TREE MORPHOLOGY AS AN ESTIMATOR OF AVERAGE SNOW DEPTH

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INTRODUCTION

We have established a site in south central Wyoming for the study of alpine-subalpine ecosystem response to atmospheric deposition, the Glacier Lakes Environments Experiments Site (GLEES). We are interested in long term studies of anthropogenic changes to such environments. The major hydrologic input to the GLEES is in the form of snow, and it would be useful to have an estimate of the long term average snow accumulation in our study area. Snow on the landscape is indicated by a severe change in the normal tree morphology above and below the snow line. Snow cover protects the trees from wind deformation (Wooldridge *et al.*, in prep.), but also provides a favorable environment for disease development. It is obvious that the tree morphology can be a strong indicator of the "snow line." If the concept of snow line can be quantified in terms of the amount of snow that causes the morphological change, a tree survey could be very useful in estimating long term snow quantity.

Snow depth and snow density determine the snow quantity. It is commonly observed that snow density at the time of maximum accumulation falls in a narrow range of values (Martinec and Rango, 1986, Bartos, 1970). Therefore, an accurate estimate of average snow depth at maximum accumulation would result in an accurate estimate of average snow quantity. It may be possible to make estimates of the snow depth variability by examining the details of the morphological changes. However, this preliminary study examined the question of whether a tree survey produces an estimate of snow depth values that are reasonable. The conclusion is that it does and that the technique warrants further work to increase the accuracy of the estimate and to determine if additional information can be extracted from the data.

OBSERVATIONS

Types of damage

Two types of damage were observed for this study: fungus damage below the surface of the snow; and wind damage above the snow level. In mountainous areas, up to 90% of the maximum snow depth occurs early in the snow season, often as early as January. Subsequent snowfall causes more compaction, densifying the underlying snow without adding very much depth (for example, Schild and Gliott, 1981). This phenomenon tends to concentrate damage associated with the snow surface in a relatively small fraction of the tree height.

Fungus

Free water forms in the snowpack beginning about the time of maximum accumulation. The cool, moist conditions promote the growth of the fungus brown felt blight (*Herptrichia juniperi*) which develops on snow covered foliage resulting in death of the needles. This is indicated by areas of dead, fungus covered needles, or defoliated branches near the base of larger trees (Figure 1). The top of the defoliated area marks the snow depth.

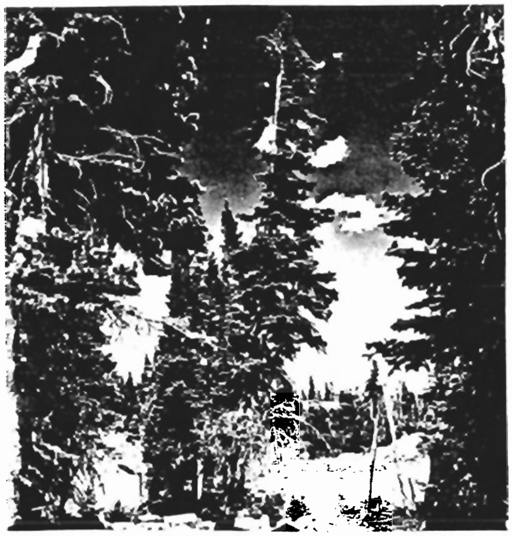

Figure 1. Fungus Damage

Figure 2. Wind Damage

Wind

The parts of the tree that are above the snow may suffer visible damage from the wind. The severity of the damage is quantitative in a way that can be used to estimate the average wind velocity (Wade and Hewson, 1979, Robertson, 1987). This damage is caused by ice abrasion and desiccation at the level of the top of the snowpack. The asymmetric deformation does not occur below the top of the snowpack and is often deliniated by a sharp line of a few centimeters above which deformation is evident (Fig. 2).

Observation technique

A 100 X 100 m grid was constructed on a detailed contour map of the GLEES. Wherever possible, trees or clumps of trees located at or near the grid points were photographed. Distance from the camera to the tree, and the angles from horizontal of the tree base and the level of snow damage were noted. These data were converted to the height of tree damage at the grid points.

Contour map

The height of the tree damage was transfered to the grid map and 1 m contours were drawn (Figure 3). The contour map was superimposed on an aerial photo taken about the time that half the snow had melted. The contours were adjusted to conform to the aerial photo more closely without violating the original point values. The resulting map shows the estimates of average snow depth at 0.5 m intervals (Figure 4)

The close correspondence between the contour map and the aerial photo shows that the tree damage and the aerial photo data are consistent. The average snow depth was determined by averaging the data at the grid points points with the result 200 ± 5 cm. snow for the watershed. The error term indicates the standard deviation in snowpack depth within the watershed.

Snow density

The start of the melt season is generally the time of maximum accumulation in this environment. At this time, there is a relatively small variation in the snow density (Martinec and Rango, 1986, Bartos, 1970). The average density derived, from a limited number of measurements was 401 kg m^{-3} (Sommerfeld *et al.*, in prep.).

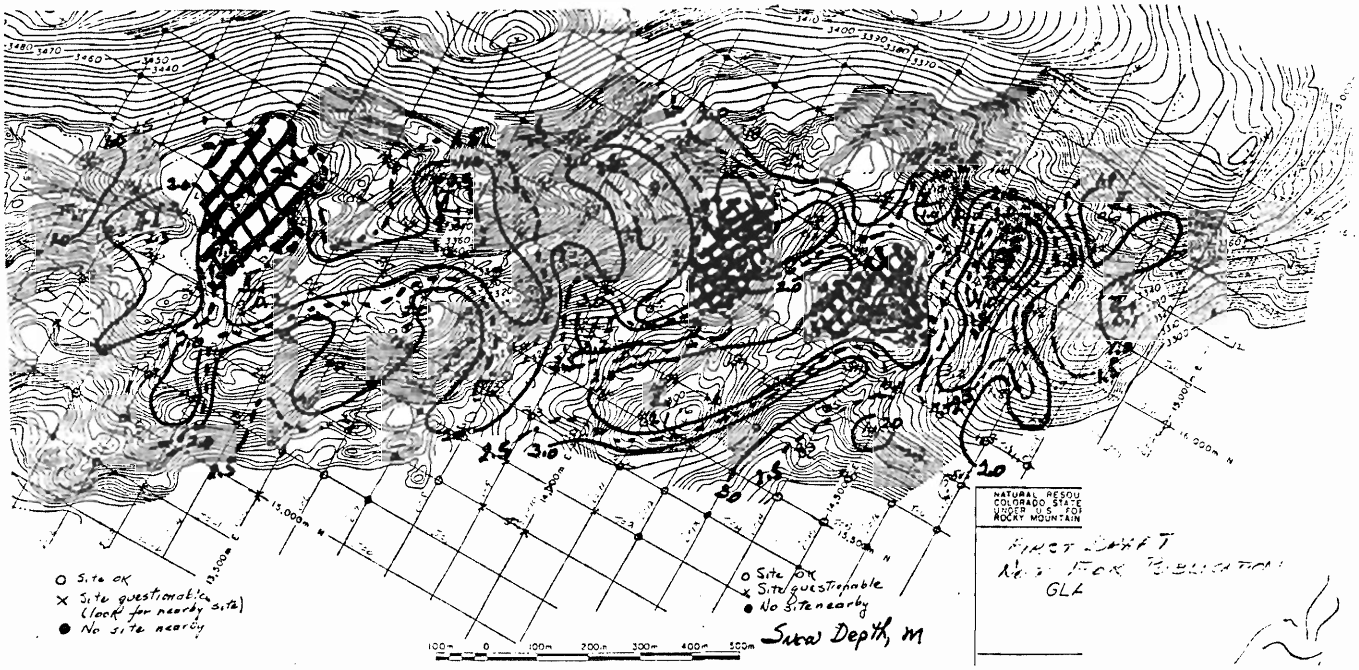

Figure 3. Initial Map of Snow Depth Contours

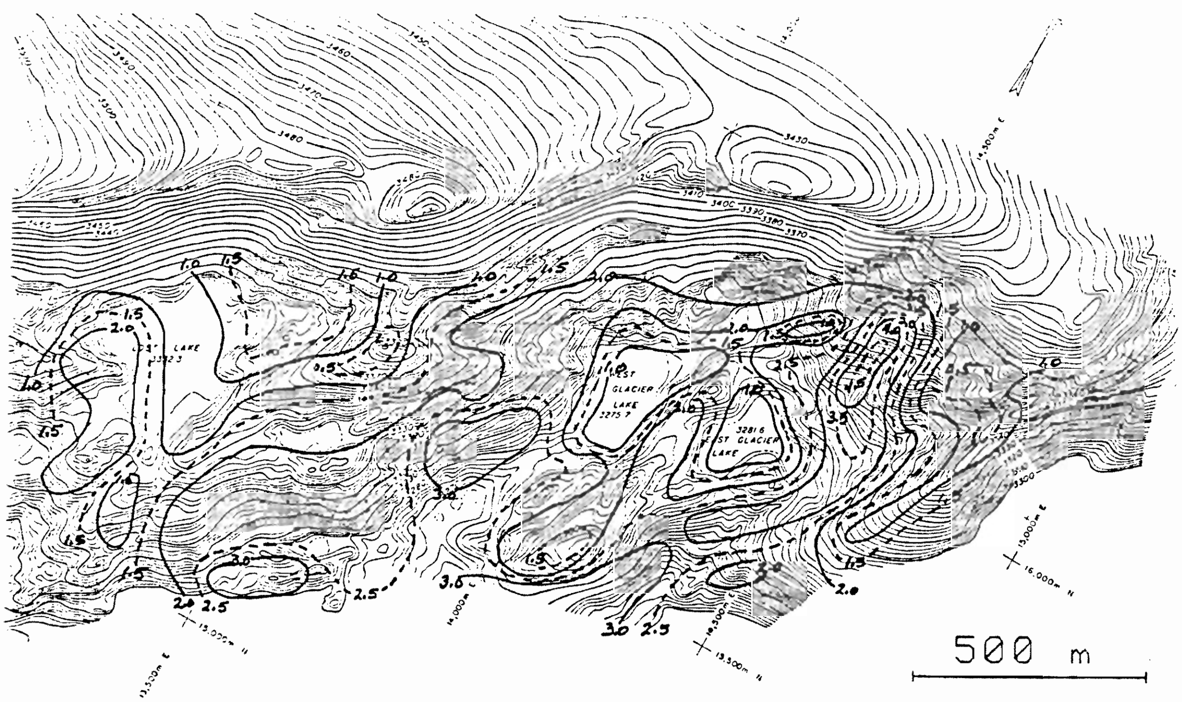

Figure 4. Final Snow Depth Contours

Water equivalent

Using the 200 cm tree morphology indicator of snow depth, and the density estimate of 400 kg m^{-3}, the resulting estimate for the average yearly snow accumulation in the GLEES is 80 cm H_2O.

Comparison with other estimates

The Wyoming Water Research Center Snowy Range Observatory (SRO) has maintained a Wyoming shielded precipitation gage at the GLEES for 9 years. The average water equivalent for November through April, 1979-1988 is 72.8 cm H2O. The Wyoming shielded gage is known to underestimate precipitation in windy climates such as the GLEES (Sturges, 1986). An estimate of the 1987-88 snow accumulation was performed using the method of Martinec and Rango (1986) giving 85 cm H2O (Sommerfeld *et al.*, in prep.). Assuming a standard error of 5 cm for snow depth and 40 kg m^{-3} (± 10%) for snow density, a lower bound on a standard error for snow accumulation based on tree morphology would be 8. An approximate P = 0.95 confidence interval would then be 80 ± 16 cm H_2O or a range of 64 to 96 cm H_2O.

DISCUSSION

Errors

Random

Errors in individual estimates were not determined. However, because these errors are random, they are expected to largely cancel in the sample size of approximately 135. Errors in the estimated snow density translate directly into errors in the accumulation estimate. Martinec and Rango (1986) give a range of about +- 10% in their average snow densities at the start of melt. This range seems to be representative of most measurements of snow density at the beginning of melt.

Systematic

Systematic errors are more important in introducing an error into the accumulation estimate. They can occur in both of the phenomena we used for our estimate.

Fungus damage

Fungus damage accumulates over the course of several years. Parts of the tree that are under the snow for the longest duration will suffer the most severe damage. The result is that the lower portions of the canopy receive the most damage. Less damage will be suffered by parts of the tree that are not wet each season or are wet for shorter perids of time, due to lower yearly accumulation. Therefore, the fungus indicator of snow depth will give a systematic bias in the data toward a low estimate of the maximum yearly snow level.

Wind damage

During low snow years, wind damage occurs to the exposed parts of the tree. There will be less accumulated damage than on the parts that are exposed every year and there may be some recovery of the damage when the parts are not exposed. This would provide a systematic bias toward a low estimate of the average snow depth using these data. A bias toward a high value may be generated by the fact that the trees tend to promote deposition particularly on the lee side. Some wind scouring may occur where there are no trees. The magnitude of this effect is unknown and is a subject for further investigation.

CONCLUSION

The estimate of average snow accumulation at the GLEES derived from a survey of tree morphology is thought to be somewhat low. Both the fungus and wind deformation indicators provide estimates of maximum accumulation in low snowfall years. The 95% confidence limits on the tree morphology estimate spans the estimates from the SRO precipitation gage and the Martinec-Rango (Sommerfeld, *et al.*, in prep.) type of estimate. We conclude that the result of the tree morphology survey at least compares favorably with other types of estimates. We think further study of this type of estimate is warranted. If the amount of underestimate could be quantified, the tree morphology survey could be a useful tool to estimated long term average snow accumulation in places where there have been no snow accumulation measurements.

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