

Estimation of Cloudiness and Solar Energy Availability in Georgia Using a Clear Sky Model

Steve D. Fischer¹, Amy Chen², Randal L.N. Mandock¹, and Gerrit Hoogenboom³

¹ Earth System Science Program, Clark Atlanta University

² University of Minnesota – Twin Cities

³Department of Biological & Agricultural Engineering, University of Georgia, Griffin, GA

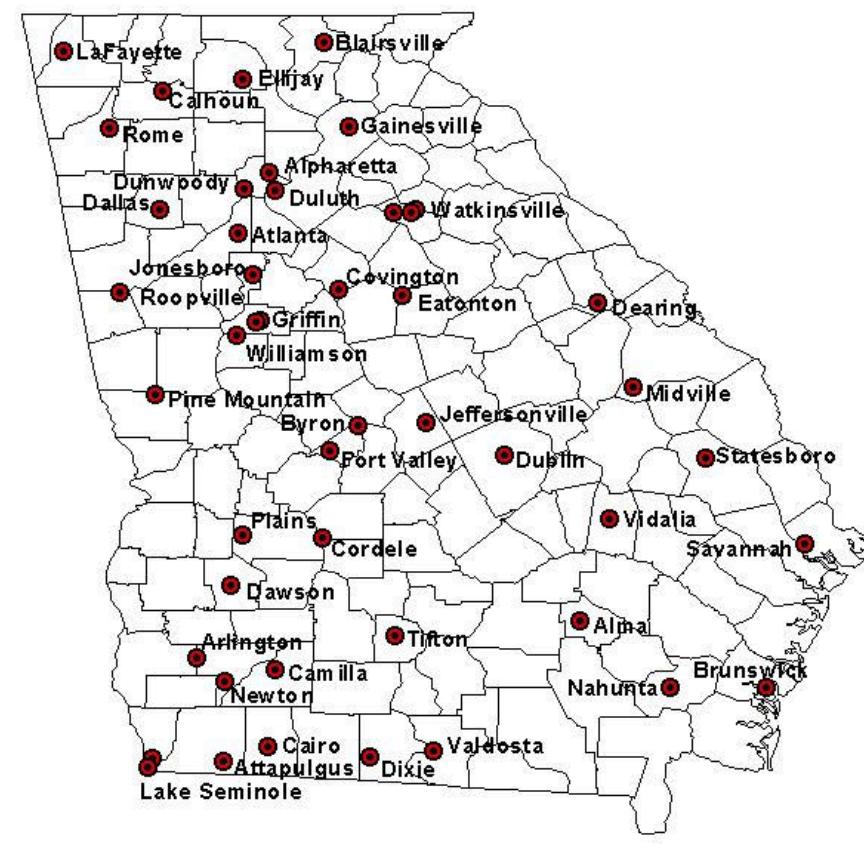
Purpose

This study seeks to determine the maximum usable broadband solar flux at over forty automated weather stations located throughout the State of Georgia. Cloudiness, being a limiting factor, will be measured throughout the day by comparing the measured solar intensities with those estimated by a solar flux model. Since data are available for a number of successive years, trends will be identified in the data if they are present.

Procedure

A modified clear sky model is used to estimate the solar energy available at the latitudes and longitudes of seven of the weather stations depicted at the right. Solar radiation sensors at these sites measure the average flux at 15 minute intervals every day. The two results, measured and computed, are compared in the study on a daily basis.

The mathematical formulation of the model follows the development of Meyers and Dale (1983). The difference between the predicted and observed irradiances is assumed to be due to clouds or haze.



Map of the Georgia Automated Environmental Monitoring Network

The underlying general equation in the model for computing irradiance at the surface of the earth takes the form:

$$I = I_o(\cos Z)T_R T_g T_w T_a \quad [1]$$

for which

$$I_o = 1353 \text{ Wm}^{-2} [1 + 0.034 \text{ Cos}[2\pi(n-1)/365]] \quad [2]$$

I_o is the irradiance at the top of the atmosphere normal to the solar radiation beam, and n is the day number (Jan 1 = 1, Dec 31 = 365, etc.).

$$T_R T_g = 1.021 - 0.084 [m(949p \times 10^{-5} + 0.051)]^{1/2} \quad [3]$$

T_R is the transmission coefficient after Rayleigh scattering, T_g the transmission coefficient for absorption by permanent gases, p the pressure in Kpa and m is the optical air mass at pressure of 101.3kpa given by

$$m = 35(1224 \text{ Cos}^2(Z) + 1)^{-1/2} \quad [4]$$

The solar zenith angle, Z , is computed using a subroutine written by The Astronomical Almanac. It takes into account the refraction of atmosphere at large zenith angles.

$$T_w = 1 - 0.077 (um)^{0.3} \quad [5]$$

T_w is the transmission coefficient for absorption by water vapor, where u is the precipitable water vapor:

$$u = \exp[0.1133 - \ln(? + 1) + 0.0393T_d] \quad [6]$$

Where T_d is the daily average dew point in °F and $?$ a constant derived for site latitude and season (Smith, 1966).

$$T_a = X^m \quad [7]$$

T_a is the transmission coefficient accounting for absorption and scattering by aerosols (Houghton, 1954), m is the optical air mass, and X is derived empirically as a residual in equation [1] for clear sky condition. The $?$ in [7] takes up a value of 3, specifically for the Georgia geographic location as suggested by Smith (1966), and X with a value of 0.95 in [7].

Results

The figure to the right shows that for clear days the model generally predicted fluxes that were slightly higher than those measured. This bias is on the order of 3.6% and should be further investigated. Exceptions to this situation tended to occur on bright days during fair weather, when fluffy, white cumulus clouds were often present. This enhanced scattering of sunlight off the clouds and created a large diffuse radiation component which was directed downward towards the sensor.

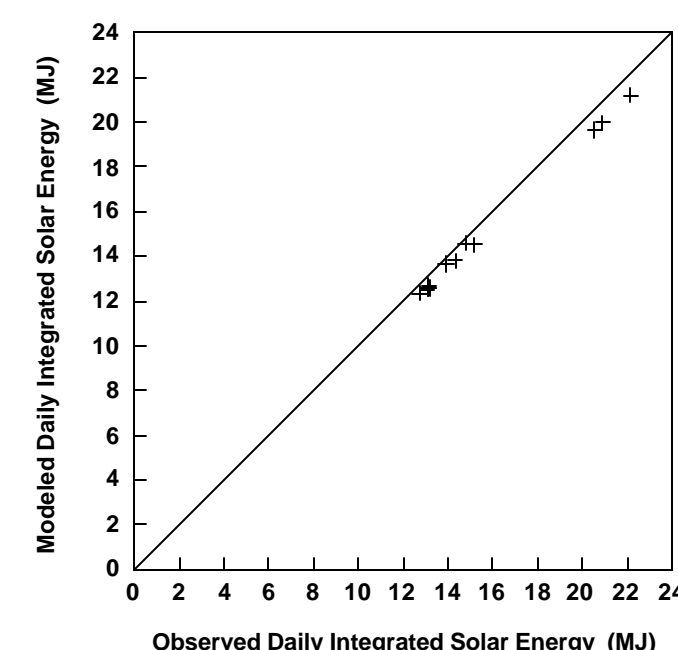
The model-predicted and measured solar radiation fluxes were integrated between sunrise and sunset every day to determine the available energy. Total annual energies were determined as well as the seasonal energies for every site are listed in the above table. The measured yearly solar energy at the surface is on the order of 5.1 GJ to 6.0 GJ, and is 2.59 GJ to 3.64 GJ less than the model predictions (standard deviation = 0.30163714 GJ; mean = 3.26 GJ). The model consistently predicted that the Alma station would receive the highest solar energy and LaFayette the lowest for all four seasons as well as the year. However, the measured data showed that the seasonal solar energy was generally higher in the summer (2.0 GJ) for the southern stations (Plains, Savannah) and lower in the winter (0.87 GJ) for one of the northern stations (LaFayette). Annual solar energy observations were highest for the Savannah station (6.1 GJ) and lowest for Bledsoe (5.2 GJ) and LaFayette (5.3 GJ).

ClearGA Model Predicted Total Energy

Station Name	Spring (KJ)	Summer (KJ)	Fall (KJ)	Winter (KJ)	Yearly (10 ⁶ KJ)
Bledsoe	1751296	2845142	2650498	1523505	8.7668
Alma	1799946	2863756	2658547	1594327	8.891
Blairsville	1690042	2846048	2645488	1460646	8.655
Duluth	1720094	2834253	2646928	1492177	8.7065
LaFayette	1689298	2830110	2639649	1458988	8.631
Plains	1788294	2841363	2665292	1573731	8.883
Savannah	1776819	2811519	2640162	1563750	8.806

Measured Total Solar Energy

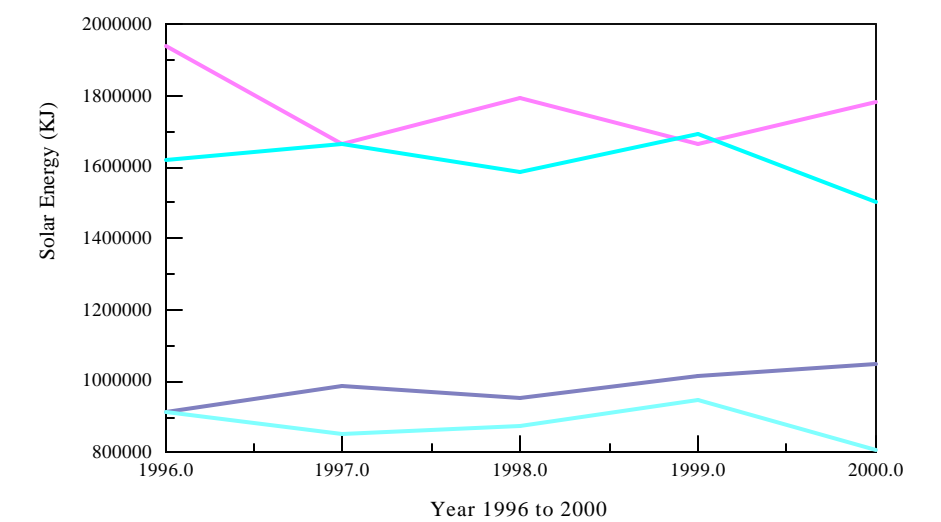
Station Name	Spring (KJ)	Summer (KJ)	Fall (KJ)	Winter (KJ)	Yearly (10 ⁶ KJ)
Bledsoe	984440	1768656	1612448	879290	5.244
Alma	1078293	1868970	1578311	966339	5.446
Blairsville	1050924	1863858	1791216	943231	5.657
Duluth	1077376	1912573	1647777	899155	5.5455
LaFayette	959045	1795178	1692606	868122	5.3215
Plains	1148337	2043662	1737173	1026674	5.967
Savannah	1208838	2053534	1708988	1083220	6.0655



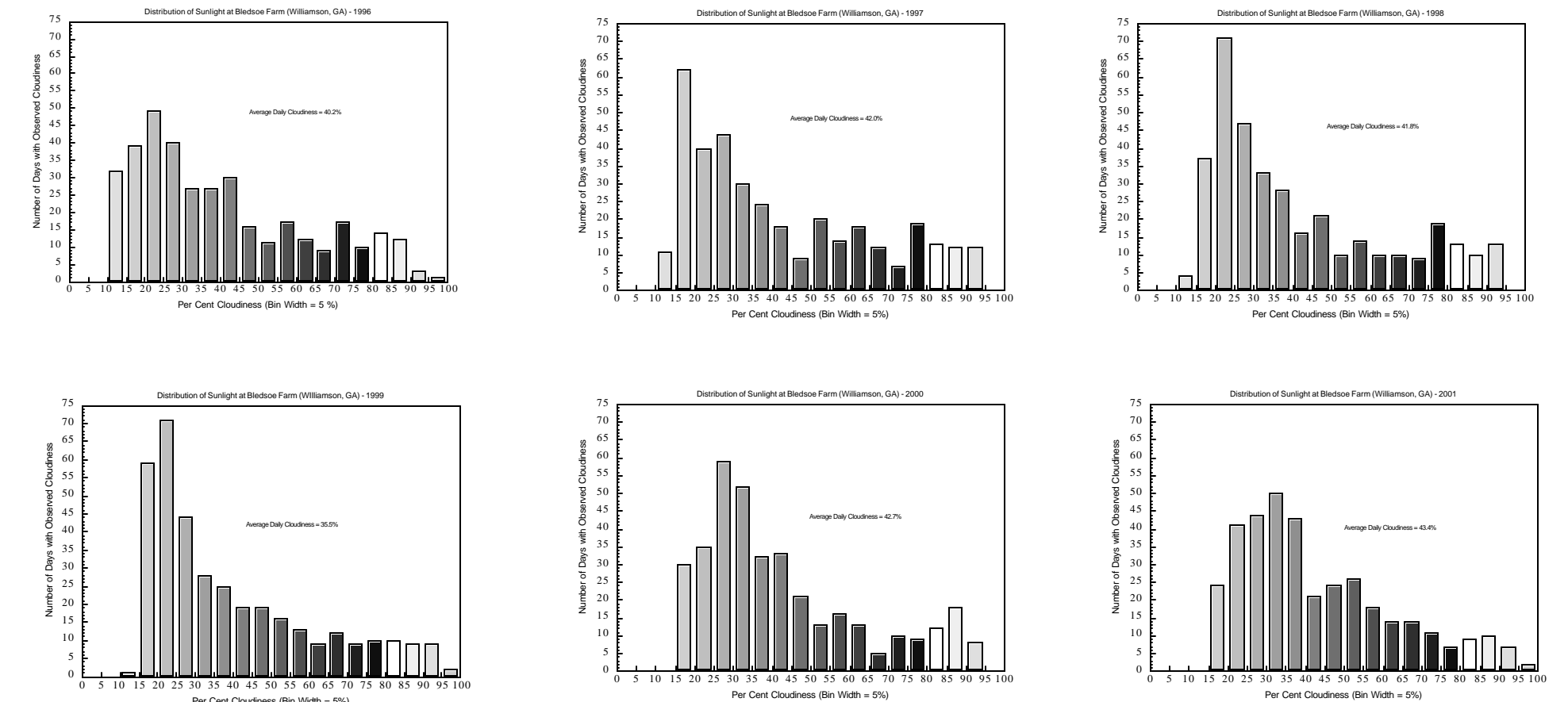
Clear sky modeled versus observed daily integrated solar energy. Data from Blairsville, LaFayette, and Savannah AEMN stations for years 1996 and 2000.

Multiyear Trend in Solar Energy at Bledsoe Farm (1996-2001)

Of special interest is the Bledsoe 1996-2000 data. A slight upward trend is evident in Bledsoe solar energy values for the spring season, rising from 0.91 GJ in 1996 to 1.1 GJ in 2000. No trends are evident in data from the other seasons.



Historical Variation in Cloudiness at Bledsoe Farm (1996-2001)



The daily average cloudiness at this site varies from only 35% to 43 %, and the yearly variation appears to have no dominant linear trend. The yearly variations in the pattern of cloudiness (histograms) show two distinct characters: (1) a peak at low cloudiness values and then falloff; and (2) a more smeared signature from low values of cloudiness to high. The minimum degree of cloudiness for this data increased from 11% to 16%, the maximum cloudiness decreased from 97% to 95%, and the average cloudiness was 42% ????

Conclusion

In this preliminary study, data from two years at seven weather stations spread across the state of Georgia are used to estimate the solar energy potential and cloudiness profile. A clear sky computer model was used to predict the maximum irradiance that each station location should receive. A comparison with the actual measured data was made. There is a difference of roughly 3.64 GJ between the model-predicted and measured yearly solar energy output. This difference is due to the presence of clouds. Future work will include obtaining data from more weather stations over a larger number of years in order to search for any persistent patterns or trends in the data. It has been suggested that global warming will modify the global distribution of clouds. If so, this trend may be apparent in a longer data set.

References

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