Rate of Accumulated Freezing and Thawing Degree Days as a Surrogate for Determining Freezing Depth in a Temperate Forest Soil

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Introduction

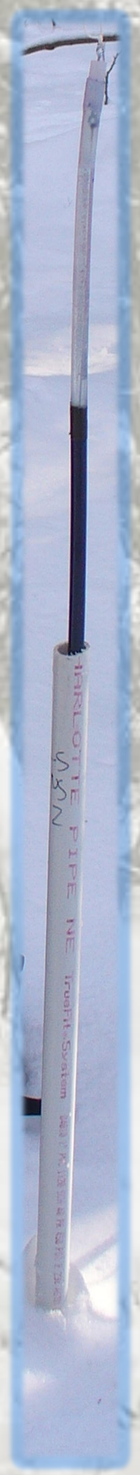
Climate simulations generally indicate that less precipitation will fall as snow in temperate forests. With changing seasonal temperatures and snowfall depths over time affecting the depth and timing of frozen soils, understanding soil freezing dynamics is challenging but necessary in order to make predictions about ecological and economic responses to future changes in freeze-thaw dynamics.

Soil freezing (frost) depth can be determined using a number of direct approaches, including the installation of frost tubes. Another approach is to use the concept of 'degree days' - Freezing Degree Days (FDDs) and Thawing Degree Days (TDDs).

The objective of this study is to evaluate the usefulness of FDDs and TDDs as a surrogate for a direct measure of frost depth (frost tubes) in soils in a temperate forest. In particular, comparing the value of accumulated FDDs and TDDs versus the rate at which they are accumulated.

Methodology

Frost tubes were used as a direct measure of soil freezing depth. The frost tubes were constructed of clear Tygon tubing, built to a length of one meter. The tubes were filled with a solution of methylene blue. Freezing depth was indicated by a color change in the dye. The length of the color change was observed and measured with a ruler approximately once every week. Each frost tube was installed into a PVC pipe. The area around the frost tube was routinely cleared of snow.



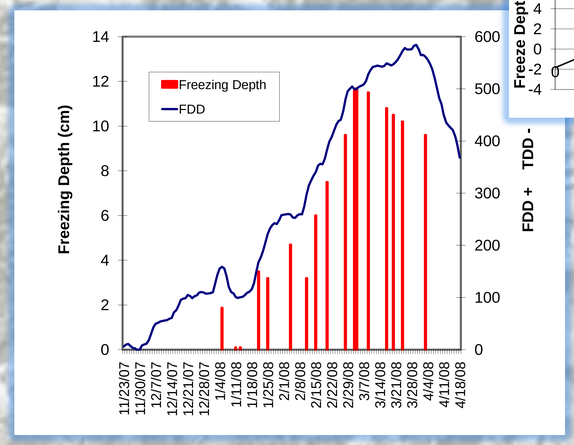
Ambient air temperatures was recorded hourly, using a HOBO K-8 datalogger. The dataloggers were installed about 1.5 meters above the ground, housed within a protective shield - protected against direct sun and precipitation

Degree-Days were calculated by subtracting mean daily temperatures from 0^0C. A negative value was recorded as a FDD, while a positive value was recorded as a TDD. A running total of FDDs and TDDs was maintained through the winter and spring seasons.

Inspecting a frost tube and downloading ambient air temperatures

Results

Accumulated FDDs and freezing depths over time are plotted in Figure 1 and show a strong correlation ($r^2 = 0.95$) . However a close examination of Figure 1 reveals two different trends, one that shows predictable relationship with freezing depth and accumulated FDDs and another later in the season that shows a decrease in freezing depth while still accumulating FDDs. Furthermore, the soil thaws dramatically after accumulating a small number of TDDs. Using slopes taken from Figure 1. (see Figures 2 and 3) a rating curve was developed to predict soil frost depth based on the rate that FDD's are accumulated (Figure 4). Based on this curve, just under 4.0 FDD/day are required to maintain a given depth of freezing soil.



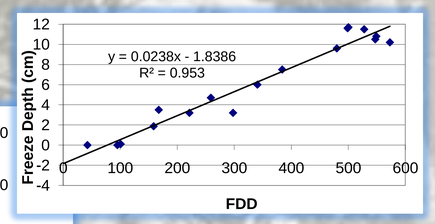


Figure 1. FDDs shown as a rising line and TDDs as a descending line. Freezing depth is shown as red bars.

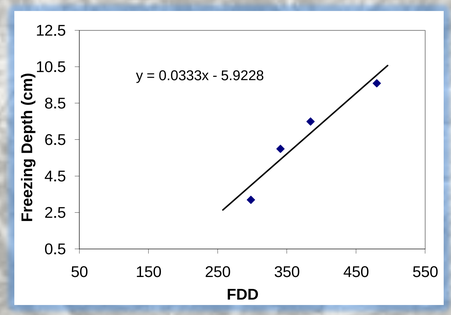


Figure 2. Average of 11.4 FDDs/day resulting in a freezing depth of 0.39 cm/day.

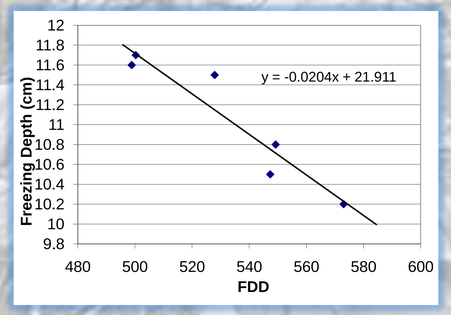


Figure 3. Average of3 FDDs/day resulting in a freezing depth of - 0.06 cm/day

Conclusion

While a strong correlation is found linking FDDs with soil freezing depths in areas free of snowpack, a better predictive tool is to relate soil freezing depth with the rate at which FDDs are accumulated (expressed as FDD/day).

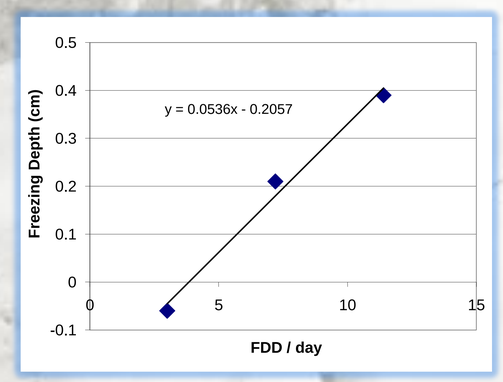


Figure 4. Rating Curve

Accumulating FDDs at a rate of less than 4.0 FDD/day will result in the thawing of frozen soils from the bottom up, while rates equal to or greater than 4.0 will increase the depth of frozen soil. As with soil freezing, the thawing of frozen soil is dependent on the rate that TDDs are accumulated. However, the rate of thawing is double that of the freezing rate, as the soil is thawed both from above and below (stored thermal energy at depth).