U. S. DEPARTMENT OF COMMERCE
CHARLES SAWYER, *Secretary*

WEATHER BUREAU
F. W. REICHELDERFER, *Chief*

TECHNICAL PAPER No. 11

Weekly Mean Values of Daily Total Solar and Sky Radiation

Prepared by

I. F. HAND

WASHINGTON
1949

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Weekly Mean Values of Daily Total Solar and Sky Radiation

Introduction

This paper presents in graphical form weekly mean values of daily total solar and sky radiation received on a horizontal surface at Weather Bureau and cooperating stations during the last 35 years. It also gives explanation of the departures from normal.

Description of stations which have been maintained less than one year together with the data from them is given in the MONTHLY WEATHER REVIEW: January 1931, p. 41; January 1940, p. 17; September 1941, p. 287; and January 1945, p. 190. As the data from some stations are for 1 year only while other stations are represented by 30 or more years of data, the results are not exactly comparable. Nevertheless, for the purpose of completeness, all data of 1 year or more are included even though some of the values are identical with those appearing in the MONTHLY WEATHER REVIEW for December 1937.

Instrumental Equipment

For the most part, Eppley pyrheliometers [1–2] served as receivers with Leeds and Northrup [3] micromax potentiometers predominating as recorders. In a few instances, Engelhard recording microammeters [2–4] were used as recorders, while the Weather Bureau at Blue Hill recently started using the Brown Electronik potentiometer [5]. Moll pyrheliometers [6], manufactured by Kipp and Zonen, Delft, Holland, were tried out at Fresno, and Miami. British-made Callendar equipment [7] was used by Dr. O. J. Seiplein at Belle Isle, Fla.

Nearly all the pyrheliometers used in determining these data were compared with Weather Bureau secondary standard pyrheliometers [8] at Blue Hill Observatory, Milton, Mass. The Bureau secondary standard silver-disk was compared frequently with Smithsonian standards at the Astrophysical Observatory of the Smithsonian Institution in Washington, D. C.

Charts

Figures 1–11 give the weekly means of daily totals of solar and sky radiation on a horizontal surface, gram-calories per square centimeter (langleys [9]). Engineers who prefer British thermal units may convert values in langleys to B. t. u. per square foot by multiplying them by the factor 3.69. The number of years of observation for each station is listed with the name of the station. Curves have been drawn through the plotted data to permit instant visualization of the annual march of radiation.

In figure 1, the curves for Honolulu and Pearl Harbor, T. H. [10] were smoothed considerably because of lack of sufficient data to determine trends. The marked dip in the trace for Miami, Fla., [11] beginning with mid-June is occasioned by greatly decreased percentage of sunshine as indicated by the data in the annual meteorological summaries for that station. The Gainesville, Fla., [12] trace is very smooth for the first 5 months, but wavers considerably during the remainder of the year. Paucity of data is a contributing cause of the irregularities.

In figure 2, the curve for New Orleans, La.,* [13] shows a curious tendency, that is, a maximum in mid-June followed immediately in July by leveling off caused by increased cloudiness associated with thunderstorm activity. Riverside, Calif., [14] has a maximum early in July with a secondary minimum in late June. As no other meteorological data are available from this station, we cannot explain the exact cause. The curve for La Jolla, Calif.,* [15] shows quite a few fluctuations in view of the large volume of data. The smaller amount of radiation at the time of the spring equinox as compared with the time of the autumn

*There is some question as to the reliability of weekly mean values for New Orleans and La Jolla. Therefore, monthly mean values were used instead. These values agree with values obtained at other stations when evaluated as a function of percent of sunshine as shown by Sigmund Fritz and T. H. MacDonald of the U. S. Weather Bureau, in a paper titled "Average Solar Radiation in the United States", published in *Heating and Ventilating*, Vol. 46, no. 7, July 1949, pp. 61–64.

equinox is due chiefly to the larger number of fogs in spring.

Based on a large mass of data, the curve for Fresno, Calif., [16] in figure 3 is the smoothest and highest trace of the group. The trace for Nashville, Tenn., [17], with far fewer data, is comparatively smooth considering the use of bituminous coal in the vicinity. The values of Albuquerque, N. Mex., [18] show extreme irregularities, due chiefly to paucity of data, but also to fluctuations in cloudiness and dust storms. The plotted points were followed closely in this particular curve to illustrate these effects.

The trace for Davis, Calif., [19] in figure 4 is irregular, owing to the small number of observations, but on the whole indicates that a vast amount of solar energy is received throughout the year. The trace for the first 7 months for Columbia, Mo., [20] is smooth, but a secondary maximum appears in early September. The Washington, D. C. [21] trace was drawn close to the actual plotted points with less smoothing than with most other traces. Nevertheless, the curve is very uniform with the single exception of 2 or 3 weeks each side of the time of the summer solstice.

Industrial smoke and short record account for most of the irregularity of the curve for Pittsburgh, Pa. [22] in figure 5. The long period of observations at New York, N. Y. [23] has smoothed out the irregularities to some extent, although the curve is not nearly as smooth as those for cities where there are sufficient data and only slight atmospheric contamination. The irregularities for Salt Lake City, Utah [24] are owing chiefly to the brief period of observation, but also to stagnation of smoke from metropolitan industrial plants and nearby copper smelters. Most of the city proper lies in flat terrain hemmed in on the east by the Wasatch Mountains and on the west and south by the Stansbury, Oquirrh, and Onaqui ranges. As a result, smoke accumulation over the city greatly depletes solar radiation at times [25].

In figure 6, the trace for State College, Pa., [26] is surprisingly smooth and uniform. The curve for Lincoln, Nebr., [27] also is smooth with a distinct bump in late June and early July, at which time the percentage of sunshine is at a maximum. Boulder, Colo., [28] is situated at a high elevation, but portions of the Rockies create a high horizon in certain directions. With a longer series of observations, we normally would expect that this trace would smooth out.

Newport, R. I. [29], and East Wareham, Mass. [30], are only 36 miles apart; however, Newport is directly on the Atlantic Ocean while East Wareham is a few miles inland. Their traces in figure 7 almost parallel each other and both are quite smooth and uniform. The curve for Put-in-Bay, Ohio [31], is fairly smooth and also shows the effect of greater percentage of sunshine in midsummer. Considering that there is considerable atmospheric pollution over Chicago, Ill. [32], that trace is fairly smooth, having been evened out by a large mass of data. The atmospheric contamination is the chief contributing cause of the smaller amount of radiation in that metropolitan city as compared with the three other stations which are close to the same latitude.

In figure 8, Blue Hill [33], Boston [34], and Cambridge, Mass. [35], with a maximum difference in latitude of only 8 minutes, have irregular traces. Boston and Cambridge irregularities are caused chiefly by smoke and other industrial atmospheric pollution, and the small number of observations. The atmosphere over Blue Hill ordinarily is comparatively free of smoke and dust, but occasionally with a wind having a northerly component, smoke blows over the observatory from the metropolitan area 11 miles distant. This and more frequent fogs than cover Boston and Cambridge, accounts for the irregular trace.

Twin Falls, Idaho [36] and Ithaca, N. Y. [37] are on the same degree of latitude; East Lansing, Mich. [38] is only one-quarter of a degree north of these two stations. Therefore, the trace for Twin Falls in figure 9 clearly shows the difference in elevation and cloudiness between the east and the west. This western station receives on the average 36 percent more radiation than East Lansing and 29 percent more than Ithaca. However, some of the loss in radiation at the two eastern stations is caused by cloudiness induced by the Great Lakes, while the higher values at Twin Falls are partially owing to nearly mile-high elevation above sealevel and less cloudiness.

Anyone familiar with Mount Washington, N. H. [39] weather will not be surprised at the irregularity of the trace for that station in figure 10, particularly as there are scarcely 11 months of data. The trace for Madison, Wis. [40] is extremely smooth, but that station has been in operation for 35 years, resulting in smoothing out the effects of local cloudiness and fogs caused by the adjoining lakes, amid which the city is situated. Toronto, Ont. [41] is a comparatively new station and hence, the irregularities should lessen with an increasing number of data.

Figure 11 clearly indicates the effect of latitude. The maximum radiation value for San Juan, P. R. [42] is only 1.7 times the minimum, while at Fairbanks, Alaska [43] the value of the maximum is 135 times the value of the minimum. Also, the maximum for San Juan, which is south of the Tropic of Cancer, occurs in late spring, with a secondary maximum in July. Secondary minima occur in late May and late June with another distinct falling off in August. Although Friday Harbor, Wash. [44] is the most northerly station of the group in continental United States, the comparatively low values in winter are due in large part to cloudiness and winter fogs.

Figure 12 is a composite of the following 30 stations:

Miami, Fla.
Gainesville, Fla.
New Orleans, La.
La Jolla, Calif.
Riverside, Calif.
Albuquerque, N. Mex.
Nashville, Tenn.
Fresno, Calif.
Davis, Calif.
Columbia, Mo.
Washington, D. C.
Boulder, Colo.
Pittsburgh, Pa.
Salt Lake City, Utah
New York, N. Y.
State College, Pa.
Lincoln, Nebr.
Newport, R. I.
Put-in-Bay, Ohio
East Wareham, Mass.
Chicago, Ill.
Blue Hill, Mass.
Boston, Mass.
Cambridge, Mass.
Ithaca, N. Y.
Twin Falls, Idaho
East Lansing, Mich.
Madison, Wis.
Toronto, Ont.
Friday Harbor, Wash.

While values for Toronto have been included, it is thought that data from this station are representative of conditions along the northern New York State border. The geographical mean of these 30 stations is at latitude 39°14′ N.; longitude 91°07′ W., or a point a few miles south of Bowling Green, Mo. The mean without Toronto is at Sunlight, Mo.

The curve is quite symmetrical, but does show slightly more radiation at the fall equinox than at the spring equinox. The maximum occurs about 2 weeks following the summer solstice, while the minimum also shows a slight lag.

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31. Solar Radiation and Sunspot Data, *Monthly Weather Review*, vol. 70, No. 5, May 1942, p. 113.
32. Solar Observations, *Monthly Weather Review*, vol. 51, No. 10, October 1923, p. 533.
33. Solar Observations, *Monthly Weather Review*, vol. 61, No. 9, September 1933, p. 277.
34. Solar Radiation and Sunspot Data, *Monthly Weather Review*, vol. 72, No. 1, January 1944, p. 43.
35. Solar Observations, *Monthly Weather Review*, vol. 68, No. 1, January 1940, p. 17.
36. Solar Observations, *Monthly Weather Review*, vol. 55, No. 1, January 1927, p. 29.
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42. Solar Observations, *Monthly Weather Review*, vol. 63, No. 5, May 1935, p. 164.
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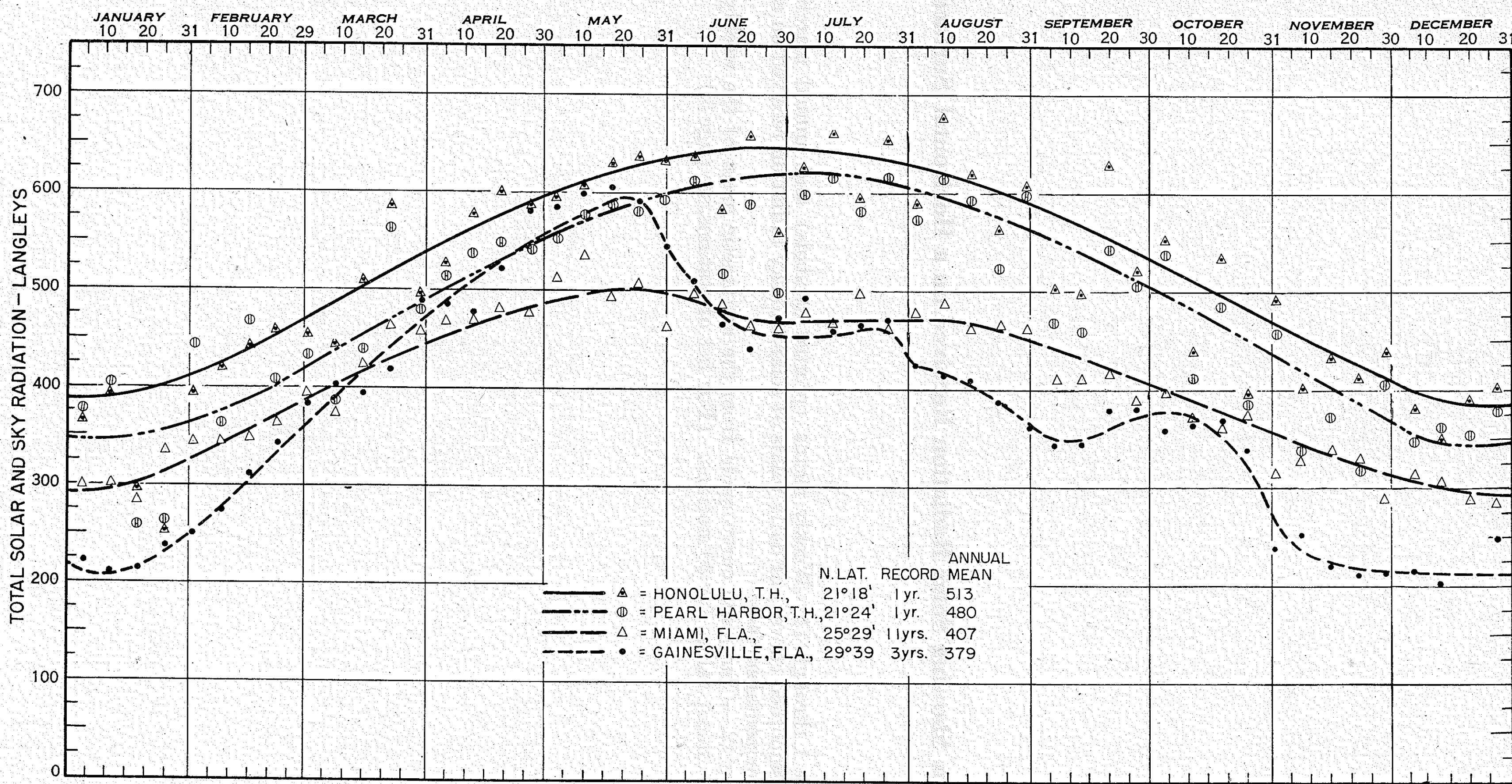
Graphs Showing Solar Radiation Received on a Horizontal Surface

Figure 1 through 11.—Weekly means (plotted symbols) and annual march (smoothed curves) of daily totals of solar and sky radiation received on a horizontal surface.

Figure 12.—Composite curve made from the arithmetic mean of the weekly mean values for 30 stations. (For list of stations, see page 3.)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TOTAL SOLAR AND SKY RADIATION—LANGLEYS
700
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N. LAT. RECORD ANNUAL MEAN
= HONOLULU, T. H., 21°18' 1 yr. 513
= PEARL HARBOR, T. H., 21°24' 1 yr. 480
= MIAMI, FLA., 25°29' 11 yrs. 407
= GAINESVILLE, FLA., 29°39 3 yrs. 379

FIGURE 1.

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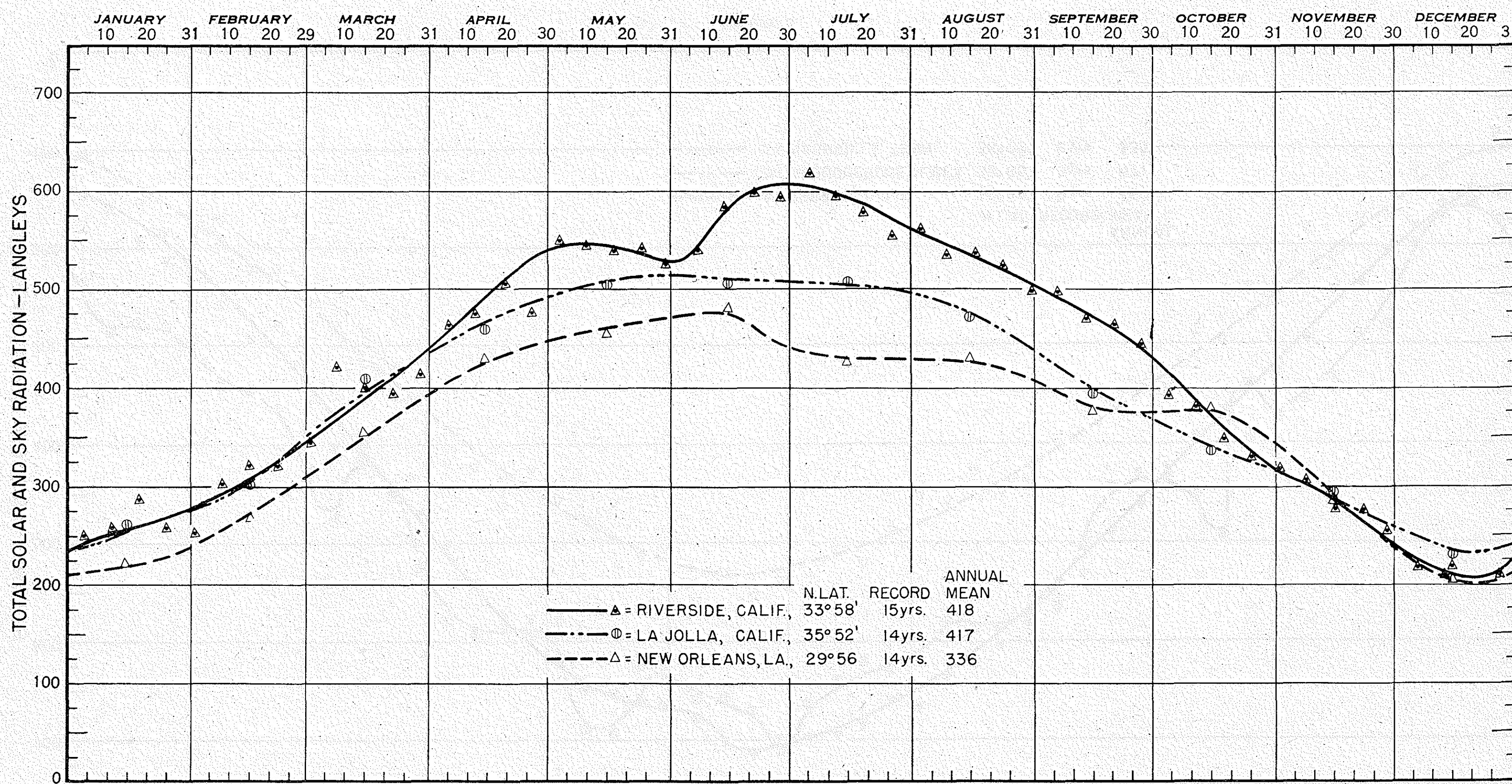
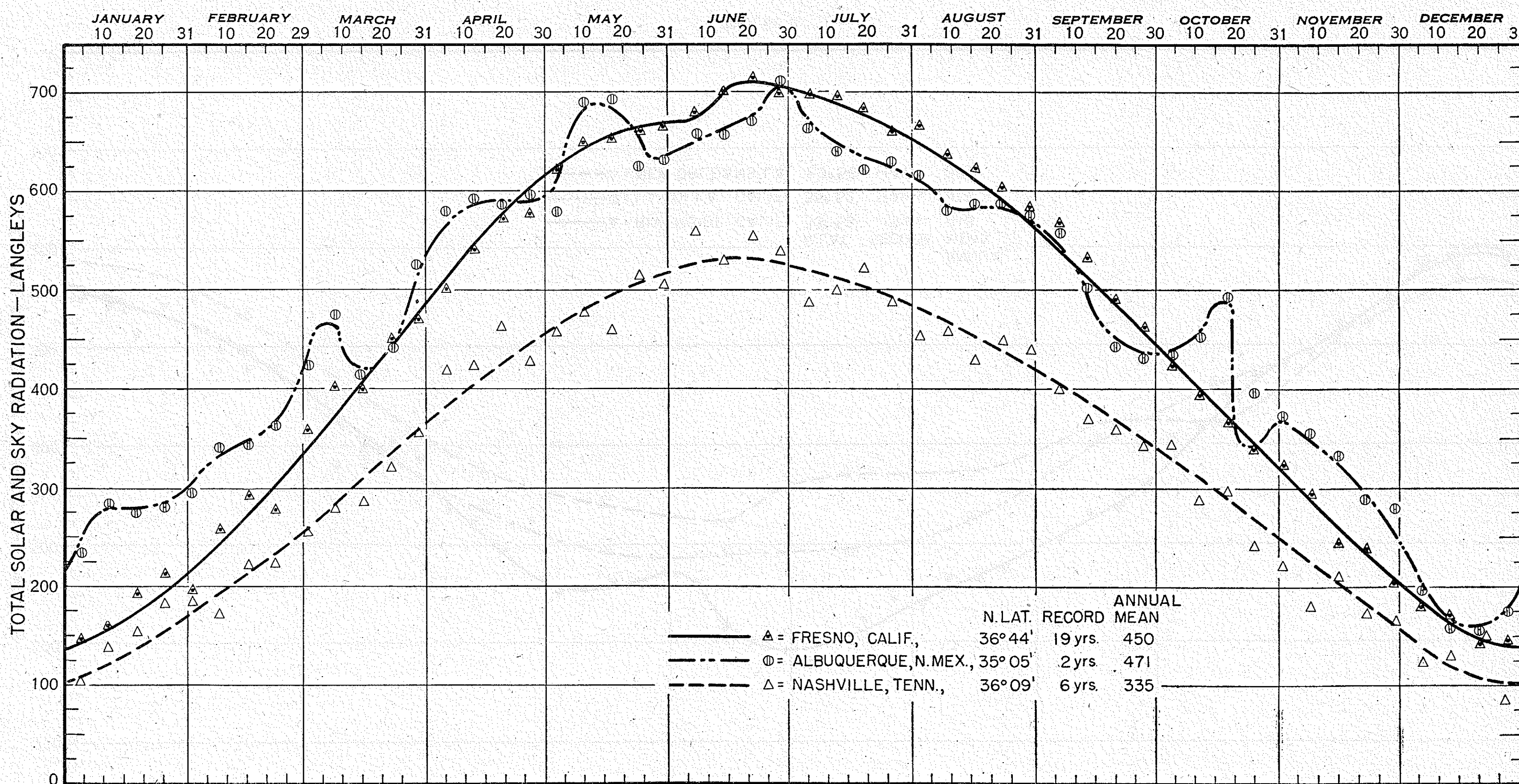


FIGURE 2.

NOTE: Plotted symbols for La Jolla, Calif., and New Orleans, La., show monthly mean values, see footnote page 1.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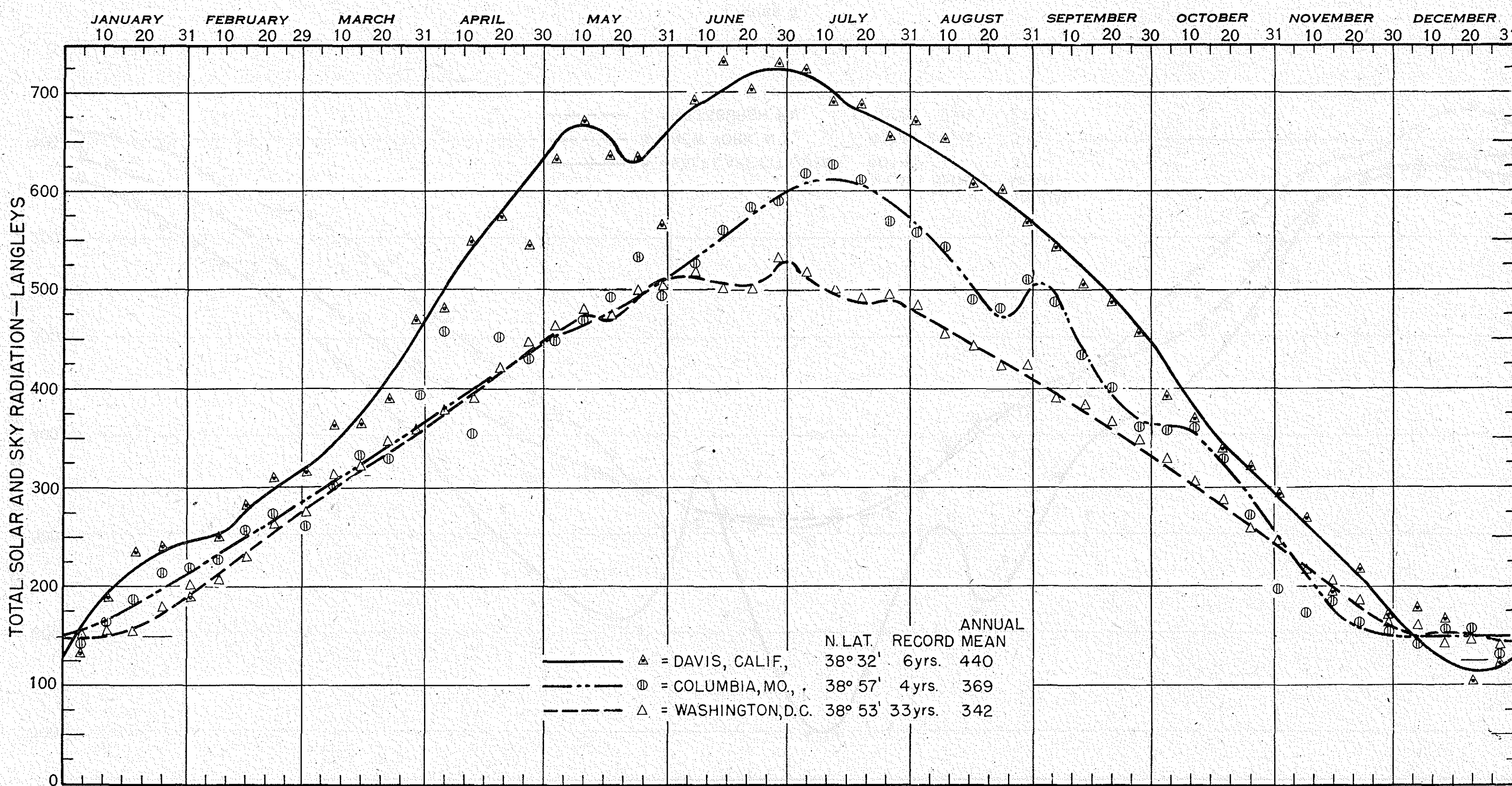
TOTAL SOLAR AND SKY RADIATION—LANGLEYS
N. LAT. RECORD ANNUAL MEAN
= FRESNO, CALIF., 36°44' 19 yrs. 450
= ALBUQUERQUE, N. MEX., 35°05' 2 yrs. 471
= NASHVILLE, TENN., 36°09' 6 yrs. 335

FIGURE 3.



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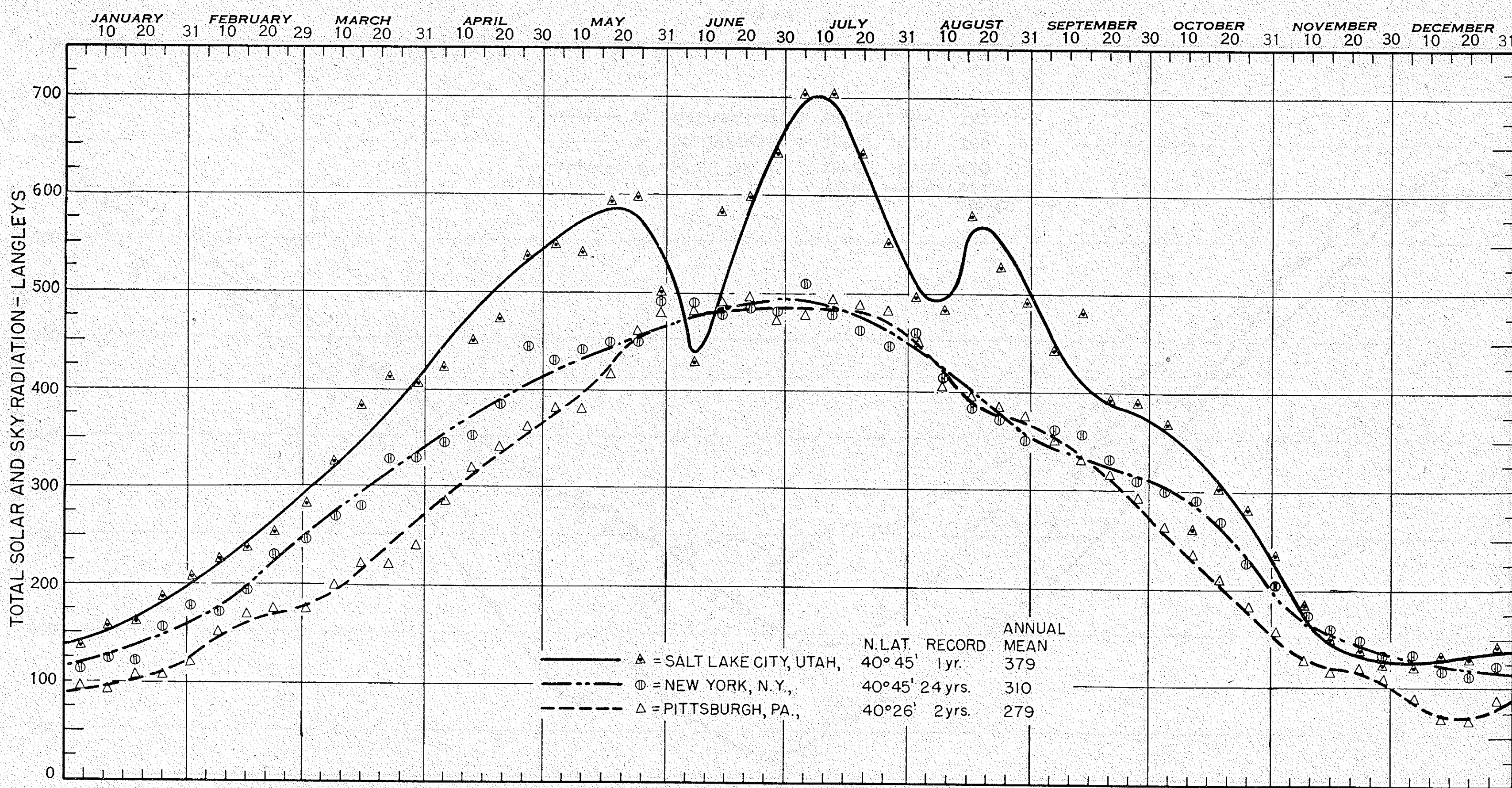
TOTAL SOLAR AND SKY RADIATION—LANGLEYS
N. LAT. RECORD ANNUAL MEAN
= DAVIS, CALIF., 38° 32' 6 yrs. 440
= COLUMBIA, MO., 38° 57' 4 yrs. 369
= WASHINGTON, D.C. 38° 53' 33 yrs. 342

FIGURE 4.



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TOTAL SOLAR AND SKY RADIATION - LANGLEYS
700
600
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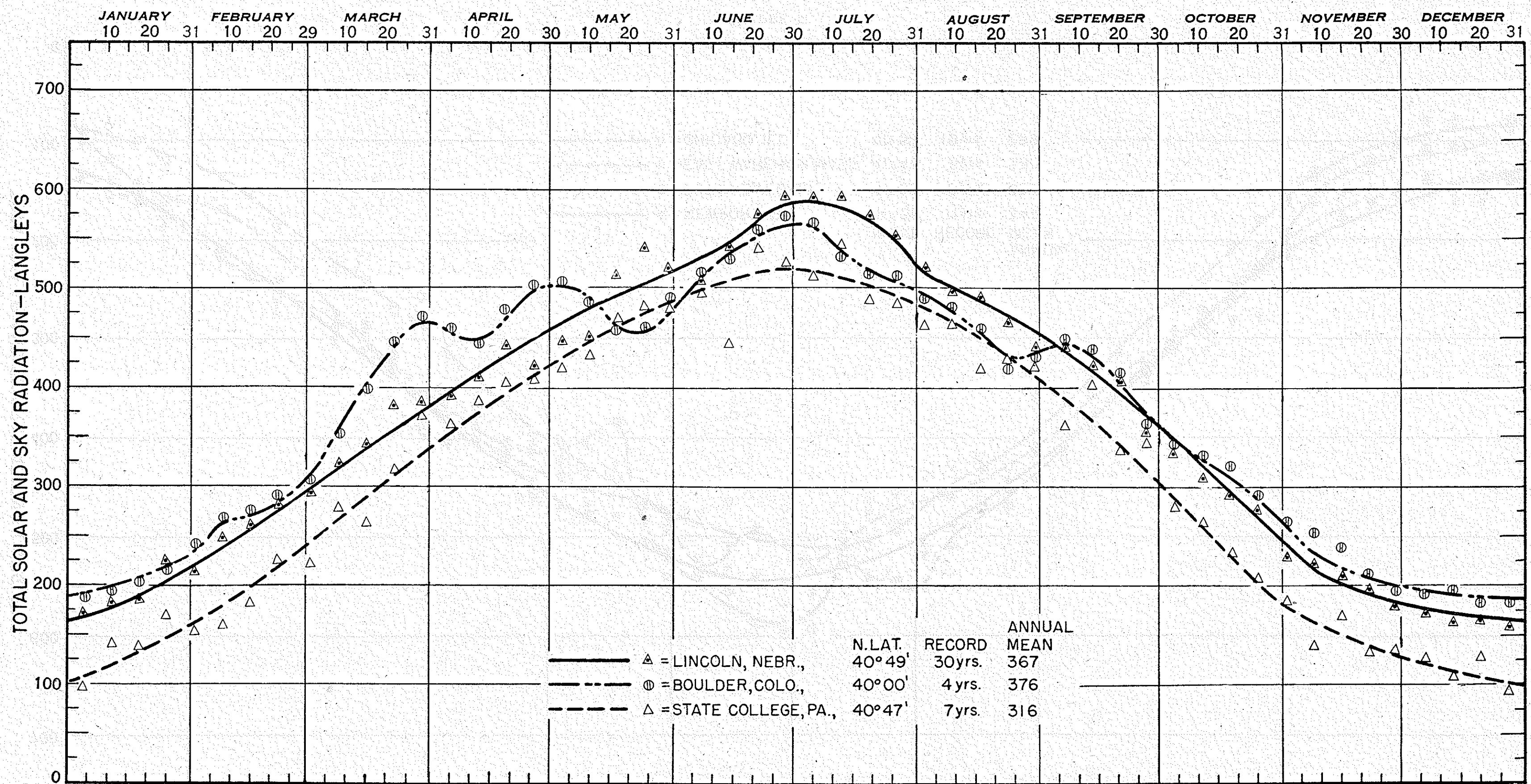
N. LAT.
RECORD
ANNUAL MEAN
= SALT LAKE CITY, UTAH, 40° 45' 1 yr. 379
= NEW YORK, N.Y., 40°45' 24 yrs. 310
= PITTSBURGH, PA., 40°26' 2 yrs. 279

FIGURE 5.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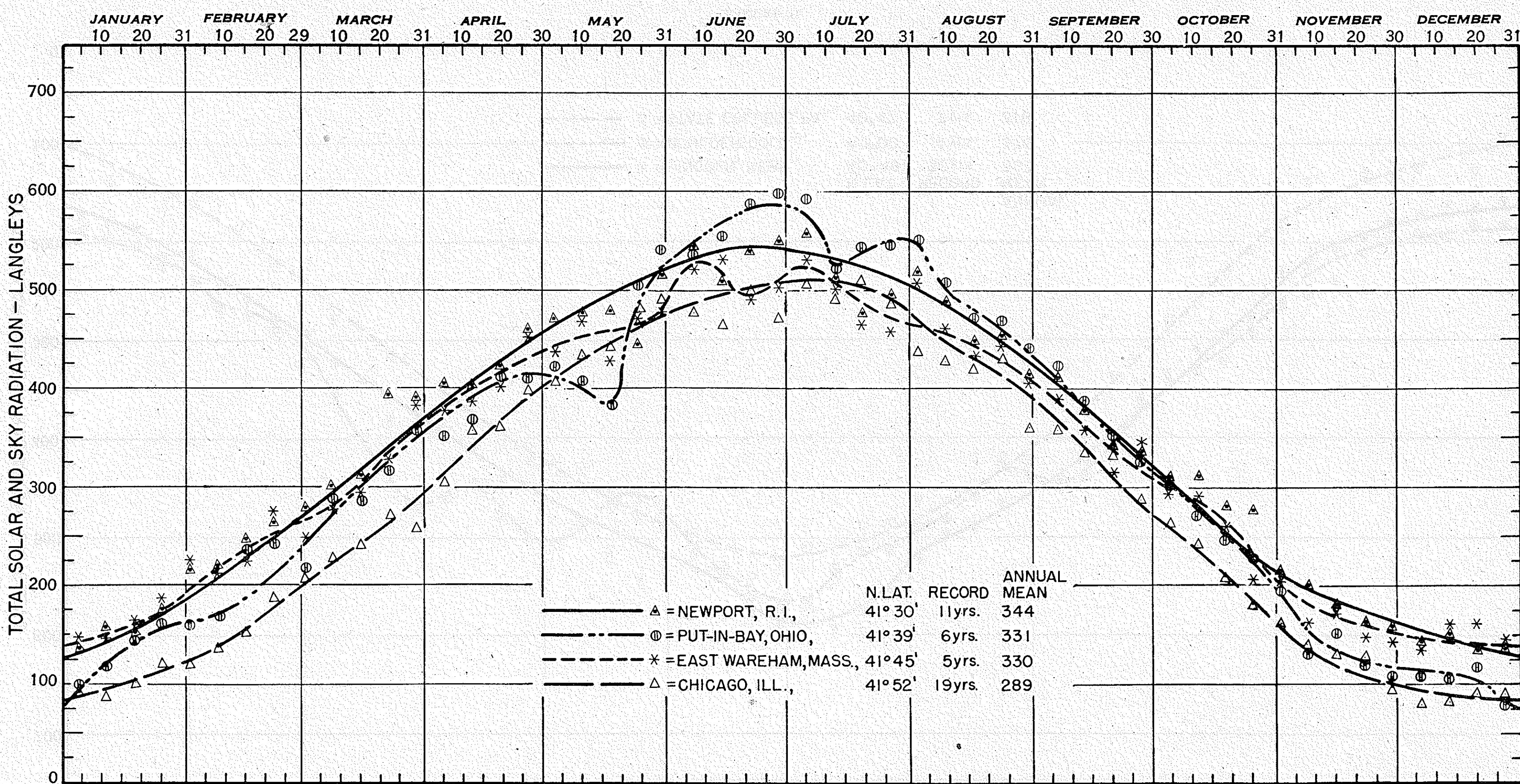
TOTAL SOLAR AND SKY RADIATION—LANGLEYS
N. LAT.
RECORD
ANNUAL MEAN
= LINCOLN, NEBR., 40° 49' 30 yrs. 367
= BOULDER, COLO., 40° 00' 4 yrs. 376
= STATE COLLEGE, PA., 40° 47' 7 yrs. 316

FIGURE 6.



JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER
TOTAL SOLAR AND SKY RADIATION – LANGLEYS
N.LAT. RECORD ANNUAL MEAN
▲ = NEWPORT, R.I., 41° 30' 11yrs. 344
⊕ = PUT-IN-BAY, OHIO, 41° 39' 6yrs. 331
✳ = EAST WAREHAM, MASS., 41° 45' 5yrs. 330
△ = CHICAGO, ILL., 41° 52' 19yrs. 289

FIGURE 7.

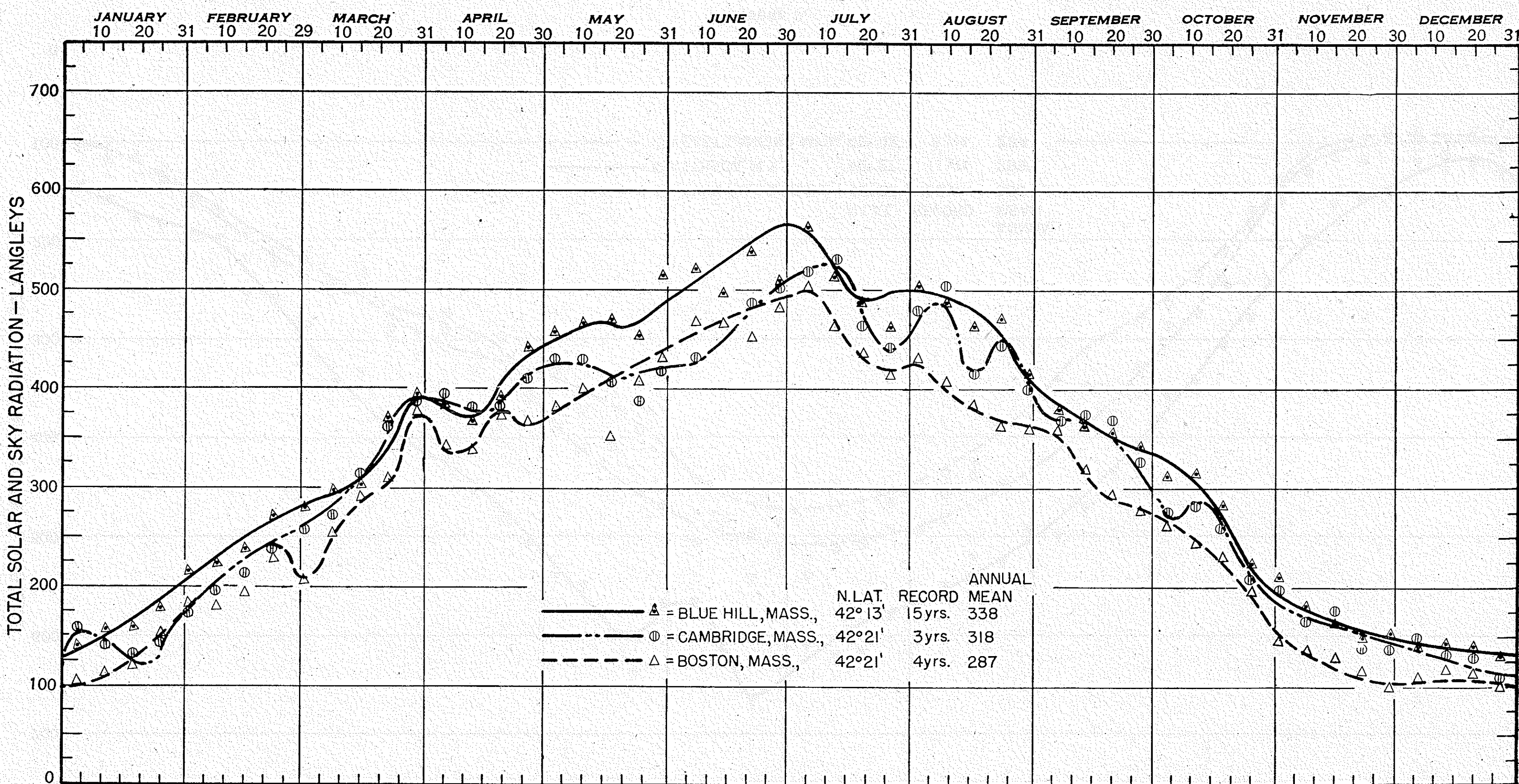
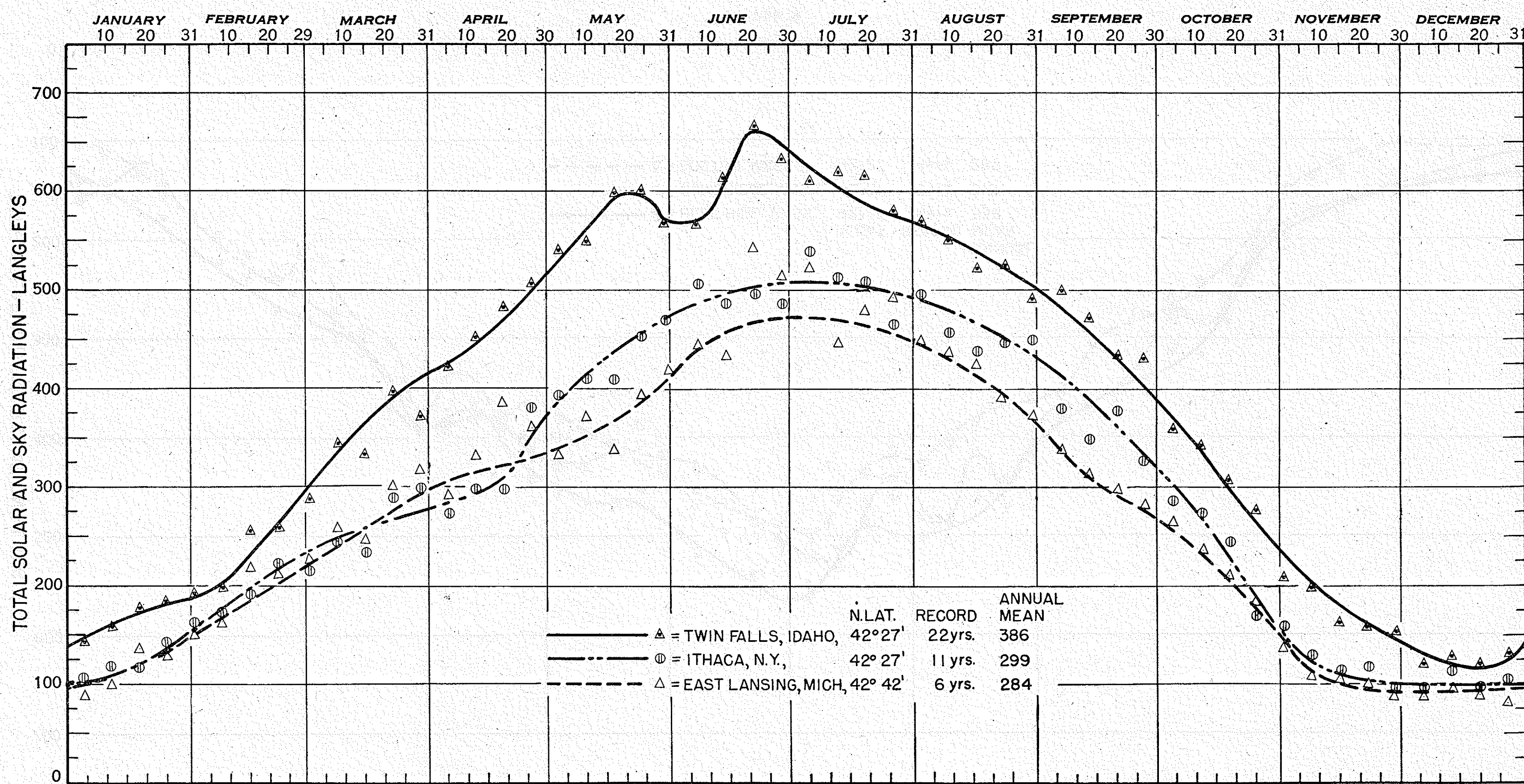

JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER
10 20 31 10 20 29 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31
0 100 200 300 400 500 600 700
TOTAL SOLAR AND SKY RADIATION — LANGLEYS
N.LAT. RECORD ANNUAL MEAN
= BLUE HILL, MASS., 42° 13' 15 yrs. 338
= CAMBRIDGE, MASS., 42°21' 3 yrs. 318
= BOSTON, MASS., 42°21' 4 yrs. 287

FIGURE 8.



JANUARY
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MARCH
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JULY
AUGUST
SEPTEMBER
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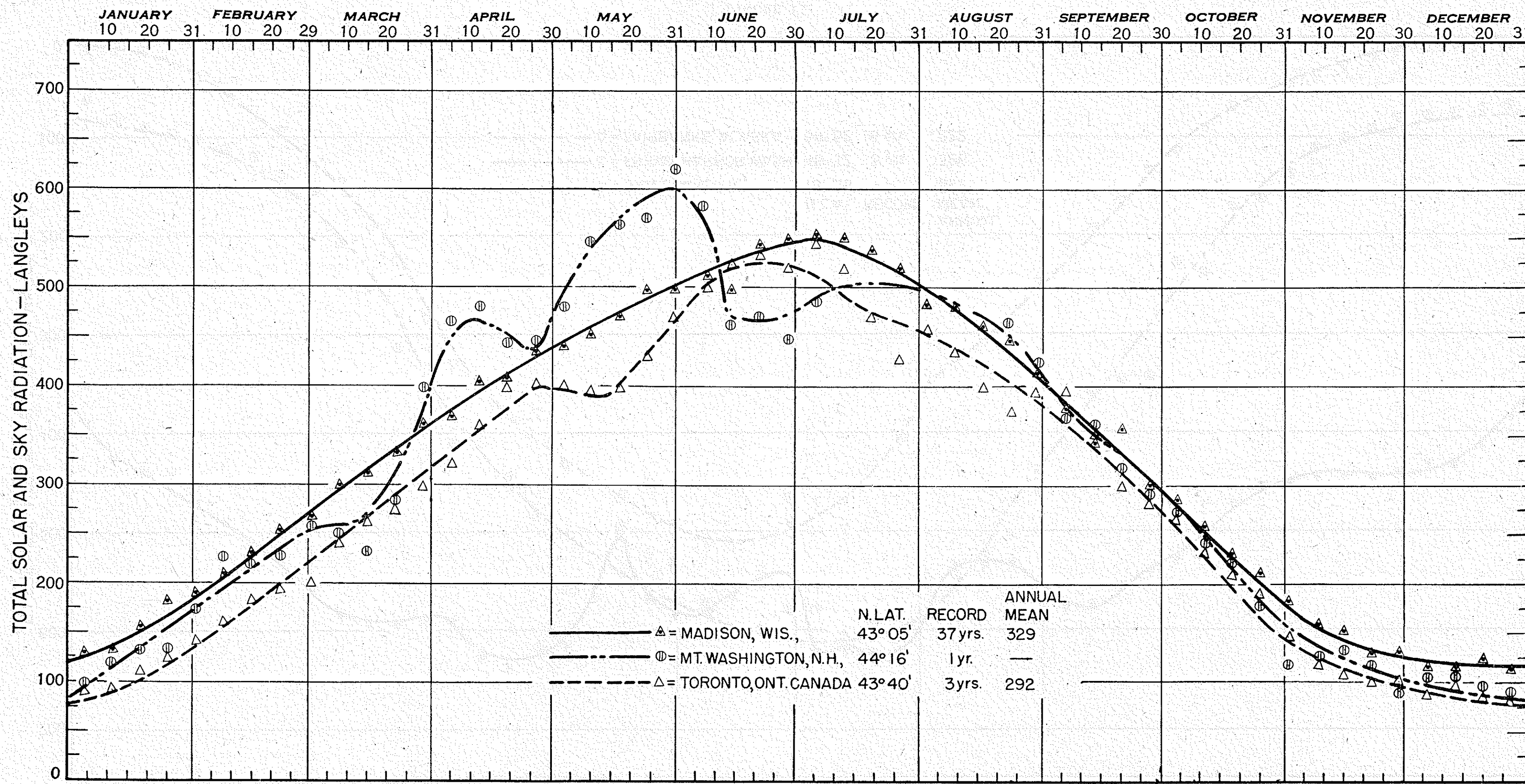
DECEMBER
TOTAL SOLAR AND SKY RADIATION – LANGLEYS
0
100
200
300
400
500
600
700
N.LAT.
RECORD
ANNUAL MEAN
= TWIN FALLS, IDAHO, 42°27' 22yrs. 386
= ITHACA, N.Y., 42° 27' 11 yrs. 299
= EAST LANSING, MICH, 42° 42' 6 yrs. 284

FIGURE 9.



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DECEMBER
TOTAL SOLAR AND SKY RADIATION – LANGLEYS
N. LAT. RECORD ANNUAL MEAN
= MADISON, WIS., 43° 05' 37 yrs. 329
= MT. WASHINGTON, N.H., 44° 16' 1 yr. —
= TORONTO, ONT. CANADA 43° 40' 3 yrs. 292

Figure 10.

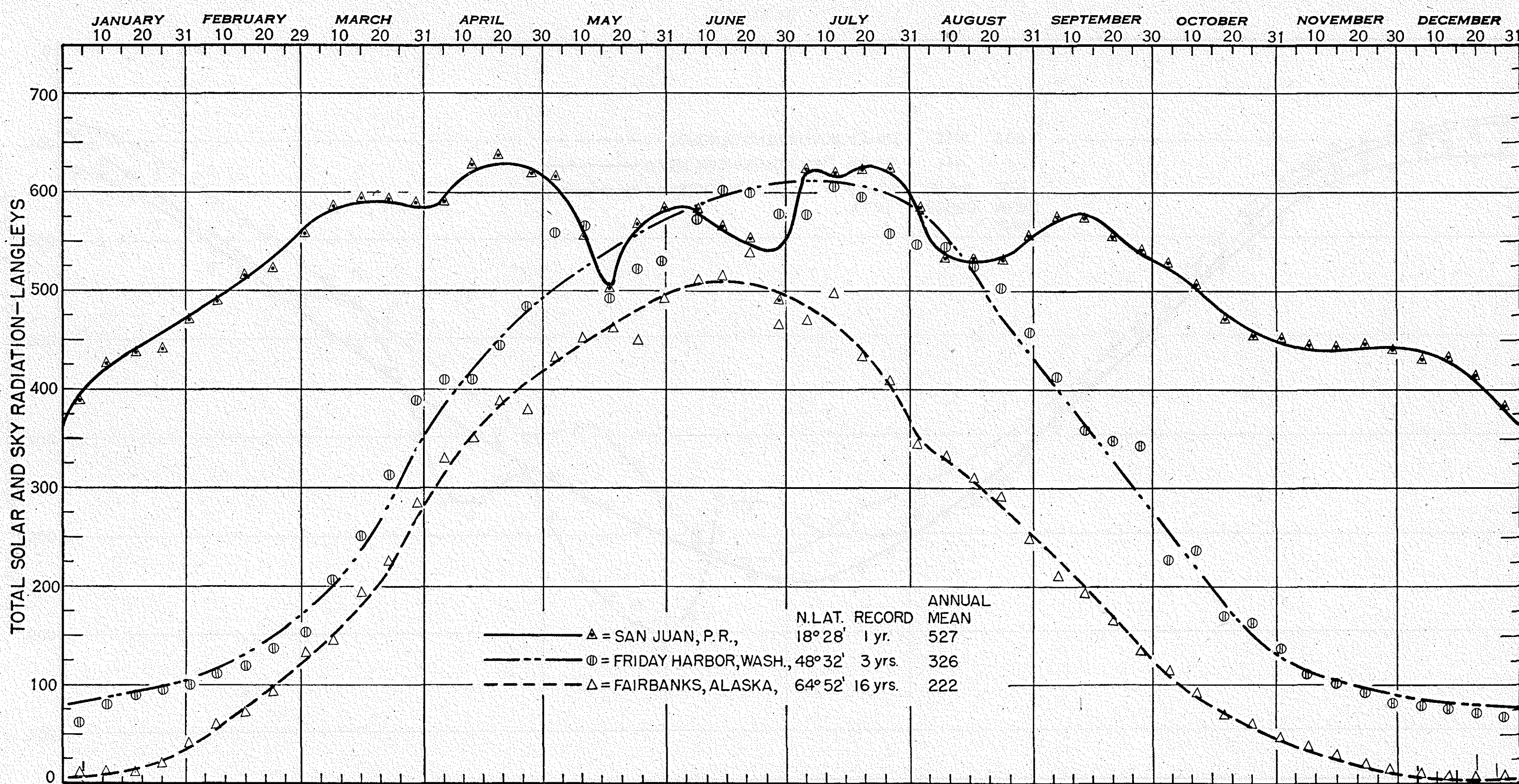

JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER
10 20 31 10 20 29 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31
TOTAL SOLAR AND SKY RADIATION—LANGLEYS
0 100 200 300 400 500 600 700
N.LAT. RECORD ANNUAL MEAN
= SAN JUAN, P.R., 18°28' 1 yr. 527
= FRIDAY HARBOR, WASH., 48°32' 3 yrs. 326
= FAIRBANKS, ALASKA, 64°52' 16 yrs. 222

Figure 11.

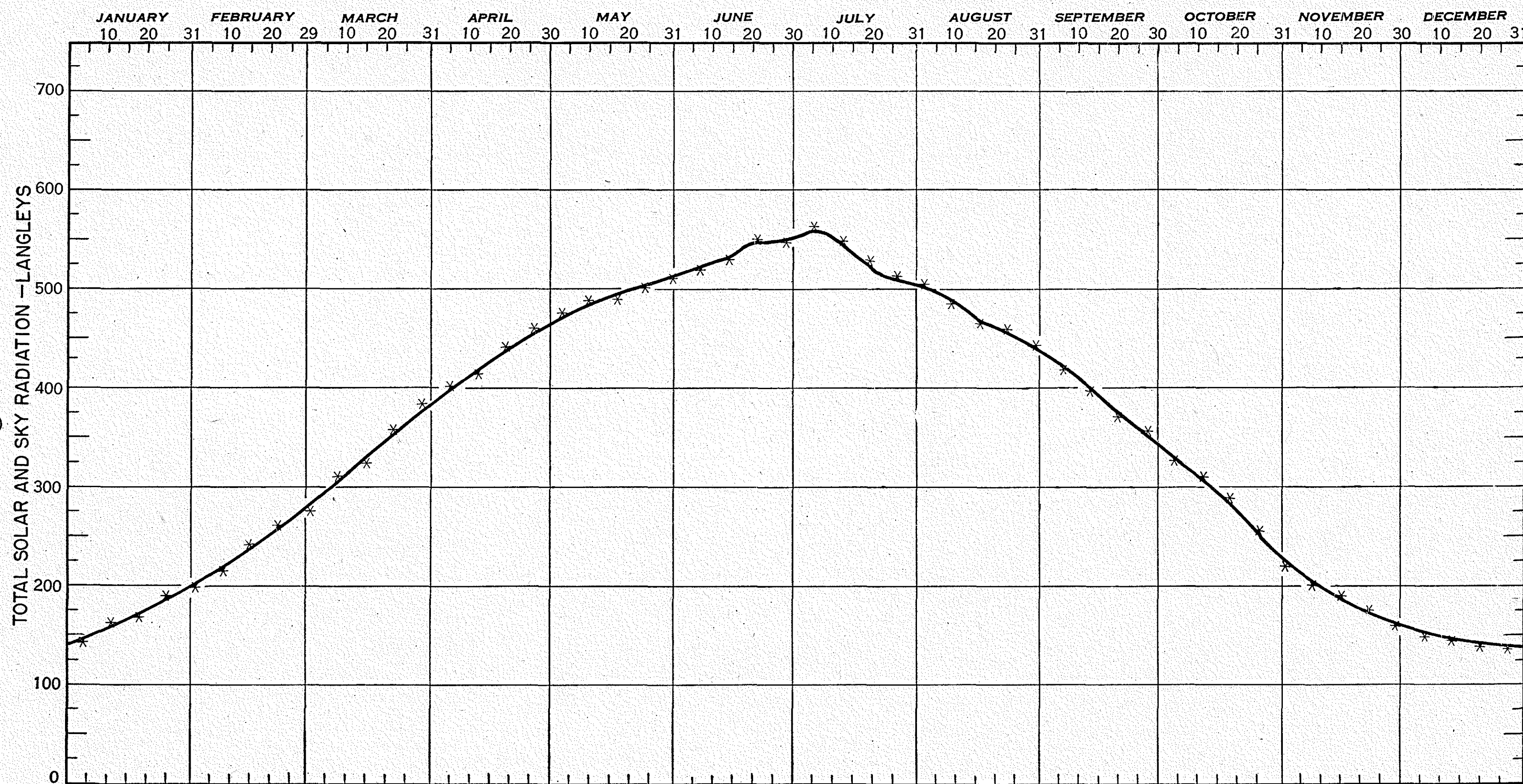
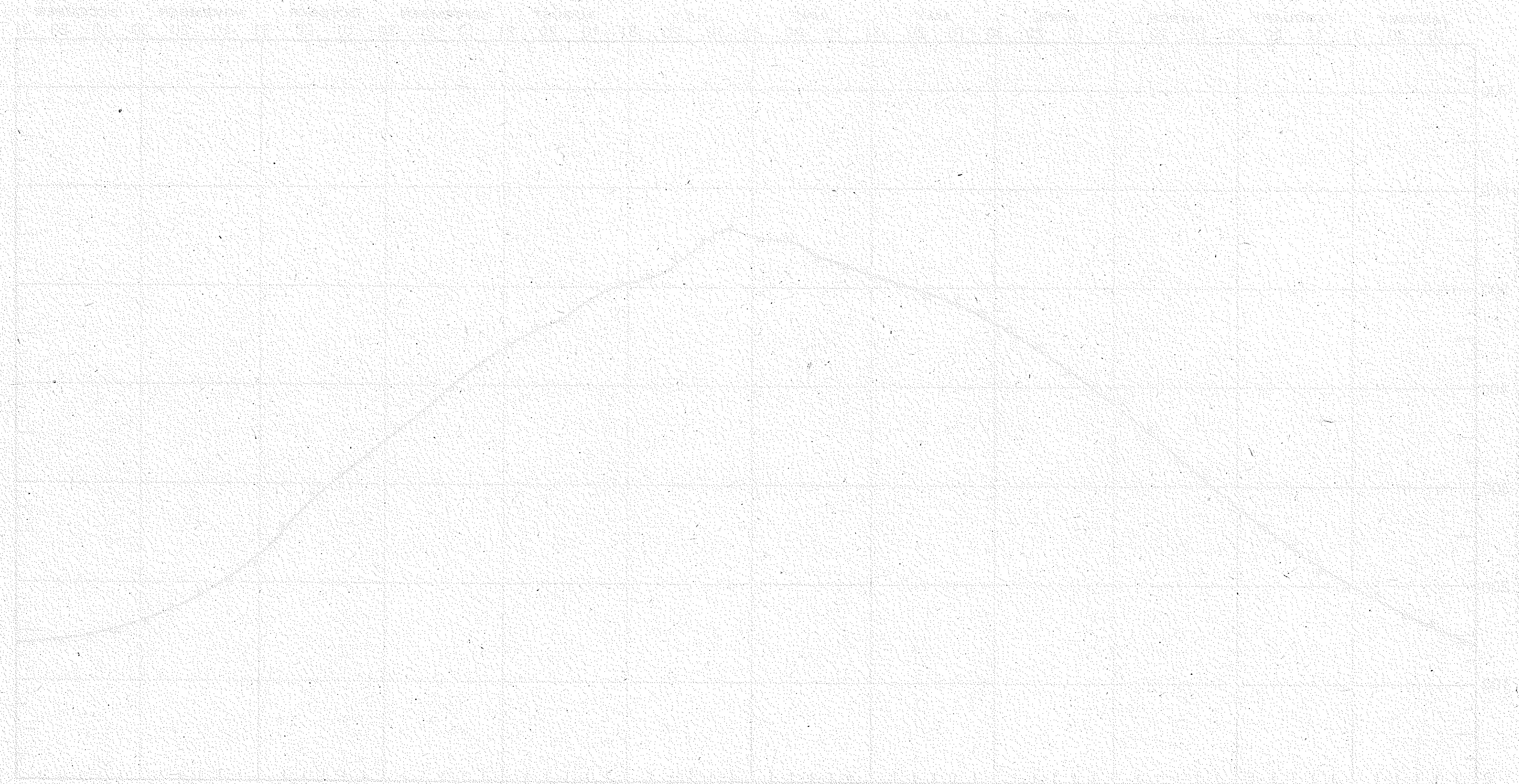


FIGURE 12.

Composite curve for 30 stations. (See page 3.)



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U. S. DEPARTMENT OF COMMERCE
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F. W. REICHELDERFER, Chief

TECHNICAL PAPER No. 11

Weekly Mean Values of Daily Total Solar and Sky Radiation

Supplement No. 1

Prepared by

SIGMUND FRITZ

WASHINGTON
1955

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. - Price 5 cents.

Weekly Mean Values of Daily Total Solar and Sky Radiation

Supplement No. 1

From time to time requests are made for the type of data appearing in Technical Paper No. 11. It is therefore desirable to keep that publication up to date, both by the addition of data from new stations and by the improvement of the curves already appearing in Technical Paper No. 11.

In order that the averages in Technical Paper No. 11 should be relatively stable, the mean values for stations which already appear will probably be recomputed after approximately 10 years of data have been accumulated from each station. However, in order to improve the distribution over the United States by adding new stations, five stations have been selected, each of which has approximately five years of data. This seems especially timely now in view of the proposed World Symposium on Applied Solar Energy which is planning to meet in Phoenix in November 1955.

The map in Figure 1, shows the location of stations for which data already appear in Technical Paper No. 11, plus the location of the five stations which have been added here. The additional five stations are: Phoenix, Ariz., Charleston, S. C., El Paso, Tex. (for which data appear in fig. 2), and Rapid City, S. Dak. and San Antonio, Tex. (fig. 3). Figure 2 shows that both Phoenix and El Paso have higher values of radiation than Charleston throughout the year. This is mainly due to the prevalence of higher percentage of possible sunshine at the former stations by comparison with sunshine at Charleston.

According to Figure 3, San Antonio and Rapid City have similar values of solar radiation during summer months, especially in May and June. In winter, as might be expected from the relative latitudes, the radiation at San Antonio is greater than it is at Rapid City.

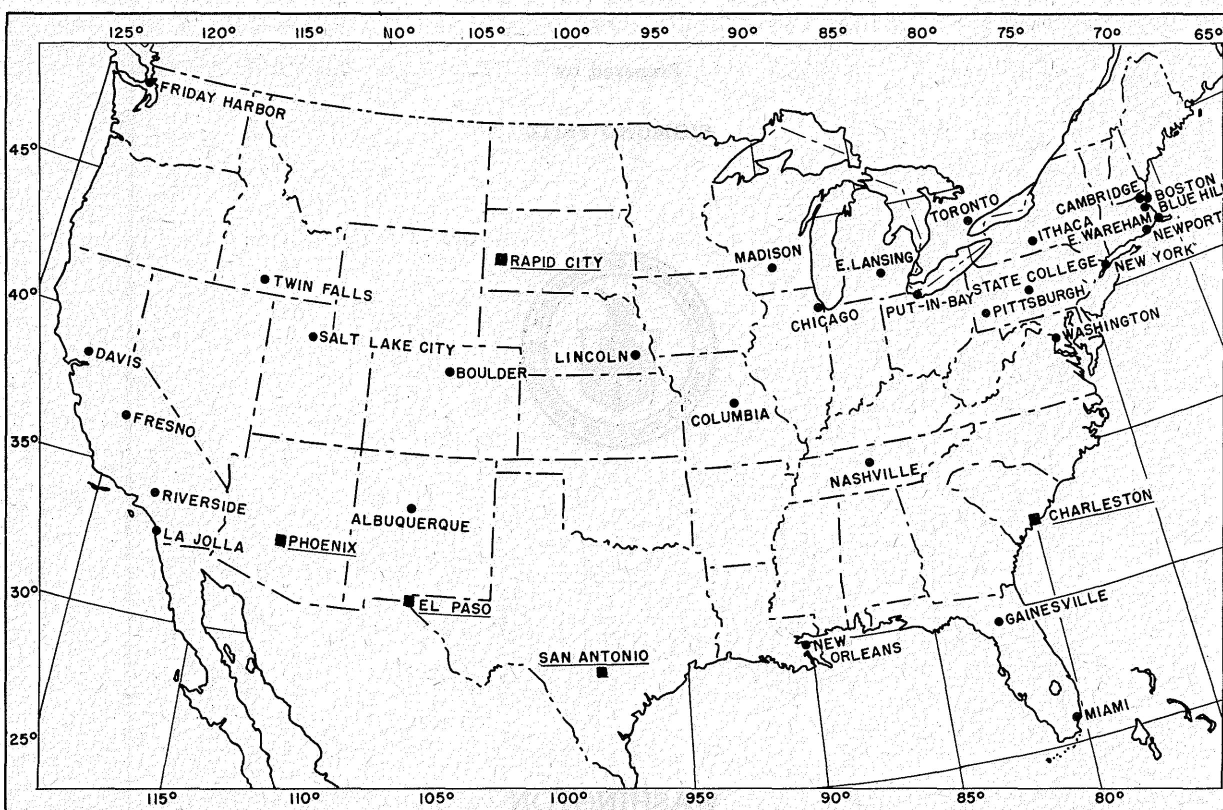

Figure 1. - Location of stations for which data appear in Technical Paper No. 11 (•) and in this addendum (■ and underlined).

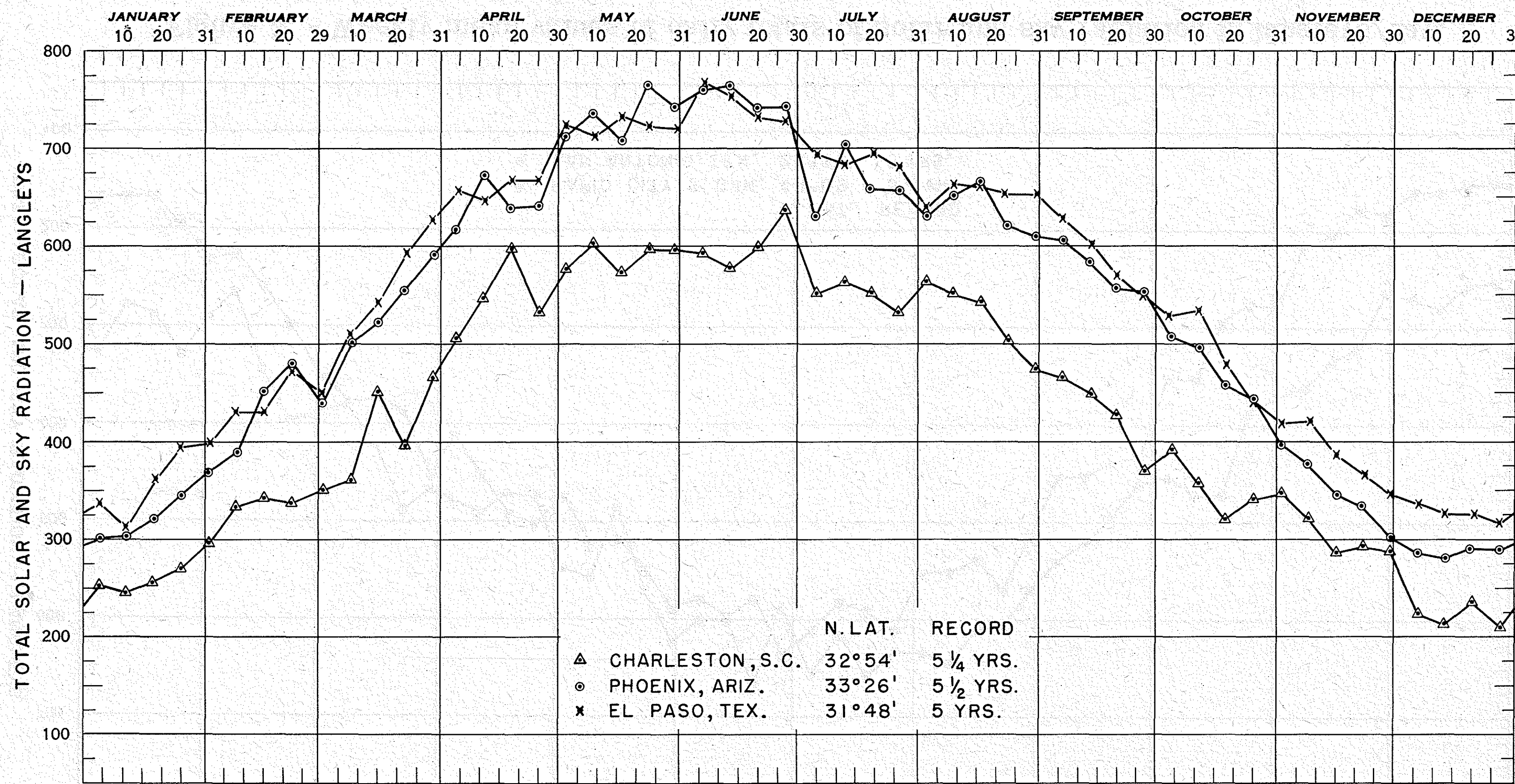

Figure 2. - Weekly mean values of daily totals of solar and sky radiation in langleys/day.

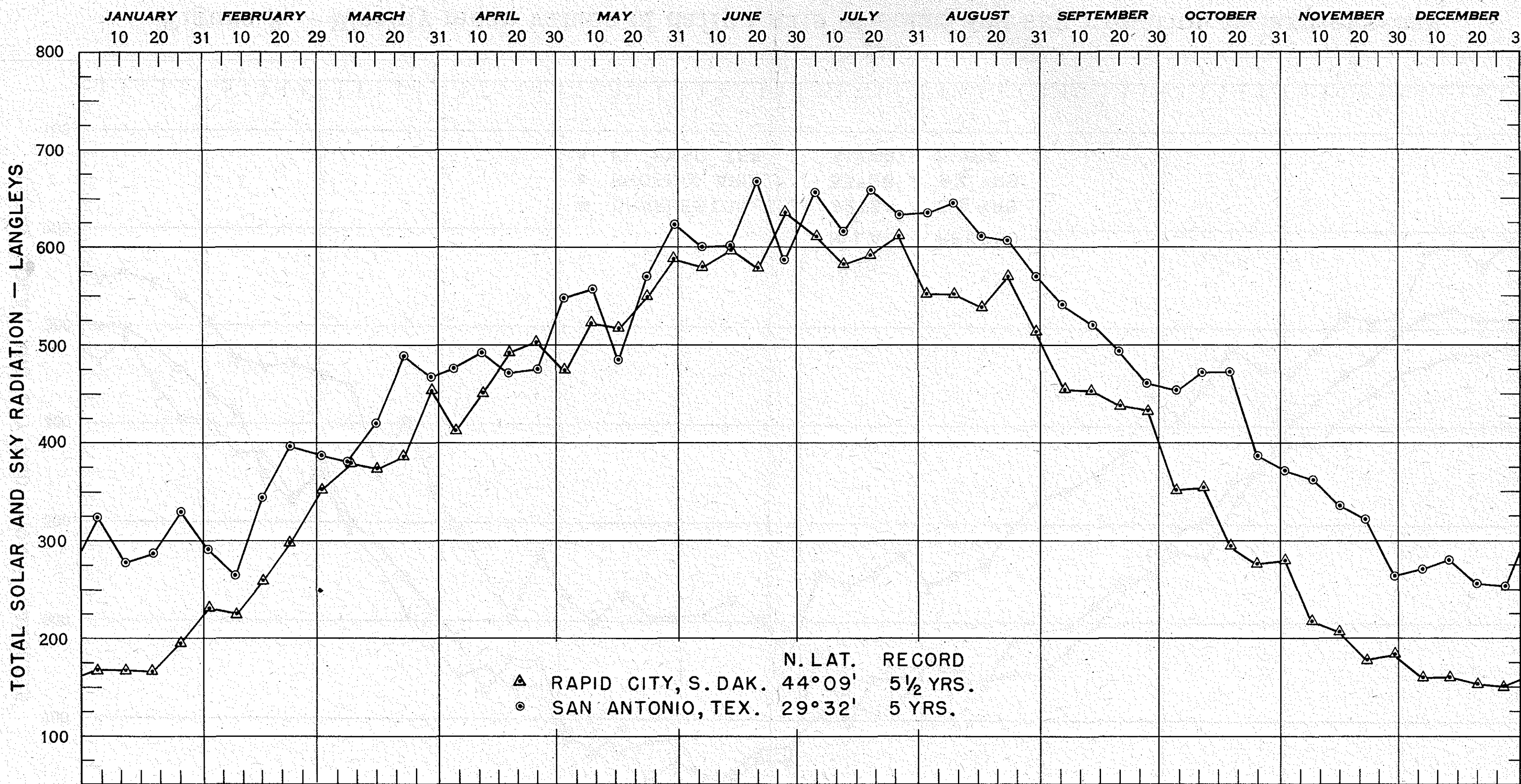

Figure 3. - Weekly mean values of daily totals of solar and sky radiation in langleys/day.