A Solar Aureole Radiometer for Atmospheric Aerosol Studies

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ABSTRACT

A method of minimizing the effects of direct solar scatter in aureole measurements is described. Experimental results for "clear" and polluted conditions are illustrated. The effects of large particles on the shape of the aureole are evident. The solar aureole irradiances at several angles from solar center and on different days are compared with conventionally measured spectral turbidities.

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1. Introduction

There is considerable interest at the present time in routine monitoring of the atmospheric haze optical thickness, commonly termed the atmospheric turbidity. There is a possibility that man's activities could increase the global atmospheric particulate loading and thus have a significant effect on world climate (SMIC, 1971).

Turbidity is measured conventionally by determining the direct solar transmission. However, there are two problems connected with such a measurement. First, one has to determine the solar irradiance above the haze layer. This can be determined by a Bouguer-Lambert plot of irradiance versus solar angle, but this requires steady haze conditions throughout the measurement period. A second problem is that the low turbidities (~ few percent) typical of remote "clean air" localities give a change in solar irradiance which is of the same order as the measurement accuracy (Laulainen and Taylor, 1974).

Measurement of the solar radiation *scattered* by the haze at angles close to the sun can be made quite accurately, even at low atmospheric turbidities. If the aerosol size distribution remains constant, then the solar irradiance scattered at any angle is a measure of the atmospheric turbidity. The influence of changing aerosol distributions can be partly removed by integration of the solar irradiance over a range of angles. This method has been used by Ångström (1974) who analyzed 10 years of total circumsolar irradiance between angles of 3°30′ and 13°30′ to the solar disc and related the data successfully to simultaneous turbidity measurements. The measurements were made at mountain sites where the background aerosol might be expected to retain a reasonably constant size distribution.

This note reports a new technique for measuring the solar aureole, two representative curves, and some preliminary results of a comparison between aureole irradiance at several angles and values of atmospheric turbidity measured by conventional means.

2. Radiometer

The main instrumental problem with solar aureole radiometers is the elimination of direct solar radiation from the detector aperture at angles of observation close to the direct solar beam. This can be accomplished by using blackened tubes. However at the high grazing angles of incidence of solar radiation encountered (~80°–90°), the reflectance of a black surface becomes nearly specular. As the direct solar radiation is 100 to 1000 times as intense as the solar aureole, internally scattered radiation creates a severe problem. The in-

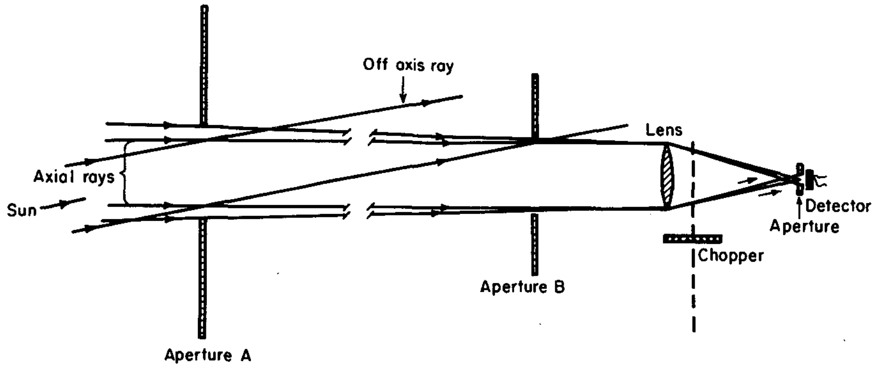

FIG. 1. Schematic of the baffling system showing the paths of axial and off-axial solar rays. Apertures A and B refer to those shown in Fig. 2.

sertion of a series of suitable baffles reduces, but does not eliminate, scattered solar radiation at the detector. At an angle of about 2° from the direct beam, this radiation can still be as much as 10% of the measured aureole intensity (Wagner and Bartsch, 1973).

The idea behind the present method of baffling is simple. The diameter of the baffling tube is made "infinite" while preserving a suitable aperture at its top end. Thus, there are no "sides" from which solar radiation can be reflected, as shown diagrammatically in Fig. 1. In practice, of course, the end aperture must be connected rigidly to the detector mounting. The method of doing this with the present instrument is shown in Fig. 2. The second aperture at B is employed in the alignment procedure. Also, the direct solar beam falls on a screen at B and graduated marks on this screen give the angle in the solar almucantar at which the aureole is observed. For angles greater than 9° off the sun, values are calculated from the solar elevation and the scale on the azimuth mount.

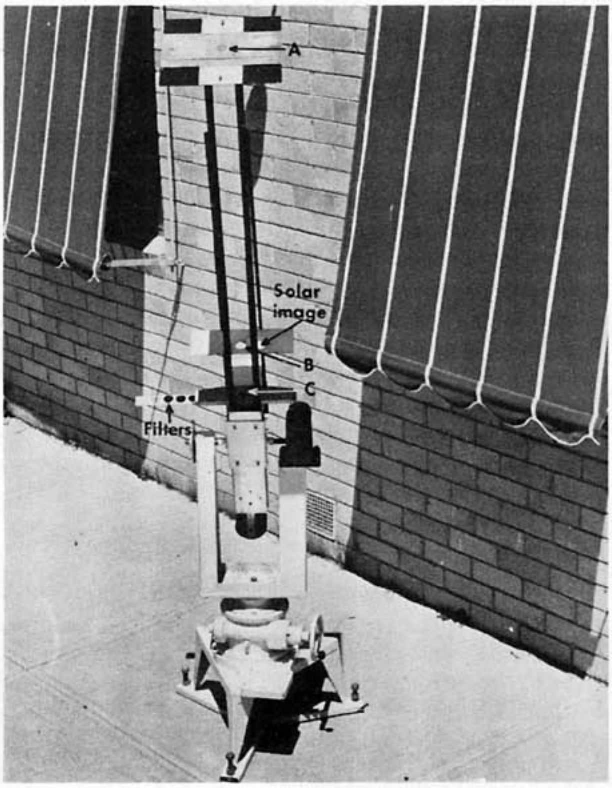

FIG. 2. Photograph of solar baffling and radiometer: A, front aperture; B, back aperture. The image of A made by the sun is shown on the scale next to B.

The detector system used at present employs a Barnes thermistor detector at the focus of a 1 inch lens with a circular aperture placed just in front of the detector. The aperture has a radius of 0.9 mm and is placed at a distance of 48.8 mm from the lens of 25 mm aperture, giving a total semi-angle of acceptance of 1.06°. The radiation is mechanically chopped and the output amplified and synchronously rectified. The filter holder contains cut-on filters for isolating parts of the solar spectrum, and there is also a holder (not shown) for placing neutral density filters in front of the cut-on filters.

The aperture A is first aligned on the detector axis by making solar transits or alternatively by placing an isotropic source at the aperture. Aperture B is then inserted at the correct location using a suitable collimated light beam through aperture A. The angular response when the sun's image drifts across the detector is shown in Fig. 3. The total semi-angle of acceptance calculated from such a trace is about 0.7° which is less than that predicted from the angular dimensions, because of vignetting effects of the lens and of aperture A. The semi-angle at half-height is 0.2°.

Measurements of solar scattered irradiance are normalized to the direct solar irradiance by inserting neutral density filters in the optical path and pointing the instrument directly at the sun. The actual solar irradiance at the ground is obtained by measurements with a standard Linke-Feussner pyrheliometer, employing similar filters (Collins and Rabich, 1971).

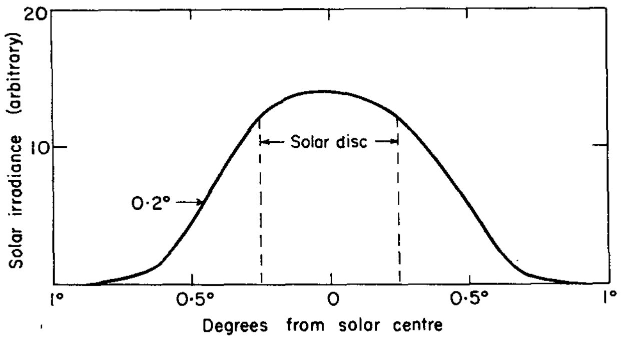

FIG. 3. Response of the radiometer as the solar image transits across in the almucantur.

Examples of the measured solar aureole are shown in Fig. 4. The spectral interval is from the shortwave limit (~380 nm) to 590 nm, obtained by using two cut-on filters at ~380 nm and 590 nm. Curve (1) was for a clear day with little visible pollution, Curve (2) for a day with considerable local pollution evident. Radiation scattered by molecules has not been subtracted. The steep rise in irradiance at angles <5°, particularly for the "clear" day, is indicative of the presence of large particles in the atmospheric haze (M. Reiche, private communication).

It was originally found that a small amount of direct solar radiation was being scattered into the beam at an angle of about 9° due to reflections from one of the aperture supports. This was reduced to a negligible amount by painting the supports matt black.

Solar aureole data are being collected at present for comparison with atmospheric turbidities. The aim is to discover what scattering angles, or range of angles, give an irradiance which is sufficiently independent of aerosol size distribution to correlate with the measured atmospheric turbidity.

3. Results

Some preliminary results taken with the present detector system are shown in Fig. 5. The solar irradiance in the almucantur at a given angle from solar center is shown plotted against the atmospheric turbidity at 500 nm. The turbidity was obtained from spectral measurements using a spectral pyrheliometer and cut-on filters similar to those used with the aureole radiometer. The values have an accuracy of about 20%. The points represent measurements made on separate clear days. On all days except for 14 April 1975 the aureole curves looked rather similar to curve (1) and for these days the aureole irradiance does correlate quite well with atmospheric turbidity. On 14 April the values at small angles are much too low for the high turbidity measured indicating a different particle size distribution, but the value at 25° from solar center is quite consistent with the other days. There was certainly a high level of pollution evident visibly on this day. However, if the *shape* of the aureole curve for very *low* turbidities is relatively invariant from day to day, then there is a possibility of measuring these low turbidities by measurement at a single angle from solar center.

Future measurements will be made with narrow-band filters and a more sensitive radiometer. Theoretical work on the relation between analytic aerosol size distributions, the solar aureole and atmospheric turbidity is also being done [see, e.g., Box and Lo (1976) and McKellar (1974)].

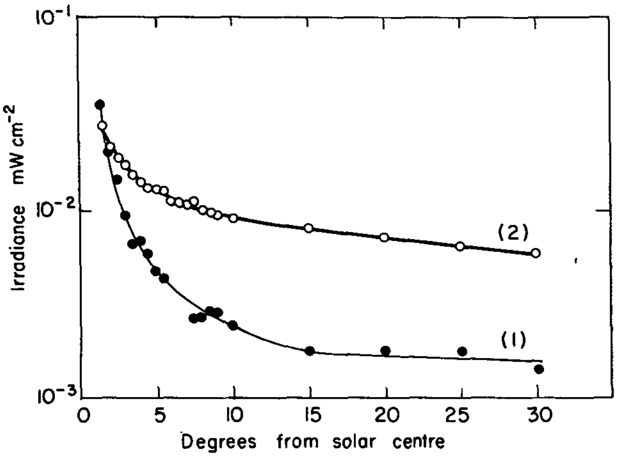

FIG. 4. Measured irradiance in the solar aureole along the solar almucantur in the 380–590 nm spectral region. Irradiance values are normalized to one airmass. Curve (1): a visually "clear" day (5 March 1975); curve (2): a day on which there was considerable atmospheric pollution from the City of Melbourne (14 April 1975).

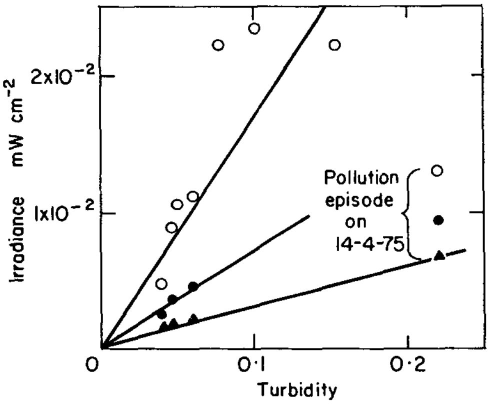

FIG. 5. Measured irradiance in the almucantur at a given angle from the solar center plotted against atmospheric turbidity at 500 nm: 5° from solar center (open circles), 10° from solar center (solid circles), 25° from solar center (solid triangles).

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