SOIL TEMPERATURE GRADIENTS IN A NORTHERN

HARDWOOD FOREST

1995

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ABSTRACT

A study was initiated in January 1993 to continuously monitor soil temperature at several depths in a northern hardwood forest in Underhill, VT. In 1993-95 treatments applied to these plots were designed to examine the effects of snow cover on soil temperature. Overall seasonal trends were similar in all three years, with soil temperatures increasing with increasing soil depth during fall and winter, and decreasing with increasing depth in spring and summer. During winter, soil temperatures in snow-free plots were more responsive to ambient air temperature than those in snow-covered plots, and were consistently 1 to 5° C (1993), 3 to 9° C (1994), and 0.5 to 2.5° C (1995) lower than those at corresponding depths in snow-covered plots. Winter 1995 differed from the two previous seasons because, in addition to soils not freezing at -30 cm when snow was present, soil did not freeze at this depth when snow was absent. Soil temperatures at -15 cm in snow-covered plots remained above freezing until early March, while temperatures at -5 cm remained slightly above freezing in early winter and slightly below in the late winter. In snow-free plots, 1995 soil temperatures reached lows of 0.5, -1, and -3° C at depths of -30, -15, and -5 cm, respectively. In contrast, 1994 soil temperatures at all subsurface depths (-30, -15, and -5 cm), in snow-covered plots, remained above freezing throughout winter, while in 1993, only at -30 cm was soil temperature consistently above freezing. When a continuous snow pack >30 cm develops in December, it appears that soil temperatures tend to stay above freezing even at depths as shallow as -5 cm. When averaged over all three years, below freezing temperatures (1 February-15 April) occurred only 0.33% of the time at -30 cm when snow was present, but 61% of the time when snow was absent.

INTRODUCTION

In January 1993 a study was initiated to continuously monitor soil temperatures at several depths within a northern hardwood forest. This monitoring provides basic information on soil temperature gradients within the forest and addresses questions about the frequency of freezing in the forest soil rooting zone. This instrumentation allows us to add soil temperature information, under a variety of environmental conditions, to the ever-increasing database being generated at the tower site.

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,

2. examine the effects of snow cover on soil temperature at various depths,

3. quantify the number of hours of subfreezing soil temperatures at various depths during winter and examine the frequency of freeze-thaw cycles, and

4. relate meteorological variables such as ambient temperature to soil temperature.

METHODS

On 15 January 1993 soil thermocouples were installed in two sets of paired, m^2 plots located near the VMC canopy research tower at the Proctor Maple Research Center in Underhill, VT. Thermocouples were installed within the upper rooting zone at 2 cm above and 5, 15, and 30 cm below the soil surface (2, -5, -15, and -30 cm). The paired-plot approach allows treatment of one plot in each pair while maintaining the second plot as a control. For a further description of these thermocouples, details of installation, or data collection procedures, please see 1993 or 1994 VMC Annual Reports.

Treatments of snow-covered vs. snow-free plots were continued in 1995, as in 1993-94, to continue 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 second plot was kept free of snow throughout winter. Average snow depths on all plots were measured and recorded and snow was cleared from snow-free plots after each snowfall.

A problem with the data collection system for one set of plots was discovered during 1995, making data collected from this pair of plots suspect. Therefore, only data from one pair of plots are included in this report. The exclusion of data from one set of paired plots altered the experimental design so that analysis of variance no longer could **be used** to detect significant differences among treatments.

RESULTS

In 1995 overall seasonal trends in soil temperature were similar to those found in 1993 and 1994. Soil temperature generally increased with depth during fall and winter and decreased with depth in spring and summer (Fig. 1). Soil temperatures at all three subsurface depths came into equilibrium with air temperature near the soil surface in mid April, (four weeks later than in 1994 and two weeks later than in 1993) and again in early September (similar in timing to 1994 and two weeks earlier than in 1993). These times, when no temperature gradients are present, 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 mid April, then continued to increase at a slower rate until mid July, although soil temperatures at -15 and -30 cm continued to increase until August. Soil temperatures then began to decrease gradually from mid July-August through mid October and then more rapidly through November. Average monthly soil temperatures fluctuated by 15 °C over the season at -30 cm and 18° C at -5 cm.

The first snowfall of the 1994-95 season occurred on 8 December 1994, but unlike the 1993-94 winter season, snow cover was completely lost during a thaw in mid January and snow never accumulated to a depth greater than 43 cm. In fact, only during two brief periods in February and March did snow depth on snow plots exceed 30 cm (Fig. 2). During the January thaw event, ambient temperatures reached 16° C and remained above freezing for nearly 10 days (Fig. 3). Despite the lack of continuous snow cover and a maximum snow depth of 43 cm, slightly less than 60% of 1993 and 1994 maximum totals (75 and 72 cm, respectively), soil temperatures in snow-free plots were generally more responsive to ambient air temperature than those in snow-covered plots. This was particularly true at shallower depths (-5 and -15 cm), although differences were less dramatic than in previous years (Fig. 3 and 4). With the exception of upward trends in mid January, temperatures at all subsurface soil depths in both treatments generally decrease throughout winter until reaching seasonal lows in March and April.

Specific results show that average daily temperatures of soil at -30 cm in both snow-covered and snow-free plots remained above freezing throughout the entire period (December 1994 to mid April 1995) and averaged 2.2° C in both treatments (Fig. 4). Soil temperatures at -30 cm in snow-covered and snow-free plots ranged from 0.1 (early March) to 5° C (during the January thaw) above freezing. During some periods of the winter, soil temperature at -30 cm in snow-free plots were actually slightly warmer than those in snow-covered plots, but differences were probably not statistically different. At -15 cm in snow-covered plots, soil temperatures remained above freezing (averaging 1.3° C; reaching 5.5° C during the January thaw) until early March when temperatures dipped slightly below freezing (reaching -0.1° C). In snow-free plots at -15 cm, soil temperatures approached freezing in mid January, just prior to the January thaw, rose to

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.

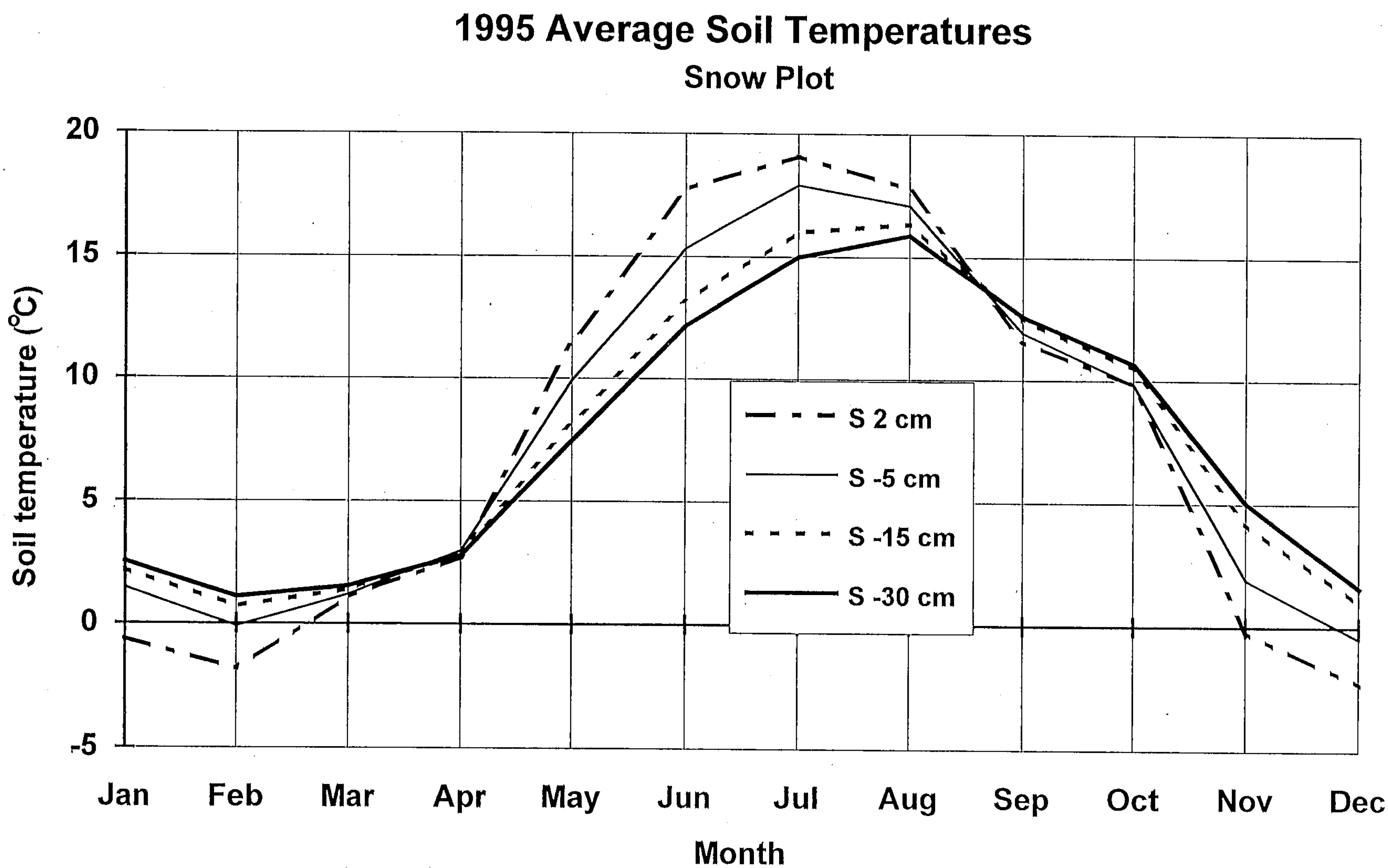


Figure 2. Average snow depth and average daily soil temperature for snow-covered (snow) and snow-free plots from 1 December 1994 to 15 April 1995 measured in a northern hardwood forest stand at the Proctor Maple Research Center in Underhill, VT.

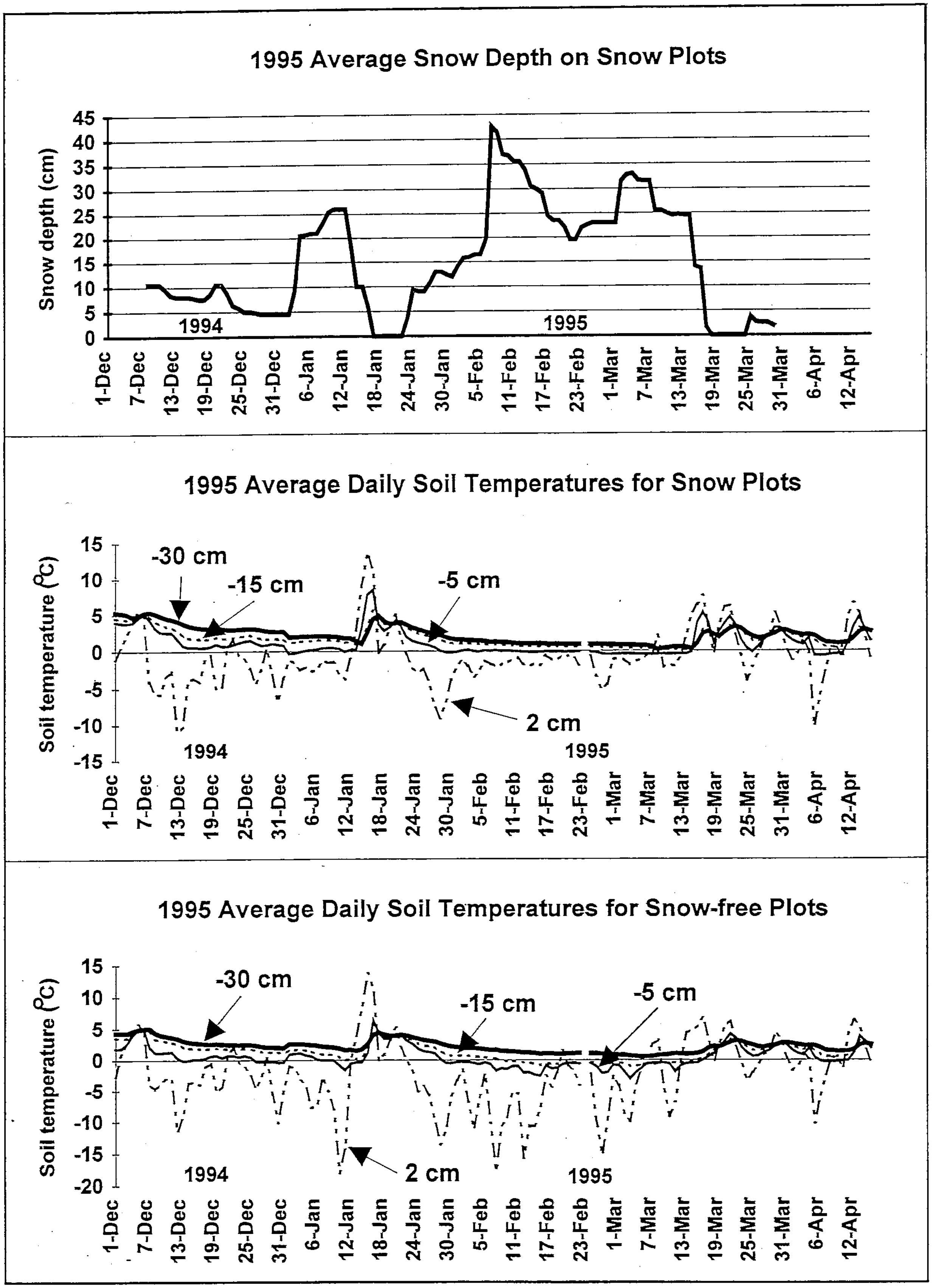


Figure 3. Average daily soil temperature measured 2 cm above and 5, 15, and 30 cm below the soil surface and ambient air temperature measured at 7.5 m above the forest floor, during January 1995, in a northern hardwood stand at the Proctor Maple Research Center in Underhill, VT.

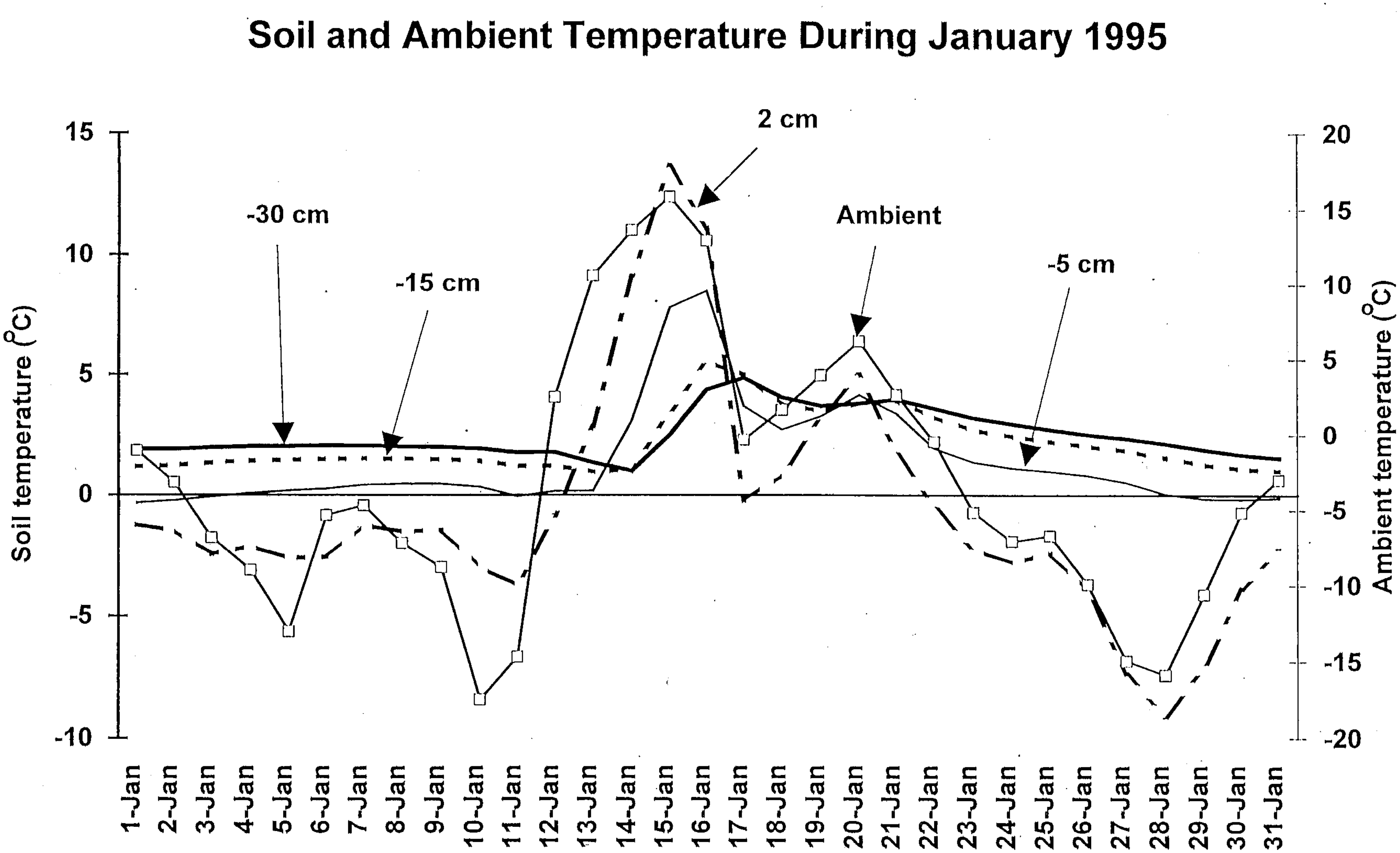
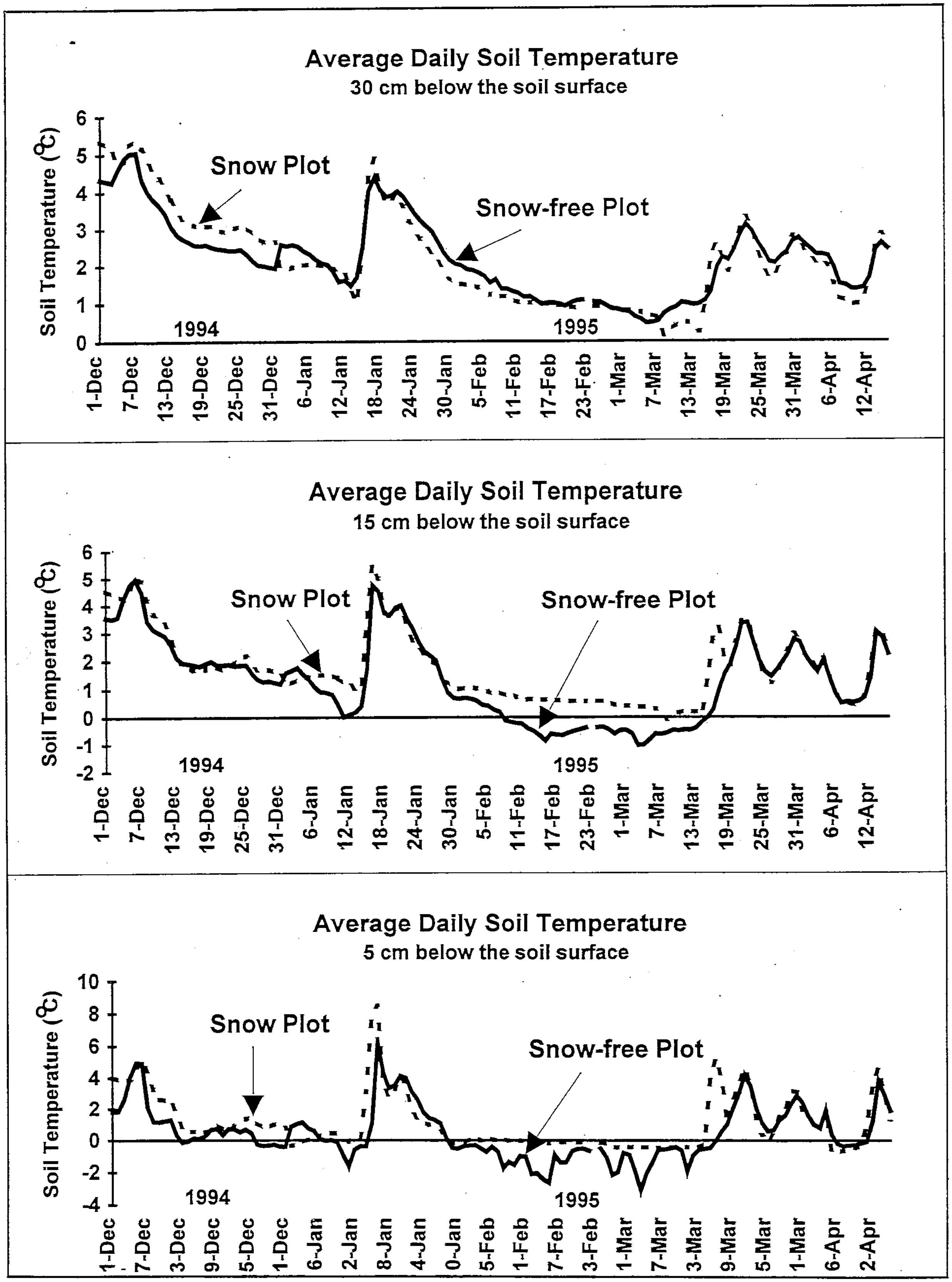


Figure 4. Average daily soil temperature from 1 December 1994 to 15 April 1995 measured at 30, 15, and 5 cm below the soil surface in snow-covered and snow-free plots within a northern hardwood forest stand at the Proctor Maple Research Center in Underhill, VT.

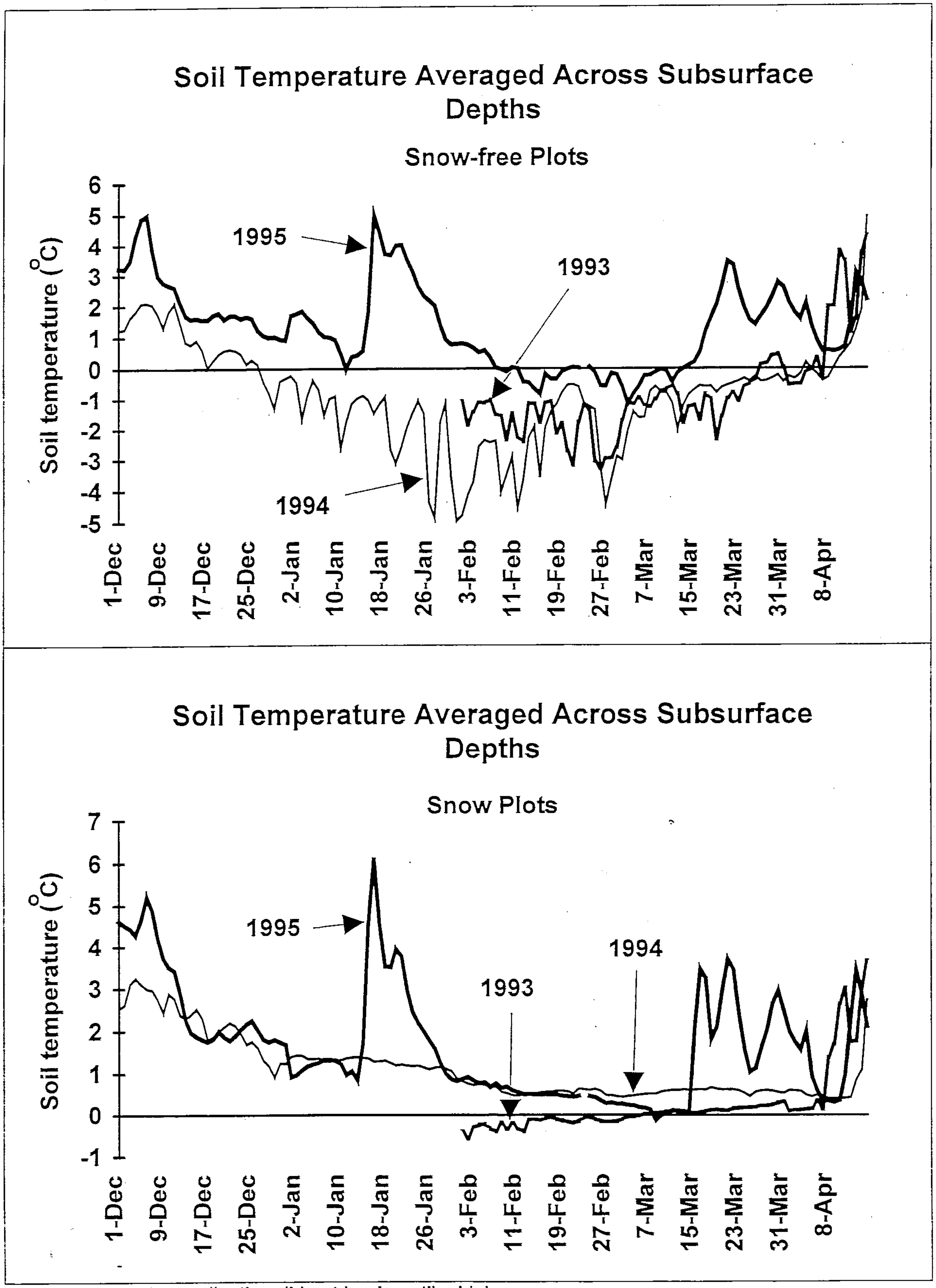


4.7° C during the January thaw, and following the thaw, went below freezing again in early February and remained near or slightly above -1° C until mid March. Soil temperatures at -5 cm in snow-covered plots remained at or near freezing throughout winter and reached a low of -0.5° C in mid March. At -5 cm in snow-free plots, soil temperatures fluxuated with ambient air temperatures, but remained below freezing throughout much of the winter and reached a minimum of -3° C in early March.

Although, trends for snow-free plots were quite similar in 1993 and 1994, soil temperatures in 1995 tended to be on average (1 December to 15 April) warmer at all subsurface depths than those recorded during the two previous winters (Fig. 5). Soil temperatures in snow-free plots averaged 2.2° C warmer across all subsurface depths in 1995 than 1994 (ranging from 2.1 to 2.3° C) and 1993 (ranging from 1.7 to 2.6° C). In snow-covered plots soil temperatures during this same time period averaged 0.6° C warmer in 1995 than 1994 (ranging from 0.4 to 0.7° C) and 0.9° C warmer than in 1993 (ranging from 0.8 to 0.9° C). When 1995 and 1994 soil temperature data for snow-covered plots are compared by soil depth, it is found that 1995 temperatures at -30 and -15 cm are generally warmer in December and during the second half of January (during the January thaw), but are actually colder in early March. At -5 cm in snow-covered plots, 1995 soil temperatures are generally colder than those in 1994 with the exception of early December and mid to late January. The extremely warm temperatures during the second half of January apparently had a large influence on the 1 December to 15 April average temperatures. Ambient air temperature measured at 7.5 m above the ground and averaged from 1 December to 15 April was also 3.3° C warmer in 1995 than 1994 and 1.8° C warmer than 1993 (Fig. 6). The warm temperatures experienced during the extended January thaw in 1995 certainly influenced both average ambient and soil temperatures in 1995, regardless of treatment. Some major differences were noted in the performance of snow-covered plots over the three years. In 1993 soil temperatures at all depths except -30 cm remained below freezing throughout most of the winter. In that year temperatures at -30 cm went above-freezing only after a snow pack of about 30 cm had accumulated. In contrast, 1994 soil temperatures on snow-covered plots remained above freezing at all subsurface depths throughout winter. In 1995 soil temperatures at -30 and -15 cm in snow-covered plots remained above freezing until early March when temperatures at -15 cm dipped below freezing.

The amount of time in 1993-95 that soil temperatures remained below freezing, at the various depths, in snow-covered and snow-free plots, is summarized in Table 1.

Figure 5. Soil temperature averaged across all three subsurface depths (-5, -15, and -30 cm) in snow-free and snow-covered plots for the period of 1 December to 15 April 1993-1995. Data were collected in a northern hardwood forest stand at the Proctor Maple Research Center in Underhill, VT.



Note: In 1993 data collection did not begin until mid January.

Figure 6. Average monthly ambient air temperature measured 7.5 m above the ground for the period of 1 December to 15 April 1993-1995 in a northern hardwood forest stand at the Proctor Maple Research Center in Underhill, VT.

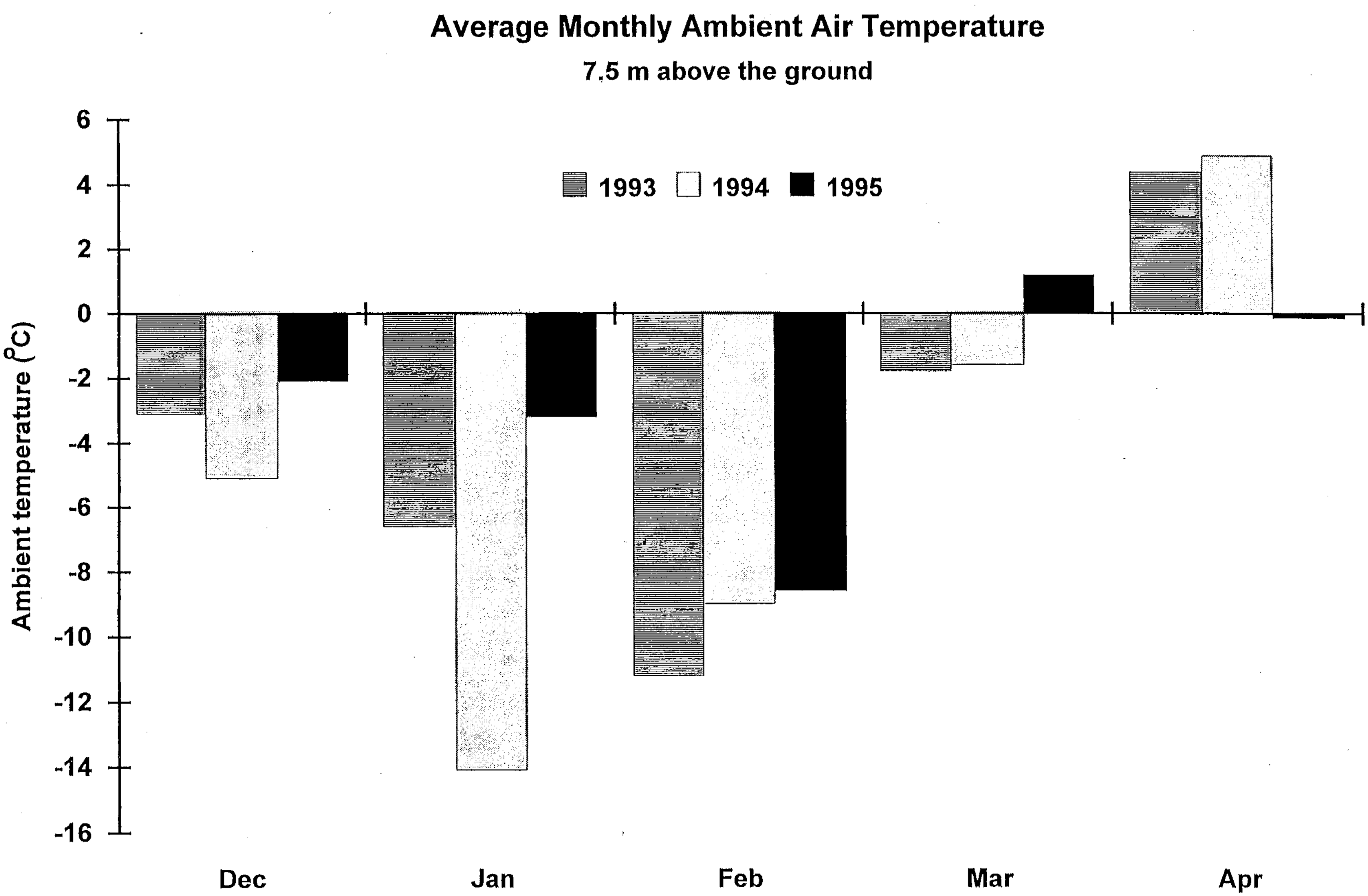


Table 1. Number of hours and % of time that subfreezing soil temperatures occurred, at various depths, between 1 February and 15 April 1993-95, in snow-covered and snow-free plots located at the Proctor Maple Research Center in Underhill, VT.

Soil	Snow-covered						Snow-free					
Depth	1993		1994		1995		1993		1994		1995	
cm	hrs	(%)	hrs	(%)	hrs	(%)	hrs	(%)	hrs	(%)	hrs	(%)
2	1572	(89)	1693	(95)	1236	(71)	1331	(75)	1277	(72)	1106	(64)
-5	1473	(83)	3	(0.2)	1041	(60)	1448	(82)	1496	(84)	1159	(67)
-15	1100	(62)	0	(0)	32	(2)	1579	(89)	1712	(96)	825	(47)
-30	23	(01)	0	(0)	8	(0.5)	1581	(89)	1691	(95)	0	(0)

In all three years the number of hours of subfreezing temperatures decreased with soil depth in snow-covered plots and generally increased with depth in snow-free plots. The exception to this pattern is in 1995 when number of hour of subfreezing temperatures in snow-free plots decreased with depth between -5 and -15 cm, and soil did not freeze at -30 cm. The most striking difference among the three years is the significant reduction in hours of subfreezing temperatures in1994 over 1993 in snow-covered plots at -5,-15, and -30 cm. This reduction in hours of subfreezing temperatures is due to the much earlier snowfall and development of a continuous snow pack in 1994, although maximum snow depths were similar (about 70 cm) in both years. Although, the number of hours of subfreezing temperatures at -15 and -30 cm in 1995 was also reduced from 1993 levels, we believe this was probably the result of generally milder ambient temperatures rather than snow cover, because soil at -30 cm in snow-free plots also did not freeze. The insulating layer of snow (snow plots) increased the number of hours of subfreezing temperatures near the soil surface (2 cm) in all three years, compared to snow-free plots. When averaged over all three years, below freezing temperatures occurred only 0.33% of the time at -30 cm when snow cover was present, but 61% of the time when snow was 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. In mature sugar maple (*Acer saccharum* Marsh.) it has been shown that when roots were exposed to freezing temperatures (-6° C) to a depth of 20 cm, that a significant reduction in sap flow rates, total sap volumes, and total sugar per tree occurred (Robitaille *et al.* 1995). These perturbations persisted for at least two years after treatment and were accompanied by increased canopy transparency (dieback). Although, soil temperatures of -6° C or lower have not been recorded at subsurface depths in snow-covered plots over the past three winters, temperatures of this magnitude were recorded at -5 and -15 cm in 1994 (based on hourly averages) in snow-free plots.

We now have temperature data at different depths for three winters in soils beneath a northern hardwood forest. The three winters were quite different in the timing of snowfall, maximum depth of snow, and duration of a continuous snow pack. In 1994, snowfall and the associated snow pack began in late November and persisted until mid to late April. No significant snowfall occurred until mid January in 1993 and a continuous snow pack did not develop until early February. Despite the difference in timing of snow events, similar maximum depths of snow were recorded in both years (about 70 cm). Result from 1993 indicate that a snow pack of at least 30 cm in depth is necessary to provide a significant moderating effect on soil temperature down to 30 cm. Bertrand *et al.* (1994) also found that a snow pack of 30 cm provided sufficient insulation to prevent roots from freezing and subsequent dieback in mature sugar maple trees. In 1995, despite a snow pack that began in early December, snow depths remained below 30 cm until early February. In fact, the snow pack was completely lost in mid January during a significant thaw event. Maximum snow depths did exceed 30 cm for brief periods in early February and early March, reaching a maximum depth of only 43 cm, but generally were less than 30 cm. Data show that in the absence of snow cover, soil temperatures can be below freezing to a depth of -30 cm for a significant part of the winter. At lesser depths of -5 and -15 cm, soil temperature in the absence of snow cover can be as low as -12 and -6° C, respectively (based on hourly averages). These depths encompass a significant portion of the rooting zone for many tree species, including sugar maple, subjecting roots (and other soil biota) to significant freezing events. These conditions usually occur during winters with extended periods of little or no snow cover. With significant snow (>30 cm) present in December, soil temperatures remained above freezing for the entire winter even at depths as shallow as -5 cm. In 1993 when significant snowfall occurred late, we found that soil temperatures dropped below freezing even to depths of -30 cm. When snow-cover did occur in 1993, soil temperatures began to rise very gradually over the winter, but still remained below freezing at all depths except -30 cm. When milder winter temperatures and significant mid winter thaw events occur, such as in 1995, soil at a depth of -30 cm or greater may not freeze even when snow is absent.

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 of -1 or -2° C. Once winter acclimated, most tree tissues are protected 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.

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.

FUNDING SOURCES

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