# SOIL TEMPERATURE GRADIENTS IN A NORTHERN HARDWOOD FOREST

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## ABSTRACT

Soil temperature is an important factor affecting establishment, growth and productivity, and survival of forest trees. In winter, soil temperature influences the degree of cold hardiness in roots of woody plants, regulates the supply of available moisture, and affects insect populations and other soil-dwelling organisms. A study was initiated in January 1993 to continuously monitor soil temperature in a northern hardwood forest stand located at the Proctor Maple Research Center in Underhill, VT. Averaging thermocouples were installed 2 cm above and 5, 15, and 30 cm below the soil surface in two sets of paired, 1 $m^2$ plots. The initial treatments applied to these plots were designed to examine the effects of snow cover on soil temperature within a hardwood forest. Snow was allowed to accumulate naturally on one plot in each pair, but was removed from the second plot after each snowfall. Soil temperatures increased with increasing soil depth during fall and winter and decreased with increasing depth in spring and summer. In 1993, late March and mid September represented the transition from soil temperatures warmer than ambient air temperature to those cooler than ambient air and *vice versa*, respectively. Generally, soil temperatures in snow-free plot were more responsive to ambient air temperature than those in snow-covered plots, and were consistently 1 to $5^{o}$ C lower than those measured at corresponding depths in snow plots. Only at 30 cm below the soil surface in snow plots was soil temperature consistently above freezing during most of the winter.

## INTRODUCTION

In January 1993 a study was initiated to continuously monitor soil temperatures at several depths within a northern hardwood forest. This monitoring will provide basic data on soil temperature gradients within the forest and address questions about the frequency of freezing in the forest soil rooting zone. Soil thermocouples were installed within the upper rooting zone in two sets of paired, 1 $m^2$ plots located near the VMC canopy research tower at the Proctor Maple Research Center in Underhill, VT. The paired-plot approach allowed treatment of one plot in each pair while maintaining the second plot as a control. Over time, this instrumentation will allow us to add soil temperature information under a variety of environmental conditions to the ever-increasing database being generated at the tower site.

The first treatments applied to these plots were designed to look at the effects of snow cover on soil temperatures during winter and early spring. Snow was allowed to accumulate naturally on one plot in each pair while the other plot was kept free of snow throughout winter.

### Objectives

The overall goals of this project are to increase our understanding of soil temperature dynamics within the upper rooting zone of a northern hardwood forest and to examine the effects of snow cover on forest soil temperatures. Specific goals are to:

1. continuously monitor soil temperature at several depths within the upper rooting zone of a northern hardwood forest,

2. examine the effects of snow cover on soil temperature at various depths within the upper rooting zone of a northern hardwood forest, and

3. relate meteorological variables such as ambient temperature, total irradiance, and wind speed to soil temperature.

## METHODS

On 15 January 1993 four-point, averaging thermocouples were installed 2 cm above and 5, 15 and 30 cm below the soil surface (2, -5, -15, and -30 cm) in each of the four plots (two sets of paired plots). Subsurface thermocouples were installed by excavating a small pit with a smooth vertical face and inserting the four ends of each thermocouple set horizontally into the face of the soil approximately 10 cm apart at each depth and 7 cm deep into the soil face. Thermocouples were patterned after commercially available ones sold by Campbell Scientific Inc. (CSI), but were made by us from bulk teflon-coated 22 gauge copper-constantan thermocouple wire. The actual thermocouple junctions were waterproofed by applying clear heat shrink tubing over which several coats of clear commercial plasti-dip were applied. Thermocouples were calibrated and referenced to

National Institute of Standards and Technology (NIST) traceable thermometers prior to installation, with individual temperature corrections developed for each thermocouple. Plots were randomly designated as snow-covered (snow) or snow-free treatments. Data from one set of plots were recorded as 15 min averages to the CSI 21X datalogger located at the VMC research tower. Because of a shortage of available channels on the datalogger, data from the second set of plots were recorded directly to a computer, also as 15 min averages, by means of an analog to digital converter (ADC "blue box") and a Turbo Pascal program.

Thermocouples were installed in mid January immediately following the first significant snow fall of the 1992-93 winter season (approx. 16 cm). Both snow and snow-free plots were cleared of snow during the installation process and no attempt was made to put snow back over the snow plots. It took two weeks for the natural snow cover to again accumulate on the snow plots and, for this reason, we have chosen not to discuss the January 1993 data.

Average snow depths on all plots were measured and recorded and snow was cleared from snow-free plots after each snowfall. On most occasions, a broom was sufficient to remove snow from snow-free plots.

## RESULTS

Soil temperatures, as expected, generally increased with depth during fall and winter and decreased with depth in spring and summer. In 1993 soil temperatures at all three subsurface depths came into equilibrium with air temperature near the soil surface in late March and again in mid September (Fig. 1). These times represent the transition from soil temperatures warmer than ambient air in fall and winter to those cooler than ambient air in spring and summer and back to warmer than ambient air. Seasonal soil temperatures increased sharply from March to May, then continued to increase at a slower rate until mid August. Soil temperatures then began to decrease in response to the decrease in ambient air temperatures, more rapidly during September through mid October and then more slowly from mid October on into early winter. Average monthly soil temperatures fluctuated by $13^{o}$ C from February until August at -30 cm and $17^{o}$ C at -5 cm.

During the period of continuous snow cover (early February to early April) soil temperatures in snow-free plots were generally more responsive to ambient air temperature than those in snow plots (Fig. 2). This was particularly true at -5 cm and was less apparent as depth increased. Absolute temperatures on snow-free plots were 1 to $5^{o}$ C lower than those at corresponding depths in snow plots. By mid February snow had accumulated to a depth of 30 cm on snow plots and that depth or greater was maintained for the balance of winter. From mid February until snow melt subsurface soil temperatures in snow plots remained at or above $-1^{o}$ C and soil surface temperatures (2 cm) did not drop below $-2.5^{o}$ C. During this same period subsurface soil temperatures in snow-free plots ranged from -0.3 to $-6^{o}$ C while surface temperatures varied closely with ambient air temperature.

Figure 1. Average monthly soil temperature measured 2 cm above and 5, 15, and 30 cm below the soil surface in a northern hardwood forest stand at the Proctor Maple Research Center in Underhill, VT.

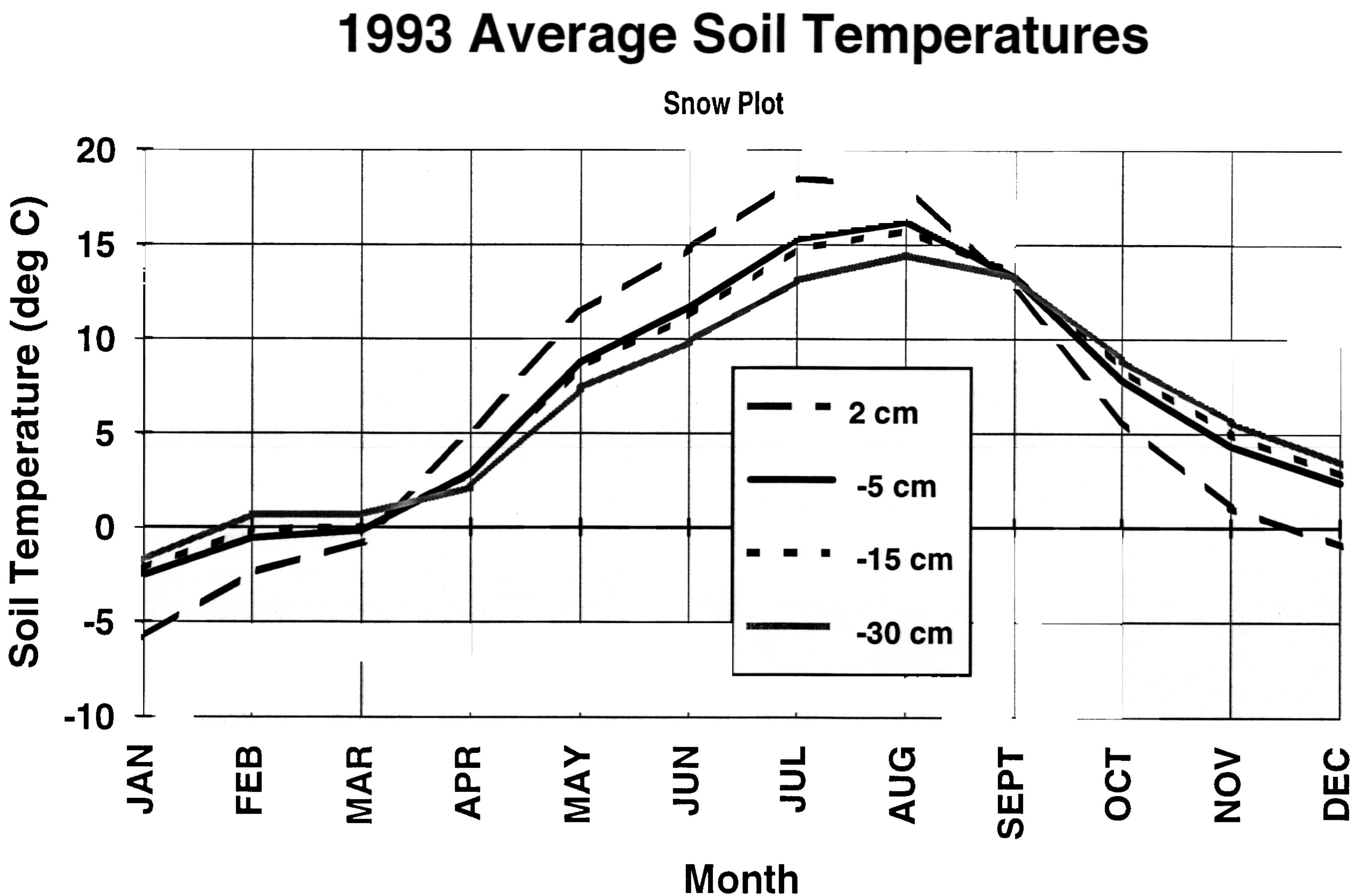
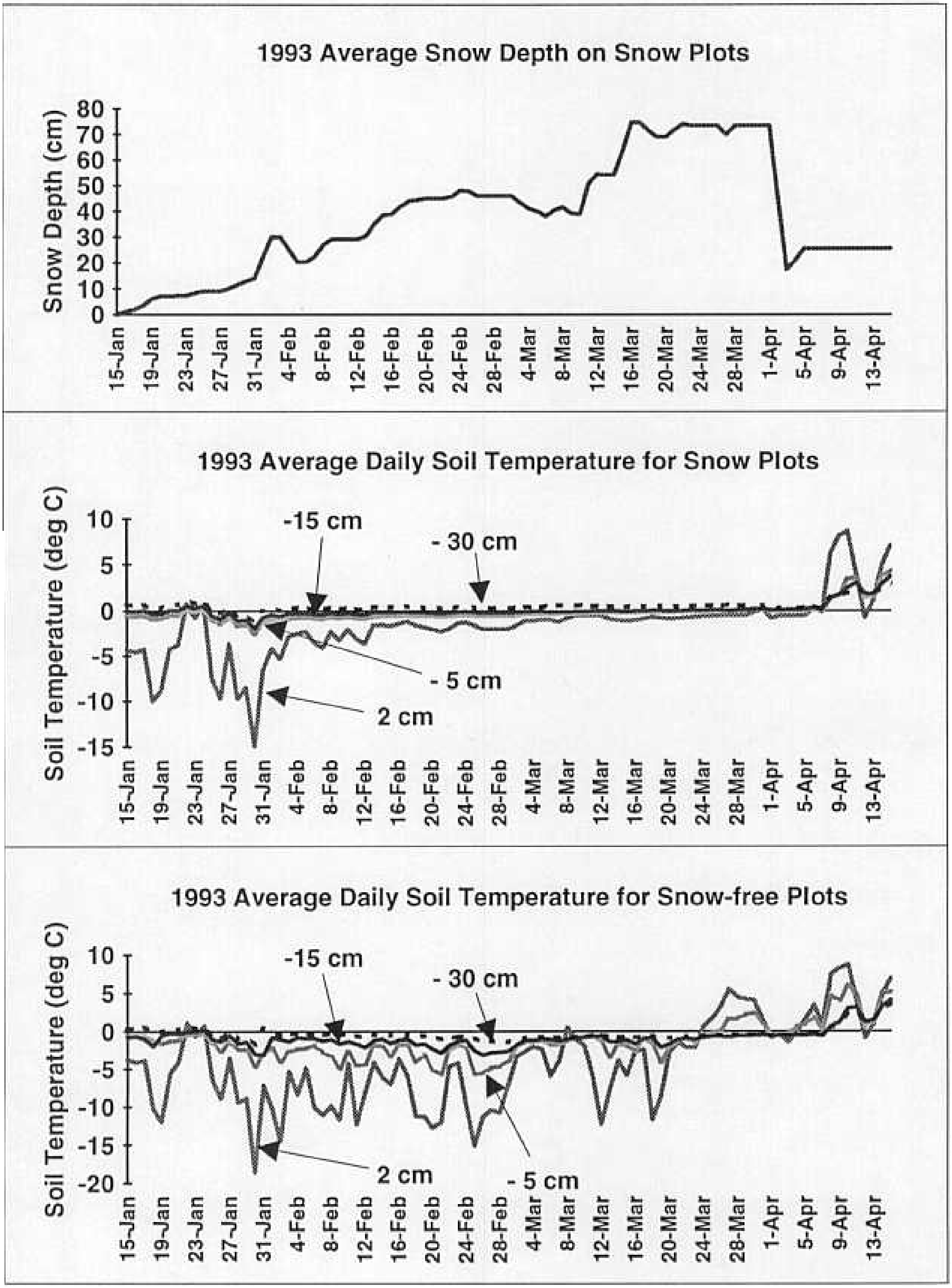


Figure 2. Average snow depth and average daily soil temperature for snow-covered (snow) and snow-free plots from 15 January to 15 April 1993 measured in a northern hardwood forest stand at the Proctor Maple Research Center in Underhill, VT.



Specific results show that beginning in early February soil temperatures at -30 cm were generally 0.5 to 0.75° C above freezing in the snow-covered plots and 0.3 to 1.5° C below freezing (-0.3 to -1.5° C) in snow-free plots (Fig. 3). At -15 cm soil temperatures in snow plots were slightly below freezing (-0.25 to -0.5° C) throughout much of the period, but increased gradually in late winter, as snow depth increased, to 0° C or slightly above in March before increasing rapidly in early April (Fig. 3). In contrast, soil temperatures in snow-free plots at -15 cm were consistently below freezing (about -1 to -3.5° C) before increasing rapidly in early April. Although soil temperatures at -5 cm were below freezing in both snow and snow-free plots, temperatures in snow plots warmed gradually throughout the winter, were less variable in temperature, and considerably warmer overall; not dropping below -1.5° C after early February (Fig. 3). Temperatures in snow-free plots at -5 cm fluctuated between -1 and -6° C until early April when temperatures in both snow and snow-free plots began to rise rapidly in response to warming ambient air temperatures.

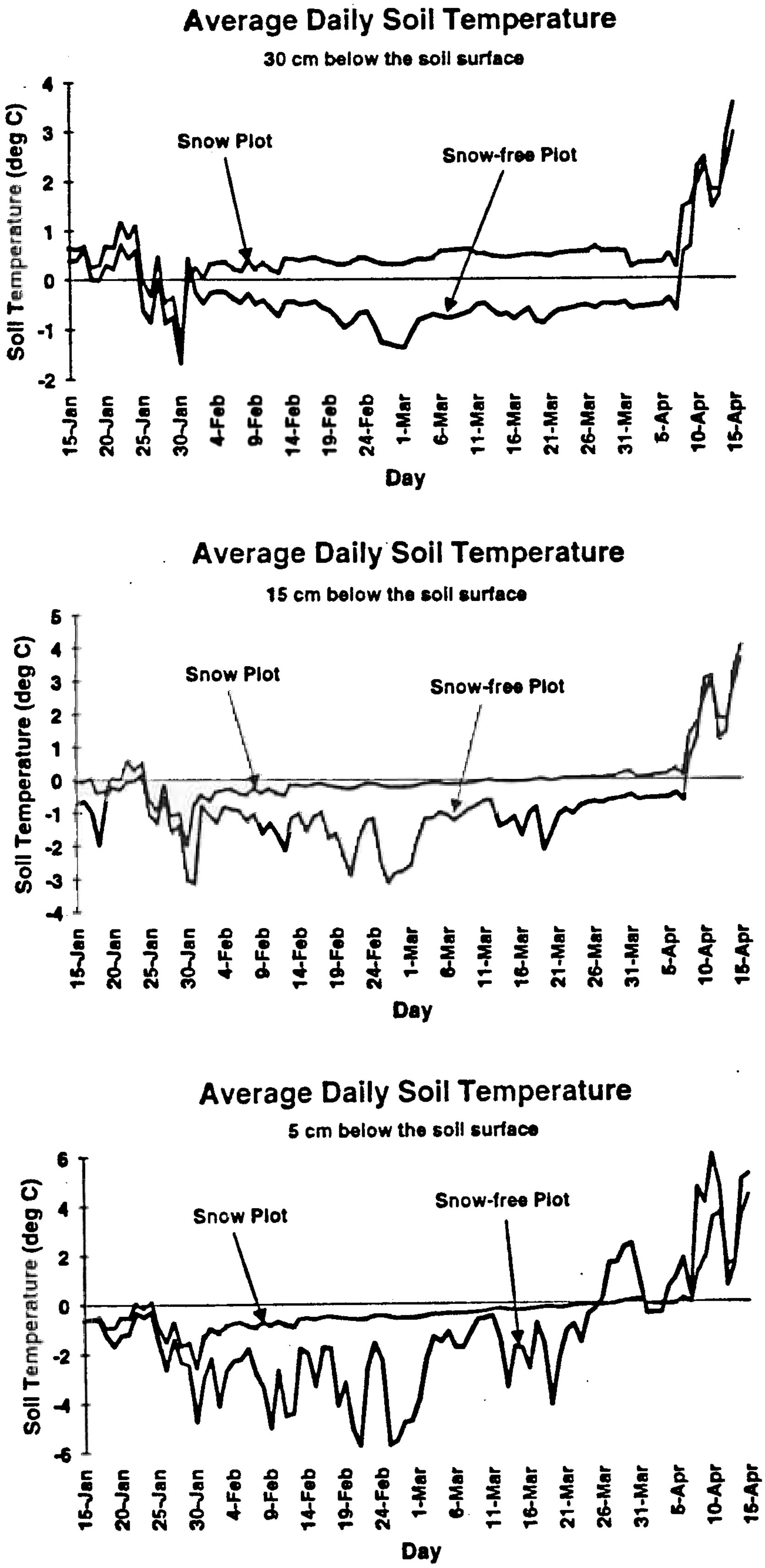
The number of hours (1 February to 15 April) that temperatures remained below freezing, at the various depths, in snow and snow-free plots is summarized in Table 1.

TABLE 1. NUMBER OF HOURS AND % OF TIME THAT SUBFREEZING SOIL TEMPERATURES OCCURRED, AT VARIOUS DEPTHS, BETWEEN 1 FEBRUARY AND 15 APRIL 1993 IN SNOW-COVERED AND SNOW-FREE PLOTS

| Soil Depth | Snow-covered | | Snow-free | |
|---|---|---|---|---|
| cm | hrs | (%) | hrs | (%) |
| 2 | 1572 | (89) | 133[illegible] | (75) |
| -5 | 1473 | (83) | 1448 | (82) |
| -15 | 1100 | (62) | 1579 | (89) |
| -30 | 23 | (01) | 1581 | (89) |

The number of hours of subfreezing temperatures decreased with soil depth in snow-covered plots and increased with depth in snow-free plots. The insulating layer of snow (snow plots) increased the number of hours of subfreezing temperatures near the soil surface (2 cm) compared to snow-free plots. By contrast, the snow-free plots, in addition to experiencing freezing ambient temperatures, also experienced more hours of warmer temperatures than the snow plots, thus decreasing the total hours of freezing temperatures. At -5 cm there was no difference in the number of hours of below freezing temperatures occurring in snow-covered and snow-free plots, although the distribution of

Figure 3. Average daily soil temperature from 15 January to15 April 1993 measured at 30, 15, and 5 cm below the soil surface on snow and snow-free plots within a northern hardwood stand at the Proctor Maple Research Center in Underhill, VT.



freezing temperatures was probably different; this will be investigated. In the snow-free plots, no difference in time of exposure to subfreezing temperatures was found between -15 and -30 cm. Below freezing temperatures occurred only 1% of the time at -30 cm when snow cover was present, but 89% of the time when absent.

## DISCUSSION

Soil temperature is an important factor affecting establishment, growth and productivity, and survival of forest trees. In winter, soil temperature influences the degree of cold hardiness in roots of woody plants, regulates the supply of available moisture, and affects insect populations (i.e., pear thrips) and other soil-dwelling organisms. Winter desiccation, a particular problem in some conifer species, results when plants are deprived of moisture due to frozen soils and possibly frozen roots at the same time water is being lost through transpiration. In winter, length and frequency of soil freeze-thaw cycles, as well as depth of freezing, influence the severity of physiological and physical perturbation to trees and other biota. Extremes in high as well as low soil temperatures can also have detrimental effects on many forest organisms.

Data from winter (1993) show that in the absence of snow cover, soil temperatures can be below freezing to a depth of -30 cm. At lesser depths of -5 and -15 cm, soil temperature in the absence of snow cover can be as low as -6 and -3$^{o}$ C, respectively. These depths encompass the major rooting zone for many tree species, subjecting roots (and other soil biota) to significant freezing events. These conditions probably occur during winters with extended periods of little or no snow cover.

Soil temperatures well below freezing are certain to cause freezing of soil water, but it is unclear if temperatures slightly below freezing also cause soil water to freeze. It seems probable that matric and solute forces in soil water may prevent freezing at temperatures -1 or -2$^{o}$ C. Once winter acclimated, some plant tissues are protected by solute effects to temperatures well below freezing, but root tissues may not be so well protected (A. Auclair, pers. comm.). There is a need for more information about the effects of freezing degree and frequency on root physiology, as well as about the occurrence of freezing and high temperature events in soils. There are limited continuous multi-depth data on soil temperatures available, so these data provide valuable information about this fundamental property of soils and its important effects on plant roots and soil biota.

Year-to-year variability in timing and amount of snow cover make it difficult to draw conclusions based on data from a single winter. In this particular season, continuous snow cover did not occur until early February. It is possible that the gradual warming in soil temperatures evident at -5 and -15 cm in snow plots was the result of early freezing and the late snow cover during the 1992-93 season. Perhaps if snow cover had occurred earlier, soil temperatures would have been more stable and warmer at these depths.

## FUTURE PLANS

We plan to continue the experiment over several winters in an attempt to characterize soil temperature patterns under a variety of winter climatic conditions. Additional analyses will be done to examine number and timing of freeze-thaw cycles and extremes in high soil temperature.

## FUNDING SOURCES

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