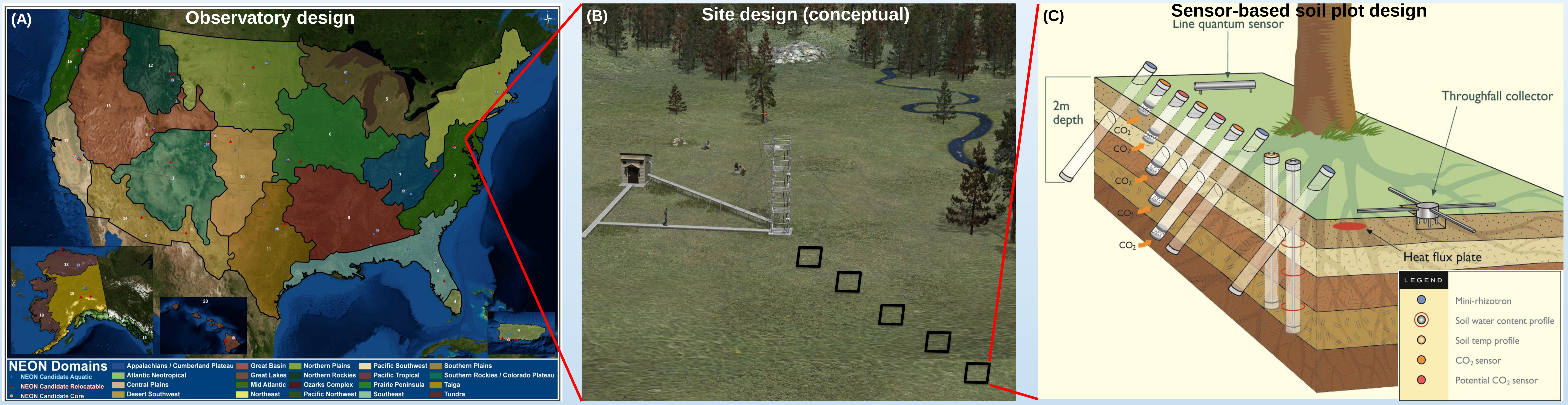

Figure 2. NEON's scalable soil sampling strategy. Locations of core and relocatable sites (A) within each of the 20 Domains (ecoregions). Core sites are minimally disturbed wildlands that will be monitored continuously for 30 yrs, while relocatable sites are managed or disturbed areas that will be monitored continuously for 5-10 yrs. Conceptual view of a NEON site (B) showing the tower, instrument hut, and 5 soil plots (black squares). Conceptual soil plot (C) showing the variety of sensors that will be deployed at each site.

The NEON soil sampling strategy was designed to be scalable so that both local scale and larger scale patterns can be detected (Figure 2). For example, NEON sites (Figure 2A) were chosen to be broadly representative of the surrounding region, local scale (~1 ha) soil variability was characterized to determine appropriate soil plot spacing (Figure 2B), and measurements will be taken throughout each soil profile up to 2 m deep (Figure 2C).

Table 1. Level 1 soil sensor data products.

Data Product	Sampling Frequency	Units
CO_2 profile	1-min	$\mu mol\ mol^{-1}$
Fine root image	~2 wk (site & season specific)	Digital image
Heat flux	1-min	$W\ m^{-2}$
PAR-line quantum	1-min	$\mu mol\ s^{-1}\ m^{-2}$
Temperature profile	1-min	C
Throughfall	1-min	mm
Water content profile	1-min	m^3 water m^{-3} soil

NEON's soil sensors will produce a variety of data products (Table 1) and all data will be made freely available via the NEON data portal. The data will be made available after undergoing different levels of processing. For example, Level 0 data represents raw sensor output, Level 1 data represents calibrated data converted to standard units that have undergone QA/QC, while Level 4 data represents derived data products, which may be based on multiple Level 1 data streams and may be spatially explicit at different scales (e.g., entire US or 1 km^2).

Provisional data, which has undergone automated QA/QC, will be available in near-real time and verified data, which has undergone additional QA/QC testing and eyes-on inspection, will be available later, with latency depending on data product complexity.

Table 2. Selected Level 4 data products derived from soil sensor data.

Data Product	Temporal resolution	Spatial extent	Spatial resolution
Soil CO_2 efflux	0.5 hr	Point	NA
	0.5 hr	~1 km^2	100 m
	1 day	US	1000 m
Soil moisture	0.5 hr	Point	NA
	0.5 hr	~1 km^2	100 m
	1 day	US	1000 m
Belowground NPP	1 day	US	1000 m

Box 2: Warming and soil carbon

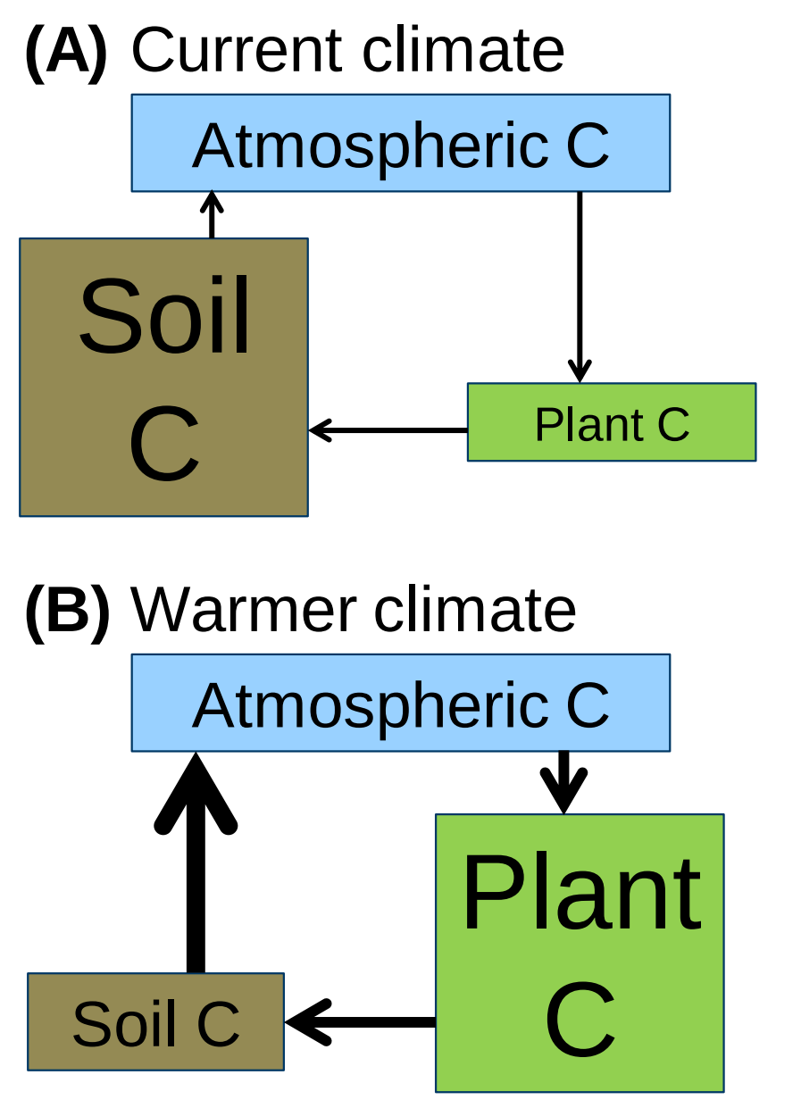
(A) Current climate
Atmospheric C
Soil C
Plant C
(B) Warmer climate
Atmospheric C
Plant C
Soil C

Figure 3. Warming at high latitudes may accelerate soil C decomposition, but this may be partially offset by increased plant C inputs to soil. Box and arrow size reflect the size of the pool and flux, respectively.

Warming in high latitudes is expected to melt permafrost and allow previously protected soil carbon (C) to be decomposed and returned to the atmosphere, thereby causing additional future warming. However, warming may also increase primary production, woody encroachment, and C inputs to soils resulting in the sequestration of newly fixed C in these regions, thereby partially offsetting 'old' C release caused by melting permafrost. The net effect of these opposing mechanisms on C storage is currently unclear, but NEON data on soil temperature, soil respiration rate, and fine root turnover, as well as other data, will be ideally suited to address this uncertainty.

Box 3: Precipitation and soil moisture

Increased temperatures over coming decades are expected to increase evapo-transpiration rates, which will reduce soil moisture. However, increases in precipitation in some regions (*e.g.*, high latitude ecosystems) may offset the increase in evapo-transpiration, whereas decreases in precipitation in other regions (*e.g.*, western US) will exacerbate increased water loss. NEON soil moisture data will allow the net effect of hydrological changes to be elucidated throughout the US.

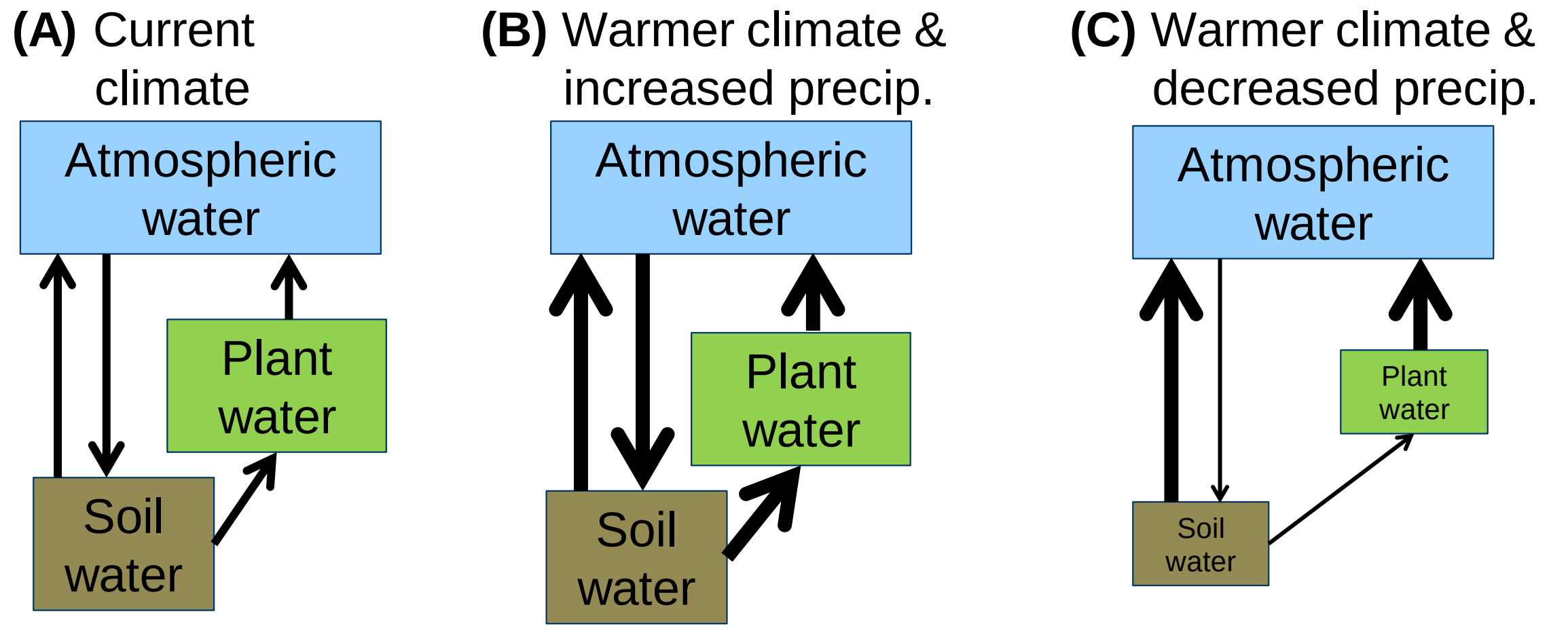
(A) Current climate
Atmospheric water
Plant water
Soil water
(B) Warmer climate & increased precip.
Atmospheric water
Plant water
Soil water
(C) Warmer climate & decreased precip.
Atmospheric water
Plant water
Soil water

Figure 4. Regional changes in precipitation and evapo-transpiration will alter soil moisture, which will impact plants and other organisms. Box and arrow size reflect the size of the pool and flux, respectively.

Box 4: Atmospheric CO_2 and soil carbon

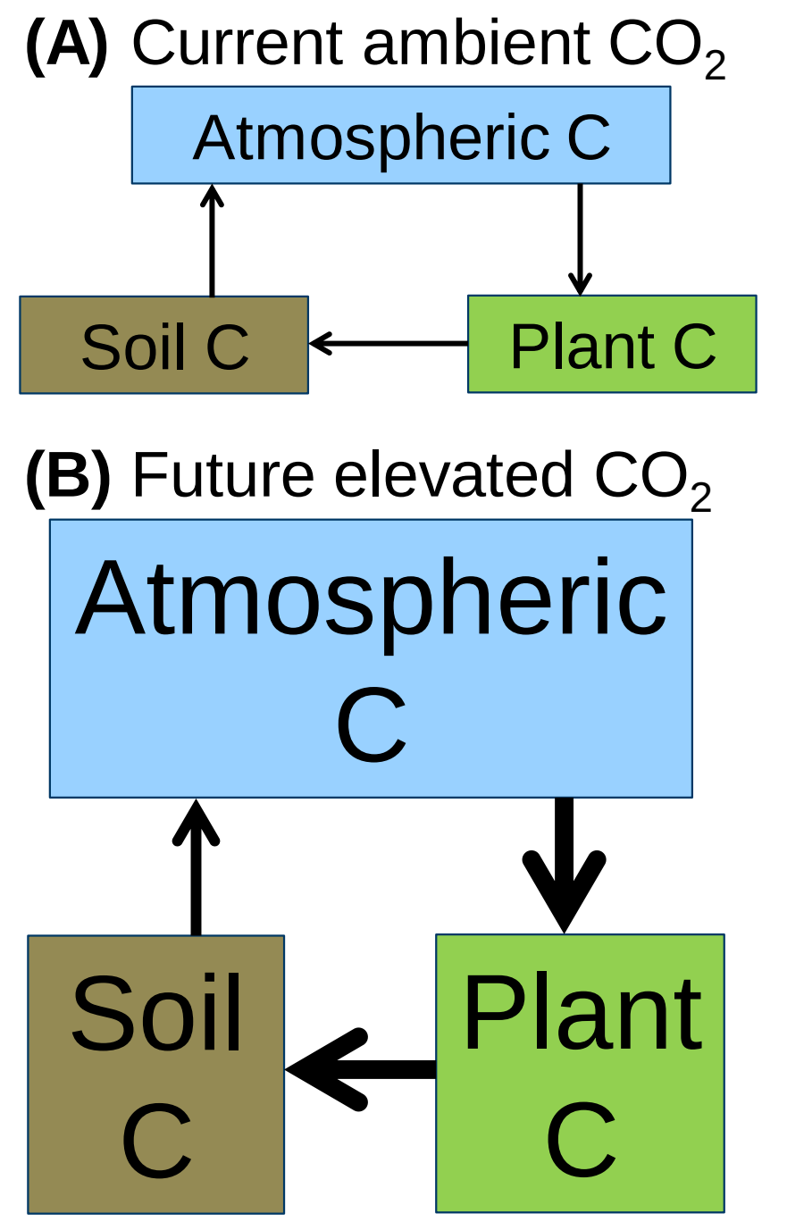
(A) Current ambient CO_2
Atmospheric C
Soil C
Plant C
(B) Future elevated CO_2
Atmospheric C
Soil C
Plant C

Figure 5. Elevated CO_2 concentrations may increase primary production and soil C sequestration. Box and arrow size reflect the size of the pool and flux, respectively.

As atmospheric CO_2 concentrations continue to rise, net primary productivity is expected to increase in many ecosystems. Increased productivity may increase carbon (C) inputs to soils and cause soil C sequestration to increase, thereby reducing the rate of increase of atmospheric CO_2. The magnitude of this feedback will like be strongly influenced by water and nutrient availability to plants. NEON data on soil respiration rate, fine root turnover, and soil moisture, as well as other data, could be used to calculate the magnitude of this feedback.

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