Comments "On the Performance of Pyrgeometers with Silicon Domes"

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1. Introduction

In his discussion of the performance of Eppley pyrgeometers with silicon domes for measuring longwave (4000–50 000 nm) radiation, Weiss (1981) concludes that significant errors in the measurement of atmospheric irradiance can result from solar heating of the silicon dome. The purpose of the following comments on the findings of Weiss is not to question the existence of a dome-heating effect, but rather to question whether the method he used to show the magnitude of the effect is valid for evaluating pyrgeometer performance. Specifically, we believe that daytime values and trends of his calculated atmospheric irradiances may be physically unrealistic and may have resulted from the type of net pyrradiometers used in his experiments.

2. Comparison of measured and calculated atmospheric irradiances

Weiss compared atmospheric irradiances measured with an Eppley pyrgeometer to corresponding irradiances calculated with the equation

$$L_c{\downarrow} = \bar{R}_n - S{\downarrow} + S{\uparrow} + L{\uparrow}, \qquad (1)$$

where $L_c{\downarrow}$ is the calculated atmospheric irradiance, $\bar{R}_n$ the net all-wave irradiance measured with Swissteco net pyrradiometers, $S{\downarrow}$ incoming and $S{\uparrow}$ reflected solar irradiances measured with upright and inverted precision spectral pyranometers, respectively, and $L{\uparrow}$ emitted longwave irradiance measured with an inverted pyrgeometer.

In his Fig. 3, Weiss shows a comparison of the measured and calculated atmospheric irradiances for a cloudless summer day when the maximum temperature reached 32°C at his Nebraska experiment site. Pyrgeometer values 1) increased gradually from ~320 W m^{-2} near sunrise to ~380 W m^{-2} shortly after solar noon, 2) remained near 380 W m^{-2} until ~1530 solar time and 3) gradually decreased to ~360 W m^{-2} near sunset. Calculated values, however, 1) varied near a value of 310 W m^{-2} from sunrise to 0830 solar time, 2) decreased to ~270 W m^{-2} between 0830 and 1030 and remained near this value until shortly after solar noon and 3) gradually increased to ~355 W m^{-2} between 1300 and 1630 and remained near this value until sunset.

A dome heating effect could have been responsible for some of the morning increase in pyrgeometer values of atmospheric irradiance, but the realism of the morning decrease of the calculated values is of more direct concern here. Experimental and theoretical work by others and experimental work here have shown that for a cloudless summer day, with no major changes in atmospheric temperature, water vapor content or carbon dioxide, atmospheric irradiance above a grass-covered surface increases in the morning after sunrise, reaches a prolonged flat maximum after solar noon and decreases in late afternoon. Such a daytime variation for a cloudless sky has been found to be strongly correlated with corresponding trends of temperature and actual vapor pressure in the atmosphere's first few meters. A smaller daytime increase occurs over snow and water surfaces. Corroborative experimental and computational evidence of this behavior can be found in Portman and Ryznar (1961), Gates (1965), Kondrat'yev (1965), Morgan and Lourence (1965) and Paltridge and Platt (1976).

Perhaps most interesting in this regard, however, are the data of Campbell *et al.* (1978) cited by Weiss. They determined atmospheric irradiances for two successive clear days (dates and location of measurements not given) by three different methods. Two methods involved calculating atmospheric irradiance as the difference between total downcoming irradiance and solar irradiance. The latter was measured with a Kipp pyranometer, while two commercially available instruments were modified and used to measure total irradiance. One was a Kipp pyranometer in which the glass domes were replaced by a polyethylene dome and a thermojunction was attached to the thermopile base to measure its temperature. The second was a Fritschen net pyrradiometer in which the lower polyethylene dome was painted, shaded and supplied with a thermojunction. The third method used to determine atmospheric irradiance was direct measurement with a custom-made pyrgeometer fitted with a KRS-5 dome. According to Campbell *et al.*, the special design of this instrument minimized effects of solar heating of the dome on its performance.

At night, results from the three methods agreed well with each other. Daytime data were extracted

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TABLE 1. Atmospheric irradiance (W m^{-2}) for two clear days determined with three different methods [from Fig. 3 of Campbell *et al.* (1978)].

Measurement	Sunrise	Mid-morning	Solar noon	Mid-afternoon	Sunset
Day 1					
Modified net radiometer	280	300	330	355	280
Modified Kipp pyranometer	280	290	310	335	280
Custom-made pyrgeometer	280	285	320	330	285
Day 2					
Modified net radiometer	265	295	325	330	290
Modified Kipp pyranometer	265	295	305	300	290
Custom-made pyrgeometer	265	285	325	315	290

from Fig. 3 of Campbell *et al.* and are summarized in Table 1. The values shown were estimated to the nearest 5 W m^{-2} for five representative times on the two clear days. As shown in Table 1, there were differences among the three measures of atmospheric irradiance that approached 10%. In spite of these differences, however, all methods showed similar daytime trends that agreed with not only the expected trends described above, but also with measured atmospheric irradiances shown in Weiss' Fig. 3. None of the methods resulted in the prolonged flat minimum from mid-morning to solar noon that he obtained for calculated atmospheric irradiance.

In his Fig. 4, Weiss shows results for a mostly cloudy day. Differences between measured and calculated values of atmospheric irradiance are small except for short periods when breaks in the cloudiness resulted in peaks in solar irradiance. Large peaks occurred near 1330 and 1410 solar time, for example. Coincidentally with the first peak, measured atmospheric irradiance decreased from ~400 to ~380 W m^{-2} in a 20 min period, while calculated atmospheric irradiance decreased from ~390 to ~295 W m^{-2}. Both measured and calculated values then returned approximately to the same values that had occurred prior to the sunny period. When the second peak in solar irradiance occurred, measured values again decreased slightly, from ~405 to 395 W m^{-2}, while calculated values again decreased by ~100 W m^{-2}, from 410 to ~305 W m^{-2}, in a period of ~20 minutes.

Because atmospheric irradiance normally decreases if a decrease in cloudiness occurs, we feel that quantitatively isolating a dome heating effect in the results described above, as Weiss did, is quite precarious. The magnitude of the decrease in his calculated values, for example, seems unusually large. If the average atmospheric content of water vapor and carbon dioxide did not change significantly for the period of recordings, which is a reasonable assumption for an overcast summer day with some breaks in the cloudiness, the large decrease in atmospheric irradiance would necessarily be caused by a decrease in effective blackbody temperature of the sky. The decrease in atmospheric irradiance from ~400 W m^{-2} to 300 W m^{-2} calculated by Weiss corresponds to a decrease in effective blackbody temperature from 16.5 to −3.5°C.

Such a large decrease could conceivably occur if the sky condition changed from completely overcast to completely cloudless in a short time, but such a change in cloudiness apparently did not occur during his measurements. From recordings of solar irradiance shown by Weiss and from his description of general sky conditions, we are led to believe that the sky was mostly overcast. In such a condition, the cloud-covered portion radiates at an effective temperature higher than that of small cloudless areas. A decrease in atmospheric irradiance of the magnitude calculated, therefore, seems unlikely.

3. Comparison with measurements at the University of Michigan

The behavior of measured and calculated atmospheric irradiances shown by Weiss is similar to that observed at an irradiance and meteorological measurement facility being operated here. Its location and elevation are 42°17′N, 83°44′W, 270 m MSL. Together with other irradiance and meteorological variables, one-minute averages of global solar and atmospheric irradiances have been recorded since August 1979 as part of a program in solar energy and meteorological research and training funded by the U.S. Department of Energy. Global solar irradiance is measured with an Eppley precision spectral pyranometer, atmospheric irradiance with an Eppley pyrgeometer with a silicon dome and incoming solar plus atmospheric irradiance with a Swissteco pyrradiometer.

The pyrradiometer is basically the same unit as that used by Weiss in his calculations, but it is adapted by the manufacturer to measure all-wave downcoming irradiances. The conversion consists of replacing a polyethylene hemisphere on the underside of the sensing plate with an enclosed and internally blackened reference cavity. The temperature of the cavity (T_c) is measured and total hemispherical irradiance ($R\downarrow$) is determined from

$$R\downarrow = R_0 + \sigma T_c^4, \qquad (2)$$

where R_0 is the voltage output of the pyrradiometer converted to irradiance units and σ is the Stefan-Boltzman constant. Atmospheric irradiance ($L\downarrow$) can be calculated as a residual in the equation

$$L\downarrow = R\downarrow - S\downarrow. \quad (3)$$

At the time radiometers for the measurements were procured in 1978, we had no prior expectations as to the behavior of atmospheric irradiance, either as measured with an Eppley pyrgeometer with a silicon dome or as calculated as a residual using the Swissteco pyrradiometer. Now that 2.5 years of continuous recordings with these instruments have been obtained, it has been possible to analyze and compare their performance for a wide variety of cloud and ambient meteorological conditions. Results show that at night, measured (pyrgeometer) and calculated values are nearly the same, regardless of cloudiness. With a cloudless sky in daytime, however, measured values increase and calculated values decrease after sunrise. In general, their behavior is similar to that obtained by Weiss. Both approach the same value near sunset, but the daytime decrease in calculated values is consistently greater than the corresponding increase in measured values.

For a uniformly overcast sky and values of global irradiance less than ~200 W m^{-2}, measured and calculated values are usually in close agreement. Breaks in overcast cloudiness that expose the sensors to direct solar irradiance, however, result in a behavior similar to that observed by Weiss, in that a decrease in calculated values occurs, that is much greater than the corresponding decrease in measured values. One would expect a temporary decrease in atmospheric irradiance also to occur when a break in cloudiness is directly over the sensors but is not large enough to allow the sun to irradiate them directly. With such a sky condition, however, large decreases in calculated atmospheric irradiance have been observed only to coincide with marked increases in solar irradiance.

4. Conclusions and recommendations

The results obtained by Weiss and those obtained here indicate that daytime values of atmospheric irradiance measured with an Eppley pyrgeometer with a silicon dome vary in a realistic manner, but those obtained from calculations from Swissteco net pyrradiometer data do not. To what extent this behavior is caused by the residual calculation procedure, the Swissteco-type pyrradiometer itself or a combination of these two factors needs further study.

The effects of dome heating on atmospheric irradiances measured with the Eppley pyrgeometer still remain to be quantified, in our opinion. That such an effect exists seems to have been shown by Weiss and also by Clark (1980) in recent tests at the Solar Data Center at Trinity University. Clark found that the output voltage of a pyrgeometer decreased by ~8% when shaded near solar noon on a cloudless summer day.

A series of detailed measurements of atmospheric irradiance with a shaded pyrgeometer next to an unshaded one is necessary to quantify the magnitude of a dome heating effect accurately. A solar-tracking occulting disc apparatus similar to that used in measuring diffuse solar irradiance could provide a practical shading technique. The unit consists of a disc 5 cm in diameter on a curved arm 1.5 cm wide and 50 cm from a pyranometer. The arm with the disc attached is fastened to a solar tracker. Having a means of measuring and controlling the temperature of the disc would enable effects of its temperature on pyrgeometer performance to be determined and taken into account. Simultaneous measurements of wind speed, temperature and dew point should accompany the irradiance measurements.

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