

## ESTIMATION OF GLOBAL MONTHLY IRRADIATION FROM SUNSHINE DURATION DATA AT SIVAS , TURKEY

H. Ibrahim ACAR  
Scholl of Vocational Education and Training,  
Cumhuriyet University , Campus  
58140 Sivas, TURKEY

### ABSTRACT

Measurements of monthly average of daily global solar irradiation on a horizontal surface in Sivas , Turkey , during 1992-1994 have been compared with their corresponding values computed by three methods. The modified Ångstrom model , the Gariépy method and the Kılıç method were used. Regression coefficients for the first and the second models were computed and employed in the prediction of global solar irradiation. The third model used the coefficients determined by altitude and latitude at Sivas. It was found that the results of the first model were in good agreement with the experimental data.

**Key words :** Global solar irradiation, sunshine duration, correlation, regression

### SİVAS' TA AYLIK ORTALAMA TOPLAM GÜNEŞ IŞINIMININ GÜNEŞLENME SÜRESİ VERİLERİ KULLANILARAK TAHMİNİ

Sivas'ta 1992-1994 yıllarında yatay düzleme gelen toplam günlük güneş ışınımının aylık ortalama değerleri üç ayrı metotla hesaplanarak aynı zaman aralığında ölçülen mütakabil değerleri ile karşılaştırılmıştır. Hesaplama Angstrom , Gariépy ve Kılıç metotları kullanılmıştır. Angstrom ve Gariépy modelleri için regresyon katsayıları hesaplanmış ve bu katsayılar toplam güneş ışınımının tahmininde kullanılmıştır. Kılıç modelinde kullanılan katsayılar ise Sivas'ın rakımı ve enlemi baz alınarak hesaplanmıştır. Gariépy metodu ile elde edilen sonuçların ölçülen değerlerle iyi bir uyum sağladığı görülmüştür.

**Anahtar Kelimeler:** Toplam güneş ışınımı, güneşlenme süresi, korelasyon, regresyon

### 1. INTRODUCTION

The solar irradiation incident on the surface of the earth is an important input parameter for many solar energy applications. Thus , the prediction of monthly average of the daily global solar irradiation is necessary to conduct feasibility studies for solar energy systems. In this paper , an attempt is made to find the best correlation between the measured and predicted global solar irradiation data. There are several models for the estimation of global irradiation at a particular site. Several workers, including Angstrom (2), Schulze (10), Page (11), Benson et al (3), Rietveld (9), Glover and Mc Culloch (12), Gariépy (6) and Kılıç (7), have developed such correlations. Three of these models are used here. Methods 1 and 3 are not different models , but different procedures.

In this article , monthly average daily global irradiation values measured from January 1992 to December 1994 in Sivas are compared with their corresponding values computed by three methods and the accuracy of these models is tested. It is seen that the results obtained can be used for many solar energy applications.

### 2. EXPERIMENTAL DATA

In this study, the experimental data for Sivas, the relevant geographical and climatological data of which are given in Table , are supplied by the State Meteorological Office of Turkey. The daily global solar irradiation measurements are obtained with Eppley Model 848 black and white pyranometers. They are estimated to be 1.5 – 2.0 per cent accurate. The bright sunshine hours data are obtained by using Campbell – Stokes type instruments.

Table 1. The geographical and climatological data for Sivas

Latitude	39° 45'
Longitude	37° 01'
Altitude(m)	1285
Yearly average temperature(°C )	8.6
Yearly average precipitation(cm)	41.5
Yearly average wind speed(m/s)	1.8

### 3. METHODOLOGY

#### 3.1. Prediction of the monthly average of the daily global irradiation on a horizontal surface.

Many models have been developed for the prediction of the amount of solar energy incident

on a horizontal plane at the earth's surface. Three of these models are used in this article because they need only a small number of input parameters.

**Method 1**

The first relation is the modified Angstrom -type equation (Angstrom 1924 and Prescott 1940), which is

$$H / H_0 = a + b ( n / N ) \tag{1}$$

The Angstrom coefficients a and b are considered to depend on ( n / N ) , δ , geographical parameters , or seasonal variations by some authors ( Glover & Mc - Culoch 1958 ) , (Rietveld 1978) , (Benson et al 1984) , (Abdalla et al 1985) , (Gariépy 1980) , (Kılıç 1982).

H<sub>0</sub> can be calculated from the following equations given by Cooper for the mean day in each month ,

$$H_0 = 24 / \pi G_{cs} f \sin \delta \sin \phi ((\pi / 180) \omega_0 - \tan \omega_0) \tag{2}$$

Where  $f = 1 + 0.033 \cos (360 n' / 365)$   
 $\tag{3}$

$$\omega_0 = \cos^{-1} ( - \tan \phi \tan \delta ) \tag{4}$$

N is calculated as

$$N = 2 / 15 \cos^{-1} ( - \tan \phi \tan \delta ) \tag{5}$$

where

$$\delta = 23.45 \sin 360 ( 284 + n ) / 365 \tag{6}$$

n and H values are the experimental data . They were supplied by the State Meteorological Office of Turkey.

**Method 2**

The second relation is introduced by Gariépy (Gariépy 1980). The Gariépy equation has been expressed in the following form:

Table 2. Calculated regression coefficients

Correlations	Regression values							
	a	b	a <sub>0</sub>	a <sub>1</sub>	a <sub>2</sub>	a <sub>3</sub>	a <sub>4</sub>	a <sub>5</sub>
Method 1	0.3088	0.2831	-	-	-	-	-	-
Method 2	-	-	0.4770	-0.0314	-	0.0461	0.0697	0.0410
Method 3	0.2714	0.4078	-	-	0.0515	-	-	-

$$H / H_0 = a_0 + a_1 T + a_2 P + a_3 W + a_4 P ( n / N ) + a_5 T ( n / N ) \tag{7}$$

Values of T , P , and W are the yearly average based on long - term records. They are given in Table 1.

**Method 3**

The third relation is proposed by Kılıç (1982) , which is

$$H / H_0 = a + b ( n / N ) \tag{8}$$

where

$$a = 0.103 + 0.000017 Z + 0.198 \cos ( \phi - \delta ) \tag{9}$$

$$b = 0.533 - 0.165 \cos ( \phi - \delta ) \tag{10}$$

Values of φ , δ and Z are given in Table 1.

Method 3 (equation 8) is the same as method A (equation 1) . The only difference is that in model 1 the a and b are constants to be determined from the correlation with the experimental data while in method 3 the a and b have been calculated from the correlation made by Kılıç (1982) using another set of data and assuming certain dependence of a and b on Z , φ , δ.

**4. RESULTS AND DISCUSSION**

**4.1 Computations by Method 1**

Equations, (3) and (4) are used to calculate f and ω<sub>0</sub> . Then , H<sub>0</sub> and N are computed using equations (2) and (5) . Next , the monthly averages of daily values of H / H<sub>0</sub> and n / N are obtained . These monthly averages are employed to compute the regression coefficients a and b in equation (1) . The results obtained for a and b are presented in Table 2 and their accuracy is expressed as the absolute percent difference between the values of H<sub>0</sub> obtained by equation (1) using the values of a and b in Table 2 and the

experimental monthly averages of H . They are given in Table 3 . Good fitting is observed;

estimations display an accuracy between 3.5 % and 7.9 % .

Table 3. Comparison of measured and estimated monthly average of daily global irradiation by method 1

		$\bar{H}_m$ Measured monthly average of daily global irradiation, MJ m <sup>-2</sup>												
		$\bar{H}_c$ Calculated monthly average of daily global irradiation, MJ m <sup>-2</sup>												
		$ e $ Absolute percent difference between estimated and measured values												
Year	Month	J	F	M	A	M	J	J	A	S	O	N	D	Annual Average
	1992	$\bar{H}_m$	5.4	8.6	11.82	15.27	15.92	17.54	18.77	18.73	15.22	10.23	6.58	
	$\bar{H}_c$	5.88	8.08	11.86	16.60	18.11	18.98	19.97	20.96	19.97	10.82	6.38	4.67	13.13
	$ e $	8.1	6.0	0.34	8.0	12.1	7.6	6.0	10.6	23.8	5.5	3.0	4.9	7.9
1993	$\bar{H}_m$	5.4	8.7	11.92	15.9	16.6	21.4	23.3	19.6	16.4	12.3	6.7	4.7	13.58
	$\bar{H}_c$	5.58	8.31	12.57	15.23	16.65	20.46	23.33	19.66	16.53	12.04	6.80	5.50	13.55
	$ e $	3.2	4.7	5.1	4.4	0.3	4.6	0.13	0.3	0.8	2.1	1.5	14.5	3.57
1994	$\bar{H}_m$	5.5	8.9	12.4	16.8	20.4	24.0	23.3	20.5	16.9	11.4	6.4	5.1	14.3
	$\bar{H}_c$	6.18	8.25	12.25	16.60	20.01	22.70	21.98	20.07	16.44	10.88	6.71	4.83	13.91
	$ e $	11	7.8	1.2	1.2	1.9	5.7	6.0	2.1	2.7	4.8	4.6	5.5	4.5

4.2 Computations by Method 2

The monthly averages of daily values of H / H<sub>0</sub> are obtained using values of T , P , W , PS and TS .These monthly averages are employed to

4.3 Computations of by Method 3

The constants a and b have been calculated using  $\phi$  ,  $\delta$  and Z values and the results are given in

Table 4. Comparison f measured and estimated monthly average of daily global irradiation by method 2

		$\bar{H}_m$ Measured monthly average of daily global irradiation, MJ m <sup>-2</sup>												
		$\bar{H}_c$ Calculated monthly average of daily global irradiation, MJ m <sup>-2</sup>												
		$ e $ Absolute percent difference between estimated and measured values												
Year	Month	J	F	M	A	M	J	J	A	S	O	N	D	Annual Average
	1992	$\bar{H}_m$	5.4	8.6	11.82	15.27	15.92	17.54	18.77	18.73	15.22	10.23	6.58	
	$\bar{H}_c$	5.77	8.38	12.52	16.73	17.30	20.43	21.85	19.66	15.73	10.68	6.21	5.32	13.38
	$ e $	6.4	2.6	5.6	8.7	8.0	14.1	14	4.7	3.2	4.2	5.9	7.9	7.1
1993	$\bar{H}_m$	5.4	8.7	11.92	15.9	16.6	21.4	23.3	19.6	16.4	12.3	6.7	4.7	13.58
	$\bar{H}_c$	5.48	8.61	13.26	14.67	16.52	20.92	22.48	19.55	16.33	11.75	5.61	5.54	13.39
	$ e $	1.5	1	10	8.3	0.47	2.2	3.6	0.25	0.42	4.7	1.9	15.2	4.10
1994	$\bar{H}_m$	5.5	8.9	12.4	16.8	20.4	24.0	23.3	20.5	16.9	11.4	6.4	5.1	14.3
	$\bar{H}_c$	6.11	8.55	12.91	16.73	20.22	23.37	22.28	19.73	16.10	10.75	6.50	4.82	14.0
	$ e $	10	4.0	3.9	0.42	0.88	2.6	4.6	3.9	5.0	6.0	1.5	4.8	4.1

compute the regression coefficients in equation (7) . The results are given in Table 2 and their accuracy is expressed as the absolute percent difference between the values of H<sub>0</sub> obtained by equation (7) using the coefficients in Table 2 and the experimental monthly averages of H. They are given in Table 4 . The error is less than 8 %.

Table 2. Hence , values of H have been computed using equation( 8 ) and the results are summarized in Table 5. The error is determined to be less than 12 % .

Tablo 5. Comparison of measured and estimated monthly average of daily global irradiation by method 3

		$\bar{H}_m$ Measured monthly average of daily global irradiation, MJ m <sup>-2</sup>												
		$\bar{H}_c$ Calculated monthly average of daily global irradiation, MJ m <sup>-2</sup>												
		e  Absolute percent difference between estimated and measured values												
Year	Month	J	F	M	A	M	J	J	A	S	O	N	D	Annual Average
	1992	$\bar{H}_m$	5.4	8.6	11.82	15.27	15.92	17.54	18.77	18.73	15.22	10.23	6.58	4.90
$\bar{H}_c$		5.7	7.97	12.16	17.73	19.01	21.34	23.00	22.26	17.54	11.56	6.23	4.12	14.05
e		5.2	7.9	2.8	13.9	16.2	17.80	18.4	15.8	13.2	11.5	5.6	18.9	12.3
1993	$\bar{H}_m$	5.4	8.7	11.92	15.9	16.6	21.4	23.3	19.6	16.4	12.3	6.7	4.7	13.58
	$\bar{H}_c$	5.26	8.30	13.16	15.76	16.93	22.02	24.95	21.81	18.37	13.29	6.84	5.42	14.34
	e	2.6	4.8	9.40	0.9	1.9	2.8	6.6	10.0	10.7	7.4	2.0	13.3	6.0
1994	$\bar{H}_m$	5.5	8.9	12.4	16.8	20.4	24.0	23.3	20.5	16.9	11.4	6.4	5.1	14.3
	$\bar{H}_c$	6.14	8.22	12.72	17.73	21.74	25.22	24.47	22.40	18.27	11.65	6.70	4.46	14.98
	e	10.4	8.2	2.5	5.2	6.1	4.8	4.8	8.5	7.4	2.1	4.4	14.3	5.2

### 5. CONCLUSIONS

The monthly average daily global irradiation in Sivas has been estimated by three methods . Comparison of the measured and predicted data shows that:

1. Global solar irradiation incident on a horizontal plane in Sivas can be predicted by modified Angstrom method , Gariépy method and Kılıç method.
2. The best accuracy is obtained using the modified Angstrom method .
3. The results obtained can be extended to places having similar climatic conditions.
4. Further analysis based on long - term records should be made to get more accuracy.

**Acknowledgement** - I thank the State Meteorological Office of Turkey for making available the bright sunshine data.

### 5. NOMENCLATURE

- a coefficient of the Ångstrom model
- b coefficient of the Ångstrom model
- a<sub>0</sub>,a<sub>1</sub> coefficients of the Gariépy model
- a<sub>2</sub>,a<sub>3</sub> coefficients of the Gariépy model
- a<sub>4</sub>,a<sub>5</sub> coefficients of the Gariépy model

- H monthly average of daily global irradiation on horizontal surface , MJ m<sup>-2</sup>
- H<sub>0</sub> daily extraterrestrial irradiation on horizontal surface , MJ m<sup>-2</sup>
- H<sub>c</sub> calculated monthly average of daily global irradiation , MJ m<sup>-2</sup>
- H<sub>m</sub> measured monthly average of daily global irradiation , MJ m<sup>-2</sup>
- n monthly average of daily hours of bright sunshine (hr)
- N the maximum daily hours of sunshine (hr)
- Z altitude , m
- φ latitude(degrees)
- T yearly average temperature , °C
- P yearly average precipitation , cm
- W yearly average wind velocity , m s<sup>-1</sup>
- δ declination angle (degrees)
- ω<sub>0</sub> the sunset hour angle (degrees)
- G<sub>cs</sub> the solar constant ,
- n' the day of year ( starting with 1 January )
- n the day the mean monthly declination angle is determined
- f the solar constant correction factor

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