THE USE OF DATA LOGGING SYSTEMS IN SNOW HYDROLOGY

756-84

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SNOW HYDROLOGY RESEARCH

Some typical problems faced by a researcher in snow hydrology are the development and/or testing of models for calculating snowmelt under various forest cover densities, or, the prediction of forest management on snowmelt in a given area. How we approach these problems depends on a number of factors including time, money and data collection capabilities.

Approach #1

As an example of one approach, let us consider the Corps of Engineers Generalized Basin Snowmelt Equations (GBSE), (U.S. Army Corps of Engineers , 1960). The equations for heavily and partly forested areas are given below as Equations 1 and 2.

$$M = .074(.53T'_a+.47T'_d) \qquad (1)$$

$$M = k'(1-F)(.0040I_i)(1-a)+k(.0084V)(.22T'_a+.78T'_d)+F(.029T'_a) \qquad (2)$$

where

M = snowmelt (in/day)
T'_a = the difference between the air temperature measured at 10 feet and the snow surface temperature (°F)
T'_d = the difference between the dewpoint temperature measured at 10 feet and the snow surface temperature (°F)
V = the wind speed at 50 feet above the snow (mi/hr)
I_i = the observed or estimated insolation (solar radiation on horizontal surface) (ly)
a = the observed or estimated average snow surface albedo (dimensionless)
k' = the basin shortwave radiation melt factor. It depends upon the average exposure of the open areas to shortwave radiation in comparison with an unshielded horizontal surface
F = estimated average basin forest canopy cover , effective in shading the area from solar radiation (dimensionless)
k = the basin convection-condensation melt factor. It depends on the relative exposure of the area to wind

One would test these equations for their area by simply collecting the required meteorologic data at a standard site and by estimating actual snowmelt by use of snowtubes and snowcourses or some other standard procedure. A comparison of predicted and observed melt is then easily done. An example of this type of study is Haverly et al. (1978).

To predict the effects of changes in forest cover density, one would either switch the equation used, or, change the parameters within the same equation while holding the meteorologic inputs constant.

Approach #2

A second option would be to use an explicit heat budget model. An example is given by the U.S. Army Corps of Engineers (1956) for a snowpack which is isothermal at 0°C, :

$$M = H_m/80 \qquad (3)$$

where

M = snowmelt (cm/day)
H_m = sum of heat components (ly/day)

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80 = latent heat of fusion (ly/cm^3)

The components of H_m are given by:

H_{rs} = absorbed solar radiation
H_{rl} = net longwave radiation exchange between the snowpack and its environment
H_c = convective heat transfer (sensible heat) from the air
H_e = latent heat of vaporization released by condensate
H_g = conduction of heat from underlying ground
H_p = heat content of rain water

Given accurate measurements and areal averages of the necessary meteorologic inputs for each term, in theory we should be able to predict snowmelt quite accurately for the area in question.

The prediction of management effects is a more difficult task because the model does not change, but the inputs do. It is then necessary to estimate how the forest cover affects the meteorologic inputs. There are many studies dealing with this question. A notable example is the work done by Miller (1955) on forest cover effects on solar radiation. Figure 1 shows the summary of Miller's work as given by the U.S. Army Corps of Engineers (1956). In the associated narrative the Corps notes "It is given only as a general guide; actual quantities for a particular area may vary considerably from the curve." For situations where approximations such as this are not satisfactory, it is clear we must develop these relationships on the site(s) of interest. Given the wide range of forest cover densities and the sampling necessary within a given forest cover to properly represent the area, a substantial sampling problem is posed. Furthermore, we are usually working on a daily basis, so we need to collect data for three or four months to get a sufficient number of data points to provide statistical precision and to get samples over the ranges of the meteorologic variables.

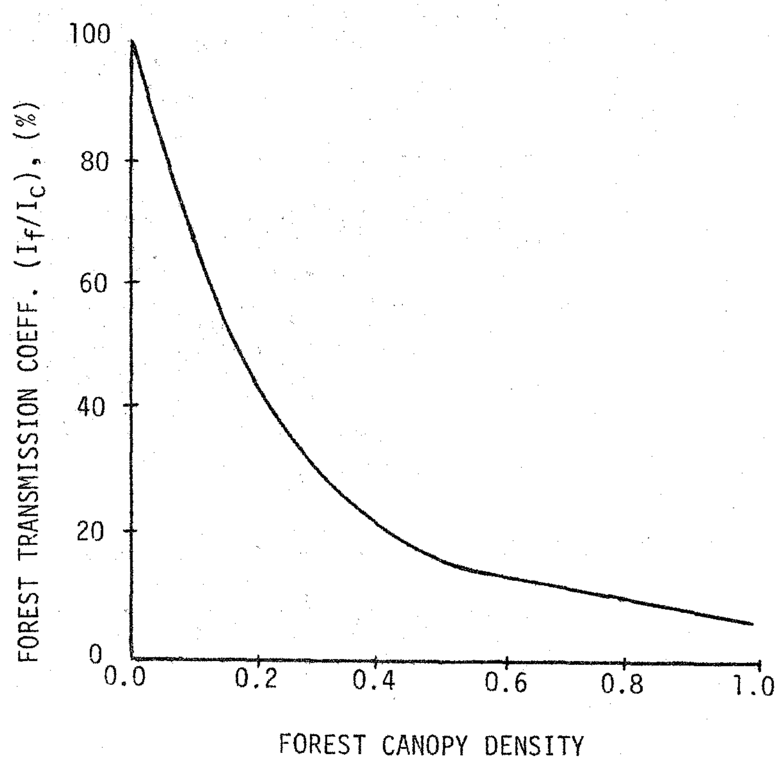

Figure 1. The effect of forest cover on solar radiation.

OPERATIONAL SNOWMELT PREDICTION

A typical problem in operational hydrology is forecasting the flows of a particular river. In regions where streamflow is fed predominantly by snowmelt the estimation of snowmelt volumes is clearly quite important. The intermountain west is a prime example of this type of region. A snowmelt model typically used in operational forecasting models is the Degree - Day Method (DDM), (Chow, 1964). It is given below as Equation 4.

$$M = DDF(T_a - T_b) \quad (4)$$

where

M = snowmelt (cm/day)
DDF = degree day factor (cm/°C/day)
T_a = air temperature (°C)
T_b = base temperature (°C)

This model spatially lumps the area for which snowmelt is being predicted. The DDF and T_b are typically fit by trial-and-error using observed records of streamflow and temperature at some nearby gage. A well known model using this approach is the Streamflow Synthesis and Reservoir Regulation Model (SSARR), (U.S. Army Corps of Engineers, 1972). Continuing to use the intermountain west as an example, it is clear that even within small drainages there is substantial variation in slope, aspect, elevation and forest cover. Therefore, it is not only possible, but very likely that a lumped parameter approach will yield poor results.

Cundy and Brooks (1981) varied the DDF in time in fitting the SSARR model to the Madison and Gallatin Rivers in Wyoming and Montana. This temporal variation of DDF improved model performance considerably. It is reasonable to believe that by incorporating spatial variation in the parameters that model fits and predictions could be improved even further.

Approach #1

Since many of the forecasting models are in a rough sense "distributed", a first solution could be to install more meteorologic stations in the basins of interest. We could then break our watershed up into finer components and have each associated with a particular station. It is clear from the present lack of gages that this is a next-to-impossible demand on our resources.

Approach #2

As in the research case, an alternative approach could be to estimate the effects of slope, elevation, aspect and forest cover on the input to our model relative to some reference station. In fact, we already do this for elevation using lapse rates. For the other factors we once again run into a substantial sampling problem.

HYPOTHESIS/QUESTION

In both the cases discussed above, a sampling problem has been posed in terms of building a relationship between a meteorologic variable measured at a standard or reference site and some other point of interest. The sampling is a problem because of the demand it puts on our resources, not because of any difficult statistical conceptualization. In considering this problem the following question was posed. Suppose I have a system available which allows me to measure the desired variables over the time interval of my choice: 24 hours, 10 hours,..., 10 minutes. Is the regression of meteorologic variable X at the point of interest (the dependent variable) on the same meteorologic variable X at a standard or reference site (the independent variable) the same if I average X over an arbitrary shorter time interval, or 24 hours (the time interval I am really interested in) ?

The purpose of this paper is to 1) discuss the implications on data collection if the averaging interval is not important, 2) describe the experiment being used to answer the question, 3) present the results of the experiment for the first month of data.

Implications

If it can be shown that the regressions between two sites for the desired meteorologic variables are independent of the averaging interval, how does this affect our sampling problem ? Consider the following example. Suppose we can use 10 minute averages to build the necessary regression(s). This means we can collect the equivalent of 144 days of data in one 24 hour period. Figure 2 shows the equivalent days of data versus the averaging interval.

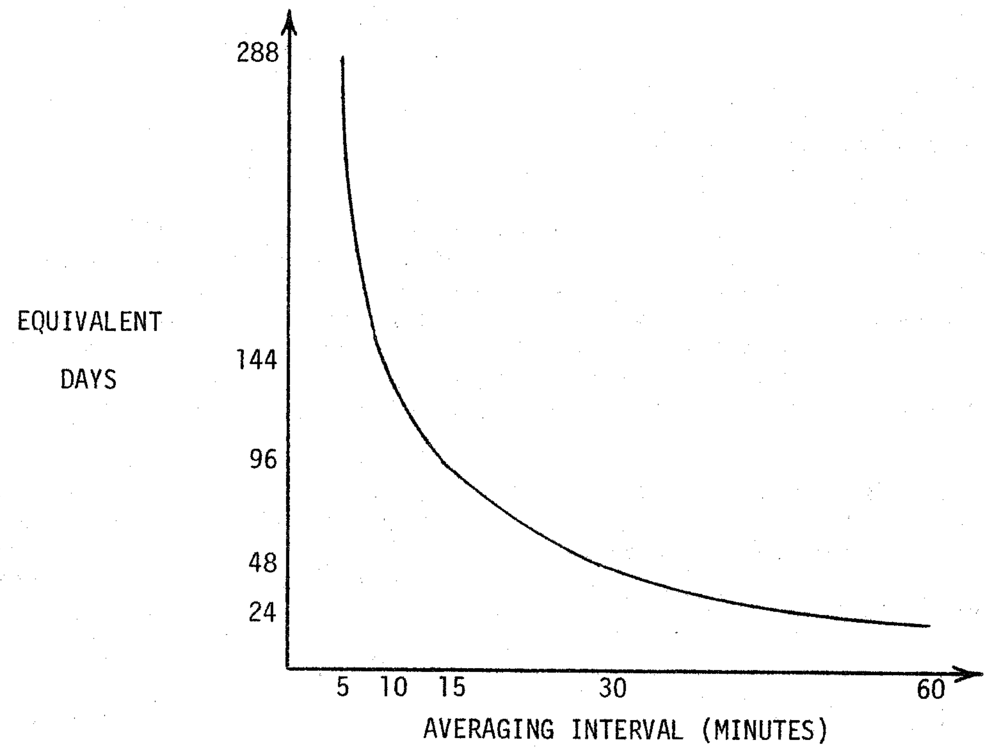

Figure 2. Equivalent days of data versus averaging interval.

This would lead to a number of benefits:

1. We can build the regressions between the desired sites in a matter of days, not weeks or months, with ample statistical precision. Furthermore, most meteorologic variables have substantial variation within a given day. Therefore, it may be possible to cover a sufficient range of the variables in a few days of sampling.
2. Only two sets of equipment are required; one for the reference site and one for the other sites of interest.
3. Data collection can be supervised continuously. Faulty sensors can be "repaired" immediately. The quality of the data is more easily assessed since someone can always be present.
4. Instruments are less subject to vandalism since they can be observed constantly during data collection.

METHODS

This section of the paper outlines the experimental procedure being used to answer the question posed above.

Variables Of Interest

The meteorologic variables measured at both the open and forested sites were chosen using the GBSE as guidelines. Table 1 shows the variables measured and their units.

Instruments

The sensors used and a brief description of each are given in Table 2. Air temperature and relative humidity were measured inside a standard instrument shelter. Wind speed was measured 3 meters above the ground and solar radiation 1 meter above the ground. Figure 3 is a picture of the sensors used.

Table 1. Meteorologic Variables and Units

Air temperature (°C)
Relative humidity (%)
Solar radiation (mV)
Wind speed (km/hr)

Table 2. Description of Sensors

Air temperature:	Accuracy ±.25°C; Temperature range -35°C to 60°C; Response time is 90 seconds in still air
Relative humidity:	Accuracy ±1%; Temperature range -10°C to 93°C; Response time is 30 seconds or less for a 63% change in relative humidity
Solar radiation:	Accuracy ±3% (without user error); Temperature coefficient error ±.15%/°C
Wind speed:	Accuracy ±.16 km/hr; Range 0-160 km/hr; Calibration equation V=1.4983+.06775*revolutions per minute (r^2=.99928)

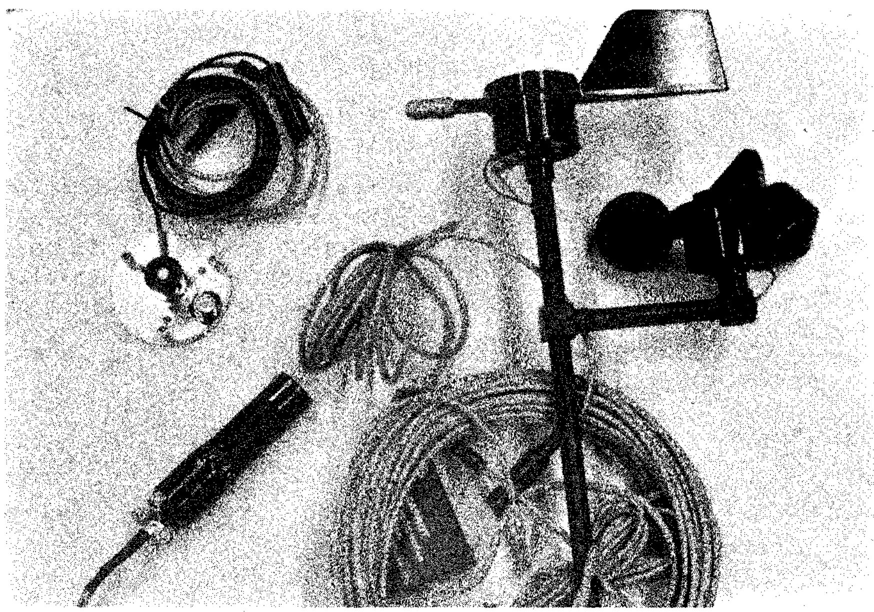

Figure 3. Meteorologic sensors used.

The measurement of solar radiation in this study requires some additional discussion. It is known that the forest canopy alters the spectral distribution of incoming radiation (LI-COR Inc., 1980). Due to this and the nonuniform spectral response of the available sensor, the radiation measurements in this study are not converted to langleys since this would only be a rough approximation. We can however compare the millivolt readings obtained remembering they represent what the sensors "observed" over their spectral response.

The sensor output was recorded on OMNIDATA digital recorders designed for each sensor. Data are recorded on Data Storage Modules (DSM) and are fed directly into a microcomputer. A DATAPOD and DSM are shown in Figure 4. With these recorders the user is given an array of recording intervals to choose from. The recording intervals and the number of observations averaged for each recording used in this study are given in Table 3 for each sensor.

Table 3. Recording Intervals.

	Rec. Int. (min)	# Of Readings Averaged
Air temperature	30	3
Relative humidity	30	3
Solar radiation	10	2
Wind speed	10	10

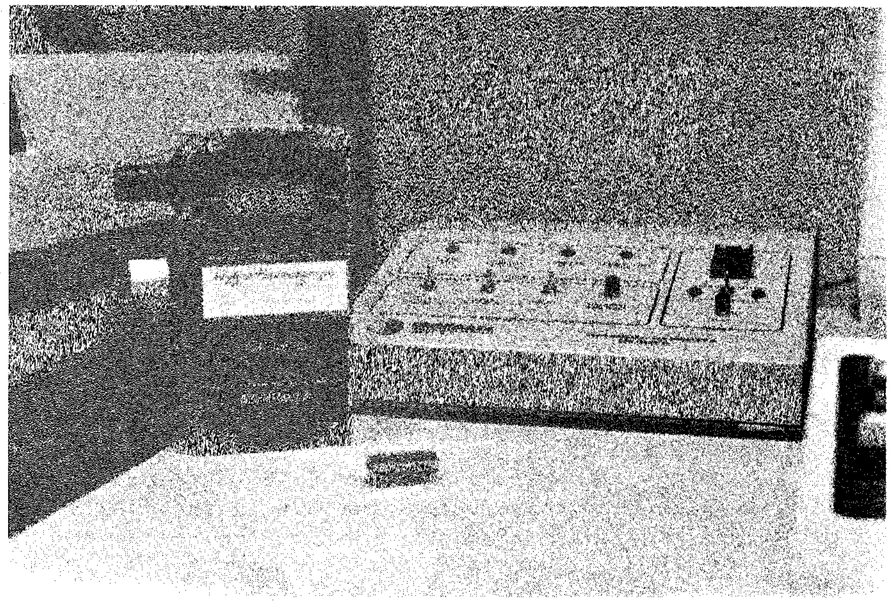

Figure 4. DATAPOD and DSM.

Study Sites

The open and forested sites being monitored are located in the Charles Lathrop Pack Experimental Forest near LaGrande, Washington. The sites are at approximatley 600 meters in elevation. Figures 5,6 and 7 show the sites pictorially and in plan view. The forested areas contain 50 year old Douglas Fir, Psuedotsuga menziesii (Mirb.) Franco, and Western Hemlock, Tsuga heterophylla (Raf.) Sarg. The dominant and codominant trees are approximately 25 meters in height. Basal area is approximately 50 m^2 per hectare with 100% crown closure.

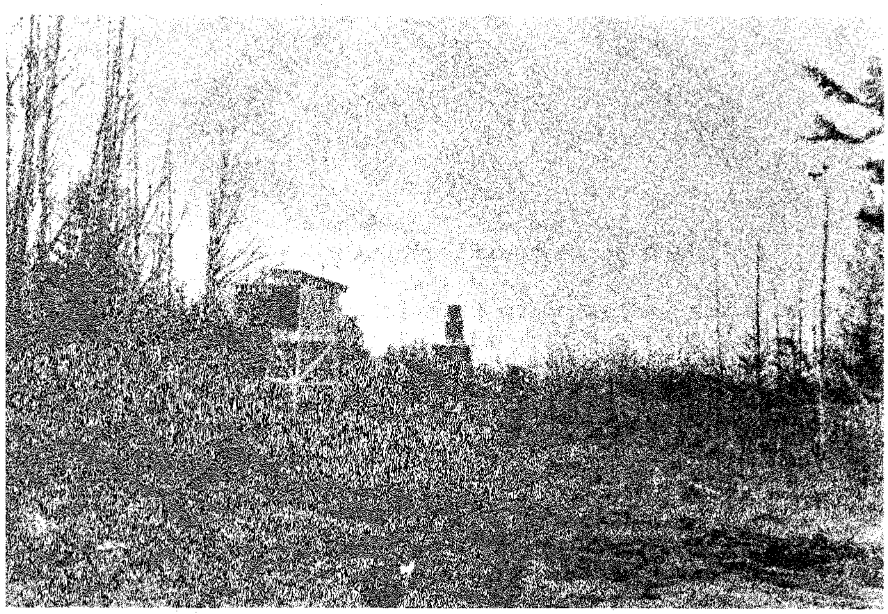

Figure 5. Open Site.

Statistical Analysis

As previously mentioned the relationships between the meteorological variables measured in the open and in the forest are going to be evaluated using regression analysis. A hypothetical scatterplot for the variable X is shown in Figure 8.

The regression model fit to the data is

$$X_{forest} = B_o + B_1 X_{open} + B_2 D \quad (5)$$

where

B_o, B_1, B_2, are fitted coefficients
D = is a dummy variable, D=1 for data pairs based on a daily average, and D=0 for data pairs based on a time interval less than daily
X_{forest} = average value of the variable measured in the forest.
X_{open} = average value of the variable measured in the open

The test to determine if the time interval of averaging is significant is

H_o: B_2 .ne. 0

vs

H_A: B_2 .eq. 0

Figure 6. Forested site.

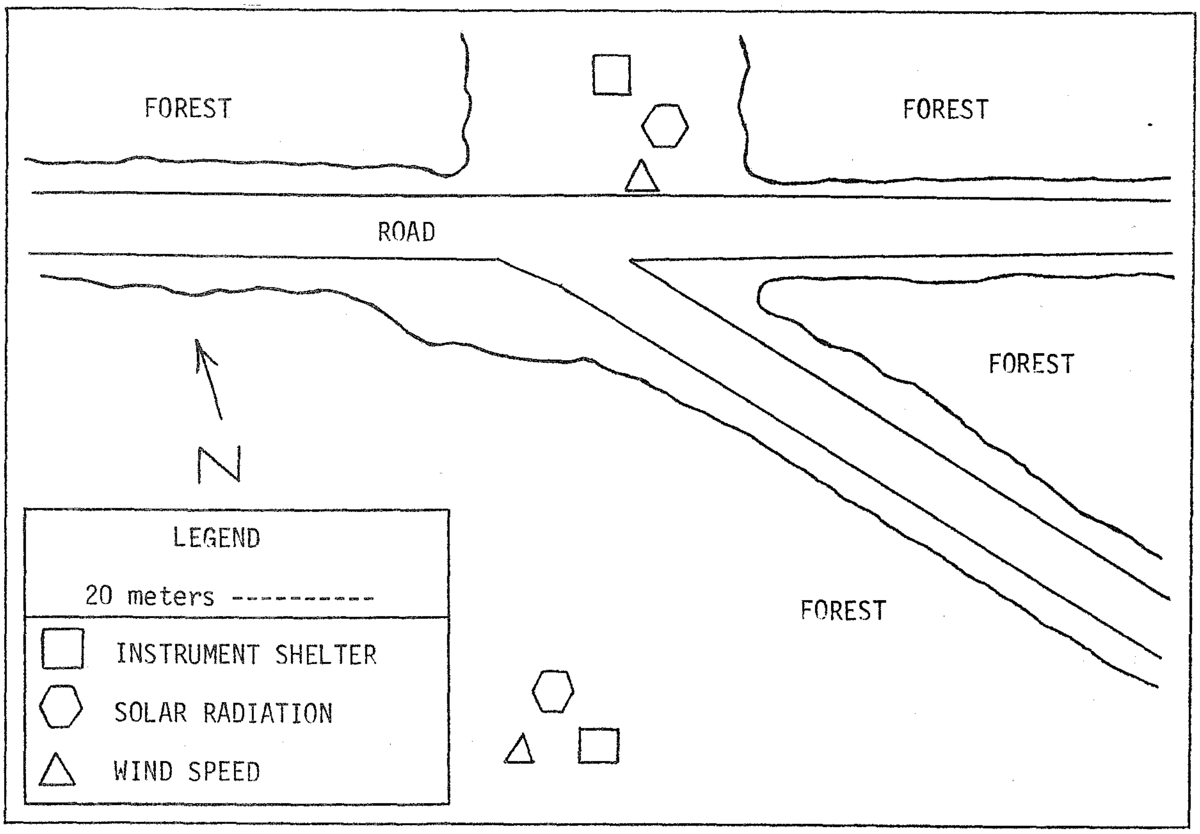

Figure 7. Plan view of the study site.

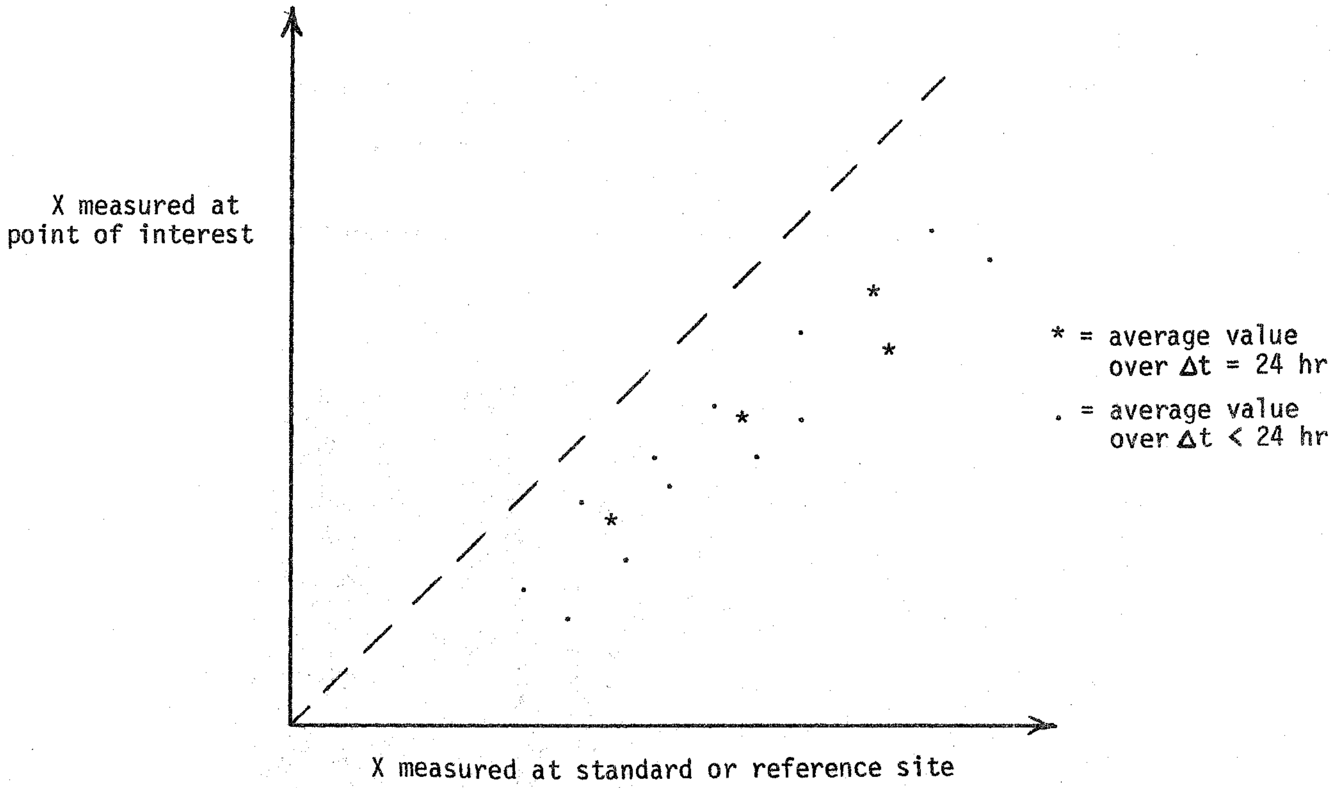

Figure 8. Hypothetical scatterplot of the meteorologic variable X.

RESULTS

The data presented in this paper were collected between March 4, 1984 and April 5, 1984 using the procedures outlined above. Data for each variable on each site for March 4, 1984 are plotted and shown as Figures 9 - 12.

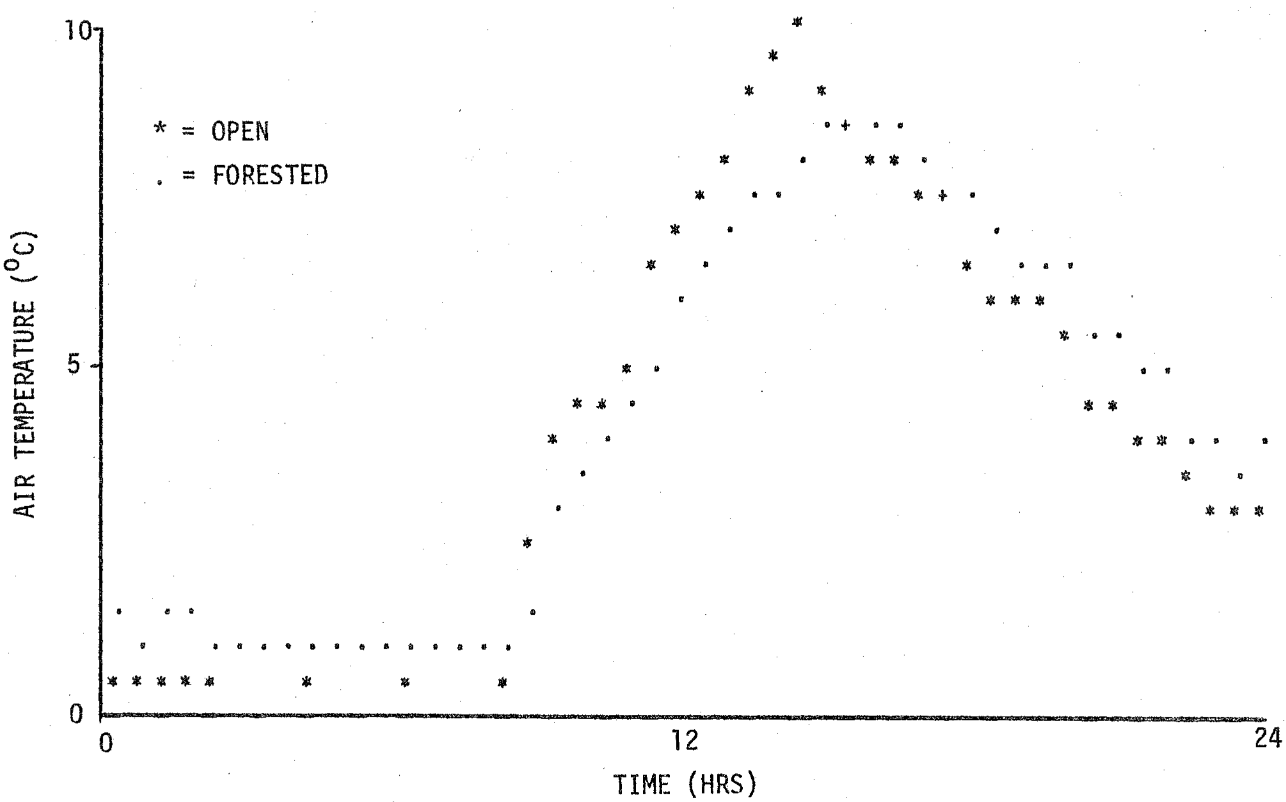

Figure 9. Air temperature at the open and forested sites for March 4,1984.

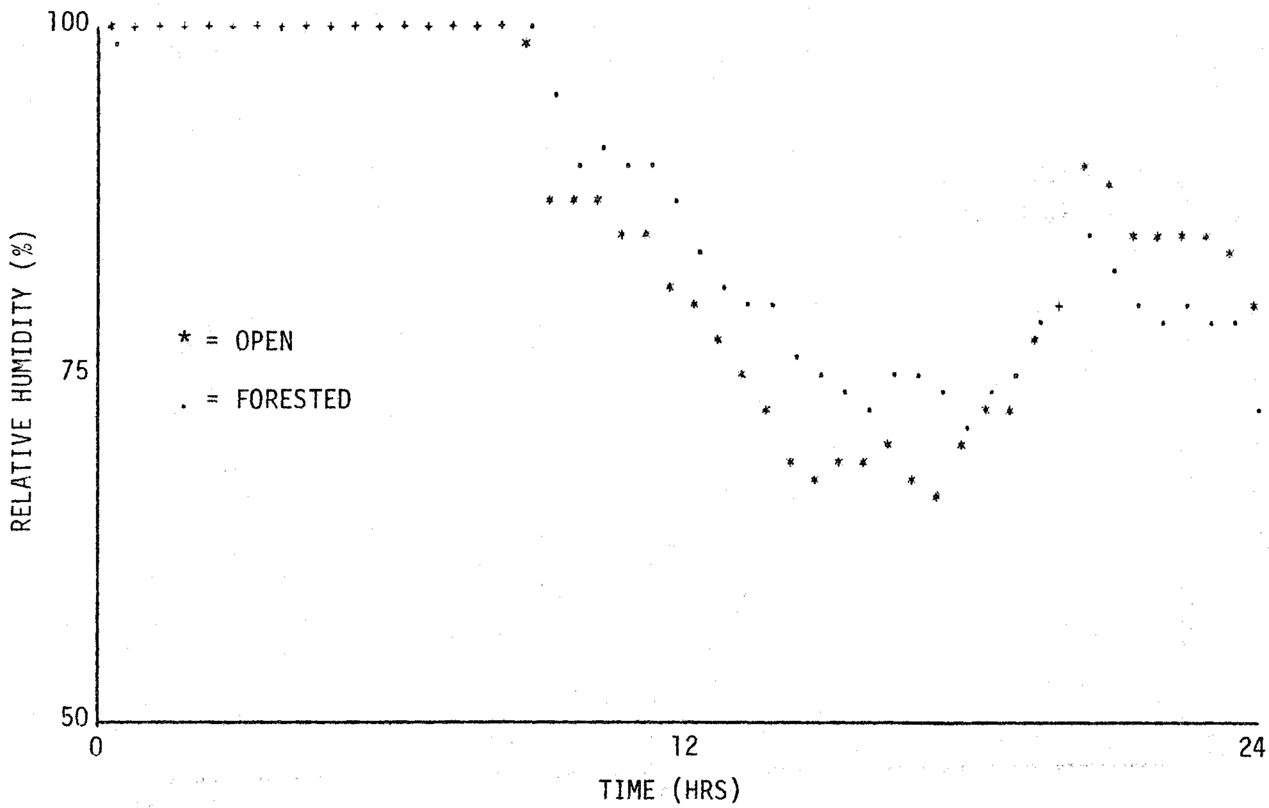

Figure 10. Relative humidity at the open and forested sites for March 4,1984.

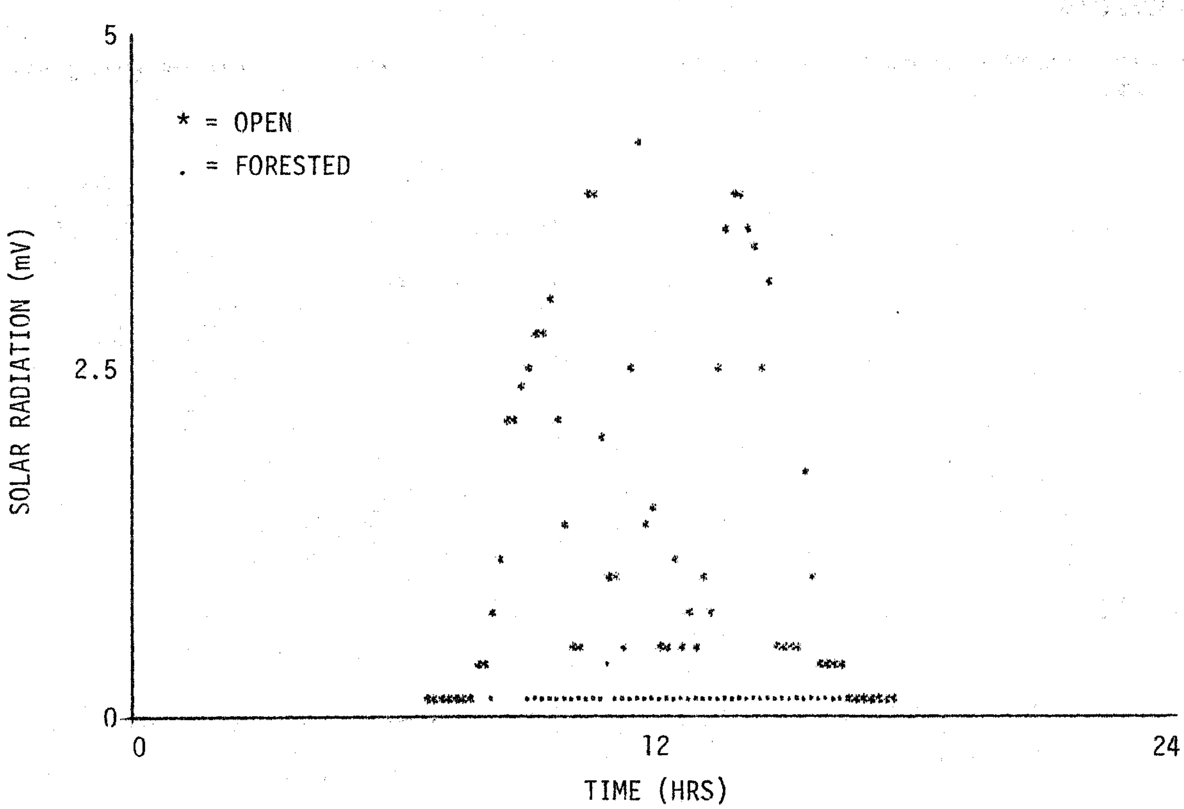

Figure 11. Solar radiation at the open and forested sites for March 4,1984.

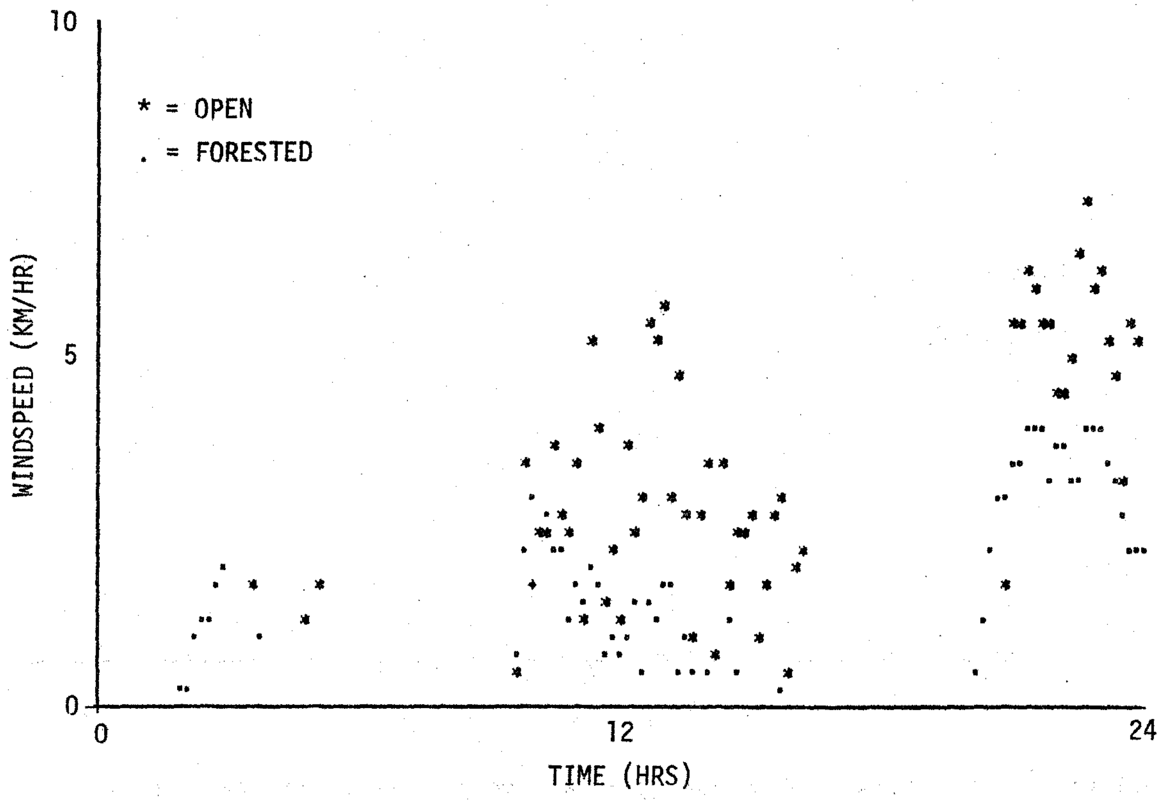

Figure 12. Windspeed at the open and forested sites for March 4,1984.

Regression Analyses

Scatterplots of the meteorologic variables in the forest versus the open are given as Figures 13 - 16.

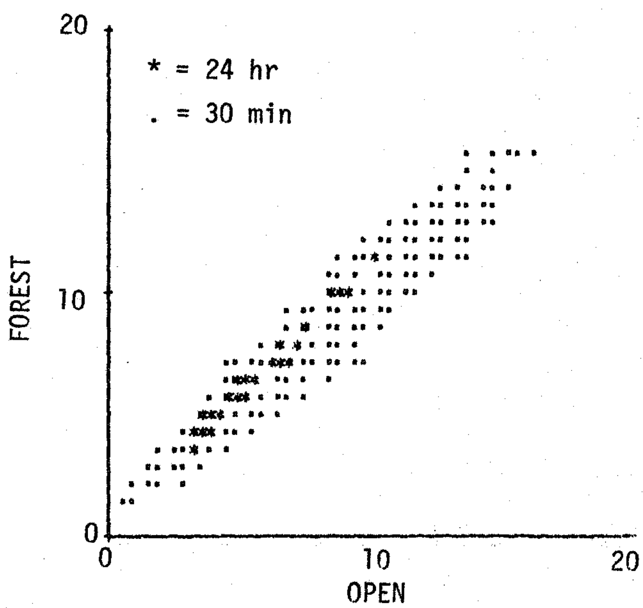

Figure 13. Air temperature (°C).

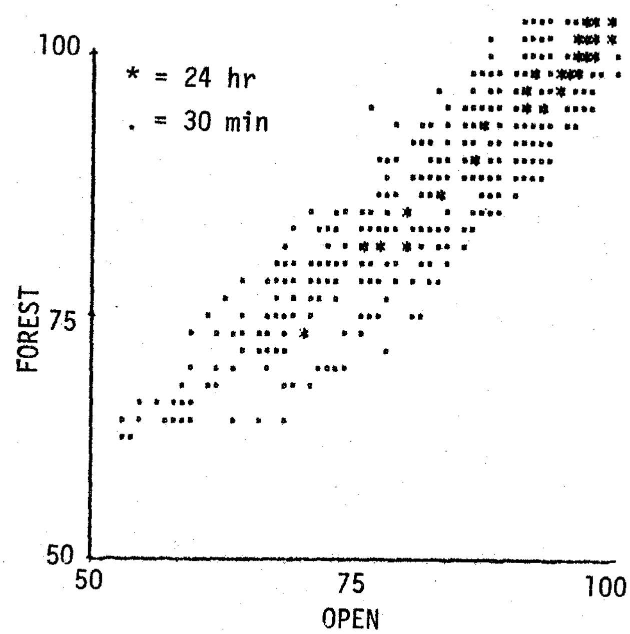

Figure 14. Relative humidity (%).

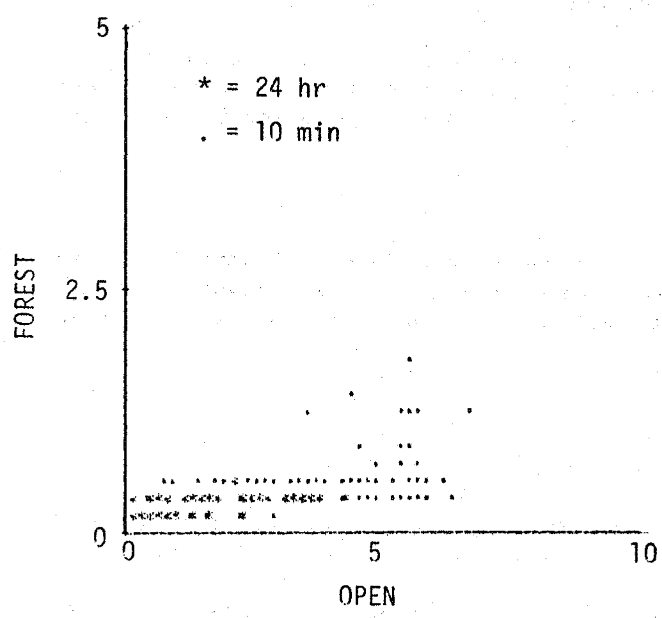

Figure 15. Solar radiation (mV).

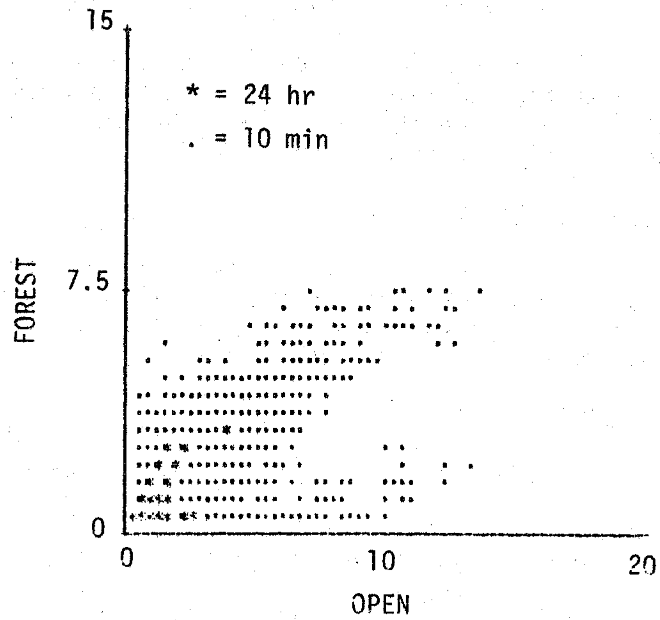

Figure 16. Wind speed (km/hr).

Table 4 contains the results of the regression analysis.

Table 4. Summary of Regression Analysis.

	B_1	p-value (B_1=0)	B_2	p-value (B_2=0)	r^2
Air temperature	.8493	p<<.001	.0095	p>.5	.936
Relative humidity	.8528	p<<.001	-.0028	p>.5	.919
Solar radiation	.0873	p<<.001	-.0001	p>.5	.585
Wind speed	.3957	p<<.001	-.0008	p>.5	.406

DISCUSSION AND SUMMARY

It is clear from Figures 13-16 that the averaging intervals used in this study did not affect the regressions between the forested and open sites. While Table 4 indicates that for all cases the regressions are statistically significant and that B_2 is not significantly different from zero, it should be noted that the tests are not statistically precise due to autocorrelation in the dependent variables. To correct this, one would reduce the degrees of freedom used in the tests to some equivalent number of independent samples, depending on the correlation structure of the data (Haan, 1977). While this autocorrelation is important in performing tests, it does not affect the estimates of the coefficients or the use of the equations for making point predictions. Putting aside statistical subtleties, the important issue is the usability of the equations describing Figures 13-16.

The relationships for air temperature and relative humidity are strong enough that they could be exploited for the purposes outlined at the beginning of this paper.

For the relationship of solar radiation in the forest versus the open the slope of the line is nearly zero (.0873). From Figure 15 it is clear that the pyranometer in the forest sensed a nearly constant input of shortwave radiation regardless of what was measured in the open. In this case the regression equation is not particularly useful.

The windspeed data is interesting since two relationships seem to be present at high windspeeds in the open. Inspection of the data indicated this was related to wind direction. Winds blowing from the open to the forest generally fall in the lower "arm" of the plot. Winds blowing from the forest to the open represent the upper "arm". It is obvious that wind direction must be considered rigorously in future analyses.

The data and results presented here support the hypothesis that a savings in time may be possible through the use of data-logging systems in regression building. Data collection is continuing to test the hypothesis over a full annual cycle and to evaluate the effect of distance between sites.

Acknowledgements

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