Proceedings of the Third
FOREST MICROCLIMATE SYMPOSIUM

Kananaskis Forest Experiment Station

Seebe, Alberta
September 23-26, 1969

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FOREWORD

The Third Forest Microclimate Symposium sponsored by the Canadian Forestry Service, Department of Fisheries and Forestry, took place September 23-26, 1969, at the Kananaskis Forest Experiment Station, Seebe, Alberta. The meetings were held in the Environmental Sciences Centre of the University of Calgary, adjacent to the Headquarters of the Kananaskis Forest Experiment Station. Sixty-six participants from Federal and Provincial Government Departments, Universities, and industry in North America were registered. Previous symposia were held at Cowichan Lake, British Columbia (1962), and at Petawawa Forest Experiment Station, Chalk River, Ontario,(1965), but this is the first time the proceedings of a symposium has been published. The symposia provide opportunities for those working or interested in the field to meet in an informal workshop atmosphere to report on their studies and discuss their progress and problems.

The symposium was opened on Tuesday morning, September 23, by Symposium Coordinator, Dr. J. M. Powell. Greetings were extended by M. H. Drinkwater, Acting Director, Alberta-Territories Region, Canadian Forestry Service, and Dr. J. B. Cragg, Director, Environmental Sciences Centre, University of Calgary. The symposium comprised five special sessions, each with invited and contributed papers, a general session of contributed papers, a field trip and several informal sessions.

On Tuesday, the special session was divided into two parts and covered the aspects of "Water relations in the forest" with Dr. L. J. Fritschen, University of Washington, giving an invited paper on evapotranspiration and meteorological methods of estimation, and H. W. Anderson, U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, covering the subject of storage and delivery of rainfall and snowmelt water in a forest environment. On Tuesday evening, Dr. W. E. Reifsnyder, Yale University, who recently spent some time in Bavaria, spoke about forestry and forest meteorology in that State and especially reported on the current work of Dr. A. Baumgartner. This was followed by the presentation of five films touching on the topics of the work of a meteorologist in a 24-hour period, forest hydrology, measurement of turbulence, and the control of evaporation, snow,and wind.

On Wednesday morning, J. Rogalsky, Meteorological Branch, Department of Transport, Toronto, gave the invited paper for the session on "Data acquisition and processing for microclimate research". After an early lunch, the party departed for a tour of the Marmot Creek Watershed Research Basin, a cooperative project underway for some 7 years in a sub-alpine tributary basin of the Kananaskis River Valley, about 15 miles south of the station. In the evening, during a visit to Banff, 43 of the participants made the trip up Sulphur Mountain via the Gondola Lift to visit the Cosmic Ray Station of the University of Calgary. Once down the mountain, many spent a relaxing time in the Upper Hot Springs Pool or in Banff.

At session four on Thursday morning, G. S. Raynor, Brookhaven National Laboratory, gave the invited paper on "Diffusion and dispersion in and near forest stands". At the afternoon session on "Climatic classification and its possibilities for forestry", Professor R. W. Longley, University of Alberta, gave the first invited paper. This was followed by a second invited paper given by W. K. Sly, Canada Department of Agriculture, Ottawa. At the conclusion of this session, the majority of the Canadian participants took part in an informal discussion on the possibilities of a national program for forest climatology. In the evening, a visit was made to an automatic weather station operated by the University of Calgary in their Chinook program; other instruments were displayed and a number of persons discussed interesting slides or films relating to their work. On Friday morning the symposium concluded with a general session of contributed papers with a summing up by L. B. MacHattie, Canadian Forestry Service, Ottawa.

In the proceedings, the invited and contributed papers, including the shorter 5-minute contributions, have been grouped according to their time of presentation. Summaries of the field trips to the Marmot Creek Experimental Watershed Basin and the automatic weather station follow the accounts of scientific sessions. Abstracts, summaries, or titles of the presentations given in the informal evening session, complete the account of the symposium.

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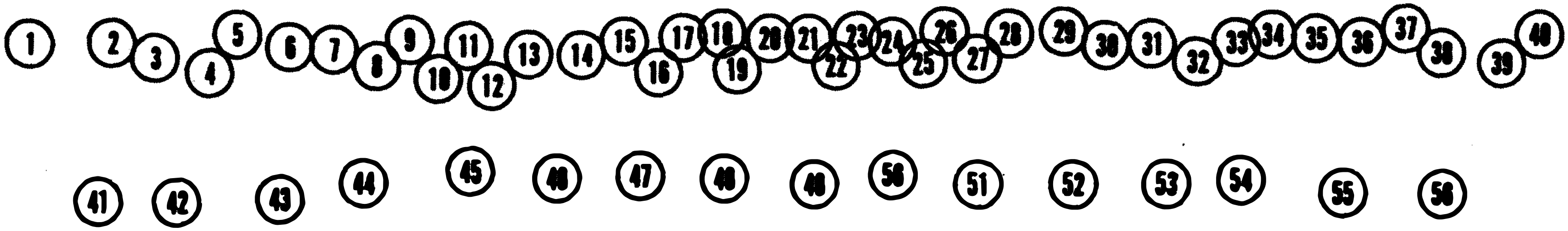

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EVAPOTRANSPIRATION AND METEOROLOGICAL METHODS OF ESTIMATION AS APPLIED TO FORESTS

By

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ABSTRACT

The energy balance of a surface is a dynamic balance. Altering one term causes the rest to change. Since the evaporation process is the largest heat sink, small changes in the evaporation rate cause relatively large changes in the other terms. Sample energy balances over free water, bare soil, and plant surfaces are presented to illustrate the effect of soil drying, plant height, and wind speed upon the evaporation rate.

Evapotranspiration can be estimated by a meteorological method. The basic assumptions of the commonly used meteorological methods are listed and discussed with respect to their application in forestry. A resulting conclusion is that the combination of the energy balance and eddy correlation technique may be the most suitable method for determining evapotranspiration from forests.

INTRODUCTION

Data on evapotranspiration and meteorological methods of estimation are limiting in forestry. However, many comprehensive experiments have been conducted in agriculture. Therefore, the discussion of this subject will be presented with the use of agricultural data to illustrate the main points. This information will be applied to forestry using an analogy between forestry and agriculture. For completeness, the discussion will include a review of the physical processes and meteorological methods.

PHYSICAL REVIEW

Evapotranspiration is the physical process of converting liquid water into vapor. This process takes place from plant and soil surfaces. Under some conditions, the plant exercises control over this evaporation process but generally speaking when water is not limiting, evaporation is controlled by the meteorological parameters and in particular the energy input.

Energy Source and Use

The primary source of energy at the earth's surface is the sun. As its rays penetrate the atmosphere, a portion of the energy is reflected from the clouds, a portion is absorbed by the atmosphere and still another portion is scattered diffusely in all directions (Fig. 1). The attenuated radiation that does penetrate the earth's atmosphere both as direct beams and diffuse scattered radiation is disposed of in two ways. A portion of it is reflected from the earth's surface, the remainder is absorbed. The energy that is absorbed heats the object which in turn reradiates energy of different wave lengths in proportion to the fourth power of its absolute temperature. An additional amount of energy is received from the atmosphere as long wave or thermal radiation. The difference between the downward and the upward components of the radiation flux is called net radiation. Net radiation is the amount of energy retained by the surface. This energy is used primarily to heat the surface, the overlying air mass, and to evaporate water. Other energy uses such as photosynthesis are neglected because they are comparatively small.

The amount of energy used to heat the soil or air and to evaporate water is strongly dependent upon the radiation input and upon wind speed which provides the exchange of air and water vapor.

The energy balance of the surface is a dynamic state. A slight change in one parameter will affect the magnitude of the other parameters. As an example, everyone has experienced the sudden comfort of shade resulting from a cloud temporarily obscuring the sun's radiation on a hot day. The relative magnitudes of the various components of the energy balance over a drying bare soil surface are shown in Figure 2.

A mathematical expression for each flux is used to further illustrate the dynamic state of the surface energy balance. Long wave radiation may be represented by (see appendix for definition of terms)

$$R = E\sigma T^4 \tag{1}$$

Energy used to heat the soil, S, or water, W, is

$$S \text{ or } W = -\lambda \frac{\Delta T}{\Delta z} \tag{2}$$

The energy used to heat the air, A, is

$$A = CpK_h \frac{\Delta T}{\Delta z} \tag{3}$$

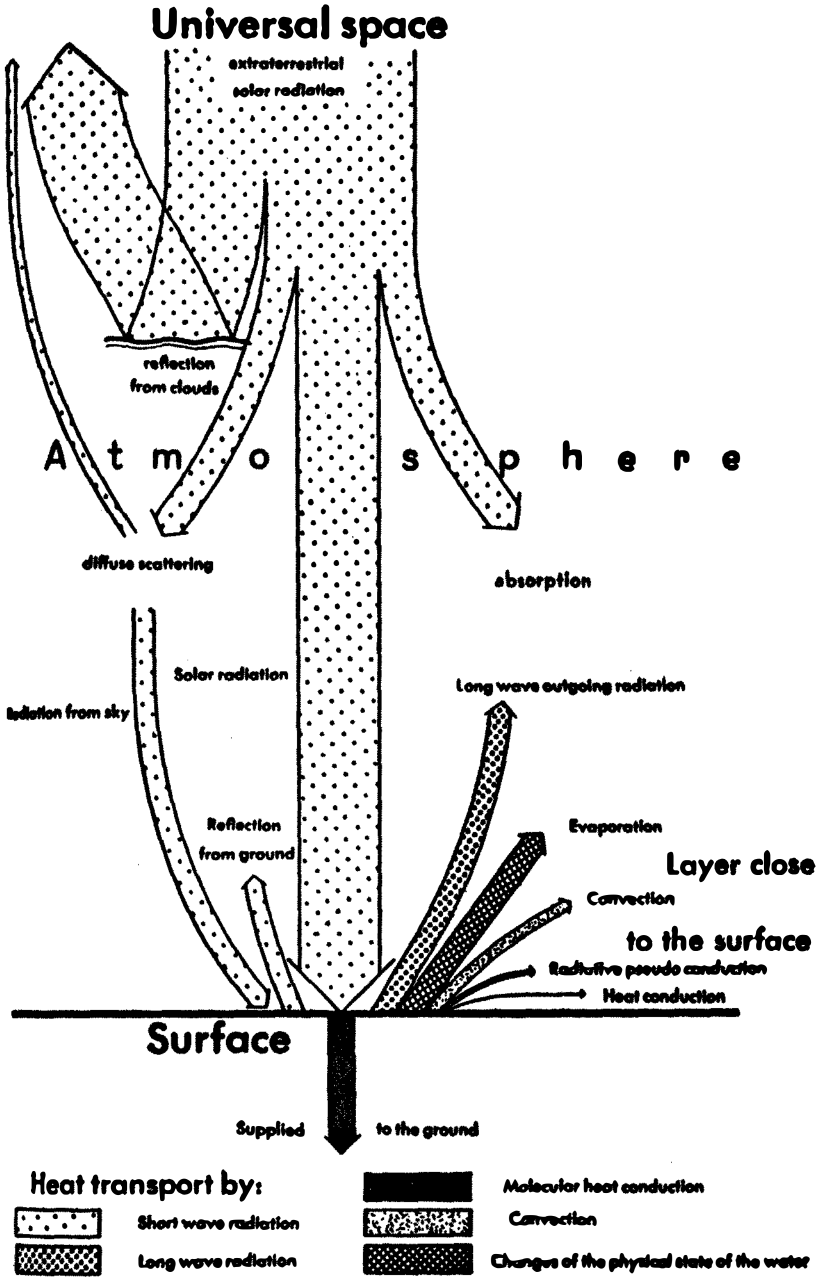


Fig. 1. Heat exchange at noon for a summer day. (The widths of the arrows correspond to the transferred heat amounts.) (From Geiger, 1957).

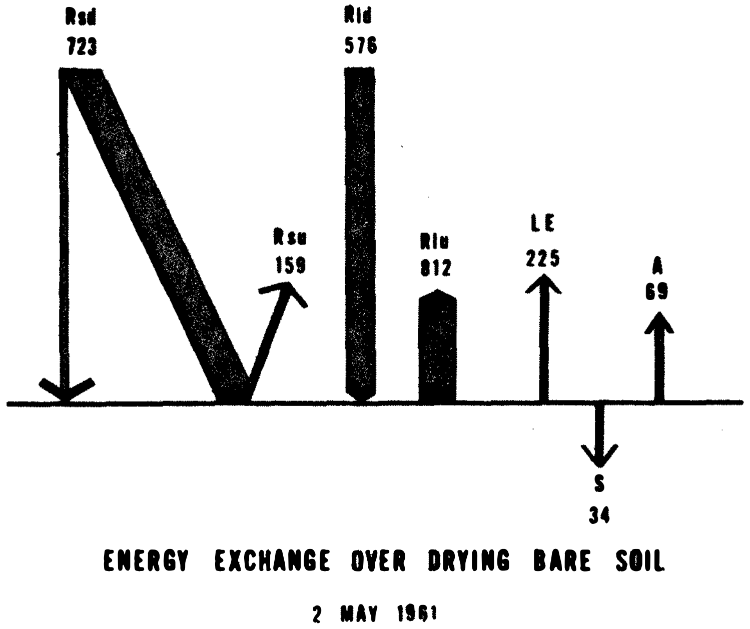


Fig. 2. The components of the energy balance over a drying bare soil surface: Rsd, short wave radiation downward; Rld, long wave radiation downward; Rsu, short wave radiation upward; Rlu, long wave radiation upward; LE, evaporative flux; S, soil heat flux; A, sensible heat flux.

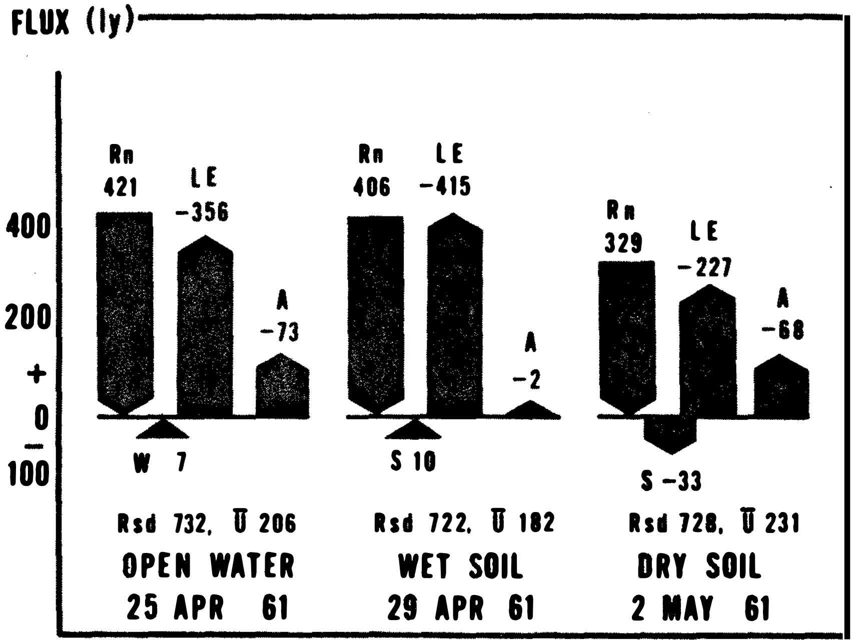


Fig. 3. Influence of surface characteristics upon evaporation: Rn, net radiation; LE, evaporative flux; A, sensible heat flux; Rsd, short wave radiation downward; U, wind speed; S, soil heat flux; W, water heat storage.

The amount of energy used to evaporate water, LE, is

$$LE = \frac{\rho L \varepsilon K_w}{p} \frac{\Delta e}{\Delta z} \tag{4}$$

All of these equations are temperature dependent. If anything is done to change the temperature of the surface, all of these relations are affected. It is not obvious how the last equation is temperature dependent. However, the saturated vapor pressure over water is a function of water temperature and nearly doubles with 10°C increase in temperatures starting with 6.1 millibars at 0°C.

Short Wave Radiation

Since solar radiation is the prime source of energy at the earth's surface, a discussion of its physical properties is in order. Solar radiation includes wave lengths from 0.24 to 4 microns. The wave length of peak intensity is 0.47 microns, blue light. The amount of solar energy incident upon any surface is a function of the time of day or year, the latitude, the slope, and the aspect. The amounts of energy received on a flat surface parallel to the earth's surface and on rough terrain are quite different. Both can be calculated from theory. In higher latitudes, the south-facing slopes receive considerably more energy than the north-facing slopes and consequently would evaporate more water.

Not all of the incident radiation is absorbed by the surface. Part of it is reflected. That not reflected depends upon the nature of the object. For example, the amount of reflection from a water surface depends upon the latitude and the time of year. Snow has a very high reflection when it is fresh. After it has aged, the reflection decreases to between 40 to 70 per cent, and just before melting may be as low as 40 per cent. Sand dunes when dry reflect 45 per cent and when wet reflect 20 to 30 per cent. Dark soil and asphalt reflect very little, 5 to 15 per cent. Similarly, coniferous forests reflect very little energy. In general,the light greens and grey greens reflect more than the dark greens.

Long Wave Radiation

The energy absorbed by an object raises the temperature of the object. It in turn reradiates energy in proportion to the fourth power of its absolute temperature. The relative intensity of radiation increases as the temperature increases, while the wave length of peak emission decreases with increasing temperatures. For example, a decrease in temperature of a black body object from 287°K to 250°K or a difference of 37° is sufficient to change the wave length of peak intensity from 10 to 12 microns and to decrease the relative amount of emitted energy by about 50 per cent.

Not all objects emit as black bodies. Some emit as a constant fraction of the energy that it could emit if they were a black body. The infrared emissivity of most natural materials is generally high, 0.9 or greater.

APPLICATION TO THE EVAPOTRANSPIRATION

Effect of Surface Condition Upon Evaporation and the Energy Balance

Under similar meteorological conditions, evaporation from wet bare soil can exceed evaporation from open water. Energy absorbed at the wet soil surface elevates its temperature and consequently vapor pressure, above that of open water where radiant energy is transmitted to a greater depth thus heating a deeper layer of water. The evaporation rate from the soil is greater because of the larger vapor pressure gradient (Fig. 3). As the soil surface dries and changes color, reflection is increased and evaporation is decreased. More energy is used to heat the soil and heat the air. Notice the drastic change in evaporation from the soil in three days. This emphasizes the importance of a shallow layer of dry soil or mulch which restricts the flow of water vapor to the surface thus reducing evaporation.

The large evaporation reduction in three days would not have been noticed if vegetation were growing on the soil (Fig. 4). On the 12th of September, the sudan grass evaporated 324 ly equivalent of water. It had not received any water for 30 days prior to this date. 324 ly is equivalent to about 5.5 mm of water per day so that the soil was getting rather dry at the end of 30 days. After irrigation, the evaporation increased to 388 ly. These days were chosen because of the similarity of solar radiation, air temperature, vapor pressure, and wind speed. The reason for the small increase in evaporation as a result of irrigation as contrasted to the bare soil is that the root system of the crop is able to conduct water from a greater depth to the surface more rapidly than can be conducted through a soil with a mulched layer.

Other evidence of difference in water loss from different surfaces is shown in Figure 5 which contrast irrigated sudan grass 100 cm in height and stubble located adjacent to each other on the same day. The sudan grass projecting into the wind extracted 213 ly more energy from the air, and consequently evaporated 3.6 mm more water than the irrigated stubble. Notice the short wave reflection is greater from the sudan grass than from the stubble.

Effect of Wind Upon Evaporation and the Energy Balance

The influence of wind speed upon evaporation from a wet bare soil on February 27 and 28 is shown in Figure 6. These days were selected because they were similar with respect to solar radiation and air temperature. Slightly more radiation was received on February 28. On February 27, the evaporation was 167 ly while on the 28th evaporation was 108 ly, the obvious difference was due to wind speed. On the former day, wind speed averaged 238 cm sec^{-1} (100 cm sec^{-1} is approximately equal to 2 mph) while on the latter day it was 96 cm sec^{-1}. As a result, more energy was used to heat the air on the second day and less energy was derived from the underlying surface to support the evaporation process.

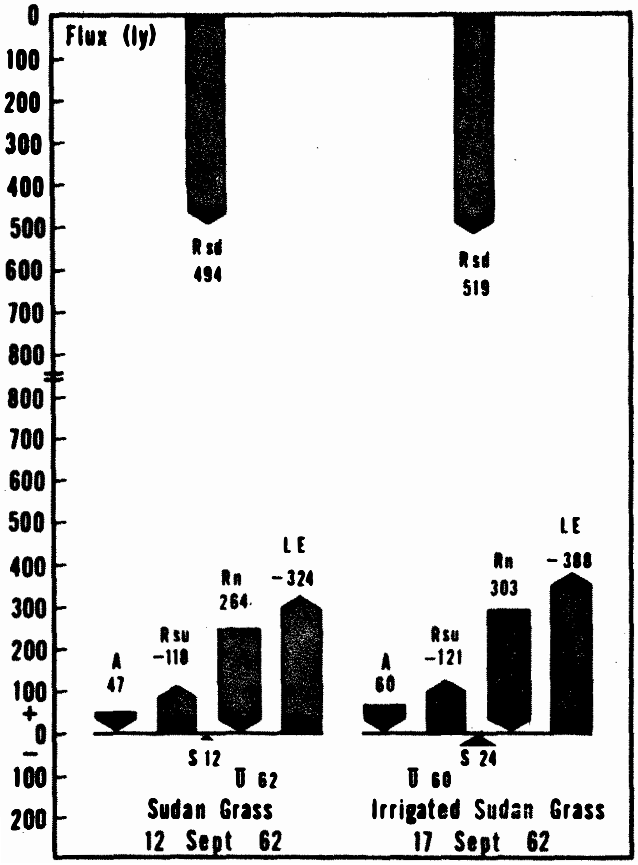


Fig. 4. Effect of irrigation upon evaporation from a sudan grass surface; Rsd, short wave radiation downward; A, sensible heat flux; Rsu, short wave radiation upward; Rn, net radiation; LE, evaporative flux; S, soil heat flux; U, wind speed.

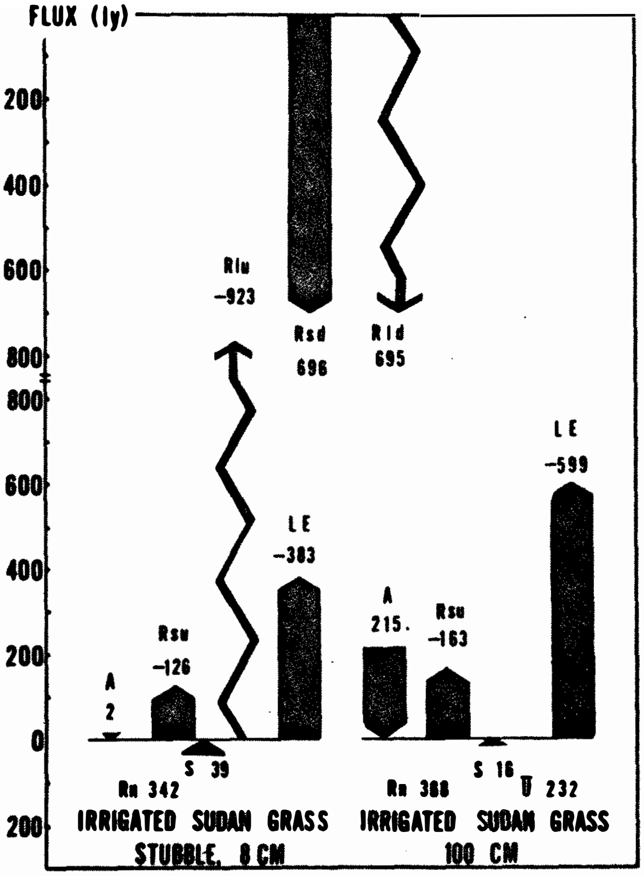


Fig. 5. Influence of surface characteristics upon the energy balance; Rlu, long wave radiation upward; Rsd, short wave radiation downward; Rld, long wave radiation downward; A, sensible heat flux; S, soil heat flux; LE, evaporative flux; Rn, net radiation; U, wind speed.

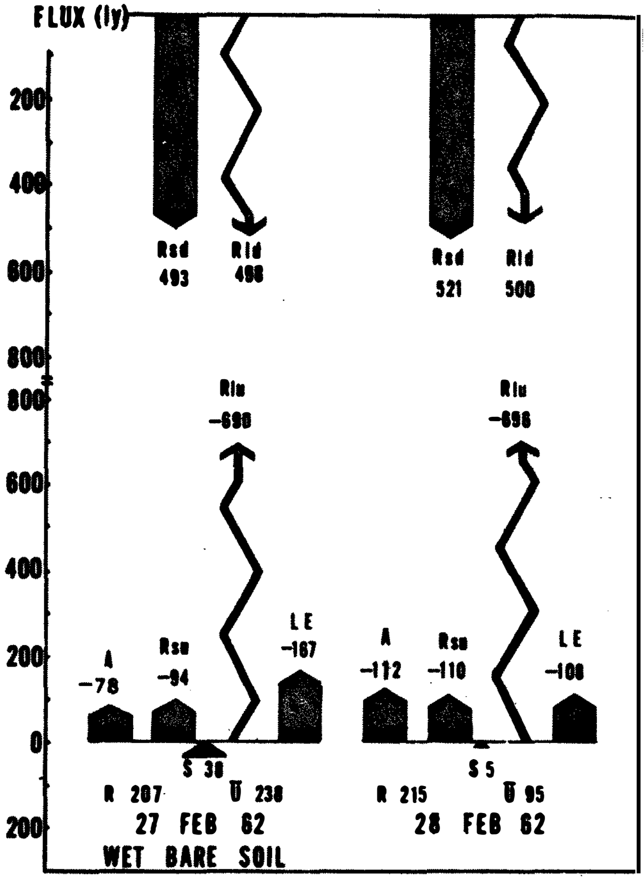


Fig. 6. Influence of wind speed upon evaporation from a wet, bare soil; Rsd, solar radiation; Rld, long wave radiation downward; Rsu, short wave radiation upward; Rlu, long wave radiation upward; Rn, net radiation; LE, evaporative flux; S, soil heat flux; A, sensible heat flux.

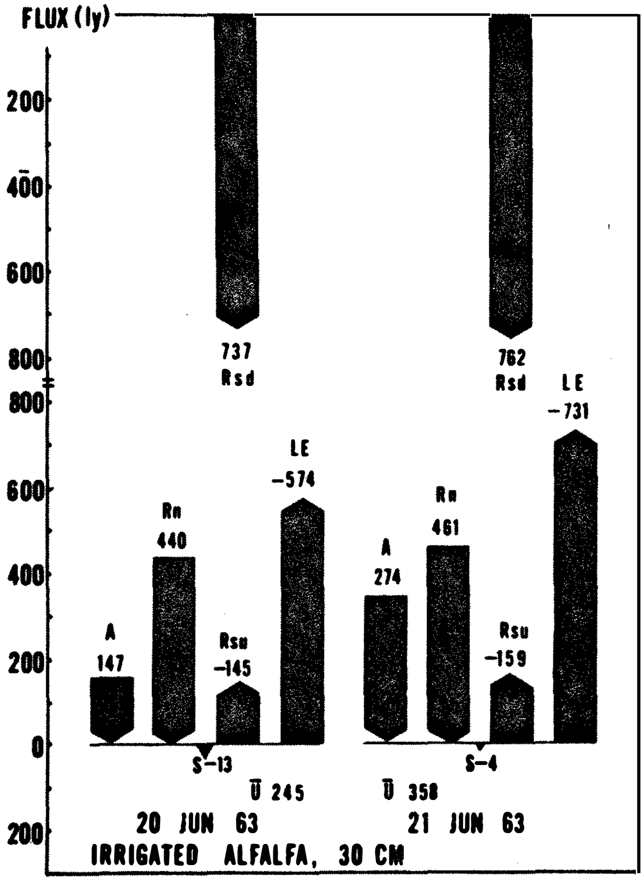


Fig. 7. Influence of wind speed upon the evaporation of irrigated alfalfa; Rn, net radiation; LE, evaporative flux; S, soil heat flux; A, sensible heat flux; Rsu, short wave radiation upward; Rsd, short wave radiation downward; U, wind speed.

The influence of wind speed upon evaporation from an irrigated alfalfa field is more dramatic because of the surface roughness. In the example, Figure 7, the alfalfa was 30 cm in height. Again, the days were quite similar with respect to solar radiation, air temperature and vapor pressure. A large difference existed in wind speeds, 245 cm sec^{-1} versus 358 cm sec^{-1}. The evaporative fluxes were 570 ly and 730 ly, respectively. Energy was obtained from the air to support this evaporative process on both days, 149 ly compared to 274 ly. Unfortunately, this type of data is not available for trees. However, an isolated tree in an arid environment could transpire a tremendous amount of water. The arid environment does not have to be in a desert, it can be on a southwest slope or on shallow soil. Hedges or windbreaks are successful in reducing the water requirement and creating a more humid environment.

The previous examples of large differences in evaporation rate or water requirements of various surfaces were due to rather small differences in wind speed or surface character. Data are not available to illustrate slope or aspect. Estimates can be calculated from incident radiation upon the surface. Contrasted to agricultural surfaces, coniferous forests are virtual deserts. Generally speaking, agricultural plants are grown on relatively level terrain having very deep soil with a large water holding capacity. On the other hand, forests generally occupy side slopes with shallow soils or rolling terrain with rocky soils, both of which have very low water holding capacity. In addition, the slope also promotes surface runoff. Therefore, the energy which could have been used to evaporate rainfall occurring on the forest goes into heating the surface and the air. The air over such a forest would be much drier than over annual agriculture crops in the same general area.

Local Winds

Another aspect of the microclimate that is very important to forestry is the local wind patterns. Local winds are initiated by differential absorption of solar radiation by surfaces. Dark surfaces absorb more energy than light surfaces. If these surfaces are not wet, then the energy is used to heat the surface and the air. The warm air rises and is replaced by air from cooler surfaces, thus establishing a convection cell. Convection cells may exist in various sizes from small scale resulting from scattered rocks among a meadow, to mountain and valleys, and to the larger scale of land versus sea. The resulting differential heating on the slopes and level terrain also promotes wind circulation. Thus, in general, there is a tendency for more wind movement over forested lands since they generally occupy slopes than over agriculture lands.

METEOROLOGICAL METHODS FOR ESTIMATION OF EVAPOTRANSPIRATION

Meteorological methods of estimation of evapotranspiration are discussed in detail in publications by the American Society of Agricultural Engineers, 1966, National Research Council of Canada, 1961, and UNESCO, 1961, among others. Therefore, only a brief review of these methods will be presented in this paper. Meteorological methods of estimation of evapotranspiration are not to be confused with the methods for estimation of potential evapotranspiration. Actual evapotranspiration is what is taking place at the time of the measurement not what could take place if water were not limiting.

The complete energy-exchange within a volume occupied by vegetation is described with the aid of Figure 8. All energy fluxes into the volume are considered to be positive. The first five terms represent the vertical fluxes, the next two terms represent the horizontal divergence of sensible and latent heat into the vegetated volume and the air space below the instrument height. The last three terms represent the storage of sensible and latent heat in the vegetated volume and in the air.

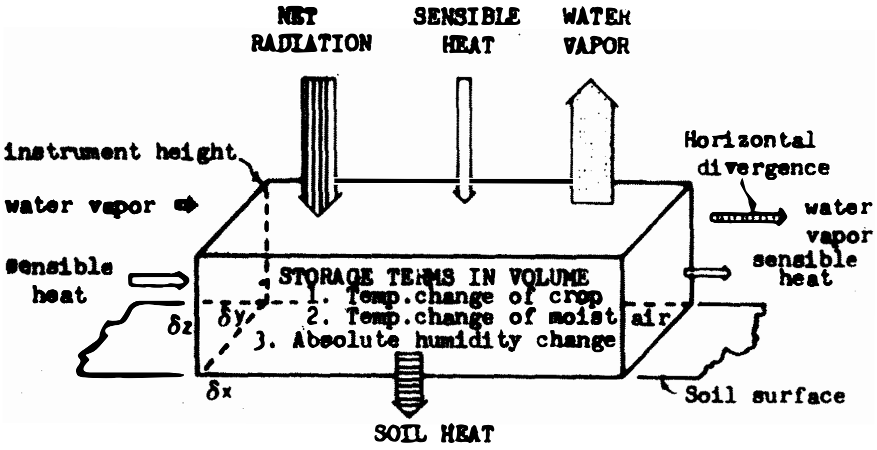
In general, the energy used in photosynthesis and stored in a vegetated volume is small compared to the other terms. For the first approximation, these terms are neglected. Furthermore, as z approaches 0, the divergence terms are eliminated reducing (5) to (6).

(See Figure 8) (5)

$$R_n + S + A + LE = 0 \tag{6}$$

Equation 6 can be evaluated over bare soil by measuring R_n, S, and LE (with a lysimeter) and solving for A. If a vegetated canopy is involved, z is not 0 and some divergence within the canopy (clothesline effect) may be present in A obtained with the lysimeter data. A large buffer area is usually provided around a lysimeter to reduce the divergence within the canopy.

Unfortunately, the flux of latent or sensible heat cannot be evaluated at the surface with meteorological models. An additional air space is required above the soil surface or canopy volume to evaluate these properties. Consequently, another zone of possible divergence is added. A larger buffer area, referred to as fetch, is required to reduce the possibility of divergence air in the air space than is required for the reduction of divergence within the canopy. This gives rise to the second assumption that the fluxes are vertical as would exist over an infinitely large area. Furthermore, the area should be homogeneous, suitable for sampling, i.e., diseased pockets, shelter woods, and roadways would not be considered suitable.



$$Rn + S + A + LE + P + \int_0^z C_p \nabla h (\rho u T)\delta z + \int_0^z \frac{L_\iota}{R} \nabla h \frac{(ue)}{T} \delta z + \int_0^z C\rho c \frac{\partial T}{\partial t}\delta z + \int_0^z C_p \rho \frac{\partial T}{\partial t} \delta z + \int_0^z \frac{L_\iota}{RT} \frac{\partial e}{\partial t} \delta z = 0 \tag{5}$$

Fig. 8. Complete energy balance of a crop volume after Tanner (1960).

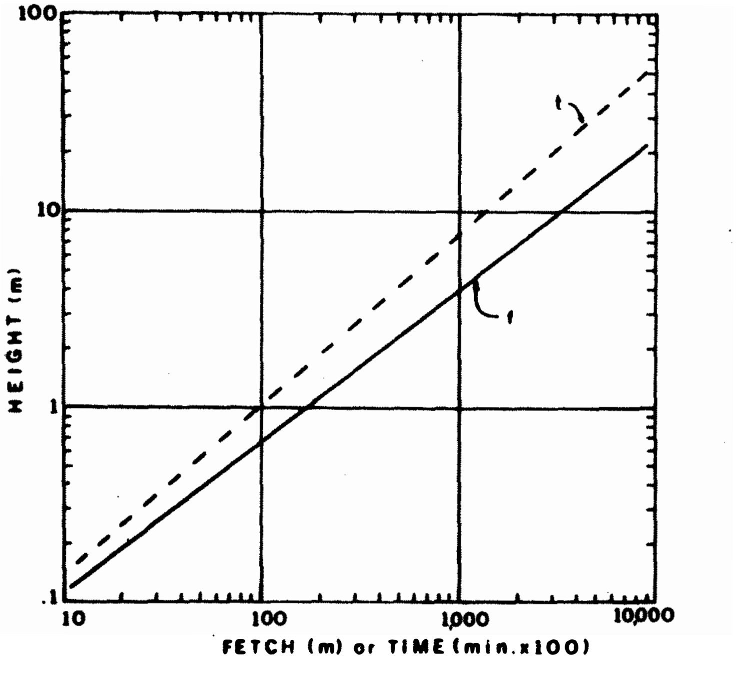


Fig. 9. Fetch and time required for 90 percent profile adjustment at various heights above the surface after Dyer (1963).

Energy Balance Method

A ratio of the similarity (3) and (4), is referred to as the Bowen ratio, (7).

$$\beta = \frac{A}{LE} = \frac{C_p p}{L\epsilon} \left[\frac{K_h}{K_w}\right]\left[\frac{\Delta T/\Delta z}{\Delta e/\Delta z}\right] \tag{7}$$

Substitution of (7) into (6) results in (8).

$$LE = \frac{-(R_n + S)}{1 + \frac{C_p p}{L\epsilon}\left[\frac{K_h}{K_w}\right]\left[\frac{\Delta T}{\Delta e}\right]} \tag{8}$$

A third assumption of equality of transfer coefficients ($K_h = K_w$) is usually employed.

The error in LE from (8) is directly proportional to the errors in $-(R_n + S)$ and indirectly related to errors in β. The error in LE caused by an error in β increases as β approaches -0.5 (i.e., half of the energy for evaporation supplied by the air mass). Equation 8 becomes indeterminate when β equals -1. β assumes large negative values over irrigated fields in arid environments, making measurements of ΔT and Δe more critical. In the morning, evening or at night when gradients are small, β cannot be determined with sufficient accuracy. Good measurements of R_n are important under all conditions, while more emphasis needs to be placed on β in arid areas than humid areas.

Aerodynamic Method

The aerodynamic method requires the use of the eddy diffusion equations 3, 4, and 9 for the vertical component of flux density of sensibility vapor and momentum. Combination of (10) and (11) results in the aerodynamic method, (12).

$$\tau = \rho K_m \left[\frac{\Delta u}{\Delta z}\right] \tag{9}$$

$$\frac{\tau}{LE} = \left[\frac{K_m}{K_w}\right] \frac{p}{L\epsilon} \left[\frac{\Delta u}{\Delta e}\right] \qquad (10)$$

$$\tau = \rho k^2 \left(\frac{u}{(\ln Z_2 + D/Z_1 + D)} \right)^2 \qquad (11)$$

$$LE = \frac{\rho L\epsilon k^2}{p} \frac{\Delta u \, \Delta e}{(\ln Z_2 + D/Z_1 + D)^2} \qquad (12)$$

Derivation of the aerodynamic equation assumes that the ratio of eddy diffusivities is constant and usually assumes that $K_h = K_w = K_m$, in addition to the basic assumptions made for the energy balance method. It is well to point out at this stage that errors in the evaporative flux are directly related to errors in the measurement of wind speed gradients, vapor pressure gradients and in the assumption that Von Karmen's constant is indeed constant (i.e., 0.4). Wind speed gradients and vapor pressure gradients are both more difficult to measure than net radiation, soil-heat flux or air temperature gradients. In addition, the determination of D requires precise wind profiles employing six to eight levels of anemometers. Equation 12 is only valid under neutral conditions. A stability parameter needs to be added for non-neutral conditions. A discussion of stability requirements is presented in American Society of Agricultural Engineers, 1966.

Eddy Correlation Method

Unlike the energy balance method and the aerodynamic method, the eddy correlation does not require the use of a similarity equation but does require the measurements of the fluctuation of vapor pressure and vertical wind speed from the mean, equation 13. The use of this equation

$$LE = \frac{L\rho\epsilon}{p} \overline{e' w'} \qquad (13)$$

assumes that the mean vertical wind speed is zero, a large uniform plane, and vertical fluxes. The main limitation of this method is that the instrumentation used is not sensitive to smaller and faster eddies, thus must be mounted 3 to 4 m above the surface. Consequently, a larger fetch is required to reduce the horizontal divergence. Furthermore, the instrumentation to date is too complicated and demanding to be used routinely.

APPLICATION OF METEOROLOGICAL METHODS TO FORESTRY

The above methods have been utilized in agriculture and have yielded valid results when the basic assumptions have been met. However, the scale in forestry is approximately 10 times greater than the scale in agriculture (Table 1). Furthermore, the vegetation is per annual rather than annual; consequently, the surface inhomogeneity becomes greater with time. The size of an individual plant in forestry is very large compared to the size of a sampling instrument; while in agriculture, they are the same order of magnitude size. For example, the average cup-diameter is approximately 20 cm, the ground projection of most agriculture plants is similar in size. On the other hand, the ground projection of a tree may be 10 m. Therefore, a standard meteorological instrument located close to an agricultural surface would tend to average out some of the surface inhomogeneity because the instrument is large with respect to irregularities while in forestry the instrument is considerably smaller than the irregularities and would tend to be influenced by them.

The stem space is much greater in forestry than in agriculture. Measurements of wind speed within the stem space suggest a greater air motion within a forest canopy than within an agriculture canopy. For example, winds of 0 to 50 cm sec^{-1} have been measured in the stem space of a cotton field, whereas winds from 1 to 2 m sec^{-1} have been measured within forest stem space (Table 1). Thus, the clothesline effect or blow-through is a much greater problem in forestry than in agriculture. This blow-through coupled with disease pockets or other inhomogenieties resulting from soil differences or cultural practices makes it difficult to apply a profile technique. Furthermore, the blow-through problem is enhanced in forestry because of forest locations with respect to mountain-valley breezes.

The fetch requirement is more severe in forestry. It is usually based upon the height of the measurement instrument above the surface. Various rules of thumb have been used for the fetch requirement, most of which result from wind tunnel studies. Elliott (1958), indicated that a maximum height, z, for suitable measurements can be found by $z = 0.86x^{0.8}\ Zo^{0.2}$ (all units in centimeters). These data were based on wind profile measurements over a runway and yield a fetch to height ratio of only 10 at z equal to 1 m. Dyer (1963), using Philip's theory, calculated the rate of profile adjustment in relation to fetch for a leading edge case and in relation to time for a horizontally uniform case. His results, extended to a 40 cm height (Table 2), suggest 53 m or a period of 20 sec is required for 90 per cent adjustment of profile and eddy fluxes. Recent data obtained by the author tend to support the fetch requirement and to suggest a time-wind dependence although the fetch requirement should apply over a wide range of wind speeds. Much larger fetch and time are required for profile adjustments when greater sampling heights are used. For example, 420 m or 132 sec is required for a 2 m height (Fig. 8). In addition to these fetch requirements,

Table 1. A comparison of selected agricultural crops and forests.

Vegetation	Deciduous coastal forest[1]	Deciduous northern forest[2]	Douglas-fir forest	Cotton[3]	Corn[4]
Plants/acre	264	673	1,250	--	29,000
Basal area					
(m/ha)	31.4	32.3	34.4		36.2*
(sq ft /acre)	137	141	150		158*
LAI**	1.8	--	9-10***	3.7	4.48
Average DBH(cm)	15.2	15.7	12.7		2.5*
Canopy height					
(m)	32	17	25	1.2	2.8
Zo(cm)	16	--	--	9	15
D (m)	29	--		0.6	1.4
D + Zo	29.2	15		0.7	1.6
U stem/U top	.13	.22	.27	.5	.15

[1] Shinn, 1969.
[2] Tourin and Shen, 1969.
[3] Fritschen, 1966.
[4] Lemon and Wright, 1967.
*Assumed stem diameter
**Leaf area index
***Needle surface area

Table 2. Fetch, fetch-to-height ratio, and time required for percentage of profile adjustment for a 40-cm height.

Per cent adjustment	Fetch, m	Fetch per 40 cm	Time, sec
90	53.0	132	20.0
80	25.5	64	10.6
70	15.5	39	6.6
60	10.2	26	4.1
50	7.0	17	2.9
40	4.9	12	2.0
30	3.8	10	1.5
20	2.8	7	1.1
10	1.0	2	0.8

the measurement site should be downwind at least 8 times the height of the highest obstacle.

The minimum sensor-height of 5 times the surface roughness used for wind profiles (Tanner, 1963) is not applied to temperature and vapor pressure when spacial sampling is utilized. The largest gradients generally occur within the first few centimeters of the surface. Hence, the bottom sensor should be located as close to the surface as possible. Another factor favoring measurement close to the surfaces is that the assumption of $K_h = K_w$ appears to be valid close to the surface where buoyancy effects are less pronounced.

With the relationship for surface roughness (equation 14) developed by Tanner and Pelton (1960), a 30 cm vegetation canopy would have a surface roughness of 3 to 4 mm.

$$\log Zo = -1.385 + 1.417 \log h \qquad (14)$$

Thus, the minimum instrument-height would be 15 to 20 mm above the surface. If a 30 m vegetation is considered, the roughness length would be approximately 3 m; thus, the minimum instrument height should be 15 m above the surface. From Figure 9, a 15-m instrument would require fetch of 5,000 m.

After considering the scale factors, the possibility of plumes of vertical fluxes, terrain, aerodynamic roughness, and fetch requirements, the energy balance method appears to be the most feasible method to use in forestry. However, the instrumentation requirements preclude frequent replication with extensive horizontal sampling. As a compromise, I would like to suggest a combination method (equation 15) which requires a measurement of net radiation and determination of

$$LE = Rn - \rho cp\ \overline{T'w'} \qquad (15)$$

sensible heat by the eddy correlations techniques (Dyer, et al., 1967). The instrumentation for this approach would be simpler than for the other methods and could be replicated more frequently. Instruments could be placed in diseased pockets, on top of the crowns, etc. to determine the horizontal variability. This method could be further refined with additional measurements of soil heat flow and energy storage in the vegetative material.

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APPENDIX

Definition of Terms

Symbol	Unit	Definition
A	cal $cm^{-2}min^{-1}$	Sensible heat flux
C_p	cal g^{-1} °C^{-1}	Specific heat of dry air at constant temperature
D	cm	Data displacement level
E	--	Emissivity
K_h	cm^2min^{-1}	Eddy diffusivity for heat
K_m	cm^2min^{-1}	Eddy diffusivity for momentum
K_w	cm^2min^{-1}	Eddy diffusivity for water vapor
L	cal g^{-1}	Latent heat of vaporization
LE	cal $cm^{-2}min^{-1}$	Evaporative flux obtained with weighing lysimeters
P	cal $cm^{-2}min^{-1}$	Net photosynthesis energy
W	cal $cm^{-2}min^{-1}$	Water heat flux
R	cal $cm^{-2}min^{-1}$	Radiation
R_n	cal $cm^{-2}min^{-1}$	Net radiation
S	cal $cm^{-2}min^{-1}$	Soil heat flux
T	°C or °K	Temperature
W	cal $cm^{-2}min^{-1}$	Water energy storage
e	mb	Vapor pressure of the air
w	cm sec^{-1}	Vertical wind speed
k	--	Von Karman's constant
p	mb	Atmospheric pressure
t	min	Time
u	m sec^{-1}	Wind speed

w	cm sec^{-1}	Vertical wind speed
z	cm	Height above the surface
Zo	cm	Roughness length
β	$cm^2 min^{-1}$	Bowen ratio
ε	--	Ratio of mole weight of water vapor to dry air
ρ	g cm^{-3}	Density of air
ρ_c	g cm^{-3}	Density of crop volume
∇_h	cm^{-1}	$\partial/\partial x + \partial/\partial y$
λ	cal $cm^{-1} min^{-1} {}^{\circ}C^{-1}$	Thermal conductivity

A SUMMARY AND EVALUATION OF AN ENERGY BUDGET STUDY OF EVAPOTRANSPIRATION AT MARMOT CREEK

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ABSTRACT

After a brief discussion of energy-budget theory, an experiment to calculate evapotranspiration by this method above the canopy at Marmot Creek in 1967 is summarized and the reliability of the results discussed. A dependence of Bowen's ratio on wind direction and sky condition was found. A procedure for obtaining a basin estimate of evapotranspiration is outlined.

INTRODUCTION

Evapotranspiration in the forest environment is one of the larger terms of the Palmen water-balance equation, but unfortunately it is practically impossible to measure it directly, so it must be calculated by indirect means. As the hydrometeorologist on the Alberta Watershed Research Program, I intend to calculate it for Marmot Creek by as many means as possible in the hope that a consensus of values will be close to the truth. An attempt to calculate it in 1965 by the eddy-correlation technique failed because of problems in space averaging (McBean,1968). In 1967 the energy budget method was attempted. A complete account of the procedure and results is being published elsewhere. This paper summarizes that study and evaluates the results.

THEORY

The machine that transforms and transports liquid water from the soil into water vapour in the air is driven by solar energy. If we can measure this energy and calculate the efficiency of the machine we can therefore calculate the amount of water it will move. The energy is best measured by a net radiometer to avoid albedo problems. The efficiency of the machine is determined by the energy-budget technique.

The energy received from the sun is used for heating the air, evapotranspiration, heating the ground and vegetation, and photosynthesis. This can be expressed as: $Q_n = Q_h + Q_e + Q_g$* + photosynthesis. Photosynthesis uses an insignificant amount of Q_n (1 - 3% according to Denmead, 1964) so is usually ignored. Baumgartner (1956) in Germany and Rauner (1958)

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* See Appendix for list of symbols.

in the U.S.S.R. found that Q_g amounts on the average to 14% of Q_n on sunny days not preceded by rain, 17% on sunny days after a rain, and 15.5% for other sky conditions. To partition Q_n between Q_h and Q_e, we use the Bowen concept: $R = Q_h/Q_e$.

Following the mathematics of Munn (1966): $Q_h = \rho C_p K_h \frac{\partial \theta}{\partial z}$ and $Q_e = 0.622 \rho L/P \; K_e \frac{\partial e}{\partial z}$ sc $R = \frac{0.64\ P}{1{,}000} \; \frac{K_h}{K_e} \; \frac{T_2 - T_1}{e_2 - e_1}$

The assumption is usually made that $\frac{K_h}{K_e} = 1$ and recent studies in Australia have demonstrated that this is true for a relatively dry and haze-free atmosphere. We can therefore calculate R by measuring the gradients of temperature and vapour pressure above the evaporating surface. Assuming the pressure at Marmot Creek tower (5,900 feet MSL) to be 820 mbs,

$R = 0.28 \frac{T_2 - T_1}{e_2 - e_1}$ with T in °F and e in millibars.

Once R is known, the amount of evaporation is calculated from: $ET = \frac{Q_n - Q_g}{L\ (1 + R)}$ and it can be seen that relatively large errors in calculating R will produce relatively small errors in the estimate of ET. For instance, if true R is 0.50 and we calculate 0.25 it makes a difference of 16% in the estimate of ET. As long as R is less than 1, errors of 100% in the estimates of it will still produce good ball-park estimates of ET. Also, it is seen from the equation for R that it will be large when the vapour pressure gradient is small, and in this case ET will also be small. So the procedure is most accurate when the evaporation rates are highest.

The assumptions in the theory are:

1. There is no flux or radiative divergence.
2. The gradients of temperature and vapour pressure are measured below the boundary layer.

Comparing results obtained by this method with those from lysimeters in irrigated plots, Tanner (1960) found good agreement in a humid area, and Fritschen (1965) obtained good agreement in an arid area. Pruitt (1963) also found good agreement except when there was advection or during periods of strong instability when the Bowen-ratio method overestimated ET by 50 - 100%.

MARMOT CREEK STUDY 1967 EQUIPMENT AND PROCEDURE

In July 1967, we conducted an intensive study to calculate ET for the lower portion of Marmot Creek Basin. On a 150-ft mast about 50 yards upstream from the Twin Creek weir, an anemometer measured wind velocity, a CSIRO net radiometer measured Q_n, and two sets of wet and dry Rosemount platinum-resistance-bulbs (protected by aspirated cylindrical shields) measured temperature and humidity gradients in the 30-ft layer above the spruce canopy. The resistance bulbs were calibrated in the laboratory, before and after the study, attached to the same recorder by the same cables and also were checked weekly during the study with four fixed resistances. The average wander from calibration was less than 0.1°F and was always in the same direction so the bulbs retained their calibration within the expected limits of accuracy. Radiation data were recorded continuously, while temperature and humidity data were recorded every ten minutes. This package produced some very interesting data over a 3-week period.

We also attempted to measure the areal variation in R using similar equipment above the pine canopy on a lighter mast at three sites in the confluence area. This phase gave good data on the variations in radiation and temperature in this area but the humidity data were very unreliable because of vibrations in the tower shaking the water out of the wet bulb reservoirs. So nothing was learned about areal variations in R.

RESULTS

The data from the 150-ft tower, however, gave some interesting clues to variations in R with weather conditions and this is probably the most significant part of the study. Other studies have shown that Bowen's ratio varies with soil moisture, but this study found a variation with wind direction and sky condition when soil moisture was not a limiting factor. The daily data are listed in Table 1 and the variation with weather in Table 2. On days with downslope winds, steep vapour-pressure gradients resulting in the very low R values were noted. It is theorized these gradients were created by subsidence at the upper-sensor level while the air at the lower-sensor level was kept moist by evapotranspiration. Conversely, upslope winds bring moist air from the lower valley above the canopy and reduce the vapour-pressure gradient and increase R. On three sunny days with west winds, the mean R was 0.06, much lower than the usual daytime values. It illustrates both the danger of transposing data of coefficients from other regions with different climatic conditions and also the likelihood of high evaporation-losses during chinook winds.

RELIABILITY OF RESULTS

1. Baumgartner (1956) found mean daytime values of R of 0.52 over a young spruce forest in Germany during a period of sunny, dry weather. This is only slightly higher than the Marmot data which include the very-low-value days with west winds.

Table 1. Marmot Creek. Energy Budget Data 0700 - 1900 hrs, July 8 - 26, 1967.

Date	R	Q_n langleys	Sky Condition	Rainfall mm	Wind m/sec	Q_h langleys	Q_e langleys	e mm	Pan Evaporation mm
July 8	0.18	298.3	Cloudy	7.35	NE/M	39.0	214.3	3.6	1.8
July 9	0.07	425.9	Sunny		W/3.2	22.2	335.7	5.6	3.3
July 10	0.07	577.9	Clear		NW/3.2	40.1	455.8	7.6	6.4
July 11	0.04	575.7	Clear		W/2.6	21.3	475.4	7.9	6.6
July 12	0.05	525.0	Clear		W/3.2	22.3	422.7	7.0	6.6
July 13	0.76	437.2	Cloudy	0.51	SW/3.3	164.4	216.8	3.6	5.3
July 14	0.54	559.7	Sunny		SW/3.0	167.5	312.2	5.3	6.6
July 15	1.21	532.7	Sunny		SE/3.3	256.0	211.1	3.5	6.4
July 16	0.28	564.1	Sunny	1.27	SE/2.7	106.5	377.4	6.3	7.1
July 17	0.06	325.9	Cloudy	6.10	NE*/2.0	15.3	264.6	4.4	9.6
July 18	0.16	552.4	Sunny		S/3.2	65.4	402.0	6.8	6.6
July 19	0.33	348.1	Cloudy		W*/2.7	72.7	220.4	3.7	4.3
July 20	0.93	289.2	Cloudy	10.14	E*/2.3	124.3	134.2	2.2	3.0
July 21	0.99	255.1	Overcast	1.29	SW*/3.1	134.8	91.8	1.5	3.6
July 22	0.68	552.5	Sunny		*/3.4	195.9	269.3	4.6	6.9
July 23	0.82	562.8	Sunny		SW*/3.0	221.0	266.8	4.5	6.9
July 24	0.71	516.9	Sunny		*/4.2	185.8	259.6	4.4	5.6
July 25	0.55	553.6	Sunny		SE/3.5	172.0	314.6	5.2	5.6
July 26	2.11	406.0	Cloudy		SE/3.6	239.3	115.7	1.9	4.6
Total				26.7				89.3	106.8
Mean	0.42	465.7				119.3	282.1	4.7	5.6

* Wind Direction Variable

Table 2. Mean daytime Bowen Ratio by wind direction and weather condition

Weather condition	Downslope wind	Upslope wind
Cloudy	0.49	0.86
Sunny after rain	0.24	0.47
Sunny not after rain	0.19	0.78

2. The calculated evapotranspiration loss is 83% of the pan loss for the period. If pan evaporation is considered an index of potential evapotranspiration, then the calculated values are practically textbook examples. The daily correlation between computed ET and pan observations, however, is very poor.

3. The calculated ET loss of 89.3 mm is 62 mm greater than the 26.7 mm of rain in the period. This 62 mm must be taken from soil moisture or groundwater storage. The loss in soil moisture at a nearby site amounted to 30 mm, (R. L. Harlan, unpublished data), so 32 mm must have either been removed from groundwater or it represents the net error of all the measurements. Unfortunately, no groundwater wells were in operation in 1967 in this part of the basin to check the groundwater loss.

4. Assuming that evapotranspiration in July would be near the maximum rate for the year, an extrapolation produces an estimated 1967 evapotranspiration for this point of about 22 inches. Assuming further (and with less justification) that this point is representative of the whole basin, this would be 4 inches higher than the average annual evapotranspiration calculated by the water balance method (Ferguson and Storr, 1969). Since July 1967 was much warmer than normal, it would be expected that evapotranspiration would be above average, and the estimated evapotranspiration is, therefore, not unreasonable.

FUTURE PLANS

It must be stressed that the daily estimates of evapotranspiration in Table 1 are for a single point in the basin and should not be assumed to be representative of the whole basin. To obtain a basin estimate of ET requires two further steps. First, a map of net radiation for the basin is needed. It is hoped that this would be obtained from a study of the variation in the components of net radiation in the basin and a comparison with the maps of direct solar clear-sky radiation prepared by Ferguson et al. (1968). Secondly, the areal variations, if any, in Bowen's ratio must be determined.

If these two steps could be completed before the cutting program begins, it would be very interesting to then repeat the procedure to determine the effect of the vegetation change on evapotranspiration.

APPENDIX

List of Symbols

ET = Evapotranspiration
Q_n = Net all-wave radiation
Q_e = Latent heat flux
Q_h = Sensible heat flux to air
z = Vertical distance
L = Latent heat of evaporation
P = Atmospheric pressure
e = Vapour pressure of air

Q_g = Vertical heat flux to ground and vegetation

ρ = Density of air

C_p = Specific heat at constant pressure

K_h = Thermal diffusivity

K_e = Water vapour diffusivity

T = Air temperature

θ = Potential temperature

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THE TREE AS A DYNAMIC SYSTEM IN FOREST-WATER RESOURCE RESEARCH

By

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INTRODUCTION

The unit of manipulation in the management of forests for any purpose is the individual tree. It stands in place from the time it first takes root as a seedling, having no means of self locomotion. However it is not static. There are some seasonal changes that are apparent. As a tree grows, its volume increases as does its surface area. In deciduous trees, the loss of the leaves in the fall is a decrease in surface area. Most would not consider a tree static during this period. Other changes are not so obvious.

The water content of a tree is an important parameter as it affects the sensible-heat regime of a stand. Seasonal variation may exist; it reportedly reaches a high in early spring and declines in fall. Daily changes may also occur; their magnitude has been reported equal to that occurring over a season.

The importance of any change in a physical property depends upon the use to which the data is put and the time scale with which one works. A slow decrease in stem water volume occurring throughout a year is not important in the daily energy balance. It might be important on a seasonal basis.

Transpiration rate of a tree is also an important dynamic parameter. The rate is not simply a "slave" to the vapor pressure gradient nor solar radiation input. The volume of water vaporized in any given time period is a function of the surrounding atmosphere, the soil environment and the degree of stomatal opening. This last is controlled both physically and physiologically. Estimates of transpiration from atmospheric or soil data only will quite likely be in error because of this interdependence.

This paper illustrates by two examples that the tree response to the external environment cannot be predicted from wholly external measurements. How one measures living-wood moisture content is highly influenced by internal-moisture stress, as is the amount of transpiration.

TREE WATER CONTENT

The usual method of measuring tree water content is to remove a wood sample and determine its moisture content by gravimetric means. This method has several variations in technique ranging from removing the samples as increment cores to sectioning an entire tree into small blocks or discs.

Water content patterns in conifers obtained by any of these methods show universal similarity. Water is most plentiful in the spring, declines throughout the summer and fall, and increases during the winter. A daily pattern shows the highest water content early in the morning before sunrise with a low near sunset. Both of these can exhibit highs differing by 20% or more in volume from the low. Is this change real?

The method of obtaining a sample for determining the water content may have more effect on the result than any actual variation. McDermott (1941) showed that the moisture content of excised twigs with both ends severed simultaneously was significantly higher than that of twigs where one end was severed prior to the other.[1] The difference between the two methods was attributed to a withdrawal of water from the excised section by the portion of the tree still attached. That is, unless both ends of a water column were severed simultaneously, the amount of water trapped in the excised section was less than that present while the section was intact with the plant.

This should not be difficult to understand. As water is lost from the stomata, a water deficit is created in the leaves. This deficit must be relieved by a transfer of water from the soil through the trees conducting system. If water is unavailable at the soil-root interface in sufficient quantity or of proper chemical quality to replace that lost, then tension is created that is present throughout the entire water conducting system. If a portion of the tree is removed, the tension reduces to zero at the cut surface. Thus water moves from the cut surface toward the root or leaf, depending upon which one the portion is still attached to.

A common instrument for obtaining wood samples from the stem of trees is an increment borer. This device is screwed into a stem by hand. As it penetrates, it cuts a cylindrical core that can be removed and submitted to various analyses. As the size of the core is usually small, less than 0.25 inch in diameter, one would think that the sampling method is quite unlike that for twigs; that both ends of the water-conducting elements would be severed simultaneously, or nearly so, so that any water withdrawal into the intact stem would be insignificant. However there are reasons why this might not be so.

The wood of standing trees is rarely straight grained. Some trees show a spiral pattern - either right or left. As an increment borer advances into xylem tissue, it cuts across the wood grain. If a cut is made perpendicular to the tracheid elements, then no water should escape the core. If not, then a bored core should have less water entrapped than that which was actually present before excision.

An increment borer advances into the wood quite fast. Therefore the water in a tracheid element must move through a finite distance in a very short time interval to be lost from an increment boring. The quicker a core is cut free from the remaining tissue, the less the water that should be lost.

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[1] J. J. McDermott, Amer. J. Bot. 28: 506 (1941).

An increment hammer takes a core similar to that of a borer but the cut is made by a hammer blow, which is almost instantaneous. This rapid severing of the tracheid elements should result in a better sample than that taken with a borer. It may still not be the correct or true value.

A comparison was made between the moisture content of bored versus hammered increment cores during the spring and summer of 1969. Approximately 400 trees (lodgepole pine: 5 - 10" d.b.h.) were sampled - 100 monthly from May to August. A bored core and a hammered core were removed from near the same point on a tree once every two hours throughout a diurnal cycle. Only the water content of the outer layer of xylem could be compared as the hammered core was only 2 cm long.

The bored cores contained much less water than those hammered. At no time - neither day nor night, May to August - were the two moisture contents the same. These results are shown graphically in Figure 1.

An attempt was made to quantify a prediction of the degree of departure by examining the data for its possible correlation with internal water tension as measured with pressure bomb apparatus (Scholander, _et al._[2]). The difference was slightly higher at tensions near 220 psig than at tensions below 150 psig. Also, there was more scatter in the data at lower tensions. However, there was insufficient correlation between the two parameters to allow the departure from hammered increment moisture values to be predicted from a knowledge of the bored value and the moisture tension. Rather, the data indicated that at any stress, the departure is consistent and in the neighborhood of 40 to 50%, dry weight basis. These data are shown in Figure 2.

TRANSPIRATION RATE

The role of the tree in transpiration is controversial. Some claim that it is simply a passive link between the soil water and atmosphere, responding only to the external environment and unable to control or limit the rate of water movement through it, i.e., a pipe. Others take an entirely opposite view. They maintain that the tree, because it is alive, has some property enabling it to completely control its interaction with the atmosphere, and that it should therefore not be considered nor studied as a physical system, but as a vital system.

Most of us do not take either extreme. Neither is it my purpose to pursue either course here. Suffice it to say that there are times when the tree does act as a simple pipe - and others when it does not. Forest meteorologists and climatologists, should be aware of this. Otherwise judgements and conclusions based on either premise will be found to err significantly at times.

To illustrate: transpiration decreases as internal water tension increases. Figure 3 shows the daily transpiration quantity of an isolated

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[2] P. F. Scholander, H. T. Hammel, E. D. Bradstreet and E. A. Hemmingsen, Science 148: 339 (1965).

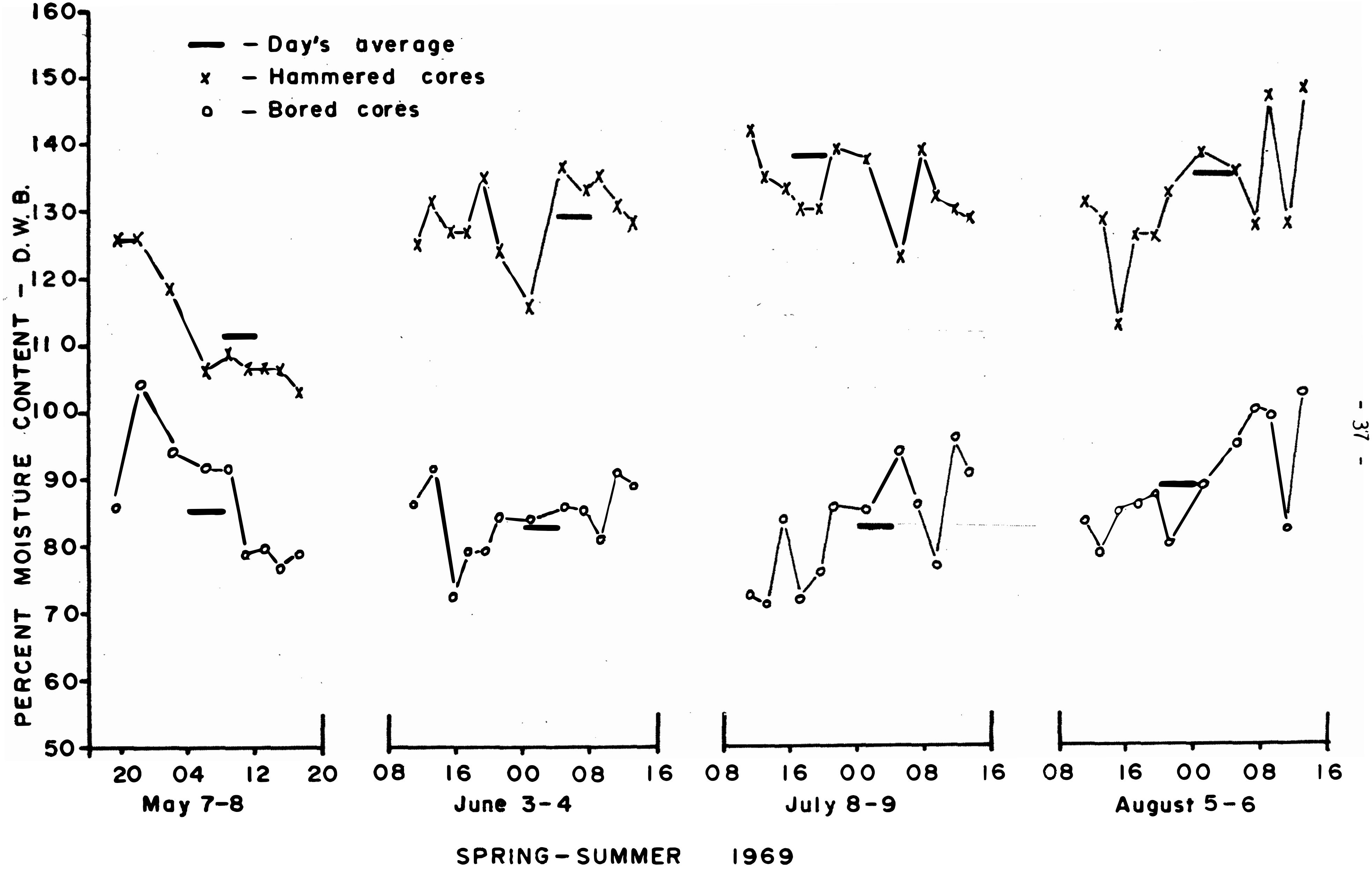

Fig. 1. Diurnal values of the water content of bored and hammered increment cores at four measurement intervals.

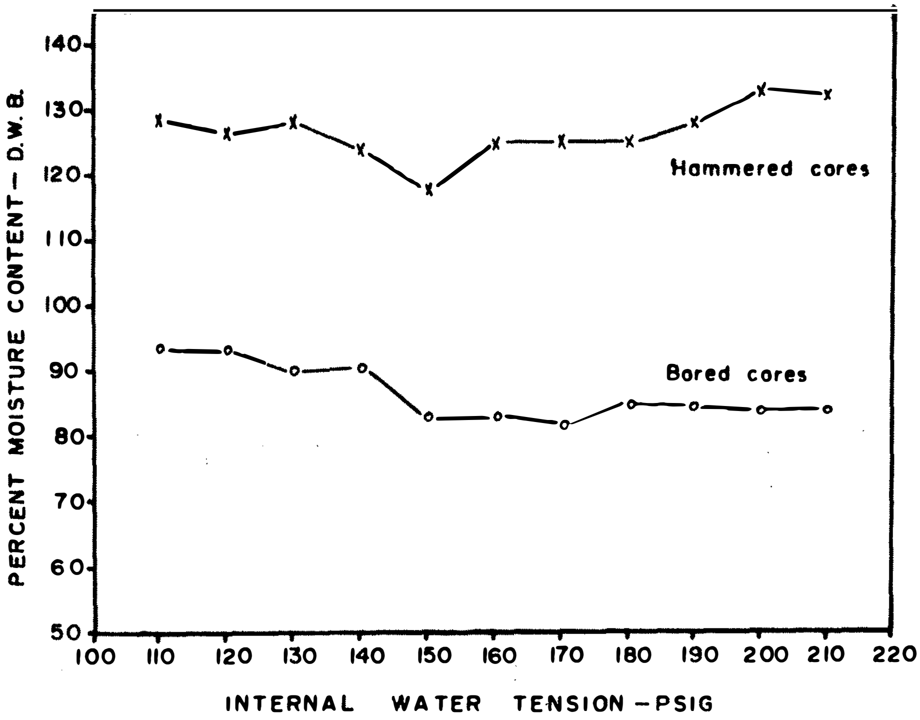

Fig. 2. The water content of bored and hammered increment cores grouped by 10 lb tension classes (at time of excision).

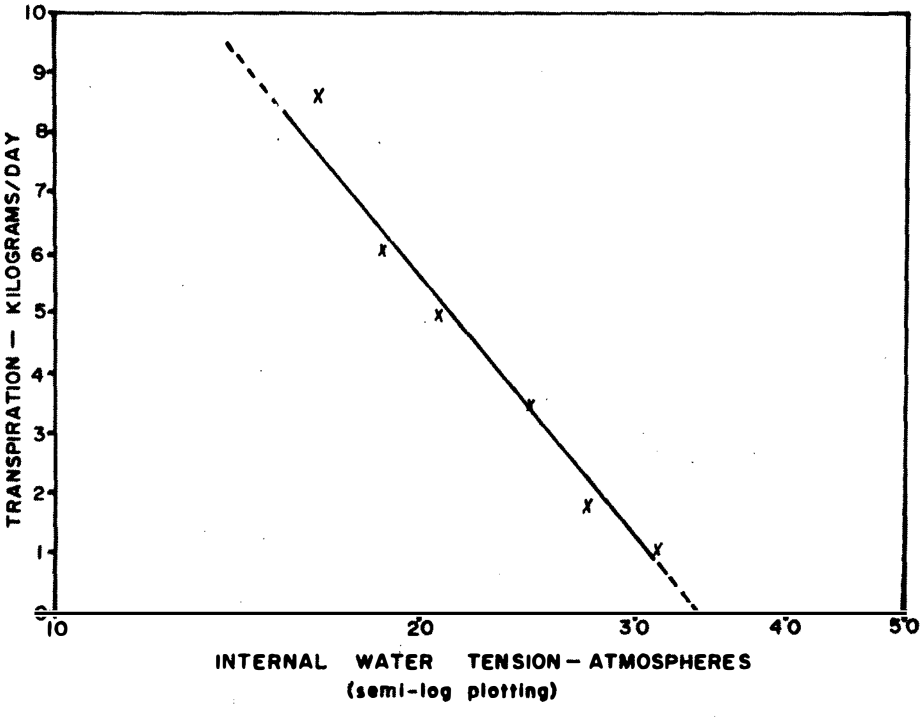

Fig. 3. Transpiration of an Aleppo pine as a function of internal water stress.

(potted) Aleppo pine tree versus the internal water tension. The amount of solar radiation received, the wind patterns, and the vapor-pressure deficit were all reasonably constant during the measurement period.

This tree represents an isolated system. Measurements were not made of the horizontal exchanges between this single tree "system" and its surroundings. But when is an area sufficiently large and homogeneous so that single or multiple point measurements made within it describe or represent the system in total?

DISCUSSION AND CONCLUSIONS

When is a tree reacting solely to its environment and when is it not. This question cannot be answered by environmental measurements alone. The tree itself should be used as an indicator.

Water content may or may not show daily or seasonal fluctuations. The fact that the water columns within the xylem are often under tension makes doubtful some of the past work on this subject. New methods - either taking such tension into account, or capable of being applied non-destructively external to the tree - are needed in order to answer this question. It appears that hammered increment cores are a better sample of water content than those taken with a borer; however the former may still not yield the correct value.

Transpiration cannot be considered to proceed at potential rate simply because the climatic parameters are favorable. There is apparently an upper limit to how much stress a tree can be subjected to before it desiccates owing to non-availability of water. In the example shown, this level was approximately 35 atmospheres. Species difference may exist. Tension measurements in mesquite of 80 to 100 atmospheres are not uncommon. I have not seen tensions higher than 16 atmospheres in lodgepole pine. (However neither has one been subjected to the harsh treatment the Aleppo pine received.) Suffice it to say, internal water tension is an easily measured parameter that should be included as an indicator of the plant's reaction to the environment whenever evapo-transpiration is estimated by mass or energy exchange relationships.

RELATIVE TURGIDITY DURING DROUGHT STRESS PERIODS OF SHORT DURATION IN NATURAL SEEDLINGS OF SITKA SPRUCE

By

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ABSTRACT

During a study of natural regeneration of Sitka spruce (Picea sitchensis (Bong.) Carr.) in South Scotland, relative turgidity or relative water content, was used to determine the role of drought on wet peaty forest sites. Aphid attack on 4-6-year-old seedlings, aggravated by drought in 1967, led to a laboratory study to determine limiting levels of cell water content. Whole seedlings were used, clipped at the root collar and placed in saturation chambers. Weekly field sampling for R.T. on wet sites was carried out throughout the 1968 growing season. On two dates, R.T. approached assumed critical levels as determined in the laboratory drydown study. Germinants were less able to avoid drying out than established seedlings.

INTRODUCTION

An investigation of the early survival and growth of natural Sitka spruce (Picea sitchensis (Bong.) Carr.) seedlings on peatlands in South Scotland was begun in 1967. Examination of 2 - to 6-year-old seedlings established in small 1/10-acre clearcut gaps at the forest of Ae showed that rooting was limited to the upper 4 inches of the organic soil horizons and mainly to litter from the 40-year-old spruce overwood. The roots did not penetrate the poorly aerated underlying Molinia peat.

The growing season of 1967 included dry spells of up to 14 days despite a mean annual rainfall of over 55 inches and mean month rain-day values of more than 55%. Drought-stress symptoms and especially attack by the aphid Elatobium abietinum Walker appeared among the younger seedlings. It became apparent that an assessment of drought stress in seedlings even on these very wet sites was required to evaluate this source of mortality. A method was sought that would enable an assessment, regularly during the growing season, of the three sites and soil types which were being compared.

Drought Stress

Relative turgidity of plant tissue is a measure of the cell water content. It is determined by weighing fresh material which is then allowed to reach full turgidity in an enclosed saturation vessel, and reweighed. After oven drying to constant weight, the relative turgidity is calculated from the formula

$$RT = \frac{\text{Fresh weight - oven dry weight}}{\text{Saturated weight - oven dry weight}} \times 100$$

(Clausen and Kozlowski, 1965).

Water deficiency of the tissues is thus compared with the fully saturated state. Kramer (1959) points out that this assumes that the fully turgid state is optimal and desirable, but a simple measure of cell-moisture lack for a given set of conditions is provided by this method. Low levels of relative turgidity are recorded at both ends of the soil-moisture scale and Bannister (1964) shows a relative-turgidity response in heath plants to waterlogging as well as to drying-out. Weatherley (1950, 1951) and Barrs and Weatherley (1962) present the technique in perspective with cotton leaf discs floated in water in the saturation chamber. They emphasize the effects of experimental technique on the results achieved and enumerate certain potential errors.

The material when first weighed should be fresh, and the saturation period should be as short as possible to prevent cell injection with moisture, and a constant temperature, about 20°C, should be maintained. However, the technique, if carefully used, is simple and repeatable, and gives consistent results.

The relation of this measure of moisture stress to soil-moisture tension has been the subject of several studies. Rutter and Sands (1956) used tensiometers and gravimetric samples to relate soil moisture tension to needle turgidity in Scots pine. They outline an important diurnal variation with a minimum around 1100 and 1500 hours. Highest point, they report, was sunrise, when the leaf turgor was in equilibrium with the soil moisture content. Slatyer and Barrs (1965) report that despite the variations in results because of technique:

> "It [R.T.] has proved to be a quantitative and valuable index of internal plant water deficits, except under conditions of only slight deficit where it has been found relatively insensitive."

Because of drought mortality recorded in the 1967 regeneration tally by the Forestry Commission Research Branch and the obvious aphid infestation after a June droughty period, it was worthwhile to adopt some measure of drought stress for the Sitka spruce seedlings under study. Since it has equal application to waterlogged as to droughty conditions, relative turgidity (R.T.) or cell water content, was selected for these peaty sites.

METHODS AND RESULTS

A laboratory study determined R.T. levels for potted seedlings dried-down to permanent wilting, and sampling in the natural seedling population throughout the 1968 growing season determined whether lethal levels were approached at any time on the hill peat sites. A standard technique was developed for all studies:-

Between 1100 hours and noon, sample seedlings were clipped at the root collar and weighed as soon as possible. In the field, with bagged seedlings, this was completed within 6 hours; in the laboratory it was done within 1 hour. The seedlings were then saturated in a plastic loaf pan with a close-fitting clear plastic lid. The cut stem ends were pushed into a 3/4-inch bed of clean coarse sand flooded with distilled water, with the seedlings remaining upright (Fig. 1).

These were placed in an incubator at 21°C for 30 hours. A pilot study of water uptake showed that there was little weight gained after this period. The saturated seedlings were then blotted surface-dry with tissue paper, reweighed, and oven-dried to a constant weight at 110°C. Needles of two age classes as well as whole seedlings were sampled and resulting R.T. levels appear in Table 1. The whole-seedling values are not significantly higher than needles ($p \leq 0.05$).

Table 1. Relative Turgidity test levels for needles and whole seedlings.

Sample	Current needles	Last year's needles	Whole seedlings
1	92.2	98.2	96.4
2	92.6	91.4	92.3
3	86.1	91.2	97.5
4	90.5	89.7	92.6
5	80.3	84.8	91.0
6	84.6	91.3	94.2
$\bar{X}$	87.7	91.1	94.0

It was felt that a whole seedling provided a more reliable estimate of water stress than levels in needles alone. In the saturation chambers, the seedling also had to make use of a more natural water transport system than a cut needle or leaf disc. Another interesting whole-seedling technique was used by Pierpoint (1967) who placed the clipped seedling in a pressure vessel and recorded pressure at which cell sap just oozed out of the cut end which was held in a soft rubber collar and exposed to the atmosphere.

Laboratory Study

Five hundred 2-year-old Sitka spruce seedlings were supplied from spaced seedbeds at Bush nursery by the Forestry Commission Research Branch. They were transplanted in November to plastic trays filled with John Innes number 2 compost and stored in a cold-frame greenhouse till required on January 23rd when they were placed in a light cabinet in the laboratory (Fig. 2). The light schedule for the cabinet was 1000 ft-c at the tray surfaces, with an 18-hours-light-6-hours-dark cycle. Water was added every second day to a photographic developing tray containing eight trays of ten seedlings each. The rate was 450 ml water to each tray after starting at field capacity. Seedlings flushed on January 29. A preliminary trial in November and December had indicated that a 14-day drydown period would be sufficient to reach the moisture content retained at 15 atmospheres by the John Innes compound (12.1% by wt). The moisture content had been reduced to 11.6% at 15 days

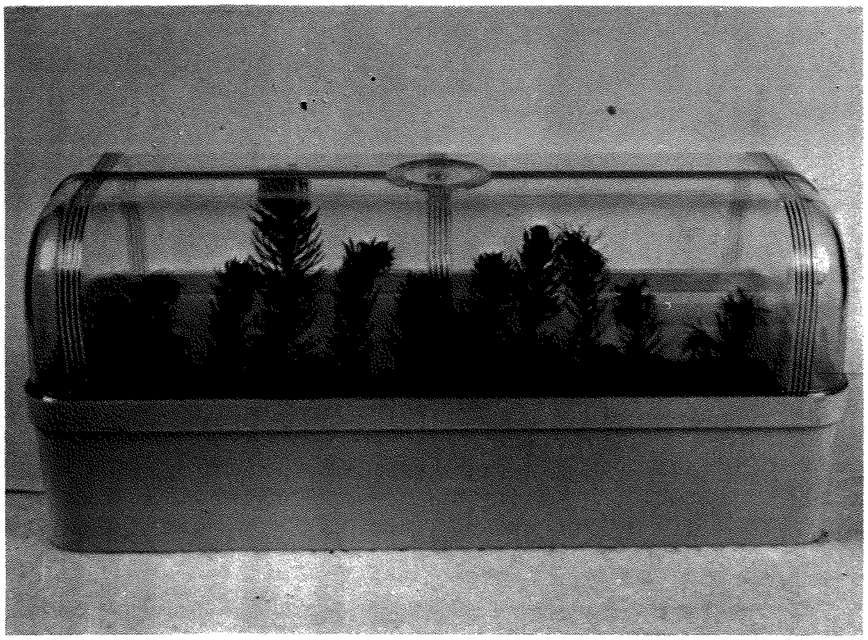

Fig. 1. Clipped seedlings in saturation chambers.

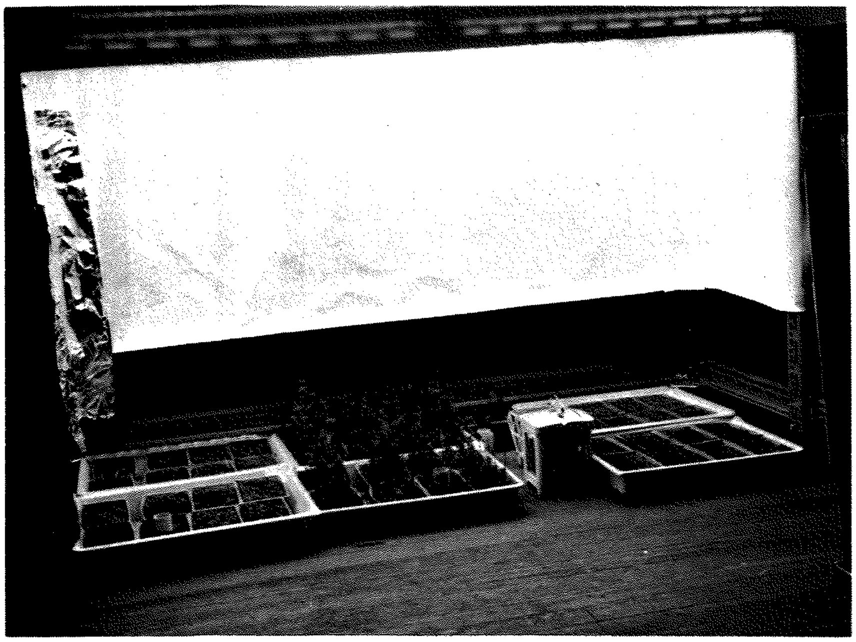

Fig. 2. Light cabinet (front removed).

and to 8.3% by the twentieth day.

On each day during drying, a tray of 10 control seedlings and a tray of 10 treated seedlings was selected at random and the seedlings were clipped for determination of R.T. A third tray of 10 treated seedlings was selected and put on a re-watering cycle for assessment of recovery rates.

On the fifth day of the drydown period, the newly flushed leading shoots wilted (R.T. 73.4%) but recovered on re-watering, and in the saturation chambers. On the seventh day (R.T. 65.7%) the needles became brittle and lost some green colour. They soon yellowed, but recovery on re-watering was satisfactory until day 10 (R.T. 40%). Needle-fall began on the twelfth day (R.T. 36.3%) by which time the seedlings did not respond to re-watering. Seedling mortality assessed by recovery on re-watering is shown in Table 2 together with R.T. levels. Re-watered seedlings appear in Figure 3 and are arranged in order of days of drought.

Table 2. Seedling drydown and survival.

Day	Soil moisture content (% by wt)		Relative turgidity %		Survival %
	Treated	Control	Treated	Control	Treated (re-watered)
0	47.6	47.6	79.6	79.6	100
1	44.0	46.5	81.7	80.1	100
2	45.0	48.6	86.5	89.0	100
3	42.9	51.5	83.1	90.4	100
4	42.9	52.1	80.5	85.8	90
5	40.5	50.5	73.4	84.2	100
6	38.1	51.6	73.6	79.9	90
7	23.8	50.8	65.7	85.2	60
8	17.9	48.6	40.0	86.0	80
9	17.9	51.8	52.6	86.8	90
10	11.9	40.2	39.8	88.6	80
11	8.6	40.6	49.2	89.7	60
12	6.9	41.7	36.3	87.0	0
13	4.0	47.1	26.1	88.0	0
14	4.0	45.2	48.2	90.1	0
15	4.0	43.8	15.0	90.4	0

The ability of the seedlings to avoid drying out in the face of very low soil moisture contents and low relative humidity (32% day - 45% night) and high air temperatures (72°F day - 56°F night) is demonstrated by these R.T. values. The limiting level reached on the twelfth day is well defined.

These levels provided a datum for field assessment in the 1968 growing season.

Fig. 3. Rewatered seedlings.

1968 Field Study

Each week during the field study, a sample of 10 natural seedlings was taken from a peaty gley site by systematic sampling with random starts along the stand edge. During particularly dry periods, additional samples were made among the new germinants. The standard technique was used for R.T. determinations. Results are presented in Table 3 for locations in clearcut gaps and within the stand.

Table 3. Seedling Relative Turgidity response during the growing season, peaty gley site.

Date	Location		R.T.	
	Open	Stand	$\bar{X}$	($\bar{X}$ mean of 10 seedlings)
April 8	98.3	100.0	99.65	
15	75.9	92.8	84.35	
25	73.9	82.7	78.30	
May 6	86.9	76.9	81.91	
14	78.9	76.0	77.48	
20	79.6	75.1	77.34	
27	78.5	76.8	73.15	
June 3	76.8	82.8	79.82	
10	82.9	86.0	84.47	
13			84.3	10 seedlings from gap centre
17	75.8	82.7	79.27	
			85.7	6 seedlings from gap centre
24	85.3	85.7	85.48	
July 1	84.4	94.3	89.36	
8	86.3	95.2	91.18	
15	95.44	100.0	97.72	
22	80.49	87.41	85.71	
29	91.16	81.22	87.43	
29 min	48.14	max 73.91	63.53	10 germinants
Aug. 5	89.77	84.22	87.06	
min	56.25	max 100.0	83.15	30 germinants
12	84.16	75.95	80.05	
min	45.45	max 97.43	58.12	10 germinants
20	98.18	95.87	97.02	
min	76.4	max 100.0	93.26	10 germinants
26	91.57	92.90	92.23	
Sept 2	98.27	100.0	99.14	

If R.T. levels approaching 40% are considered to be in the lethal range and 50% is indicative of severe moisture stress, these were approached by 1968 germinants on two occasions during the growing season.

These are: July 29 min. 48.14%
29 max. 73.91%
mean 63.53%

Aug. 12 min. 45.45%
max. 97.43%
mean 58.12%

Values for seedlings in the 1/10-acre gaps are not less than for seedlings within the stand. Excerpts from weather records indicate a relatively short dry-period leading to drought stress in the superficially rooted seedlings (Table 4). Soil moisture content at 3 in. depth decreased from 73% to 42% (by volume). Wilting point moisture content (15 Atmos) was 32% for this peat type.

Table 4. Weather extract (with soil-moisture sampling).

Date	Relative Humidity %	Temperature (°C)	Rain	Soil moisture content (vol)
July 15	-	-	0.48	
18	-	-	0.02	66.7
22	80	13	0.25	
23	70	16	-	
24	70	17	-	
25	68	15	-	61.9
26	64	16	-	
27	60	18	-	
28	58	17	-	
29	60	15	-	
30	60	15	-	
31	70	13	-	
Aug. 1	52	20	-	56.4
2	50	20	-	
3	56	16	-	
4	56	16	-	
5	70	24	-	
6	52	17	-	
7	42	18	-	
8	40	18	-	41.7
9	60	16	-	
10	44	19	-	
11	68	16	-	
12	70	16	-	
13	-	-	0.55	63.9

* The single-lathe Stevenson screen was placed on the ground. 1400 hr values are presented.

DISCUSSION AND SUMMARY

It is difficult to determine the relative degree of drought avoidance and drought tolerance in plants (Levitt, 1963). The ability of the plant to take advantage of relative atmospheric humidity, dew, and to change the leaf attitude, are examples of avoidance. Beyond that level the stress between root and top becomes greater and approaches the limit of tolerance.

Because of the very low moisture contents likely to occur in the surface-rooting-zone of the Sitka spruce seedlings sampled and their ability to thrive, it is apparent that avoidance mechanisms are at work. However, the attribution of mortality to a drought-and-heat complex by the Forestry Commission Research Branch surveyors seems to be supported by this study in 1968 and by the onset of aphid attack in 1967. The lethal level of 12 days drought with R.T. of 36%, according to the laboratory determinations, is merely an indication of the scale of these effects. The conditions in the light cabinet are quite remote from field conditions. The potting compost does not have the water retention capacity of peat and has different temperature characteristics. However, until further field sampling can be carried out under drought conditions, either in the open or induced under a polythene tent, the 40-50% R.T. is an interim guideline for moisture stress in young seedlings. It is in the same range as that reported by Pharis (1966) for Douglas fir (45%), and by Jarvis and Jarvis (1963) for Norway spruce (40%), pine (38%), birch (40%), and aspen (54%). Kramer (1959) sums up the need for such an index of moisture stress:

> "Most of the controversy on this subject [transpiration/soil moisture stress] could have been avoided had it been realized more clearly that plant processes are controlled directly by the water content of the plant and only inherently by the water content of the soil. If the diffusion pressure deficit or the relative turgidity of the leaves had been measured, it would have been possible to correlate physiological processes with the water conditions inside the plant. If, in addition, the moisture tension of the soil at various stages of drying had been known it would have been possible to correlate soil and plant water conditions with the course of transpiration and other processes. It seems that in all studies of the effects of water on plant growth, we need an accurate characterization of plant water conditions (R.T.) as well as of soil water conditions. This is essential to indicate when water becomes a limiting factor within the plant."

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SEASONAL VERTICAL PROFILES OF MOISTURE AND TEMPERATURE WITHIN SOIL AND AIR LAYERS OF ASPEN AND OPEN SITES

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Chalk River, Ontario

ABSTRACT

The effect of three stocking densities of aspen stands on the moisture and temperature within five lower layers of air up to 200 cm above the ground, and within six upper soil layers down to 90 cm was studied.

Daily measurements taken during the 12 weeks of the vegetative period in the summer of 1968 showed that all aspen stands, except the low-density stand in its upper soil layers, increased, at a highly significant level, the soil-suction pressure at all depths by strongly drying out the soil. Even more marked was the effect on soil temperature. At all three stockings and at all depths in the soil profile, the temperature was significantly lower, as compared to that in the open site.

The relative humidity inside the stands is directly proportional to the stand density and to the height where the measurement is taken. Thus, the low-density stand had no significant effect on the relative humidity when compared with the open site, but the medium-density stand had a significant effect up to 25 cm above the soil surface, and the high-density stand showed a highly significant effect up to 100 cm above the surface and a significant effect at 200 cm.

The low-density stand did not affect the air temperature in the five air layers observed, but stands of medium and high density lowered, at a highly significant level, the air temperatures at all observed levels above the surface.

On the whole, it can be concluded that aspen stands in this geographical region affect important climatic and soil factors in a highly significant way.

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STORAGE AND DELIVERY OF RAINFALL AND SNOWMELT WATER AS RELATED TO FOREST ENVIRONMENTS

By

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My discussion is intended to serve as a background for the general subject of "Forest-water interactions -- other than evapotranspiration." I shall try to outline some of my ideas on the fundamental entities of this part of forest and water interactions, examine some of the assumptions, and introduce some hypotheses which seem to me worth testing. For much valuable detail concerning microclimate, I refer you to two fine reviews which have helped to bring out the state of the science, that by Miller (1965) and Reifsnyder (1967b).

We will be examining forest and tree interfaces, the inputs of water to forests, the processes acting on that water, and the outputs in terms of water control and water delivery. In somewhat greater detail we will be considering forests as trees, as part of the microterrain, and as part of the soil. We will consider three groups of hydrologic processes: (a) those affecting fog drip, falling rain, snow accumulation, and snowmelt; (b) those affecting water storage and delivery processes; and (c) those affecting energy transfers. If I occasionally infringe on discussions of evapotranspiration processes, I hope I will be forgiven; I shall try to omit reference to evapotranspiration as a loss and consider only its influence on the processes of storage and delivery of rainfall and snowmelt water.

The Forest as Trees

In these days of systems analysis, model building, and computer-aided simulation, everyone is looking for analogues. If we look at some simple analogues of how trees perform, we may get some insight into spacial and time distributions of the mass and energy transfers which are involved in the study of microclimate in the forest environment.

First, consider the tree as a shed or an umbrella. The hypothetical forester who could not "get in out of the rain" will bear witness to the intercepting ability of the tree. In this role, different tree forms have widely different effects on the distribution of water reaching the ground; some forms spill a large part of the intercepted water at tree margins, both as drip from rain and as melting or sliding snow. In other tree forms, the shed effect is combined with a downspout effect; that is, stemflow, which may amount to as little as 1 percent or as much as 15 percent of the precipitation. In an applied hydrology example, Holton _et_ _al_. (1967) assumed that the greatest intake of water into the soil is in the vicinity of plant stems, so the basal area of stems was his index of the effective areas of rapid infiltration.

The forest as a sponge is a familiar analogy in literature. That the tree environment absorbs large amounts of water is little questioned; however, our ability to squeeze the sponge and retrieve the water is turning out to be somewhat less automatic than was hypothesized in earlier literature.

The tree as a fence affects the distribution of snow, modifies the interception of fog, and generally slows the "old devil" wind. Some of these effects have been discussed by Budyko (1956). He pointed out that trees are most effective when they grow in open stands. Open stands destroy wind vortices both in the forest and in adjacent areas up to 30 tree heights distant to the leeward.

The tree is an insulator, generally dampening fluctuations in the general air temperature. Trees slow advective heat transfer by dampening the wind. Radiative heat is mostly intercepted and reradiated rather than transmitted through the tree canopy.

The tree as a surface may have some characteristics which we have little appreciated. Besides the roughness, porousness, pliability, and non-random orientation of parts, the surface is far from chemically inert. At times the surface is a "salt bed", as evidenced by the salt content of stemflow and drip water (Bollen, 1967).

The tree as a radiator receives and disposes of energy and water in ways genetically determined by the non-random assemblage of its limbs and leaves. As has been suggested by Zinke (personal correspondence, 1960), the conical shape of conifers in the high mountain forests is probably not accidental -- possibly minimizing the impact of damaging ultraviolet rays. On a finer scale, the orientation of leaves has been shown to respond not only to direct radiation, but even to rainfall. For example, the leaves of koa-haole in Hawaii's Kona (dry) areas, fold up at the first drop of rain, thereby minimizing interception loss.

The tree acts as a chimney as warm air rises along the trunk and heats the tops of trees[1]. This phenomenon is indicated as another effective heat-transfer mechanism of trees.

A tree's role as an injection well is suggested by stemflow. But the well may operate even in clear weather as snowpack waters flow along ice lenses or density interfaces, only to reach the well around the tree trunk. And Raymond Rice reminded me (personal correspondence, Nov. 1969) that the depression in the snow around tree trunks is often repeatedly created between storms then refilled during storms, thus augmenting the "well effect" of tree boles.

The tree as a pump creates a moisture storage space in the soil by transferring moisture to the atmosphere, and part of the moisture may be condensed on adjacent snowpacks. Circumstances during which the pump is regulated by internal resistance in the tree as well as external tree characteristics are now being intensively studied.

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[1] My interpretation of some detailed infra-red photographs shown to me by Philip G. Langley, Pacific Southwest Station.

All these analogues serve chiefly as clues to some of the "favorite paths" that water and energy may take in their transfer within forests. I will touch on the physics of some of these analogues later in discussing the hydrologic processes that affect storage and delivery of rainfall and snowmelt water.

A Tree as Part of the Terrain

The tree adds to the terrain an order of roughness, an element of lift, and a degree of influence on air mass conditions. Terrain roughness is sometimes importantly augmented, as in patterns of groups of trees with openings. At other places trees smooth the terrain; for example, where trees grow taller in the draws than on adjacent slopes. Our ability to modify the forests gives us some control over terrain effects on water. We may expect that when forests are modified with specific consideration of the terrain and forest interactions, control over water will become even more effective.

The Forest as Part of the Soil

We all recognize the forest as a former of the soil, as a mechanical stabilizer of soil that is formed, and as a weathering agent of rock. Thus, the forest builds a reservoir for water storage, controls the paths of water delivery, and exacts a toll in the form of evapotranspiration. So, can we suggest an analogue? The failure of hydrologists to find happiness in simple reservoirs when explaining hydrologic performance suggests that the reservoir analogue has some serious limitations in the real world.

Water Inputs

Water inputs to our system may be as rain, atmospheric moisture, and/or snow. In general, perhaps even universally, our measurements of these inputs are so subject to error that any evaluation of microclimate effects based on input measurements is likely to be nearly meaningless. This is particularly true if snowfall, misty rain, or fog plays any significant part in the input process. An even rainfall may be subject to large errors of measurement (Court, 1960): "Two identical rain gauges 10 feet apart on a windy ridge top can differ consistently in catch by 50 percent of the smaller." Average errors of 18 percent and maximum errors of 40 percent in precipitation measurements were reported by Glander (1966).

Time and spacial variation of precipitation can mislead us in estimating average precipitation for watersheds. These variations are associated with different synoptic events in complex ways. Hiser (cited by Singh, 1968) defines six types of precipitation-producing events in Illinois. These were cold front, warm front, stationary front, squall line, warm air mass, and cold air mass types. Singh (1968) has pointed out that each of these types of storms can initiate different streamflow responses from a basin.

Atmospheric moisture, other than precipitation, can play a direct part in the input of water to the systems. On ridge tops of Lanai, Norfolk-Island-pine intercepted moisture in clouds and thus added 30 inches to annual precipitation (Ekern, 1964). In colder environments, hoar frost may contribute 3 to 4 inches of water during a winter (Berndt, 1969). Condensation of moisture on snow of as much as 0.07 inch per day was measured by West (1959).

Kittredge (1948, p. 118) found at Mt. Wilson in southern California one year increases under trees of 25 to 38 inches (107-166 percent increases over precipitation in the open). Remozov and Pogrebnyak (1965) concluded that condensation in forests on plains increased water by 5 to 6 percent. Each of these inputs -- rain, atmospheric moisture, or snow -- are characterized by wide differences in particle size, electric charge, adhesiveness, fall velocity, and dielectric constants. Lack of measurements of such properties increases the possibility of errors in studies of processes involving inputs.

When rain falls, the forest soil gets wet, but not uniformly. The shed effect may deposit 1-1/2 shares of water at the branch margin of individual trees and another large share at the trunk. Different species perform differently, and the same tree may perform differently in one storm than in another. A windy storm may shake droplets from limbs and foliage, making for a more even distribution of rain reaching the soil under the tree (Grah and Wilson, 1944). A misty rain may drop most of its rain water on the windward margins of each tree (Kittredge, 1948).

What happens to the rain intercepted on the foliage and stems? A few years ago this question had a very simple answer -- it just evaporated -- no complicated energy and mass relations were involved -- it just evaporated. Now, interception interpretations vary as widely as the measured amounts. Interception loss of snow can be of only trivial amounts because there is not enough energy for evaporation (Miller, 1967). On the other hand, other workers have reported as much interception as 5 to 6 inches per year; interception losses exceeded "Potential Evaporation" by factor of 5 (Rutter, 1967; Leonard and Eschner, 1968; Helvey, 1967). The dichotomy of interpretation is real in the time scale, but not in separating the West from the East; in most of western North America, where snow is the dominant form of precipitation, interception losses are significant from <u>rain</u> in spring, summer, and fall and an occasional storm in winter.

Even the process of interception is being questioned. Is water absorbed into leaves? Is water transferred downward through leaves to dry soil? Does the energy required to evaporate intercepted water affect energy available for transpiration? What is the surface detention of interception, is it represented by the regression constant in the equation Interception = function (storm precipitation) (Zinke, 1967)? In misty rains and clouds, is interception negative? To escape the problem of measurement, one group of watershed researchers measure only throughfall under the forest. The alternative is to develop detailed knowledge of the energy and mass behavior in the tree and tree environment (Knoerr, 1967; Harr, 1967). The evidence favors this approach, for interception results are often contradictory or inadequate in explaining water losses (Hoover and Leaf, 1967; Eschner and Helvig, 1968).

Snowfall

If measuring the distribution of rain is a problem, the distribution of snow and the processes are doubly so. We do not know how to measure the input, the input does not stay put, and additions and extractions occur in amounts which surprise us. Rarely does snow just fall. It swirls about until it finds a surface to attach to -- a tree, or the snow-covered ground. Depending on its path, the individual snow crystal may take only a few seconds or as much as a few weeks to reach the ground. Then snow may take off again to the atmosphere or to a new ground location.

We may conclude that whether our water inputs are as rain, snow, or atmospheric moisture, we have serious measurement problems.

Storage Processes

We may consider water storage from two points of view: storage on those surfaces which are exposed to the free air and radiation, and storage of water in subsurface areas such as within plant systems, in soil, and in subsoil. Wetness of surfaces causes major changes in heat balances by changes in reflectivity and emissivity (Kennedy and Edgerton, 1968). That our knowledge of emissivity is woefully inaccurate was deplored by Miller (1965), who cited reports by Buettner and Kern (1963) that the emissivity of the Sahara was somewhere between 0.69 and 0.91 -- not essentially 1.0, as is often assumed.

I have mentioned storage on vegetative surfaces in discussing interception storage. Good summaries are found in Kittredge (1948), Helvey and Patric (1963), and Zinke (1967). Storage on soil surface includes storage in the forest floor or litter, and in depressions in the soil surface. In amount, the forest floor may range from negligible amounts to more than 20 tons of oven-dry material per acre (Kittredge, 1948). Water storage and losses from the forest floor vary widely. Mader and Lull (1968) reported maximum storage of 0.45 inch in a 4.7-inch-deep pine litter, with a mean summertime storage of 0.25 inch. Aldon (1968) reported losses from the forest floor amounting to as much as 1.09 inches of moisture during summer-thunderstorm periods. Similarly, Rowe (1955) reported about one-tenth inch of water was stored per inch depth of forest litter. In a 4-year period when precipitation averaged 49 inches, the water evaporated from the forest floor ranged from 3.0 to 5.3 percent of the precipitation for floor depths of 1 inch to 3.6 inches. The loss from 1 inch of litter was about 15 times the storage capacity; from 3.6 inches, about 7 times the storage capacity. Total replenishable storage deficit was greater for bare soil than for soil covered with 1-1/4 inches of pine litter; the bare soil lost 10.7 inches of water per year by evaporation; soils covered with 1/2 inch or more of litter lost about 7 inches (Rowe, 1955).

The forest floor as a heat sink during freezing was studied by Thorud and Anderson (1969). They found that bare soil froze 55 percent faster than litter-covered soil. A 2-inch snow layer increased freezing time, but snow and pine litter together increased freezing times 54 percent over the time for the same thickness of litter alone, and 123 percent compared to snow alone. Water in the litter decreased freezing time as much as 61 percent. Hence, we may conclude that the forest floor and the soil beneath this is an important sink for energy, and therefore differences in forest floor conditions may cause significant differences in the microclimate.

The measurements of the storage of water in depressions on soil surfaces have largely been the results of infiltrometer tests. Depression storage generally was about 0.1 to 0.2 inch. Water in depression storage may be delayed in some soil types, as we learn from some recent studies of resistance of soil to wetting (DeBano and Letey 1969). Thus the forest as a sponge may not always be fully active, and some water stored in depressions may be largely lost, especially after summer-drying periods in the western United States.

The microclimate of water surfaces and the heat balance in flowing streams has been studied in considerable detail recently (Brown, 1969; Edinger, 1968). Brown reported wide differences in the amount of heat absorbed by flowing streams and stream bottoms. Bed rock bottoms absorbed as much as 25 percent of the energy, but gravel bottoms apparently were an insignificant energy sink. He reported wide differences in stream temperatures between shaded and unshaded streams -- as much as 11° F in May.

Winter exposure of streams and their margins may be important to water storage. Wilson (Walter T. Wilson, personal communication, about 1947) attributed freezing at stream margins as the cause for temporary reductions of groundwater contributions to streamflow. The formation of frazil ice in streams has also been related to the rate of cooling; here too, the insulating effect of the forest may play a significant ameliorating role. That large water surfaces such as lakes have major influences on the radiation balance has been reported by McFadden and Ragtozkie (1967).

Snow Surfaces

Snow surfaces represent an environment of major hydrologic importance, and forest interactions with snow surfaces create microclimates of great diversity. I will discuss some of the impacts of forests on the distribution of falling snow, and on additions to and losses from the snowpack caused by rain, evaporation, condensation, and drifting. Later I will discuss the melting of snowpack and the disposition of snowmelt waters.

Falling snow is almost a misnomer if we consider the complex path that snowflakes take from the free atmosphere to deposition in forests and forest openings. First, the forest and forest openings convert a nearly horizontal flowing stream of snowflakes to a turbulent mixture which only in a statistical sense is falling. Kuz'min (cited by Miller, 1964) reported the average angle of falling snowflakes was only 4 degrees from the horizontal. Rarely in the Sierra Nevada is wind not a factor during snowfall; Court (1957), for example, found that only 2 percent of the precipitation fell during calm periods.

Part of the falling snow is intercepted on the trees but only part of this is lost by evaporation. Many of the interception processes play an important role in the location and characteristics of snowpacks (Miller, 1964, 1966). Without quantitative measurement of many of these complicated processes, any estimates of interception loss must be considered only approximate and tentative. Estimates consistently fall in the range of from 6 to 10 percent of the precipitation (Rowe and Hendrix, 1951; Anderson, 1963; Anderson, 1967); there lies a hint as to the proper emphasis which should be given to this evaporative loss in snowpack management.

Temporary storage of snow in trees has shown a rather consistent maximum of about 0.2 inch (Goodell, 1959; Miller, 1964; Satterlund and Haupt, 1967). However, for individual storm periods and for individual broken-top trees, snow platforms have built up with the equivalent of 5 to 10 times that amount maximum. Miller (1966) has described the transport of intercepted snow during snow storms, and Hoover (1960) has stressed the role of snow sliding and blowing from trees in the build up of snowpacks. I should emphasize again, however, that interception loss in the snow-zone environment is not solely snow alone. Rain storms in this environment, especially summer and fall storms, are typically subject to high interception losses. These losses are significant to microclimate evaluations and may have hydrologic significance in some places.

Snow Accumulation

How snow accumulates in various parts of forests and openings in forests under different conditions of topography and meteorology may explain the differences in snowpack between years and may serve as guides on how snowpacks can be managed. Snow accumulation was studied at 250 individual points in the central Sierra Nevada of California (Anderson, 1967). I analyzed snow accumulation during 16 periods from December 10, 1957, to March 28, 1958. The periods differed widely in meteorological conditions. Points selected for analysis had maximum differences in topography and forest conditions, and adequately sampled openings in forests, forest margins near openings, and continuous forest.

Snow accumulation was related to the meteorological, topographical, and forest variables by means of reduced-rank-principal-component analysis (Burket, 1964; Wallis, 1965).

Storm characteristics, which include both precipitation occurring during storms and storm wind, explain the largest part of the variation in snow accumulation. However, other variables contributed to the total explained variation, which ranged from 85 to 93 percent. Of the 23 variables retained as effective in explaining variation in snow accumulation, 12 represented interactions of storm and topography or curvilinearity in meteorological relations -- snow accumulation, like the rest of nature, is apparently "damned unlinear".

These analyses suggest that snowpack accumulation may differ greatly with two contrasting types of forest cutting -- individual-tree selection versus strip clear-cutting. If both cuts remove 60 percent of the trees, the average increases in snow accumulation (over that of 12.1 inches in a dense forest) could be:

	Inches	Percent
Selection-cut	1.5	12
Strip-cut	5.3	43

Significantly, about 30 percent of the increases in snow associated with the strip cutting was to be found in the margins of the cut areas.

Delivery Processes

The delivery of water involves the paths the water takes, the rates of delivery, and the amounts. Each significantly affects water supply, water quality, and the control of flood waters and associated sediment production. The delivery processes I will discuss include snowmelt and the effects of microclimate on snowmelt, the surface and subsurface paths that water takes to become streamflow or water stored in aquifers, and the water in transit at any time.

Study of water-delivery processes promises to avoid some of the major problems which have cropped up in the lumped systems of hydrologic analysis. Those systems include such techniques as unit graph-analysis, where a unit of rainfall excess is always delivered at the gaging station in a particular distribution pattern. The lumped systems also include simple reservoir analogies (Overton, 1967), and the application of simple coefficients to rainfall (Mitchell, 1967). Analyses of these kinds have proved useful for simple design problems. But they have failed under extreme conditions, which of course are the ones of primary interest. They also have failed to add to our understanding of how water is delivered and how we may better manage that delivery from forest areas.

Let us consider first the surface and subsurface delivery. The concepts of surface runoff, infiltration capacity, and surface detention as controlling water delivery come into vogue about once every ten years. However, as has been pointed out by Anderson (1962) and Yevjevich (1968), for forest watersheds these concepts have little relationship to the way water is actually delivered. Rather, the water usually enters the surface soil readily and then takes a variety of paths to reach channels for delivery.

Subsurface movement of water on slopes has been widely studied in recent years. Often, water entering the surface soil flows downward until it reaches a layer of different texture. Then it flows along this interface in a downhill direction until it finds places for further penetration. Such lateral flow of water has been measured and described by Whipkey (1967), McDonald (1967), and Minshall and Jamison (1965). Sometimes the lateral flow occurs at the B-horizon of the soil, or at a layer of finer soil-texture, but sometimes the flow is simple drainage such as reported by Hewlett and Hibbert (1967). That simple drainage of soil, below normal field capacity, was an important source of long-term delivery of water was reported more than 25 years ago by Edlefsen and Bodman (1941). In their experiments, extending through 2 years, drainage from soils reduced the water held to about eight-tenths of field capacity. The concept of field capacity, though useful as an approximation of water retention, actually interfered with our understanding the processes of delivery of sustained streamflow from watersheds during dry periods.

Snowmelt

Snowmelt processes control delivery of most of the water from the mountain forest of the western United States. In California, for example, snowmelt supplies more than half of the water of the State (Colman, 1955). Research has indicated forests play a major role in snowmelt and that forests may be cut in ways to control snowmelt for specific purposes of maximizing the water yield, delaying snowmelt runoff, or minimizing local flood runoff (Anderson, 1963).

How a forest affects snowmelt depends on its density, the height of its trees, and the position of the trees with regard to their neighbors and to topography. The specific role of a forest is determined by its effect on wind, shade, radiation, and latent and sensible heat transfers. The vulnerability of the snowpacks to melt processes varies widely. Fresh dry-snow may be nearly immune to melt. It may reflect as much as 90 percent of the incoming solar radiation, its thermal quality is nearly 100 percent, and its capacity to lose heat by radiation to the sky is high. In contrast, wet snow under warm humid conditions may melt rapidly by absorption of latent heat from condensation. Radiation melting of wet snow may be up to 5 times as great as with dry snow, for its minimum albedo is 50 or 60 precent. Wet snow effectively prevents transfer of heat to the atmosphere; Budyko (1956) calls this the "ventil effect" in which the snow acts as a one way heat valve. Forest cover over snow intercepts much of the radiation, cutting off the supply of radiant heat. Let us examine some examples of rapid snowmelt under conditions where snowmelt has important hydrologic consequences -- the rain-on-snow flood.

Rain-on-snow Floods

That rain does not melt much snow has been known by hydrologists for some time. However, snow does melt during rainstorms. The two major sources of the heat that melts the snow are known to be sensible heat conducted to snow by convection and latent heat released by condensation on the snow. I have tried to quantify the roles of rain, sensible heat, and latent heat, in augmenting rain on snow "flood water" for three major storms: the December 21-23, 1964 storm at Government Camp, Oregon (elevation 3,900 feet) and two storms at Central Sierra Snow Laboratory, California (elevation 6,700 feet), those of February 1, 1963 and December 21-23, 1967. Basic data measured were snowmelt, rainfall, and air temperature. Assumptions which were made in these calculations are that effective sensible heat transfer may be represented by degree-day factors at the Snow Laboratory and that snowmelt by latent heat might be taken as a difference between total melt and snow melted by rain and sensible heat.

Melt by rain was calculated by the equation which relates melt to the rain temperature from 0°C times rain in inches/203. Condensate was calculated from melt by latent heat times the ratio of the latent heat of melting to the latent heat of evaporation.

My calculations produce these approximate distributions of results:

Floodwater Source:	CSSL 2/1/63	GOV'T CAMP 12/21-23/64	CSSL 12/21-23/67
	Inches		
Rain	7.8	11.5	16.0
Snow melted --	3.4	4.3	7.5
by rain	(0.5)	(0.5)	(0.7)
by sensible heat	(0.3)	(1.4)	(2.7)
by latent heat	(2.6)	(2.4)	(4.1)
Condensate	0.3	0.3	0.5
Total	11.5	16.1	24.0

We see that snowmelt (plus condensate) produced about 30 percent of the "flood water" in each storm. Melt by latent heat was the principal cause of snowmelt, exceeding the melt by sensible heat and melt by rain in each storm. The role that different microclimates created by watershed management might play in modifying latent and sensible heat transfer to the snowpack under these rain-on-snow conditions needs study. Is wind the dominant factor in latent and sensible heat transfer to the snowpack? If so, the forest's effects on wind may be a major way that forest conditions may affect snowmelt. Studies have shown that forests can play a dominant role in modifying the ablation of the snowpack during spring, reducing the rate of melt by 40 percent (Anderson, 1956). Is this effectiveness different during rainstorms?

Spring Snowmelt

What conditions of snowpack permit melting to start? Nearly all the heat involved comes from the snow-atmosphere interface and from radiation on the snow; we should look at these sources of energy for the initiation conditions. We would expect that we will do better in explaining the initiation of snowmelt if we consider the processes of conversion of the first snowflake and its associated atmospheric vapor to liquid water. Only later does the snowpack become "wet" and ablation of the snowpack takes place. This ablation of the snowpack is what is ordinarily meant when one talks about snowmelt.

How much heat is required to initiate ablation conditions in a snowpack? The elements of the heat budget have been summarized by Reifsnyder and Lull (1965, p. 85). Three requirements must be met. The first requirement is to bring the snow to 32°F; the second is to satisfy the water holding capacity of the pack; and the third is to supply calories to melt the ice-water mixture ((80 calories/gram) times the thermal quality).

Differences in thermal quality of snow may cause wide variations in heat requirement to initiate snowmelt. The usual assumption of 97 percent thermal quality (3 percent of unfrozen water) probably does not apply to active ablation periods. In California, thermal quality as low as 75 percent has been measured in studies of snowpack melt (Anderson, McDonald, and Gay, 1963); daily average quality of 82 percent was reported. In Colorado, Leaf (1966) reported minimum thermal quality of 88 percent during active-melt periods. Wide differences in snow quality can make for important differences in the heat budget over short periods.

Ablations of snowpacks have long been associated with degree-day factors computed from average daily or hourly air temperatures. That such factors are empirical has been recognized; however, they are still used for more fundamental heat relations, but do not usually contribute much better predictions of snowpack ablation. Degree-day factors predict snowmelt for a particular forest, topographic, and climatic environment because other elements of the heat inputs (and losses) tend to be highly correlated with air temperature and advection conditions. However, these conditions can differ from year to year at the same place. For two years with nearly equal April 1 snowpacks (1949 and 1951) degree-day factors averaged for 25 points differed by 54 percent (Anderson, 1956, Table 1). Differences were greater in open environments and less in forest environments. Year-to-year variation in the degree-day factors within the forest were only 36 percent of those in open areas.

Interestingly, although the trees on the north side of the forest openings increased the ablation rate, they still had the effect of reducing the year-to-year variation in ablation rates, as did trees casting shade from the south of openings.

Wind-Forest Relations to Snowmelt

The forest effect on wind is undoubtedly a major control of ablation of snowpacks. Wind affects the transfer of sensible and latent heat to the snow and losses of heat by evaporation. Characteristics of the wind which reach the snow may vary widely, not only in velocity, turbulence, and direction, but also in heat and moisture content. That the forest and snowpacks can alter the wind as well as be affected by the wind seems clear. The effects of forest on general climate of snow zone areas was outlined by Miller (1955). Studies of snowpack ablations have indicated that forest conditions influence snowmelt for long distances to the windward. In a study of 32 snow courses, Anderson and Pagenhart (1957) found that the amount of forest canopy one-quarter mile to the windward affected ablation rate of snowpacks, dense forest having less melt to the leeward than open forest. In a study of 163 snow courses, Anderson and West (1965) found that effects differed with forest density one-half mile to the windward of a snow course. One-half mile leeward of a snow course, water equivalent of snowpacks and melt of April 1 and May 1 (average of 3 years, 1958 to 1960) with forest densities to windward of 66 percent and 33 percent canopy would be:

SNOW WATER EQUIVALENT UNDER TWO FOREST CANOPIES

Date	66% Canopy	33% Canopy
	------------- Inches	-------------
April 1	33.1	41.0
May 1	27.9	33.7
April melt	5.2	7.3
Degree day factor, (inches/°Day >35°F)	0.058	0.080

We see that snow melted faster leeward of the thin forest. For average expected temperatures after May 1, the two forests would have equal snow on about June 5; but snow leeward of the thin forest would last until June 11, and that leeward of denser forest until June 16. These estimates are for identical site conditions at the snow course itself. Such mesoscale influences of forest condition will have obvious implications in any studies of microclimate in the forest.

Snow Storage

In the control of moisture and energy in the forest environment, snow is preeminent. But, through manipulation of the forest, we can affect snow's role over wide limits. The primary energy-balance relations in the forest-snow environment have been explored by Miller (1955, 1965). The variations in snow accumulation and melt with terrain and terrain-forest interaction are exemplified in papers by Mixsell _et al_. (1951), Packer (1960), Anderson and West (1965), and Anderson (1967). Some management of forests for water supply through control of snow were proposed by Church (1934), Kittredge (1953), and Anderson (1956, 1963).

Let us summarize what we can do in forest manipulation to modify snow storage and control snowmelt.

1) If we cut openings in the forest, we can increase snow water storage by as much as 40 percent (Anderson, 1967).

2) If we cut forests in such ways as to provide shade and reduce long-wave radiation to the snow, we can slow snowmelt by 40 to 50 percent (Anderson, 1956).

3) If we cut forests or leave forests so as to provide shelter from the winds, we can (in maritime climates) reduce latent and sensible heat transfer to the snow and thereby reduce snowmelt contribution to short-period (few days) floods by perhaps 50 percent (Anderson, 1969).

4) By removal of trees we can make snowmelt more effective in producing water, for we reduce by 8 inches or more each year the soil moisture deficit that must be satisfied by rainfall or snowmelt.

5) By cutting forests in patterns that will permit air cooled by contact with the snow to be trapped, we may further delay snowmelt (Anderson, Rice, and West, 1958; West, 1959).

6) By providing trees to shelter snow on what would otherwise be exposed windswept ridges, we can reduce evaporation, saving 2 to 3 inches of water per year (West, 1959).

Conclusion

The processes of storage and delivery of rainfall and snowmelt water in the forest environment will need to be more accurately quantified as demands on forests for water and other products increase. Results from basic microclimate studies may be expected to play an increasingly important role in the evaluation of hydrologic inputs and outputs of forest areas.

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DISTRIBUTION OF PRECIPITATION IN YOUNG AND OLD ASPEN STANDS

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ABSTRACT

This paper presents stemflow data on a per tree and per rainfall basis. It also presents general equations expressing stemflow as a function of basal area per tree and amount of rain per rainfall. These provide for the calculation of stemflow for other trees in the stands and for trees in other stands of similar age stocking and climate. The measurements of stemflow and throughfall were made at Petawawa Forest Experiment Station, Chalk River, Ontario, between 16 July and 19 October, 1968.

Stemflow was measured in two aspen (Populus grandidentata Michx.) stands. In a 5-year-old stand, stemflow was measured from eight sucker aspens. In a 55-year-old stand, stemflow was measured from 13 mature aspen trees in the overstory and from 10 red maple (Acer rubrum L.) trees in the understory. Stemflow data were analysed from rainfalls ranging from 1 to 26 mm per storm for the mature aspen and red maple and ranging from 1 to 42 mm for the young aspen.

Curves for regressions of stemflow on the tree basal area showed that there was a close relationship between stemflow per tree and both tree basal area and gross rainfall. Overall slopes of the curves were influenced strongly by the last, the slope in general increasing with rainfall quantity. Curves also varied with tree species and tree age.

Expressing stemflow on a per tree basis instead of on an area-depth basis for a stand permits greater flexibility and precision in calculating volume of stemflow in different parts of the same stand and possibly in extrapolating to aspen stands of similar age stocking and climate. Expressing stemflow on a per tree basis also permits a realistic perspective of the disposition of water that runs down tree stems and enters the forest soil.

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[1] Paper presented by Dr. Jan Čabart

CONSIDERATIONS IN THE QUANTITATIVE EVALUATION OF ECOSYSTEM MOISTURE REGIMES

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INTRODUCTION

The main purpose of this paper is to generate some thought and effort toward the improvement of the measurement and description of ecosystem moisture regimes.

By ecosystem moisture regime I understand the closely interacting system of atmospheric, edaphic, and vegetative moisture regimes of a particular site. Moisture regime of the ecosystem may be studied from a hydrological or a biological point of view. In hydrological studies, the quantitative exchange of water between the three components and the total gain or loss of water in the ecosystem is under consideration. For biological purposes, the qualitative aspect of the water is of the greatest importance i.e., the water potential in the soil and plants and the vapor pressure of the air and their relationship. For example, the hydrologist wants to know the amount of water lost through transpiration, while the plant physiologist or ecologist is interested in the internal water-potential of the plant when transpiring at a particular rate.

Importance of Water to Plant Growth

When water supply is adequate and the transpiration demand of the air is low, plants are in a state of full turgidity. At high transpiration demand and low soil-water potential, loss of water from plants exceeds uptake, and their water contents become less than at full turgidity. This relative water content (RWC) was expressed by Weatherley (1950) as the ratio of existing water content to the water content at full turgidity on a dry-weight basis, and was called relative turgidity (RT).

$$RT = \frac{\text{Fresh Weight - Dry Weight}}{\text{Fully Turgid Weight - Dry Weight}} \times 100$$

Slatyer (1955) reported reduction of growth in cotton, sorghum, and peanuts when RWC decreased to 90%. Catsky (1965) found that 5 - 10% reduction in RWC caused 50% decrease in photosynthesis. Slatyer (1955, 1960) found that reduction of RWC is caused by the lowering of water potential in the tissues (Fig. 1). Plants with unlimited water supply lose water into the air through transpiration in a varying rate according to atmospheric conditions. The water loss from the plant is replaced with a continuous stream of water from the soil

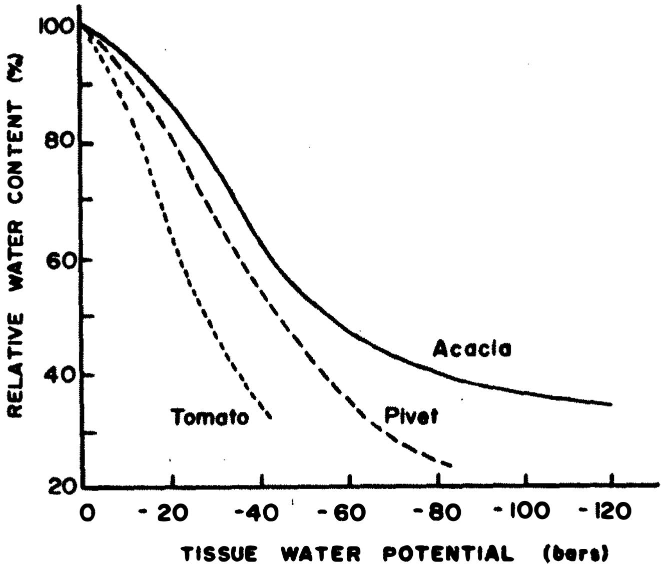

Fig. 1. Relative water content/water potential for three types of leaf tissue (after Slatyer, 1962).

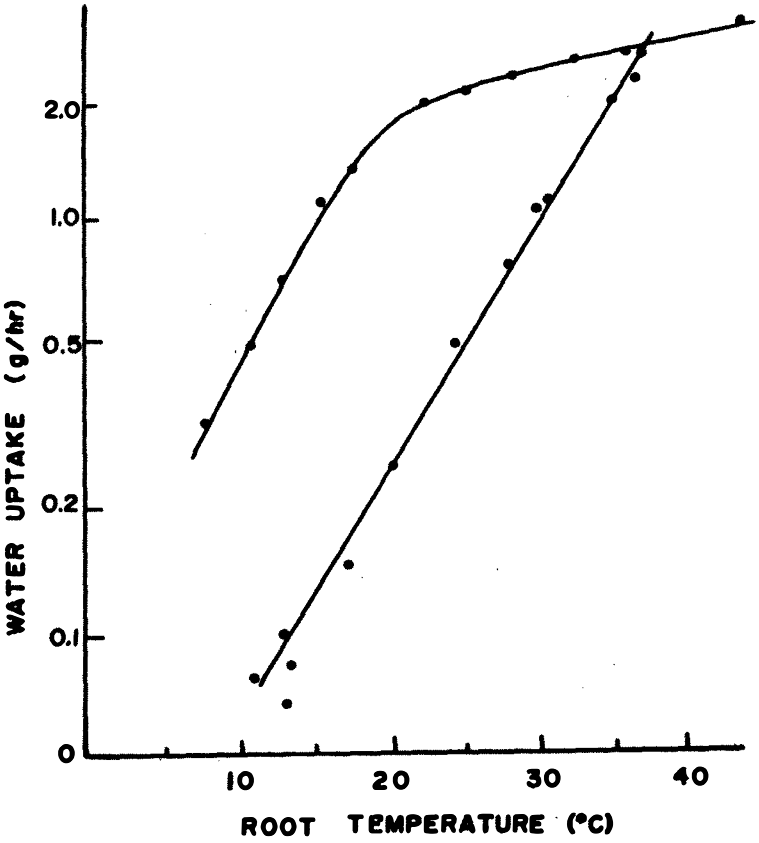

Fig. 2. Water uptake by bean roots grown under low (17°) (●), and normal (24°) (○) temperatures, as a function of increasing temperature (after Kuiper, 1964).

to the leaves. This transpirational stream encounters resistances to flow in the soil and within the plants. To maintain the flow against all resistances a potential gradient must exist from soil to leaves. Therefore, the magnitude of water potential in the leaves is a function of the sum of resistances and the transpiration demand. Consequently, the external factors regulating transpiration potential and soil-water availability need to be measured in the study of ecosystem moisture regimes.

FACTORS CONSIDERED FOR THE MEASUREMENT OF ECOSYSTEM MOISTURE REGIMES

(1) Soil-Water Potential

Soil-water potential is the sum of matric and osmotic potentials. In most forest soils, osmotic potential is negligible and matric potential is often measured with calibrated fibre glass-resistance units. Total water potential may be measured with a thermocouple psychrometer developed by Richards and Ogata (1958).

(2) Soil Temperature

Kuiper (1964) found that with falling root temperatures, there was a decrease in water uptake by tomato roots (Fig. 2). Babalola _et al_. (1968) studied the effect of soil temperature on the transpiration rate of Monterey pine and reported sharp reductions in transpiration with decreasing soil temperatures, especially at high soil-water potentials. Therefore, measurement of soil temperature is also necessary for the study of water availability.

(3) Transpiration Demand

Transpiration from leaves was expressed by Tanner (1968) according to the following equation:

$$E = \frac{\rho\varepsilon}{P} \cdot \frac{e_i - e_z}{r_i - r_a}$$

Where ρ , ε and P are density of moist air, ratio of molecular weight of water vapor to air, and atmospheric pressure, respectively; e_i and e_z internal and external vapor pressure; and r_i and r_a resistances to vapor movement. Resistances to vapor movement are controlled by plant properties and $\frac{\rho\varepsilon}{P}$ can be regarded as a constant. Therefore, the driving force of transpiration is $e_i - e_z$. According to Cowan and Milthorpe (1968), e_i is not less than 95% of the saturation vapor pressure at leaf temperature.

Gates (1965) found that leaf temperature does not exceed air temperature when the radiation absorbed is less than 0.5 cal cm^{-2} min^{-1} (Fig. 3). This condition exists if the micro environment is shaded or the sky is overcast with alto-cumulus or heavier clouds. For bright, sunny conditions, difference between leaf and air temperature ($T_l - T_z$) may be found from the energy diagram of Gates (1965) (Fig. 4) if the air temperature, wind speed, and radiation absorbed by leaves is known. Radiation absorbed can be calculated

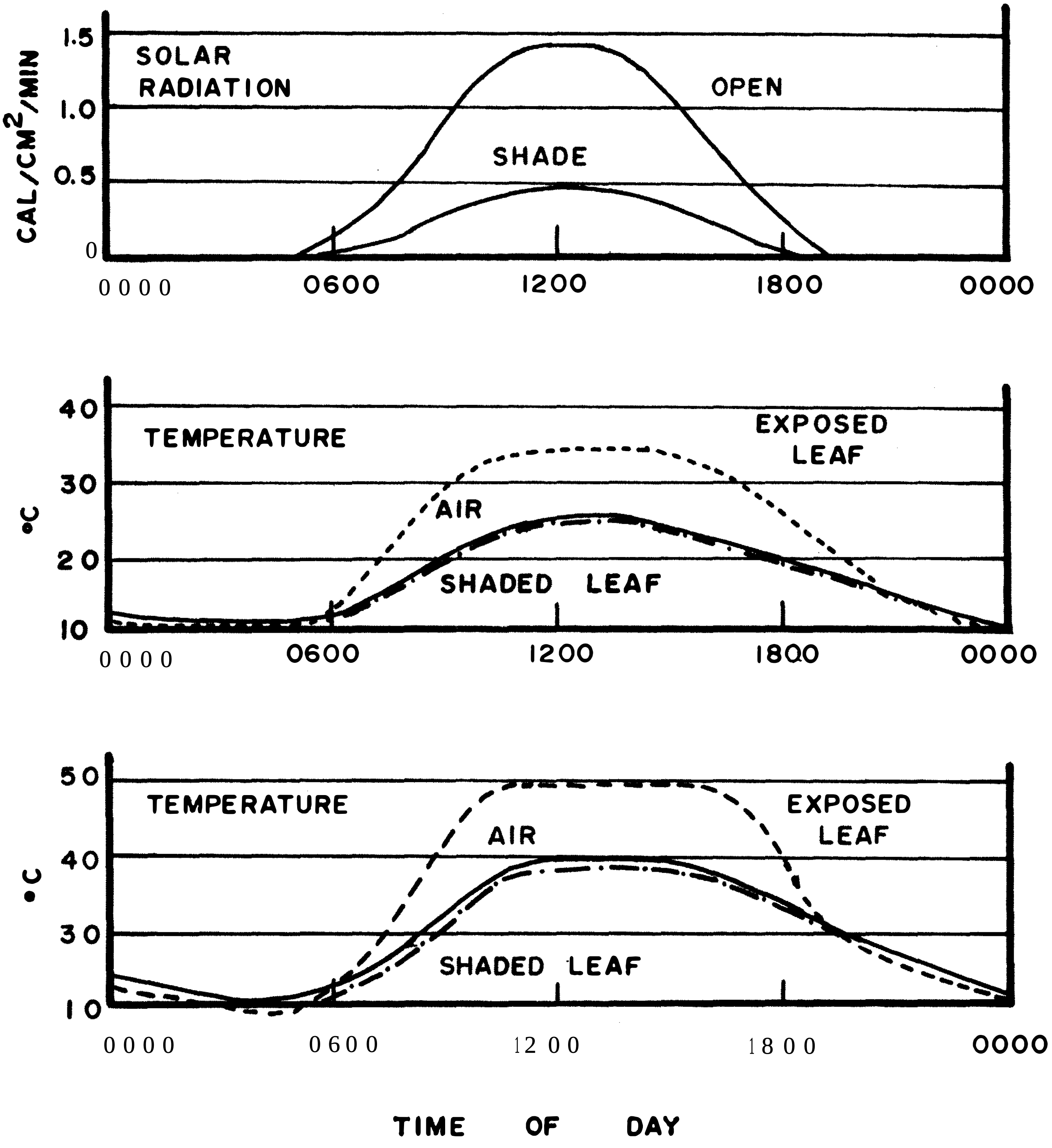

Fig. 3. Illustration of solar radiation, air temperature and leaf temperature relationships on a cool and a warm summer day with clear sky (after Gates, 1965).

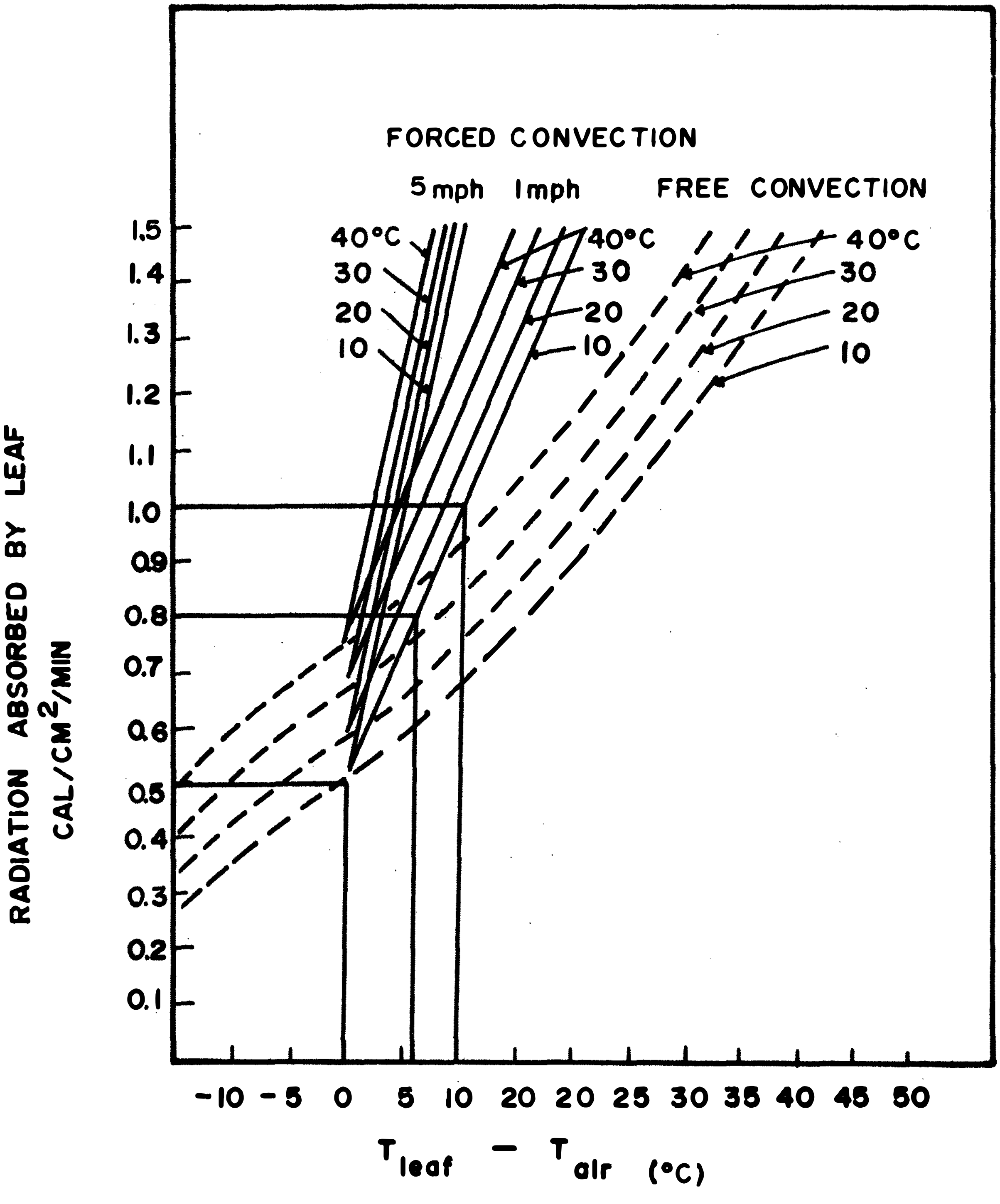

Fig. 4. Energy diagram for computing leaf to air temperature difference when the radiation absorbed is given. Curves represent energy dissipation by leaf through reradiation + free convection and reradiation + forced convection at 10°, 20°, 30°, and 40°C (after Gates, 1965).

from measured or computed insolation with 0.7 as the mean absorptance factor. If a minimum wind speed of 1 mile/hour, air temperature not less than 10° C and a maximum insolation of 1.4 cal cm^{-2} min^{-1} were assumed, the following $T_1 - T_z$ values may be used in the noon hours during summer:

0° c - in shade or under heavy clouds
+ 7° C - under cirrus clouds
+10° C - under bright sunshine

The above $T_1 - T_z$ values may be used for the estimation of $e_i - e_z$. If $T_1 \veeeq T_z$ than $e_i - e_z$ will be approximately equal to the saturation deficit of the air at measured air temperature and relative humidity. Under light overcast or bright, sunny condition, $e_i - e_z$ will be approximately equal to the saturation deficit of the air calculated at air temperature + $(T_1 - T_z)$ and at measured relative humidity of the air. Because of great day-to-day variations in atmospheric conditions, saturation-deficit values should be calculated daily from the maximum air-temperature and associated minimum relative humidity to represent the most severe conditions of the day.

(4) Tissue-Water Potential

Tissue water potential indicates the moisture condition in the vegetation component of the ecosystem. The lowest daily potential values in the foliage, (during the most unfavorable edaphic and atmospheric conditions of the day), should be used for the evaluation of moisture regimes. The magnitude of water potential in the foliage can be measured with the pressure - bomb technique as described by Scholander et al. (1964).

In summary, the measurements considered necessary for the recording of ecosystem moisture regimes are:

(a) Soil-water potential
(b) Soil temperature
(c) Air temperature
(d) Relative humidity
(e) Tissue-water potential
(f) Observations of weather conditions

The expression of an ecosystem moisture regime with numerical values in different vegetation types or land forms is of great importance in the ecological evaluation of forested lands. However, the comparison of sets of several factors is very difficult because their relative importance is not known. The water potential in the foliage seems to be a suitable single factor for moisture regime description, because it reflects both the edaphic and atmospheric conditions. However, direct field measurements cannot solve the problem, because the same species in identical physiological conditions does not occur on every site, and similar environmental conditions induce different water potentials, depending on species and physiological condition. The relationship between external factors and water potential in a species can be found experimentally in controlled environments. Based on such studies, the field measurements of edaphic and atmospheric factors could be reduced to a single term - the expected daily maximum water potential in the studied species. This value would have wide applicability and would facilitate the quantitative evaluation of ecosystem moisture regimes.

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COMPUTER MAPPING OF THE MARMOT CREEK SNOWPACK AND THE INFLUENCE OF TOPOGRAPHIC AND FOREST STAND VARIABLES ON THE PACK

By

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INTRODUCTION

In 1961, Marmot Creek experimental watershed was established on the eastern slopes of the Rocky Mountains in Alberta within the spruce-fir cover type. The spruce-fir type is one of the major cover types in Alberta and occupies the source area for most of the streamflow of the prairie provinces. Two main objectives were set for the research on the basin in order to develop forest-management methods for spruce-fir consistent with water yield, regime, and quality requirements of the area:

(1) to determine the relation between the hydrology and the physical characteristics of the basin,
(2) to evaluate the effect of commercial timber harvesting and subsequent re-growth on water yield, regime and quality.

The annual precipitation on Marmot Basin is about 35 in. of which 70-75 per cent is snow (Storr, 1967). The greatest effect of logging on the hydrology of the area will be in the redistribution of snow and alteration of energy relations and hence snow melt. Therefore studies associated with snow accumulation and melt have received high priority in the research program.

STUDY AREA

Three sub-basins plus a confluence area constitute the 3.6 sq mile Marmot Creek Watershed, located at 50°57'N. latitude - 115°10'W longitude. Elevation rises from 5,200 ft above M.S.L. to 9,200 ft at the western boundary. General slopes up to 24 per cent exist in the lower part of the basin and up to 50 per cent above treeline. Treeline is at 7,000 - 7,500 ft with 40 per cent of the basin being above this elevation.

The forested area consists mainly of Engelmann spruce (*Picea engelmanni*) - subalpine fir (*Abies lasiocarpa*) stands 60-70 ft high with crown closure averaging 70 per cent.

OBJECTIVES

Two types of study are being carried out in the watershed program: companion studies conducted both on and off the basin, and the paired watershed approach. The latter implies establishing the relation of a particular hydrologic parameter between treatment and control sub-basin, carrying out the treatment, and evaluating the effect on the designated parameter using the established relation. This assumes that the two basins are independent of one another, i.e., cover manipulation on the treatment area does not influence the control area with regard to the parameter of interest. Treatment and control basins on Marmot Creek share a 2-mile border and it may well be that logging the treatment basin would alter both wind patterns and energy relations on the control. Therefore, pre- and post-treatment snow-accumulation patterns are needed for both the treatment and control basins. The first objective of this study is to quantify snow accumulation by various areal breakdowns and establish the pattern on the basins for several years before treatment. The second objective, which is closely associated with the first, is to determine the relations between snow-water equivalent and variables of topography (elevation, slope, and aspect) and forest type (basal area).

PROCEDURE

Various methods of snow measurement have been used on Marmot Basin and have been described previously (Golding, 1968). None of the sampling was sufficiently intensive to define patterns of snow accumulation to the degree required, so a 1 x 10-chain grid was established on the watershed. In March, 1969, at the approximate time of maximum pack, depth and snow-water equivalent were measured at 1,200 points within the forested part of the basin. For 200 of these points, spaced at 5 x 10-chains, the following data was recorded at the time of the forest inventory: aspect, slope, elevation, stand height, and basal area per acre.

Patterns of Snow Accumulation

To achieve the objective of quantifying snow-water equivalent of the pack for particular areas, a computer contour program was used with the xy coordinates of each of the 200 points and a z value obtained by averaging the snow-water equivalent measured at the five locations adjacent to each of the 200 points. This was done to smooth out variations in snow pack caused by small-scale topographic and stand conditions.

The program was devised by Cole, Jordan, and Merriam (1967) specifically for contouring structural data in geology. It fits a quadratic surface by the least-squares method to the xyz coordinates. A rectangular grid is then superimposed on the xy-coordinate system and the value of the quadratic surface at each grid point is calculated. A rectangualr cell in the xy-coordinate system is centered on each grid point. The cell is enlarged if necessary to include at least five data points. A plane is then fit by least squares to the quadratic residuals from original data points for each cell. The quadratic value of the grid point at the center of the cell is then modified by adding or subtracting the local linear value at that point. This is repeated progressively from grid point to grid point. These modified grid values are used as the basis for contouring. A second program may then be used with the modified grid values to calculate areas and volumes within or between specified contours, and within particular areas.

Relation of Snow Pack to Topography and Stand Density

The relation of snow-water equivalent to elevation, aspect, slope, and basal area of the stand was examined graphically and formed the basis for a multiple regression and correlation analysis of combinations of these variables and analysis of covariance involving snow-water equivalent, elevation, and slope. The independent variables used are shown in Table 1.

RESULTS

Snowpack Contouring

For the first run the contour interval chosen was 1.0 in. requiring 13 intervals to cover the range of water equivalent (0.0 to 12.7 in.). The superimposed rectangular grid consisted of 2,000 intersections. The plotted contour map bore little resemblance to a rough plot of the original data. This was due not only to the poorly defined trend in the data but probably also to the large number of contour intervals used and the discontinuities of the original data grid. Figure 1 indicates the lines along which measurements were taken at 1-chain intervals. The program has calculated values for areas where no data exist as well as for areas having data. Each of these values in turn influences adjacent values in the final contouring.

A second run of the program is being carried out, but results are not yet available. In this run, the number of contour intervals has been reduced to five from 13, and the superimposed grid from 2,000 intersections to 400, approximately equal to the original data grid.

Relation of Snow Pack to Topography and Stand Density

The means, units, and coefficient of variation for each of the variables used in the regression analysis are given in Table 1, along with the coefficients for the correlation of each variable separately with snow-water equivalent. Correlation coefficients larger than 0.13 are significant at the 95 per cent probability level; larger than 0.18 at the 99 per cent level.

The multiple regression program used was written at the University of British Columbia and is described by Kozak and Smith (1965). With all 14 variables included in the model the regression was significant at the 99 per cent level of probability. Variables were eliminated successively with the new regression re-calculated each time. Not until only four independent variables remained did all contribute significantly to the regression. These variables are given in Table 2 with the regression statistics.

DISCUSSION

Refinements in the computer contour program described in this study are required to provide a means of comparing total snowpack from place to place and year to year in an objective, repeatable manner. Reducing the number of contour intervals from 13 to five and the number of grid intersections from 2,000 to 400 will smooth out small scale irregularities and produce a more

Figure 1.

MARMOT SNOW STUDY

Snow-water equivalents and depths
measured at 1-chain intervals along
horizontal lines, March 1969.

Scale 1 inch : 0.4 miles

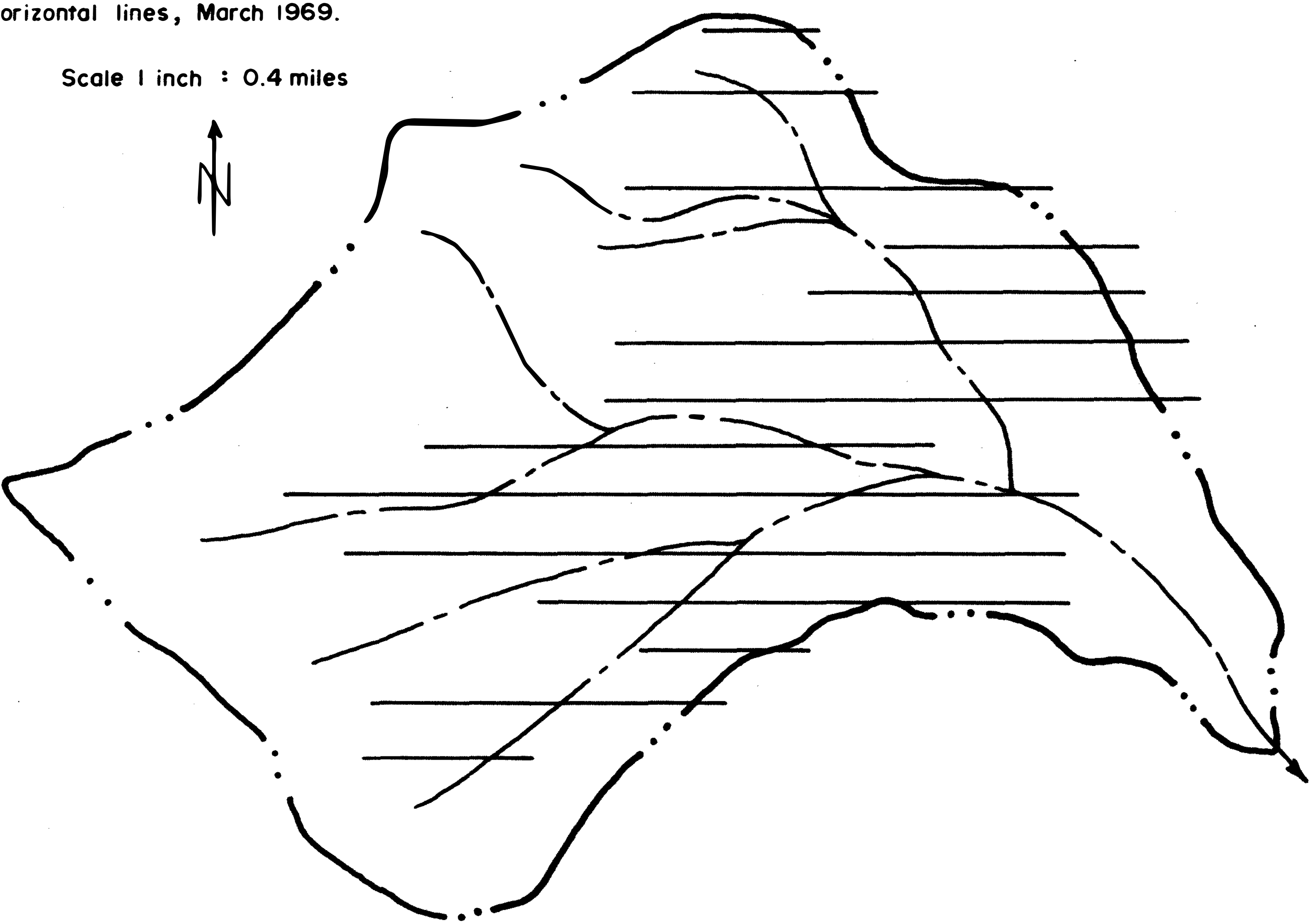

Table 1. Statistics on the variables used and their simple correlation with snow-water equivalent

Variable	Units	Mean	Coefficient of variation (per cent)	Correlation coefficient[a]
elevation	feet	6,398.48	7.21	0.25
elevation^2	feet	41,152,100	14.66	0.25
slope	percent	35.736	41.46	-0.23
slope^2	percent	1,495.43	83.49	-0.19
slope^3	percent	71,309.6	130.18	-0.14
aspect	degrees	155.102	47.83	-0.02
aspect^2	degrees	29,532.1	89.02	-0.03
aspect^3	degrees	64,671.0	127.14	-0.03
(basal area /acre)	feet^2	163.807	44.17	-0.22
(basal area /acre)^2	feet^2	32,042.1	69.04	-0.19
(basal area /acre)$^{-1}$	feet^2	0.007837	139.80	0.15
elevation x aspect	feet - degrees	1,001,440	50.01	0.01
elevation x slope	feet - percent	228,132	41.07	0.20
aspect x slope	degrees - percent	5,559.9	73.29	-0.12

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[a] Coefficient, r, for the correlation of each variable separately with snow-water equivalent.

Table 2. Statistics associated with the regression of snow-water equivalent and the four independent variables contributing significantly to the regression

Variable	Regression coefficient	Variance ratio	Significance
elevation^2	1.438×10^{-7}	19.09	99% level
slope^3	1.344×10^{-5}	8.99	99% level
basal area /acre	-5.715×10^{-3}	5.16	95% level
elevation x slope	-1.814×10^{-5}	16.75	99% level

Constant term	4.775
Standard error of estimate	2.468
Multiple correlation coefficient	0.418
Total explained variance (R^2)	0.174

usable map. Snow measurement will be extended so that there will be no large, unsampled areas within the contoured area.

The variables used in the regression, other than snow-water equivalent, were not measured specifically for this study but were part of the forest inventory carried out in 1964. Other variables would have been preferred, for example, crown closure instead of, or in addition to, basal area/acre, but for a first look at the relationships they filled the need. Aspect and slope were in reality micro-relief features and not general relief features which may have a greater influence on snow accumulation. Topographic features interact with storm characteristics, such as wind direction, but these interactions were not studied because of the single measurement of snow-water equivalent at maximum pack.

In a study previously reported (Golding 1969), it was shown that snow-water equivalent was highly correlated with elevation (*r*'s of 0.990 - 0.999 for time of maximum pack) for five snow courses in the same forest-cover type, with approximately the same slope and aspect, on a ridge in the centre of the basin. It was also shown that snow-water equivalent was highly correlated with basal area/acre (*r*'s of 0.30 - 0.51) (Harlan and Golding 1969). In the present study the correlation of water equivalent with elevation and basal area was highly significant but accounted for much less of the variance in the simple regressions (*r*'s of 0.25 and 0.22 respectively). That is, when variation in other factors is kept to a minimum a greater proportion of the variation in water equivalent is attributable to elevation and basal area.

Packer (1962), using essentially the same variables as used in this study (except for his exclusion of slope), constructed a model in which 92 per cent of variance was explained. Explained variance in the present study was 17.4 per cent for the model: Snow-water equivalent = F (elevation^2, slope^3,
basal area/acre,
elevation x slope)

Anderson (1967) reported a study of snow accumulation for 16 periods in one winter. Explained variance attributed to all variables was 86 per cent, with 82 per cent attributable to storm characteristics (precipitation at an index station, storm winds, clear sky, dewpoint, and elevation). For measurements made only at maximum pack, an index of storm characteristics would not likely be significant even if an additional variable, year, were added.

The higher explained variance for water equivalent on the central ridge of Marmot Basin suggests that the model should include a variable to index the relative position on the basin. This would be the location relative to ridges, valleys, and general aspect. This is especially important on a basin of extreme topographic variation such as Marmot Creek. The difficulty is in devising a suitable index.

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A METHOD OF ASSESSING FOREST INFLUENCE ON POINT MEASUREMENTS OF HYDROLOGIC PARAMETERS

By

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ABSTRACT

There is a need in hydrologic research for evaluating quantitatively the influence of environmental and site factors, particularly forest cover, upon point measurements of specific parameters. To define the cumulative influence of adjacent trees on a specific hydrologic parameter, snow accumulation, the Bitterlich point-sampling technique was used with four angle/sizes: 73.66, 104.18, 147.34, and 208.38 minutes (corresponding to basal-area factors, as used in forestry, of 5, 10, 20 and 40). Correlation and regression analyses were carried out relating snow-water equivalent at 50 points with point density determined by the four angle sizes. The study area was in relatively homogenous spruce (*Picea engelmanni* (Parry) Engelm.)-fir (*Abies lasiocarpa* (Hook.) Nutt.) with similar slope-aspect conditions on a ridge in the central part of Marmot Creek experimental watershed.

Snow-water equivalent was best correlated with point density determined with angle size 147.34 minutes, in which case correlations for seven of the 10 measurement dates were highly significant (i.e., at the 99 per cent level of probability), the other three being significant at the 95 per cent level. There was a trend of increasing correlation from January to April.

HEAT PULSE VELOCITY IS AN INDICATOR OF TRANSPIRATION

By

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SUMMARY

Measurements of heat pulse velocity (HPV) have been demonstrated as descriptive of an individual tree's response to its environment. However, the complexity of a tree's water conducting system and the difficulty of obtaining velocity measurements representative of the whole water-conducting xylem makes the method unacceptable as a valid indicator of transpiration rate. These problems may have been overemphasized.

Two experiments have been conducted to determine empirically the correlation between measurements of heat pulse velocity made in the lower part of a stem and vapor or weight loss by the tree. Both show excellent correlations. The data from these experiments is displayed in Figure 1.

My previous reservations against using HPV magnitude as indicative of transpiration were based on the contention that we have just not measured T and HPV in enough cases and over a wide enough range of soil moisture to establish a linear relationship between the two. However, internal water stress in the Aleppo pine experiment varied from 11 to 32 atmospheres during a two-week interval. This is a greater range of stresses than I have measured under natural conditions.

Since such a drastic treatment had no apparent effect on either the linearity nor correlation, it appears to me that we should start utilizing HPV as at least an indication of the transpiration rate of a tree relative to that of the same tree at some different time.

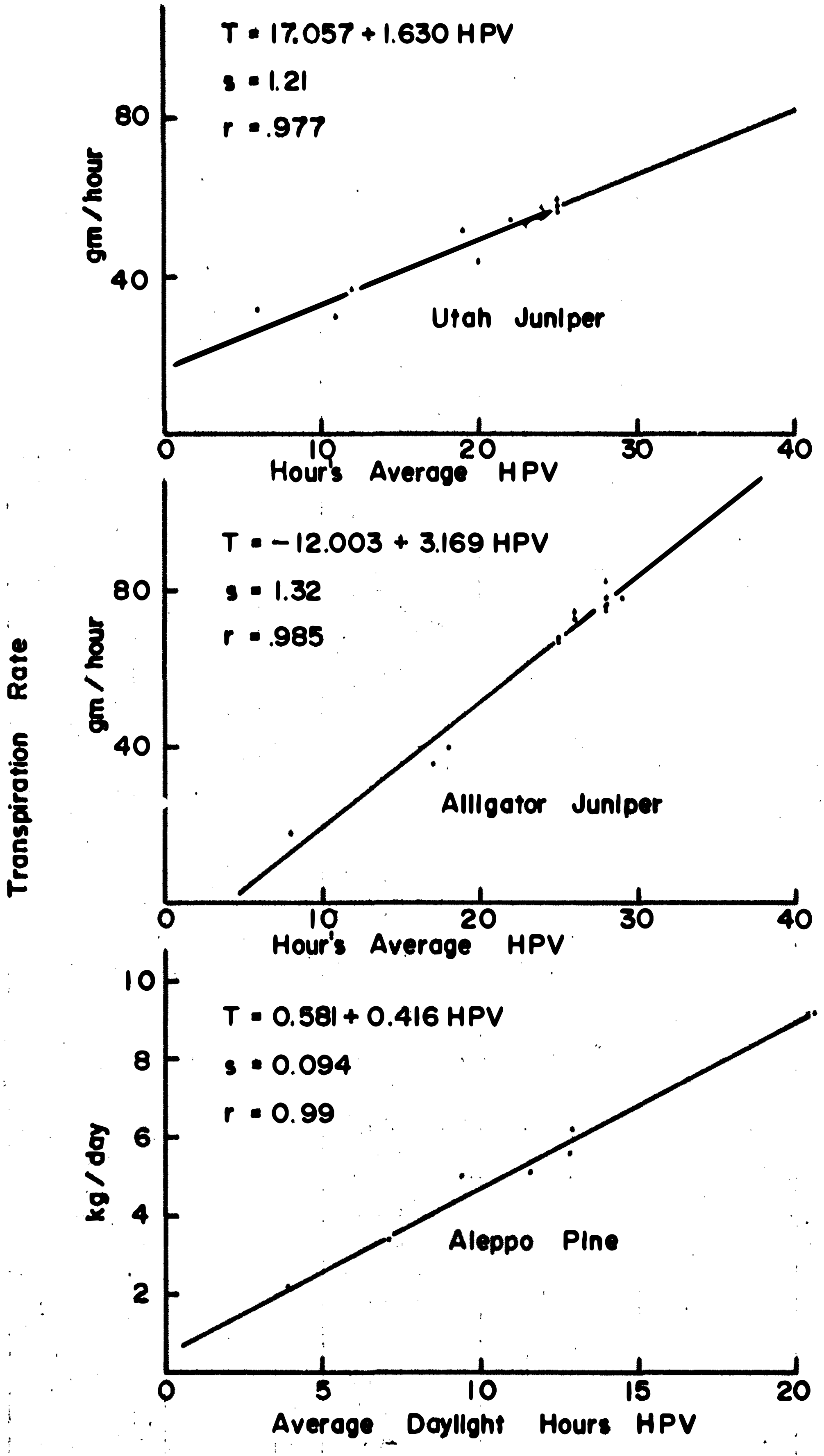

Fig. 1. Transpiration rate in gm/hr or kgm/day as indicated by heat pulse velocity measurements.

INFORMATION SYSTEMS CONSIDERATIONS

By

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INTRODUCTION

Development of sophisticated and efficient data generation and processing systems is usually expensive in terms of equipment and human labour. So called "SIMPLE" programs are seldom simple to implement, and more often major program development can become an agonizing exercise before all of the bugs are removed. Once established and in operation, it becomes costly and time consuming to change or redevelop these systems. Usually there are various ramifications in changing a set of computer programs which are not apparent or of concern to the user of the service. It, therefore, becomes imperative to investigate thoroughly, plan comprehensively, and build with discretion to obtain the required results from data accession and processing systems.

Available data files are often in an undesirable format for electronic processing and historical precedent often prevails, or even dictates continuation of inefficient techniques, recording procedures and formats for the sake of conformity within a long record. Therefore, before you begin a new program, ensure that the equipment, procedures, and resultant formats you adopt are going to be economically processible using the equipment at your disposal.

DISCUSSION

In establishing data acquisition systems, look for economic, fail-safe (backup) systems, and rapid and economically convertible output formats to machine-sensible media. These conversions should be precosted by someone engaged in that type of work. The raw data must in some way be humanly or electronically decipherable. As you are aware, it can be disastrous to find out after six months of operation that a resistor was improperly hooked up in a recording device and that you have a mass of good data except that the most significant parameter is completely unreliable. Entire projects have failed on such a "technicality". You should, therefore, be able to spot-check your data for validity as they are gathered, whether visually, mathematically, or by machine, but "immediately" as defined by the nature of your study. You must decide whether losing two days of data are not critical or losing two hours are not critical.

Do not accept every well-intentioned promise regarding equipment reliability. The best equipment can fail. Do not compromise beyond the degree of completeness that you must have. However, be realistic about demands for completeness and accuracy. Are one or two missing records, or days, really statistically significant?

Never mind the manufacturer's specifications regarding the accuracy of a specific instrument. What you must consider is your requirement and the accuracy of your other data. Stop fretting about one instrument, even though the error is a number of times the manufacturer's specifications, if it doesn't significantly affect your final results.

These points are indeed only commonsense and don't particularly apply to data processing problems but now extend this logic to your requests for processing. Do NOT ask the computer people to develop massive programs with sophisticated equations and computations to five-figure accuracy when you and the computer systems adviser both know that the overall data accuracy simply doesn't warrant it. It may look good in a publication but your computer systems expert is probably justifiably disturbed because he invariably has plenty of other priority work where the sophistication is justified. Second, consider the computer programs development and processing costs and, most important, the turn around or delivery time you require. Ask your data processing people for a cost and delivery time estimate. The only real control on data processing requests is to charge for all programming, computing, and processing services, and let the customer decide what he wants for himself. Although economic justification has been severely criticized by many scientists and others, it still appears to be almost the best criterion in setting priorities. This is why everyone MUST eventually be charged full costs for all computer support work.

To develop a satisfactory and effective data processing system, it is necessary to conduct thorough preliminary investigations regarding procedures, techniques and requirements. You may find that proven systems and package programs are adaptable at a fraction of the cost and time needed to develop specialized procedures, and may produce the required results or at least preliminary studies in considerably less time. One should not be the prisoner of an existing system or always refer to precedent for methods. However, keep an open mind and carefully consider the cost/benefit ratio of nearly parallel systems development, particularly if you are not sure of your final approach and need a preliminary analysis to assess your project or your data. Consider realistically the extent to which computer support is actually required. A fast pre-programmed utility package may eliminate most of the drudgery and provide interim answers quickly and very economically for rapid clerical analysis. In other words, is it really necessary for the computer to cross every t and dot every i? It's a question of dignity versus dollars, or is it perhaps vanity to insist that computers do "all" the work. In data processing jargon we refer to some requests as IBM jobs meaning "It's Better Manually". Seriously, some jobs being done by computer should be done manually. A manager may not have clerical support staff for two or three weeks of manual effort, but perhaps he should call Office Overload and spend $500 before expending more funds on computer program development.

Establish liaison in advance with the people who will do your processing. Don't talk only to the manager but, if possible, see the senior programmer or systems designer responsible to make the system work. He may ask some embarrassing or even naive questions from your point of view, but they are better answered in advance.

Often people use the most economic data gathering facilities available and save hundreds of dollars, but they only display the vaguest concept of how the data output can be manipulated for effective processing. Then they are obliged to spend thousands of unnecessary dollars to process the output because they didn't know or didn't ask about the problems involved or, more commonly, they accepted a salesman's explanation of how simple and easy it would be. If possible, get cost estimates for a few alternative approaches. Assess the cost/benefit of the available alternatives and then make the final decision regarding your instrumentation and procedures to obtain the best overall dividend from your investment. Overall economy and effectiveness are important. To effect this, the entire system to the finished product should be assessed for feasibility, time and cost.

If the data input cannot be provided in a conveniently processible format, reconstitute it by machine to a form which meets all immediate and anticipated processing requirements. More important, use a simple and general approach and format rather than specifically designed formats and specially oriented procedures. This is because people frequently change their approach after looking at a preliminary analysis, and a simple organization helps to make further reorganization for reanalysis economic. Don't close your mind to the development of flexible or general approaches even though you feel you know precisely what you want in advance. Clients often change their minds, especially in a research area, and only you the client know which other areas you may wish to explore. Try to build in some simple provision for likely alternative procedures. Whereas you may be happy to go back to the drawing board when you discover or anticipate something new, the programmer is ill because he is throwing a perfectly beautiful system into the wastebasket.

Designing a versatile and flexible data processing system involves considerable planning and needless to say some discretion. To illustrate what is meant by building in provisions for alternative procedures consider a utility computer program to produce a probability matrix with parameter selection for either axis; independent and/or overlapping class definitions for each parameter; further contingency limitations on the input file; selection of control break for output; optional provision for computation of various correlation statistics; and an option for exclusive or inclusive probabilities. Then add a general input format into which parameters from other sources may be substituted electronically and you have a few thousand possible analyses at your disposal with one program.

Apply preliminary quality control procedures wherever possible, but seek an expert with sound experience in quality control methods. It is very easy to double and triple check the same logical point unwittingly and overlook another point which could or should be checked.

In the design of data processing systems, mathematical and other scientific know-how is only one-half of the battle. There is almost invariably a considerable amount of data manipulation involved between program segments and computer devices, which demands another type of expertise, familiarity with computer languages, programming techniques and computer software systems. In our own experience, total systems effectiveness has in some instances been improved thirty-fold through the application of methods learned during a period of years. The lesson here is to leave the programming to fully-experienced programmers and concentrate on mastering the art of communication across the scientific-technical language barrier. Once achieved, this can be a truly gratifying human experience far superior to communication with a machine.

In conclusion, may I say that computers are wonderful; they are here to stay and can do marvellous things at fantastic speeds provided the people involved know where, when and how to employ them effectively, and also when to say no thank you to the computer.

AN OPERATIONAL SYSTEM FOR (1) SAMPLING AND SENSING MICROMETEOROLOGICAL ELEMENTS, AND (2) LOGGING AND PROCESSING MICROMETEOROLOGICAL DATA[1]

By

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ABSTRACT

A system was built to sample and store air from 10 heights at 2 locations above and within vegetation. The sampling system consists of 2 sets of storage systems so that one set of 20 samples can be analyzed for CO_2 and water vapor concentrations while another set of 20 samples is being taken. At each height at each of the two locations, air is drawn into the sampling system through 10 horizontally spaced ports. Each of these ports includes radiation-shielded thermocouples for measuring air temperature.

Net radiation and visible radiation are measured with traversing systems operated at several heights within the vegetation system.

Wind speed and temperature data are taken at 4 locations, two of them coinciding with the locations of air sampling for CO_2 and water vapor concentrations. Wind speeds above the vegetation are measured using 6 cup anemometers at each of the 4 locations, and are logged at 5-minute intervals using printing counters. Wind speeds within the vegetation are measured using heated thermocouple anemometers.

The CO_2 and water vapor concentrations are measured using infrared analyzers. The data are recorded on strip-chart recorders because the sampling system requires frequent monitoring.

The sensitivity and errors involved in the sampling, analyzing and logging equipment have been investigated.

Air temperature, within canopy wind speed, net radiation, visible radiation, and soil heat flux data are logged on a 100-channel magnetic tape data logging system. The scanner rate of the system is 50 channels per second. The scan initiation rate can be set at 1 per second, 1 per 10 seconds, 1 per minute, 1 per 10 minutes, or 1 per hour.

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[1] Contributed by the Northeast Branch, Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, in cooperation with the New York State Agricultural Experiment Station at Cornell University, Ithaca, New York. Department of Agronomy Series Paper No. 866. Supported in part by the Atmospheric Sciences Laboratory, U.S. Army Electronics Command, Ft. Huachuca, Arizona.

The range of inputs to the data logging system can be varied, i.e., ±9.999 millivolts, ±99.99 millivolts, ±999.9 millivolts, or ±9.999 volts. This covers the range of outputs of most sensor systems.

The system has a printer output as well as a magnetic tape output. In using the printer, the scan rate is 4 channels per second. The printer output capacity is essential for spot checking the sensor/logging system function.

Data are logged on magnetic tape in 8-character units per data word, including 2 characters for channel identification, 1 character for range, 1 character for sign (±), and 4 characters for data. Data are recorded in BCD on 7 tracks at a packing density of 200 BPI.

Data are processed by transferring the tape to tape drives of a central processing unit. Disk storage facilitates processing long segments of data. The degree of difficulty in programming for tape processing is in proportion to the sophistication of the computer system being used. It has been our experience that programming for a CDC 1604 computer was relatively easy, while programming for an IBM 360/65 was extremely difficult.

INTRODUCTION

The micrometeorological sampling systems in use at the USDA-ARS Microclimate Investigations project at Ithaca, N.Y. are the results of several years' effort at construction, modification, and acquisition of equipment.

The micrometeorological elements usually sampled are:

CO_2 concentration
H_2O vapor concentration
Air temperature
Net radiation
Shortwave radiation
Visible radiation
Soil heat flux
Wind speed
Wind direction

The system was designed for use in agricultural crops, but many of the principles would be valuable in forest micrometeorology as well.

The sampling system for CO_2, H_2O vapor, and temperature was developed by Johnson, Drake, and Lemon (1). As a homemade device, it is unique and has many interesting features.

THE CO_2, H_2O AND TEMPERATURE SAMPLING SYSTEM

In this system, air samples are drawn from the field to an instrument trailer for storage and subsequent analysis for CO_2 and water-vapor concentration The same air that is sampled is used to aspirate radiation-shielded thermocouples in the field.

Air is sampled (and thermocouples aspirated) at 10 ports equally spaced along manifolds 3.5 meters long. Ten of these manifolds are placed horizontally at 10 selected levels above and within the crop. The intake ports are radiation shields for thermocouples.

In the design of this sampling system, the following factors were considered:

(1) The sampling device should not disturb the air flow of the environment to any large degree. This problem would be greatest in short, dense plant communities where air flow is relatively low. The use of 10 horizontally spaced ports helps alleviate this problem.

(2) The sampled air should be moved rapidly and in large enough volume to minimize errors caused by leaks, absorption/desorption, and evolution of organic materials out of plastics. The pump and bypass system is designed to achieve these needs.

(3) The components of the system at the sampling site should be highly reflective to visible radiation, highly emissive to long-wave radiation, and low in mass and volume to avoid altering the temperature field in the plant community and to assure adequate shielding of the thermocouples from radiant-energy exchange.

(4) The system should provide representative spacial sampling consistent with vegetation involved and the objective of the measurements. For instance, this system with 10 ports along 3.5 meters is judged adequate for agricultural crops, but may be inadequate for forest studies.

(5) Leaks at any point along the sampling, storage, and analysis system must be avoided. If air is pulled long distances, pressure drops considerably, and "small" leaks may not be insignificant, particularly if the leaks occur where there are high ambient concentrations of CO_2 or water vapor.

Figure 1 shows the sampling intake in a soybean crop. The most prominent and important parts of the air intakes are the radiation shields for the thermocouples. These cylindrical radiation shields, diagrammed in Figure 2 are approximately 2 inches across and consist of two concentric aspiration zones. The outer concentric aspiration zone enters into the aspiration manifold separately from the inner aspiration zone. This outer aspiration zone helps maintain the interior of the radiation shield near ambient air temperature, and reduces the conduction and radiation errors inside the shield. It should also help prevent a layer of heated air from the external surface of the radiation shield from being drawn directly past the thermojunctions.

Fig. 1. Sampling system air intake manifold and radiation shields mounted in a soybean crop.

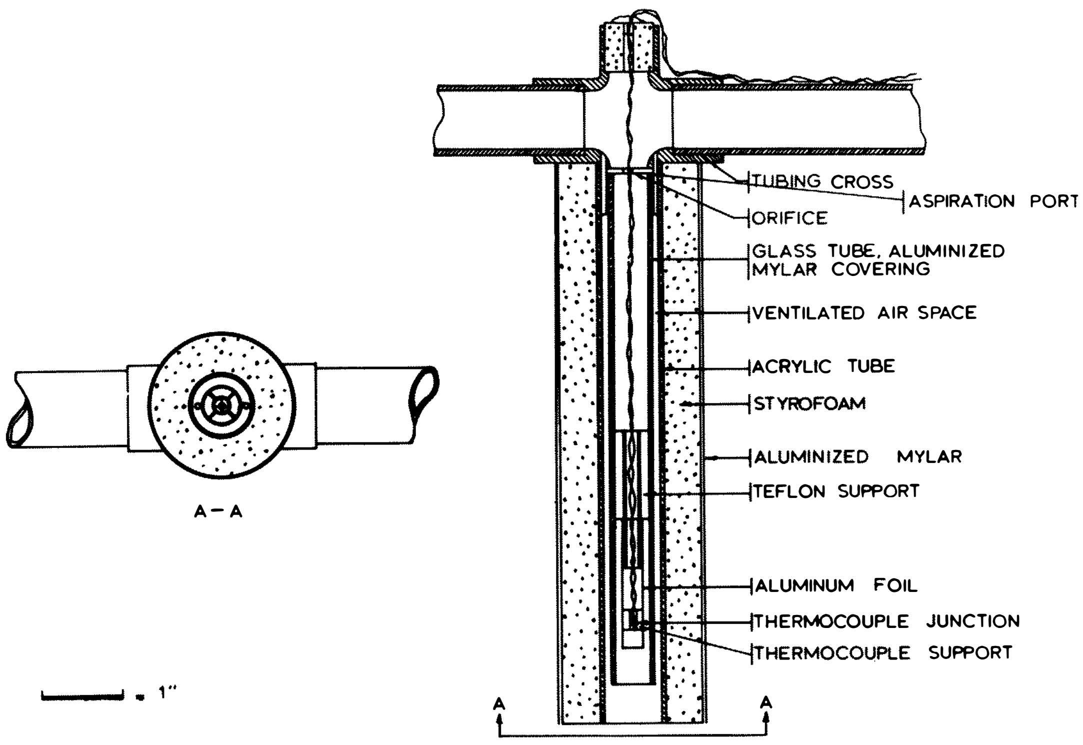


Fig. 2. Cross section diagrams of a radiation shield with the thermocouple installed.

The outside of the radiation shield consists of a layer of aluminized mylar, with the mylar side out. The aluminum layer reflects solar radiation, but has a low emissivity for long-wave radiation. Hence, the layer of mylar is needed for reradiation.

The next layer is a ½-inch thick cylinder of styrofoam, which functions as a low-mass insulator to prevent conduction of heat from the aluminized mylar outer shield and helps prevent direct entrainment of boundary-layer air surrounding the shield.

The styrofoam is cemented to itself from two semicylinders, and fits tightly against an acrylic plastic tube. The acrylic tube is cemented to the outside of the manifold cross, and provides a rigid insulating support for the outer shield.

An aspirated air space exists between the acrylic tube and the next element of the shield, which is a glass tube cemented to the inner side of the manifold cross. Slots in the manifold cross allow this portion of the radiation shield to be aspirated independently of the inner space around the thermojunction.

Moving inward, the next part of the radiation shield is the 15-mm glass tube with an aluminized mylar covering. Inside this glass tube a spider-like teflon spacer centers a cylinder of 3-mil aluminum foil. Inside the aluminum foil cylinder is another spacer which holds the thermojunction in place. Aluminum foil is used because it reflects radiation from the thermojunction well. Thus, the thermojunction temperature should be mostly a function of the aspiration air drawn past it.

Flow rates were equalized along the 10 sampling ports of the manifold by inserting a plug with orifice at the manifold end of the radiation shield. The largest size of orifice was chosen that allowed less than 5% variation in aspiration rate along the manifold.

Originally the aspiration rate was computed to be about 2800 cm^3/min through each shield. This is equal to a stream velocity of about 140 cm/sec through the orifice, but only about 15 cm/sec past the thermocouple. Later it was found that the air sampling pumps were not strictly maintaining this aspiration rate owing to friction along the sampling apparatus. Furthermore, the aspiration rate was rather low anyway. A secondary aspiration-system was then installed to aspirate each of the 10 levels in parallel. This system increased the aspiration rate through each port by a factor of 3. Subsamples of the aspiration air are now drawn back to the instrument trailer for analysis of CO_2 and H_2O vapor.

THE THERMOCOUPLE SYSTEM

The air-temperature system was designed to measure temperature differences (ΔT) from level to level in the 10-level system. This arrangement gives 9 temperature differences. The air temperature at the bottom level is measured by referencing it to an ice bath.

The thermojunctions were made from 29 gauge copper and constantan wire. Figure 3 diagrams the arrangement in part. The system has one junction in each radiation shield (for each ΔT hookup), or 2 electrically isolated junctions in each shield. To maintain resistance symmetry in the thermopile, the lengths of wire connecting the upper junctions to the lower junctions of each T system were maintained constant. This was achieved by running the wire connecting sampling

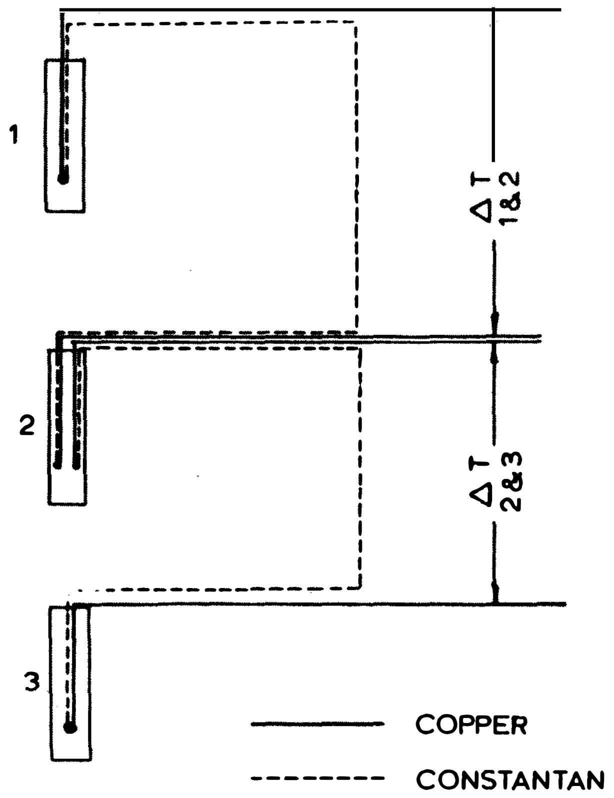


Fig. 3. Wiring schematic of the temperature profile (Δ T) system illustrating only one ΔT junction of the 10-junction system.

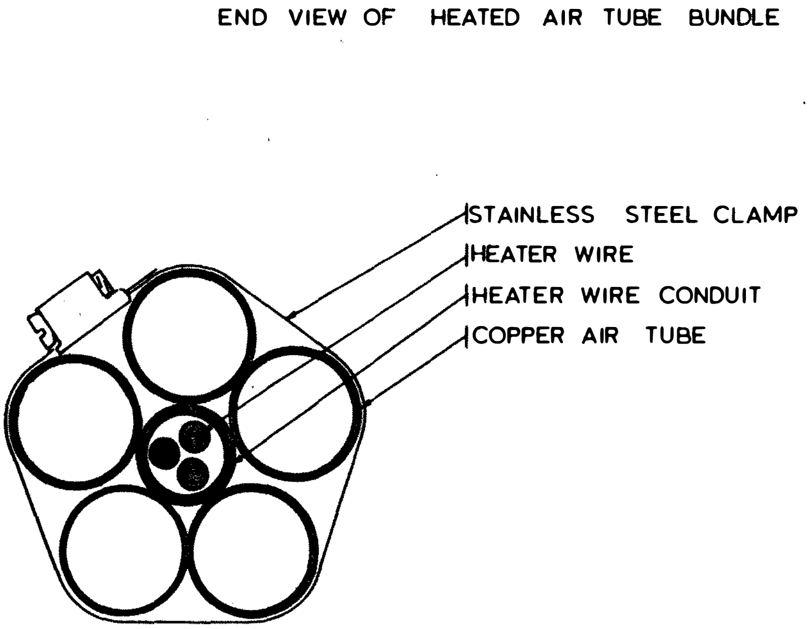


Fig. 4. Cross section of air sampling tubes leading from field to the instrument trailer.

port No. 1 of one level to sampling port No. 10 of the other level, then back to port No. 2, then back to port No. 9, etc..

A $\frac{1}{4}$-inch length of shrink-tubing was installed over each thermojunction for electrical insulation. This shrink-tubing also provided time lagging for the system.

The output of the 10-unit thermopile is connected by cable to the input of a 100-channel digital magnetic recording system.

THE AIR SAMPLING SYSTEM

Copper alloy tubing was used to draw the air from the manifold sampling system into the instrument van for temporary storage and subsequent analysis.

Copper alloy was chosen for several reasons:

1. It was available as surplus government property.
2. It can be made leak-proof and does not degas organic materials.
3. It can be bundled together and heated as a unit to prevent moisture condensation.

Figure 4 shows a cross section of the sampling tubes in the field. The tubes leading back to the instrument trailer from the 10 sampling heights are divided into two groups of 5 tubes each. In the center of the bundle is a "heater tube". Insulated nichrome heater wires are strung inside this tube, and heat conduction to the surrounding sample-air tubes prevents moisture from condensing on the walls. The heating rate is varied by a power variac.

The air from the field is pulled in by carbon vane, oil-less, rotary air-pumps. Twenty of these pumps are located under the main instrument-van. Diaphragm pumps, which can be positively sealed, may work better, but they are more expensive for the same air delivery capacity. The pumps used have a 1.1-CFM maximum capacity (without back pressure).

The intake and exhaust ports have felt filters. The intake filter traps particles coming in from the field, and the exhaust filter traps much of the carbon dust produced by natural wear of the carbon vanes of the pumps.

One of the biggest problems with this sampling system was the development of leaks around the rotating shaft of the pump. Michael Johnson, a machinist on the project, fitted a hard metal sleeve and double seals on the shaft, face to face, with lubricant between (1). The pumps when tested with these seals proved to be leak-free around the rotating shaft.

Two methods are used to test the air-sampling system for leaks. The $\frac{1}{2}$-in. copper alloy tubes leading from the sampling mast to the pumps are tested with compressed air. Both the plumbing connectors from this tubing to the pumps, and the pumps, are tested with bottled CO_2 and a 0- to 500-ppm CO_2 analyzer. With the output from a pump connected to the CO_2 analyzer, CO_2 is released near the plumbing and near the pump itself. If there are leaks, the CO_2 analyzer will readily detect them. After over 200 hours of use, the pumps with double seals are still leak-free. However, with the plumbing involved with 20 pumps, some leaks have been detected (and corrected) at the beginning of each year's research.

THE AIR-SAMPLE STORAGE AND ANALYSIS SYSTEM

The air-sample-storage system consists of 40 storage units. The system was designed to fill 20 of these units simultaneously, while the other 20 units are being analyzed sequentially. With 20 units being filled simultaneously, two 10-level sites can be sampled simultaneously.

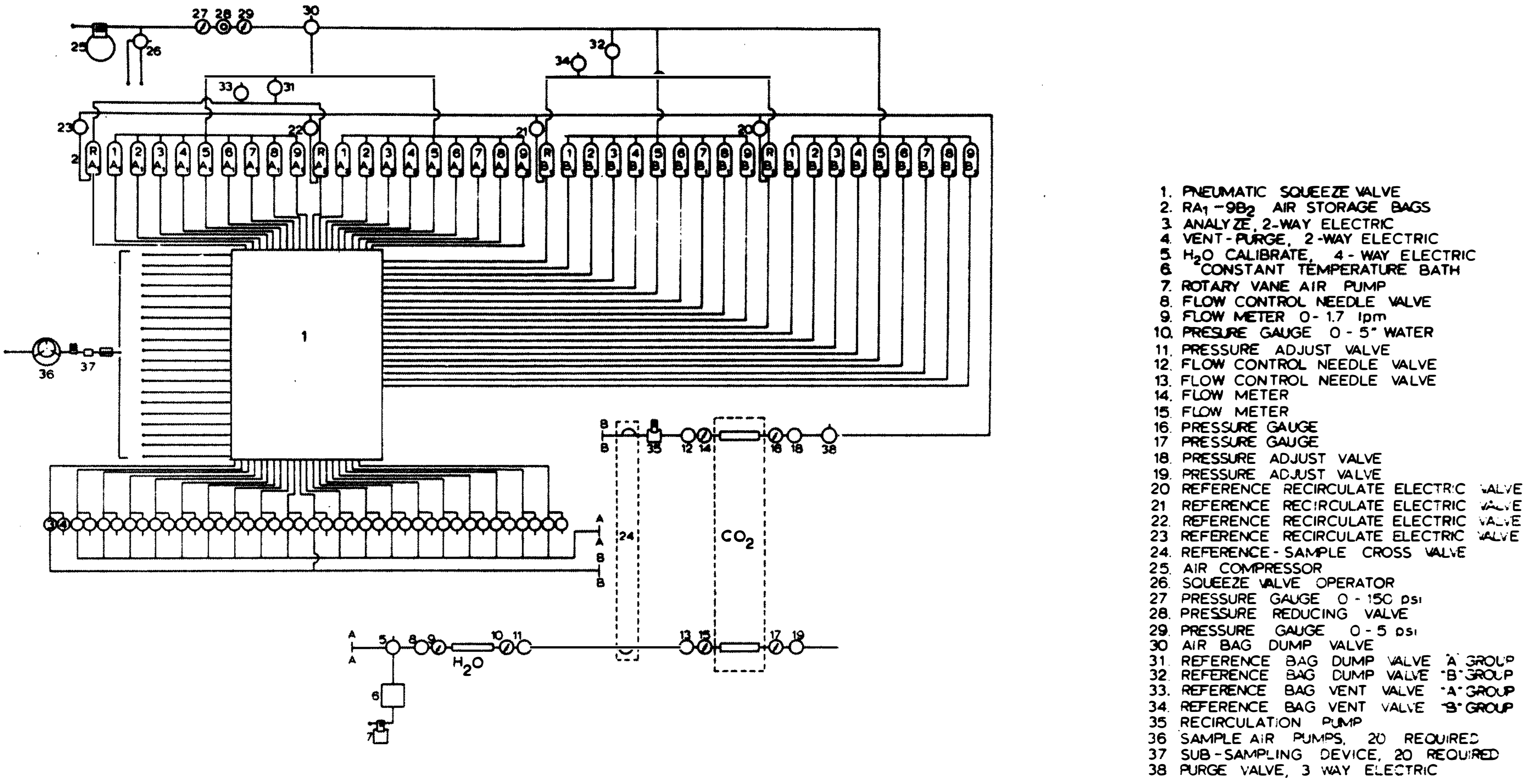
Figure 5 is a schematic illustrating the automated sampling system for CO_2 and water vapor. As the air leaves the sampling pumps, much of the air is simply exhausted through a relief valve. This relief valve consists of a weighted conical-tipped plunger which rests in a small 3/8-inch cylinder machined to match the conical shape of the plunger tip. The remainder of the air flows through a scintered metal filter and a capillary with a small needle that is fitted to bounce up and down as air flows through, thus keeping the capillary free from obstructions.

The subsampled air that remains after the excess is exhausted is forced to a 4-way squeeze valve, pneumatically operated by compressed air. Figure 6 illustrates the operation of this valve for one sampling-level of the system. This valve consists of a blade which can be pushed one way or the other against a flat frame. Short sections of latex tube are squeezed, or relieved, shutting off or opening a set of 20 air lines at a time. This valve directs the sampled air to the proper set of 20 storage bags, and leaves the other 20 bags open for analysis. The electrical operation of the squeeze valve and all other solenoid valves in the system are controlled by an automatic programmer constructed by G. Drake (1).

The air is stored in laminated bags housed in 8-liter glass jars. Figure 7 shows an early model of the sampling system, which has only 4-liter glass jars. The bags were constructed from laminated polyethylene-aluminum-mylar material with the use of a roller-type heat sealer. Leaks and weak points around the neck were avoided by heat-sealing a molded polyethylene flanged nipple to the bag. The equipment for heat sealing the bags and the intake-output neck were built at the station by M. Johnson(1).

Twenty bags are filled at a rate of about 0.2 liter per minute over a 30-minute period while the other 20 bags are being analyzed and then purged. The pressure between the air sample and the jar containing it is atmospheric while the bags are being filled. When the system switches over to the analyzed half of the cycle, 0.3 PSI air pressure is applied to each of the 20 jars. This is enough pressure to force the air from the bags through the analyzers at 1 liter per minute.

The air samples from each site are analyzed sequentially. From Figure 5 one can see that the air flows through the multiple squeeze valve into the single-cell infrared water-vapor analyzer and then through the sample cell of the infrared CO_2 analyzer. A cross valve, labelled No. 24 in Figure 5, allows the sample cell gas and the reference cell gas to be interchanged on the CO_2 analyzer.



1. PNEUMATIC SQUEEZE VALVE
2. RA$_1$ - 9B$_2$ AIR STORAGE BAGS
3. ANALYZE, 2-WAY ELECTRIC
4. VENT-PURGE, 2-WAY ELECTRIC
5. H$_2$O CALIBRATE, 4-WAY ELECTRIC
6. CONSTANT TEMPERATURE BATH
7. ROTARY VANE AIR PUMP
8. FLOW CONTROL NEEDLE VALVE
9. FLOW METER 0 - 1.7 lpm
10. PRESURE GAUGE 0 - 5" WATER
11. PRESSURE ADJUST VALVE
12. FLOW CONTROL NEEDLE VALVE
13. FLOW CONTROL NEEDLE VALVE
14. FLOW METER
15. FLOW METER
16. PRESSURE GAUGE
17. PRESSURE GAUGE
18. PRESSURE ADJUST VALVE
19. PRESSURE ADJUST VALVE
20. REFERENCE RECIRCULATE ELECTRIC VALVE
21. REFERENCE RECIRCULATE ELECTRIC VALVE
22. REFERENCE RECIRCULATE ELECTRIC VALVE
23. REFERENCE RECIRCULATE ELECTRIC VALVE
24. REFERENCE-SAMPLE CROSS VALVE
25. AIR COMPRESSOR
26. SQUEEZE VALVE OPERATOR
27. PRESSURE GAUGE 0 - 150 psi
28. PRESSURE REDUCING VALVE
29. PRESSURE GAUGE 0 - 5 psi
30. AIR BAG DUMP VALVE
31. REFERENCE BAG DUMP VALVE 'A' GROUP
32. REFERENCE BAG DUMP VALVE 'B' GROUP
33. REFERENCE BAG VENT VALVE 'A' GROUP
34. REFERENCE BAG VENT VALVE 'B' GROUP
35. RECIRCULATION PUMP
36. SAMPLE AIR PUMPS, 20 REQUIRED
37. SUB-SAMPLING DEVICE, 20 REQUIRED
38. PURGE VALVE, 3 WAY ELECTRIC

AN AUTOMATIC SAMPLING SYSTEM FOR CO$_2$ AND H$_2$O

Fig. 5. Schematic of air sample storage and analysis system for CO$_2$ and water vapor. See text for fuller explanation.

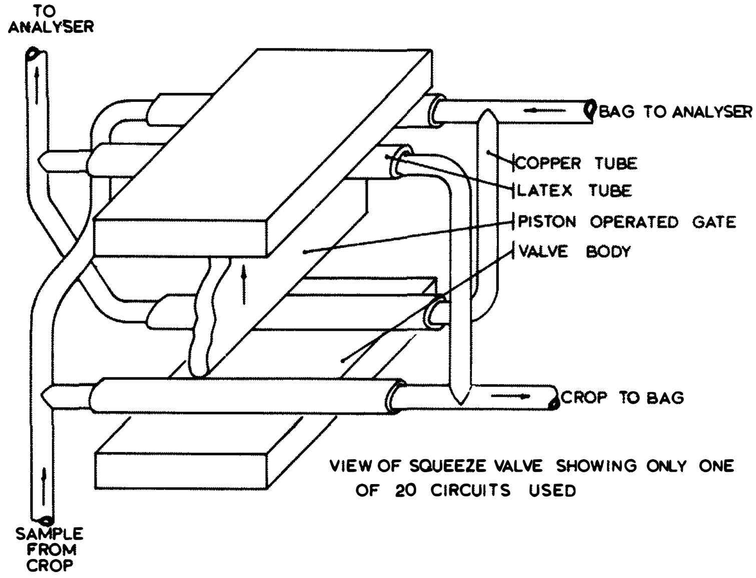


Fig. 6. Schematic illustrating the operation of the 4-way squeeze valve utilized in filling sample bags and directing the air flow from the bags to the water vapor and CO_2 analyzers.

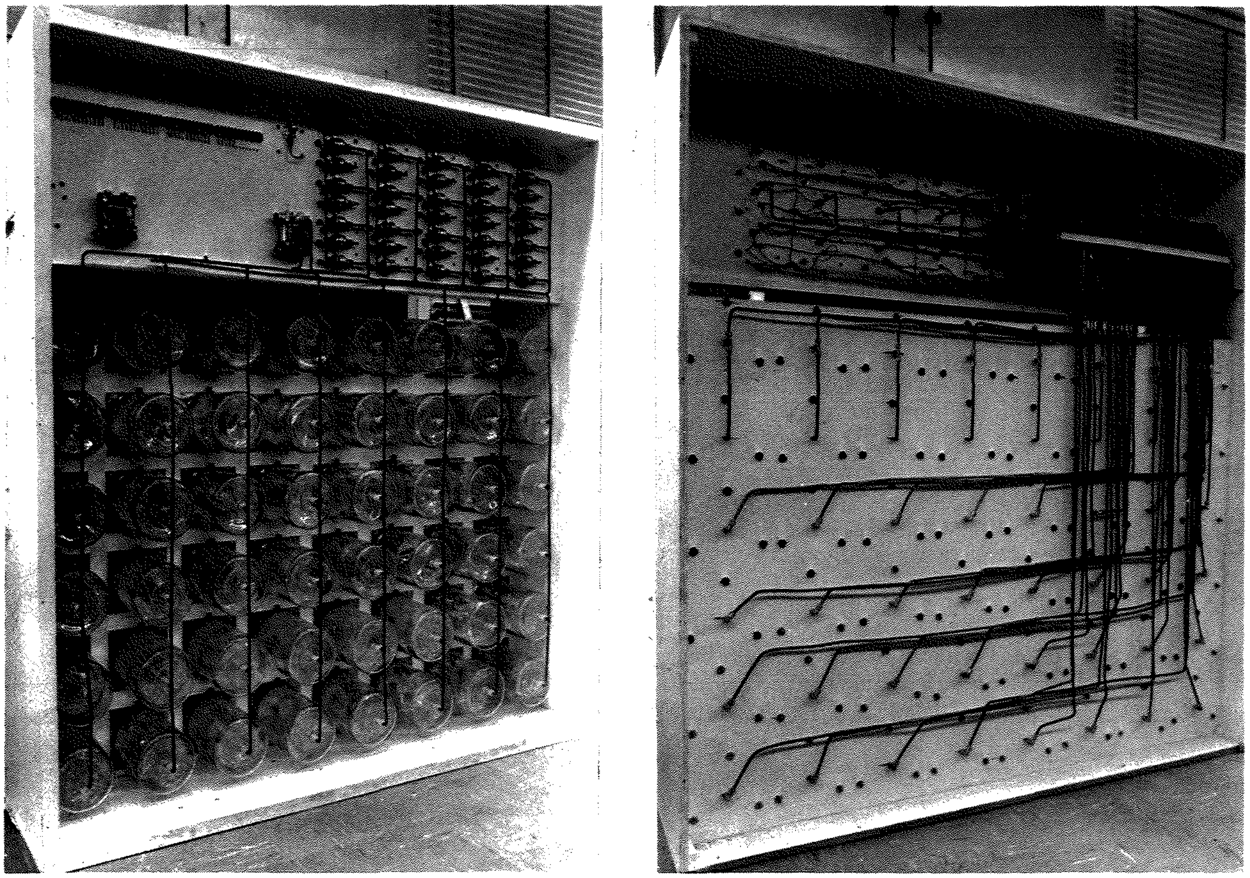


Fig. 7. View of an early model of the air sample collection and storage system. The left side (front view) shows the jar with bags inside and the bank of halves controlling flow to the analyzers and controlling the purging of the bags at the end of a run. (Labels 3 and 4 in Fig. 5). The right side (rear view) shows the plumbing and 4-way squeeze valve in the upper right corner (Label 1 in Fig. 5).

After each sample is analyzed, a valve opens and vents the bag (Label No. 4, Figure 5) to the atmosphere. The 0.3-PSI pressure between the bag and the jar containing it forces all of the air out of the sample storage bag.

The CO_2 analyzer is a long-path dual-cell infrared analyzer. One level out of each of the two 10-level sampling units must be used as a reference for this analyzer. This is usually the top level. In Figure 5, the four reference samples are labelled RA_1, RA_2, RB_1, and RB_2. While gas is being analyzed for CO_2 from any given site, the reference gas is continuously being pumped through the reference cell of the CO_2 analyzer at the same rate and pressure as the sample gas.

The absolute CO_2 concentration of the reference gas is obtained by an analyzer which continuously monitors CO_2 from one of the reference sampling levels. The water vapor analyzer is an absolute unit, calibrated in gm/m^3 of water vapor, so the concentration of water vapor from all levels is obtained directly.

The infrared water vapor analyzer is a single-beam instrument (2). A 4-sector light chopper rotates in front of the infrared radiation source. This light chopper is coated with a film transmitting at two wavelength bands, one located at a water vapor absorbing band (2.60μ), and the other at a water vapor transmitting band (2.45μ). Water vapor in the analyzer path absorbs more radiation at one wavelength than another, resulting in unequal energy at the detector when the radiation is chopped. The source radiation is chopped 3600 times per minute. This chopped radiation impinges on a lead sulfide photocell after passing through the analyzer cell. The output of the photocell is amplified and rectified, and comes out as a DC signal.

The infrared water vapor analyzer is calibrated with the use of a water bath equipped with a small refrigeration unit and a proportional temperature controller. Water is bubbled through the bath, saturating it at a given temperature, and then passed through the analyzer. A calibration curve is established, and then the calibration is monitored throughout the period of use by switching the infrared hygrometer input to saturated air from the water bath at the end of each 30-minute run. The hygrometer is housed in a box to prevent rapid temperature fluctuations. The instrument does "drift" with temperature changes; hence, frequent calibration checks are required to correct the water-vapor-profile data.

The outputs from the CO_2 and water vapor analyzers are recorded by strip-chart recorders and the data reduced directly to obtain profiles. This allows an immediate check on the system function.

The construction and operation of the CO_2 and water vapor storage and analysis system is the most complex part of the whole micrometeorological system. The coverage of its construction and function has been very brief, and covers mostly principles rather than details. Undoubtedly, many modifications of the system would work just as well or better.

The sampling system as described was designed for obtaining 30-minute mean value profiles of CO_2 and water vapor concentration to use in heat balance and aerodynamics techniques of computing CO_2 and H_2O vapor flux density. Current interest in eddy correlation techniques would require much more rapid sampling and sensing.

TEMPERATURE, RADIATION, AND WIND SYSTEMS

The main temperature sampling system coinciding with the sampling 10 levels and 2 sites for the CO_2 and water vapor was described earlier. Two other air temperature masts were constructed for use at other locations. These masts have only one radiation shield per level. All the temperature data are recorded on a 100-channel data logger to be described later.

Incident shortwave radiation (incoming total, diffuse, and near infrared) are sampled with pyranometers located above the vegetation. These radiation data also are logged on magnetic tape.

Net radiation is sampled both above and within the vegetation, typically at two locations. Within vegetation, six traversing systems were devised for pulling radiometers back and forth through vegetation for distances up to 75 ft. Each traversing system has a reversing motor, and the radiometers trip a switch to reverse the direction of travel at each end of the system. A weight-and-pulley system, patterned after a block and tackle, is used to keep the electrical leads from getting tangled up as the radiometers travel back and forth. The traversing system has been used to tow light sensors as well as net radiometers. These net radiometers and light data are recorded on the magnetic tape data logger.

Soil heat flux is usually measured at two locations by heat flow transducers.

Wind speed within the crop is measured at 4 locations by heated thermocouple anemometers. Seven of these units are used at each location. The electrical output from these sensors is filtered to remove 60 Hz heater current, and the output fed into the data logger.

Above-crop wind speed also is measured at 4 locations by cup anemometers. Six anemometers are used at each location. The pulsed output from each rotation of the cup anemometer is fed into a bank of printing counters. The printing counters can print the accumulated counts at 5-, 10-, 15-, 20-, 30-, or 60-minute intervals. A 5-minute interval has usually been used. The printing counter can be set to accumulate counts continuously, or to print and reset the counters to zero. Each channel of the two 12-channel units will print up to 5 digits of information, (or up to 99999).

Since cup anemometers do not require rapid-response recording systems, use of a printing counter frees the frequent-interval recording system of the 100-channel magnetic tape recorder for other uses. The printing counter gives a periodic display of the data; thus one can check anemometer performance periodically.

The 5-minute printouts of the printing counter are adjusted to the magnetic tape recorder schedule. Since CO_2 and H_2O data are accumulated as 30-minute averages, the 5-minute printouts of the cup anemometer data can be punched directly onto the cards and accumulated in data analysis in any time period combination desired.

Wind direction is recorded continuously on a strip-chart recorder.

DATA LOGGING

As mentioned earlier, CO_2 concentration and water-vapor-concentration data are recorded by strip-chart recorders. Most other data, except for wind direction and cup anemometer data, are logged on a 100-channel magnetic tape data logging system. Typically, 28 channels are used for heated-thermocouple anemometers, 40 channels for air temperature, 12 for net radiation, and several others for solar radiation.

Figure 8 diagrams the flow of information and the controls of the data logger. Signals from up to 100 inputs are fed into a reed relay scanner. From the scanner the signal may pass through a patch panel which controls the signal level presented to the amplifier by factors of 10, or the signal may pass directly to the amplifier. From the amplifier information flows to the analog-to-digital convertor, thence to the serializer, and thence to magnetic tape.

Controls allow manual entry of numeric information (for tape identification and processing purposes). Clock information may be recorded at the beginning of each scan, or deleted as desired. A Begin Channel and an End Channel selector switch permits one to record information from any set of channels between the selector switch positions.

The scanner rate of the system can be set to 50 channels per second or to 4 channels per second. The latter scanner-rate was included so that a paper tape printer (not illustrated in Figure 8) could be used for checking out the systems. This paper tape printer has proved to be invaluable for debugging the sensor and logger functions. No magnetic tape data logging system should be without a printer for checkout purposes.

The scan initiation rate of the logger can be set at 1 per second, 1 per 10 seconds, 1 per minute, 1 per 10 minutes, or 1 per hour. So there is a 3600-fold range in time intervals over which data may be taken. Once a scan is initiated, it overrides the scan initiation function. For instance, if one is logging 51 channels of data, and the scan initiation rate switch is set at 1 per second, the actual scan initiation rate will be 1 per 2 seconds.

The range of inputs to the data logging system can be varied, i.e., ±9.999 millivolts, ±99.99 millivolts, ±999.9 millivolts, or ±9.999 volts, by use of the patch panel illustrated in Figure 8. This capability covers the range of outputs of most sensors. The input ranges are changed by inserting pinboard cards into groups of 10 channels that are to be changed. Each channel may be changed independently of all others.

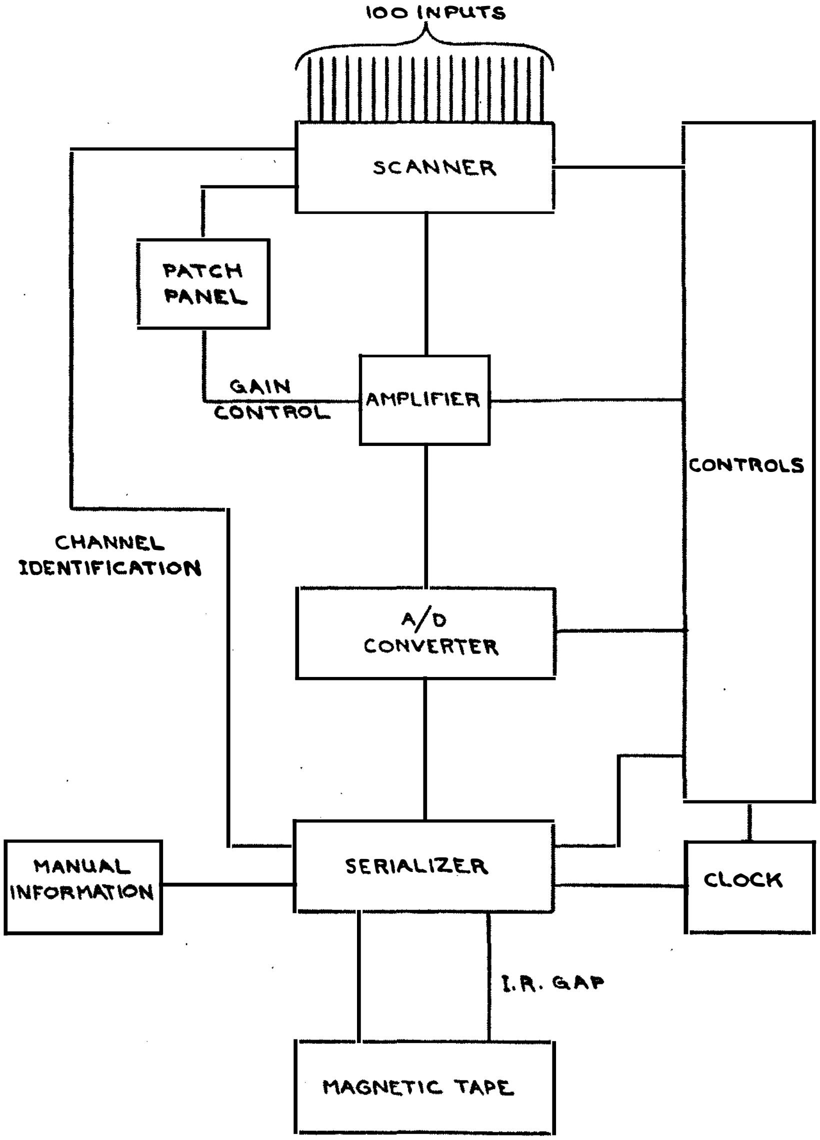


Fig. 8. Schematic diagram representing the controls and flow of signals in the 100-channel magnetic tape data logging system.

Data are logged on magnetic tape in 8-character units per data word, including 2 characters for channel identification (00 to 99), 1 character for input range identification (as described in the previous paragraph), 1 character for sign (±), and 4 characters for data. Data are recorded on ½-inch tape in BCD on 7 tracks at a packing density of 200 BPl. Figure 9 illustrates the data format on the tape.

This data logger was a custom built, one-of-a-kind system. There were some delays in delivery, and problems with the system function. In 1968 and 1969 it has given good service. However, one should choose off-the-shelf data logging equipment if possible.

Since often we wish to log more than 100 channels of information, a sharing procedure was worked out. The input pins to the data logger were spread out over a 2-ft. x 3-ft. input board for easy access. Four-pin connectors were used, which can be disconnected easily. Two pins of the connector were used for sensor signals, and another for shielding. By using the quick-disconnect connectors, more than one type of sensors could be used, but at different times. For instance, on certain days only light penetration into the crop canopy was measured. The light sensor leads could be quickly plugged into the input board, and later disconnected to make room for other data inputs.

The data that were logged on magnetic tape were processed by an IBM 360/65 computer[2] at Cornell University. Because of problems associated with logging the data, the computer-controlled tape reading procedure had to be modified by using a special subroutine written for us by Cornell University computer service personnel.

The data logging system was purchased with the view of processing tapes with a Control Data Corporation 1604 computer. But by the time the system was delivered and made operational, the computer was being phased out and replaced by an IBM 360/65. Some tapes were read on the CDC 1604 systems without any problems. However, the IBM 360/65 was much more difficult to use.

1. The system was set up to handle only "labeled" tapes. To get around this required special programming.

2. The system was set up to reread a tape file 100 times in case of error. Turning the tape recorder off and on between runs in the field caused tape reading errors at the beginning of new runs. Rereading a file 100 times and still not reading correctly was very wasteful of time. This problem required special programming to bypass the system reread feature.

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[2] Mention of proprietary products is not to be construed as endorsement by the U.S. Department of Agriculture.

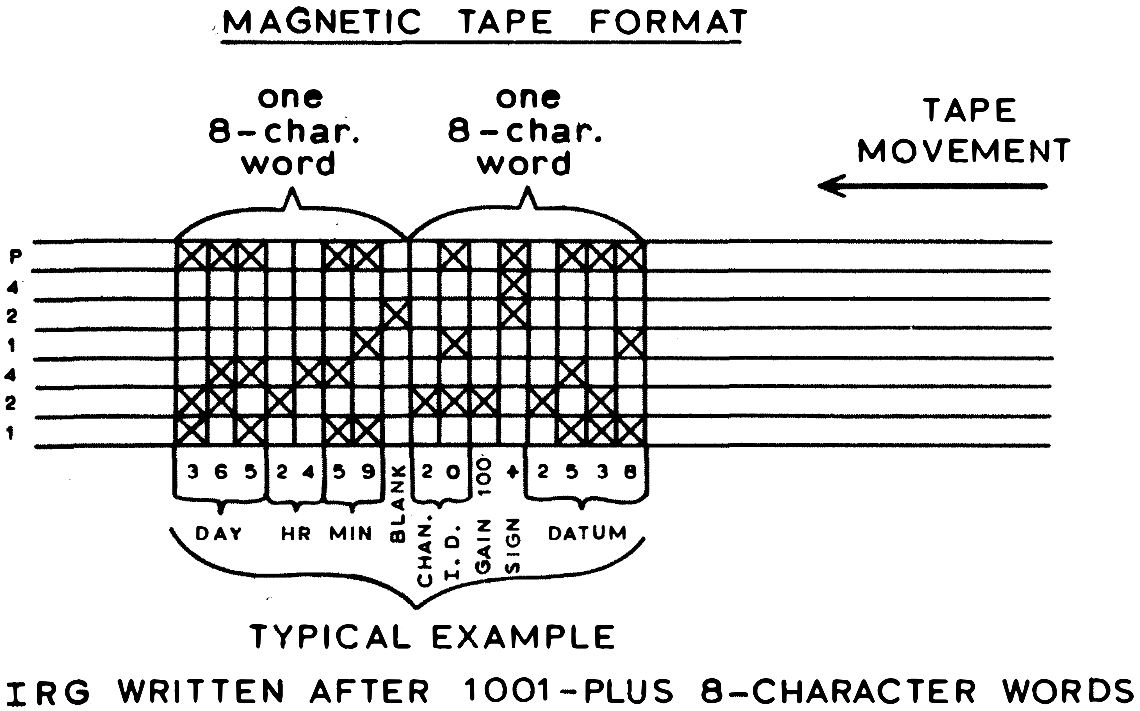

Fig. 9. Format of data recorded by the 100-channel magnetic tape data logging system.

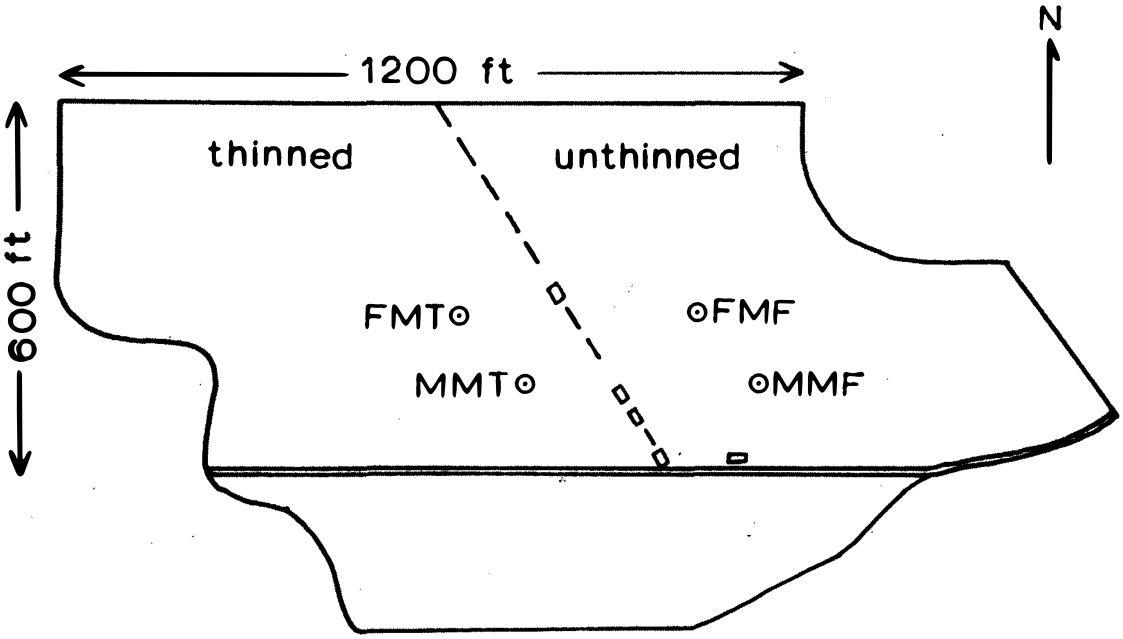

Fig. 10. Diagram of the lay-out of the 1968 corn field at Ellis Hollow, Ithaca, New York. The field instrumentation was located at FMT (Forward mast thinned), MMT (main mast thinned), FMF (forward mast full), and MMF (main mast full).

3. The IBM 360/65 operations allowed only computer-service personnel to use the machine. The setup with the CDC 1604 allowed individuals to reserve time to process their own personal jobs. The older system was much more convenient to us in this respect.

4. Only one (slow) 7-track tape drive unit was available with the IBM 360/65 system.

The problems in using the IBM 360/65 were finally resolved by reading the data from a 7-track field-logged tape onto a disc, editing and writing the data again on to 9-track tape. The 9-track tapes were then used for final data-processing. Reading and editing the 7-track tape was time-consuming and costly. Processing the 9-track tape usually required only about 10 minutes of computer time for a complete tape.

It has been our experience that a small, readily accessible computer has more advantages in processing field-logged magnetic tapes than does a large, complicated, relatively remote facility.

The routinely processed micrometeorological data were printed out in intervals of 30 minutes (or as a complete run, whichever was shorter) with 5-minute subintervals. The data printed out were averages, maxima, minima, and standard deviations. Also, some of the 30-minute averages were punched on cards for further analysis.

ANALOG RECORDING SYSTEM

In addition to the digital magnetic tape system, a 7-channel FM analog recording system is also used to record data requiring a higher frequency response recorder. This instrument has a record/reproduce capability of from 15/16-inch to 60 inches per second. In addition to the basic tape recorder, input filters, differential amplifiers, one dual-trace monitor oscilloscope, and 7 output monitor meters have been assembled.

This system has been used to record outputs of heated thermocouple anemometers, differential pressure transducers, small wire, fast-response thermocouples, a vertical anemometer tachometer, a fast-response CO_2 analyzer, and photocells. Currently, it is used mostly as the recording instrument to measure flux of CO_2 and heat by the eddy-flux method.

In the past, data from this instrument were digitized by an A to D convertor and processed with a CDC 1604 computer. Currently, data are put through analog inputs to an IBM 1800 computer, which digitizes and processes the information.

SOME EXPERIMENTAL RESULTS

During 1967 and 1968, the primary experiment was a variable-density experiment in corn. During a 30-minute interval, within-crop wind, air temperature, and above-crop net radiation data were logged. During the

the next 30-minute interval, the within-crop wind was dropped, and within-crop net radiation included. This alternation was repeated while data were being logged.

During August and September 1968, special studies of wind flow and partitioning of energy into latent heat, sensible heat, photosynthesis, and soil heat were conducted. Seven periods were covered which included data from parts of all of 13 days.

Figure 10 shows the field layout for the 1968 experiment. The left-hand side of the field as shown in the figure was thinned three times during the season, while the right-hand side remained at the original planting density of 26,000 plants per acre. The field arrangement was used to take advantage of prevailing northwest winds when weather was good.

The mast sites are designated by FMT (forward mast, thinned), MMT (main mast, thinned), FMF (forward mast, full density), MMF (main mast, full density). The air samples for CO_2 and H_2O vapor analysis were taken at the MMT and MMF sites. Wind speed and air temperature measurements were also made at those sites. Only wind speed and air temperature (using another type of system having a single aspirated radiation shield per level) measurements were made at the FMT and FMF sites.

Figure 11, shows wind speed profiles and leaf area density (F) for the sites on August 15, 1969. The thinned corn had a stand density of 18,000 plants per acre. The lower wind speeds are averaged from 1800 to 2030 EST. The higher wind speed profiles show that the total air flow past each mast was nearly the same from 0800 to 1730 EST. However, 30-minute profiles vary from site to site, and 5-minute profiles are even more variable.

CO_2 and water vapor profiles for August 15, 1968 are shown in Figure 12 and temperature profiles in Figure 13. During the daylight hours, the CO_2 profiles have a more pronounced minimum in the unthinned corn than in the thinned corn. Also the thinned corn has less CO_2 near ground level. The water vapor profiles show a pronounced hump at the 120-cm sampling level in the unthinned corn. The temperature profiles during the daylight hours also show a hump near 120 cm, which is more pronounced in the unthinned than in the thinned corn. All the above differences are caused by differences in plant density, which in turn affect radiant energy exchange and aerodynamic transport in the vegetation.

Soil heat flux and net radiation at 6 levels were also measured in both the thinned and unthinned crop.

By the energy balance method (3), transfer coefficients were computed for each of the runs on August 15, 1968. The transfer coefficient, K, is given by

$$K(z) = \frac{R(z) - S}{\frac{d}{dz}\left(\lambda C(z) - c_p \rho T(z) - \ell \rho_w(z)\right)} \qquad (1)$$

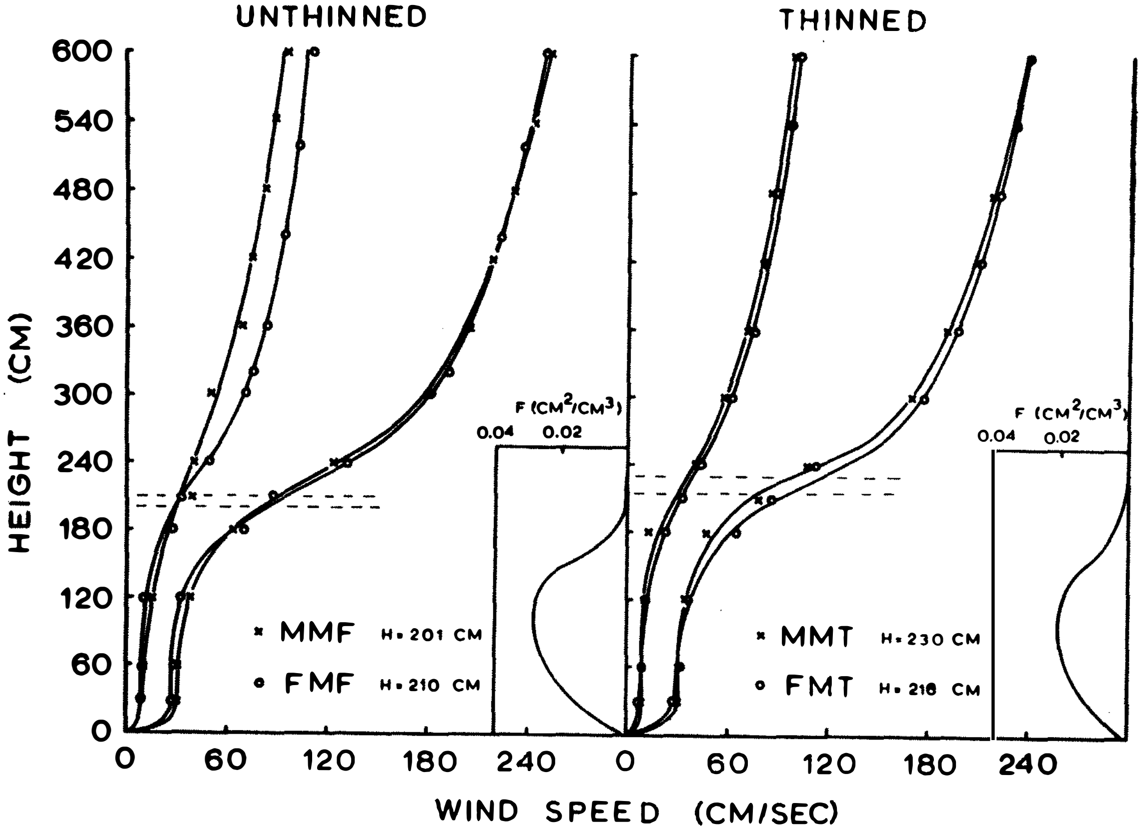

Fig. 11. Wind speed profiles averaged over the period 0800 to 1730 EST (higher wind speeds) and over the period 1800 to 2030 EST (lower wind speeds). Also included are the leaf area density distributions for the unthinned and the thinned portions of the cornfield and the average corn heights (H) at the four mast locations. August 15, 1968, Ellis Hollow, Ithaca, New York.

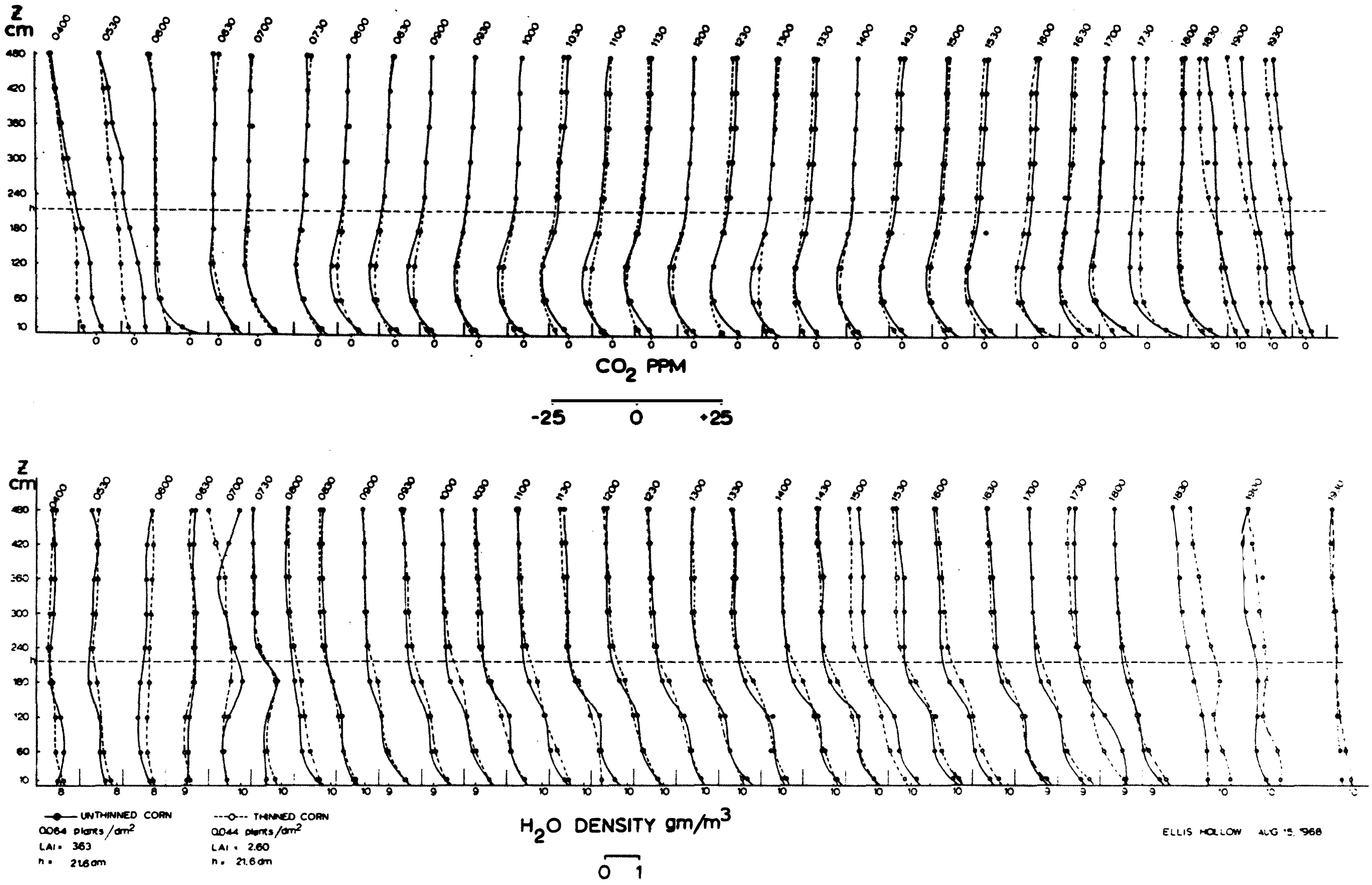

Fig. 12. Carbon dioxide and water vapor profiles in an unthinned and a thinned corn crop, August 15, 1968.

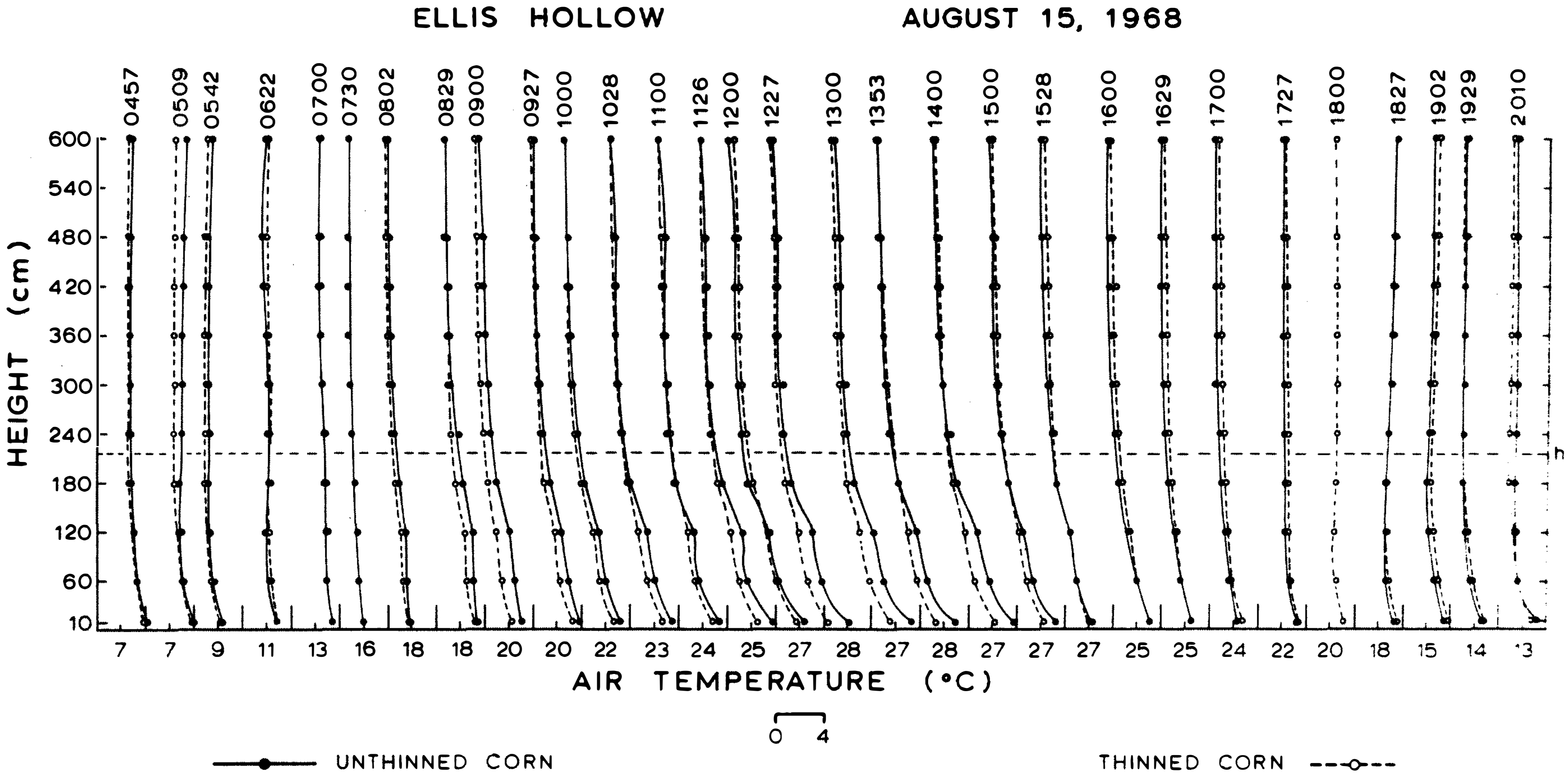

Fig. 13. Temperature profiles in an unthinned and a thinned corn crop, August 15, 1968.

where z = height above ground
R = net radiation flux density
S = soil heat flux density
C = CO_2 concentration
ρ_w = water vapor density
T = air temperature
λ = thermal conversion factor for CO_2 fixation
c_p = heat capacity of air
ℓ = latent heat of evaporation

The profiles of air temperature, CO_2 concentration, and water vapor concentration were smoothly drawn from actual data points. Values at 15-cm intervals were punched onto cards, and these values were used to compute transfer coefficients and flux densities at various heights. Net radiation at six levels was fitted to a quadratic equation

$$R(z) = A + Bz + Cz^2 \qquad (2)$$

with A, B, and C chosen to minimize the root mean square of the deviation of the six values from R(z) at the given z.

An error-analysis technique by Groom (4) was applied to all the data used in the energy balance method for computing transfer coefficients and flux densities of heat, water vapor, and carbon dioxide. The uncertainties used in this method were (units = cal/cm^3):

$$\ell\Delta\rho_w = 0.5795 \times 10^{-3} \times (\pm 0.01)$$

$$\lambda\Delta C = 0.48 \times 10^{-5} \times (\pm 0.1)$$

$$c_p\rho\Delta T = 0.2844 \times 10^{-3} \times (\pm 0.05)$$

The soil heat flux density was estimated to have an uncertainty of ± 0.05 cal/cm^2/min. The net-radiation uncertainty was taken as the r.m.s. value obtained in its computation according to Equation (2).

Figure 14 shows the computed transfer coefficients, K, for 1200 EST, August 15, 1968 for both the thinned and unthinned corn. Horizontal bars represent the uncertainty of the computations according to the technique Groom used (4).

The most noticeable feature of the vertical profile of transfer coefficient is that there is a pronounced minimum between 120 and 180 cm. This minimum is especially pronounced in the unthinned corn. The shapes of the water vapor and temperature profiles explain why the K profile shows a minimum there. Evidently, the corn crop canopy tends to suppress mixing air from above as the leaf area density gets large. Figure 11 shows that the leaf area density goes up quite rapidly between 180 and 120 cm. Another factor which may suppress mixing in this canopy is the fact that the corn was hill-dropped 18 inches apart in 15-inch rows. Thus the stand structure was quite uniformly dense, leaving fewer channels for air flow than would exist in wider row corn.

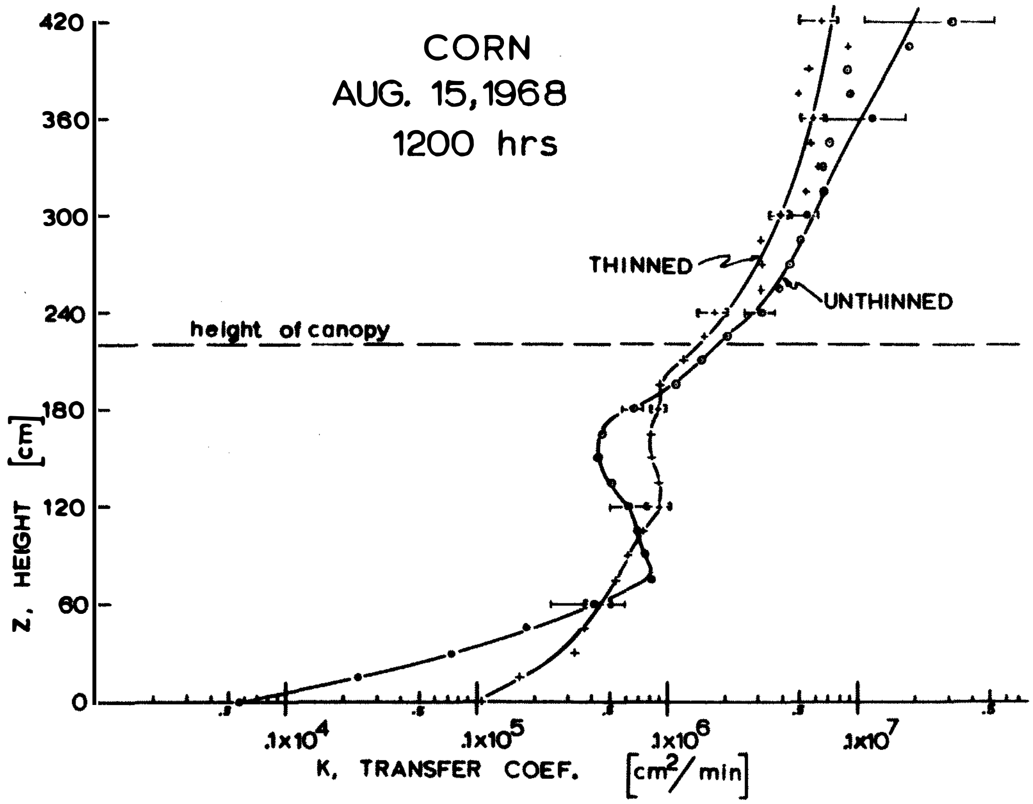

Fig. 14. Transfer coefficient as a function of height at 1200 EST computed at 15-cm intervals. The horizontal bars represent the uncertainty range in the calculations.

Another feature of the K profile in the unthinned corn is that it drops off more rapidly than the K profile in the thinned corn as the ground level is approached. This is probably due to denser vegetation restricting vertical motion near the ground, and due to denser vegetation shading more of the soil surface, resulting in less buoyant convection.

The wind speed profiles shown in Figure 11 have almost no gradient from 120 cm down to 30 cm. This phenomenon means that the momentum balance approach (3) cannot be applied to this crop system, since the momentum balance requires that a wind speed gradient exist to compute a momentum-based transfer coefficient, K_m

$$K_m = \frac{\tau(z)/\rho}{du/dz} \qquad (3)$$

where z = height
τ = shearing stress
ρ = air density
u = wind speed

The problem of du/dz approaching zero or even becoming negative is also always met in forest stands (5).

The shape of the wind speed profiles in this vegetation throws some doubt on the special assumptions of the momentum balance approach to computing transport in dense crops. But transport does occur, and it may be that transport is enhanced by thermal or mass diffusion buoyancy.

The diurnal courses of latent heat, sensible heat, and photochemical-energy-flux density at several heights for August 15, 1968 are currently being computed, but will not be included here.

APPLICATIONS TO FOREST MICROMETEOROLOGY

The systems described here appear to work very well for agricultural crops. Many of the components of the overall system, such as the gas storage and analysis apparatus, the data logging system, and the principles of radiation shielding, are just as applicable to forest micrometeorology. Problems may arise in deciding on spacial sampling arrangements for gas analysis, temperature, and net radiation. Most tree-crowns do not close near the top; they even may not overlap at all. Flow may be around rather than through dense crowns.

The trunk space in forests may allow wind to blow through directly (5) or even somewhat randomly.

The physical size of the typical forest system itself presents many more practical obstacles to constructing, testing, and servicing sampling systems.

ACKNOWLEDGMENTS

The assembly of the data logging system, the construction of the sampling and sensor system, and the processing of microclimate data has been a team effort, involving professionals, skilled technicians, graduate students, and programming and computer specialists, including Edgar R. Lemon, Michael N. Johnson, George M. Drake, Douglas W. Stewart, Steve Powers, R. Wayne Shawcroft, Melinda Groom, and Ronald M. Cionco.

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(2) Wood, R. C. 1958. Improved infrared absorption spectra hygrometer. Review Sci. Instrum. 29:36-42.

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(5) Allen, L. H. Jr. 1968. Turbulence and wind speed spectra within a Japanese larch plantation. J. Appl. Meteorol. 7:73-78.

APPENDIX

LIST OF IMPORTANT EQUIPMENT

1. Pumps: Gast Manufacturing Co.
   Model 0211

2. CO_2 Analyzers:
   - (a) Differential: Mine Safety Appliance Co.
     Model Lira 100
   - (b) Total: Mine Safety Applicance Co.
     Model Lira 200
   - (c) Fast-response (Modified): Beckman Instruments Co.
     Model 315

3. Data logger: A. D. Data Systems, Inc.
   (Custom-built)
   - (a) Paper Tape Printer: Hewlett-Packard Co.
     Model M37 565A
   - (b) Digital Tape Recorder: Digi-Data Corp.

4. Analog Recorder/Reproducer: Sanborn/Ampex Model 2007

5. Printing Counters: Machinery Electrification
   Model MEK ZDG $\overline{\underline{V}}$

6. Water Vapor Analyzer: Modern Controls
   (Custom-built)

7. Cup Anemometers:
   - (a) Cardion West
     Counter Register Control Model 20-23
     Transmitter Model B-25
   - (b) C. W. Thornthwaite Associates

8. Heated Thermocouple Anemometers: Hastings-Raydist Inc.
   Air Meter Model RM-1x
   Probe Model N-7B

9. Quartz Thermometer: Hewlett-Packard Co. Dymec Division
   Model DY-2800A

10. Air Sample Storage Bags (Polyethylene-Aluminum-Mylar):

    Milprint, Inc.
    4200 N. Holton Street
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POWER-SPECTRUM ANALYSIS OF THE ENERGY CONTAINED IN SUNFLECKS[1]

By

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Unreported experiments performed at the Connecticut Agricultural Experiment Station have indicated that the phenomenon of shade tolerance may be related to the speed with which the photosynthetic apparatus of plants in the understory responds to sudden increases in light intensity. Leaves of shade-tolerant species may be able to open stomata and commence assimilation of carbon dioxide and water rather more quickly than leaves of shade-intolerant species. Indications are that shade-tolerant species may respond in a matter of minutes, whereas shade-intolerant species may require ten minutes or longer. We undertook a field study to determine the solar energy available in sunflecks of different durations in two forest stands of widely differing crown characteristics. One was a second growth hardwood stand with a closed canopy; the other was a heavily thinned red pine stand.

Measurements of global and diffuse shortwave radiation were made at two locations at ground level in each stand. Similar measurements were also made in the open nearby to approximate above-canopy radiation data. Data were collected automatically at one-half-minute intervals throughout the daylight period. From these data, the direct beam component of the sunlight could be calculated. Data obtained during two cloudless days in July 1968 (one day in each stand) were used in the analysis.

In order to estimate the energy in the sunflecks available for photosynthesis, the data were subjected to a standard power-spectrum analysis. Since only an analysis of the sunflecks was desired, data from those periods when the radiometers were in leaf shadows were eliminated. In order to partially correct for non-stationariness of the time series, radiation values measured on a horizontal surface were converted to normal incidence radiation by the cosine law. Lastly, in order that the power-spectrum estimates would be in correct units, the square root of the normal-incidence energy was used as the basic input.

The two stands showed greatly different sunfleck patterns. In the hardwood stand, there was a predominance of short-duration, low-intensity sunflecks, although large holes in the canopy produced sunflecks of forty or fifty minutes duration. By contrast, the red pine stand produced few sunflecks of very short duration and relatively more sunflecks with a duration greater than ten minutes. In both of the stands, short-duration sunflecks were generally of low intensity, whereas longer sunflecks had a higher intensity. The maximum intensity that the sunfleck could have in both stands can be represented approximately by the equation

$$y = 0.0667x$$

where y is the maximum intensity in langleys per minute and x is the duration of the sunfleck in minutes.

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[1] Research supported by the Atmospheric Sciences Section, National Science Foundation, NSF Grant GA-913.

The power-spectrum analysis showed that most of the energy was contained in sunflecks of greater than ten minutes duration. This was true in both stands (Table 1). About ten percent of the energy was contained in sunflecks of three to ten minutes duration and a very small percentage was in sunflecks of less than three minutes duration. It should be noted that the total amount of energy in the short-duration flecks was relatively constant even though the percentages varied, inasmuch as the higher percentages were associated with lower total energy for the observation period.

Because most of the energy is contained in long-duration sunflecks in both stands, it can tentatively be concluded that short-duration sunflecks do not contribute greatly to total photosynthetic assimilation. It seems likely that a steady state model for photosynthesis in direct sunlight under forest canopies is appropriate.

Table I. Distribution of direct-beam energy in sunflecks*

Percentage of total

Period	Hardwood				Red Pine	
(min.)	Location 1		Location 2		Location 1	Location 2
	AM	PM	AM	PM	all day	all day
10	90	74	81	91	87	91
3-10	8	13	12	7	12	8
3	2	13	7	2	1	1
Total** (langleys)	389	80	149	255	293	375

* Sunflecks only--shaded observations deleted from analysis

** 6-hour periods for hardwoods; 8½-hour periods for red pine; energy on surface facing sun.

DIODES FOR TEMPERATURE MEASUREMENT

By

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ABSTRACT

Attempts to use diodes for temperature sensors as suggested in the literature failed. Investigations of various types of diodes reveal that the desirable characteristics should include high conductivity, and low leakage. They should not be gold-doped or treated in any way to increase their speed and recovery time. A Fairchild FD-300 silicone planar diode has these desirable characteristics. When supplied with a 0.5 milliamps current, the diode has a sensitivity of 2 millivolts per degree centigrade from 0 to 100°C and a repeatability within 0.05°C. It exhibits long-term stability as a temperature sensor.

DISPERSION INTO AND WITHIN FORESTS[1]

By

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ABSTRACT

Experimental studies of disperson into and within a 10.5-m-tall pine forest have been conducted at Brookhaven National Laboratory for 5 years. In support of these studies, measurements of wind speed, temperature, and turbulence were taken in, over, and outside of, the forest. Wind speeds were measured at several heights in the open, at the edge, and at four distances in the forest by sensitive anemometers. Temperatures were measured with aspirated thermocouples at four or more heights at one location in the forest and one in the open. Turbulence measurements were taken with two sensitive bivanes, one usually mounted in the forest and the other at a similar height in the open. Data were collected intermittently and classified with respect to wind direction relative to the forest edge, wind speed, gustiness, and cloudiness. They were analyzed by means of normalization with respect to reference locations above and outside the forest and by computation of correlation coefficients and regression equations between each location and selected reference positions.

Orderly and predictable relationships were found between wind speeds in the forest and those in the clearing and above the trees. With winds penetrating the forest edge, speeds in the trunk space were greater than those in the canopy for a distance of about 60 m. With a longer fetch through the forest, wind speeds varied little with height to mid-canopy.

Since the crown acts as the major active surface in the forest, lapse rates below were generally opposite in sign to those over open terrain, but also exhibited a distinct diurnal cycle. During the day, a temperature inversion was found beneath the canopy and a negative lapse rate above. During the night, an isothermal layer or a slight lapse below the canopy and an inversion above were typical.

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[1] This work was carried out under the auspices of the U.S. Atomic Energy Commission and the New York State Museum and Science Service and was supported in part by U.S. Public Health Research Grant No. AP-81 to Dr. E. C. Ogden from the National Air Pollution Control Administration.

Analysis of eight bivane runs showed that σ_u, σ_v, and σ_w were smaller in the trunk space than at similar heights in the open but were much larger in the canopy. The intensity of turbulence also showed a maximum in the crown. Graphs of spectral density and spectra of the u, v, and w components are presented. In the trunk space, turbulent kinetic energy was much less than in the open but increased with height and reached comparable values above the forest. No significant difference in peak frequency was found between the open and the forest spectra.

Dispersion tests from a continuous point source, lasting about 40 min. each, were conducted from the clearing upwind of the forest edge, from within and from above the forest. Although a variety of tracers were used, strained ragweed (Ambrosia) pollen was most frequently employed. Releases were made at distances to 60 m. from the forest edge and to 14 m. in height, usually from three locations simultaneously. Area source releases were provided by pollen from a field of ragweed outside the forest edge. Data from a number of selected tests are presented. In contrast to dispersion in the open, the plume was widened both vertically and horizontally at the forest edge. Rate of loss of particulates was greater in the forest than over open terrain and occurred primarily in two stages and by two mechanisms, impaction on the foliage in the first 10 m. where wind speeds were still relatively strong and by deposition beyond 50 m. in the forest where forward transport of the plume became slow.

Releases just inside the forest edge with penetrating winds resulted in rather narrow plumes. Releases at low levels inside the forest followed the mean above-canopy wind in some cases but not in all. Much material released in the forest rose upward and penetrated the crown while many particles released above the canopy descended to the trunk space. Spores and pollens of three dissimilar sizes and shapes (Ambrosia, Lycopodium and Cronartium) dispersed in a similar fashion when released from the same location in the trunk space but larger spores of Osmunda travelled a shorter distance and decreased in concentration more rapidly.

DISPERSION INTO AND WITHIN A DOUGLAS-FIR STAND[1]

By

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ABSTRACT

A three-dimensional sampling grid was established within a 45-year-old stand of Douglas-fir adjacent to a 12.1 ha clearcut for the purpose of studying the dispersion of Fomes annosus (Fr.) Cke. spores and fluorescent particles into and within the stand in relation to meteorological parameters.

A total of 111 rotorod samplers were used to trap the tracers within a canopy volume of 20 m in height, 210 m in width and 270 m in length. Wind speed and direction and air temperature were monitored on five towers located on a line perpendicular to the forest wall.

Thus far, 16 simultaneous three-location releases have been made with instantaneous point sources. The data from one release are presented.

INTRODUCTION

Diffusion and dispersal of gasses, pollutants, pollens, and spores into the atmosphere from point, line, and area sources has received a great deal of attention in the past and will receive more attention in the future because of air pollution problems. Many models have been developed to predict the spread of materials in the free atmosphere. However, diffusion and dispersal of aerosols into vegetative canopy has received only limited attention because of the difficulties involved. The importance of this type of investigation cannot be overemphasized because the spread of insect and pathogenic microorganism are controlled in part by transport of gasses and particulate within canopies. Economic losses could be limited if the spread and build-up of insects and pathogens could be predicted.

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[1] This research was supported in part by the Atmospheric Sciences Research Technical Area, ASL, USAECOM, Ft. Huachuca, Ariz.

Biological staining techniques have made possible simultaneous studies of dispersion of ragweed pollen into a forested area from several sources (Raynor et al.,1966). These results indicate that the penetration of ragweed pollen into a forest can be predicted from meteorological data. Dosage measurements compared favorably with values calculated from Sutton's (1947) diffusion equation modified for deposition by Chamberlain (1953).

Similar studies are needed for smaller biological materials which may penetrate farther into the forest. Ragweed pollen is about 20 microns in diameter and has a settling rate of 1.56 cm sec^{-1}. Additional information is needed concerning the viability of the deposited material and the probability of infection by forest pathogens. One such organism is Fomes annosus (Fr.) Cke. It is a forest fungus of great potential pathogenic abilities and spreads by airborne asexual and sexual spores of 5 microns in size.

The purpose of this paper is to present a description of an experimental site and materials used to study the dispersion of spores of Fomes annosus and fluorescent powders into and within a forest canopy.

EXPERIMENTAL METHODS

The experimental site is located about 70 miles south of Seattle near Mount Rainier, at the confluence of the Maschel and Nisqually rivers. The naturally regenerated vegetation in the area following a forest fire in the 1920's consists of Douglas-fir, bracken fern, salal, trailing blackberry, hop clover, geraniums, and other herbs and short shrubs. The trees are 20 to 30 m high and are of class 4. The vegetation has been sampled by established forestry procedures to facilitate relating this stand to other stands.

A sampling grid was established between the interface of a clearcut and a forest. Owing to the prevailing wind systems, vegetation irregularities, and topography, a parallelogram-shaped sampling grid was established (Fig. 1). The grid consisted of nine rows spaced at 30 m intervals, lettered A to I with row A being at the forest wall interface and 7 columns spaced at 30 m intervals. The 9 x 7 grid established 63 sampling nodes. Along colums 2 and 6, non-climable towers were erected at rows A, C, E, and G and along row 4, climable towers were established at A, B, E, and D, with one additional climable tower located at AA4. All towers with the exception of AA4 and G were 21 m high. AA4 and G were originally 30 m high. G4 has since been extended to 37 m.

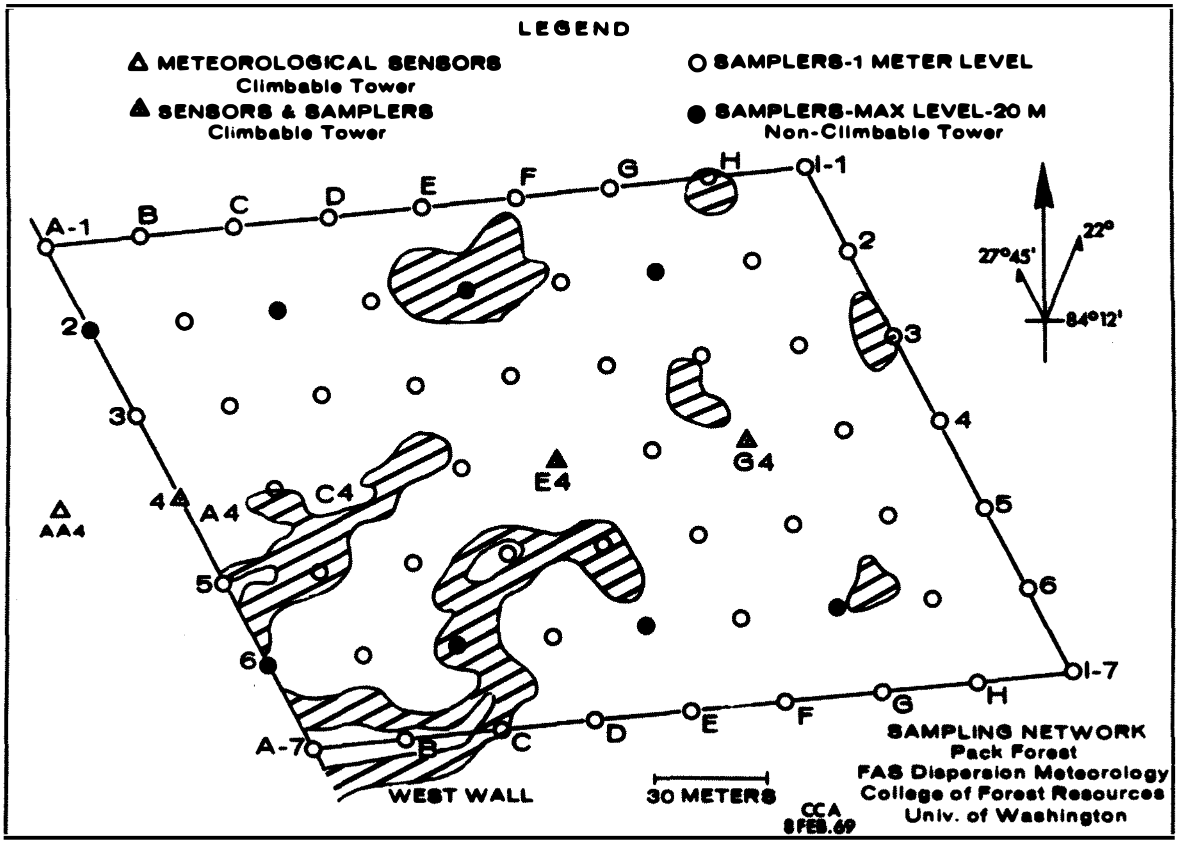

Fig.1. Map of the experimental site showing the location samplers, meteorological sensors and significant disease holes.

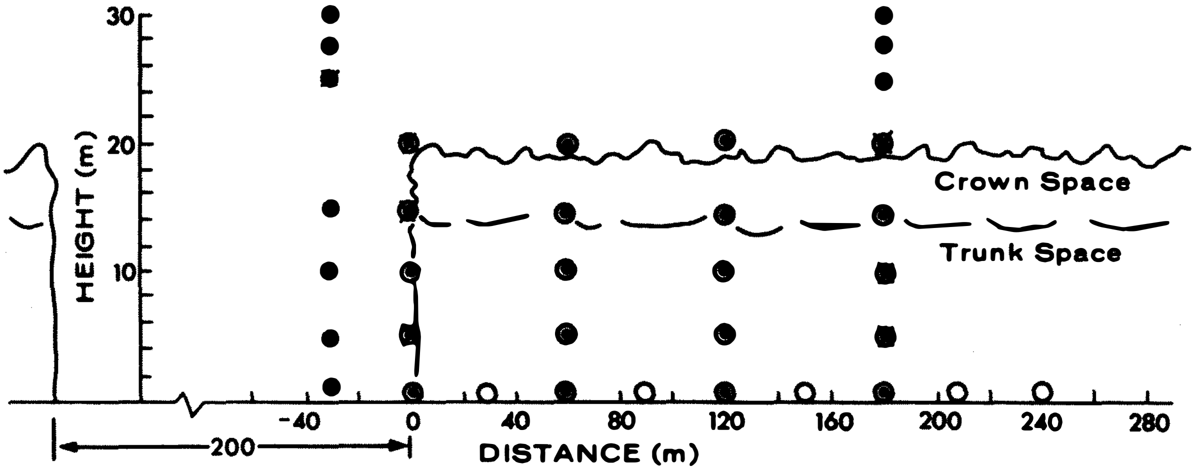

Fig.2. Location of meteorological sensors and samplers along column 4; wind vane (X), temperature sensor and anemometer (●), and sampler (O).

Rotorod samplers were located 1 m above the forest floor at each of the 63 sampling nodes. In addition, samplers were located at 5, 10, 15, and 20 m on all towers with the exception of AA4. A total of 111 sampling positions were utilized.

Meteorological parameters consisting of air temperature and wind speed and direction were monitored at various locations on the climable towers. For specific location, refer to Figure 2.

Air temperatures were determined by measuring the forward voltage drop across a silicon diode, Fairchild FD300, with 500 microamps current flowing through it. The diode was mounted in the middle of 2 concentric cylindrical radiational shields which were aspirated. The nominal voltage drop across the diodes was approximately 0,6v, and the temperature sensitivity was 2 mv per degrees centigrade.

Wind speed was measured with sensitive cup-type anemommeters similar to that described by Fritschen (1967). The essential features of the anemometer include a photoelectric chopper with 2 pulses per revolution and a threshold sensitivity of 6 cm sec^{-1} and a linear response of up to 20 m sec^{-1}.

Wind direction was determined by wind vanes with balsa wood tails mounted on a single-turn potentiometer, Heliopot, model TP, 1000 ohms. This potentiometer has a starting and running torque of 0.1 ounce inch.

The output from all meteorological sensors was recorded at 2-minute intervals on a data logging system located in a mobile laboratory at position AA5. The salient features of the data logging system (Fritschen, 1969), include an integrated voltmeter with 1 uuv resolution and 6-digit capacity, a 100-channel 2-pole scanner, 30 biennary solid state counters with decimal translator and 1-inch 8-channel paper tape punch.

Thirty grams of yellow, orange, and green fluorescent powders, each 5 microns in diameter and with a density of 4, were released at various locations. Three methods of release have been used; 1) the powder was mixed with water and sprayed with an atomizer, 2) the powder was dispersed in dry form with a hand-operated Hudson garden duster, and 3) the powder was blasted into the atmosphere from a tapered cylinder with a 600-pound charge of compressed air. When spores of Fomes annosus were used, they were atomized into the atmosphere from a water solution.

RESULTS AND DISCUSSION

Since the data are still being processed, only preliminary evaluations are available. Thus, the results from run 2, release 5 will be presented because they are interesting.

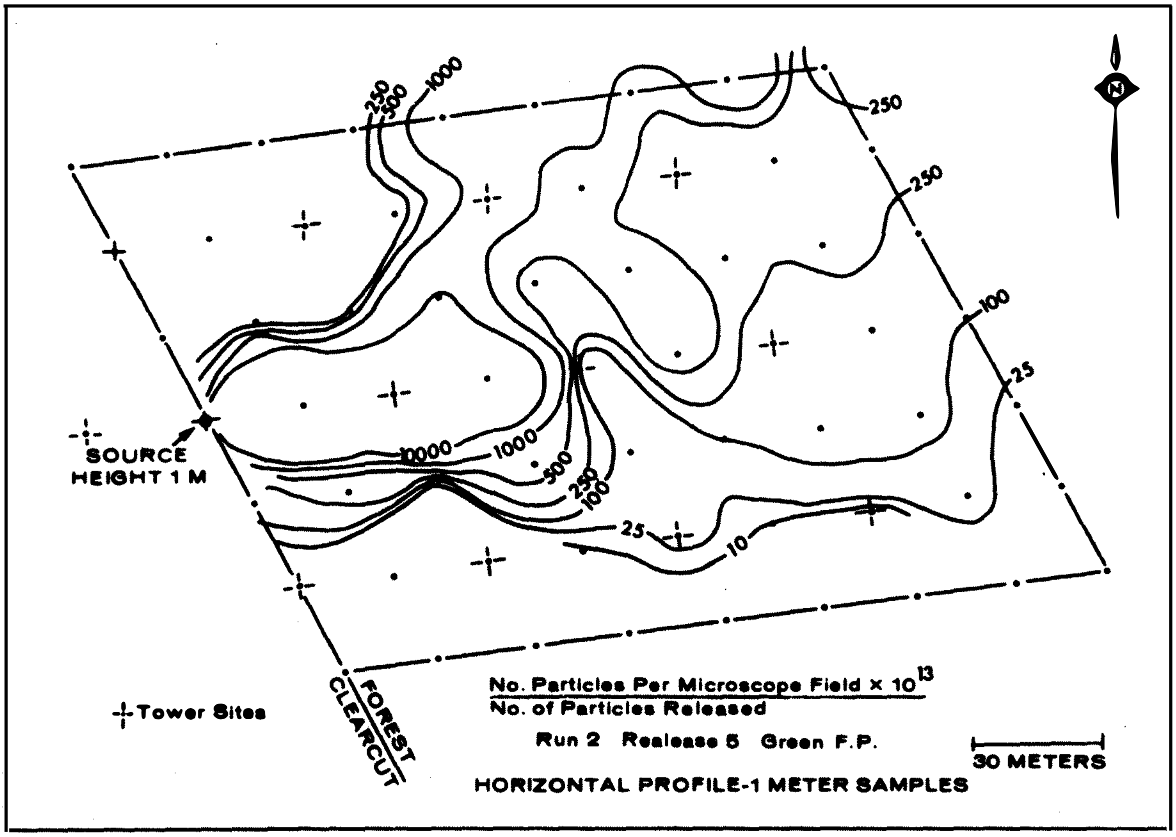

Fig.3. Ground level concentration of green fluorescent particles released at 1 m on A4. Concentration is number of particles per microscope field X 10^{13} number of particles released.

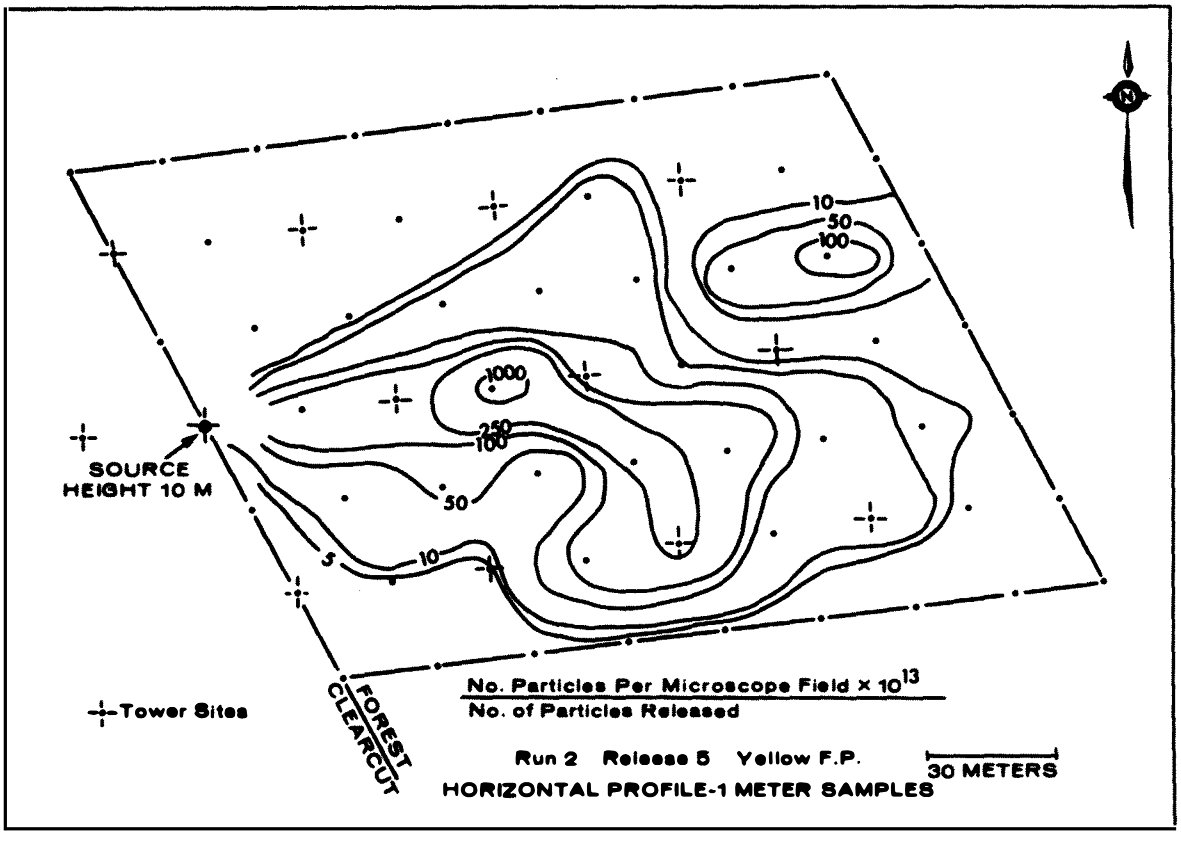

Fig.4. Ground level concentration of yellow fluorescent particles released at 10 m on A4. Concentration is number of particles per microscope field X 10^{13} ÷ number of particles released.

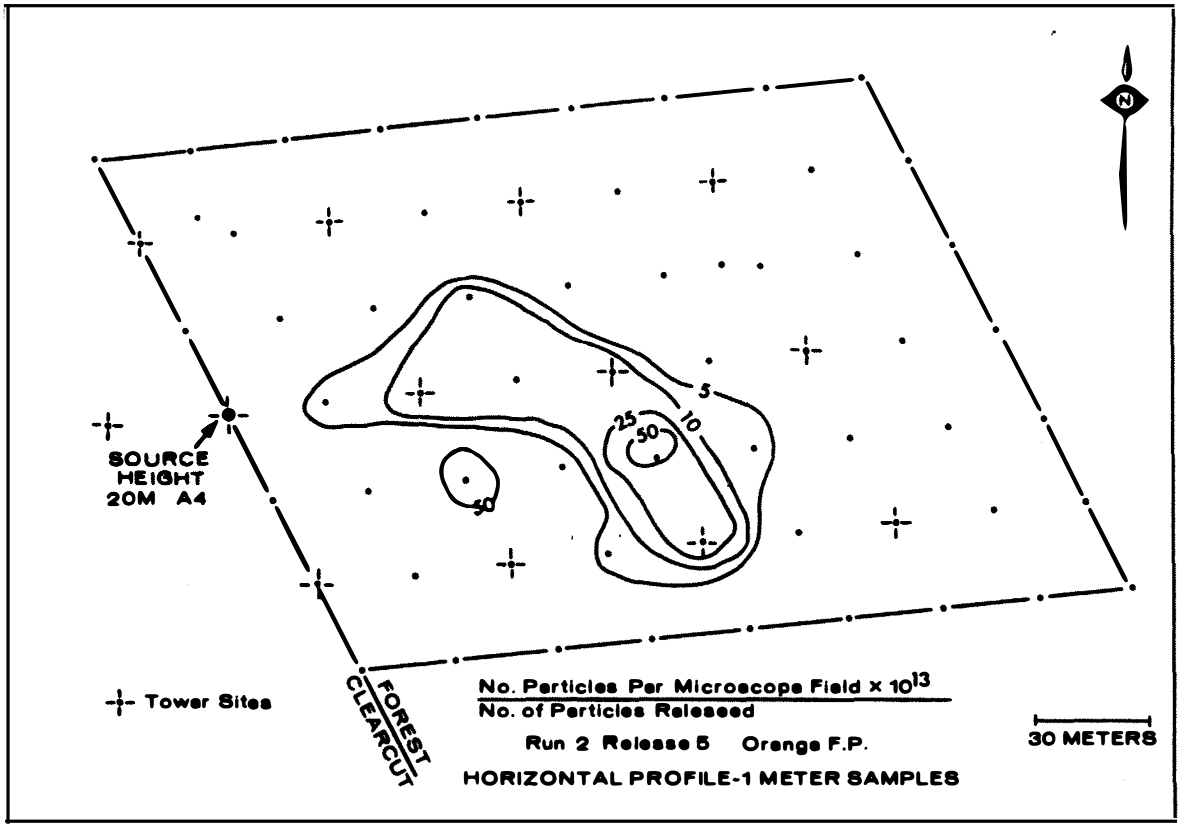

Fig.5. Ground level concentration of orange fluorescent particles released at 20 m on A4 . Concentration is number of particles per microscope field X 10^{13}÷number of particles released.

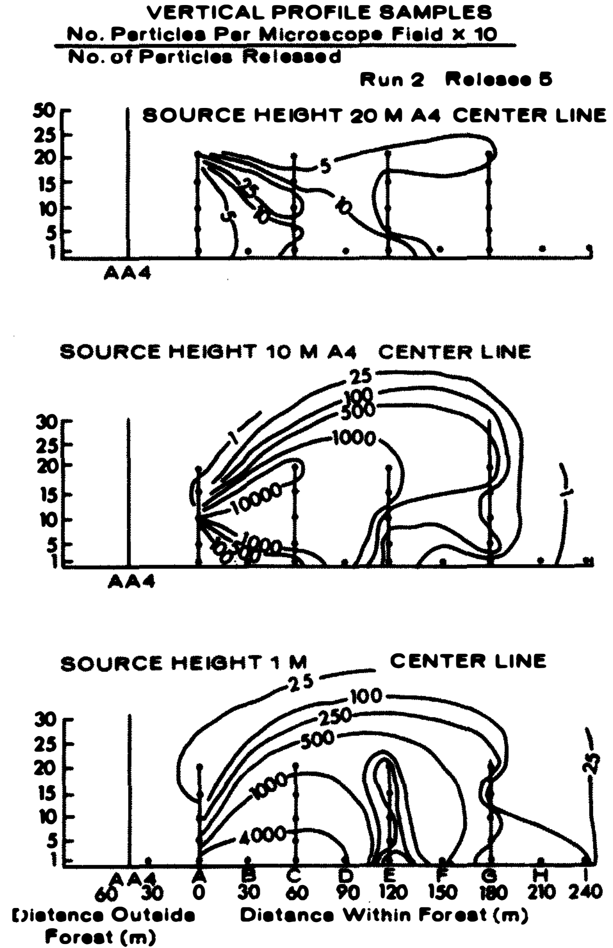

Fig.6. Center line(4) concentration of fluorescent particles released at 1 m, 10 m and 20 m on A4.

Green fluorescent particles were released at 1 m height, yellow at 10 m and orange at 20 m from tower A4 located at the interface on the center line of the grid. The powders were dispersed over a 5-min. period with the hand operated duster. Ground level concentrations are shown in Figures 3, 4 and 5. Green particles tended to spread out towards the northeast corner of the grid (Fig. 3), yellow particles which were released immediately below the crown tended to spread out towards the southeast corner of the grid with the highest concentration occurring at D4 (Fig.4). The orange fluorescent particles did not occur at ground level on the grid until line 3. The ground-level concentration was oriented from the northeast to the southwest (Fig. 5).

The drift of the powder and penetration into the stand appears to be related to disease holes. For example, the northeasterly drift of the powder released at 1 m appears to be oriented along a line between the C4 and E2 holes (Fig. 1). The greatest penetration of the powder release at 20 m occurred at the E5 hole.

The center-line cross-section concentrations of the various powders are shown in Figure 6. Notice that the powder released at 1 m tended to disperse upward and out of the grid towards the G tower. The powder released at 10 m also appears to spread upward and out of the grid. However, localized concentrations on the ground appeared at D and G locations. Contrary to the powders released beneath the stand, the powder released at the top of the stands appears to penetrate the stand around D. The center-line concentrations from the 1 and 10 m releases resembles the cross section of wind speed (Fig. 7). The lowest wind speed occurring at E4 was associated with dense vegetation in that area.

Cross sections perpendicular to the center line are shown in Figures 8, 9, and 10. Figure 8 illustrates how the powder released at ground level spread out both horizontally and vertically. Greatest concentrations are at position 1 on the E and G cross sections. The 10-m release tended to spread out as it moved out of the grid with greatest concentrations to the right of the center line (Fig. 9). The particles from the 20-m release penetrated the stand in sections C and E to the right of the center line (Fig. 10).

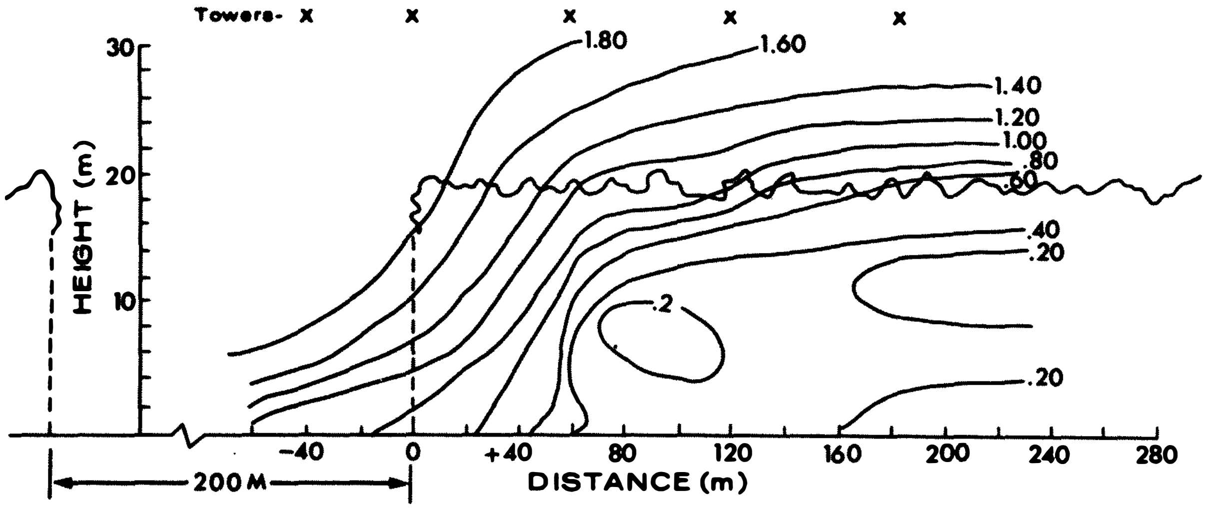

Fig.7. Wind speed (m sec.$^{-1}$) along the center line during release of powders.

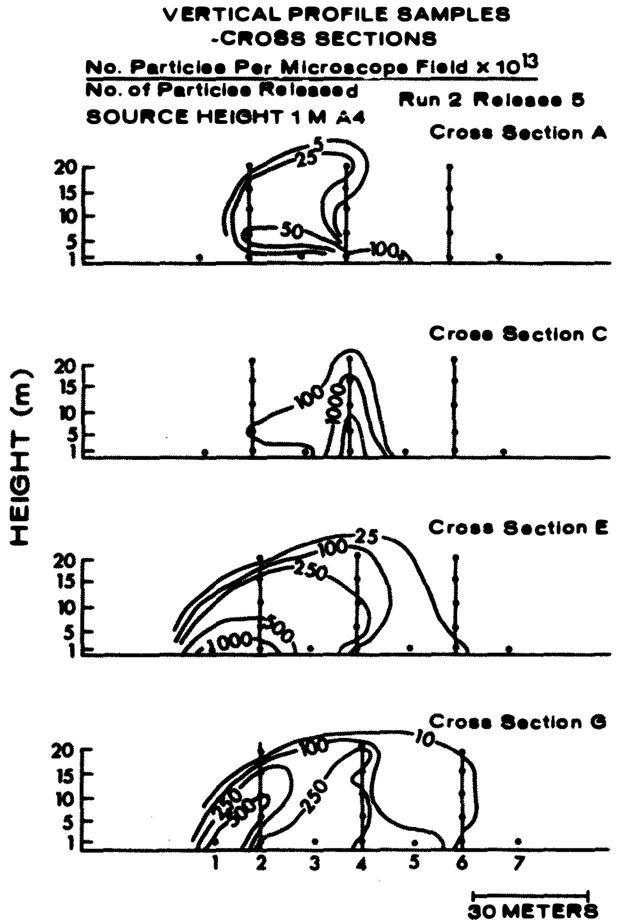

Fig.8. Concentration on cross sections A, C, E and G of fluorescent particles released at 1 m on A4.

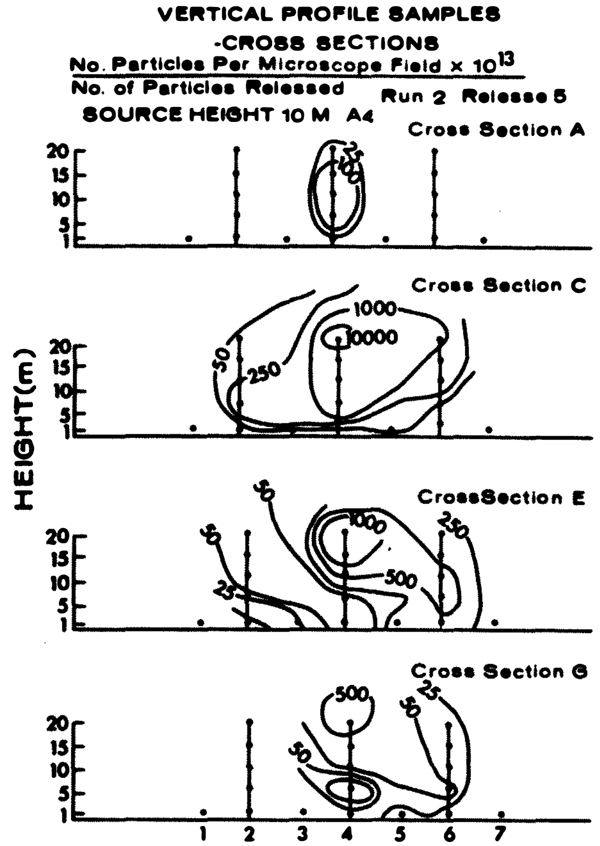

Fig.9. Concentration on cross sections A, C, E and G of fluorescent particles released at 10 m on A 4.

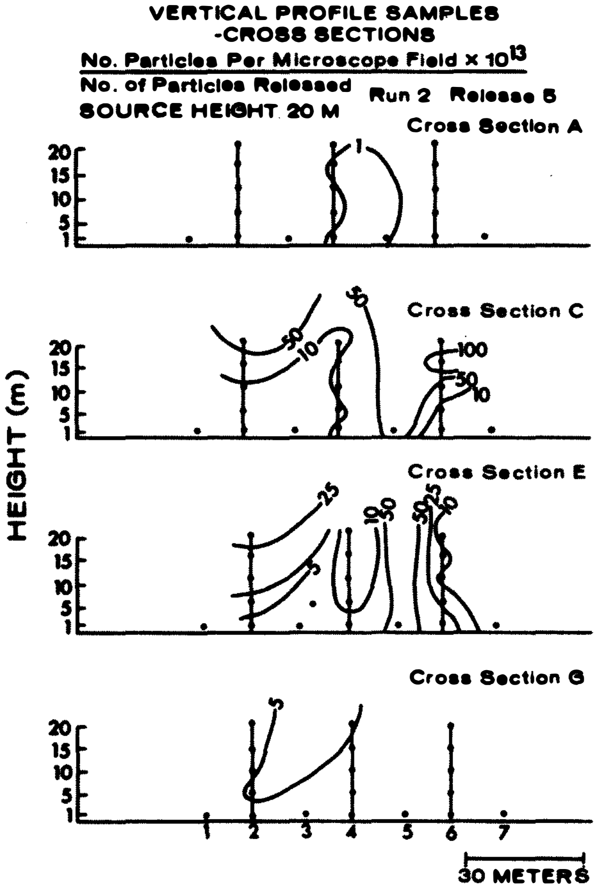

Fig.10. Concentration on cross sections A, C, E and G of fluorescent particles released at 20m on A4.

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AIR MOVEMENT IN RELATION TO ODOR RESPONSES OF BARK AND AMBROSIA BEETLES

By

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SUMMARY

Progress in the identification and synthesis of potent attractants for several destructive bark beetle species in North America has emphasized the need for a body of knowledge concerning the most effective use of these attractants under field conditions, to sample or control these insects. Present control attempts have emphasized directing natural attacks to certain trees or stands and destroying the broods by treatment or utilization of the trees.

These insects find the trees or logs they attack by the sense of smell. Their biology is such that they are capable of searching over a wide area in the forest and finding scattered suitable brood material there. They have the capacity to fly several miles. Under natural conditions, initial "pioneer" attacks produce strong secondary attraction by beetle-produced chemicals, and this leads to mass attacks by other beetles concentrating on these trees.

The above indicates that the distribution and dispersion by air of odors from attractive trees must play an important role in beetle response. Beetles fly upwind to odor sources, presumably maintaining direction against the wind by visual reference to the ground. Their anemotaxis takes them to the source of an attractive odor. Field observations and published data on response during the day of bark beetles show various response patterns, but often there is a small morning peak, mid-day decrease and then a large late-afternoon or evening peak. A hypothesis was formulated that such bi-modal response patterns were based on the daily changes in air speed and turbulence typical of sunny days, which are preferred times for beetle flight. A series of analyses of beetle response throughout flight days, in relation to air movement and other physical factors, was carried out in 1968 and 1969. Collections of beetles were made at half to two hour intervals and air movements and other factors were measured each time.

Air movement was studied with the release of small puffs of titanium tetrachloride smoke in the center of a 10-ft or a 4-m circle. A series of 20 separate puffs constituted a pattern for a given time. The direction, speed, vertical movement, and time for dispersion to invisibility were determined for each puff. This method has limitations but gives information from direct observation that could not otherwise be secured without complex and expensive instrumentation.

The studies have emphasized that wind velocity and air dispersion rate, which is related to velocity, are factors of much importance in the response of beetles to odor sources. Beetles cannot fly against winds that are too strong; much vertical and lateral movement of odor plumes make it difficult for beetles to track them; very low wind speeds fail to provide the directional clues needed for orientation upwind. Many factors complicate the interpretation of beetle-response patterns. For example, direction of wind *per se* is important because it determines the population of beetles in the surrounding forest that will be affected by a plume of attractive odor. Air temperature is of primary importance to beetle flight and if it is too low they will not respond, regardless of suitability of the currents. The response of beetles within an area depletes the population, thus affecting the numbers responding later.

Air pollution meteorology and other studies of dispersion of airborne material provide a basis for considering odor meteorology. However, the study of odor distribution in the forest concerns air movements near the ground, within stands, and over a smaller distance than usually considered by meteorologists in air pollution studies.

LATERAL GUSTINESS AND DISPERSION OF SMOKE PUFFS

By

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SUMMARY

One method of putting a quantitative value on the dispersive power of the atmosphere used by Dr. Chapman involves timing the disappearance of small standardized smoke puffs.

A second technique of obtaining the standard deviation of the azimuth angle of a small light weight vane (Turner, 1968) was used to obtain a series of measurements in conjunction with two runs of smoke-puff measurements by Chapman.

Assumptions of isotropy and that particle dispersion (σ_Y) is proportional to lateral gustiness ($\sigma_\theta \bar{U}$ or σ_v) lead to an inverse relationship between the latter parameter and the duration (t) of the smoke puff.

Figure 1 shows the duration of smoke puffs against lateral gustiness. The inverse relationship is not inconsistent with the values obtained inside a forest stand (crosses). However, the measurements taken in an open field (circles) indicate that t is more closely related to the $-4/3$ power of σ_v.

The significant feature of these comparisons is the fact that two simple techniques involving direct observation and unsophisticated equipment can provide what appear to be acceptably consistent results.

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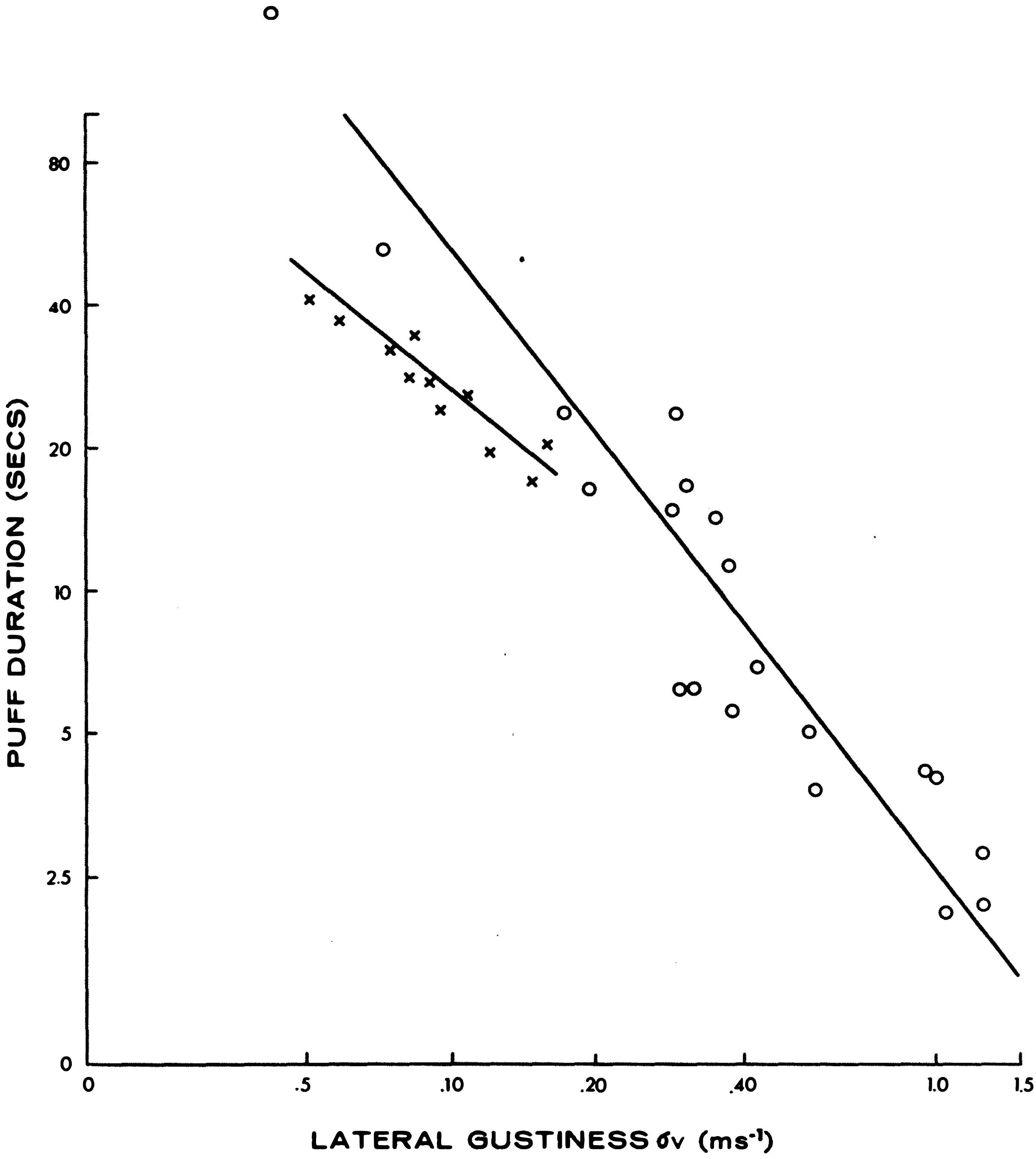

Fig. 1. Comparison of two estimates of turbulence

COMMENTS ON ZERO-LIFT BALLOONS

By

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ABSTRACT

Smoke diffuses, leaving the eye to follow only the slowest moving, least turbulent air. In contrast, zero-life balloons appear attractive as unbiased, visible indicators of air trajectory.

Balancing for zero-lift requires complete shelter from wind; but if done in shade, subsequent exposure to sunshine gives (theoretically) 60 to 80 ft/min ascent due to 5° to 10°C temperature rise in the balloon. Observations with red balloons at Petawawa Forest Experiment Station (Chalk River, Ontario) suggest temperature rise was not greater than 10°C over ambient.

On overcast days, successive balloons may follow closely similar trajectories. But on sunny days, convection is rampant; ascent at 400 ft/min is common. One clear balloon rose 1500 ft in 3 min after an initially slow ascent for 5 min. A black balloon rose 4000 ft the first 7 min, then 400 ft in the next 3 min.

Our experience with about 25 balloon flights is that a balloon may drift relatively horizontally for several minutes, (staying below 400 ft, say), but once it has risen rapidly with a convection current it rarely comes back down to its former elevation.

Hence, seeking to trace essentially horizontal air trajectories on a sunny day is illusory. When tracing back upstream to see where the air comes from that it measured as it passes a meteorological tower at 100 or 200 ft above ground level, one needs to realize that some of this air will have arrived at this level from above or below it. The farther upstream one goes, the smaller the proportion that will have come via an essentially horizontal trajectory. The proportion travelling horizontally for one mile on a sunny day appears quite small.

FROST HARDINESS, RESISTANCE TO HEAT, AND CO_2 UPTAKE IN SEEDLING AND MATURE STAGES OF PINUS CEMBRA L.

By

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There are important climatic differences between ground level and higher above (Geiger, 1961; Tranquillini and Turner,1961). Temperatures fluctuate more widely and more quickly within 10 cm of ground level (Fig. 2) than at 2 m (Fig. 1). Hence, as seedlings grow from the soil surface to the height attained by a mature tree, they pass through different environmental conditions. How 5-year-old seedlings of stonepine (Pinus cembra L.) and mature trees of the same species react to frost, heat, and CO_2 uptake and how these reactions relate to their natural environment, shall be discussed here briefly. The results are from experiments in the Klimahaus at timberline (2,000m) on Patscherkofel near Innsbruck, Austria.

FROST HARDINESS

Frost hardiness refers to the lowest temperature that does not cause damage to tissues after three hours of exposure, in accordance with similar investigations by Ulmer (1937), Pisek and Schiessl (1946), and Tranquillini (1958). In general, short photoperiods and low temperature cause an increase in frost hardiness (Moschkow, 1935; Pisek and Schiessl, 1946; Tumanow et al., 1965).

Mature stonepine reaches a maximum frost hardiness of -43°C in December. Towards spring, frost hardiness decreases slowly until April, after which rising temperatures, increased photoperiods, and melting of snow cause an increase in the rate of dehardening. Mature trees reach their minimum frost hardiness (to -6°C) in July (Fig.3).

Seedlings have a maximum frost hardiness (to -40°C) in November and a minimum hardiness (to -4°C) in August (Fig. 4). Both in seedlings and in mature trees, needles produced in the current season withstand only -2°C in August. These new needles increase their frost hardiness quickly, especially in the mature tree where a resistance to -10°C is reached by September. By October, new needles of mature trees withstand temperatures as low as -36°C and those from seedlings -30°C (Fig. 3 and Fig. 4).

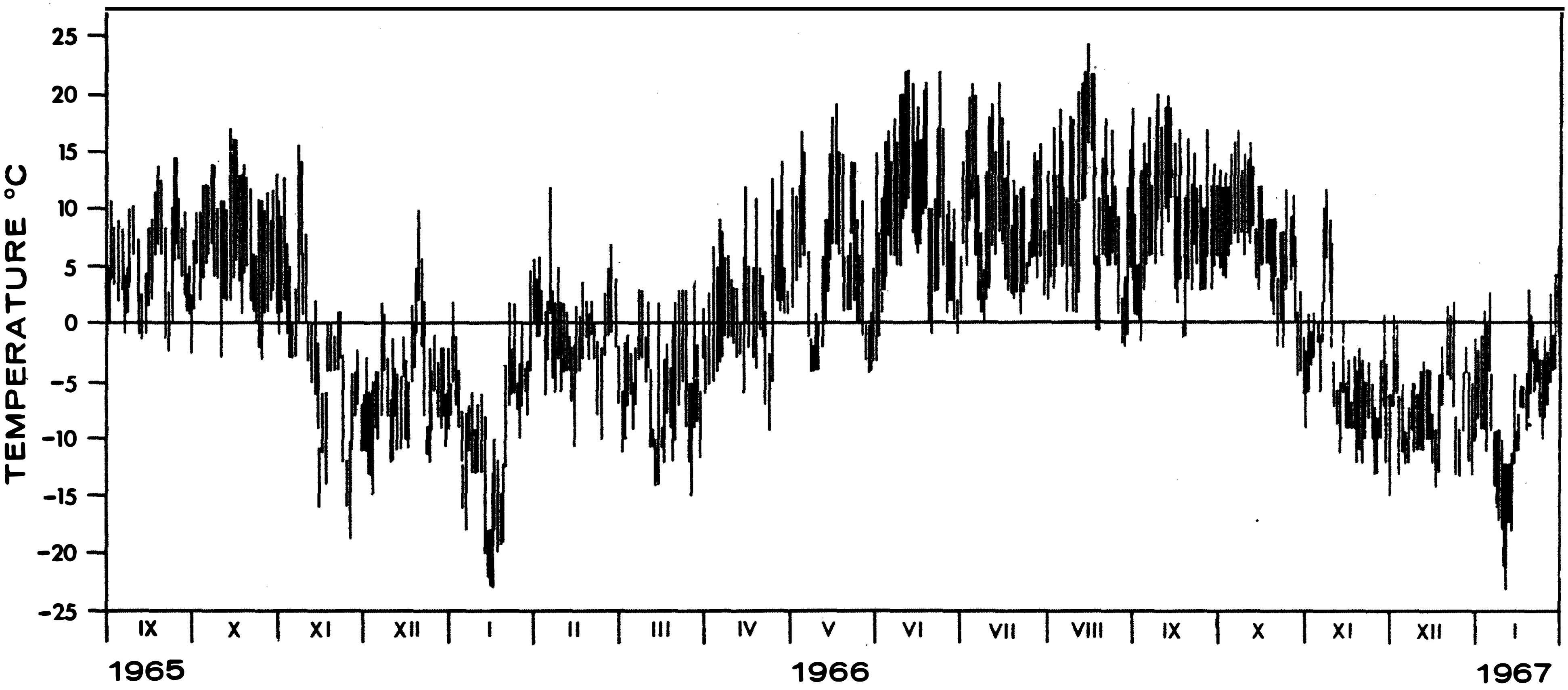

Fig. 1. Air temperature extremes at Patscherkofel (2,000 m), from sensors placed amongst the needles of a Pinus cembra branch 2 m above ground level.

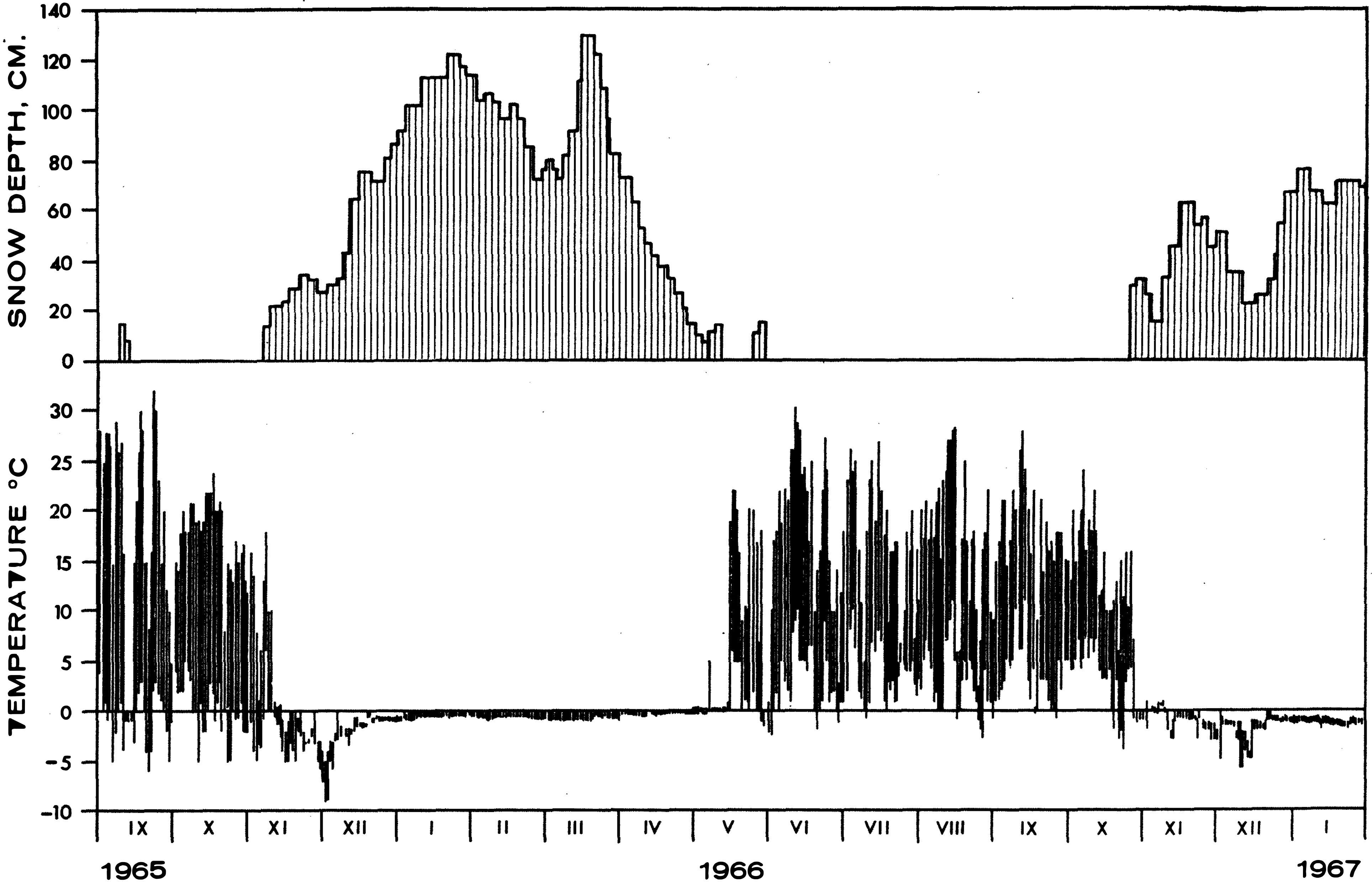

Fig. 2. Top: Seasonal changes in snow depth at Patscherkofel (2,000 m). Bottom: Air temperature extremes from sensors placed amongst the needles of a *Pinus cembra* seedling 10 cm above ground level.

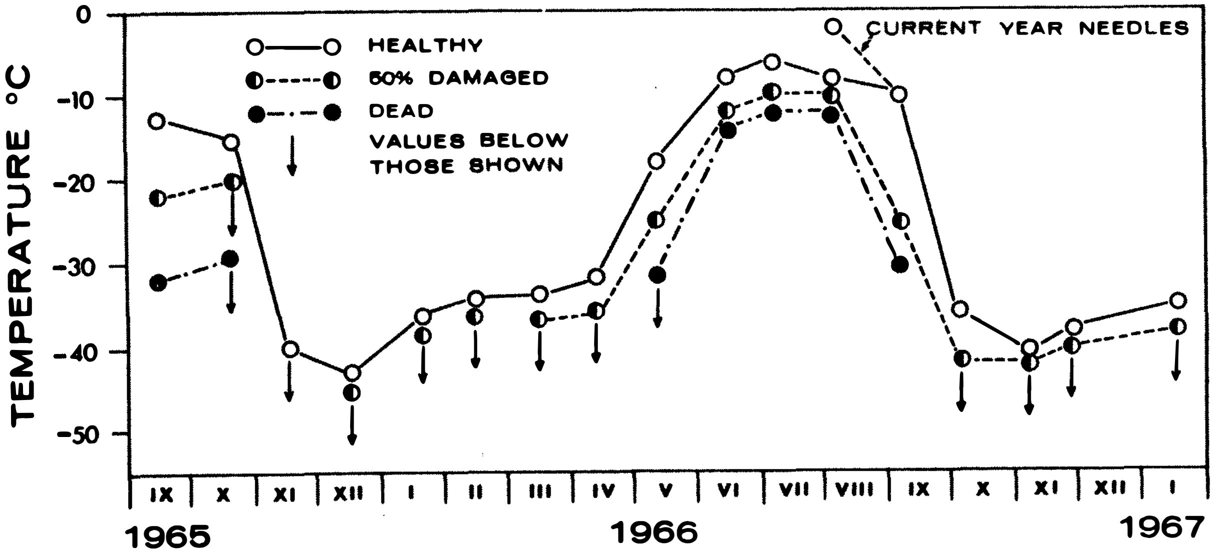

Fig. 3. Frost hardiness values (in °C) for needles of a mature Pinus cembra tree.

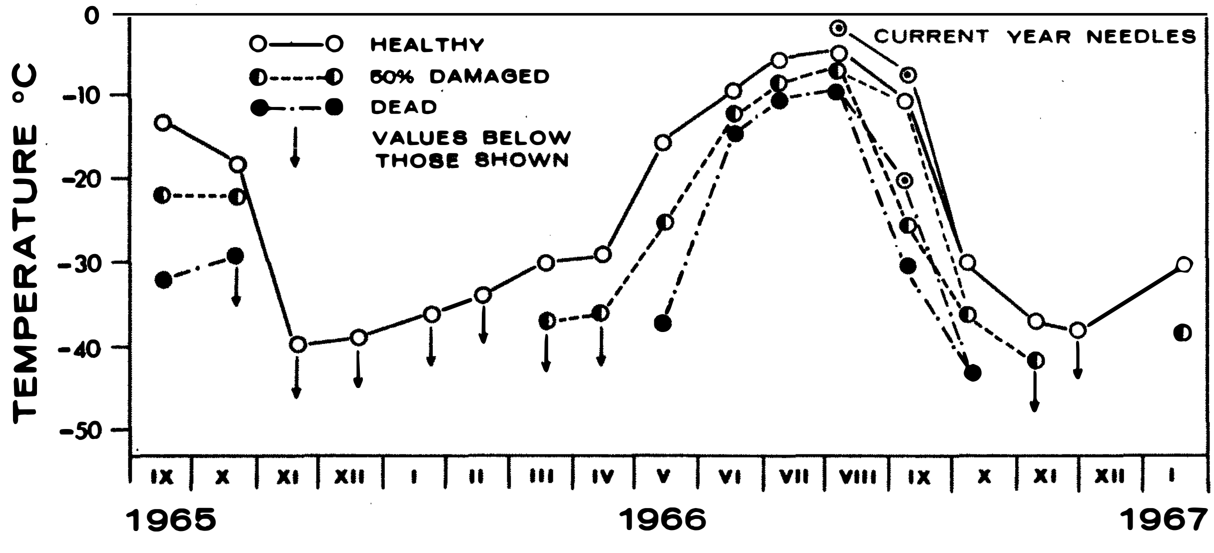

Fig. 4. Frost hardiness values (in °C) for needles of a Pinus cembra seedling from outside.

There are no other great differences in frost hardiness between mature trees and seedlings. A snow cover that prevents exposure of seedlings to low temperatures results in seedlings being less hardened in winter than mature trees. In summer, higher temperatures near the ground than at the canopy level of mature trees might be the reason why seedlings display less summer frost hardiness than do mature trees. (Figs. 3 and 4).

RESISTANCE TO HEAT

Resistance to heat refers to the highest temperature that does not cause damage to tissues after 30 minutes of exposure.

Resistance to heat and frost hardiness show similar seasonal fluctuations, with maximum resistance to heat occurring in January (Figs. 5 and 6). In mature trees, there is a regular and continuous decrease in resistance to heat from February until July when the minimum (at 44°C) is reached (Fig. 5). In contrast, seedlings that are under a snow cover continue to have a relatively constant and high resistance (to 48°C) until June (Fig. 6). Near ground level where there is more risk of heat damage, seedlings do not deharden as much as mature trees. The seedlings maintain a relatively constant resistance to a temperature of 46°C throughout the summer and towards winter, resistance to heat increases again (Fig. 6).

CO_2 UPTAKE

The uptake of CO_2 was measured as mg CO_2 per gram dry weight of photosynthetically active material per hour in a wind tunnel at 16°C, and at a relative humidity of 60%, with a light intensity of 30,000 lux, in accordance with similar measurements by Pisek and Winkler (1958 and 1959), Tranquillini (1957 and 1959), and Bamberg, Schwarz, and Tranquillini (1967). Branches of the mature tree were brought to the laboratory and tested 8 hours after cutting and again at 32 and 56 hours. Potted seedlings were tested 16, 40 and 64 hours after they were brought into the greenhouse.

Both the mature tree and seedlings showed large fluctuations in their photosynthetic activity during the year (Figs. 7 and 8). In the mature tree, there is a significant peak of CO_2 fixation in October at a time when needles from the current growing season are photosynthetically efficient. With temperatures as low as -9°C by the end of October, CO_2 uptake decreases towards winter; in December to March, inclusive, there is very little CO_2 fixation. After May, temperatures do not fall below -4°C and photosynthetic activity is high. A spring peak in activity occurs in June and July when the buds are not yet open. The mid-summer drop in rate of CO_2 uptake reflects the high respiration rate of new growing needles. (Fig. 7).

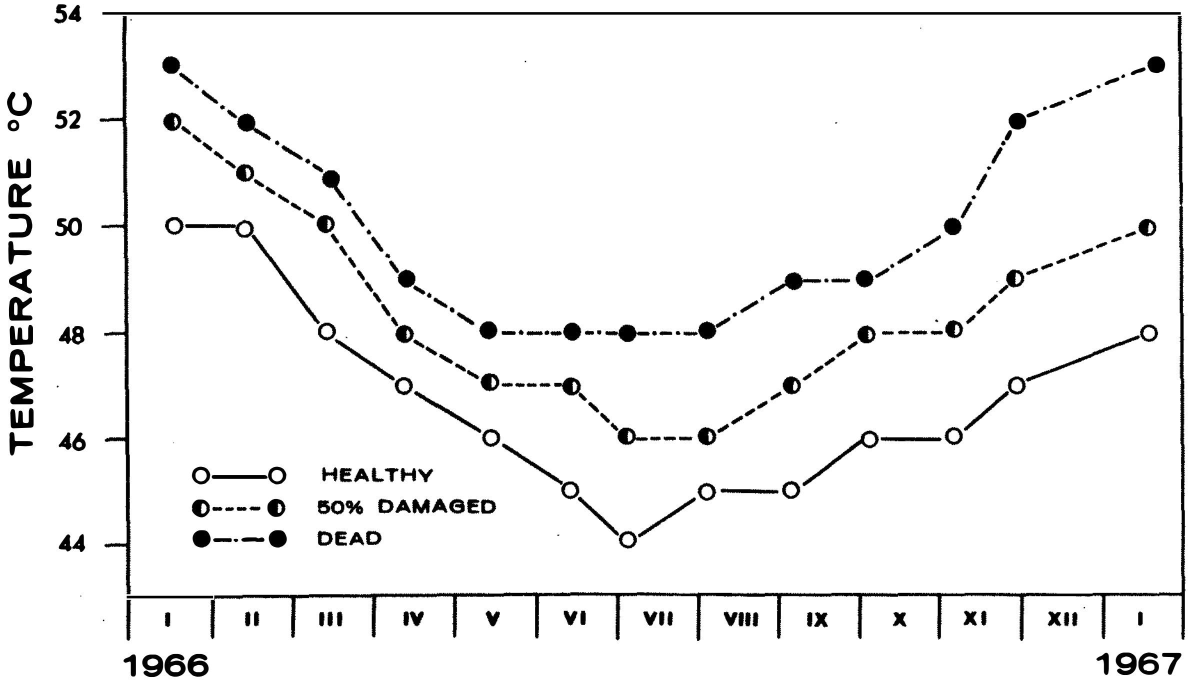

Fig. 5. Resistance to heat (in °C) for needles of a mature Pinus cembra tree.

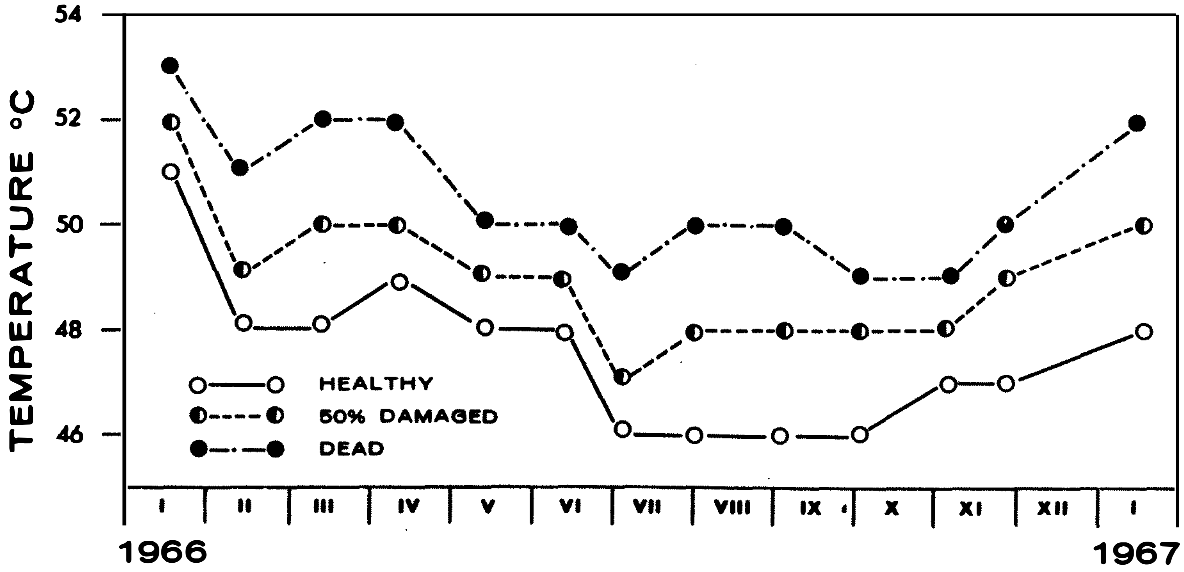

Fig. 6. Resistance to heat (in °C) for needles of a Pinus cembra seedling from outside.

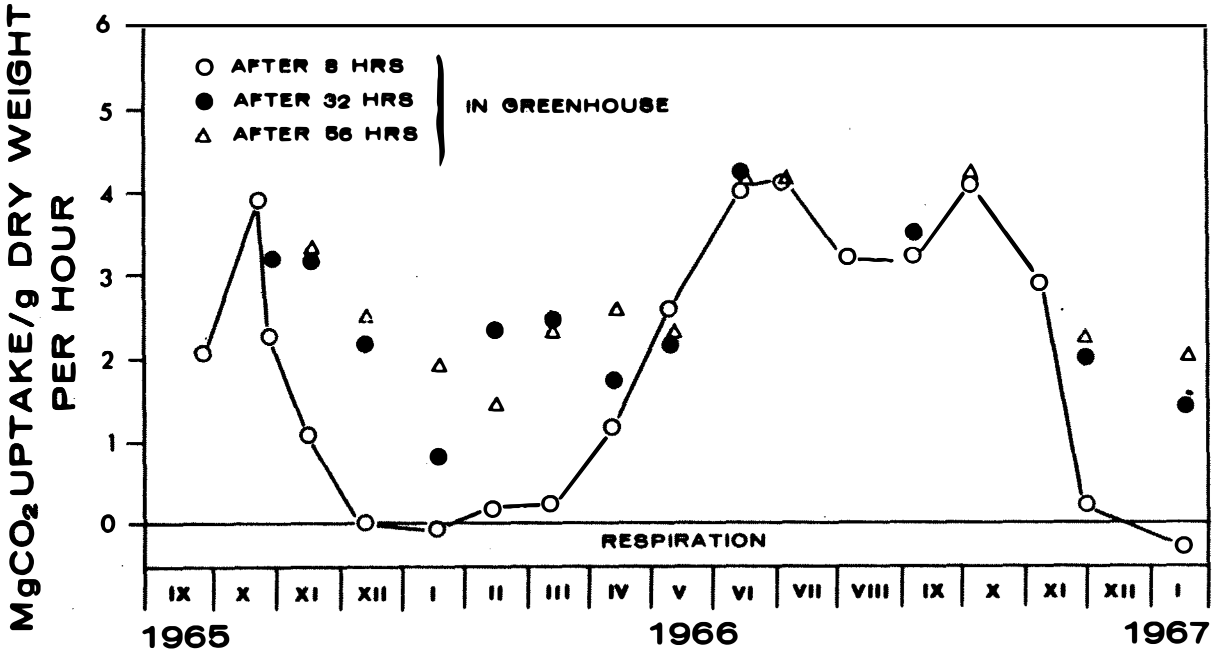

Fig. 7. Milligrams of CO_2 uptake per gram dry weight of photosynthetically active material per hour, in branches cut from 2 m above ground level on a mature *Pinus cembra* tree.

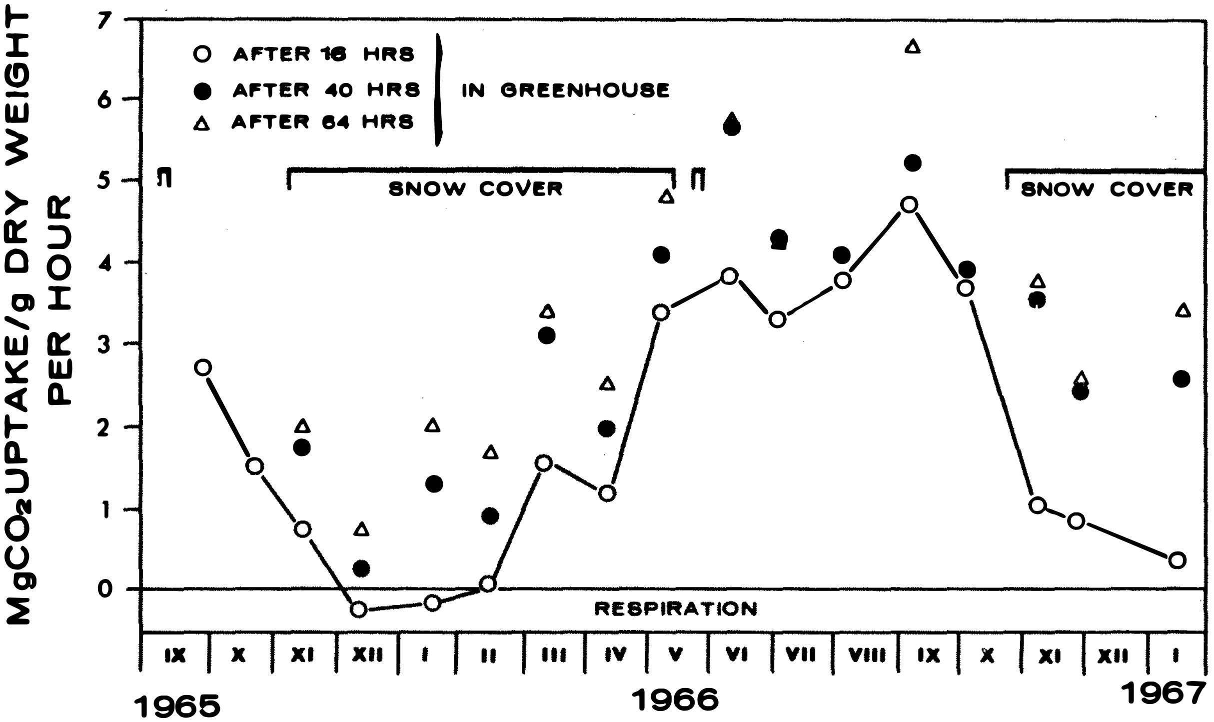

Fig. 8. Milligrams of CO_2 uptake per gram dry weight of photosynthetically active material per hour, in needles of a *Pinus cembra* seedling from outside.

In pine seedlings, the October peak in CO_2 uptake is missing. Seedling CO_2 uptake decreased as early as September when temperatures dropped to -5°C near ground level. Uptake of CO_2 increased in seedlings during spring, although reduction of light by the snow cover inhibited photosynthetic activity. The first peak in activity occurred in June as soon as the snow had melted. After the young needles were well developed in September, a second and higher peak of activity occurred. Needles of the current growing season are more efficient for CO_2 uptake in September than are the older ones. Seedlings show a higher potential for CO_2 fixation than do branches from mature trees. After exposure to optimum conditions for three days in summer, seedlings could take up more than 6 mg CO_2 /g dry weight/hr., whereas trees under optimum conditions in summer took up only 4 mg (Figs. 7 and 8). For seedlings, the photosynthetically active period is shorter but seedling efficiency in taking up CO_2 is higher than in mature trees of Pinus cembra. In terms of CO_2- uptake response, mature stonepine and 5-year-old seedlings appear to be well adapted to their respective environments.

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CORRELATION OF NET PHOTOSYNTHESIS RATES WITH FACTORS OF ENVIRONMENT WITHIN THE CROWN OF A LARGE CONIFER

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ABSTRACT

Net photosynthesis and principal factors of the environment were measured within the crown of a 27-m-tall Douglas-fir in western Washington. Net photosynthesis rates and patterns varied significantly depending on vertical and lateral location in the crown. Highest rates were always located about 40 per cent of the crown length from the top. Rates on the south side were significantly higher than other sides at the same height. Multiple regression analysis of periodic mean-environmental factors of solar radiation, ambient air temperature, vapor pressure, and ambient CO_2 accounted for 70 per cent to 84 per cent of total variation in net photosynthesis rates. Radiation was the single most important factor accounting for variation.

MICROCLIMATE AND CO_2 FLUX IN A COSTA RICAN TROPICAL RAIN FOREST

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(Title only - to be published elsewhere. Reprints available on request).

CLIMATIC CLASSIFICATION FOR ALBERTA FORESTRY

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ABSTRACT

An examination is made of the reasons for classifying climates, and the problems associated with determining a boundary to an area. In general the Köppen system of climatic classification is adequate and the determination of boundaries is relatively simple. It fails to give enough information about vegetation types in Alberta's forests, and a suggestion is made on how we could proceed if we wish to classify the forest lands of Alberta in more detail.

INTRODUCTION

When, in the long distant past, man began to travel, he must have become aware of differences in climate. The Teutonic tribes migrated with their herds from the Asian steppes, where rainfall was deficient, to western Europe where rain was plentiful. To the wanderers of the Sinai Desert, the land of Palestine was a land flowing with milk and honey because the rainclouds from the Mediterranean gave moisture for the Palestinian crops. On the other hand, residents of the tropical rain forest area were at times forced to move into the drier fringe lands of the sub-tropical desert. In these and other migrations, the tribe was moving to a region with a different climate.

As travel and communication expanded, people began to recognize and speak of the variation in climate. The Greek classification of polar, temperate, and tropical proved only a beginning, for the class groups were much too large to distinguish important variations.

PURPOSES OF CLASSIFICATION

But what is an important variation? For what purpose do we want to classify climates? The most important purpose for classifying climates is in order that one may compare the climates of two different, and probably widely separated, places. By describing the climates of Arizona and Arabia as both being hot and dry, we may conclude that certain characteristics of the one district are also true of the other district.

By recognizing that there are types of climate, one is able to estimate with fair accuracy the climate and vegetation of one district by knowing that these are similar to those of a known district.

One characteristic of a locality is the fauna and flora of the district. A plant, and particularly the climax vegetation, of a district has adjusted itself to the vagaries of the weather. The vegetation is a function of the soil as well as of the climate, but because the soil has been produced by the climates of the past the relationship between the climax vegetation and the climate is close.

SYSTEMS OF CLASSIFICATION

Köppen, the father of modern climatic classification, accepted the hypothesis that the vegetation is a measure of the climate. His first classification in 1923, and his subsequent revisions of his classification, were attempts to delineate different vegetation regimes by means of the climatic elements and their averages.

Others have followed Köppen. The main problem with which many of these climatologists were concerned most frequently was trying to identify the boundary between desert and steppe country from those areas where normally rainfall is sufficient for continuous growth during the warm season of the year.

The system of classification which examines this problem of water supply most fully is one devised by C. W. Thornthwaite. Water loss from the soil and through plants is a function of the air temperature, the humidity, the vertical distribution of these, the wind, and other factors as well as the type of vegetation. Thornthwaite attempted to take these factors into consideration and to develop a better method of determining the boundary of the area where the land becomes too dry to grow crops other than grasses. Although the Thornthwaite system has many features that are better than the Köppen classification, the complications in making the necessary calculations in the former are such that its use is limited. For this reason, it has failed to supplant the Köppen system of classification of climate.

In the Köppen classification, one major division, the B-type climates, is devoted to the areas of insufficient rainfall. Trees do not grow in these desert and steppe regions except near water courses and springs where the trees can find water during the dry periods. For this reason, the B-type climates are of no interest to foresters.

The remaining climates of the temperate and polar zones are divided into three major groups, the C-, D-, and E-type climates. These are subdivided to bring out differences within each major group. In Alberta, except for high mountain peaks, one finds only D-type climates, which was Köppen's method of describing a "humid microthermal climate".

The areas of the earth with a humid microthermal climate are found adjacent to the arctic climates, the E-type climates, where trees do not grow. In North America, most of the areas north of 40°N have a D-type climate. Exceptions are found in a narrow strip along the Pacific coast, and some steppe areas in the vicinity of the mountains. The far north is, of course, Arctic.

In Europe, the D-type climates are found in Scandinavia, Poland, Roumania, and the U.S.S.R. In Asia, because of the extensive steppe area, the southern boundary is not far from the 50°N parallel. Parts of China south of 50°N, have also a D-type climate. Only a narrow area along the Arctic Ocean is Arctic. D-type climates are unknown south of the equator.

BOUNDARY PROBLEMS

Köppen defined his zonal boundaries by climatic elements. The decision to do this was based upon the hypothesis that these zonal boundaries gave a satisfactory identification of vegetation changes. But the concept that there is a sharp boundary between two different climatic zones is difficult to comprehend. The spatial distributions of temperature and precipitation are continuous as the mathematician defines continuous. With vegetation patterns, there are discontinuities introduced by soil changes, such as along a rock outcrop or at a lake shore. Yet it is not hard to conceive of the pattern having continuity. Basic to the concept of climatic classification is the ability to draw a boundary between two different climatic types.

The problem is similar to that of the lawmaker who attempts to define the time when a young man or woman is old enough to be able to drive a car, or to vote in elections. Nothing of real significance occurs between the time a boy is 15 years 11 months and the time he is 16 years old. Yet in Alberta he may not have a licence to drive a car at the first of these two times and may at the second. In both instances we are making a division in a continuous variable, a division which can be justified in considering the overall problem but which has no more significance than another line close by. It is this lack of clear definition of the boundary between two zones that gives rise to the different systems of classification. Different scientists have considered that they have discovered better criteria by which to identify the boundary. The Köppen classification is the choice of many climatologists, not because it is perfect, but because the different zones seem to have clear meanings and the approximate boundaries are easily determined.

Although the Köppen system presents in general a satisfactory classification, two reports have come to my attention that bear upon the system.

First, Hare questioned the boundary line between the D-type humid microthermal climate and the E-type Arctic climate. Köppen considered that the transition was along the tree line which, he concluded was along the isotherm for 10°C (50°F) for the warmest month. In western Canada, the two lines are close together, but the paucity of long-term climatological observations in the Northwest Territories leaves in doubt the location of the 10°C isotherm. In an analysis of the climate of northern Labrador, Hare (1950) concluded that trees were growing in an area where the mean July temperature was below 50°F. It may be that the spruces which grow along the tree line in Labrador are able to survive because they have a longer period above some threshold temperature of, say, 42°F, and so compensate for a lack of warmer summer temperatures by having a longer growing season. In other words, the criterion for growth may really be the number of heat units above some base temperature such as 40°F rather than the occurrence of one warm month.

Another interesting item has come to my attention, but I have lost the reference. A study was made in central Sweden of the survival of spruce seedlings, and it was discovered that the chance of survival was related to the distance the seedlings were transferred from their original habitat. Even a transfer of 50 miles affected the ability of the seedling to resist disease and other dangers, and therefore the probability of survival. The results of this study suggest that the acclimatization of plants is much more specific than I personally had imagined.

These examples are not given to refute the concept of classification of climates. In fact, they can be used to show clearly that forest growth is governed by the climatic elements, but that the relationship is more complex than any of our presently used systems would suggest. It may be that we need to examine our criteria once again.

CLIMATIC ZONES IN ALBERTA

Let us examine the climatic zones in Alberta, as determined by the Köppen classification (Fig. 1).

There is an area in southeastern Alberta which has an arid, steppe, climate. Its dimensions are unknown, and any boundary that may be drawn is based upon the definition used. If one takes the definition used in drawing the map found in "The Atlas of Canada" (1957) and the 1931-1960 averages, only two stations (Brooks and Vulcan) qualify as belonging to this arid region, and, according to another definition, even these two are rated as having sufficient moisture.

If one examines the moisture demand and supply by methods developed by Thornthwaite (Laycock, 1964), one discovers that along the South Saskatchewan River there is a mean moisture deficit of 10 inches if one assumes a water storage of 4 inches at the beginning of summer.

After examining the records and studies on the area, one concludes that there is an arid area in southeastern Alberta, but the size of the area and intensity of the aridity is unknown. As far as the forest areas of Alberta are concerned, this problem is not important. Trees are present in southeastern Alberta in the region only along rivers where moisture is adequate and in the moist Cypress Hills. The lack of forests may come from the frequent droughts, or may be caused by the grass fires that sweep the region.

All systems of classification separate out the Arctic regions. In Alberta, the tops of the mountains have an Arctic climate because of the decrease of temperature with height. Information is lacking that would permit one to relate the tree line, which has been used to identify the boundary of the Arctic climatic region, with weather because the observation stations are below this level.

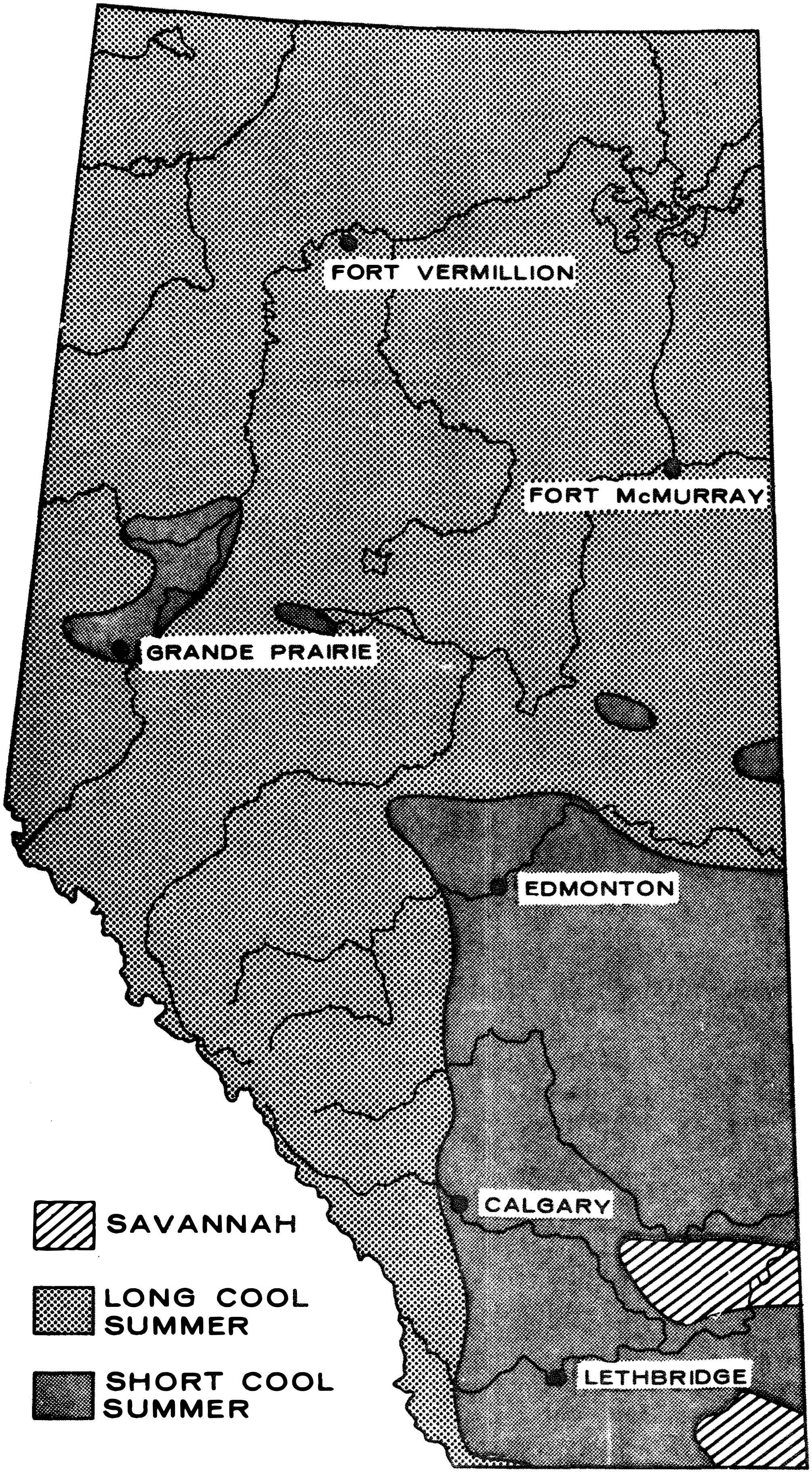

Fig. 1. Köppen Climatic Zones (1931-1960) for Alberta

One may use an assumption which has been proposed for general purposes to determine the altitude at which the mean temperature in July is 50°F and thus determine the Köppen boundary of the Arctic climate. The results in the Banff area are: 7250 ft (Banff), 7350 ft (High River), 7090 ft (Kananaskis), 6500 ft (Lake Louise), 6890 ft (Pekisko) and 6830 ft (Turner Valley). Trees are growing at 7500 ft on Sulphur Mountain; therefore, one is forced to wonder which of the assumptions are in error. The altitude of the tree line may be obtained approximately by estimating the height of the 50°F isotherm for July, but the answer can be in error by 500 ft.

Except for the two small areas discussed above, Alberta has a D-type, humid microthermal climate, with adequate moisture distributed throughout the year. Köppen subdivided the D-type climates into several subclasses. Of these, two are found in Alberta, the Dbf with warm summers, and the Dcf with short cool summers. The dividing line, according to Köppen, is the line along which the period with mean temperatures over 50°F is 120 days. In Alberta, this line is found to enclose a rectangle in southeastern Alberta extending to just north of the Edmonton-Lloydminster line and just west of the Edmonton-Calgary line. There is also a small area in the upper Peace River country which has a Dbf climate.

Does the Köppen system give sufficient resolution when it divides the forest area of Alberta into two zones only? If we are interested in a more detailed classification, on what should we base our classification?

If we accept the philosophy of Köppen and others, then any change from the Köppen divisions must be based upon the vegetation prevailing. Does the line between Dcf and Dbf mark a transition between one type of climax vegetation and another? What are the different vegetation zones as one moves southward from the Caribou Hills to Waterton Park. A report by Knight and Duffy (1967) divides a 30-square-mile area west of Whitecourt into six different sub-areas in which the vegetation differs from lodgepole pine in the best area to muskeg in the worst. The differences among the areas cannot all be ascribed to climatic differences, but Knight and Duffy imply that microclimatic differences are a major cause for vegetation differences.

The differences that explain why lodgepole pine grows in one area and muskeg in another are unknown. According to Köppen the major difference where moisture is not a limiting factor is summer temperature. Are there other important climatic elements? What of winter minimum temperatures? These certainly influence the growth and productivity of fruit trees of the Okanagan Valley. And a number of studies have shown that frost hollows which have been denuded of trees may stay in that condition because low winter temperatures kill the young saplings. Soil temperatures too must influence growth and there may be other factors than mean summer temperatures.

If we then wish to classify the climates of the forest areas of Alberta, it would seem that this could best be done by selecting a small area where the vegetation is seen to differ. Then by installing thermographs in the different types of vegetation, and by the temperature traverses on suitable days, the microclimates of the area can be distinguished. Out of this study there should come information on the climatic conditions necessary for the growth of the different vegetation covers. Although, as noted above, these conditions may not be directly applicable to another region, it would be hoped that the modification in the conditions would be slight.

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CLIMATIC INTERPRETATION IN RELATION TO FORESTRY

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ABSTRACT

Historic classifications of climate, including those of Köppen and Thornthwaite, do not adequately fulfil the requirements of present-day land use planners. Information is required, not in terms of climatic variables, but in terms of the response of plants to these climatic variables.

Long-term records are necessary for the development of the required bio-mathematical models, and the full use of existing data is essential. Agrometeorologists in Canada have used standard climatological and astronomical data to develop techniques for estimating such fundamental parameters as potential evapotranspiration, soil water content and rate of crop development towards maturity. These basic concepts are then used to provide information that can be interpreted in terms of land capability for agriculture.

Techniques developed for agricultural conditions cannot be expected to solve forestry problems without considerable modification. Agrometeorologists have demonstrated an approach that has provided results useful for agricultural land classification. A similar approach to the more complicated problems may well produce useful results.

INTRODUCTION

Climatic classification, which pre-dates the ancient Greeks, was largely descriptive for many centuries, it being based on notes and reports by travellers and explorers. Important contributions to the development of classification systems were made by the Greeks who divided the hemisphere into three broad temperature zones, and by Köppen and Thornthwaite in the 1920's and 30's when organized observational data had become available and again by Thornthwaite in 1948 when he developed his rational classification involving the concept of potential evapotranspiration. In recent years, a new approach to climatic classification has become necessary because those concerned with land-use planning require assessments of outputs and inputs that can be subjected to economic appraisal. Information is needed not only in terms of climatic variables but also in terms of the response of plants to these climatic variables. This involves the development of bio-mathematical models which provide a quantitative assessment of the effect of weather on plant growth or crop production. Because plants respond to the total environment, the use of derived environmental parameters, such as soil moisture, in a crop-weather model should give better results than the use of the single climatic variables.

BASIC TECHNIQUES

In agriculture, two main approaches have been used in developing so-called crop-weather models:

1. The climatological approach - in which climatic means or totals are related to yields or similar crop production parameters.

2. The micrometeorological approach - in which selected elements of the microclimate are related to measureable reactions of plants, such as transpiration rate or growth.

The shortcomings of the climatological approach lie in the difficulty of establishing meaningful coefficients and in the physical interpretation of these coefficients. The micrometeorological approach may have a sound physical basis, but the instrumentation required is such that records are rarely available on a large scale basis.

Researchers, particularly in Australia and Canada, have settled for a compromise and developed techniques for estimating crop production from standard climatic data used in physically and physiologically meaningful models. Members of the Agrometeorology Section, Plant Research Institute, have made appreciable progress along these lines and have developed models that provide data useful for land classification in Canada. Techniques have been developed for estimating the following from standard climatic data:

1. Daily potential evapotranspiration (Baier and Robertson, 1965).

2. Daily changes in soil moisture content in six or less horizons of the soil profile and actual evapotranspiration (Baier and Robertson, 1966).

3. Daily rate of crop development towards maturity (Robertson, 1968).

4. Suitability of climate for the survival of ornamental trees and shrubs (Ouellet and Sherk, 1967).

5. Probable irrigation requirements for various water-holding capacities of soils and consumptive-use rates of crops (Baier and Russelo, 1968).

6. Probable dates of the occurrence of freezing temperatures in spring and fall (Robertson and Russelo, 1968).

APPLICATIONS TO AGRICULTURE

Climatic Estimates of Irrigation Requirements

Estimates of the timely water needs by irrigated crops in newly developed areas are essential for designing irrigation systems and determining the necessary water reserves. Such planning has to be based on probable extreme conditions rather than averages. Probabilities or risk of weekly and seasonal crop water requirements estimated from 30-year daily climatic data were recently published for 59 weather sites across Canada. Average (50% risk) seasonal irrigation requirements for soils holding a maximum of 4 inches available water were almost nil in Maritime climates along the East and West Coasts and varied from 5 to 12 inches on the Prairies. Those based on 10% risk were 3 to 5 inches higher (Coligado, Baier and Sly, 1968). The differences between the requirements for 50% and 10% risks indicate how much more water is necessary to meet the water needs not only in 5 but rather in 9 out of 10 years (Baier and Robertson, 1969). Maps are being prepared showing water deficiencies and dates of critical temperatures to be included in the Canada Land Inventory data bank.

Climatic Index

Even in areas where irrigation is impractical, the probable requirements characterize the climate in terms of severity and frequency of droughts. The total of seasonal irrigation requirements (IR), precipitation (P), and water available in the soil at the beginning of the growing season (CS) may be considered as the amount of water required by a crop when production is not limited by lack of moisture. The contribution of seasonal precipitation (P) to this amount represents the degree to which the crop demand for water can be satisfied by precipitation only. Sly (1969) proposed an index $\left(\frac{P}{P + IR + CS} \right)$ that can be used for comparing climates in relation to potential crop production. The indices ranged from above 80 in eastern Canada to the mid-forties on the southern Prairies and to the twenties in some of the inter-mountain valleys of the Rockies. These ranges were associated with distinctive types of vegetation. A good relation also existed between the indices and the climatic phases being suggested for Canada's section of the World Soil Map.

Wheat Zonation Map

Williams (1968) developed a technique for estimating temperature normals on the Prairies from latitude, longitude, and elevation based on regression equations developed by Hopkins of the National Research Council. The Biometeorological Time Scale developed by Robertson (1968) uses day and night temperatures and daylength to estimate the rate of crop development. Combining the results from Hopkins and Robertson's research, Williams (1969) devised a method to estimate the normal mean daily minimum temperature at the time wheat would mature. Use of this zonation map will be helpful in determining which parts of the 20-30 million acres undeveloped, arable land on the Canadian Great Plains should be climatically suitable for the production of wheat or alternative crops. Attempts to grow crops in climatically unsuitable areas would be very wasteful of resources and development funds.

APPLICATIONS TO FORESTRY

It is realized that many assumptions made in the foregoing paragraphs do not apply to forestry. Before going into detail, however, we should realize that often a simple and practical method is required to evaluate land use and natural resources. For example, potential evapotranspiration may be modified by local environmental factors but its concept and estimation from climatic data for a large area where the ultimate is a broad assessment of potential water loss is still valid. Other examples for building bridges between climatology and the climate in forest stands are the topoclimatic maps produced by Lee and Baumgartner (1966) showing the orientation of slopes and the corresponding radiation indices as a function of maximum annual solar radiation.

Encouraging results of estimating responses of forest trees to climatic parameters, including calculated soil moisture, were reported by Zahner and Stage (1966). They could explain about 72% of the variation in annual shoot-growth of red pine in Michigan by variations of moisture stress during certain periods of both previous and current growing seasons. Basal area increment of western white pine in northern Idaho could be explained by moisture stress, which accounted for a 28% reduction in the variance of growth remaining after the effects of temperature and precipitation per se had been removed. The complete model accounted for 78% of the total variation.

CONCLUSIONS

Long-term standard climatic data and special plant observations are necessary for the development of the plant-weather models illustrated in this paper. Since such homogeneous phenological and climatological records are rarely available, special data collection programs have to be carefully designed and conducted over several years at a number of sites located in various climates. Besides suitable data, the success in developing plant-weather models also depends on a sound knowledge of the physical, physiological, and bio-chemical responses of plants to their environment.

Only some facets of these complex interactions are as yet understood. The approach to follow in agriculture and more so in forestry during the following years is to collect meaningful and comparable data, to develop simplified plant-weather models, and to test the performance of these models under a variety of environmental conditions. When the outcome of these tests is satisfactory, then large-scale applications are justified and recommendations of far-reaching consequences for land use and natural resource development are well founded.

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"OASIS EFFECTS" CAUSED BY THE CYPRESS HILLS

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ABSTRACT

The Cypress Hills rise approximately 2000 feet (600 m) above the prairie of southeastern Alberta and southwestern Saskatchewan. On the Alberta portion, which comprises almost 200 square miles (520 square km), the heavily forested northern edge slopes steeply from the flat and almost treeless summit. The Saskatchewan part, while lower in relief, covers 500 square miles (1300 square km) and has scattered forests on its slopes and summit. The entire unit represents a unique biological-climatological island environment when compared to the surrounding prairie and presents an ideal situation to study relationships between climate, biota, and land forms. The present discussion reports the results of airborne measurements of the meso-climatic effect of the Hills on the air passing over them. An instrumented aircraft was used to obtain the data. This information demonstrates the "oasis effect" produced by the relatively more moist and forested hills when compared to the semi-arid surrounding prairie.

The atmospheric boundary layer experiences a distinct discontinuity at the northern edge of the Cypress Hills, in air flow, air temperature, dew point temperature, and surface temperature. The air flow becomes more chaotic, and stream lines become more compressed compared to that over the prairie. Further, dew-point temperature and air temperature lapse-rate steepens at the approach of the Hills and surface temperatures generally decrease.

INTRODUCTION

In 1870 after a brief survey, the Dominion Botanist John Macoun wrote (15):

> "In all my wanderings, I never saw any spot equal in beauty to the central plateau of the Cypress Hills. The grasses and other forage plants of the Hills were those peculiar to coolness and altitude, but were all highly nutritious, and most identical with those found on the higher plateau at Morley (an area near Banff). In all the valleys, and on the rich soil of the higher grounds, the grass was tall enough for hay. No better summer pasture is to be found in all the wide northwest than exists on these hills, as the grass is always green, water of the best quality always abundant, and shelter from the autumnal and winter storms always at hand."

From pioneer days, travellers in the Canadian west looked to the Cypress Hills to provide welcome relief from the rigors of the surrounding prairie. Captain John Palliser noted in 1859 (17):

> "The Cypress Mountains formed indeed a great contrast to the level country through which we were travelling. They are covered with timber ... the soil is rich and the supply of water abundant ... they provide a perfect oasis in the desert we have travelled."

The term "Cypress" was probably first applied by Metis and voyageurs at Chesterhouse near the junction of the Red Deer and South Saskatchewan Rivers. The windblown pines on the high Cypress Hills plateau likely reminded them of similar areas in France where Cypress trees do exist. To the Blackfoot, the region is called "Katewius Netumoo", the "Hills of Whispering Pines". The area is steeped in pioneer lore. It was once a "no-man's land"--a buffer between Blackfoot and Sioux. It was also an ancient hunting ground, a source of timber and of pure, cold water. For 50 years, Canadians, Americans, Indians, and half-breeds fought for supremacy in the area, and so it also of necessity became a place of interest to the North-West Mounted Police.

Recently, William Stegner summarized much of the background of the Cypress Hills in his historical narrative, "Wolf Willow"[1]. He related much of what is important historically but left scientific details for others. Geological data and conclusions have been reported by the Alberta Society of Petroleum Geologists (1) and by Russell (19). Detailed maps, with geological and topographical descriptions, are contained in these reports, together with complete literature reviews. The Cypress Hills are widely recognized as an erosional remnant (19) (3). Of particular interest is the fact that the gravel and conglomerate capped plateau is non-glaciated. The most recent continental ice sheet came to a halt at the northern edge of the plateau and left there many unusual surface features characteristic of stagnant ice and periglacial activity. To the west and east, the ice ground and groaned its way southward. Recent studies and reports regarding this point have been published by Westgate (20), Jungarius (13), and Broscoe (3).

Biological and ecological surveys have been conducted by Breitung (2), Cormack (5), Godfrey (9), King (14), Rand (18), and McConnell (16).

General Climate

The climate of the prairie area surrounding the Cypress Hills is characterized by relatively long, hot, and dry summers, and cold, sharp winters. The effective precipitation is relatively low because of high evaporation rates induced by strong winds and low humidity. At Medicine Hat the hottest month is July with a mean temperature of 70°F (21°C). January is coldest with a mean daily temperature of 19.5°F (-7°C). A high of 109.5°F (43°C) and a low of -61.6°F (-52°C) have been recorded. Annual precipitation is 13 inches (33 cm), annual mean winds are westerly at speeds of approximately 16 mph (7 m/sec) with a peak in the winter months.

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[1] Stegner, Wallace; Wolf Willow, Viking Press Inc., New York 1963; 307 pp.

The highest elevation of the Cypress Hills plateau is 4810 feet (1460 m) a.s.l., which is 2730 feet (830 m) higher than Medicine Hat, the nearest principal city, 35 miles (56 km) to the north-west. The plateau lies 1500 to 2000 feet (450 to 600 m) above the average surrounding prairie terrain. Although reliable climatic data from the Cypress Hills region are singularly lacking, it is estimated that the daily mean temperature for July is 59°F (15°C) with an average annual precipitation in excess of 20 inches (50 cm). The effectiveness of this rainfall is enhanced by the reduced evaporation rate. Hence the vegetation is more luxuriant and many slopes, particularly the northern scarp, are covered with dense, mixed deciduous and ooniferous forests. Two main vegetational divisions have been suggested (2): 1) the forest, which is almost entirely restricted to north slopes and inner-plateau valleys and 2) the grassland, which covers the remainder including the almost treeless summit plateau.

The transition between the divisions at the summit is very abrupt. Elsewhere at lower elevations, snow accumulation in ravines and coulees provides the moisture that allows trees and shrubs to encroach considerable distances onto the grasslands.

RESEARCH PROBLEM

Few natural areas provide such an excellent opportunity to study climatic-topographical-biological relationships as do the Cypress Hills. The formation is relatively small (15 x 150 miles) (24 x 240 km) and hence research logistics are simplified. The hills rise relatively abruptly and are almost completely surrounded by the prairie, which produces a convenient but unique island-oasis. Figure 1 presents a westerly view of the northern escarpment with the abrupt transition from forest to non-forest land. Figure 2 shows a north-easterly view of the summit plateau, overlooking the summit to the prairie. Figure 3 illustrates the dense vegetation on a northerly slope leading up to the summit plateau.

In this area many detailed studies are possible to clarify relationships between the atmosphere and the surface. The atmospheric boundary layer adjusts to the increase in surface elevation and also to the changing physical characteristics of the surface. Although many problems await our attention, present studies are directed toward 1) quantitative comparison of the climate of the Cypress Hills with that of the surrounding prairie, 2) determining the climates that exist within the Cypress Hills complex, 3) relating quantitatively the various climates to the topography, with a view to clarifying phenomena in the boundary layer as the surface increases in elevation. Instrumentation is located: 1) at 8 surface sites which are believed to present distinct and representative climatic situations, 2) in an aircraft which provides for the extension of surface observations upward as high as the effect of the Hills can be measured. Additional data are being obtained from the weather observation stations of the Department of Transport at Lethbridge, Manyberries, and Medicine Hat, Alberta, and Swift Current, Saskatchewan.

Surface Observations

Eight observing stations have been established in the Alberta portion of the Cypress Hills, and in the prairie to the immediate north and south. Sites were chosen that would provide data from the general area of maximum relief

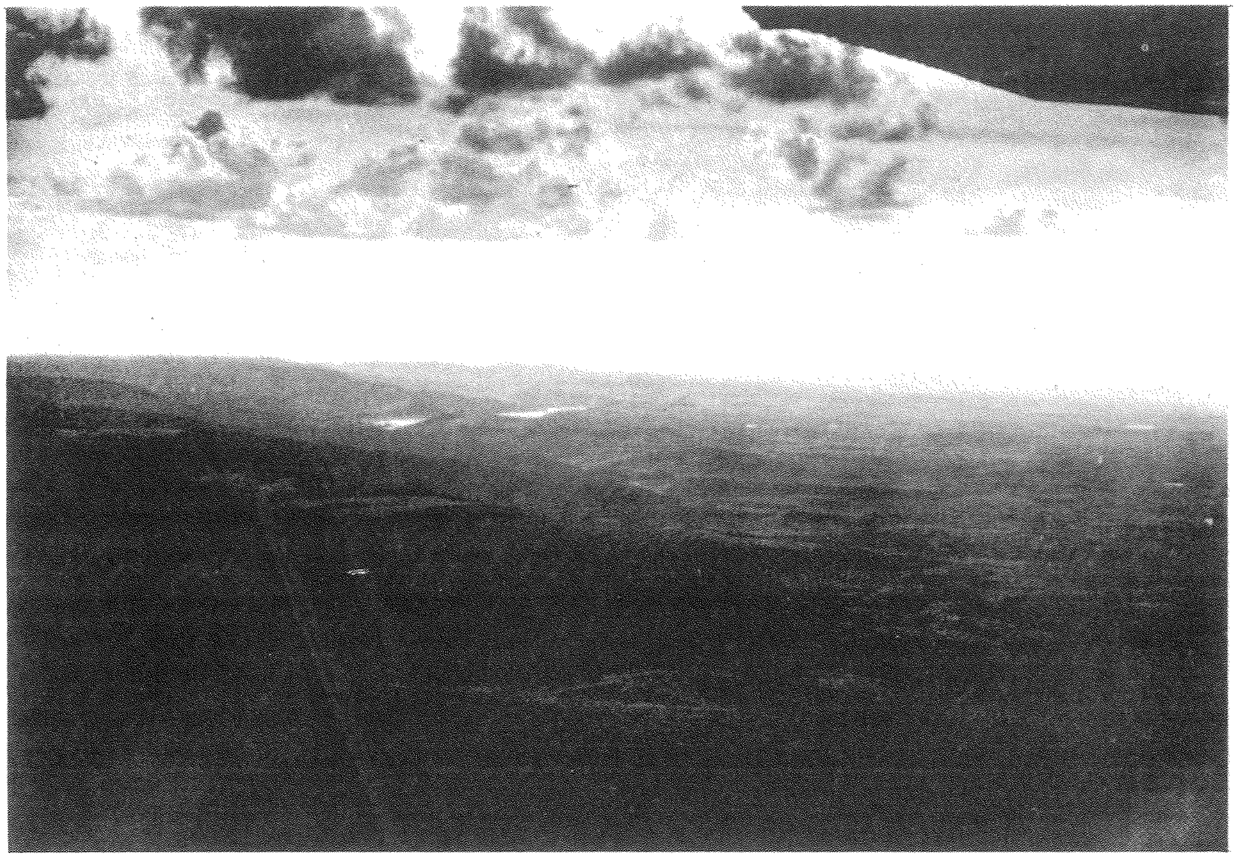

Figure 1
Westerly view of northern escarpment of Cypress Hills. Note abrupt changes from forest to non-forested surface.

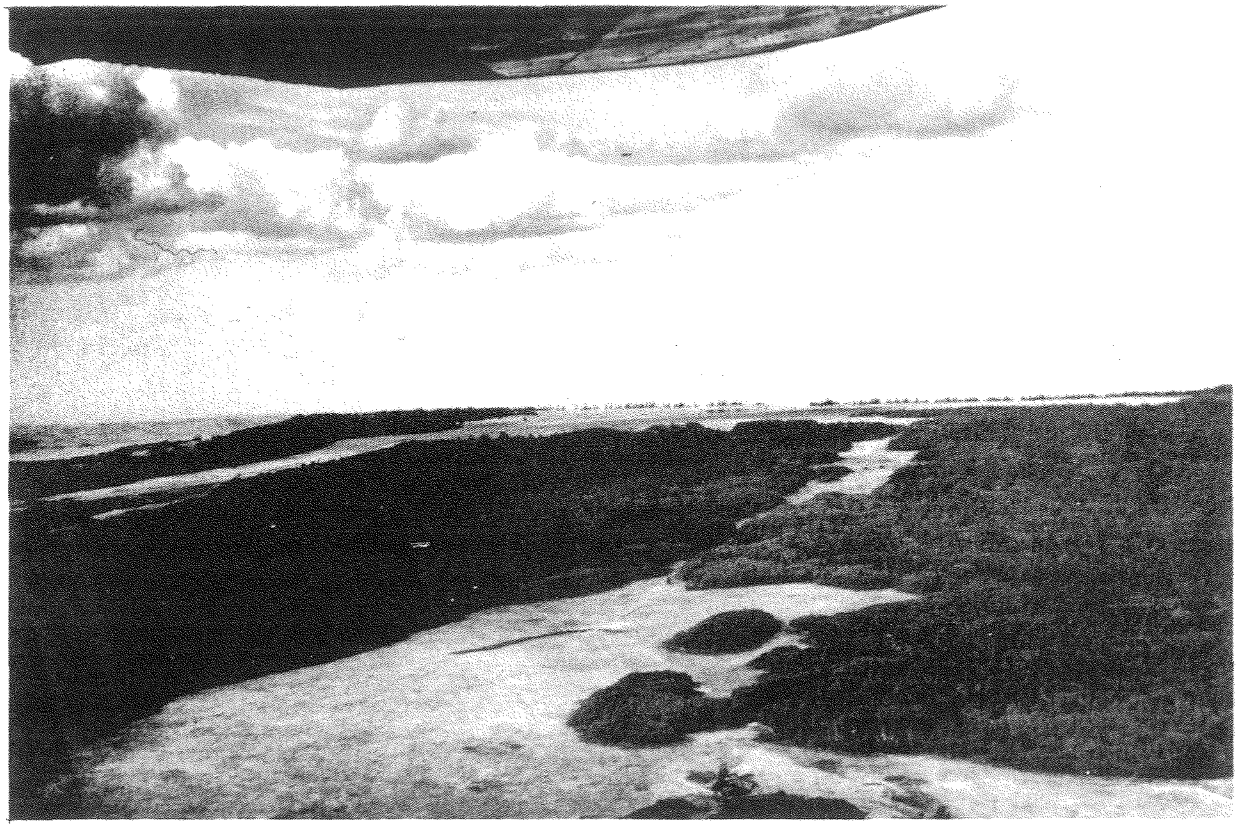

Figure 2
Summit plateau of Cypress Hills looking northeast. Note the sharp transitions from grassland to forest and almost treeless summit plateau.

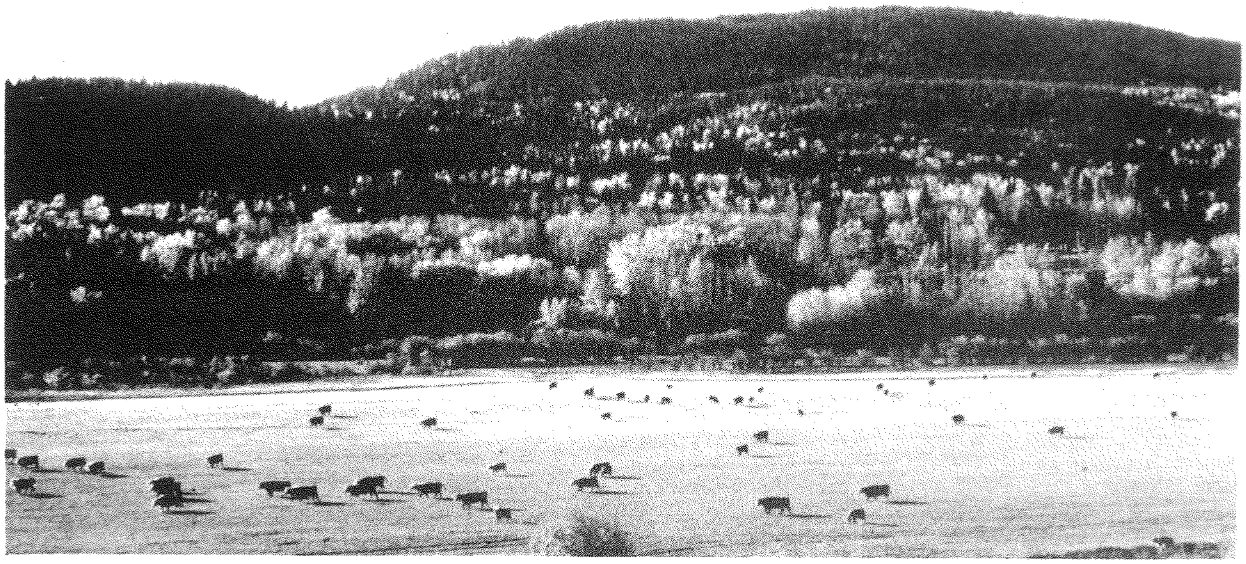

Figure 3
Northern escarpment of Cypress Hills. Note the heavily forested slope with mixed deciduous and coniferous trees.

and would be representative of major kinds of terrain encountered in the Cypress Hills and vicinity. In this work, it is assumed, for example, that measurements made at the site on the forested north slope would be similar to measurements made elsewhere in the Cypress Hills on forested north slopes. Figure 4a and 4b show the location of the Cypress Hills in relation to other broader geographical features and also presents a topographical map of the entire Hills complex. Figure 5 is an enlarged map of the Alberta study area, showing the location of the 8 observing sites. The four sites that are considered to be most important are circled. These sites provide a complete sampling of surface weather in a NW - SE transect from north of the plateau, over the plateau, and to the south. They are the most heavily instrumented. The remaining four stations are designed for obtaining data to show the degree of horizontal variation along the summit plateau, and to determine the climatic transition from a forested to a non-forested situation. Table 1 presents an outline of the type of weather observations taken at the 8 sites. Each site is surrounded by a barbed-wire fence to keep out wild game, stock, and tourists. Figure 6 illustrates the nature of site number 1 in Figure 5.

A detailed description of Cypress Hills soils is available from Gravenor et al. (10), Jungarius (13), and Wyatt et al. (21). A detailed description of the surface observing sites is also available (12).

Observations of surface weather are carried out throughout the year. During the summer period each site is visited twice daily to examine all instruments for proper performance and to make observations. All data are taken in a standard manner, in accordance with the Canadian Department of Transport Manual of Observation. This schedule begins as soon as snow melt is sufficient to make the country roads passable. The twice-daily visits are discontinued about September 1. During the intervening winter months the sites are visited weekly to change the hygrothermograph charts, and to observe snowfall, weekly miles of wind, and snow on the ground. A snow vehicle is required for most of these visits. Frequently, conditions become very bitter during winter months, with much snow, blowing and drifting snow, and low cloud. Clogging of the Stevenson Screens with fine snow is frequent with stoppage of the clocks, and v-lever linkages on the hygrothermographs. The hair of the hygrometer becomes coated with snow or frost with a subsequent continual indication of 100% relative humidity. This condition persists until an observer cleans the instrument or the frost accumulation on the hairs sublimes. Only then does the instrument perform properly. This results in a frequent loss of data and no solution is yet available.

It is anticipated that surface observations will continue as outlined above for 8 - 10 years. This period is required to sample a sufficient number of seasonal situations to be confident that the data are representative, reliable, and complete. Analysis of data will be performed at frequent intervals to maintain a continuous appraisal of weather patterns and events in the study area. Climatic models will be developed and tested with the data as they become available.

Airborne Observations

The airborne observations are made from an instrumented Piper Cherokee "6" (Pa-32-300). It is possible to measure intermittently or continually,

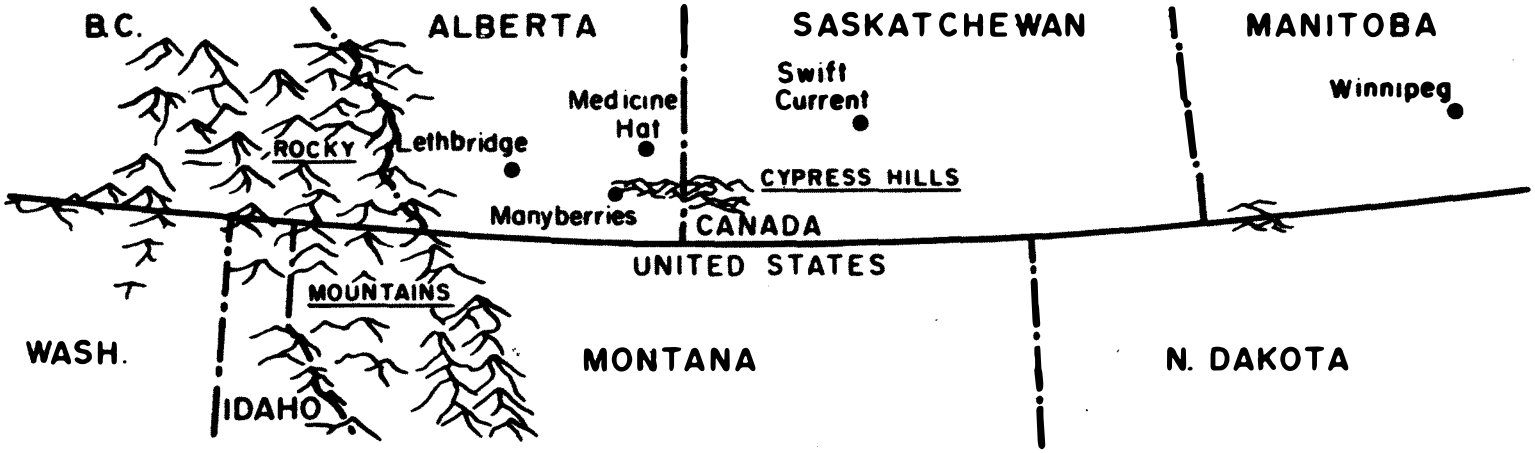

FIG. 4A. LOCATION OF CYPRESS HILLS IN RELATION TO OTHER GEOGRAPHICAL FEATURES.

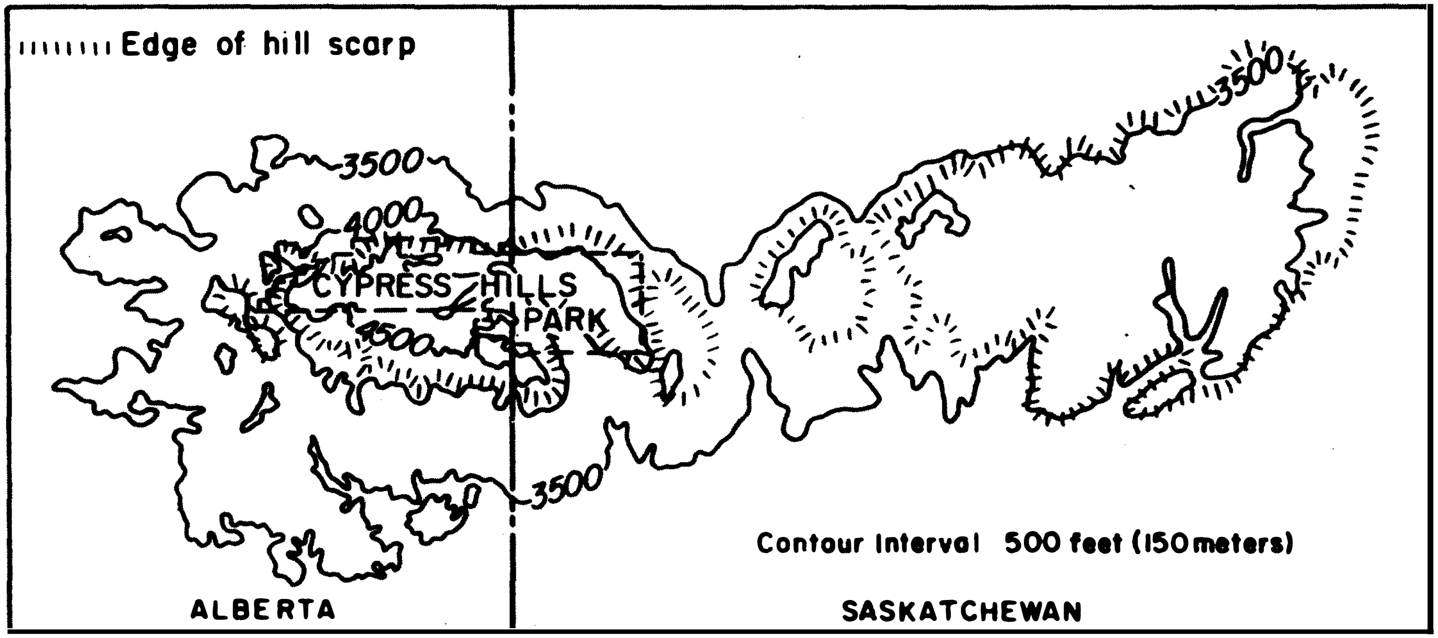

FIG. 4B. TOPOGRAPHICAL MAP OF ENTIRE CYPRESS HILLS COMPLEX.

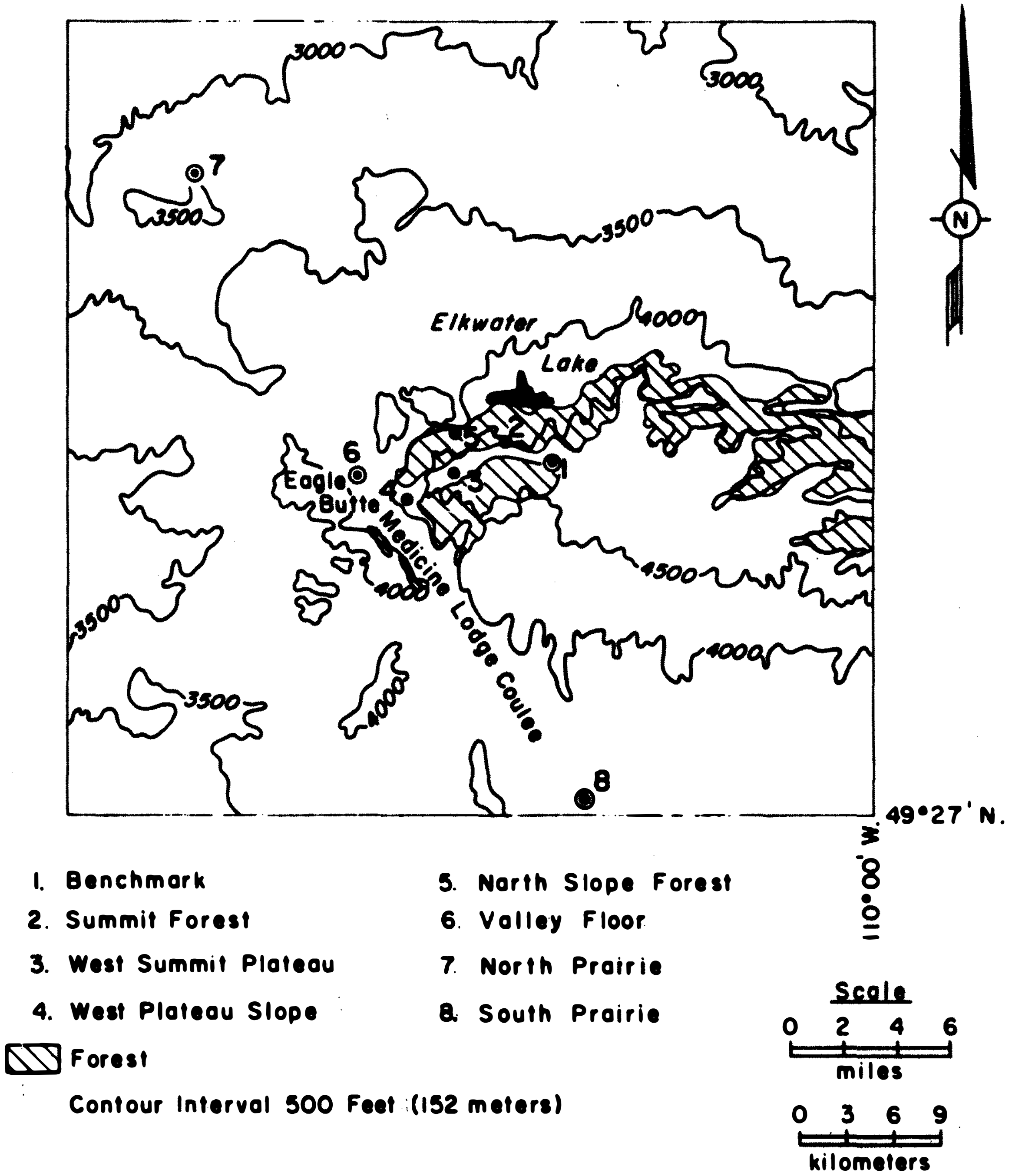

FIGURE 5

ENLARGED SECTION OF ALBERTA STUDY AREA OF CYPRESS HILLS SHOWING LOCATION OF SURFACE OBSERVATION SITES

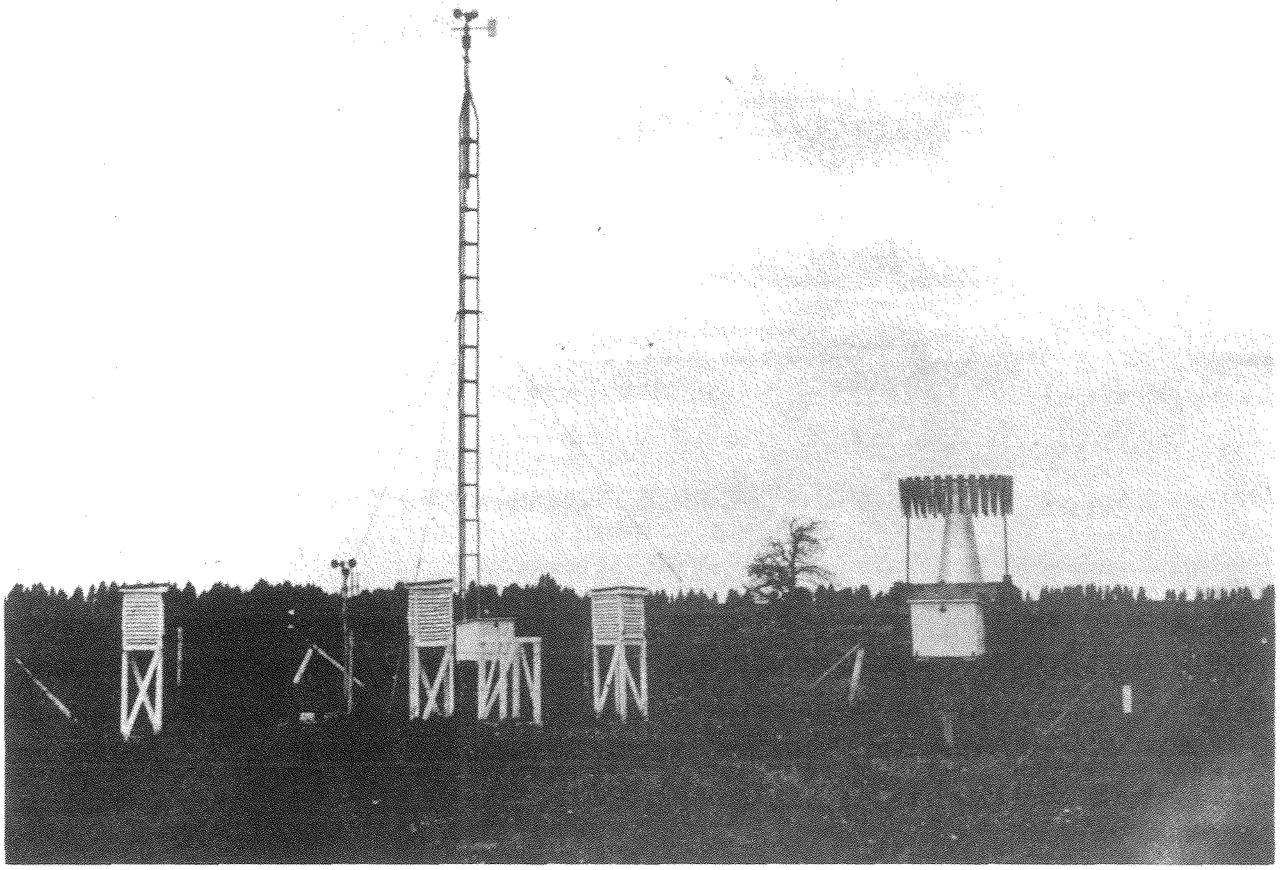

Figure 6
One of eight surface observing stations in Cypress Hills. Trees in the distance indicate the edge of the north summit plateau.

Table 1. Weather observations at 8 sites in the Cypress Hills,

	Observing site							
Observation	Summit bench mark	Summit forest	West summit plateau	West plateau slope	North slope forest	Open Valley	North Prairie	South Prairie
Daily maximum temperature (1)	X	X	X	X	X	X	X	X
Daily minimum temperature (1)	X	X	X	X	X	X	X	X
Grass minimum temperature	X	X	X	X	X	X	X	X
Standard rain gauge (4)	X	X	X	X	X	X	X	X
Tipping bucket rain gauge	X					X	X	X
Totalizing anemometer (2) (4)	X	X	X	X	X	X	X	X
Anemograph (wind speed & direction) (3)	X						X	X
Hygrothermograph (1)	X	X	X	X	X	X	X	X
Sling psychrometer (4)	X	X	X	X	X	X	X	X
Black porous disc atmometer (4) (9)	X				X	X	X	X
Class "A" evaporation pan (4) (5)	X					X	X	X
Soil temperature (4 & 8 inch "L" thermometer) (6)	X	X	X	X	X	X	X	X
Soil temperature (7)	X							
Snow fall (8)	X						X	X

(1) Screen height 1-1/2 meters
(2) 2 Meters
(3) 10 Meters
(4) Observed at 0800 and 1700 hrs.
(5) Complete with water temperature and anemometer at pan rim height.
(6) Observed at 0800 and 1700 hrs.
(7) 5 cm, 10 cm, 20 cm, 50 cm, 150 cm and 300 cm observed at 0800 and 1700 hrs.
(8) Sacremento gauge and Knipfer shield, 3 Meters
(9) 1-1/2 Meters

air and surface temperature, air dew-point temperature, albedo, solar and sky short-wave radiation, reflected short-wave radiation, and three vectors of air movement. A detailed description of the instruments and data acquisition system will be published at a later date. The aircraft contains a radio altimeter and radar equipment which permits accurate determination of distance between the aircraft and ground surface and ground speed. Over flat terrain, altitudes of 50 feet (15 m) can be accurately maintained with safety. Over hilly areas experience has shown that the minimum safe altitude is highly dependent on wind speed and direction. Therefore a constant density-altitude is flown rather than maintaining a fixed distance between aircraft and surface. The aircraft has been found to have enormous capability to extend meteorological observations upward into the atmosphere. Further, a large horizontal coverage is possible in a short time. Figures 7 and 8 show the aircraft and some of the instruments and mountings on the wings.

Air flow over the Hills was first qualitatively determined by smoke-tracer tests on three separate days when winds were from the west. A summary of findings from these intermittent tests is presented in Figure 9. An oil fog generator and general chemical smoke pots were placed at the various positions indicated, to determine air flow near several prominences. Smoke plumes were photographed from the aircraft. It is to be noted that Figure 9 is diagrammatic and air streams were drawn from photographs. The figure is presented to show the complex nature of westerly flow over the Hills. Of particular interest is the existence of a well defined rotor in the valley when wind speeds were in excess of 7 - 9 mph (18 - 20 m/sec). At 4 - 5 mph (8 - 10 m/sec) and less, wind flow followed the contours of the valley. Over the plateau less well defined rotors would form and then break up at the positions indicated when wind speeds were in excess of 7 - 10 mph (18 - 20 m/sec). Wind-tunnel testing of models of the terrain is contemplated as part of future experimentation. Wind flow and patterns over the Cypress Hills is considered to have a marked effect on moisture and vegetation distribution. Also, areas of enhanced or reduced rainfall, drifting of snow, evaporation patterns, air drainage, and inversion formation are related to air flow characteristics.

Wind speeds were measured by a radar and gust system in the aircraft from an altitude of 50 feet (15 m) to 1500 feet (450 m) above the surface. Part of these data are shown in Figure 10. It should be pointed out that the data are wind speeds longitudinal with the aircraft direction of flight. Flight paths were chosen that were oriented into the mean wind direction to negate drift. The numbers in Figure 10 are the arithmetic average of four flights at each altitude.

It is to be noted that the wind profile is much steeper over the summit than over the prairie to the west and south. Considerable variability existed in the valley and these data are not shown. The dotted lines join points of equal wind speed and point to the compression of stream lines over the prominences. The turbulence parameter T is an arbitrary number that gives an indication of the degree of turbulence according to:

$$T = K \left[\frac{\Sigma (U_i - U_{i+1})}{N-1} \right]$$

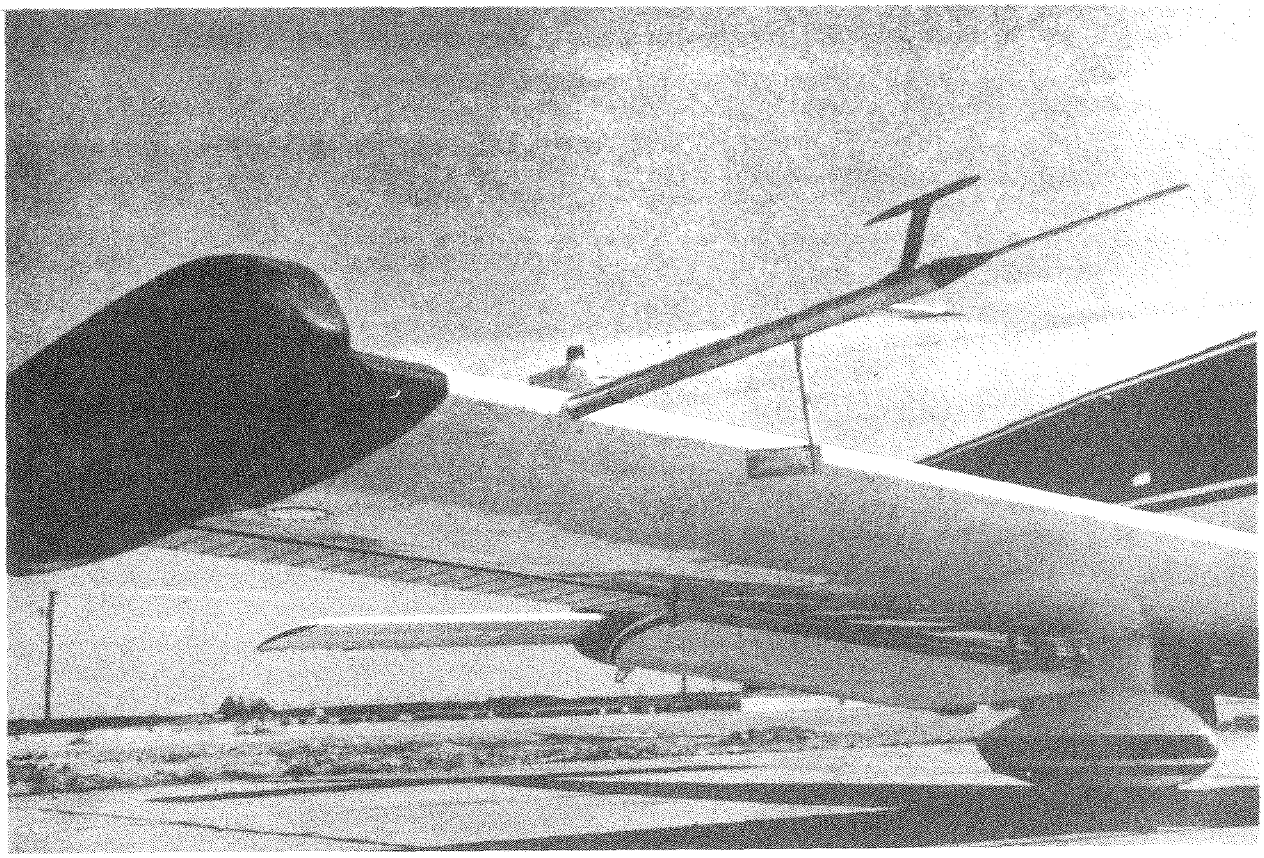

Figure 7
Wing tip instrumentation required for measurement of u v w. Boom and casing contains angle-of-attack vanes (pitch and yaw), attitude gyros, accelerometers and pressure transducers. The wing pod contains electronic components associated with instrumentation in the casing.

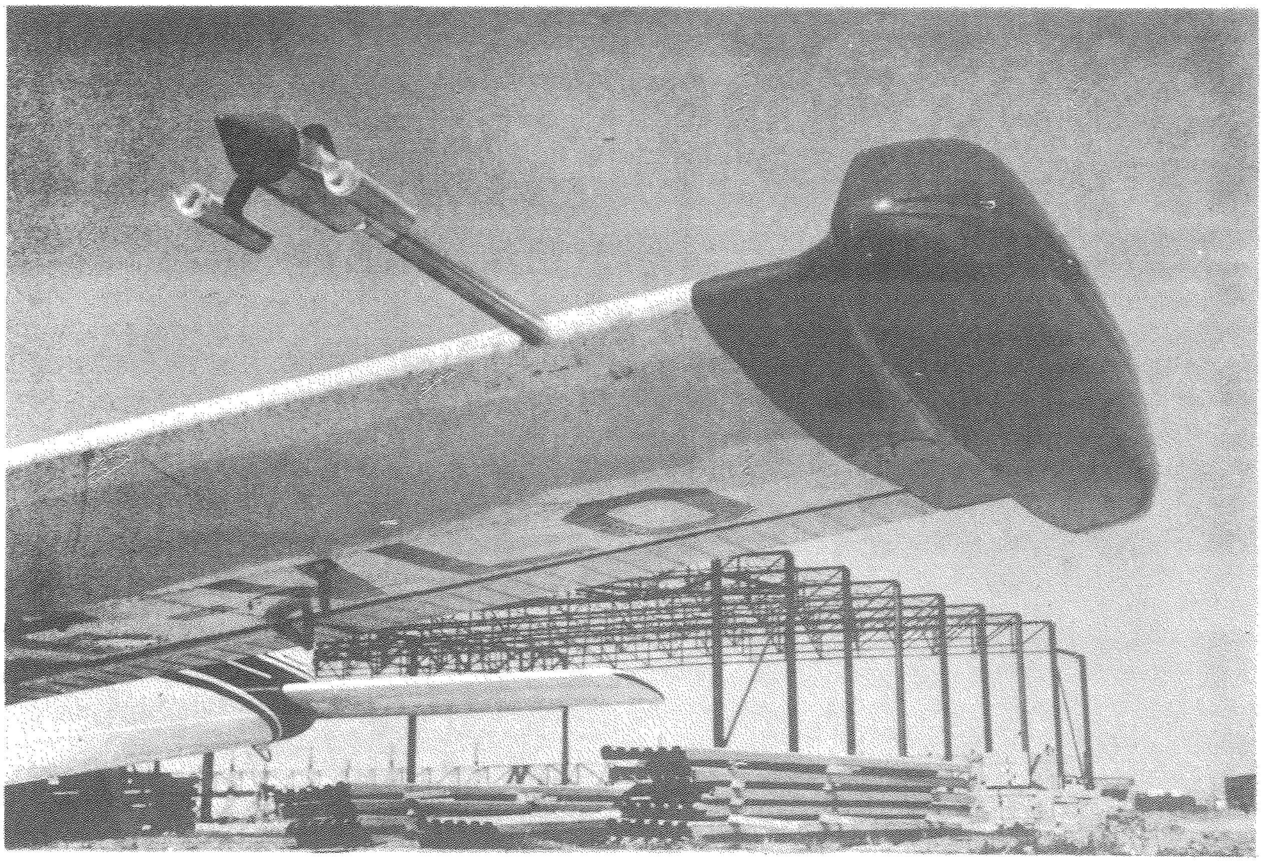

Figure 8
Wing tip instrumentation on a Cherokee "6" aircraft. Instrument casing on the boom contains temperature, dew point and psychrometric instrumentation. Tip pod contains power supplies and components associated with the transducers in the casing.

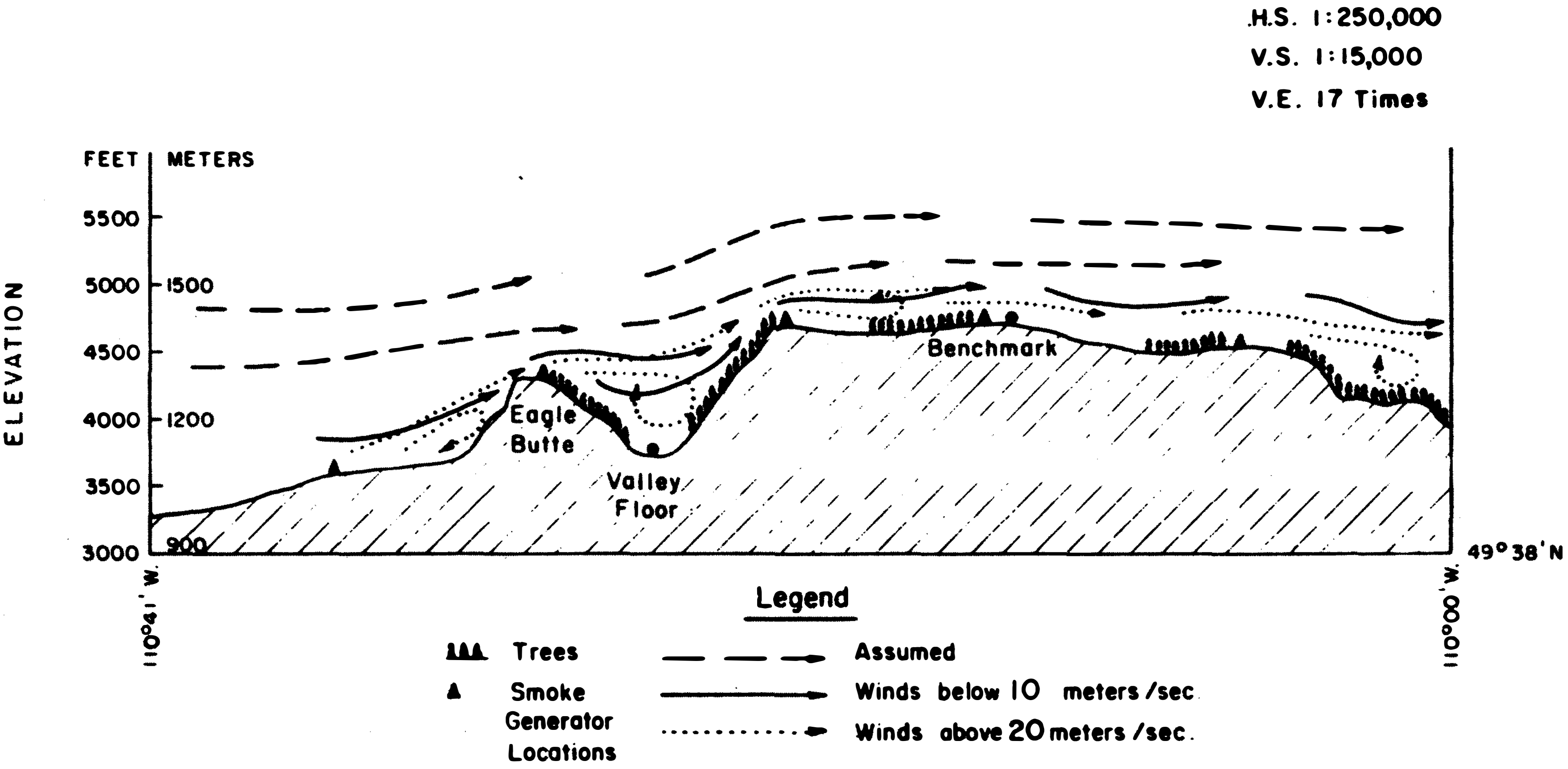

FIG. 9

WEST - EAST CROSS - SECTION OF CYPRESS HILLS WITH SCHEMATIC REPRESENTATION OF WIND FLOW DEDUCED FROM SMOKE TRACER TESTS.

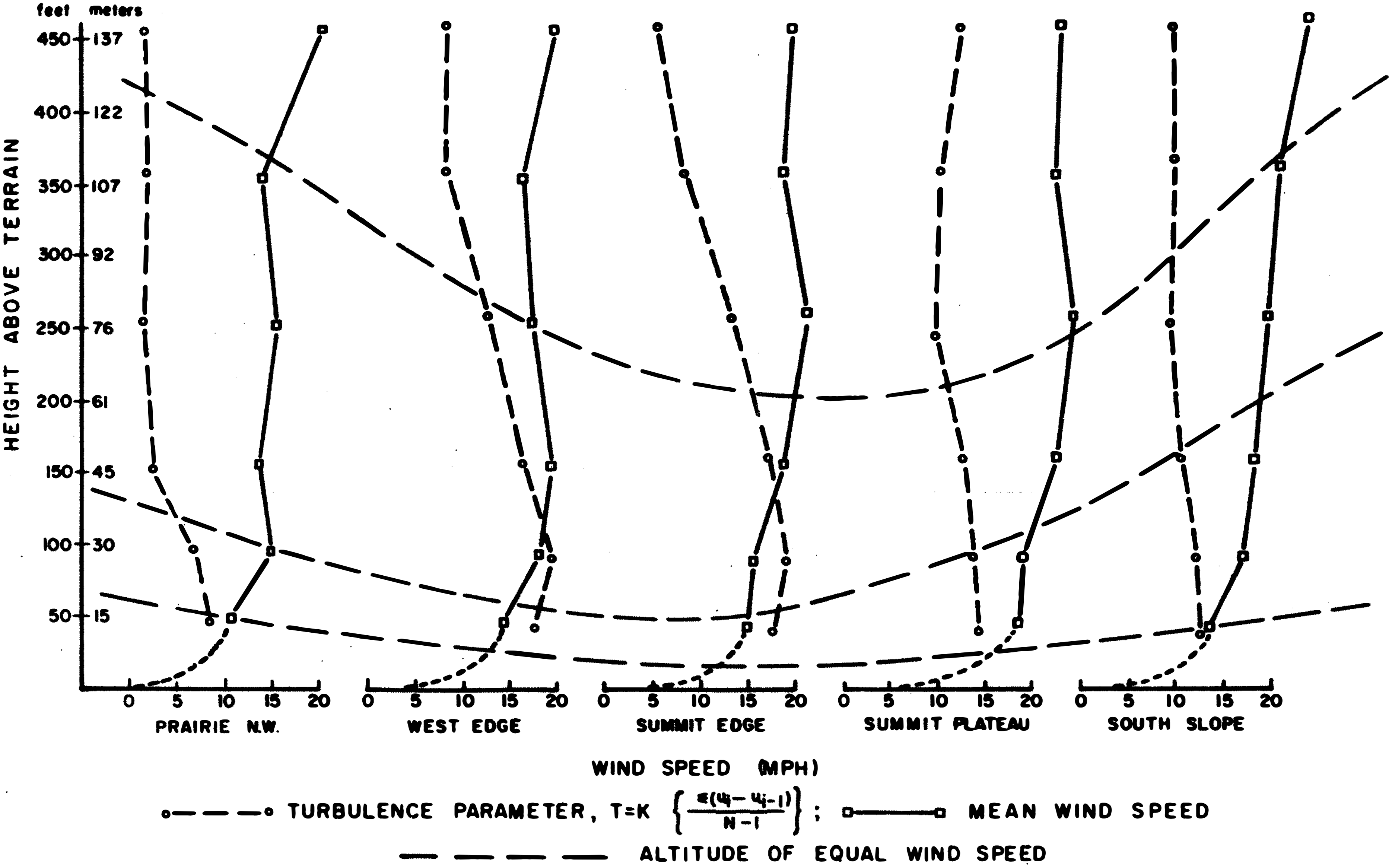

FIGURE 10 AIR FLOW CHARACTARISTICS OVER NW - SE TRANSECT OF CYPRESS HILLS

where $(U_i - U_{i+1})$ is the difference between the individual wind speed observation at a given altitude, and N is the number of observations at that altitude. K is a coefficient used for convenience to place the values on the scale shown in Figure 10. These values point to the marked terrain induced turbulence particularly at the leading edge of the prominences. These findings are similar to those of Frenkiel (8).

During the first season of this study, the aircraft instrumentation was incomplete and only a few data are available regarding temperature phenomena. In Figure 11, observations of surface temperature taken with an infrared thermometer are presented. All readings are corrected for surface emissivity. Emissivity was approximated on the actual ground track with the use of a large emissivity box similar to those of Fuchs and Tanner (6) (7), and Buettner and Kern (4), and measurements were made on a calm clear night. The emissivity of relatively dry virgin prairie surfaces was found to vary from .94 to .96 depending on the sparseness of vegetation. A value of .95 was used for these surfaces. Tall green prairie grass 4 - 6 inches (10 - 15 cm), that completely covered the ground at higher elevations near the Cypress Hills, had an emissivity of .95 to .97 depending on the density of the grass vegetation. A value of .96 was used. Emissivity values for forest were estimated from those obtained from very tall, green grass 20 inches (50 cm) with a bunchy canopy, which varied from .96 to .98. A value of .97 was thus adopted for forest. Bare soil surfaces were not encountered over this particular ground track but elsewhere emissivities varied from .91 to .94 depending on soil texture. The heavier soils tended to have the higher emissivities. Emissivity for water was taken as 1.0 although this value may be too high (6) (7). The instrument chart trace was examined and points were taken at 5 second intervals. The ground track was examined for type of terrain and the appropriate emissivity was applied and a new graph plotted. The corrected graph is shown in Figure 11. Values of surface temperature are accurate to 1.0°C and temperature differences are accurate to 0.2°C. A complete report of this research phase will be published at a later date.

It is to be noted from Figure 11 that the surface is highly variable in temperature with occasional sharp decreases on the approach to the Hills from Medicine Hat, caused by small lakes and sloughs. On this day, the surface temperature gradually decreased as the surface elevation increased. An unusual 118°F (48°C) was measured at the Valley site despite the elevation. Over the summit toward the south the coolness of the forest and plateau meadow compared with the south prairie area is noteworthy. Air temperature is seen to remain relatively uniform at 5400 feet (1620 m) which is approximately 400 feet (122 m) above the plateau. However, dew point temperature shows a uniform increase at this height, then decreases beyond the Hills to the south. This particular effect is more noticeable in Figure 12. Dry bulb temperatures at 5200 feet (1550 m) remain relatively uniform over the Hills and increase during day time heating. There is a slight effect of the Hills in air temperature at 0800 MST with residual nocturnally cooled air over the plateau. A suggestion of daytime heating is also noted near the Hills at 1200 and 1600 MST. However, as the day proceeded, an increase in dew point temperature occurred over the area and to the south. On another day after a period of rain similar measurements were made in a vertical profile. These data are shown in Figure 13. Transects were flown over the same ground track as that of Figure 12 at

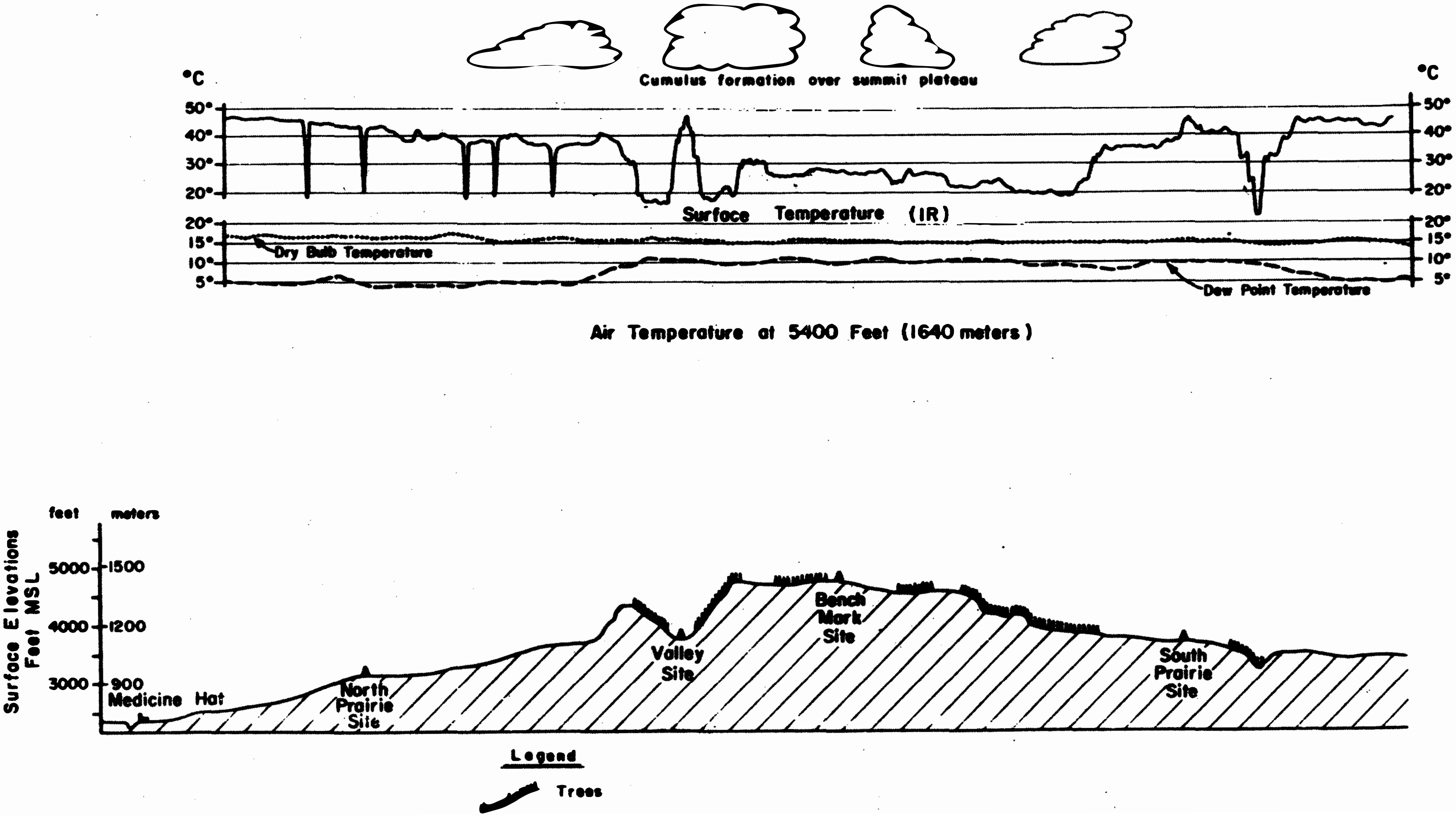

FIGURE 11 CYPRESS HILLS TRANSECT OF SURFACE AIR AND DEW POINT TEMPERATURE, JULY 19, 1967 1100 MST.

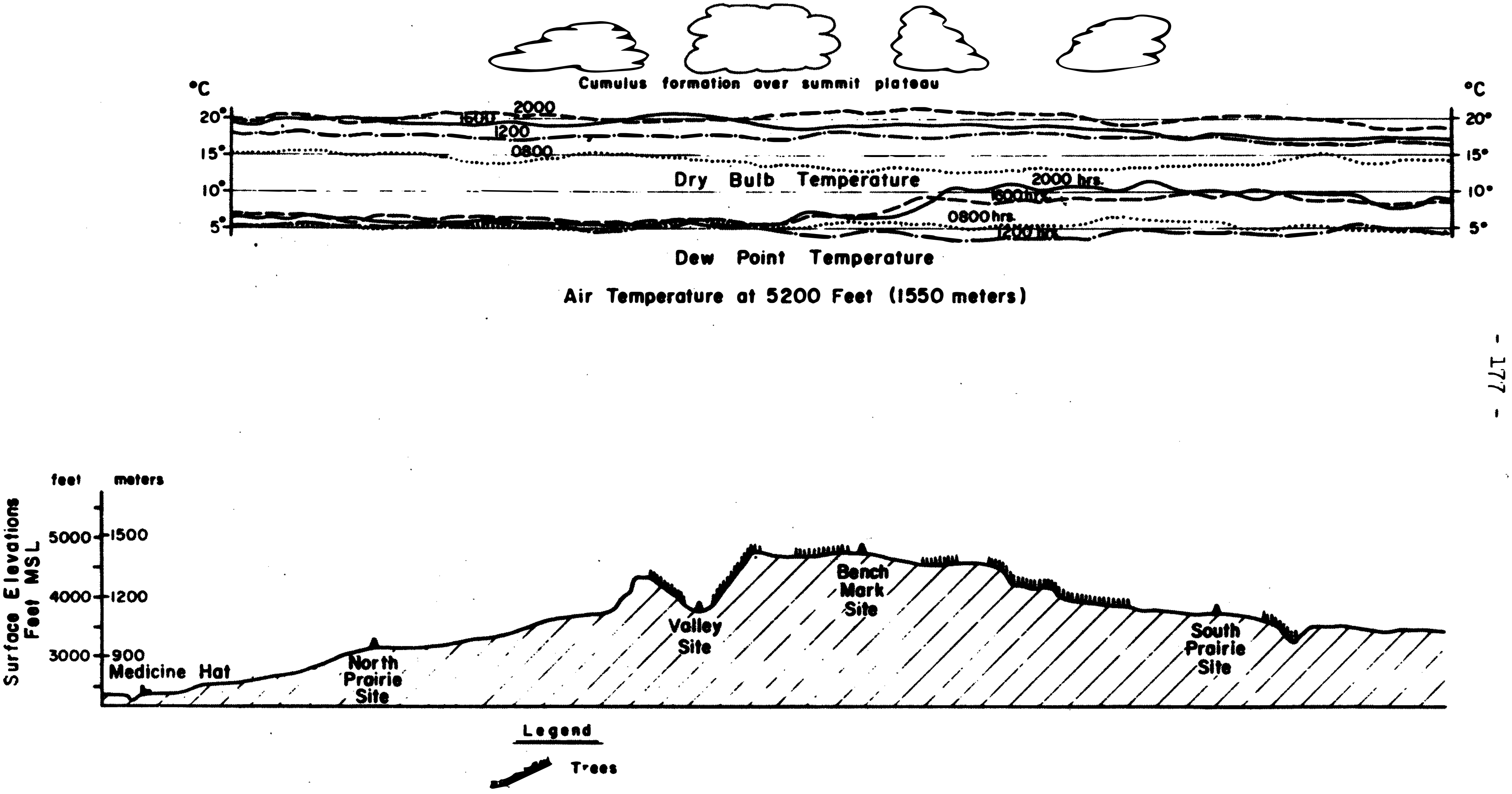

FIGURE 12 CYPRESS HILLS TRANSECT OF AIR AND DEW POINT TEMPERATURE AT VARIOUS TIMES ON JULY 19, 1967

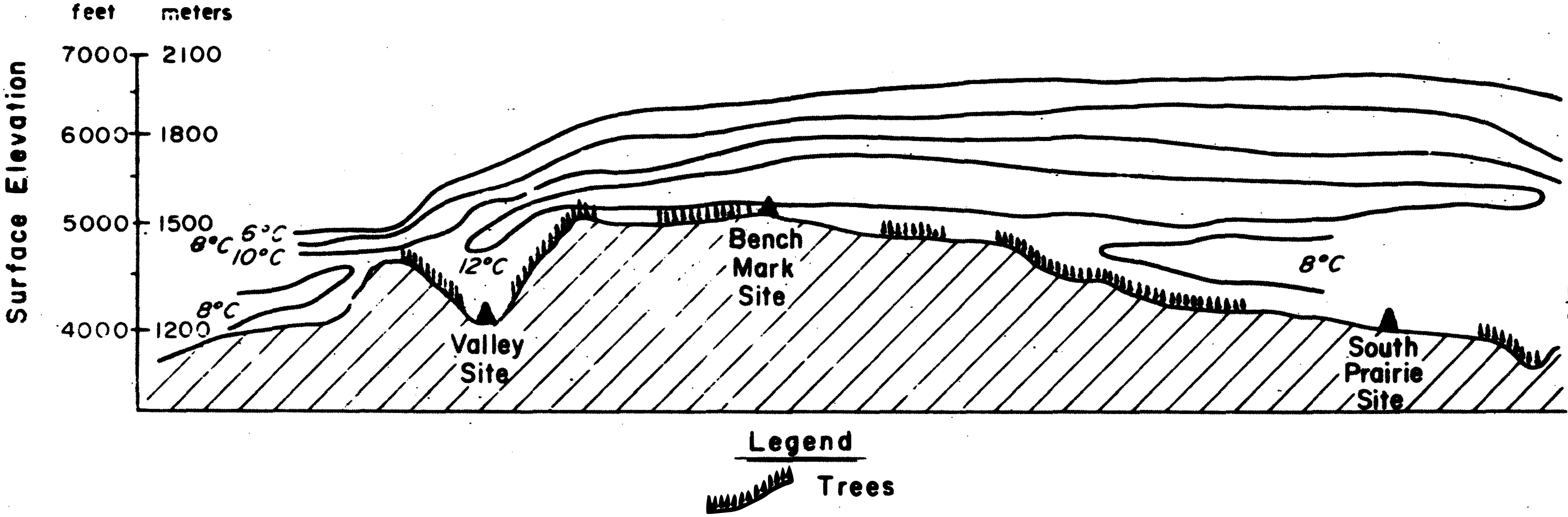

FIGURE 13 CYPRESS HILLS HEIGHT – DISTANCE TRANSECT OF DEW POINT TEMPERATURE ON JULY 22, 1967, 1500 TO 1650 MST.

100 feet (30 m) elevation intervals beginning at 5000 and continuing to 6800 feet (1520 - 2060 m). The lines of equal dew point temperature show a "Hills-oasis effect" which persists for a considerable distance downwind, suggesting a "moist air plume" rising from the plateau and forest and extending downwind before diffusing into the ambient prairie atmosphere. Similar results were obtained by Holmes over prairie lakes in the same area (11). The airborne observations illustrated here represent selected situations. It must be emphasized that the observed effects were found to be highly variable when taken over a number of days. On many days no effects could be measured regardless of altitude or time of day.

SUMMARY

Climatic studies described above were initiated in the Cypress Hills to study certain relationships between surface features and the atmosphere. This area is particularly interesting because of the unusual nature of the Cypress Hills land-form. This convenient and elevated area is cooler and more moist than the surrounding level prairie and consequently presents a unique surface biological-climatological environment. Further, the effects of the Hills can be measured in the atmosphere to a considerable height above the summit. Consequently, data are being obtained from surface sites as well as from an instrumented aircraft. The information will be used to relate quantitatively the climate to the nature of the surface.

The atmospheric boundary layer experiences a discontinuity at the northern edge of the Cypress Hills in regard to air flow, air temperature, dew point temperature, and surface temperature. Air flow becomes more chaotic, dew point temperature and air temperature lapse rate steepens at the Hills and the surface temperature generally decreases.

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SOLAR CLIMATE CALCULATOR

By

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Robertson and Russelo (1968) recently published a computer program that can calculate times of sunrise, sunset, and daylength for any latitude and longitude and can estimate the hourly and daily values of solar energy on a horizontal surface in the absence of an atmosphere. The program was written in Fortran II and was designed for running on an IBM 1620 computer. Because of our need for such data in our micrometeorological studies, we decided to adapt the program to Fortran IV in a version that could be run on both the IBM 360/50 computer and the IBM 7094-7040 direct coupled system available at the Yale Computer Center.[1] In this adaptation, we made a number of changes in the program and output format as detailed below.

The major change is in the way in which the solar ephemeris is calculated. Robertson and Russelo used Fourier series approximations of the solar declination, the equation of time and radius vector given in the Smithsonian meteorological tables (List, 1958). The data are for the year 1950 and ignore leap years. Our program calculates these data for noon local time for each day of the year for which the solar data are being calculated taking leap years into account. The method used is that presented in the Supplement to the American Ephemeris, 1946 (U.S. Naval Observatory, 1945). The calculations consider the solar climatic data to be symmetrical about solar noon.

For the calculation of solar energy outside the atmosphere, the sun is considered to be a point source and the solar constant to be 1.95 langleys per minute, the currently accepted value. The value of the solar constant can be readily changed since it is identified as "SCON" in a DATA statement in the program. A mathematical integration of the energy equation is used rather than the straight line approximation used by Robertson and Russelo. Although data are tabulated to tenths of langleys, the figures are probably good only to the nearest whole langley. Listed data are grouped by month.

In addition to sunrise, sunset, and daylength tables, a table of the clock time of solar noon is included. The program prints out all tables except when the designated latitude is greater than 60°. In higher latitudes, only the solar energy table is calculated and printed because of inherent uncertainties in the calculation of solar-climate data. Inasmuch as the time taken by the program on the Central Processing Unit of the IBM 7094 computer was less than 10 seconds, we decided that it was not worthwhile to include printout options as was done in the original program by Robertson and Russelo.

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[1] The program as listed will run on the 360; to convert to a 7094, DMOD must be changed to AMOD in statements 9001 and 9002.

Sunrise and sunset data are for an observer on the plane of the horizon and are for an unobstructed horizon. Time of sunrise or sunset for an elevated observer or for an obstructed horizon can be calculated from Table V and Va, reproduced from the Supplement to the American Ephemeris, 1946. Time of sunrise and sunset are assumed to occur when the center of the solar disk is geometrically 50 minutes below the horizon. This corresponds to a semi-diameter of 16 minutes and an atmospheric refraction at the horizon of 34 minutes. Correction for other atmospheric conditions can be made from Table Vb.

Considering the limits of accuracy as stated in the Supplement, as well as checks we have made against data published by the U.S. Naval Observatory, we believe that the calculated time data will be in error no more than ± 1 minute for any place on the earth between 60° north and south latitude and for any year in the 20th Century.

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C                   PROGRAM SOLAR  -  RIMCIF 009
C
C  WRITTEN BY G. FURNIVAL, E. WYLER, W. REIFSNYDER AND T. G. SICCAMA
C            YALE SCHOOL OF FORESTRY,  DECEMBER 1969
C
C THIS PROGRAM CALCULATES SOLAR CLIMATE DATA AND PRINTS OUT TABLES OF HOURLY AND
C DAILY VALUES OF SOLAR ENERGY OUTSIDE THE EARTH-S ATMOSPHERE,DAY LENGTH,TIME
C OF SUNRISE,TIME OF SUNSET,AND TIME OF SOLAR NOON.
C
C ONE CONTROL CARD IS REQUIRED FOR EACH LOCATION ON EARTH FOR WHICH CALCULATIONS
C ARE DESIRED. THEY ARE PLACED AS DATA CARDS AT THE END OF THE PROGRAM DECK.
C
C           COLUMN 1-4      YEAR
C           COLUMN 15-30    STATION IDENTIFICATION (16 ALPHAMERIC SYMBOLS)
C           COLUMN 31       SIGN OF LATITUDE (N=+,S=-)
C           COLUMN 32-33    LATITUDE, DEGREES
C           COLUMN 35-36    LATITUDE,MINUTES
C           COLUMN 38       SIGN OF LONGITUDE (W=+,E=-)
C           COLUMN 39-41    LONGITUDE, DEGREES
C           COLUMN 43-44    LONGITUDE, MINUTES
C           COLUMN 52-55    MERIDIAN OF STANDARD TIME ZONE (W=+, E=-)
C
      INTEGER STALA2,STLON2,DECL2,DCLO2
      REAL LNOON
      DOUBLE PRECISION MNLONG,SLONG,DLONG,ANOM,SANOM,DANOM,PPI
      DIMENSION NAME(8),MONDOY(12),MONTH(12),TITLE(9,4),SS(31,12,4),X(4)
     1,ENERG(12)
      DATA TITLE/3*4H    ,4H DAY,4H LEN,4HGTH ,3*4H    ,
     1  4H  TI,4HME O,4HF SU,4HNRIS,4HE, L,4HOCAL,4H STD,4H TIM,1HE,
     2 4H   T,4HIME ,4HOF S,4HUNSE,4HT, L,4HOCAL,4H STD,4H TIM,4HE    ,
     3 4H TIM,4HE OF,4H SOL,4HAR N,4HOON,,4H LOC,4HAL S,4HTD T,4HIME /
      DATA    MONTH           /4H JAN,4H FEB,4H MAR,4H APR,4H MAY,4HJUNE,
     14HJULY,4H AUG,4HSEPT,4H OCT,4H NOV,4H DEC/
      DATA  MONDOY           /31,00,31,30,31,30,31,31,30,31,30,31/
      DATA E,SCON,PI,PPI,RAD,RAH,FIRST,THIRD,ROW,A1,A2,A3,SLONG,SANOM,
     1  DLONG,DANOM,DSUN,SINOB,COTOB,SINE /
     2  0.0167234,1.95,3.1415927,0.62831854D+01,0.01745329,0.2617994,
     3  1.570796,4.712389,0.9997203,0.33445635E-01,0.3495545E-03,
     4  0.50615E-05,0.48860636D+01,0.62413117D+01,0.17202789D-01,
     5 0.17201967D-01,-0.23842E-04,0.39784786,2.3060358,-0.01454389/
C
C                                 EXPLANATION OF CONSTANTS
C
C  PPI=2.0*PI  RAD=180.0/PI  RAH=12.0/PI  FIRST=PI/2.0  THIRD=3.0*PI/2.0
C  ROW=1.0-E*E   A1=1.916294*RAD  A2=0.020028*RAD  A3=0.00029*RAD
C  SLONG=(279.95656-20.5/3600.0)*RAD  SANOM=357.60087*RAD
C  DLONG=0.98564735*RAD  DANOM=0.98560026*RAD  DSUN=SLONG-279.95223*RAD
C  SINOB=SIN(23.44371*RAD)  COTOB=COTAN(23.44371*RAD)
C  SINE=-SIN(50.0/60.0*RAD)  E=RAD*3449.449/3600.0  SCON=SOLAR CONSTANT
C                                 READ CONTROL CARD
 1000 READ(5,2) NYR,NAME,STALA2,DECL2,STLON2,DCLO2,ZONAE
    2 FORMAT(I4,10X,8A2,2I3,I5,I3,7X,F4.0)
      STALA = STALA2
       STLON= STLON2
        DCLON = DCLO2
       DECLA = DECL2
      IF(STALA.LT.0.0) DECLA=-DECLA
      IF(STLON.LT.0.0) DCLON=-DCLON
      STALA=STALA+DECLA/60.0
      STLON=STLON+DCLON/60.0
```

```
      IF(NYR.LT.1900.OR.NYR.GT.2000) WRITE(6,801)
  801 FORMAT(1H0,-YEAR NOT IN 20TH CENTURY-)
      IF(ABS(STALA).GT.90.0) WRITE (6,802)
  802 FORMAT(1H0,-LATITUDE GREATER THAN 90 DEGREES-)
      IF(ABS(STLON).GT.180.0) WRITE(6,803)
  803 FORMAT(1H0,-LONGITUDE GREATER THAN 180 DEGREES-)
      IF(ABS(STLON-ZONAC).GT.7.5) WRITE (6,804)
  804 FORMAT(1H0,-POSSIBLE ERROR-STATION MORE THAN 7.5 DEGREES FROM STAN
     1DARD MERIDIAN-)
       IF(ABS(STALA).GT.90.0.OR.ABS(STLON ).GT.180.0) GO TO 1000
      COSL=COS(STALA*RAD)
      SINL=SIN(STALA*RAD)
      LNOON=12.0+(STLON-ZONAC)/15.0
      DO 40 I=1,4
       DO 40 J=1,12
         DO 40 K=29,31
         SS(K,J,I) = 0.0
   40 CONTINUE
C                                INITIALIZE EPHEMERIS
      IF(NYR.LE.1966) DAZ=(NYR-1968)/4+365*(NYR-1966)
      IF(NYR.GT.1966) DAZ=(NYR-1965)/4+365*(NYR-1966)
      DAZ=DAZ+STLON/360.0-0.25
 9001 MNLONG=DMOD(SLONG+DLONG*DAZ,PPI)
 9002 ANOM=DMOD(SANOM+DANOM*DAZ,PPI)
      IF(MNLONG.LT.0.0) MNLONG=MNLONG+PPI
       MONDOY(2)=28
       IF((NYR/4)*4.EQ.NYR)  MONDOY(2)=29
      IDAY = 0
C                                BEGIN DAY LOOP
       DO 110 I=1,12
                    WRITE(6,66) NAME,STALA2,DECL2,STLON2,DCLO2
   66 FORMAT(1H1,///,13X,-SOLAR ENERGY IN LANGLEYS OUTSIDE ATMOSPHERE AT
     1-,1X,8A2,1X,-LAT-,1X,2I4,1X,-LONG-,1X,2I4,1X,-FOR HOUR ENDING(TST)
     2-///)
           WRITE(6,701) MONTH(I),NYR
  701 FORMAT(/// 16X,A4,3X     ,-DAY      12      11      10       9       8
     1   7       6       5       4       3       2       1  DAILY-/16X,I4,
     2 4X,-NO      13      14      15      16      17      18      19      20
     3 21      22      23      24   TOTAL-///)
       J = MONDOY(I)
      DO 109 K=1,J
        IDAY= IDAY + 1
C                                COMPUTE EPHEMERIS
      MNLONG=MNLONG+DLONG
      ANOM=ANOM+DANOM
      BNOM=ANOM
      CTERM=A1*SIN(BNOM)+A2*SIN(2.0*BNOM)+A3*SIN(3.0*BNOM)
      TLONG=MNLONG+CTERM
      RHO=ROW/(1.0+E*COS(BNOM+CTERM))
      SIND=SIN(TLONG)*SINOB
      COSD=SQRT(1.0-SIND*SIND)
      APSUN=ARSIN(SIND/COSD*COTOB)
      IF(TLONG.GT.PPI)TLONG=TLONG-PPI
      IF(TLONG.GT.FIRST.AND.TLONG.LE.THIRD) APSUN=PI-APSUN
      IF(TLONG.GT.THIRD) APSUN=APSUN+PPI
      TIME=(MNLONG-DSUN-APSUN)/RAH
      IF(TIME.LT.-12.0) TIME=TIME+24.0
      IF(TIME.GT.12.0) TIME=TIME-24.0
C                                DAYLENGTH,SUNRISE,SUNSET,LOCAL NOON
      DIGA=SINL*SIND
```

```
      BIGB=COSL*COSD
      COSS=(SINE-DIGA)/BIGB
      IF(COSS.LT.-1.0) COSS=-1.0
      IF(COSS.GT.1.0) COSS=1.0
      HOURS=ARCOS(COSS)/RAH
      IF(ABS(STALA).GT.60.0) GO TO 111
      X(4)=LNOON-TIME
      X(1)=2.0*HOURS
      X(2)=X(4)-HOURS
      X(3)=X(4)+HOURS
  111  DO 41 KL = 1,4
      IX=X(KL)+0.0067
        H = IX
         SS(K,I,KL) = H + (X(KL)-H)*0.60
   41 CONTINUE
C                                 CALCULATE HOURLY ENERGIES
      COSS=-DIGA/BIGB
      IF(COSS.LT.-1.0) COSS=-1.0
      IF(COSS.GT.1.0) COSS=1.0
      HOURS=ARCOS(COSS)/RAH
      ITEST=HOURS+1.0
      RHO2=RHO*RHO
      ANN=DIGA*60.0*SCON/RHO2
      B=BIGB*60.0*SCON/(RHO2*RAH)
      ZINO=0.0
      DO 500 NUM=1,12
      ENERG(NUM)=0.0
      IF(NUM.GT.ITEST) GO TO 500
      UL=NUM
      IF(UL.GT.HOURS) UL=HOURS
      ZIN1=ANN*UL+B*SIN(RAH*UL)
      ENERG(NUM)=ZIN1-ZINO
      ZINO=ZIN1
  500 CONTINUE
      TOTAL=2.0*ZIN1
      WRITE(6,702) K,IDAY,ENERG,TOTAL
  702 FORMAT(17X,I2,I7,12F7.1,F6.1)
      IF((K/5)*5.EQ.K) WRITE (6,709)
  109 CONTINUE
  110 CONTINUE
      IF(ABS(STALA).GT.60.0) GO TO 1000
C                                 PRINT DAYLENGTH TABLES
      DO 112 I=1,4
      WRITE(6,708) NAME, NYR
  708 FORMAT(1H1//// 57X,8A2,1X,I4)
      WRITE (6,709)(TITLE(J,I),J=1,9)
  709 FORMAT(1H0,49X,9A4/56X,- IN HOURS AND MINUTES-)
      WRITE(6,710) MONTH
  710 FORMAT(///31X,-DATE-,12(2X,A4)//)
      DO 130 II = 1,31
      WRITE(6,711) II, (SS(II,J,I),J=1,12)
  711 FORMAT(28X,I4,3X,12F6.2)
      IF((II/5)*5.EQ.II) WRITE(6,709)
  130 CONTINUE
  112 CONTINUE
      GO TO 1000
      END
                                                   CARD COUNT 0177
```

SOLAR ENERGY IN LANGLEYS OUTSIDE ATMOSPHERE AT CAMELS HUMP, VT. LAT 44 18 LONG 72 55 PER HOUR ENDING(TST)

JAN 1970	DAY NO	12 13	11 14	10 15	9 16	8 17	7 18	6 19	5 20	4 21	3 22	2 23	1 24	DAILY TOTAL
1	1	45.8	40.4	30.0	15.4	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	265.8
2	2	46.0	40.6	30.2	15.5	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	267.2
3	3	46.1	40.8	30.4	15.7	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	268.7
4	4	46.3	41.0	30.6	15.9	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	270.4
5	5	46.6	41.2	30.8	16.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	272.1
6	6	46.8	41.4	31.0	16.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	274.0
7	7	47.0	41.6	31.2	16.5	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	276.0
8	8	47.3	41.9	31.4	16.7	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	278.1
9	9	47.5	42.1	31.7	16.9	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	280.3
10	10	47.8	42.4	32.0	17.2	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	282.6
11	11	48.1	42.7	32.2	17.4	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	285.1
12	12	48.4	43.0	32.5	17.7	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	287.7
13	13	48.7	43.3	32.8	18.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	290.3
14	14	49.1	43.6	33.1	18.3	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	293.1
15	15	49.4	44.0	33.4	18.6	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	296.1
16	16	49.7	44.3	33.8	18.9	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	299.1
17	17	50.1	44.7	34.1	19.2	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	302.2
18	18	50.5	45.0	34.5	19.6	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	305.5
19	19	50.9	45.4	34.9	19.9	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	308.8
20	20	51.3	45.8	35.2	20.3	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	312.3
21	21	51.7	46.2	35.6	20.7	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	315.8
22	22	52.1	46.6	36.0	21.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	319.5
23	23	52.5	47.0	36.4	21.4	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	323.3
24	24	53.0	47.5	36.8	21.8	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	327.2
25	25	53.4	47.9	37.3	22.2	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	331.1
26	26	53.9	48.4	37.7	22.6	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	335.2
27	27	54.3	48.8	38.1	23.1	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	339.4
28	28	54.8	49.3	38.6	23.5	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	343.6
29	29	55.3	49.8	39.1	23.9	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	348.0
30	30	55.8	50.2	39.5	24.4	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	352.5
31	31	56.3	50.7	40.0	24.9	6.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	357.0

CAMELS HUMP, VT. 1970

TIME OF SOLAR NOON, LOCAL STD TIME
IN HOURS AND MINUTES

DATE	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	11.55	12.05	12.04	11.56	11.49	11.49	11.55	11.58	11.52	11.41	11.35	11.41
2	11.56	12.05	12.04	11.55	11.49	11.50	11.56	11.58	11.51	11.41	11.35	11.41
3	11.56	12.06	12.04	11.55	11.49	11.50	11.56	11.58	11.51	11.41	11.35	11.41
4	11.57	12.06	12.03	11.55	11.48	11.50	11.56	11.58	11.51	11.40	11.35	11.42
5	11.57	12.06	12.03	11.54	11.48	11.50	11.56	11.58	11.50	11.40	11.35	11.42
6	11.58	12.06	12.03	11.54	11.48	11.50	11.56	11.57	11.50	11.40	11.35	11.43
7	11.58	12.06	12.03	11.54	11.48	11.50	11.56	11.57	11.50	11.40	11.35	11.43
8	11.58	12.06	12.03	11.54	11.48	11.51	11.57	11.57	11.49	11.39	11.35	11.44
9	11.59	12.06	12.02	11.53	11.48	11.51	11.57	11.57	11.49	11.39	11.36	11.44
10	11.59	12.06	12.02	11.53	11.48	11.51	11.57	11.57	11.49	11.39	11.36	11.44
11	12.00	12.06	12.02	11.53	11.48	11.51	11.57	11.57	11.48	11.38	11.36	11.45
12	12.00	12.06	12.02	11.52	11.48	11.51	11.57	11.57	11.48	11.38	11.36	11.45
13	12.00	12.06	12.01	11.52	11.48	11.52	11.57	11.56	11.48	11.38	11.36	11.46
14	12.01	12.06	12.01	11.52	11.48	11.52	11.57	11.56	11.47	11.38	11.36	11.46
15	12.01	12.06	12.01	11.52	11.48	11.52	11.58	11.56	11.47	11.37	11.36	11.47
16	12.01	12.06	12.00	11.51	11.48	11.52	11.58	11.56	11.47	11.37	11.36	11.47
17	12.02	12.06	12.00	11.51	11.48	11.52	11.58	11.56	11.46	11.37	11.37	11.48
18	12.02	12.06	12.00	11.51	11.48	11.53	11.58	11.55	11.46	11.37	11.37	11.48
19	12.02	12.06	11.60	11.51	11.48	11.53	11.58	11.55	11.45	11.37	11.37	11.49
20	12.03	12.05	11.59	11.51	11.48	11.53	11.58	11.55	11.45	11.37	11.37	11.49
21	12.03	12.05	11.59	11.50	11.48	11.53	11.58	11.55	11.45	11.36	11.38	11.50
22	12.03	12.05	11.59	11.50	11.48	11.54	11.58	11.55	11.44	11.36	11.38	11.50
23	12.04	12.05	11.58	11.50	11.48	11.54	11.58	11.54	11.44	11.36	11.38	11.51
24	12.04	12.05	11.58	11.50	11.48	11.54	11.58	11.54	11.44	11.36	11.38	11.51
25	12.04	12.05	11.58	11.50	11.48	11.54	11.58	11.54	11.43	11.36	11.39	11.52
26	12.04	12.05	11.57	11.49	11.49	11.54	11.58	11.53	11.43	11.36	11.39	11.52
27	12.04	12.04	11.57	11.49	11.49	11.55	11.58	11.53	11.43	11.36	11.39	11.53
28	12.05	12.04	11.57	11.49	11.49	11.55	11.58	11.53	11.42	11.35	11.40	11.53
29	12.05	0.00	11.57	11.49	11.49	11.55	11.58	11.53	11.42	11.35	11.40	11.54
30	12.05	0.00	11.56	11.49	11.49	11.55	11.58	11.52	11.42	11.35	11.40	11.54
31	12.05	0.00	11.56	0.00	11.49	0.00	11.58	11.52	0.00	11.35	0.00	11.55

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TABLE V

CORRECTIONS TO SUNRISE AND SUNSET FOR 1′ DIFFERENCE IN ALTITUDE OF SUN

Date / Latitude	Dec. 22 June 22 June 22 Dec. 22	Jan. 4 June 8 July 6 Dec. 9	Jan. 11 June 1 July 13 Dec. 3	Jan. 16 May 26 July 19 Nov. 27	Jan. 22 May 20 July 25 Nov. 21	Jan. 28 May 14 July 31 Nov. 15	Feb. 3 May 7 Aug. 7 Nov. 9	Feb. 11 Apr. 28 Aug. 16 Nov. 1	Feb. 22 Apr. 17 Aug. 27 Oct. 21	Mar. 21 Mar. 21 Sept. 23 Sept. 23
°										
0	0.073	0.072	0.072	0.071	0.071	0.070	0.070	0.069	0.068	0.067
20	0.078	0.078	0.077	0.076	0.076	0.075	0.074	0.073	0.072	0.071
30	0.087	0.086	0.085	0.084	0.084	0.083	0.082	0.081	0.079	0.077
35	0.093	0.092	0.091	0.090	0.089	0.088	0.087	0.085	0.083	0.081
40	0.102	0.101	0.100	0.098	0.097	0.095	0.094	0.092	0.090	0.087
45	0.114	0.113	0.111	0.109	0.107	0.105	0.103	0.100	0.098	0.094
50	0.132	0.130	0.127	0.125	0.122	0.119	0.116	0.113	0.108	0.104
55	0.161	0.157	0.153	0.149	0.144	0.139	0.134	0.128	0.122	0.116
60	0.22	0.21	0.20	0.191	0.182	0.172	0.162	0.153	0.143	0.133
62	0.27	0.25	0.23	0.22	0.21	0.192	0.179	0.166	0.154	0.142
64	0.36	0.32	0.29	0.26	0.24	0.22	0.20	0.183	0.167	0.152
66	0.78	0.53	0.42	0.35	0.30	0.26	0.23	0.20	0.183	0.164
68	...	...	2.72	0.61	0.42	0.33	0.27	0.23	0.20	0.178
70	...	...	...	...	1.52	0.50	0.35	0.28	0.23	0.195
72	...	...	...	...	...	...	0.56	0.35	0.27	0.22
74	...	...	...	...	...	...	...	0.52	0.32	0.24
76	...	...	...	...	...	...	...	...	0.41	0.28
78	...	...	...	...	...	...	...	...	0.64	0.32
80	...	...	...	...	...	...	...	...	...	0.38
82	...	...	...	...	...	...	...	...	...	0.48
84	...	...	...	...	...	...	...	...	...	0.64

TABLE V A

DIP

Elevation in Feet	Correction
	′
0	0
100	+11
200	+15
300	+18
400	+21
500	+24
600	+26
700	+28
800	+30
900	+32
1000	+34
2000	+48
3000	+58
4000	+67
5000	+75

TABLE V B

CORRECTION TO ADOPTED REFRACTION

Pressure in.	Pressure mb.	Temp. in Deg. F. −60	−40	−20	0	+20	+40	+60	+80	+100	+120	+140
in.	mb.	′	′	′	′	′	′	′	′	′	′	′
3	102	−29	−30	−30	−30	−30	−31	−31	−31	−31	−31	−32
6	203	−25	−25	−26	−26	−27	−27	−28	−28	−28	−29	−29
9	305	−20	−21	−22	−22	−23	−24	−24	−25	−26	−26	−26
12	406	−15	−16	−17	−18	−20	−20	−21	−22	−23	−23	−24
15	508	− 9	−11	−13	−14	−16	−17	−18	−19	−20	−20	−21
18	610	− 4	− 6	− 8	−10	−12	−13	−14	−16	−17	−18	−18
21	711	+ 2	− 1	− 4	− 6	− 8	−10	−11	−12	−14	−15	−16
24	813	+ 7	+ 4	+ 1	− 2	− 4	− 6	− 8	− 9	−11	−12	−13
27	914	+13	+ 9	+ 6	+ 3	0	− 2	− 4	− 6	− 8	− 9	−10
30	1016	+19	+15	+11	+ 7	+ 4	+ 2	0	− 2	− 4	− 6	− 8
33	1118	+26	+20	+16	+12	+ 9	+ 6	+ 3	+ 1	− 1	− 3	− 5

The quantities taken from these two tables are to be multiplied by the quantity from table V, and then added algebraically to the time of sunset with the sign as given. Subtract algebraically from the time of sunrise.

A TECHNIQUE OF THERMO DEW-POINT RECORDING IN NORTHERN ALBERTA

By

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SUMMARY

The technique of mobile thermo dew-point recording, although by no means new, serves two purposes - one, the investigation of temperature variations under forest cover; and two, the investigation of the reliability of climate-station data as indicative of its locale. This technique functions as one of the two basic data sources for the Forest Climatology Study in Northern Alberta; the other data source being the Daily Climatology Computer Cards. The project's purpose is the ultimate production of forest climatic zones in Northern Alberta.

The mobile recorder[1] consists of two resistance probes - dry bulb and dew point - mounted on the front of the vehicle. This arrangement resulted in continuous chart records. By maintaining a constant speed of 30 m.p.h., thus ensuring proper ventilation of the probes, the time constant was found to be .9 sec. (Djurfors, 1969).

Owing to a definite lack of information of like studies, a test site - Spring Creek Basin, Alberta - was chosen in order to evaluate both the instrument and results obtained. Preliminary analysis indicates differences of as much as 9°F in air temperature and dew-point differences of 20°F with corresponding topographic differences being less than 200 ft. Maximum and minimum temperature and sunset-traverse results are presented in detail in the paper itself.

As a conclusion, the author would highly recommend a much greater use of mobile techniques for providing possibly the best indicator of spatial thermal variations under a variety of atmospheric conditions.

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[1] Foxboro-Yew Thermo Dew-point Recorder adapted for the purpose of mobile detection.

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REVIEW OF WINTER DESICCATION IN CONIFERS:
HOW ALBERTA'S FOREST CONIFERS SURVIVE THE WINTER

By

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Swanson (pp. 34-39) dealt with the tree as a vital participant in evapotranspiration, showing how large amounts of water may be transpired and how foliage may tolerate high moisture tensions. Time strictures have forced me to cut out much of my planned talk, but I will do the best I can.

The tree is indeed a vital, in fact, the vital constituent in the forest hydrological balance. I propose to discuss how trees in our northern climate might cope with the stress built up during winter when their normal water supply is apparently cut off by freezing of stems, soil, and roots.

Parenthetically, I think I should draw a clear distinction between desiccation injury and frost or cold injury. They are similar in that resistance to each seems to be related to similar properties of the protoplasm (Pisek and Winkler, 1954). However, our forest trees can withstand, after appropriate hardening, almost any low temperature, even those exceeding -50°C., without injury, whereas prolonged, unbroken periods of much less severe temperatures, or other unfavourable weather, such as warm winds, can lead to much desiccation damage. The literature is full of examples (e.g., Cayford et al., 1959; Conkle et al., 1967).

Examples in the literature all more or less vaguely dismiss such damage as excessive drying (caused generally by such things as drought the previous summer and warm windy weather following freezing of the ground), without considering how the trees manage to cope with the lesser drying stresses that occur every winter.

The discussion can be divided into two parts, loss of moisture and replenishment of moisture. Deciduous trees solve the problem of moisture loss simply by discarding the great bulk of their transpiring surface area and tightening up the rest. Evergreens, however, do not.

First, let us consider moisture loss. Although some moisture is lost from stem and twigs, this is very little compared to the amounts lost by transpiration from the vastly greater surface area of the foliage. That such transpiration continues throughout the winter has been shown by lysimetric studies by Kusano (1901), Weaver and Mogensen (1919), and more recently by Kozlowski (1943). Other methods used to measure moisture loss in winter have included vapour absorption and simple gravimetric determinations of foliage moisture contents.

Generally speaking, transpiration in winter is greatly reduced from summer rates, principally through the closing of stomata. Measured cuticular-transpiration rates in conifers ranged from about 1/50 to 1/250 of rates in autumn, when stomatal transpiration was taking place. Pisek and Berger (1938) induced cuticular transpiration by drying leaves until the stomata closed, then measuring the continuing rate of moisture loss until death occurred. Evergreens generally gave rates under 10 mg/g (fresh wt)/hr, deciduous trees about 25 mg/g/hr, and herbs and succulents from 50 to over 100 mg/g fresh wt/hr. For *Pinus sylvestris* and *Picea excelsa*, they found rates of 3.3 and 3.7 mg/g/hr, respectively; figures in fact remarkably close to those found by lysimetric studies under winter conditions by Kusano (1901) (3.3 mg/g/hr) and by Kozlowski (1943) (5 to 15 mg/g/hr). Figures given by Weaver and Mogensen (1919) were on an area basis.

Since we have no direct measurements of winter moisture-losses from Alberta conifers, we are on uncertain ground in local estimates, but these figures may be used to indicate the order of magnitude of the problem of water replenishment.

The following table uses information gathered for use in fire research, and illustrates how disciplines can overlap:

Consider an example tree in a lodgepole pine and in a white spruce stand; with a 10" dbh and an 8' crown width:

	Lodgepole Pine	White Spruce
Crown weight	81	113
plus unmerchantable stem	14	17
total slash weight (Kiil 1967)	95	130
% needles (Kiil 1968)	40%	38%
dry weight needles	38	50
for fresh weight, add 100%: (Kiil 1968)	76 lbs	100 lbs

Up to 30% of the fresh weight of the needles may be transpired before reaching a lethal deficit, according to Pisek and Winkler (1953). Using meteorological data, Hygen (1965) calculated from daily mean atmospheric-saturation deficits that this amount would be transpired 10 times in an average winter in Norway; or say, 12 times in Alberta.

We can now calculate the moisture needed to maintain levels in our example Alberta pine and spruce.

	Lodgepole Pine	White Spruce
Fresh weight of needles	76 lbs	100 lbs
Total transpiration during winter (approx. min.) 30% x 12	274 lbs	360 lbs of water

These quantities would be greatly increased by any weather that results in opening of the stomata (Ehlers 1915) of by any unusual increases in the atmospheric-saturation deficit or by high winds.

Obviously, a problem of considerable magnitude, when one reflects that the stem is frozen. But are stems actually frozen? Could they be supercooled, permitting passage of the liquid water? The stepped curve of temperature measurements during cooling indicates that the sap is indeed frozen (Lybeck, 1959; Zimmerman, 1964; Johnson, 1959). The fact that such freezing effectively prevents the ascent of sap has been repeatedly observed in the wilting of the foliage above the cooled stem. In most conifers, the temperature of freezing was -1.9°C. Although supercooling could be observed to as low as -8.7°C., spontaneous freezing took place within half an hour without further cooling (Lybeck, 1959).

Fortunately, the trees do, after all, survive the winter: How, then, do the needles manage to replenish their lost moisture?

A number of possible routes may be considered. There is, first, the possibility of interception of atmospheric moisture in the form of rime or hoar frost. In a study mentioned earlier this week by H.W. Anderson, Berndt and Fowler (1964) found that such interception could amount to as much as 3-4" during an entire winter in Eastern Washington, with deposits of .08 - .06" per day during periods of accumulation. I question whether a significant amount of this would be absorbed by foliage, the bulk being shaken or melted to the ground.

Under such conditions, arithmetic shows that deposition could occur for 50 to 80 days per winter. In Alberta, where the winter typically lasts about 150 days, this leaves 70 to 100 days when moisture losses can still occur, building up a lethal deficit still 5 to 7 times. In any case, I cannot recall observing hoar frost or rime deposition on trees in Alberta more than half a dozen times per winter, not 50 to 80. Maybe a study of this would be a fruitful project here. However, even under Washington conditions it clearly cannot even account for half the water supplied to the foliage, although it constitutes a significant credit to the water budget.

Another source of water is the reservoir capacity of the bole of the tree. A table of our example trees may aid in consideration here.

Lybeck (1959) reports that calorimetric studies of frozen spruce wood showed that about 40% of the dry weight was not frozen at as low a temperature as -20°C. Other studies in other crops (esp. Greathouse, 1935) showed that such water remained unfrozen to -50°C in properly hardened-off plants. It is hence termed unfreezable water, and is generally thought to be bound to cell walls and other cell constituents. Under conditions of extreme moisture stress, however, it might be available to the foliage.

	Lodgepole Pine	White Spruce	
Density of wood	30	27	lbs/cu ft
Approx. volume (50' tree)	40	40	cu ft
Dry weight of bole	1200 lbs	1080 lbs	
Approx. total weight of moisture contained (100%)	1200 lbs	1080 lbs	
	(Kiil 1968)		
Weight of unfrozen water (40%)	480	432	
	(Lybeck 1959; Greathouse 1935)		
Total winter transpiration	274	360	
As % of unfrozen water in bole	57%	83%	
As % of total bole water	23%	33%	
May minimum water content of needles	103%	87%	(of dry wt.)
			(Van Wagner 1967)

Michaelis (1934) observed that the bark of a green alder twig, near the surface of the snow, achieved a temperature of +30°C while the air temperature ranged from -2 to +4°C. Such a differential is certainly impossible in the stems of forest trees because of the shade effect, but a differential of even 5°C may well be sufficient to raise stem temperatures above freezing air temperatures.

Such thawings of the stem may provide opportunities for re-distribution of moisture tensions among foliage, twigs, and bole. There are no data on the tolerable moisture deficit of the cambial tissues in the bole, but it is not likely to be any greater than that of foliage, or about 30% of its fresh weight. Thus, our example lodgepole pine might be able to survive on its bole-water reservoir, but our example white spruce would not. However, our examples were 10" dbh and smaller trees have much more foliage in proportion to the bole. The smallest lodgepole pine with sufficient bole water would be about 7" dbh. Yet the smaller trees survive. We must postulate water conduction up the frozen stems from the frozen soil.

Periodic thawing of the stem when air temperature approaches melting point would thaw the sap, permitting it to flow. But by what mechanism would it flow? The generally accepted theory holds that continuous cohesive columns of water are drawn up to the foliage by evaporation from the stomata. Freezing drives out the dissolved gases, which cause embolisms in the conducting vessels upon thawing. This has been demonstrated in glass capillaries and observed in wood (Lybeck, 1959). However, closer inspection shows that not all tracheids have bubbles in them. Furthermore, it has been found that experimentally cooled stems re-conduct water immediately upon thawing (Johnson, 1959) and rapid movement of dye has been observed in Norway spruce stems upon periodic thawing in the winter (Brøndbo, 1965 cited by Hygen, personal communication). It may be that the smaller, denser, heavy-walled summer wood tracheids remain unblocked by embolisms, and sap movement here gradually dissolves bubbles out of the thin-walled springwood by diffusion. At any rate, rapid conduction does occur upon thawing.

But now we come to the still unanswered question-where does the water come from? For the soil beneath the snow does not thaw during short warm spells (Longley, 1967; Ashwell and Rhodes, personal communication), and presumably the roots in this frozen soil also remain frozen and blocked (Ashwell and Rhodes, personal communication).

The soil temperatures during the coldest months, December, January, and February, in the Marmot Creek Basin over the period from December 1965 to February 1969, generally did not go below -3°C, only rarely falling to -4°C or -5°C, at the surface. At a depth of 12" to 18", the temperatures were about 0 to +.5°C. Therefore, the sap in roots running through this zone of soil was only 1 or 2°C colder than the measured freezing point of sap in twigs.

It has been observed that alfalfa shoots beneath the soil enlarge and extend during winter with soil temperatures below -5°C. The shoots exude large droplets of extremely sticky and syrupy sap; thick, but liquid (Colatelo, personal communication). It is possible that sap in tree roots may also resist freezing through greater concentration of solutes than is present in stems. The freezing point might be further depressed by "root pressure", such as has been observed in white spruce and white pine (White et al., 1958) during summer. An increased concentration of solutes would lead to greater osmotic pressures during winter, especially if not drawn upon by active stomatal transpiration. The potential positive pressure of 2M sucrose is in the order of 50 atmospheres, which could lead to a depression by 2°C of the freezing point (Handbook of Physics, Am. Soc. Phys.).

The question of moisture absorption in cold soil is dealt with by Kramer (1940 and 1942), who found that rate of uptake at 1° may be reduced to 25% of that at 25°C. However, this is adequate to supply the reduced transpiration and is evidence that uptake can occur. That roots of pines commonly extend to great depths is shown by several studies (Brown and Lacate, 1961; Boldt and Singh, 1964). Spruce is generally a shallow-rooted tree but usually has some roots extending below 2 ft depth (Wagg, 1967; Jeffrey, 1959). Thus with uptake possible and liquid sap present in the roots, conduction can occur during periodic thawing of the stem.

As observations are made farther to the north, however, the problem becomes more acute. Near Whitehorse, in the Yukon, the soil down to 8" remains below -5°C for several weeks every winter and exceeds -10°C for extended periods from time to time. Surely, the root sap must be frozen at these temperatures. Yet the trees survive. Moisture must still move.

Let us now do some more arithmetic (shall I say flux equation?) to determine just how much and how fast the sap needs to flow.

	Lodgepole Pine	White Spruce
Cuticular transpiration	10% fresh wt/12 days	11% fresh wt/12 days (using data of Pisek and Berger, 1938)
Water available for cuticular trans.	15% of fresh wt	15% (Max., after Pisek & Winkler, 1953; Hygen, 1965)
Days survival w/o replenishment:	18 days	16 days

(cf. Hygen (1965) gives about 12 days (av.) for Norway spruce).

Moisture loss/12 days	7.6 lbs	11 lbs (from Table 1)
Moisture conducting area:		
dbh base 10"	48 sq in	57
1/2 way up (8")	30	38
2/3 way up (6")	15	19
1 lb water = about 30 cu in		
Moisture loss/12 days	228 cu in	330 cu in
and vertical movement near crown must be	228/15 = 15 in	330/19 = 17.4 in/12 days
or about	1.25 in/day	1.5 in/day

When one re-examines reports of stem blocking upon freezing, one finds that authors are somewhat equivocal: transpiration practically ceases, almost stops, is negligible. Aha!

In Norway, winter-dye-injection experiments with a glycol/water mixture gave rates of transport averaging 1-2 in/day when temperatures remained below -1°C. When the temperature remained between -1 and 0°C, the rate shot up to 17 in/day and went as high as 40 in/day above 0°C (Brøndbo, 1965, Personal communication from Prof. Hygen, Vollebek). Swanson (1965) calculated the mean rate of water ascent in Engelman spruce as 1.2 in/hr from temperature flux data, at temperatures between -30 and -5°C.

Only one observation is available from Alberta, where over a 42-day period including one 3-hr spell above freezing, a pure water dye movement averaged 1.4 in/day (Ridgway, 1968, Personal communication).

How was the dye transported upwards? In the first observation, the glycol content might have helped. In the second and third a warm period or high radiation might have accounted for thawing and hence most of the movement. However, the possibility of movement in frozen stems and roots becomes credible, and appears to be necessary to maintain water balance in the foliage.

A recent concept of super-dense or polymerized water has appeared in the physics literature (Deryagin, 1969; Lippincott *et al*., 1969; Anonymous, 1969; Willis et al., 1969). This water, made by condensation in glass capillaries and thought to occur naturally at interphases and boundaries, does not freeze at temperatures as low as -50°C. It has the curious and highly relevant ability to creep up the walls of the capillary containing it (Deryagin, 1969; Bellamy et al., 1969), and what is a tree trunk, but a bundle of capillaries?

Thus the "unfreezable" water observed in trees by Miss Lybeck and others might be in the form of polywater, which might be sufficiently mobile to creep upwards at the low rates necessary to compensate for losses. Such polywater might confer additional protection from desiccation by virtue of an extremely low vapour pressure suggested by the observation of negligible evaporation from an open dish (Lippincott, 1969).

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OVERSTORY THINNING IN MIXED CONIFEROUS FORESTS AND THE EFFECT ON GROUND FUEL MOISTURE WITH EMPHASIS ON FOREST FIRE CONTROL

By

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Five billion dollars--this is the total annual cost of hostile fire in the United States (5). It includes the loss from actual physical damage and the costs of fire departments, fire-protection insurance operation, and research and development. Forest fire costs make up approximately 5 per cent of this total (5).

Table 1 indicates fires over 100 acres in size which occurred in California during the period 1954-1960 (1). It is evident that the fire problem is concentrated in a few large fires. A small percentage of fires consistently accounts for a large percentage of the area burned.

Table 1. Fires in California over one hundred acres in size, 1954-1960*

Year	Per cent of all fires	Per cent of total area burned
1954	6.0	92.3
1955	4.8	96.1
1956	2.7	92.1
1957	6.1	93.4
1958	4.3	89.8
1959	4.9	95.1
1960	2.5	88.1

* Paul Casamajor, Wildland Fire Problems (Operations Research Center, University of California, 1962), p. 7.

Large fires, over 100 acres in size, are California's problem. On the average, 3 per cent of the fires are producing 90 per cent of the burned area (1). Conflagration is the term given to large-disaster fires (8).

The conflagration problem has no easy solution. Of the presently available alternatives that could contribute to solution of the large fire problem--i.e., prevention of ignitions, overcoming effects of topography, weather modification, fuel modification, and more and better fire control--the last two seem to be the best (4).

Large systems of conflagration barriers are employed in California and other parts of the Western United States. Conflagration barriers consist of fuel-breaks and natural barriers. Fuel-breaks are areas strategically located at key fire defense points, such as ridges, on which the fuel has been modified. Heavy fuel has been changed to light fuels. Changing heavy brush to perennial grass and cleaning up slash and ground debris and thinning understory trees in timber stands are examples. The continuity of hazardous fuels is broken. Resistance to fire line construction is thus reduced. Fire intensity is reduced also. Safer access and attack points are provided.

In building fuel-breaks, the forester or fireman must decide how much to thin. If he thins too little, fires may escape across the fuel-break; if he thins too much, the climate near the ground may be changed. Reports in the literature show that such changes may result in higher temperatures, lower fuel moisture, and greater number of days when disastrous crown fires can break out (2, 3). The forester must also decide the type of living ground-fuel to encourage on fuel-breaks.

In a trial at the Stanislaus National Forest, in Central California, we found that within the range of fuel moistures investigated, thinning as much as 80 percent of the crown cover did not appreciably affect fuel moisture and that in the timber type investigated, the living ground cover should be maintained. These findings can serve as guidelines for future fuel-break planning and building.

Levels of Crown Closure

A team of foresters and forest firemen conducted a field survey to decide on preliminary needs for thinning fuel-breaks in timber. The team decided that in typical ponderosa pine (*Pinus ponderosa* Laws.) stands on the west side of the Sierra Nevada, crown closure ranging between 20 and 80 percent density would be necessary to achieve a balance between timber management objectives and successful fire control.

Several fire-weather factors can be affected by fuel-break thinning levels. Fuel moisture was chosen for study because it is an important element of fire danger.

A section of ridgetop in mature ponderosa pine, medium pine reproduction, and brush which was fire fuel type 6 (7), and exposed to the prevailing winds and weather, was chosen as the test site. Elevation, aspect, and terrain and fuel were nearly constant over the 4.5-chain section and differences due to these factors were taken to be negligible. Crews selected four fuel-break study areas with crown closure densities of 80 percent, 60 percent, 40 percent, and 20 percent. Crown closure was measured by a specially constructed viewer with 2-inch grids. Each study area was 1 chain long (with the ridge) and 300 feet wide. A one-half chain buffer strip separated each area.

Slash and brush, chiefly manzanita (*Arctostaphylos* sp.), were removed from within each study area and standing trees were pruned to 10 feet to conform to standard fuel-break design for the area. The ground cover, consisting of bear clover (*Chamaebatia foliolosa*), was left intact.

Four standard fuel-moisture sticks were placed at random over each study area. The sticks were hung 12 inches above the ground--at least 6 inches above living ground cover. Temperature, relative humidity, and wind speed and direction were taken by manual readings each time the sticks were weighed. Precipitation was recorded by a rain gauge placed next to the study area.

Fuel moisture and weather readings were taken daily in the morning (8-11 a.m.), noon (11 a.m. - 2 p.m.), and afternoons (2-5 p.m.) during the 1962 and 1963 fire seasons. The sticks were rotated after each weighing to reduce variability due to stick differences. At the end of the second fire season, 1963, the readings were compiled and the replicated fuel moisture readings for each area were averaged and broken down by times of day.

The distributions were distinctly abnormal, being significantly positively skewed (g-statistics) even after a logarithmic transformation. The data were transformed to the log-log form for variance and regression analyses (Table 2). Predicted values were retransformed to the original scale for plotting.

Table 2. Analysis of variance of fuel moisture based on log-log transformation of average fuel moistures

AFTERNOON

Variation due to	Degrees of freedom	Mean square	F	$F_{.05}$	$F_{.01}$
Treatments:	(3)				
Linear	1	0.047385	2.11	3.85	6.66
Quadratic	1	.011534	<1	3.85	6.66
Cubic	1	.045781	2.03	3.85	6.66
Error	840	.022498	--	--	--
		NOON			
Treatments:	(3)				
Linear	1	.150961	16.12	3.91	6.81
Quadratic	1	.004403	<1	3.91	6.81
Cubic	1	.000289	<1	3.91	6.81
Error	191	.009366	--	--	--

The data showed that noon fuel moistures were inversely proportional to crown cover (Fig. 1), but there was no significant trend in afternoon fuel moistures as crown cover changed (Fig. 2).

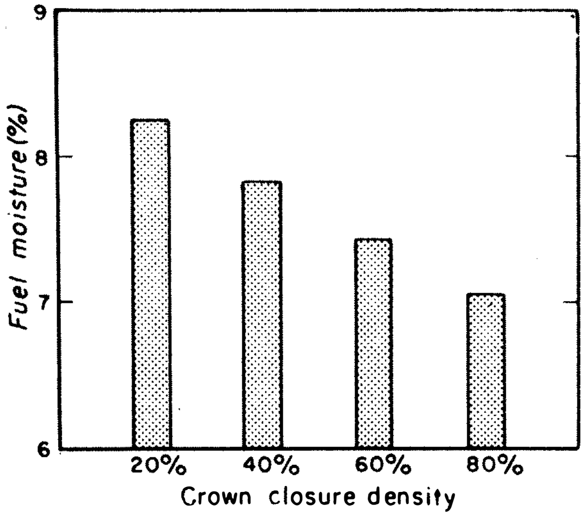


Fig. 1. Average fuel moistures, by crown closure classes - noon, 1962-63.

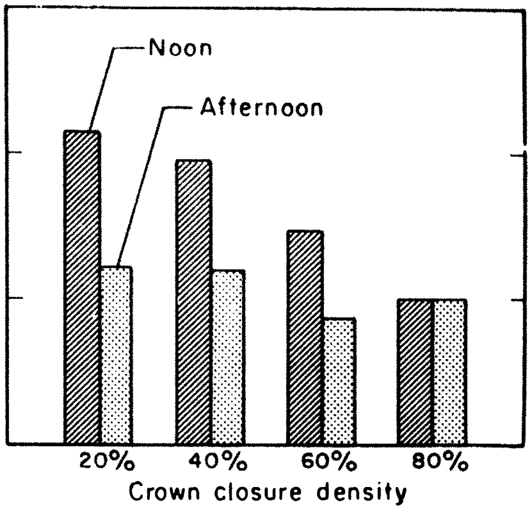


Fig. 2. Average fuel moistures, by crown closure classes - noon and afternoon readings, 1962-63.

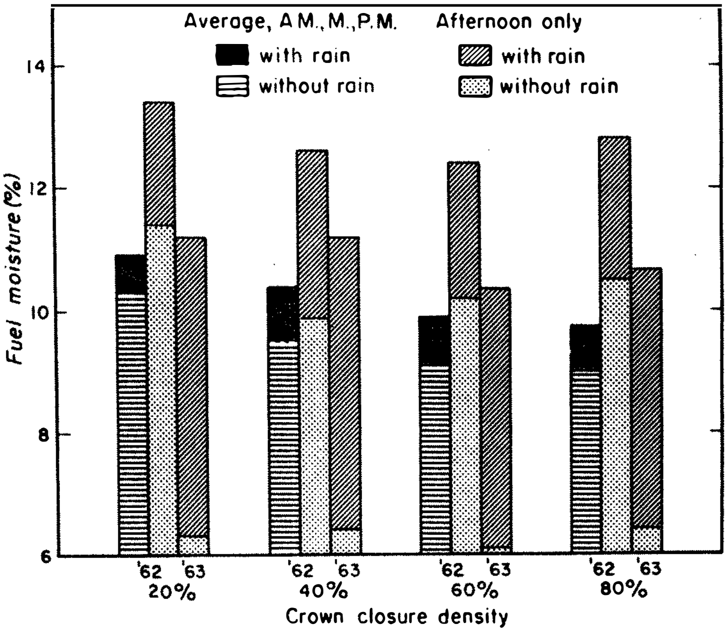


Fig. 3. Average fuel moistures, by crown closure classes, average of all readings, 1962, and afternoon readings, 1963.

RESULTS AND DISCUSSION

Perhaps the denser crown closure intercepted more rainfall. Rainstorms occurred during early summer and each fall before fire season was officially declared over. Separation of the data according to rain and no-rain days showed that fuel moisture still appeared to decrease as crown closure increased (Fig. 3), but the differences were not statistically significant.

To determine if the averages could hide potentially important relationships, we separated the data according to air temperature, relative humidity, and wind speed readings (Fig. 4). Again, this separation showed no significant differences in fuel moisture.

Finally the data were separated by days after rain to see if living ground fuel dried out sooner under open cover and thus might reduce the effectiveness of a fuel-break. But this premise was not supported by data relating fuel moisture 1 and 2 days after rain to crown closure (Fig. 5).

Why fuel moisture differed so little may be explained by Tappeiner's work (6). He showed that the "drying power of the air"--defined as the combination of the drying effects of temperature, relative humidity, and wind--over shaded bear clover was one-fourth that over open bare ground. Tappeiner attributed this partly to the high transpiration rate of bear clover and to the depth and density of its root system.

Bear clover was the dominant live ground cover on the study areas. Its density was determined for each fuel-break study areas by gridding each area and estimating percentage densities; density was then compared with the fuel moisture readings. Relation of crown closure to ground cover was as follows:

Crown closure	Ground cover
- - - - (percent)	- - - -
80	0
60	35
40	40
20	80

Fuel moisture was directly proportional to the density of live ground cover.

We concluded that fuel-breaks in typical ponderosa pine types on the west side of the Sierra Nevada can be constructed and maintained by thinning as much as 80 percent of the overstory without appreciably affecting fuel moistures near the ground and that the normally occurring living ground cover, bear clover, should be maintained. This ground cover is of relatively low flammability, which will aid fire control.

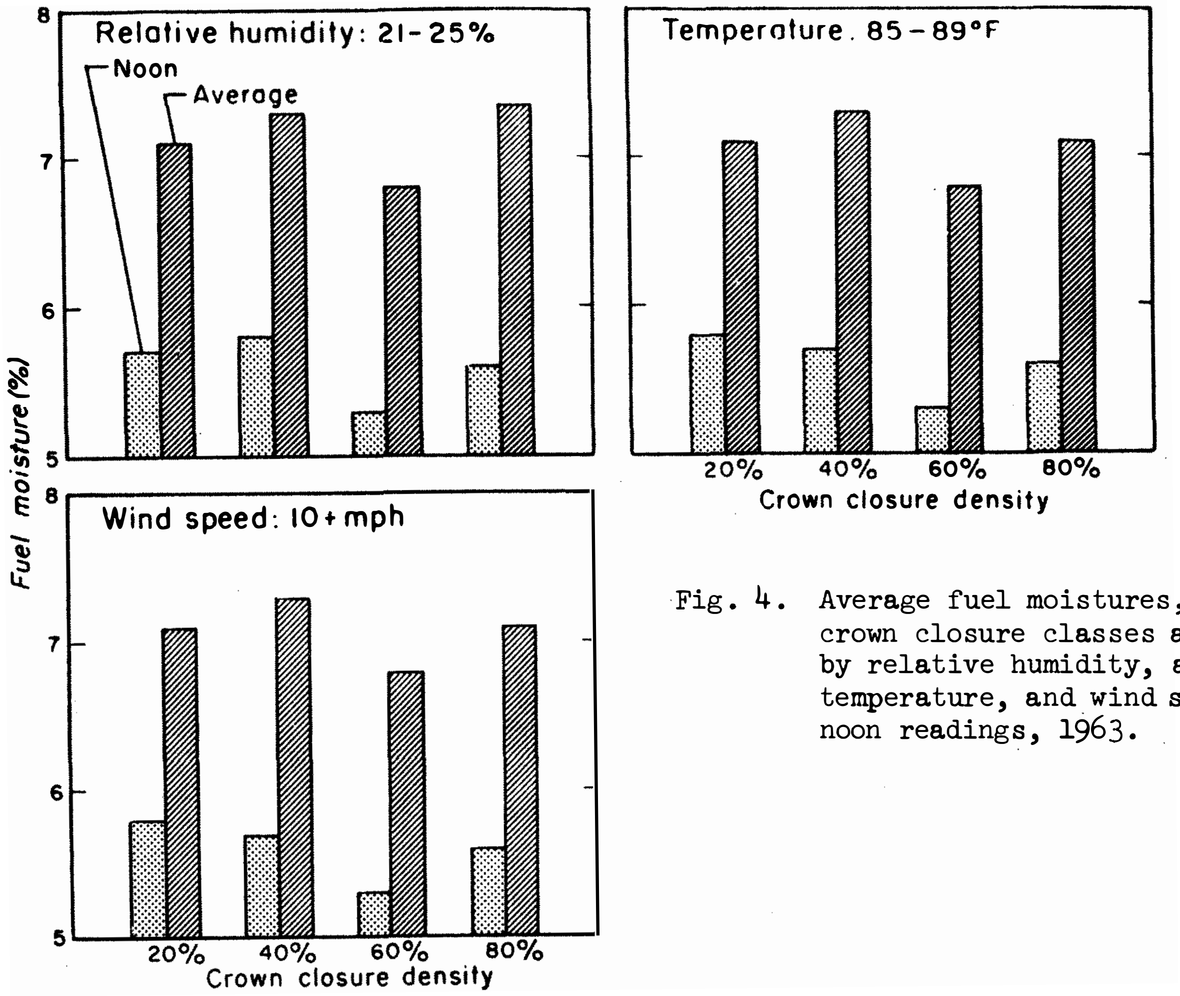
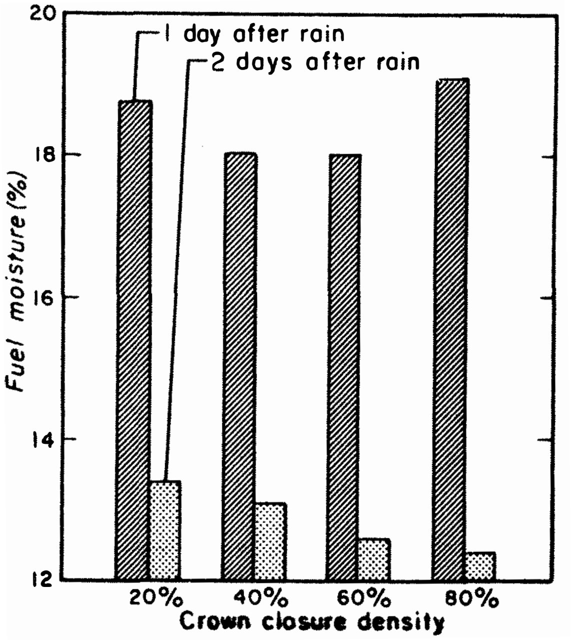


Fig. 4. Average fuel moistures, by crown closure classes and by relative humidity, air temperature, and wind speed-noon readings, 1963.

Fig. 5. Average fuel moistures by crown closure classes, 1 and 2 days after rain in the afternoons, 1962-63.



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THE ROLE OF CLIMATE IN THE BRITISH COLUMBIA CANADA LAND INVENTORY

By

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INTRODUCTION

My objective this morning is to give you some insight into the problems, methods and applications of climate in the field of renewable resources as applied in the Canada Land Inventory in British Columbia. (I might add that British Columbia is the only province in Canada that has to date become directly involved in an extensive climatological field-survey programme although Prince Edward Island, Ontario and Alberta as you heard yesterday, have started exploring its potentialities).

As many of you know, land capability surveys by governments anywhere in the world are a relatively recent innovation. (The Canada Land Inventory is one of these).

In 1964, a nation-wide federally sponsored programme called the Canada Land Inventory was initiated to determine the physical capability of the land for renewable resource production; more specifically, to determine the physical capability of the land to sustain agriculture, forestry, wildlife, or recreation.

Under this programme, British Columbia formed six groups; those concerned with physical capability directly such as Agriculture, Forestry, Wildlife and Recreation, plus Present Land Use and Socio-Economic Surveys. The anomalous sixth group is the Agro-climatology Sector. Its function is broader than the name as all capability sectors are serviced in varying degrees by climate.

Many have wondered why British Columbia is involved in climate to the relative exclusion of the other provinces. In British Columbia, topography varies from sea level to 12,000 feet elevation, from flat to steeply mountainous (10 major mountain ranges and innumerable minor ones) from a mediterranean to a tundra climate, in all, 9 major climate zones are represented compared to 3 for Alberta and Ontario and 1 in Prince Edward Island.

Without paying careful attention to the climate in each region, physical-capability analysis becomes meaningless.

HISTORICAL DEVELOPMENTS AND OBJECTIVE

Climate data were first collected on the Pacific Coast of British Columbia in the late 1870's. Since that time an ever increasing network of stations has developed along the coast and in the valley bottoms of the coast and interior. Daily observation of precipitation and maximum and minimum temperatures predominate, although at synoptic weather stations and at several agricultural research stations, more sophisticated observational programmes are maintained. Unfortunately, 90% of the total network of 396 stations is concentrated below 3000 feet, while 80% of the land is above this elevation (Fig. 1). As the Canada Land Inventory is to survey all lands regardless of elevation, then the problem of assessing the regional, sub-regional, and local climates becomes much more challenging. With this in mind, a climate inventory scheme had to be designed to sample and measure the time-space-degree relationships of as many relevant climatic parameters as possible for each area, in addition to reviewing the historical record station by station to determine as much as possible its validity and representativeness.

PROBLEMS ASSOCIATED WITH THE OBJECTIVE

It is immediately obvious that the information requirements of each capability group are different. In some instances, such as Forestry and Wildlife, the real role of climate in determining their physical capability was quite obscure. The Forester and the Wildlife Biologist could not decide what climatic parameters are significant to his discipline other than for instance, that a fail correlation exists between higher rainfall and higher capability for wood production, essentially more water - more wood. It was felt that time-space-degree-probability information of heat and moisture (surplus or deficit) were important to the forester.

The Wildlife Ungulate Biologist was particularly concerned with snow depth, duration, distribution and formation of snowpack, the distribution of heat and moisture and their influence on the development of grazing and browsing plants along with the occurrence of thermal belts and extreme minimum temperatures.

The Recreationist, of course, was concerned with human comfort, as influenced by time-space-intensity of precipitation, wind, sunshine, and temperature. Wind as it influences camping comfort, canoeing and boating generally, afternoon temperatures and humidities as are water temperatures for swimming.

The Agriculturist needed information on frost frequency of occurrence, intensity, duration and areal distribution, heat-unit accumulations for varying thresholds and time periods for different crops, along with frequency and intensity of drought or moisture surplus. (In parts of British Columbia, moisture surplus can be equally important as severe drought).

The second problem is the historical record available. The impetus for weather-observing-network development in Canada came from commercial aviation; hence, most of the emphasis has been in this direction. Although considerable time and effort has been invested in the co-operative climatological network presently in operation in the province, the limits of the basic-network design (observer-oriented as opposed to user-oriented) and inadequate funding has led to a network and historical record grossly inadequate for the needs of the Agriculturist, Forester, Wildlife Biologist, Recreationist, Hydrologist, Geographer, Pedologist, and even the Climatologist and Meteorologist, keeping in mind the differences in needs of the synoptic meteorologist and the bio-climatologist.

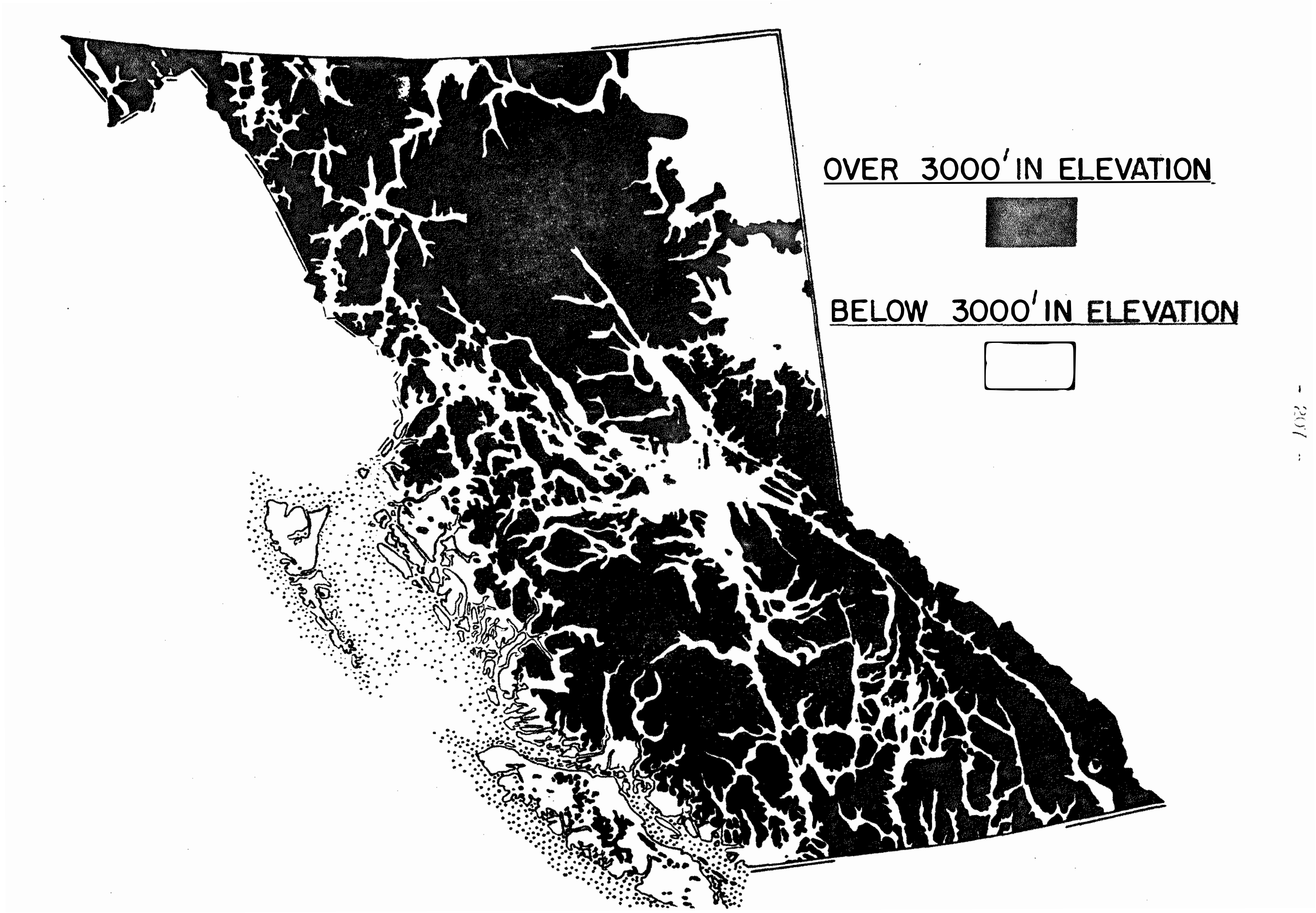

Fig. 1. Areas over and below 3000 ft. in elevation in British Columbia.

As most of the development is taking place in the presently remote areas away from the valley-bottom location of the existing network, there is no representative climate data in the side valleys, upper slopes and on the large areas of the interior plateaux. Because much of the Forestry, Wildlife, Recreation, and in some instances, Agriculture, has developed in these areas, there is some cause for concern.

Climate has loosely been defined as "weather through time". To obtain an adequate data-series for each parameter, network stations should be in operation for a number of years particularly in mountainous terrain where 30-40 years of data may be required. Minimally useable data may take 10 years to gather while statistically valid data may take 30 years.

Another feature of the existing record is its quality. A number of established stations have suffered from poor siting in the sense that they only represent a very local microclimate. Further, secular changes in the station's surroundings, i.e., removal of trees, encroachment of buildings, and urbanization, produce a record that is neither homogeneous nor representative.

In summary, then, the Inventory was faced with the need for information on specific climatic requirements for each Sector and, having this, the need to assess all available information and acquire new information to achieve the level of detail and precision necessary.

TRANSECT PROGRAMME

As previously noted, an Agroclimatology Sector was established in 1964. A pilot programme was started in the Prince George-Quesnel area of the interior plateau. Here, a technician-maintained, autographic, short-term network was established to record temperature continuously in conjunction with storage raingauges. To lessen the chance of lost records, dual raingauges were used. The network was designed to sample along and across readily observable or anticipated climatic gradients. As an aid in making the decisions, the vegetation pattern of distribution is observed to provide a gross stratification of the area in conjunction with slope, aspect, and elevation.

As much as possible, network density was tied to the expected variability of the region, with networks being more dense in mountainous country than in flat. If at all possible, a base station was included in each major transect as a control. Relationships developed in the network were then related to these base stations.

In order that each base station might be positioned within the regional climate, and the site examined for unusually microclimatic influences, each site was visited with the intention of evaluating the observers' method, and examining it for undue encroachment of buildings, trees or anything that might influence the precipitation catch or temperatures. Similarly, boom-mounted thermistor temperature-sensors were traversed through the station site under a variety of synoptic conditions in order to determine if "frost pocketing" or other phenomena were occurring that might make the record exceptionally different from its surroundings. This mobile sensing-technique is also used to link up remote stations with base stations under a variety of day and nighttime conditions. Data are either recorded directly or plotted on a small-scale topographic base along with vegetation information. Vegetation has been found to be, among other things, a good indicator of natural frost-pocket conditions in undisturbed land.

In addition to the on-site assessment of each station, all information relating to its history such as changes in location or instrumentation are evaluated for possible effects on the data series.

All remote stations are attended by trained technicians weekly, bi-weekly, monthly, or six-monthly. Additional hourly and daily visual observations are made of such diverse phenomena as fog, snow drift, and frontal movements.

Besides the technician-operated network, a number of co-operator stations are maintained for the project by other government departments, ranchers, farmers, etc.

In all, 700 temporary remote recording-stations are presently in operation. This full network is maintained in an area for a minimum of 2 years after which it is gradually phased out with only a skeleton control-network left in operation. At the 5-year mark all stations are terminated. In addition to the 700 temporary stations there are usually 20 to 30 Meteorological Branch stations which are used for the historical base control.

DATA REDUCTION AND PUBLICATION

All data collected in the field are used as computer input on an IBM System 360 Model 40 computer. A series of regression-correlation programmes have been designed for relating the remote station to the base station and historical record and produce statistics on normalized seasonal precipitation, mean maximum, minimum and daily temperatures, frost-free season, growing-degree days (both for various thresholds). Frost probabilities, potential evapotranspiration, and soil-moisture-deficit statistics are also produced. A system using principal-component analysis is being attempted but with varying results owing to the diversity of disciplines to be serviced.

Maps of frost-free period, growing-degree days, seasonal precipitation, mean temperatures, and many others are drawn at a scale of 1 inch equals 4 miles. Reduced copies of a temperature map and a climate capability for Agriculture map are given in Figures 2 and 3. You will note that the information is mapped as an isopleth rather than as an isoline; this is to facilitate input into the Canada Land Inventory geo-information system.

In addition to the map materials, sundry reports are produced, including probability tables and regional-climate summaries.

SUMMARY

The integration of available analysis-techniques and the attempt to extend climate-data use into the field of renewable resources have proven to be most fruitful. Further extension of this type of approach can add considerable refinement and in many cases make integrated land-evaluation programmes possible.

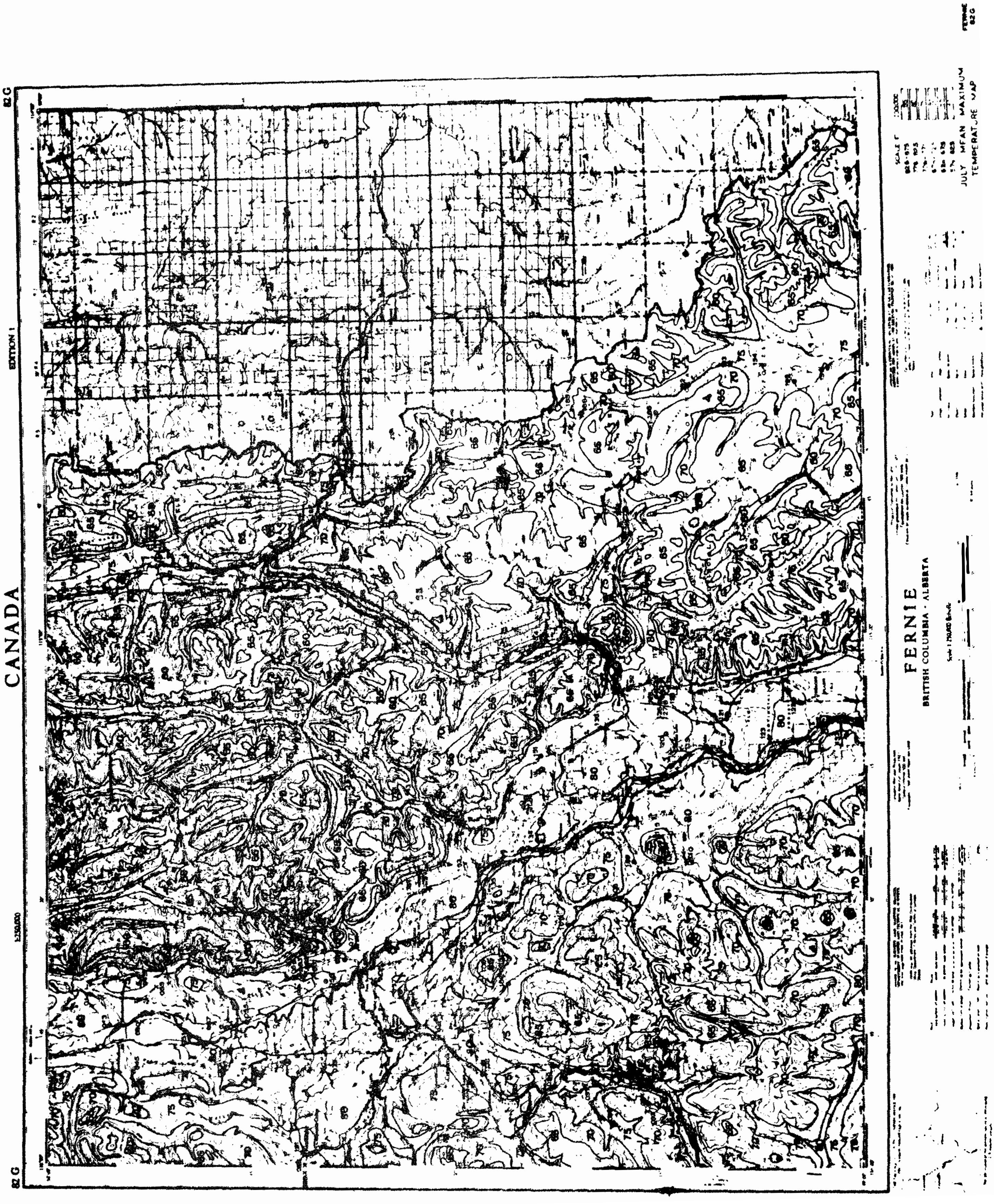

Fig. 2. July mean maximum temperature map for the Fernie area of south-eastern British Columbia.

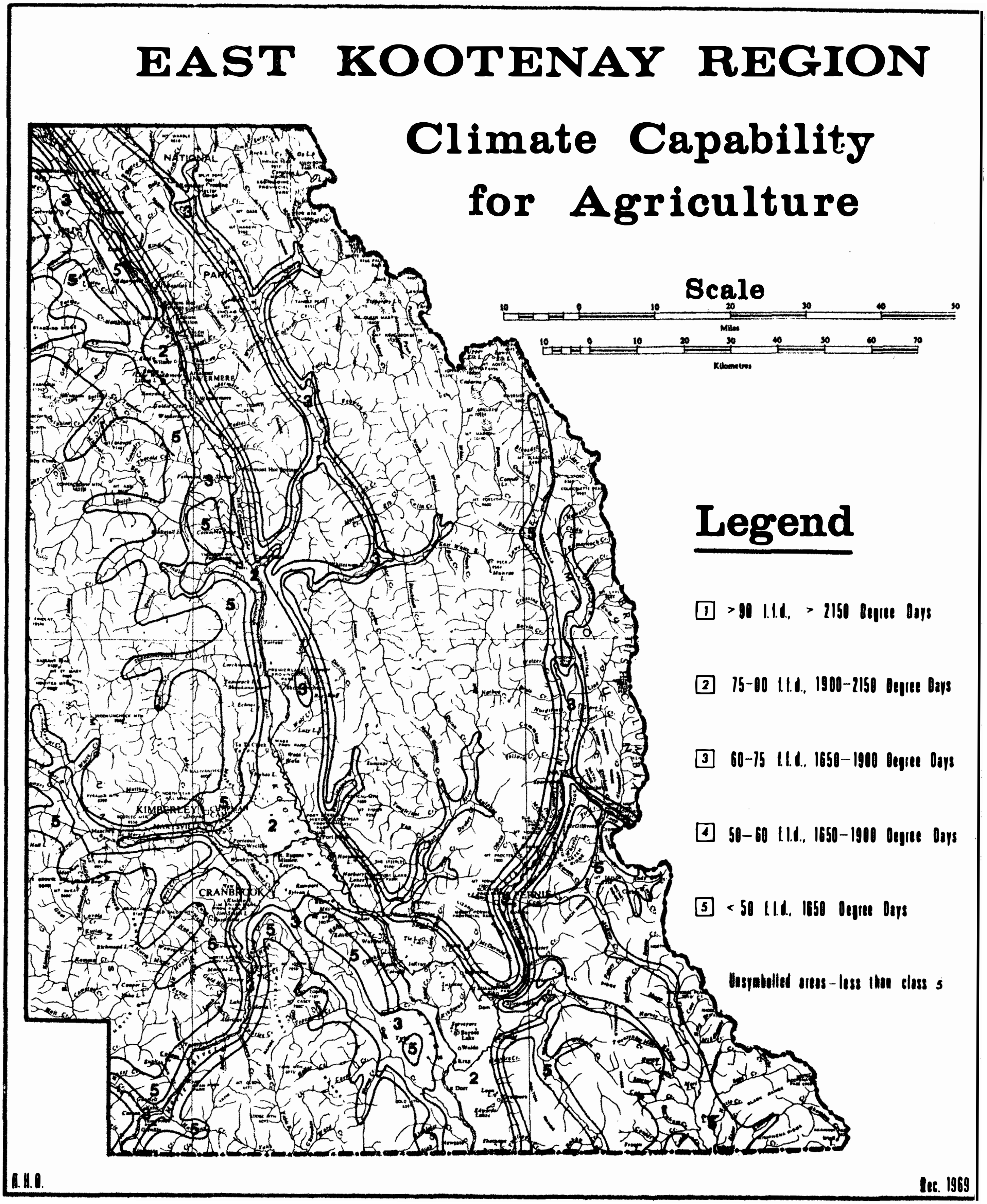

Fig. 3. Climate capability map for agriculture for the East Kootenay region, British Columbia.

ACKNOWLEDGEMENTS

This programme is supported by the Agriculture and Rural Development Act, Canada Land Inventory, Ottawa. It is administered provincially by the British Columbia Department of Agriculture. Their support is gratefully acknowledged as is the considerable help of the British Columbia Forest Service, Research Division, Victoria, B.C.

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DIURNAL TEMPERATURES IN THE KANANASKIS VALLEY IN SUMMER

By

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ABSTRACT

Thermograph observations (at 4 ft) on a cross-section of the Kananaskis valley show a valley-bottom inversion in mid-afternoon averaging 4°F on clear days; the inversion is mainly attributed, with reason, to differential evapotranspiration.

With valley sides about 3,000 ft high, the nocturnal inversion was found to be mainly concentrated in the first 70 ft. The average for all nights was 5°F in this layer out of a total inversion of 6°; for clear nights 7° out of 10°. When nights were grouped by amount of inversion in the 70-ft layer, the average nocturnal wind speed (at 33 ft) was found to be the same (3.0 ± 0.5 mph) for all classes between 3° and 10°F inclusive.

MICROCLIMATE RESEARCH IN THE DRUMMOND GLACIER VALLEY - 1969

By

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SUMMARY

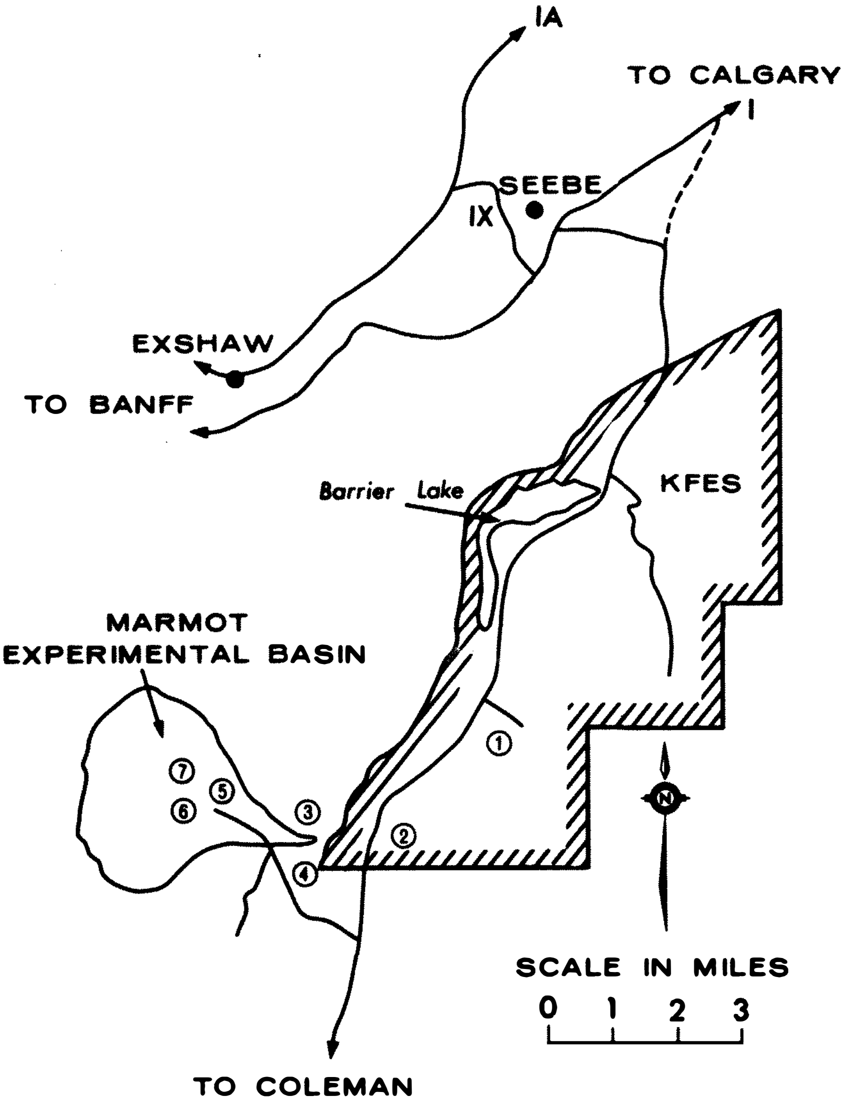
The research mentioned in this paper is part of the Red Deer Valley Project carried out by the Department of Geography, University of Calgary, beginning in 1962. The Drummond Glacier is situated at the headwaters of the Red Deer River in Banff National Park, about 20 miles north of Lake Louise, and has an approximate area of 5 square miles.

The project undertaken in 1969 proposed to study the relationship between glacier melting and climate. A number of metal poles were installed on the glacier surface to measure melting during certain intervals of time, and rock cairns were set up at the glacier snout to measure ice-front recession. Two weather screens were set up - one on the glacier tongue, and the other at the campsite, located at the top of the treeline. Temperature was measured at both screens, and solar radiation was measured at the camp site. Also, current weather, including cloud cover, was observed at the campsite.

As the data collected has not been fully analyzed, no conclusions can be mentioned at this time. However, it might be noted that some problems were encountered which hampered the collection of data. Unfavorable weather prevented measurement of glacier melting at regular intervals between mid-June and mid-July. A visit from black bears at the end of July, with resulting destruction of food supplies and tents, ended the project a month earlier than anticipated.

MARMOT CREEK EXPERIMENTAL WATERSHED

FIELD TRIP



STOPPING POINTS

① In situ transpiration evaluation

② Marmot experimental basin overlook

③ Marmot main stream gauging station

④ Water quality - groundwater installations

⑤ Meteorological observation station

⑥ Forest - meteorological research site

⑦ Snow pillow installation

MARMOT CREEK EXPERIMENTAL WATERSHED
FIELD TRIP

Stop 1. Transpiration of Individual Trees.

- R. H. Swanson, Canadian Forestry Service

Transpiration is the process whereby water is evaporated from the soil via a plant's water conducting system. The amount of water thus vaporized is a considerable quantity--up to that which falls as annual precipitation. From the hydrologist's point of view, such vaporization represents a loss in the water budget of a land area.

It has been hypothesized that different species of trees transpire differing volumes of water. Lysimeter and potted plant studies tend to confirm this hypothesis. However, this has never been successfully demonstrated on anything approaching the extent of a watershed--even a very small one. It is likely that differences between individual trees are small--especially on the relatively dry sites found on most mountainous watersheds. Nonetheless, the potential for water yield improvement through species conversion is a tantalizing goal, and it will remain so until proof for or against the hypothesis above is brought forth.

The studies being conducted at this stop are aimed at developing a technique for estimating the transpiration of an individual tree *in situ*. The heat-pulse-velocity method is used to estimate upward xylem sap movement. The rate of this movement in conjunction with wood moisture content and conducting xylem basal area can be used to estimate the transpiration rate of a given tree. In this study, our main concern is describing the moisture content on area of the conducting xylem, and the average heat pulse velocity over that area.

Stop 2. Marmot Basin Overlook

- E. C. Wyldman, Alberta Departments of Lands and Forests

Marmot Creek Experimental Watershed

Purpose: The evaluation of the effect of commercial timber harvesting and cover manipulation on stream flow and water quality.

Administration: Authority for research in, and management of, the basin is vested in the Alberta Watershed Research Co-ordinating Committee.

Description: Covered in a published brochure.[1] A more detailed description of the geology and geomorphology is included here.

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[1] Marmot Creek experimental basin. Can. Dep. Forest. and Rural Develop. 1966. 8 p.

Geology and Germorphology

The Marmot Creek basin is generally covered by twenty to thirty feet of light brownish-grey, silty, calcareous till. A large percentage of the till consists of rock fragments of limestone, sandstone, dolomitic siltstone and light grey quartzite. Continuing processes of slump, creep, rock slides, and sheet flow have resulted in thicker surficial deposits along the stream bottoms and in down-valley depressions. There are a number of thick elongated ridges or till moraines on the valley slopes and on the floor of the Middle Creek cirque. In outcrop, these moraines exhibit thicknesses of some 60 to 80 ft.

The underlying bedrock dates from Late Paleozoic to Early Cretaceous age. The rock units generally strike N25-35°W across the basin and dip at 15° to 20° west back into the basin.

A resistant quartzite member of the Rocky Mountain Formation, of Late Paleozoic age, forms the bottom step outcropping across the base of the confluence area. Marmot Creek has cut a deep gorge through this bench as the creek leaves the basin and drops to the valley below. The quartzite step supports erosional remnants of till moraine over one hundred feet thick. The next resistant bedrock step is formed by the Spray River Siltstone, of Lower Triassic age.

This Spray River Siltstone outcrops along Marmot Creek and underlies most of the confluence area as well as the bottom part of the Cabin Creek Sub-basin. The Spray River Siltstone is platy to flaggy-bedded at the base and laminated with shale.

Overlying the Fernie Group, the interbedded sandstone, shale, and coal beds of the Kootenay Formation, of Upper Jurassic to Early Cretaceous age, form the steep middle and upper portions of the sub-basins. The Kootenay Sandstone beds exhibit local faulting where exposed by the eroding sub-basin tributary streams.

The Kootenay Formation is capped by a massive conglomerate (the Cadomin member) of Lower Cretaceous age, that dips westward into the axis of an overturned syncline, the back limb of which forms Mount Allan.

Future: The basin is still undergoing calibration. No concrete plans have yet been made for any timber removal. However, the plan for the evaluation of a commercial harvesting method is being assembled now.

Stop 3. Main Stream Gauge.
- M. Spitzer, Water Survey of Canada, Department of Energy, Mines and Resources

Water Survey of Canada has found that the Marmot Creek basin has presented opportunities to study the runoff phenomena of very small basins. Until the inception of this basin, Water Survey of Canada was gauging only large or moderately large-sized basins. Thus Marmot Creek basin serves as an ideal site for the study of runoff parameters from a tiny basin. Of prime concern to Water Survey of Canada is the field of multiple regression analysis, using the runoff, meteorological and other hydrologic data being collected in the basin. With multiple regression techniques, attempts will be made to predict and compute runoff parameters for ungauged basins of all sizes. Inherent as a part of this study, the transposition scalar factors must be ascertained when one applies data from a basin of one size to that of another basin of a different size. A study is also being conducted to differentiate the contribution to surface water runoff from the alpine and forested regions.

Water Survey of Canada operates five gauging stations within the basin. One station is operated on the main stem below the junction of the three major tributaries and is used to measure total outflow from the basin, including the groundwater contribution. Gauging stations are located on each of the three major tributaries. The fifth station is located at tree line and gauges runoff from the alpine area.

Little data-analysis has yet been undertaken awaiting sufficient data to warrant intensive studies. Some simple correlations of mean monthly-flows between sub-basins have been done but no multiple regression studies have been made.

Stop 4. Water Quality and Groundwater Instrumentation.
- T. Singh, Canadian Forestry Service, acting on behalf of Water Quality Division, Department of Energy, Mines, and Resources, and Research Council of Alberta.

The active program of the Groundwater Division of the Research Council of Alberta includes the evaluation of the groundwater resources of the province. The realization of program objectives requires an understanding of groundwater regimes (including the occurrence, movement, and quality of groundwater) in the hydrogeological environments of foothill and mountainous areas of the province. The Marmot Creek basin project has provided opportunity for the study of interactions among parameters of the hydrogeological environment (including the climatic, topographic, and geologic conditions present) and properties of the groundwater regime in a mountainous area. These interactions are being investigated quantitatively from analyses of data obtained from hydrogeological reconnaissance, drilling programs, and the groundwater observation-well records.

Geohydrology

The tributary streams of Marmot Creek originate in the headwalls of the sub-basins as perennial springs and flow downward in a generally perpendicular path across the strike of the steeply dipping, underlying Kootenay and Fernie Formations. In the lower part of the sub-basins where the surface slope is lower, the streams are increasingly influenced by the structure of the underlying bedrock, as in the lower part of the Cabin Creek Sub-basin.

Groundwater exists in the Marmot Creek basin generally under water-table conditions, being recharged in the spring and early summer by infiltration from snowmelt and rainfall and gradually depleting during the late fall and winter to supply stream baseflow. Marmot Creek and its tributary streams are acting as V-shaped drains in the steeply dipping water-table that is a subdued replica of the basin surface. Where the slope of the water is less than the overlying topographic surface, a contact spring or boggy area has usually developed.

Groundwater Instrumentation

During the 1964 and 1965 field seasons, seventeen water-table-observation-well and piezometer sites were established in accessible parts of the confluence area and adjacent sub-basins. Thirteen of the installations are equipped with Stevens F-type recorders.

Water-table-observation wells were spaced over the basin and topographic divides to obtain the necessary control required to construct a water-table topographic-map. Piezometer were set into underlying bedrock and in the more permeable zones within the surficial material to reveal any existing hydraulic variations within the groundwater reservoir. The more concentrated network of wells at the bottom of the confluence area provides the closer control necessary to establish the phreatic divide and detect the presence of underflow southward down the plunge slope of the Rocky Mountain quartzite bench.

In 1968 a drilling program was carried out, test holes being drilled into the Kootenay, Fernie and Spray River Formations; bail tests were performed to evaluate hydraulic conductivities of those formations, and measurements were made of change in fluid potential with depth.

Water Quality

As part of the International Hydrologic Decade Program in Canada, the Water Quality Division, Inland Waters Branch, Department of Energy, Mines and Resources, is conducting a surface-water-quality study in this basin. Its purpose is to determine the effects on water quality of planned environmental changes, such as forest manipulation, forest removal, and associated activities.

The sampling program was initiated in 1964 and sampling stations were set up on Middle (Fork) Creek, Twin Creek, Cabin Creek, and Marmot Creek. Samples have been collected on a weekly basis from March to November and for the remaining months of each year. This year sampling has been reduced to a monthly basis only and will continue on this basis until the year prior to the scheduled planned forest removal program for the basin.

The planning water-quality program one year prior to environmental changes and continuing two or more years after such planned changes take place is to increase sampling to a weekly basis during normal stream-discharge and to semi-weekly, daily or more often, if deemed necessary, during high discharge. This program will provide benchmark data under natural forest conditions and water quality characteristics and patterns before, during, and following a planned forest cover removal program.

The analytical program for waters from this basin consists of the normal physical and chemical parameters for surface waters plus copper, lead, and zinc and it is now being modified to include pollution parameters such as total organic carbon, total nitrogen and organic phosphates. The waters of this basin contain appreciable quantities of calcium and magnesium bicarbonates and sulfates. Alkali salts are low and nitrates and phosphates are in the 0.05 mg/l range. Heavy metals are almost absent (0.003 mg/l).

Mineral concentrations vary similarly from year to year with seasonal change and during run-off. There has been little or no significant change in non-carbonate hardness of these waters during high run-off periods, which indicates that the mineral content is essentially a solution of carbonates.

Stop 5. Meteorological Observation Station.
- D. Storr, Meteorological Branch, Department of Transport.

Meteorological research includes:

1. Study of the amount, distribution, and variability of precipitation in the basin, with a network of 33 gauges recording rainfall patterns and a network of 11 gauges measuring total precipitation.

2. Study of wind speed and direction during snowfall--to assist in the design of tree-cutting blocks in the vegetative-manipulation phase of the program.

3. Comparison of vapour pressure at mountain stations with that in the free atmosphere--to determine if a similar vapour pressure excess exists at Marmot Creek to that found in the Caucasus and Alps, and to investigate possible causes for the excess.

4. Study of snow accumulation, ablation, and melt--in cooperation with Canadian Forestry Service researchers.

Stop 6. Forest-Meteorological Research Site.

- D. L. Golding, Canadian Forestry Service, and D. Storr,
Meteorological Branch, Department of Transport

Evapotranspiration Research

Objective: to calculate by meteorological methods the evapotranspiration from the basin.

Methods and results to date: the water-balance method gives a rough approximation of average annual evapotranspiration, but is not useful for shorter intervals.
The eddy-correlation method failed because of space-averaging problems.
The energy-budget method has provided a point estimate for a 19-day period in July 1967. A map of clear sky insolation has been prepared by computer techniques and is being checked by measurements of components of net radiation in the basin. From this, it is hoped to prepare maps of net radiation for the basin. Further energy-budget studies are planned to determine areal variations, if any, in the Bowen ratio and, hence, calculate areal estimates of evapotranspiration for the basin.
Temperature, humidity, wind, and radiation data are being collected to estimate evapotranspiration by the Penman method.

Hydrologic Properties of the Forest Floor

The characteristics of the forest floor (i.e., the predominantly organic layers above mineral soil) are important in the context of forest hydrology. The water-holding capacity and infiltration rate of litter and humus are among those factors that determine the rate and amount of overland flow and erosion resulting from snowmelt and rainfall. A study was carried out on Marmot Basin to determine the hydrologic properties and other characteristics of the forest floor under three main cover-types of the East Slopes (mature spruce-fir, partially cut spruce-fir, and immature lodgepole pine) on three predominant aspects (north, east, and south). Following is a summary of the results:

(a) Water held by forest floor under spruce-fir significantly greater than under pine (0.76 in. to 0.33 in.).

(b) Weight of forest floor (dry matter) greater under spruce-fir than under pine (43 to 28 tons/acre).

(c) Infiltration rates very high under all cover types with no measurable difference between them.

(d) Pine stands 150-200 years old are similar to spruce-fir stands with respect to the hydrologic properties of the forest floor.

On the East Slopes, pine usually originates on spruce-fir sites after fire (as is the case on Marmot Basin). The main implication of this study is that after fire, the hydrologic properties of the forest floor have deteriorated significantly revelant to erosion and water quality and the effect remains for many years (the immature pine on Marmot is 30-35 years old).

Stop 7. Snow Measurement.
- W. H. Poliquin, Eastern Rockies Forest Conservation Board.

Snow depth and water equivalent have been measured on Marmot by various methods, e.g., snow stakes read from helicopter, storage precipitation gauges, 10-point snow courses, 1x10-chain grid. A snow pillow has been installed recently to supplement the snow-pack data being gathered on the basin.

CHINOOK WEATHER RESEARCH STATION VISIT

By

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On the evening of September 25, a visit was arranged to one of the University of Calgary's Chinook Research Weather Stations at Camp Chief Hector.

The University has seven weather stations located along the Bow Valley from the Rocky Mountains to Calgary. These stations are located at sites that may present a time base for the chinook movement and record meteorological parameters such as temperature, relative humidity, and wind direction and speed. The site visited is the most westerly station of the network and is located about 7 miles northeast of Seebe and about 15 miles from Kananaskis Forest Experiment Station.

This station is in a position to intercept air flowing from the west through the Bow Valley and eastern exit of the Rocky Mountains. The other stations are located in other positions suitable for the interception of the western flowing Chinook air as it moves down the valley toward Calgary. The most easterly station is located on the University of Calgary Campus.

INSTRUMENTATION

The Camp Chief Hector site is equipped with a Belfort Hygrothermograph housed in a Stevenson Screen and a Berkeley instrument 661013 Teladvisor automatic weather station.[1] The weather station is a complete data-gathering system designed for unattended measurement of certain atmospheric conditions in a limited geographical area and the transmission of the data in 8-unit, ASCII code to a low-energy, solenoid-operated tape perforator. The system automatically measures ambient temperature, barometric pressure, wind direction, relative humidity, and wind speed. A 3-cup anemometer with mechanical counter is included for recording total wind passage. Each sensor is mounted in a housing with its associated Teladvisor Angular Position Digitizer or, in the case of the cup anemometer, its Teladvisor Rate of Rotation Digitizer. Initiation for readout may be set at seven predetermined intervals; in addition, the system may be initiated manually when required. The University is using a 10-min. interrogation to detect temperature and relative humidity inflections and deflections of Chinooks and frontal passages.

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[1] Berkeley Instruments are no longer in business but their tooling, plans and spare parts have been taken over by Towner Systems, Alameda, California 94501.

The sensors convert data directly into the mechanical form of a shaft or pointer position or into angular velocity (wind speed), and these mechanical quantities are converted into electrical pulse trains by the digitizers, which eliminates the necessity for electrical analog-to-digital conversion at the main programming unit. These pulse trains are transmitted to the programming unit, contained in a fiberglass weatherproof box, which sequences and converts the data into 8-unit, ASCII code for recording by the tape perforator.

This automatic weather station has operated intermittently since October, 1967. Several problems in the equipment serviceability have been encountered and the basis of most trouble was found to be the supply voltage. If this voltage supply drops lower than 12.3 volts, then the tape punch will not advance the paper to meet the required gauge of punched tape. The power supplied to this unit is from a 12-volt storage battery (13.2 volts fully charged) and is kept fully charged by a Telon thermoelectric generator which operates on propane gas.

A GAS-EXCHANGE-CHAMBER FOR USE IN THE FIELD AND IN THE LABORATORY

By

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When measuring CO_2 uptake and transpiration of a plant in a chamber there is commonly a problem of excessively high temperature and humidity inside the chamber. Increased temperature in the chamber can cause heat damage to the plant, and any condensation of water influences light conditions and CO_2 measurements. Attempts to counteract this problem have included Tranquillini's heat-absorbing filter, Bosian's water-cooled cuvette, and Lange's "Klappkuevette" which is open for 4 minutes then closed for 2 minutes for measurement, but none of these attempts was very satisfactory.

The Sirigor-Chamber (Fig. 1) constructed by Koch at the Botanical Institute, Munich and by engineers of Siemens-Erlangen seems to provide most of the requirements for gas-exchange studies. For laboratory tests, temperature and moisture in the chamber can be set to a certain value. In the field, air temperature inside the chamber follows exactly the air temperature outside.

A system working on the Peltier principle, instead of compressor cooling, controls the temperature by variation of current instead of an on-off system. Inside the chamber is a fan, with adjustable speed which causes the air to circulate past the plant tissue and the cooler. The water coming from the plant's transpiration is taken out of the chamber by a bypass system with a water-vapour trap.

The CO_2 gas exchange is determined in an open system by the principle of a differential measurement between the CO_2 content of air passing the plant in the chamber and the CO_2 content of the ambient air (Fig. 2). For transpiration measurements, the chamber works as a closed system. A pump (P_2) in the bypass system draws the air out of the chamber into the water-vapour trap (WVT) and back into the chamber. If the outgoing water-vapour (OUT) is the same as the incoming water-vapour (IN), the water condensed in the electronically controlled water-vapour trap is equal to the transpiration. It is actually calibrated from the airflow and the dew point in the bypass system (BY).

This equipment was tested, used, and found satisfactory under the extreme conditions of the Negev desert by Lange, Koch and Schulze, and on Nebelkogel in the Austrian Alps by Moser, and under normal conditions near Munich by Baumgartner for several years. More details about this chamber may be found in Siemens-Zeitschrift, May 1968.[1]

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[1] "Siemens-Zeitschrift", 42 Jahrgang, Mai 1968, Heft 5: 392-404, by W. Koch, E. Klein, and H. Walz.

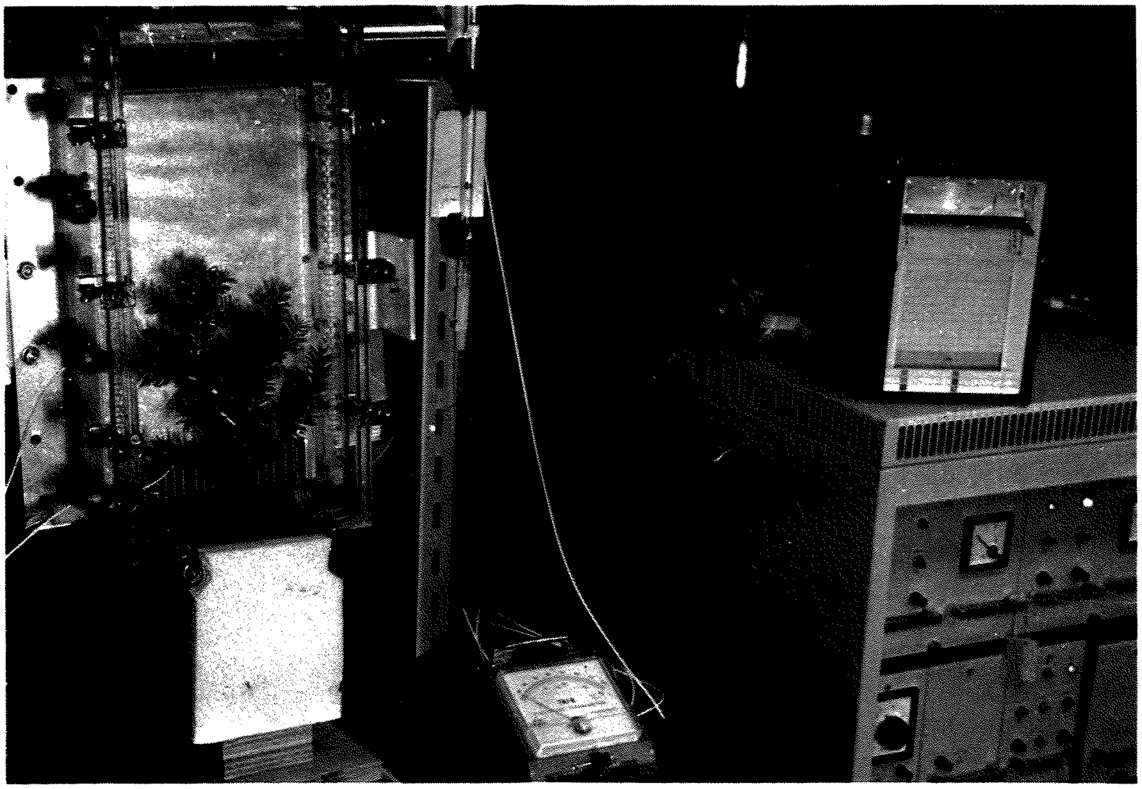

Fig. 1. Fully climatized gas-exchange chamber containing a fir branch (left). Electronically-controlled system for temperature and humidity regulation, and recorder (right).

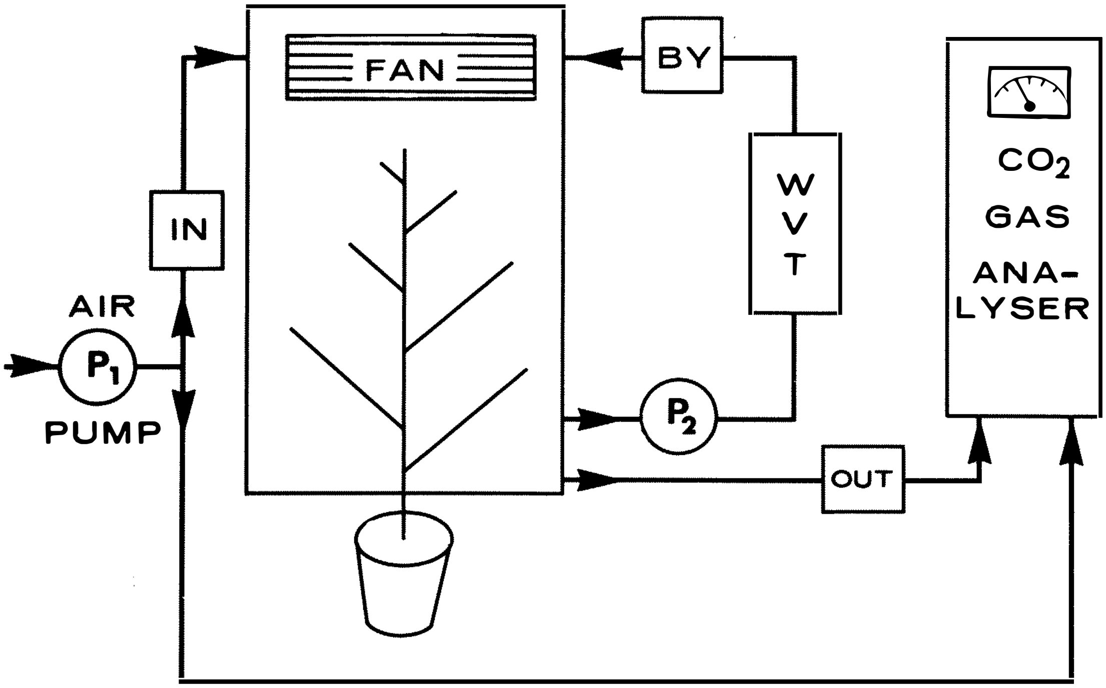

Fig. 2. Simplified diagram of a chamber for measurement of CO_2 and transpiration of plants.

A FOREST CLIMATE CLASSIFICATION FOR CANADA - DISCUSSION[1]

J. C. Macleod, Forest Fire Coordinator, Canadian Forestry Service, Ottawa, introduced the subject of a national forest-climate zonation in Canada to some 40 Canadian participants at the Symposium. His remarks were prompted by requests he had received from Dr. P.J.B. Duffy, Canada Land Inventory Program Coordinator, and Dr. J. S. Maini, Tree Biology Program Coordinator, both of the Canadian Forestry Service, Ottawa, who requested that the topic be raised at the meeting.

Duffy requested that the group consider a cohesive program of climatological research to serve broad forestry subject areas. One item that is needed is a national forest climate zonation, analogous to the Canada Land Inventory Climates of Canada for Agriculture. While there seems to be considerable meteorological data available, these data have not been interpreted for forestry. Such an interpretation would, if it were to be useful, require analysis for (1) forest land capability classification, (2) partition of the environment for field research projects, (3) fire danger rating on a broad scale, (4) miscellaneous subjects such as regeneration, trafficability, permafrost.

We would like to encourage studies of regional forest climates following a national classification system. The regional studies could develop piecemeal, with emphasis on a regional scale (perhaps 1:250,000) and regional problems, and lead to a forest-climate zonation using existing data and their interpretation for a number of significant parameters. The development of a national classification system would require regional specialists to examine the correlation of analytical methods and mapping techniques.

Maini stated that in order to make maximum use of the information from our field experiments, it is necessary to develop a climatic classification of Canada from the forestry point of view. Such a classification would have a tremendous impact on our silvicultural program, tree improvement and breeding program, and our understanding of the role of climatic parameters in vegetation patterns. The relevance of various classification systems presently in existence should be examined and applied as such or in modified form for forestry. Needless to say that biologists should have some input in developing a suitable classification system so their biologically meaningful parameters (climate) are incorporated in the classification.

The rest of the discussion was chaired by Dr. J. M. Powell, during which time almost all of the participants present expressed their views or made comments. Generally, all felt that there was a need for a forest-climate

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[1] Prepared by J. M. POWELL, Canadian Forestry Service, Calgary, Alberta.

classification in Canada, that such a classification should be able to fit the immediate need of most forest users, although obviously modifications would be necessary for any specialized group of users. All felt that a first approximation of a forest-climate zonation on a regional scale would be most useful, and has long been desired, but unlike for an agricultural crop, the necessary parameters for a broad spectrum classification are not so easily defined. Much meteorological data exist, although their direct application to a natural or planted forest stand, or individual tree, may require further study and extrapolation to increase their correlative value. The existing meteorological data can be used at the provisional forest-climate zonation stage, but the meteorologist or climatologist requires the necessary parameters for input from the forester. The climatologist can supply zonations for length of growing season, number of degree days, available soil moisture, etc., but can the forester interpret such data to his use or particular problem?

The problem is being tackled in some regions. In British Columbia, a forest climate classification, in relation to the Canada Land Inventory land capability study program, is being developed, through a series of short-term observational networks in designated areas of the Province, to provide a basis for establishing the variation of selected parameters in these areas (see paper by Marshall p. 205). In Alberta, a preliminary study was started in 1969, with the initial aim to prepare a map of forest climate areas of Alberta showing similar climatic characteristics for forest growth. A field technique being used in this study to help establish parameter division boundaries is reported elsewhere (see summary by MacIver p. 188). No other studies on forest-climate classification appear to be underway in other regions although their desirability is evident. Many comments were made on the parameters needed for a classification, possible approaches or methods of analysis, and the various aspects of forestry that could use such a classification.

As to how it should be done? It was strongly recommended by the participants that the Coordinator group of the Canadian Forestry Service in Ottawa be requested to review the subject, including information on the climatic parameters necessary for forestry studies, and recommend guidelines for any national forest-climate classification that is desired. It was felt that no region was suitably set up to investigate the requirements on a national level. The existing regional studies should continue on their present lines and should not necessarily be considered as pilot studies for a national classification system, for their designated objectives would probably differ.

HOHER NEBELKOGEL - A METEOROLOGICAL AND BOTANICAL RESEARCH STATION IN THE AUSTRIAN ALPS AT AN ALTITUDE OF 10,500 FEET

By

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SUMMARY

High above timberline, surrounded by the glaciers of the Stubaier Alpen, the environment and reactions of plants are being studied. The 6-10-hr hike to this station takes one to an altitude that is seemingly devoid of vegetation (Fig. 1). But closer examination of the rocks and crevices reveals, besides lichens and some mosses, *Saxifraga* spp., *Cerastium uniflorum* and *Primula glutinosa*. In summer, the area around Hoher Nebelkogel station is covered with one of the most interesting plants, *Ranunculus glacialis*, the highest occurring angiosperm in the Alps. But 3 ft of snow and severe storms may also be present at this time of year.

To understand how plants can stand this environment, we recorded the climatic factors. The research station (10 by 10 ft) was equipped with recording instruments for temperature, radiation and wind speed (Fig. 2). The sensors were located near the plants on the north and south slopes with one located 6 ft above ground. Electrical signals from the sensors were recorded on paper tape and fed to a computer. A camera took pictures of the test area four times a day. These pictures recorded snow depth, snow drifts and developmental stage of the plants. During the summer months, CO_2 exchange measurements on plants were also taken. The recording system was powered by three 24 V, 70 Amp-hour batteries, which were charged by a wind generator or, if necessary, by a small gasoline power-plant.

Laboratory experiments have shown that the frost hardiness of *Ranunculus glacialis* leaves is not very high. At a temperature of -7°C irreversible damages can be found (Moser, 1968). At this altitude one would expect temperatures as low as this quite often during the growing season, usually occurring in conjunction with snowfalls. Because the snow insulates plants from these low temperatures, only leaves above the snow or ice cover suffer damage.

Ranunculus glacialis hibernates with roots and buds under the soil surface. In spring, leaves begin to develop under the snow and start to take up CO_2. Even in cases where the snow occasionally remains on some slopes during the summer, *Ranunculus glacialis* can still survive. A knowledge of microclimate aids in understanding how plants survive in these extreme conditions. Further investigations are in progress at Hoher Nebelkogel.

REFERENCE

Moser, W. 1968. Neues von der botanischen Forschungsstation "Hoher Nebelkogel"/ Tirol. Jahrbuch 1968, 33. Band, des Vereins zum Schutze der Alpenflanzen und -Tiere e.V., Muenchen, Page 1-9.

Fig. 1. Microclimatic and botanical research station on Hoher Nebelkogel, 10,500 feet, in the Austrian Alps. Wind generator in the middle.

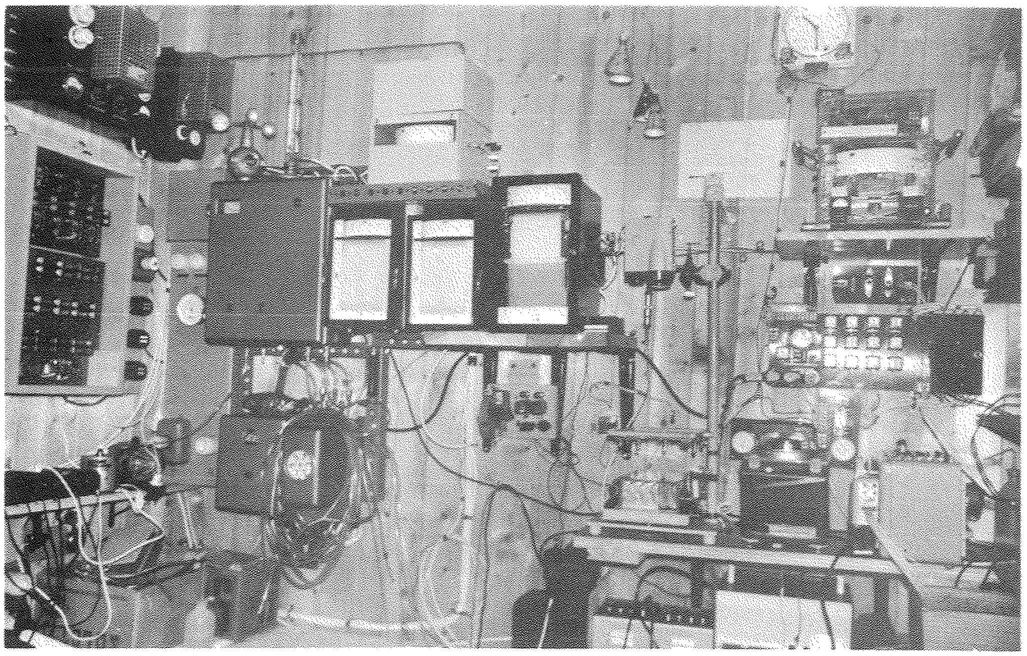

Fig. 2. Instrumentation for temperature, radiation, wind speed, and CO_2 measurements. Left: Infrared gas analyzer with recorders for gas exchange measurements. Right: Digital converter system for climatic data and paper tape output.

FOREST IRRIGATION RESEARCH AT WEYERHAEUSER COMPANY

By

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ABSTRACT

A pilot study designed to measure the effects of forest irrigation on growth of 20-year-old Douglas fir was begun near Centralia, Washington in the summer of 1969. Four types of treatments are being tested: thinned-irrigated from above the crowns, thinned-irrigated from below the crowns, thinned-no irrigation, and no thinning or irrigation. The effects of each treatment will be assessed from measurements of internal water stress, stem-growth rates, and several environmental parameters. Preliminary data indicate that water stress of trees can be greatly reduced by sprinkler irrigation.

REDBELT WINTER INJURY OF LODGEPOLE PINE FOLIAGE IN THE KANANASKIS RIVER VALLEY

By

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ABSTRACT

Pictures illustrating redbelt winter injury of lodgepole pine foliage were taken in June 1956. The injury is thought to have resulted from sharp temperature rises, caused by arctic air in the valley bottom being abruptly displaced by strong Chinook winds during December 21-27, 1955. These winds must have brought warm, dry air down to the surface where it impinged with particularly sudden effect on exposed needles, trees, and slopes. To the physiologist, desiccation may seem to be the mechanism of injury; but topographically, it was only the trees that were exposed to the inferred temperature rises that showed obvious evidence of injury. Trees at higher elevations must have been subjected to as desiccating an atmosphere, but showed no injury.

VISIBLE PLUMES ABOVE TREES - A METEOROLOGICAL OR AN ENTOMOLOGICAL PHENOMENON?

By

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(Title only)

FIRE WHIRLS AND FIRE BEHAVIOR

By

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PRELIMINARY TIME LAPSE MOVIES OF SMOKE PLUMES

By

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(Title only)