

Radiative Temperatures in the Willamette Valley¹

The stream of radiant energy incident upon the surface of the earth is absorbed, reflected, and transformed by myriad elements, each with differing thermal characteristics. The absorption of radiation is balanced effectively by the processes of convection, change in stored energy, latent-energy exchange, and emission of radiation. These dissipation processes are all temperature dependent, and the temperature of an exchanging surface adjusts to an equilibrium value that depends upon the relative effectiveness of the dissipation processes.

The equilibrium surface temperature of a landscape unit is related to the efficiency of that unit in absorbing and dissipating energy. Budyko (1958) discussed the temperature of natural surfaces and suggested that this may be a better parameter for use in bioclimatic studies than the degree-days that are accepted widely at present. Only recently have the means for such surface temperature measurements become generally available (Lenschow and Dutton, 1964).

We shall examine equilibrium temperatures attained by several different surfaces under intense solar irradiation that is characteristic of cloudless summer skies in the Willamette Valley. The observed values are a contribution to an inventory of surface temperatures of various landscapes; comparisons among the temperatures attained under these uniform conditions will contribute to a better understanding of the role of surface characteristics in the transformation of solar energy.

Field Experiments

The field experiment included a survey of surface temperatures with the aid of an infrared thermometer. The measurement conditions and techniques employed have a bearing on the interpretation of infrared temperatures.

Conditions of Measurement. Measurements reported here were made between 1230 and 1345 hours, PDT, on August 2, 1967, during a period of clear, dry weather. My measurements at the site of the Corvallis Agricultural Weather Station showed that the air temperatures within the instrument shelter changed slowly from 34°C at 1230 hours to 36°C at 1345 hours. Incoming solar radiation, measured with a Kipp pyranometer, was steady during the period of measurements. The initial value at 1230 hours was 1.22 cal cm⁻²min⁻¹, and subsequent values were: 1300, 1.24; 1315, 1.24; 1330, 1.22; and 1345, 1.21. Winds were light during the period of measurement.

Methods of Measurement. The surface temperature measurements were obtained with an infrared thermometer² that senses radiation emitted by the target surface in the wavelengths between 8 and 14 microns. The thermometer's field of view was 3 degrees, so the radius of the sampled area is about 1/40th of the distance between the instrument

and the target. The resolution of the thermometer is given as 0.5°C, and its absolute accuracy is 2°C for a target above 0°C with an emissivity of unity. A battery-powered, frequency-controlled inverter³ provided 120 volts AC for mobile operation of the infrared thermometer.

A helicopter was used as an observation platform above the sampled surfaces. Observations were made between 60 and 100 m above the surface, though no height effects could be distinguished on temperatures measured from heights as great as 250 m. *Special Considerations in Infrared Thermometry.* Several factors influence the accuracy obtained in infrared thermometry. These include transmissivity of the atmosphere, emissivity and reflectivity of the target surface, and instrument drift.

The influence of absorption and emission characteristics of the atmospheric gases between the instrument and the target is minimized by restricting the sensitivity of the instrument to the 8-14 micron band of the radiation spectrum. Lorenz (1966) reported that these effects could be neglected if the distance to the target did not exceed 100 m, providing measurement accuracies of 1-2°C were acceptable.

The emissivity of the target surface also plays a role in the accuracy of the measurements. The most direct effect can be seen by differentiating the Stefan-Boltzmann Law

$$L_g = \epsilon \sigma T^4 \text{ (cal cm}^{-2}\text{min}^{-1}) \quad (1)$$

where L_g is the emitted radiation flux density, ϵ is the emissivity, σ is the Stefan-Boltzmann constant, and T is absolute temperature to produce

$$dL_g/L_g = d\epsilon/\epsilon + 4dT/T \quad (2)$$

so that if a constant flux is received by the measuring instrument

$$d\epsilon/\epsilon = -4dT/T. \quad (3)$$

Thus at 298°K, an error of 1.0°C will be induced by a 1.3 percent error in the estimated target emissivity, unless the emissivity is compensated for by surface reflection. Because reflectivity of an opaque surface is equal to $(1 - \epsilon)$, the failure of the target to emit will be precisely compensated for if the flux of longwave radiation incident upon the target originated from a source at the same temperature as that of the target.

Two points are pertinent to our discussion of temperatures measured by infrared radiometry. First, the infrared thermometer is restricted to the 8-14 micron band of the longwave spectrum, and there is little emission by the atmosphere in the 8-14 micron region of the radiation spectrum. Consequently, under clear skies there is little compensation for the deviation of surface emissivity from unity (Lorenz, 1966), and equation (3) applies to our measurements. Strictly speaking, however, equation (3) is based on the entire spectrum and upon the assumption that the target surface emits as a gray body. Second, the emissivity of vegetative canopies is uniformly high because of properties of the individual leaf elements and the "trapping" effect when leaves are assembled into a canopy. For example, recent reports (Fuchs and Tanner, 1966) give canopy values of 0.976 for sudangrass and 0.977 for alfalfa. The emissivity values for nonvegetated natural surfaces are not as precisely known, but generally range about 0.9. All temperatures reported in this paper are observed temperatures; appropriate corrections for emissivity would raise the figures slightly for water and vegetation, and perhaps substantially for soil and concrete.

³ Terado Corporation, St. Paul, Minnesota 55108. Trav-Electric Model 50-160.

¹ Paper 818, School of Forestry, Oregon State University, Corvallis, Oregon 97331.

² Barnes Engineering Company, Stamford, Connecticut 06902. Infrared Thermometer IT-3.

Instrument drift may be eliminated conveniently with a simple blackbody. For a reference standard during the measurements, I used a water-filled, copper container equipped with an agitator, a suitable cone-shaped cavity, and a mercury thermometer.

Because of these factors, the readings obtained by the infrared thermometer may be within 2-3°C of the absolute value. The sampling problems encountered in measuring a mean surface temperature are not worked out, however. Therefore, the measurements reported here are best viewed in a relative sense.

Results and Discussion

Measured Values. Measurements reported here were obtained near Corvallis during the 1¼-hour period centered on solar noon August 2, 1967. The samples included a variety of the landscape features common to the central Willamette Valley. The data are presented in Table 1, ordered with respect to maximum temperatures. Data

TABLE 1. Midday temperatures of various surfaces. Infrared thermometer measurements made under cloudless skies in August 1967.

Surface	Range (°C)	Midpoint
Ploughed fields	53-59	56
Urban Corvallis	46-57	52
Burned fields	46-56	51
Dried grass	40-45	42
Stubble fields	34-42	38
Clover fields	30-34	32
Coniferous forests	29-31	30
Deciduous forests	27-29	28
Irrigated corn	23-26	24
Willamette River	18-20	19

of this type, not conducive to statistical analysis, are presented merely in terms of the temperature range observed, with the midpoint of the range indicated for ease in making qualitative comparisons between surfaces.

In general, the variability within a particular surface was only 1-2°C; the wider ranges shown result from observations over several different sample units. Also, as one would expect, the surfaces with the higher temperatures showed greatest variation, both within and between sample units.

Relationship to the Surface Heat Budget. Solar radiation reaching a surface may be partly rejected by reflection, partly stored, partly dissipated by convection into the air, and partly utilized in the evaporation process. The efficiency of these transfer processes determines the equilibrium temperature of the exchanging surface. The processes are well understood for leaf elements (Knoerr and Gay, 1965, among others) and are now becoming better defined for vegetated surfaces (Gates, 1970).

The role of the transfer processes may be discussed with reference to the tabulated data in Table 1. The albedo, or reflected fraction of solar radiation, plays a direct role. Although albedos were not measured over these surfaces during the experiment, work here (unpublished) and elsewhere (Robinson, 1966, Chapter 6) allows the following albedos to be estimated with confidence: Willamette River, burned and ploughed fields, 7-10 percent; coniferous forest, 10-12 percent; deciduous forest, 15 percent; dry grass and stubble, 15-20 percent; and green crops, 20-22 percent. Note that the

coldest and the warmest surfaces have the lowest albedos. Apparently, efficiency in absorption need not correlate well with the surface temperature.

The availability of water for evaporation plays the major role in setting the equilibrium temperature level. For example, the irrigated corn was about 24°C, but an adjacent, nonirrigated cornfield was about 30°C. Also, the river was the coldest surface sampled, at 19°C. The large heat capacity of such a surface, however, contributes to a low temperature, despite a low albedo. The lack of water for evaporation at the surface of the ploughed and burned fields, combined with their low albedos and heat capacity, results in the high temperature levels observed there.

The forest stands also have low albedos, but they maintain low temperatures. Individual leaves in the open forest canopies are able to exchange energy effectively by convection as well as by evaporation. As noted elsewhere (Lorenz and Baumgartner, 1970), forest canopies seldom deviate far from air temperature. This finding holds in conifers even when water may not be freely available for evaporation.

Summary

An aerial survey of various surfaces was made with an infrared thermometer under cloudless skies. The temperatures reported can be compared readily because uniform weather conditions prevailed during the midday period of the measurements. The temperatures also may be referenced against a screen air temperature of about 35°C.

In general, vegetation remained near or somewhat below screen temperature, but nonvegetated surfaces rose considerably above. The differences are related to the relative efficiencies with which the surfaces partition absorbed solar radiation into reradiation, storage, convection, and evaporation. The availability of water for evaporation plays a major role in establishing the equilibrium temperature of a surface. Information on equilibrium temperatures contributes to a better understanding of the thermal response of irradiated natural surfaces.

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Literature Cited

- Budyko, M. I. 1958. Temperature of the active surface and its bioclimatic significance. Trans. N.A. Stepanova and G. S. Mitchell, U.S. Weather Bureau, Washington, D.C. 1960.
- Fuchs, M., and C. B. Tanner. 1966. Infrared thermometry of vegetation. *Agron. J.* 58:597-601.
- Gates, D. M. 1970. Physical and physiological properties of plants. *In Remote Sensing*. National Academy of Sciences, Washington, D.C. 423 pp.
- Knoerr, K. R., and L. W. Gay. 1965. Tree-leaf energy balance. *Ecology* 46:17-24.
- Lenschow, D. H., and J. A. Dutton. 1964. Surface temperature variations measured from an airplane over several surface types. *J. Appl. Meteor.* 3:65-69.
- Lorenz, D. 1966. The effect of the long-wave reflectivity of natural surfaces on surface temperature measurements using radiometers. *J. Appl. Meteor.* 5:421-430.
- Lorenz, D., and A. Baumgartner. 1970. Oberflächentemperatur und Transmission infraroter Strahlung in einem Fichtenwald. *Arch. Meteor. Geoph. Biokl., Ser. B*, 18:305-324.
- Robinson, N., ed. 1966. Solar radiation. Elsevier Publishing Company, Amsterdam. 347 pp.

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