DESIGN, CONSTRUCTION AND COMPARISONS OF THE PERFORMANCE OF DIRECT-BEAM VIEW-LIMITING TUBES

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ABSTRACT

Two direct-beam view-limiting tubes with different design characteristics were constructed for direct solar radiation measurements with a portable spectroradiometer. Applications of the view-limiting tubes include the determination of diffuse component from a simultaneous global radiation measurement. Measurements of the spectral irradiances with the screening tubes could also be used to characterize atmospheric turbidity and atmospheric water vapour. To investigate errors introduced by circumsolar radiation due to the differences in the opening angles, comparisons of the direct spectral irradiances measured with the two tubes were carried out in two different weather conditions between 300 nm and 1100 nm at 2 nm intervals. The comparisons showed that the spectroradiometer registered between 0.5% and 5% more radiation with the wider tube in the UV (300 -400 nm) region depending on the atmospheric conditions. On the other hand, there was no systematic differences in the visible and near infrared regions indicating that the error caused by the interception of circumsolar radiation by pyrheliometers is spectrally sensitive.

1. INTRODUCTION

Various pyrheliometers have varying degrees of field of view. Therefore, they receive varying degrees of circumsolar radiation making radiation comparisons of the instruments difficult. This is because the intensity of the aureole fluctuates with the turbidity of the air so that comparisons between two instruments may give different results on different occasions. Deepak[1] defined solar aureole as a region of enhanced brightness surrounding the sun's disk which is due to the predominantly forward scattering of sunlight by aerosols.

WCRP[2] estimated that deviations of normal incidence pyrheliometers from cavity type absolute pyrheliometers range from 2 W/m^2 at direct radiation values of 1000 W/m^{2}to 4-5 W/m^2 at values of 500-600 W/m^2 due to the effect of circumsolar radiation. The amount of circumsolar radiation intercepted varies with the air mass and atmospheric turbidity and according to Igbal(3), can lead to errors of 1 - 3% in measurement of the direct normal irradiance depending on the pyrheliometer used. Also, Angstrom and Rodhe[4] estimated that pyrheliometers could give irradiances 1-8% too high depending on the size of the aperture (1-13^0), and the product of the atmospheric turbidity and the air mass(mB).

Major[5] argued that as a result of the geometry of the screening tube of pyrheliometers, the direct radiation excluded by diffusometers is not equal to the vertical component of the direct radiation measured by pyrheliometers. This is due to the different amount of circumsolar radiation measured with the actual direct beam by different pyrheliometers.

Remembering that the sun subtends only a finite angle of 32' (~ 1/2^0) at the earth, pyrheliometers inevitably measure some circumsolar radiation together with the direct beam since their opening angles are necessarily wider than that subtended by the sun.

The WMO recommended a full-view angle of 5° for investigations of optical depths with photometers in order to minimize the effects by the solar aureole especially during conditions of high turbidity [6]

A LICOR (model LI-1800) spectroradiometer was used for this experiment. The LI-1800 is a self-contained, battery operated and microprocessor controlled spectroradiometer with a spectral range of 300-1100 nm. It has a spectral resolution of 6nm and a wavelength accuracy of ± 2nm.

2.1 PURPOSE OF THE DIRECT-BEAM VIEW-LIMITING TUBE

A Teflon dome with a 180° field of view was originally provided with the instrument. This gives the equipment the capability for the measurement of the global radiation which is the sum of the direct portion of sunlight and the diffuse component of sky light received together on a horizontal surface. It could also be used for the measurements of the diffuse irradiance. The diffuse irradiance is the downward scattered and reflected radiation coming from the whole hemisphere with the exception of the solid angle subtended by the sun's disc. However, for measurements of the direct-beam irradiance (comprising mainly of unscattered and unreflected solar radiation), a view-limiting tube was required.

2.2 DESIGN OF THE DIRECT-BEAM VIEW-LIMITING TUBES

Considering a circular collimating tube illustrated in fig. 1, let

r = Receiving aperture (mm) [also called the radius of receiver]

L = Length of the tube (mm)

R = Radius of the limiting aperture (mm) [also called the radius of the field stop]

Then we define the following parameters and angles also depicted in fig. 1:

Z_o = View Angle = tan-1 (R/L)
[full view angle = 2 tan-1 (R/L)]

Z_s = Slope Angle = tan-1 ((R-r)/L)

Z_1 = Limit Angle = tan-1 ((R+r)/L)

C_r = Collimation Ratio = L/2R

According to Iqbal(3), the World Meteorological Organization (WMO) recommends the following limitations for pyrheliometers:

$$1^0 \leq Z_s \leq 2^0 \quad \text{and} \quad L/r. \geq 15.$$

From the two conditons, we have $Z_0 \leq ,4^0$

Two different tubes were designed and constructed for direct solar radiation measurements with the spectroradiometer. The first which is a simple colimator tube, was made of hard cardboard in 1990 and placed above the standard cosine receptor of the instrument.

The tube has a length of 270 mm and the diameter of the circular field stop at the front is 44 mm. In addition to the frontal circular field stop, there are three circular diaphragms to minimize errors introduced by circumsolar sky radiation entering the tube and reflecting against the inner wall. The aperture of the tube is 9.4° as shown in table 1.

In 1991, a second tube with a 5-degree field of view was constructed to meet the recommendations of WMO[6]. The length of this new tube is 500 mm and the radius of the limiting aperture (or the radius of the field stop) is 21.8 mm. The other parameters are given in table 1. In this case, the collimator tube was fitted with several circular diaphragms to reduce stray light. The 2.5° - half angle circular cone with appropriate

collimating diaphragms used for the collimator tube in 1991 was intended to minimize the registration of circumsolar radiation and it is consistent with sufficient tracking tolerance as recommended by WMO[6]

Fig.1 and table 1 show the design criteria used in establishing the physical dimensions of the direct-beam modules for the LI-COR solar spectroradiometer (LI-1800).

For comparison, parameters are also shown in the table for the Normal Incidence Pyrheliometer (NIP), Linke - Feussner Pyrheliometer (LFP), and absolute Cavity Radiometer (ACR).

2.3 OPERATION OF THE DIRECT-BEAM MODULE

The direct-normal irradiance view-limiting tube is mounted over the Teflon-dome receiver. The module is then adjusted to flush with LI-1800 box and the locking screw tightened for a snug grip on the dome assembly.

Having fitted the tube at right angles to the receiving surface of the receptor, the radiometer is oriented so that the tube is aligned to the direction of the incident solar rays. The focusing of the sun is facilitated by using the diopter and target located on the side of the module (fig.1)

2.4 APPLICATIONS OF THE DIRECT-BEAM MODULE

Apart from the measurements of the direct beam solar irradiance, other applications of the direct-beam module include determination of diffuse component of the spectral solar irradiance distribution from a concurrent global radiation measurement. It should be pointed out however, that the associated error in the measurement in this case, could increase [7,8]. With careful consideration of the bandpass characteristics of spectroradiometers, direct-beam spectral irradiance measurements can also be used to characterize atmospheric turbidity and water vapour using techniques similar to those developed for filter-based sunphotometers.

3. COMPARISONS OF THE PERFORMANCE OF THE VIEW-LIMITING TUBES

Comparisons of the direct spectral irradiances measured with the two tubes were carried out in order to investigate errors introduced by circumsolar radiation due to the differences in the opening angles. The comparisons were done by divinding the spectral irradiances measured at 2nm intervals with the new tube by those measured with the old tube. The first comparison, was carried out at a prevailing atmospheric turbidity of $\beta = 0.06$ and an average air mass of 2.0. It could be seen from fig. 2 that the spectroradiometer registered less than 0.5% higher readings with the wider (older) tube in the UV-A region (300-320 nm) and that there are no systematic differences in the visible and infrared regions. The discontinuities at 760 nm and 940 nm which are absorption bands of oxygen and water vapour respectively are due to short term variations in these gases.

The second comparison (also indicated in fig. 2), was carried out at a higher turbidity ($\beta = 0.08$) and an average air mass of 3.0. In this case, the older tube with an opening of 9.4° accepted about 5% more radiation in the UV-B (300-320nm) than the newer tube with (5.0°). The difference decrease to about 1 % at 400 nm. Between about 550 to 1000 nm, there are no appreciable systematic differences in the irradiance received by the two tubes. From 1000nm however, the newer tube seemingly received more radiation which gradually increased to about 2% at 1100 nm. This increase appears to be due to the temperature sensitivity of the silicon photodiode detector which increases from about 0.5%/C at 1000nm to 1-2%/C at 1100 nm. The temperature difference between the two measurements was about 1°C.

The average percentage differences in the direct (broad-band) irradiance measured by the two tubes at different B values are given in table 2. The values are much lower than that shown for the narrow-band (2nm) analyses. This shows that the error caused by the interception circumsolar radiation by pyrheliometers does not only depend on the air mass and atmospheric turbidity, but that it is also spectrally sensitive.

It should be pointed out, that the higher differences in the UV bands are expected since Rayleigh scattering is predominant within this range. Forward scattering of solar radiation by atmospheric aerosols is also known to be more significant in the UV than other regions in the solar spectrum.

For the atmospheric conditions prevalent during the first comparisons, Angstrom and Rodhe [4] predicted that with an aperture of 9.4°, a pyrheliometer should give an irradiance of about 2% too high in comparison with one with a full view angle of 5°. For the prevalent weather conditions during the second comparisons, the predicted difference in the extra radiation due to the difference in the apertures of the two tubes is about 3.5%. From the spectral point of view, the results of the comparisons presented above fall within these predictions especially within the UV bands. However, the results of the broad-band comparisons show that the differences in the irradiances received by the two tubes are far less than those prognosticated. The generally low average differences could be due to the incorporation of appropriate collimating diaphragms in the two tubes.

4.0 CONCLUSION

Two direct-beam view-limiting tubes with different characteristics were designed and constructed for direct solar radiation measurements with an LI-1800 spectroradiometer. The direct spectral solar radiation measurements could be used for the determination of diffuse component from a simultaneous global radiation measurement. Measurements of the direct-beam spectral irradiances with the screening tubes could also be used to characterize atmospheric turbidity and water vapour aloft.

Investigations of the errors introduced by circumsolar radiation due to the differences in the opening angles between 300 nm and 1100 nm at 2nm intervals showed that the spectroradiometer registered more radiation (between 0.5% and 5%) with the wider tube in the UV region (300 - 400 nm) depending on the atmospheric conditions. There was practically no systematic differences however, in the visible and near infrared regions. The error caused by the interception circumsolar radiation by pyrheliometers has therefore been shown to be spectrally sensitive.

Attention should be paid to the apertures of pyrheliometers used to measure the direct component of solar radiation especially in conditions of high atmospheric turbidity.

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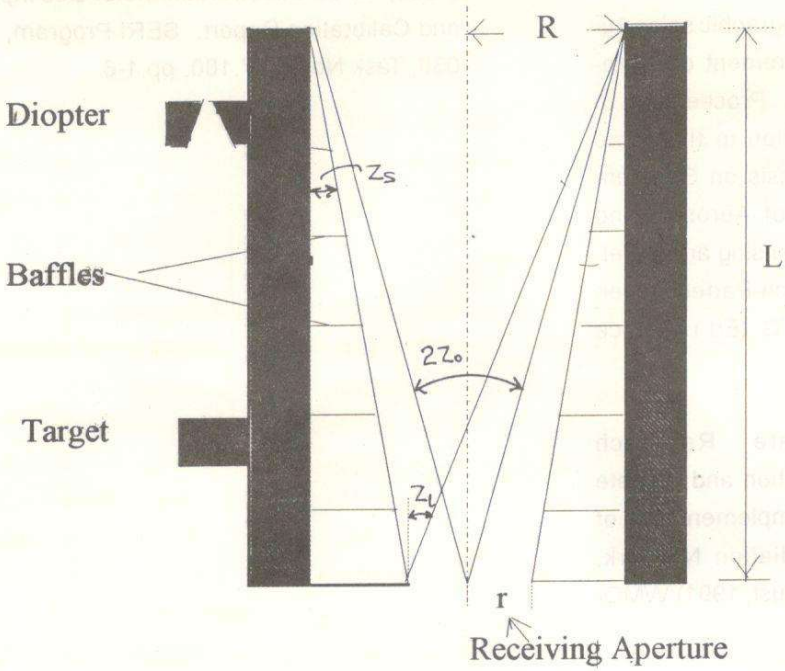


Fig. 1: Schematic cross-sectional view of the direct-beam module defining the field of view $2Z_o$, the slope angle Z_s and the limiting angle Z_l, and showing the diopter and the target used for aiming.

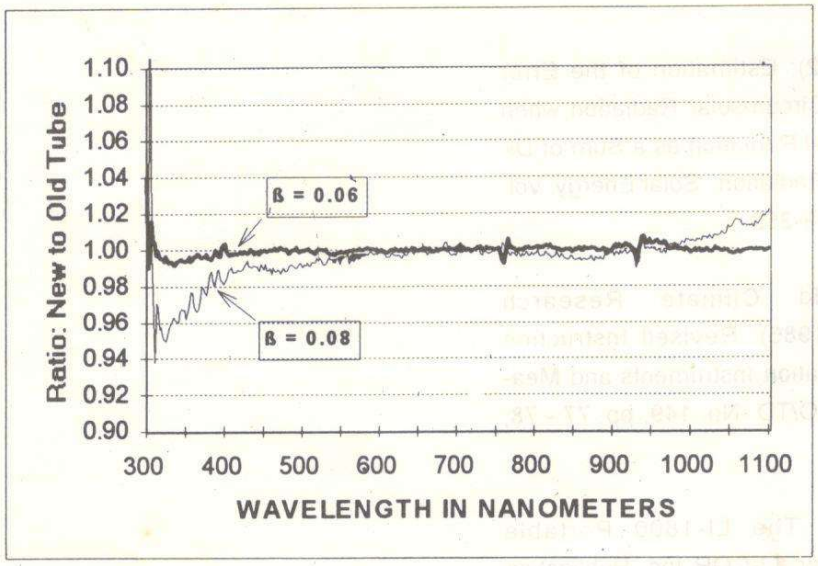


Fig. 2: Comparison of the direct spectral irradiance measured with the old (1990) and new (1991) direct-beam view-limiting tubes at $\beta = 0.06$ & $\beta = 0.08$.

Table 1: Design parameters for the view limiting module. The limit angle and the collimation ratio are calculated from the field of view and slope angle. For comparison, parameters are shown for LI-COR solar spectroradiometer (LI-1800), Normal Incidence Pyrheliometer (NIP), Kipp & Zonen Linke-Feussner Pyrheliometer (LFP), and Absolute Cavity Radiometer (ACR).

Parameter	LI-1800 (Old)	LI-1800 (New)	NIP	LFP	ACR
2Zo	9.4	5.0	5.7	10.2	5.0
Zs	1.49*	0.77	2.08	1.1	0.73
Z_t	7.80*	4.20	3.65	9.1	4.26
Cr	6.14	11.49	10.0	5.6	11.45
R(mm)	22.0	21.8	10.0	6.3	7.97
r(mm)	15.0*	15.0	2.75	5.0	5.64
L(mm)	270	500	200	70.3	182.5

*Based on the estimate of r ≅ 15.0 mm.

Table 2: Average percentage differences in the direct (broad-band) irradiance measured by the two tubes at different β values.

Prevailing Turbidity	UVB 300-320nm	UVA 320-400nm	UV 300-400nm	VIS 400-700nm	IR 700-1100nm	TOTAL 300-1100nm
β=0.06	0.4	-0.4	-0.2	0.0	0.0	0.0
β =0.08	-0.8	-2.9	-2.4	-0.6	0.1	-0.4