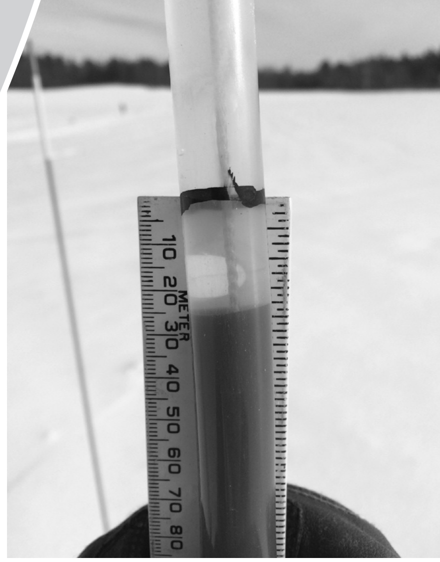
INQUIRY & INVESTIGATION

# Tracking Environmental Change Using Low-Cost Instruments during the Winter-Spring Transition Season



ELIZABETH BURAKOWSKI, SARAH SALLADE, ALIX CONTOSTA, REBECCA SANDERS-DEMOTT, DANIELLE GROGAN

**Abstract**

*The winter-spring shoulder season, or vernal window, is a key period for ecosystem carbon, water, and energy cycling. Sometimes referred to as mud season, in temperate forests, this transitional season opens with the melting of snowpack in seasonally snow-covered forests and closes when the canopy fills out. Sunlight pours onto the forest floor, soils thaw and warm, and there is an uptick in soil respiration. Scientists hypothesize that this window of ecological opportunity will lengthen in the future; these changes could have implications across all levels of the ecosystem, including the availability of food and water in human systems. Yet, there remains a dearth of observations that track both winter and spring indicators at the same location. Here, we present an inquiry-based, low-cost approach for elementary to high school classrooms to track environmental changes in the winter-spring shoulder season. Engagement in hypothesis generation and the use of claim, evidence, and reasoning practices are coupled with field measurement protocols, which provides teachers and students an authentic research experience that allows for a place-based understanding of local ecosystems and their connection to climate change.*

**Key Words:** *Winter; snow; phenology; inquiry; curriculum; data collection.*

## ○ Introduction

The winter-spring seasonal transition opens with snowmelt and concludes when the leaves of trees, plants, and shrubs reach their maximum size and fill out their canopies. Commonly referred to as mud season in seasonally-snow covered forested ecosystems, many birds, insects, fish, and wildflowers take advantage of high stream flows, rapidly warming soils, and abundant sunlight hitting the forest floor during this shoulder season. In a warming climate, this window of ecological opportunity is expected to lengthen in some locations and completely disappear in others (Grogan et al. 2020; Contosta et al. 2017; Creed et al., 2015).

Many classroom studies of ecosystems and climate change focus on global impacts and deal with examples in faraway places, and the local investigations that are available focus on the growing season and run well into summer vacation. As an alternative, the winter-spring transition in an outdoor classroom provides a perfect opportunity for teachers to use inquiry-based learning to study important science topics addressed in the Next Generation Science Standards (see Supplement 1, *The Winter-Spring Shoulder Season Timeline Activity*, available with the online version of this article), perform longitudinal studies, build vertical science literacy, and spiral curriculum related to the local environment across grade levels.

As a group of five scientists and five science teachers in New England, we partnered to create an authentic research experience that enhanced student learning about ecosystems and climate change (see Hagan et al., 2020; Zoellick et al., 2012; Dibner & Pandya, 2018). Students tracked changes in the vernal window in outdoor classrooms using low-cost measurement protocols. Using the schoolyard or nearby sites allowed students to engage in inquiry in their local environment, generate hypotheses based on observation, and answer research questions through teacher-directed or self-designed projects.

## ○ Setting the Stage: The Winter-Spring Shoulder Season Timeline

We used a 5E model of instruction to engage students in the concepts of ecosystem cycling and climate change in their local environment (see Supplement 1). First, we *engaged* by presenting students with a primer on weather and climate, and then information about the winter-spring shoulder season, including data from a scientific research site (see the "Engage" section in Supplement 1, and see Supplement 2, *Tracking the Vernal Window Using GLOBE Protocols*, available with the online version of this article). Next, students *explored* by arranging eight ecological events (Table 1) that take place within the winter-spring transition, represented by photos mounted on cards colored to correlate with the event's role in the ecosystem: energy flow (orange), water cycle (blue), and carbon cycle (green). Students worked in small groups (four to six students) to arrange the cards into hypothesized sequence and timing.

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**Table 1.** Eight ecological events that take place within the winter-spring transition divided by the event's role in the ecosystem. Bolded events are those that students can most easily measure in their outdoor classroom/local environment.

| Energy Flow (orange) | Water Cycle (blue) | Carbon Cycle (green) |
|---|---|---|
| **snow-free date** | peak streamflow | soil thaw |
| stream temperature warm-up | river/lake/stream ice-out | **budburst** |
| **start of snow melt** | | **canopy closure** |

As they worked in their groups, students used logical reasoning based on their prior knowledge of winter-spring seasonal transitions. Scientists emphasized that this is the same process used when they developed their own hypothesized vernal window timeline of ecological events studied in Contosta and colleagues (2017). The students *explained* by regrouping to critique and defended their timelines and identify patterns across groups. The activity naturally elicited hypotheses and research questions that could be investigated using teacher-directed or student-designed research projects that *elaborated* on a variety of field measurements outlined below. In this step, teachers considered their students' age and abilities to determine the appropriate level of inquiry (Banchi & Bell, 2008).


**Figure 1.** Protocols used to track environmental change during the winter-spring transition include (**A**) snow depth, (**B**) canopy green-up, and (**C**) soil frost depth. Photographs A and C by E. Burakowski. Photograph B by R. Pinnsoneault.

## ○ The Outdoor Classroom

We made sure to communicate with teachers that the outdoor classroom should be accessible in a safe location tucked away from heavy foot traffic. We encouraged them to work with school administrators and facilities/grounds personnel to get approval prior to installation of instruments. Schools that participated in our program set up their research sites in the late fall in forests adjacent to the school, on school lawns, or in protected courtyards. Signage describing the student experiment was implemented at one of the five schools to help deter vandalism and/or other interference (Clarin et al., 2014).

## ○ Field Measurement Protocols: Elaborate

In this study, we primarily used GLOBE measurement protocols to gather information about the winter-spring transition in outdoor classrooms. GLOBE stands for Global Learning and Observations to Benefit the Environment, a global citizen science program for students (globe.gov). Participation in GLOBE is optional but provides students with an opportunity to report their data to an international database with other students from around the world.

Although it may be possible for students to complete field measurements on all eight ecological events used to determine the vernal window, it is not necessary to do so. As indicated above, you can get an accurate picture of the winter-spring transition by collecting data exclusively on snow melt and canopy closure. In addition, there are many ways to obtain data on these topics, including using GLOBE Protocols, using similar measurement protocols developed by other groups of scientists, or accessing online data (see the "Elaborate" and "Extensions" sections in Supplement 1). The protocols used during this study are briefly described below and are available in more detail in Supplement 2.

### *Snowpack Depth (ages 5+)*

Students collected snowpack-depth data by inserting a metal meter stick ($5 to $10) vertically into the snowpack (Figure 1a). In regions with ephemeral snow, it is important to report zeroes during periods of no snow coverage between snowstorms. Snowpack is important for soil frost due to its insulation properties. In the absence of snow, soil frost can deepen substantially when temperatures plummet well below 0°C.

### *Canopy Green-Up (ages 5–7 budburst only, ages 8+ expanding)*

For many temperate, midlatitude tree species, the timing of budburst and canopy leaf out depends largely on temperature (Cleland et al., 2007). In the fall, students identified dominant tree species in their outdoor classroom while the leaves were still present. They selected and flagged a branch accessible at eye level. In mid to late winter, students were introduced to the four phenophases (dormant, swelling, budburst, expanding) by forcing dormant buds indoors on plants like forsythia (*Forsythia* sp.). At the outdoor classroom, students tracked the phenophase of buds on each flagged branch as they progressed from dormant to swelling, burst, and expanding (Figure 1b). Canopy closure is declared when the leaf length is no longer changing, indicating they have reached maximum size.

### *Soil Frost Depth (ages 8+)*

Soil frost depth was measured using a soil frost tube (Figure 1c), which consists of a two-layer tube constructed out of clear, flexible aquarium tubing housed in rigid PVC tubing (Gandahl, 1957; Rickard & Brown, 1972). The inner, flexible tube is filled with a dye solution (e.g., food coloring, methylene blue, or fluorescein dye). When soil frost forms, the solution in the tube freezes, extruding the colored dye and clearly indicating how deep the soils have frozen. Participating schools installed three tubes in the fall before the ground froze at the outdoor classroom, spaced 5–10 meters apart to help capture spatial variability within the site and to provide backup in the event of equipment failure. Detailed soil-frost tube construction instructions are available in the Soil Frost Protocol at globe.gov. Each tube costs about $30 to construct.

### *Soil Respiration (ages 14+)*

Soil respiration results from the activities of roots and soil organisms and is used as an indicator for soil biological activity. Winter soil respiration is a function of soil temperature and soil freezing, which in turn are a function of snowpack depth. Shallower snowpacks provide less insulation, thus potentially contributing to decreases in soil respiration (thus less carbon loss to the atmosphere) if soils are exposed to more frigid conditions (Contosta et al., 2016; Monson et al., 2006). We used an established protocol that employs the soda lime method for measuring soil respiration (Grogan, 2012). With this method, a "mini-atmosphere" is created over the soil by inverting a bucket over a preweighed jar containing soda lime (Figure 2). As roots and microorganisms in the soil respire, $CO_2$ is released into the bucket's mini-atmosphere, and soda lime absorbs the $CO_2$, gaining mass in the process. In the fall, students installed three chambers and one blank (control) at their monitoring site to measure cumulative soil $CO_2$ emissions during winter and spring. At the end of the winter-spring shoulder season, students retrieved and reweighed the jars to determine how much $CO_2$ the soda lime absorbed, and thus was emitted from the soil. Each chamber costs about $50 to construct. For more details, see Supplement 3, *Soil $CO_2$ Flux Sampling Instructions*, available with the online version of this article).

## ○ Data Analysis: Evaluate

Students evaluated their original hypothesized vernal window timelines, considering their collected data, and discussed possible reasons for the discrepancies. During this step, the scientists emphasized that revisiting and revising hypotheses was a key part of the scientific process. Students were asked to consider how the sequence and/or timing of events would change in a warmer, less snowy winter compared to a colder, more snowy winter. Students at some sites compiled data and made graphs comparing differences in the length of the vernal window between multiple sites at the same school and/or over multiple years (see student graphs in Supplement 2). Four students from Old Town High School and two students from Newport Middle and High School applied for and received travel funding support from GLOBE to attend and present results at the 2019 Northeast GLOBE Student Research Symposium (GLOBE SRS), one of six held across the United States in 2019 (GLOBE, 2020, https://videohall.com/p/1841).


**Figure 2.** Installation of a soda lime bucket to measure soil respiration. (**A**) Students cut a "cookie" of soil around the perimeter of the bucket using a serrated bread knife, and then (**B**) a mason jar of soda lime is placed on a stand underneath the bucket and left to collect soil emissions of carbon dioxide until the canopy closes in late spring. Photographs by E. Burakowski.

## ○ Teacher Feedback

Mr. Ed Lindsey's high school classroom in Old Town, Maine, tracked the vernal window using the bundled GLOBE protocols described above in 2019 through 2021. "It starts with a phenomenon, in this case the transition from winter to spring. Students engage in argumentation over competing models of how the natural world works to explain a sequence of phenomena in the vernal window timeline activity. After collecting data to confirm or reject their hypotheses, the students either gain the comfort of resolution or the productive tension of non-resolution."

In Nashua, New Hampshire, Dr. Rob Pinsonneault noted about his AP Environmental Science students, "Experiential learning about their immediate environs paid dividends in terms of making them care. The connection between the opening of the vernal window, and the now-seen actions below the surface [in soil respiration] were not lost on the students and served to give them a greater systems-based understanding of their habitat, their home."

In Newport, New Hampshire, Ms. Catherine Burke's eighth-grade students were very excited to find out if their hypothesized timeline of ecological events during the vernal window was close to that year's data collection. This experience increased their interest in the climate of their region and how it compared to the other sites in the state. "It was a project that wasn't specifically for an assigned unit, and it made them feel like they were scientists," Ms. Burke said.

## ○ Project Summary

Upon conclusion of this project there are a few notes for teachers who want to try this work in their own classrooms. First to note is that Supplement 1 provides detailed instructions on how to complete a project similar to the one discussed here. It also includes information about where to find data that students might use instead of collecting their own and provides ***extensions*** to connect this work with other subject areas, including American history and English. Included in its "Evaluate" section are instructions to help students use the "claim, evidence, reasoning" model to share with the teacher about what they expect the order of events to be next year or in five years (McNeill & Krajcik, 2011).

Both the concepts and work encompassed in the winter-spring transition season lend themselves well to curriculum spiraling (Bruner, 1960). Children as young as kindergarten can observe simple changes in their environment as the season changes, while early elementary students can benefit from making basic measurements of snow depth and budburst date. Older students can tackle more tedious measurements of leaf length and more challenging equipment setup, such as frost tubes. Finally, high school students are well poised to dig into the chemistry of soil respiration and understand the more intricate connections between matter and energy cycling. When a whole school or district is involved, there is also greater likelihood that data will be collected over multiple seasons, which allows for both a deeper understanding by students and a greater capacity for data analysis by students and scientists to track environmental change. Spiraling, multiyear data collection, and low-cost equipment also make this project easily implemented in a variety of other settings, including homeschool and nature centers. Major challenges posed by this project for teachers are similar to other outdoor, classroom-based work, including time, availability of a forest plot near the school, and student safety (e.g., tickborne disease and poison ivy), but of particular note is that the timing of observations may overlap with end-of-year standardized testing. As a result, alternative education programs have been most successful in project implementation to date.

## ○ Acknowledgments

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Elizabeth Burakowski, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, NH, elizabeth.burakowski@unh.edu; Sarah Sallade, Growing Places, Littleton, NH, sarah.silverberg@gmail.com; Alix Contosta, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, NH, alix.contosta@unh.edu; Rebecca Sanders-DeMott, United States Geological Survey, Woods Hole Coastal and Marine Science Center, Woods Hole, MA, rsanders-demott@usgs.gov; Danielle Grogan, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, NH, danielle.grogan@unh.edu.