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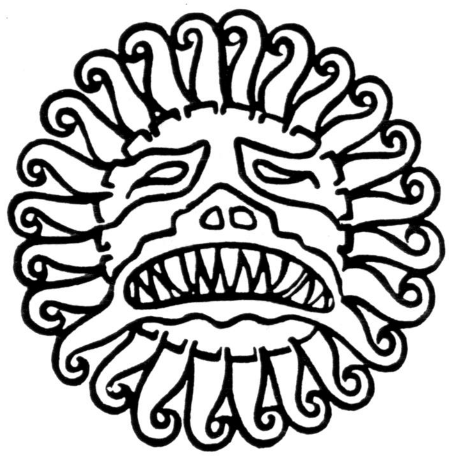

Solar Radiation in the Pacific Northwest

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Bulletin 874

The Authors and this Bulletin

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This investigation was supported in part by Cooperative State Research Service funds under the McIntire-Stennis program.

Work was conducted under research center project 0118 and 0309.

The Cover

The cover symbol is the ancient Persian one for Mithras, the sun, the light, the truth (taken from SYMBOLS, SIGNS AND SIGNETS by Ernst Lehner, Dover Publications, Inc., New York, N.Y.).

Abstract

Solar radiation, diffuse and direct, on a horizontal surface was estimated at 40 stations in the Pacific Northwest where direct measurements were unavailable, using a mathematical solar radiation model. These estimates were combined with existing measurements from 15 stations to develop detailed maps of mean daily solar radiation, by month and annual. The maps are the most detailed and accurate now available in this region. Use of the maps is discussed.

April, 1979

SOLAR RADIATION IN THE PACIFIC NORTHWEST

Donald R. Satterlund and Joseph E. Means

Introduction

Land managers have long recognized that solar radiation is one of the most important environmental characteristics of any area. It is the primary forcing variable in energy exchange processes that determine ecosystem distribution, composition and productivity. It melts snow and powers the hydrologic cycle. It also strongly influences land use and agricultural practices.

More recently, the unprecedented increases in the cost of fossil fuels, their impending shortage, and the adverse environmental impacts associated with their use have focused attention on solar radiation as a source of energy to meet the direct needs of society.

If we are to manage and use solar energy effectively, whether in developing forest management to modify snow melt in our mountains, or in the design of solar heating devices to dry agricultural crops or heat our homes, we must know how much solar radiation occurs at any particular place. We must also know how solar radiation varies from season to season.

Unfortunately, only limited data have been collected in the past and details of the solar radiation climate are limited. The most widely available maps are those in the *Climatic Atlas Of the United States* (2) which are based on data available in 1962 from 117 stations scattered over the country. Published data for most months are available from only 14 sites west of the continental divide in Idaho, Montana, Oregon and Washington. These very general maps are inadequate for today's detailed data requirements.

Our objective was to rectify this deficiency and provide maps showing in greater detail the solar radiation climate of the Pacific Northwest.

Solving the Problem

Solving the problem of limited solar radiation data required indirect means of estimating solar radiation in places where direct measurements were unavailable. Analytical techniques have long been available for determining direct beam solar radiation in the absence of an atmosphere for any point on the earth based on geometric relations between the earth and the sun at any time (3,4).

Atmospheric effects, particularly the presence of clouds, greatly modify the amount of solar radiation received at any site. Cloud cover over the earth is highly variable, both in space and in time. However, observations of cloudiness are made at many more weather stations than are measurements of solar radiation. In the Pacific Northwest, regular observations of sky cover are available at 49 stations, mostly airports; and at several mountain passes and other places. At seven stations, both sky cover observations and solar radiation measurements are available.

A computer model was developed that took the effects of the atmosphere, including cloudiness, into account. Details of model development and verification are presented elsewhere (6), but a brief description of the model and results follows.

Three solar radiation submodels: direct beam solar radiation; scattered solar radiation from the cloudless portion of the sky; and solar radiation reflected from, and transmitted through clouds (scattered) were linked to yield insolation at the surface as:

$$I_t = (I_{ds} + I_s)(1 - C) + (I_{do} + I_s)\, C \exp(-d), \quad [1]$$

where I_t = solar radiation received on any unit surface (ly/min);

I_{ds} = direct beam solar radiation on any unit surface (ly/min);

I_s = scattered clear sky solar radiation on any unit surface (ly/min);

I_{do} = direct beam solar radiation on a unit horizontal surface (ly/min);

C = cloud cover, expressed as a decimal; and

d = an empirical coefficient.

The estimates of instantaneous solar radiation at each hour (I_t) were integrated using a trapezoidal approximation, yielding output of mean hourly, and by summation, mean daily solar radiation for the mid-date of each month. The method of summing hourly values to obtain mean daily solar radiation automatically accounted for the variable amount of clouds at different hours of the day. In the Pacific Northwest, cloud cover varies by hour throughout the day and by season. Mean daily cloud cover, by months, at different locations, ranged from 0.11 to 0.88.

Tests of model estimates against measured mean daily solar radiation in both the Pacific Northwest and Northeastern United States revealed that the estimates of mean daily solar radiation were excellent, with an r^2 exceeding 0.99 and a standard error of estimate of less than 7%. No seasonal pattern of error was evident, nor did errors exhibit any relation to cloud cover.

Results

We concluded that our model estimates were accurate enough for us to use cloud data observations from airports, mountain passes, and other stations to supplement existing measurements to develop a detailed set of maps of mean daily solar radiation, by month and annual, for the Pacific Northwest.

The maps are based on data from 55 locations. All available data were used to develop the maps. They were largely collected over the period 1948 to 1970, and consist of 5 to 10 years for each location. The estimates for adjacent locations may be based on observations from two completely different time periods. The 15 solid symbols represent measured mean daily solar radiation for all or most months (2). The open symbols represent estimates based on observations of sky cover (5). The triangles are data from mountain passes; the circles represent data from airports and other relatively low elevation stations. The first map identifies the location of each station.

The data in the maps represent mean daily solar radiation, both direct and diffuse, received on a horizontal surface in units of langleys (ly). A langley denotes one gram calorie per square centimeter. It is equivalent to 3.687 British thermal units (Btu) per square foot or 4.1855 joules (J) per square centimeter.

From these maps, it is clear that the mountain systems of the region are major controls in the distribution of solar radiation. The physiographic effect is more pronounced in some places than others, reflecting the sources and movement of prevailing air masses and the regular seasonal progression of the sun's altitude relative to a horizontal surface.

In late fall and early winter, the low solar altitude combined with general cloudiness west of the Great Plains results in low solar radiation throughout the region. Radiation increases only slightly in the interior Columbia Basin and from north to south.

By late winter through spring, the effect of the higher mountain systems becomes dominant. The higher mountains are all much cloudier than the interior basins and plains around them and the isoinsolates (lines of equal solar radiation received at the surface) are closely spaced. The effect of solar altitude is largely obscured.

The summer fogs, trapped along the coast by the Coast Range stand out in midsummer, but the physiographic effect in the interior is greatly reduced, except in the northern Cascades and Rocky Mountains.

Late summer and early fall mark a return to a radiation climate characterized by an increasing north-south gradient of insolation as the effect of decreasing solar altitude becomes predominant, but before it is largely obscured by the general cloudiness of late fall and early winter.

Using the Maps

The maps presented herein tend to confirm that estimates of mean daily solar radiation based on our computer model compare in accuracy with measured solar radiation. However, even measured values are not free of error. For example, when instruments at Twin Falls, Idaho and Great Falls, Montana were calibrated during October, 1966, they were found to register 2.5 and 15.0% too low, respectively (1). Because of possible error in the records, the National Weather Service stopped publishing solar radiation data from 1972 until 1975.

The uncorrected measurements of solar radiation provide the base in these maps, both directly and indirectly, for the development of the model estimates that were used. If any maps of mean daily solar radiation were to be developed at all, there was no other source of data. Therefore, all users should be aware of the limited quality of the solar radiation data upon which these maps are based. They represent the best long term data available, but errors of up to 15% for any given station during a given month are possible. In mountainous areas where even cloud cover data are unavailable, as across northern Washington and central Idaho, more uncertainty exists.

Despite these limitations, these maps provide a much more detailed and accurate representation of solar radiation, diffuse and direct, received on a horizontal surface in the Pacific Northwest, than has been available. Errors between stations are somewhat compensating, and each isoinsolate at any point is located on the basis of measurements or estimates from several nearby stations.

Keep in mind that these maps represent *only* solar radiation received on a horizontal surface. Their use for estimating solar radiation on sloping surfaces is subject to increasing error as the degree of slope increases, and such estimates may be grossly misleading.

For example, on a clear day in winter, a steep south slope may receive considerably more solar radiation than a horizontal surface, but on a clear day in summer, it may receive less. A steep north slope on a clear day in winter may never receive direct beam solar radiation, but only a small amount of scattered radiation from the sky or reflected from surrounding surfaces. Yet, it may receive almost as much solar radiation as a horizontal surface in summer.

On the other hand, under completely overcast skies, there may be very little difference in the amount of solar radiation received by different slopes, regardless of season. These constantly changing relationships make extrapolation of the data in these maps to slopes very dangerous. The computer model upon which these maps are based takes these constantly changing relationships into account, but estimates must be determined directly for any given slope, not extrapolated from estimates of insolation on a horizontal surface.

For most purposes, total solar radiation, including both direct beam and diffuse components, is the characteristic of interest. However, many solar energy technologies require a concentrated energy flux (for example, certain high temperature heating applications and solar electrical generation processes). Direct beam is the most highly concentrated form of solar radiation received at the earth's surface and its concentration can be enhanced by reflection and refraction techniques. These maps are not directly applicable for determining direct beam solar radiation, but they are suitable for identifying locations likely to be most favorable for technologies requiring a concentrated energy flux. The model upon which these maps are based can be easily modified to provide estimates of direct beam solar radiation received on any surface.

Within the limitations described, these maps should prove useful for many purposes. We hope that they help to meet the needs of a wide audience, from agronomists and architects to watershed and wildlife managers, and all others having an interest in the solar radiation environment of the Pacific Northwest.

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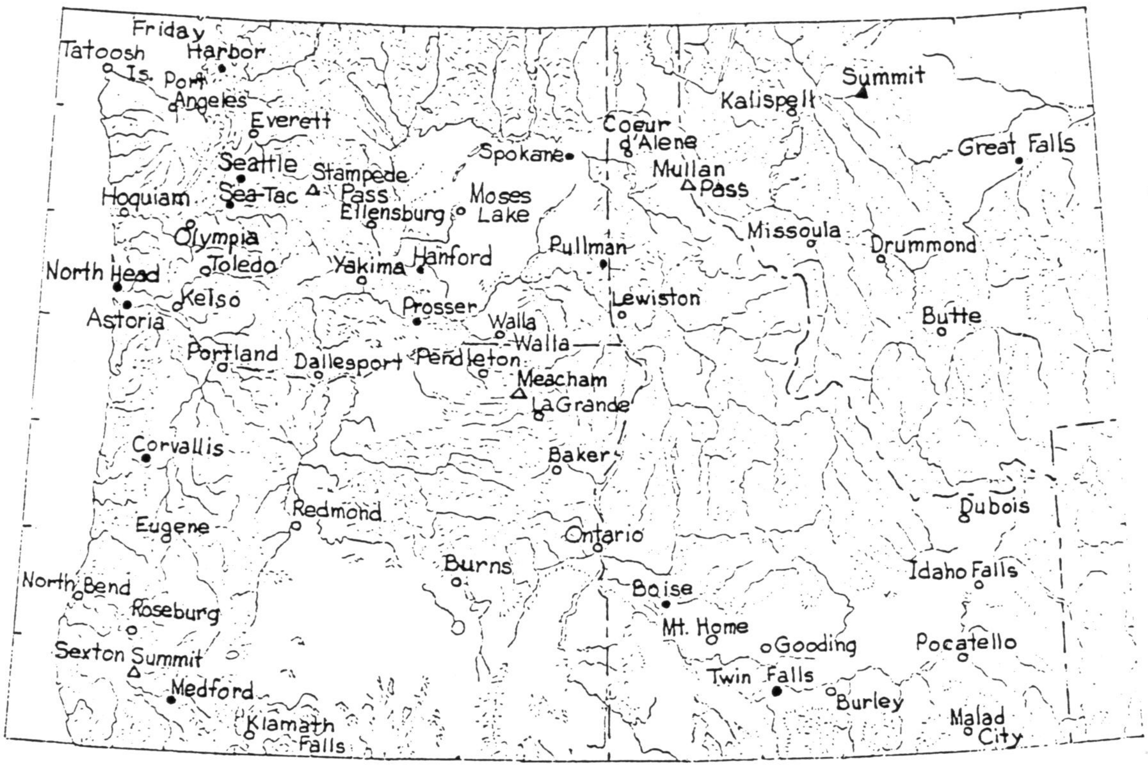
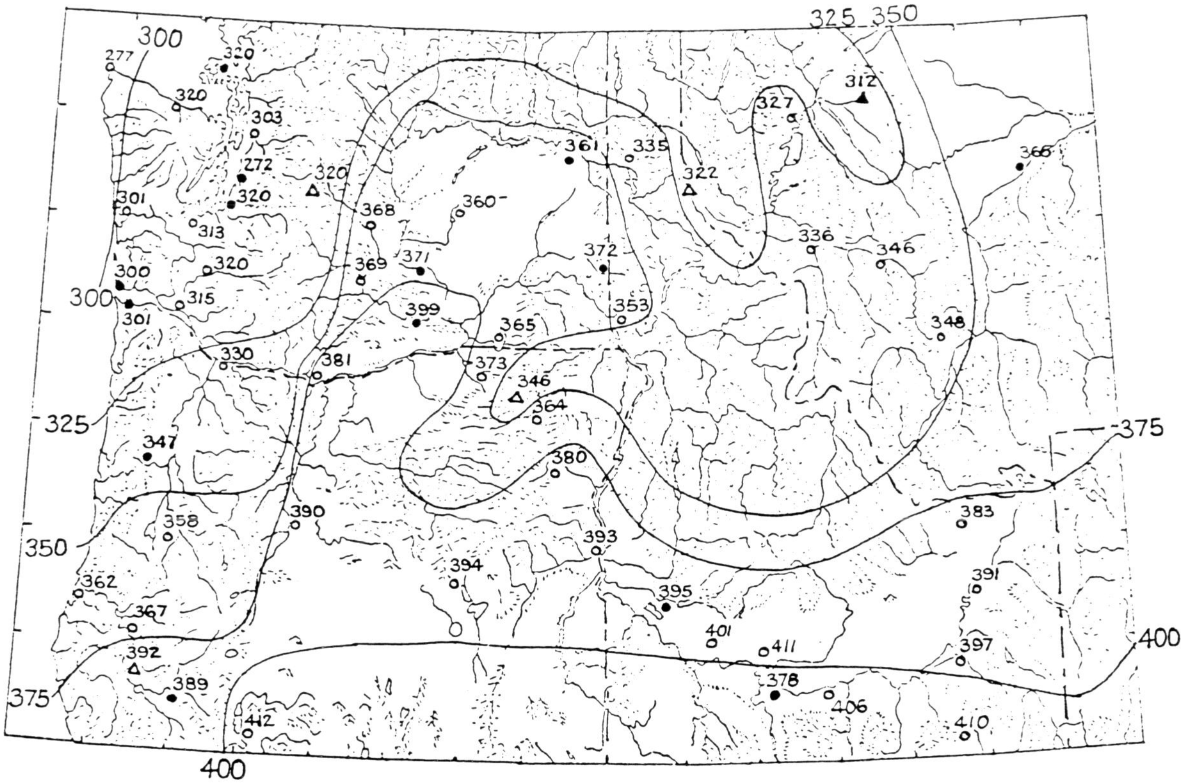
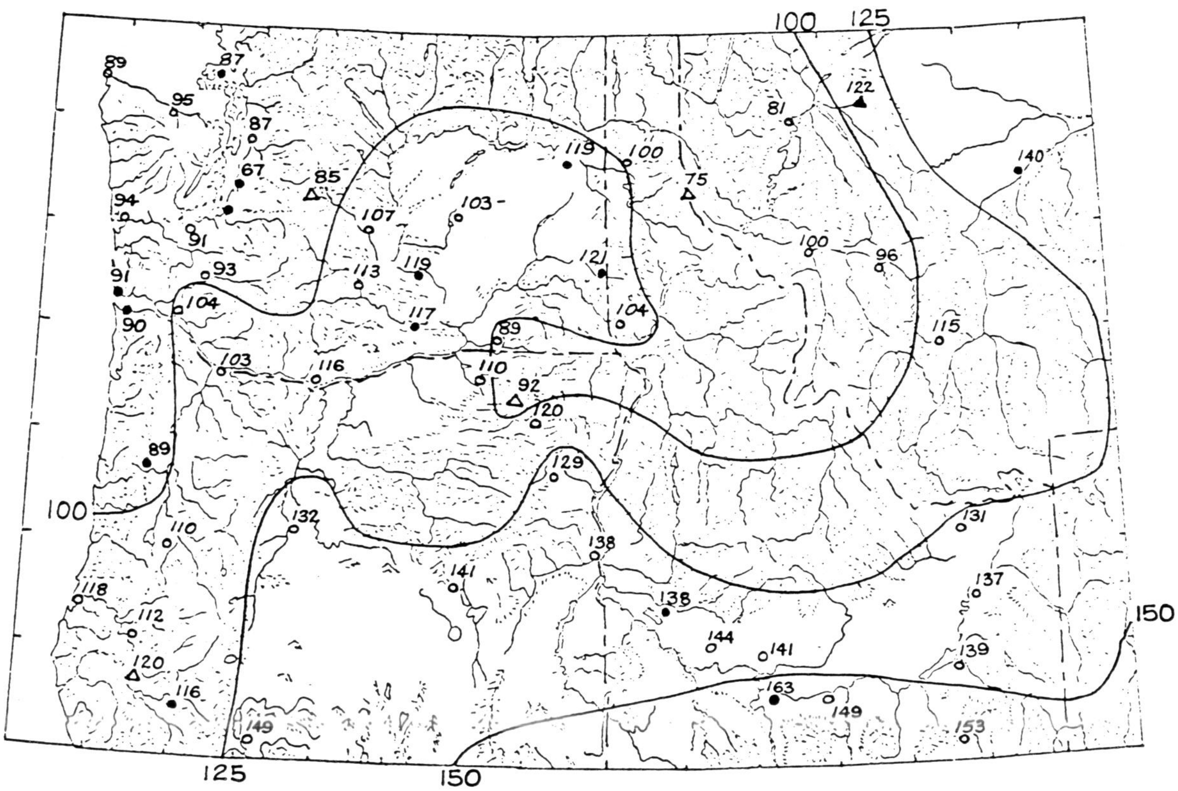


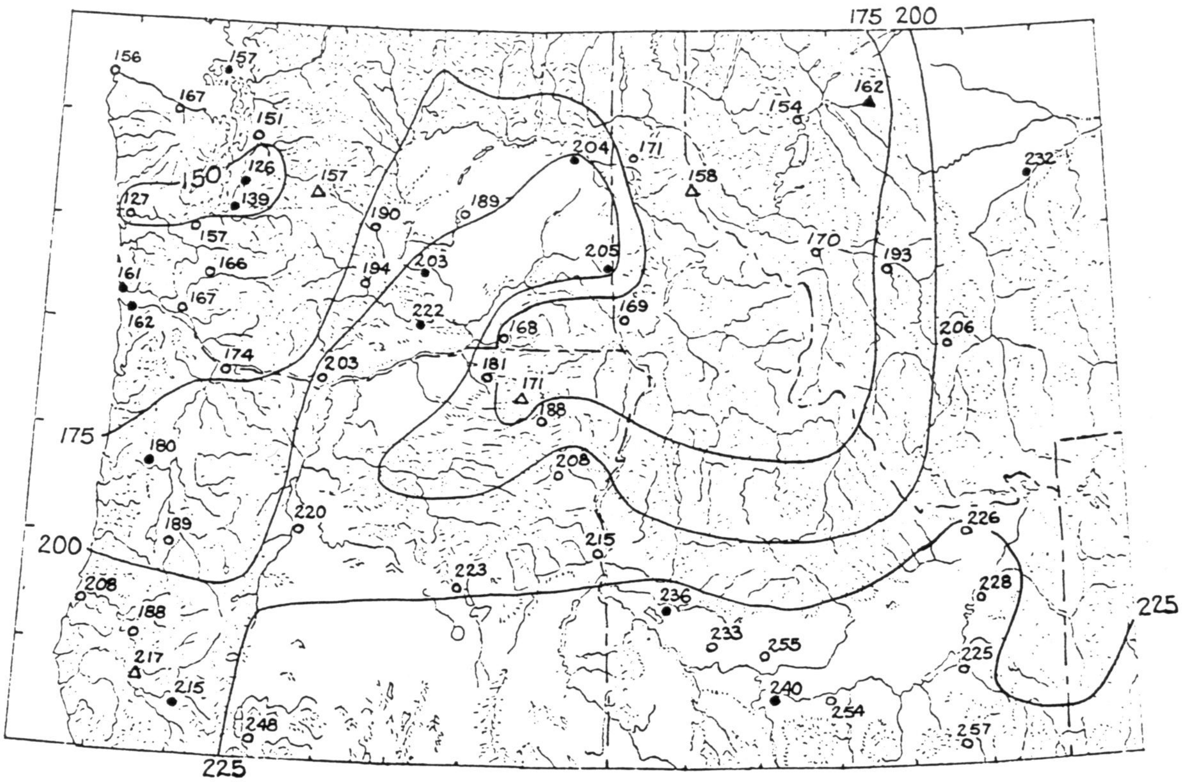
1. Station locations. On this and all other maps, solid symbols represent mean daily solar radiation for all or most months. Open symbols are estimates based on observations of sky cover. The triangles are data from mountain passes and the circles represent data from airports and other relatively low-elevation stations.



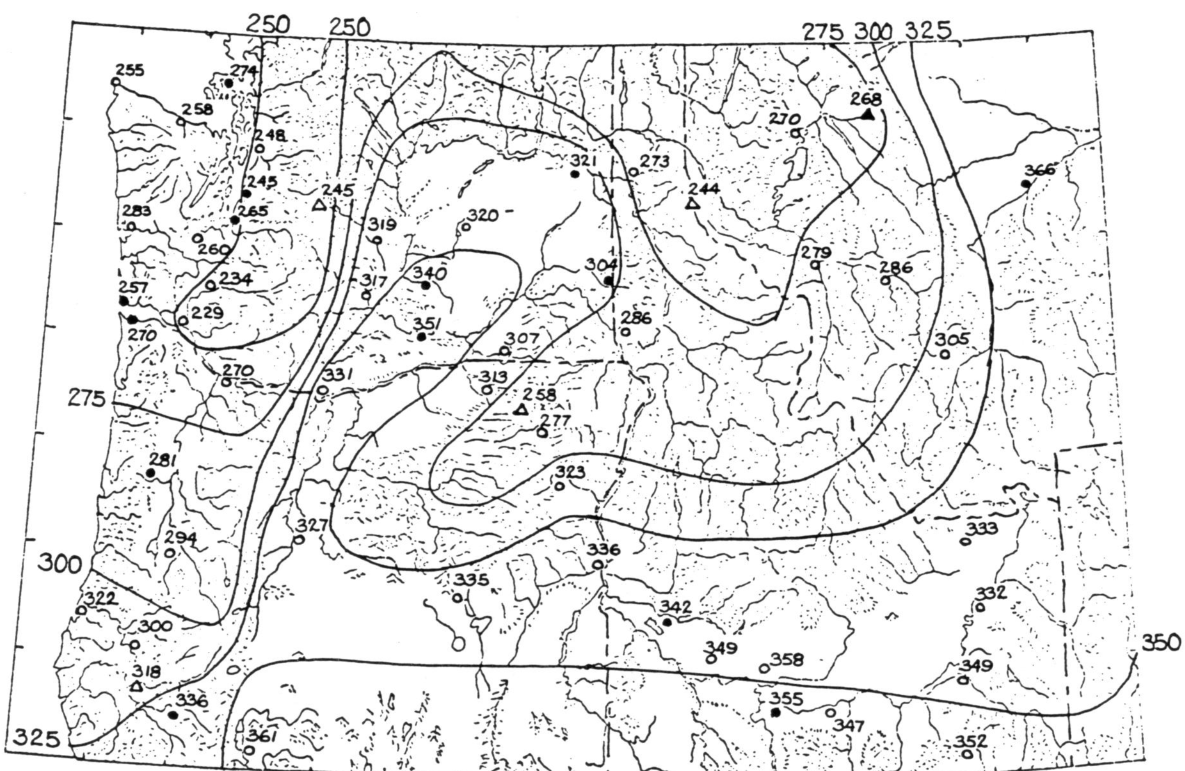
2. Mean daily solar radiation, direct and diffuse, in langleys: annual.



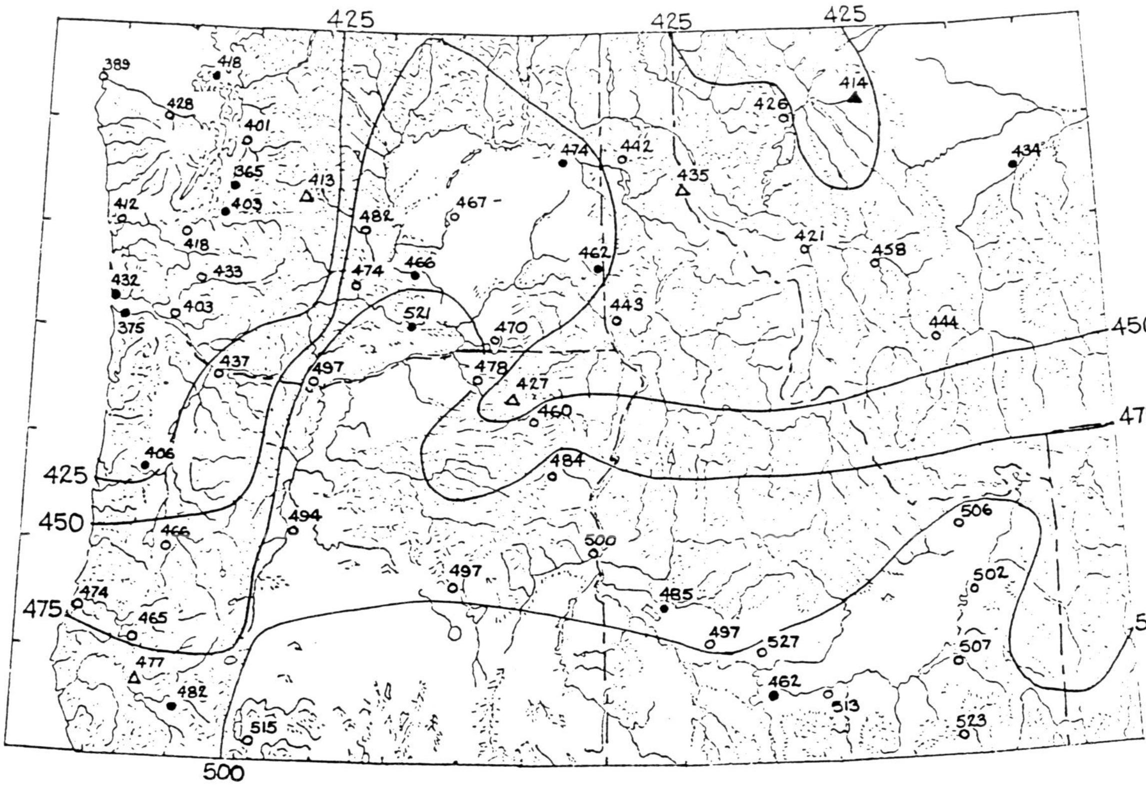
3. Mean daily solar radiation, direct and diffuse, in langleys, January.



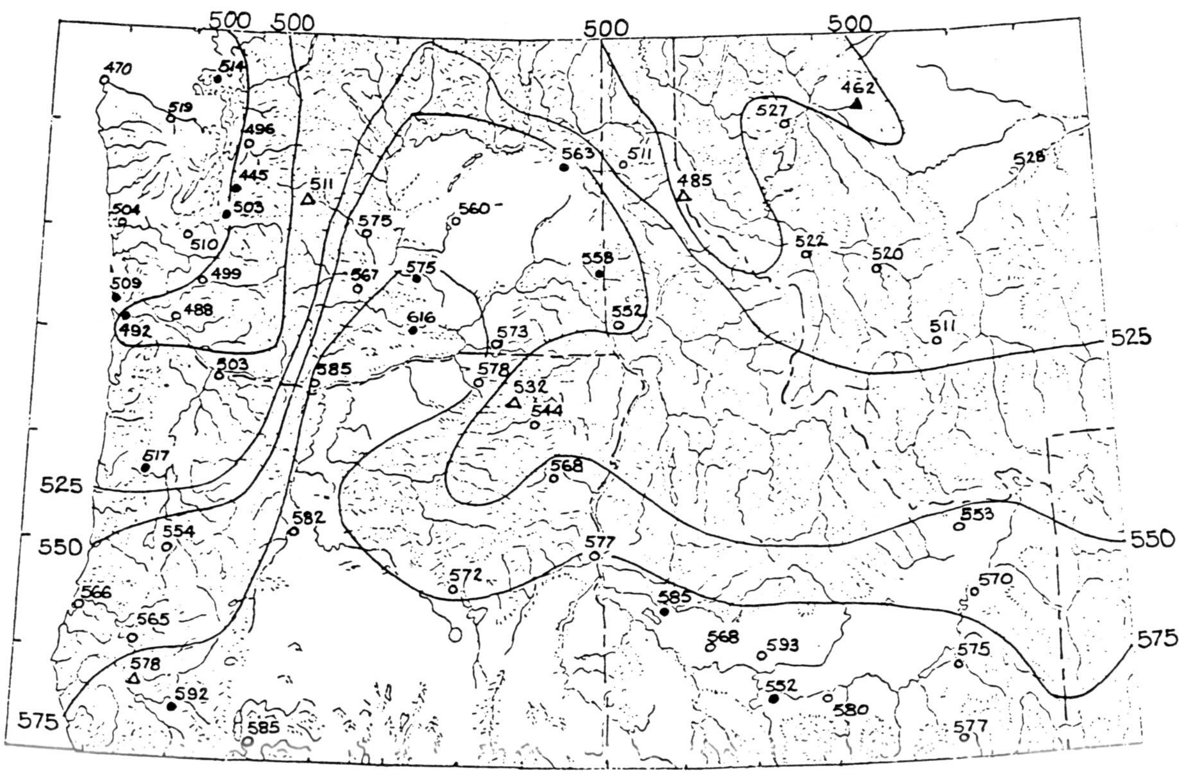
4. Mean daily solar radiation, direct and diffuse, in langleys, February.



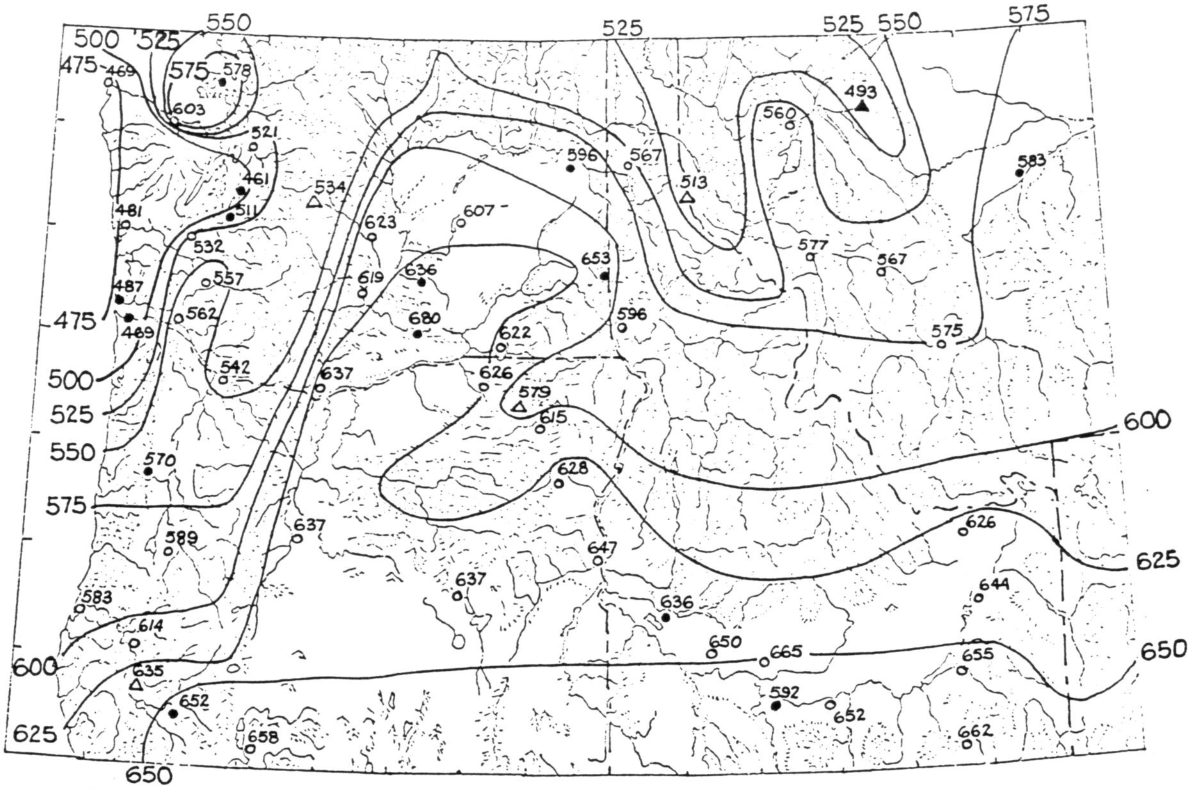
5. Mean daily solar radiation, direct and diffuse, in langleys, March.



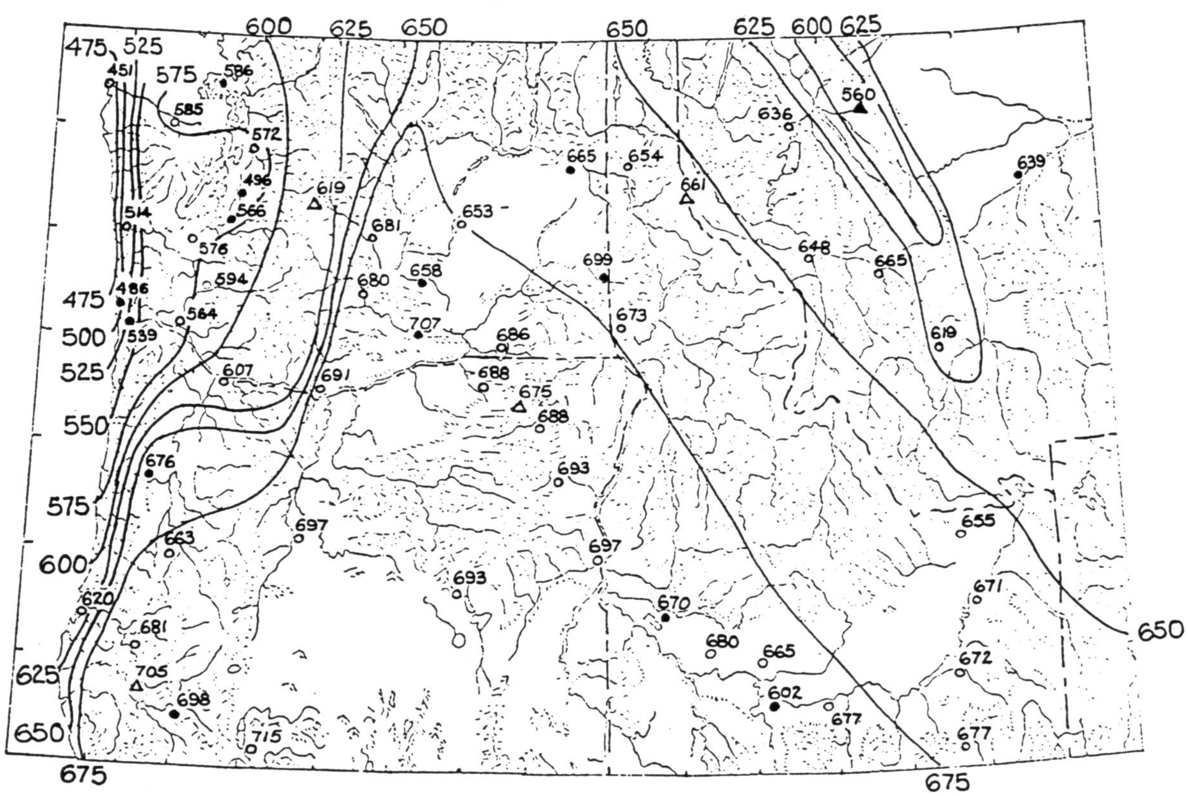
6. Mean daily solar radiation, direct and diffuse, in langleys, April.



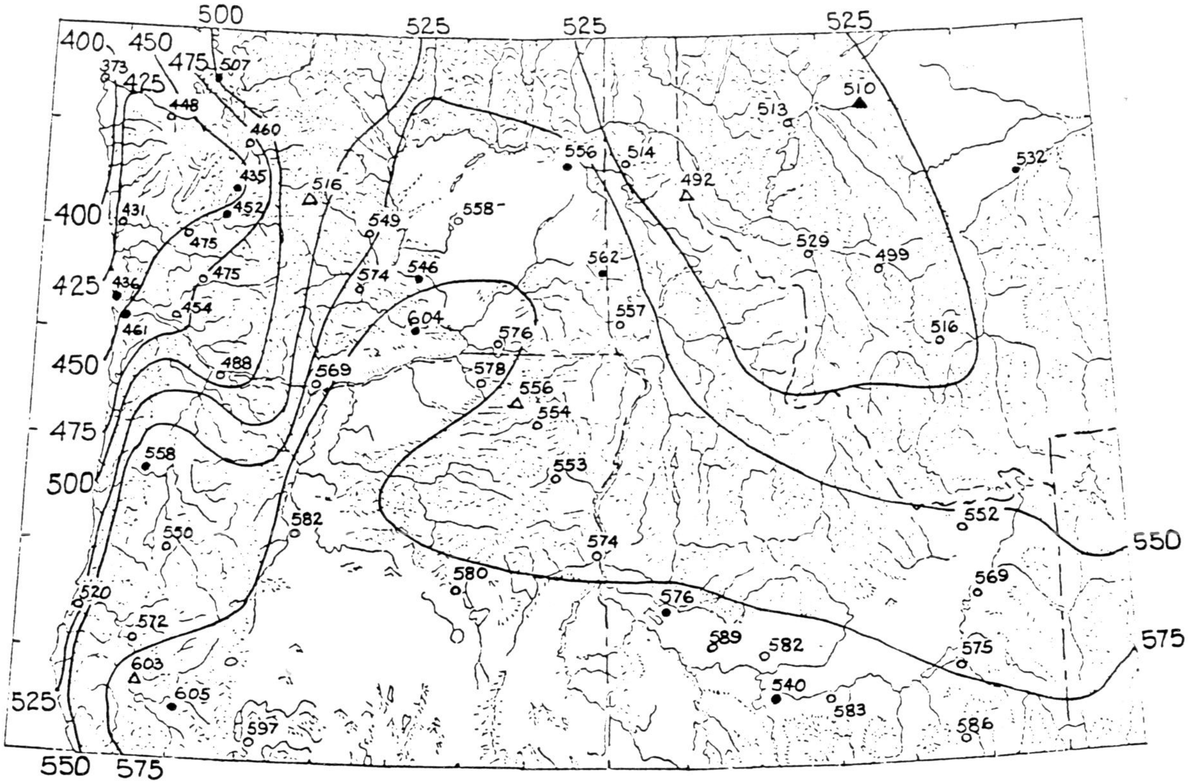
7. Mean daily solar radiation, direct and diffuse, in langleys, May.



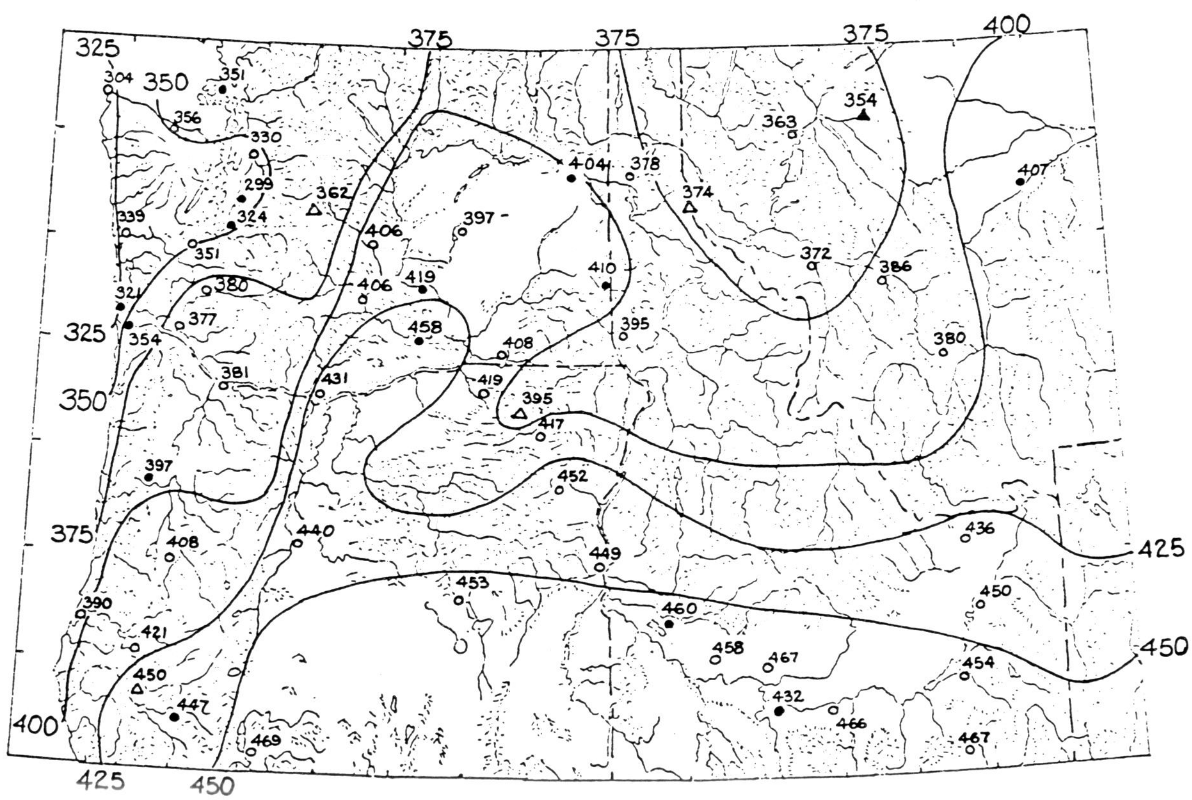
8. **Mean daily solar radiation, direct and diffuse, in langleys, June.**



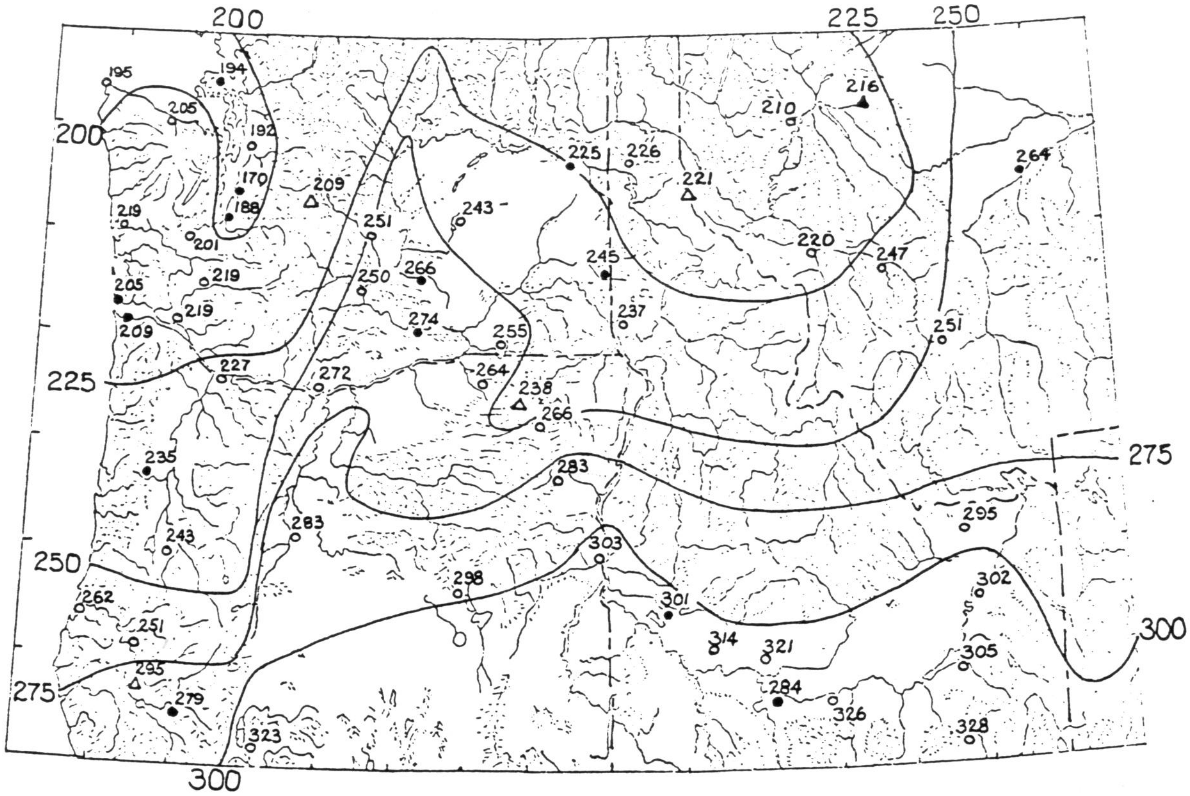
9. **Mean daily solar radiation, direct and diffuse, in langleys, July.**



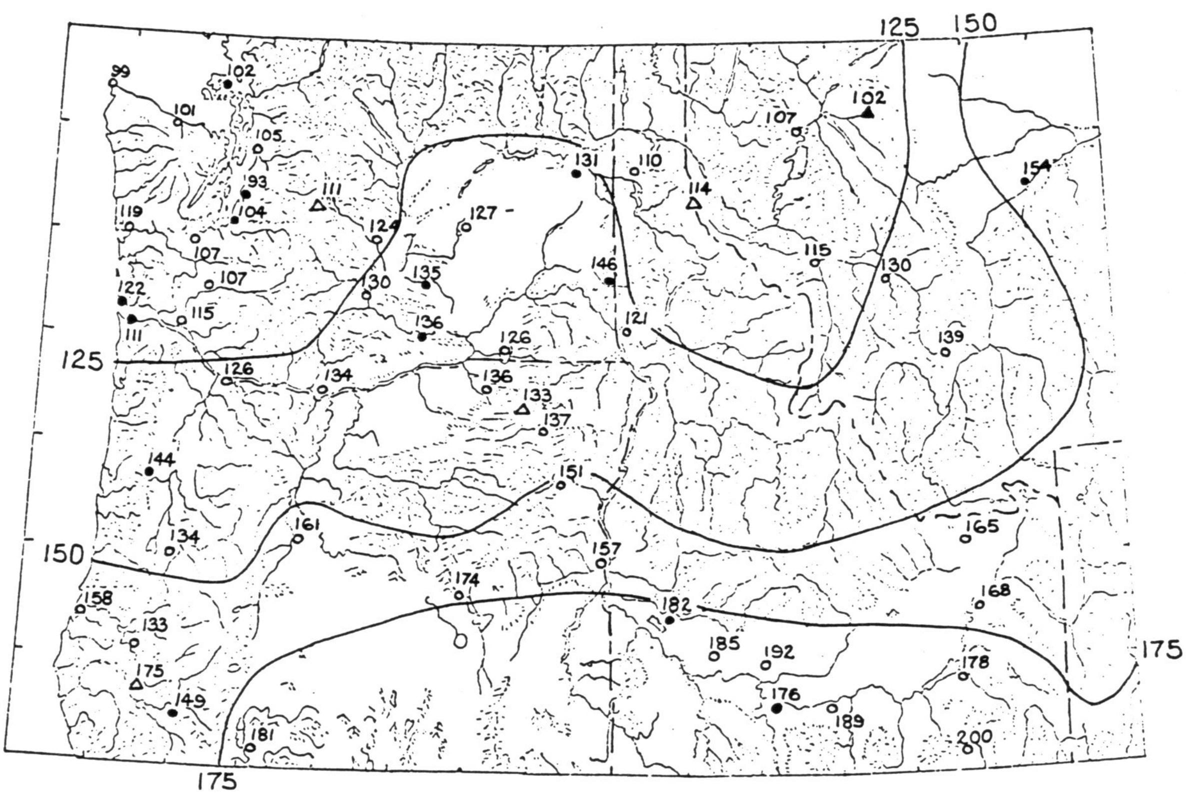
10. Mean daily solar radiation, direct and diffuse, in langleys, August.



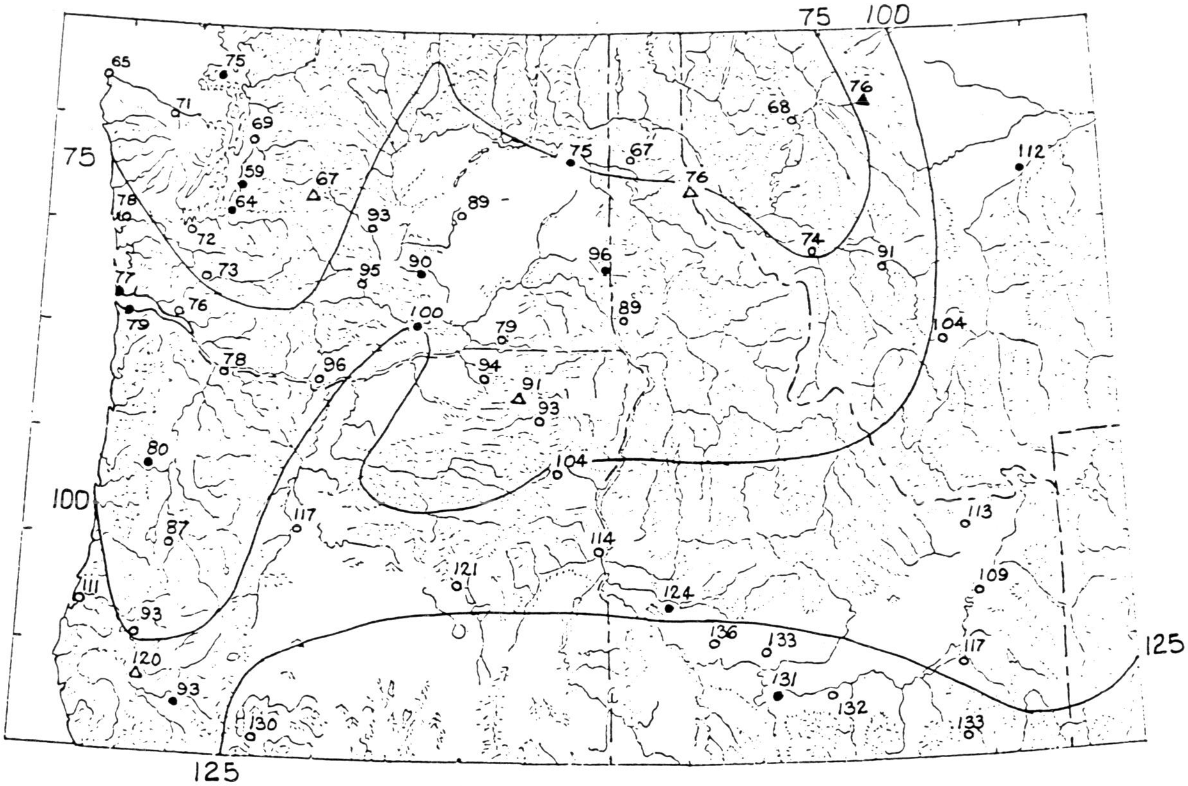
11. Mean daily solar radiation, direct and diffuse, in langleys, September.



12. Mean daily solar radiation, direct and diffuse, in langleys, October.



13. Mean daily solar radiation, direct and diffuse, in langleys, November.



14. Mean daily solar radiation, direct and diffuse, in langleys, December.