A Photoelectric Coronameter for Atmospheric Turbidity Studies

Glenn E. Shaw and Charles S. Deehr

Geophysical Institute, University of Alaska, Fairbanks 99701

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ABSTRACT

Atmospheric aerosols scatter light predominantly in the near-forward direction to cause a brightening near the sun (the solar aureole). Measurements of the brightness gradient and absolute radiance in the solar aureole can be used to infer information about the size distribution of aerosols. A photoelectric coronameter is described which allows accurate measurements of the sky radiance to be made in the aureole region. The instrument has potential application in background aerosol monitoring and air pollution studies.

1. Introduction

There is increasing concern among atmospheric scientists that background turbidity values may be inexorably increasing as a result of human industrial activities. If this hypothesis is correct, then, as several investigators have pointed out (Rasool and Schneider, 1971; Mitchell, 1971; and others), significant climatic perturbations could occur. There is, therefore, an increasing interest in establishing new methods of sensing seasonal variations and secular changes in natural aerosol loading at remote locations as a baseline above which the effects of human activity can be measured.

The purpose of the present contribution is to describe the theory and operation of an instrument which has been developed for making precision measurements of the sky brightness within a few degrees of the solar limb.

It is well known that the sky brightness is considerably enhanced in the circumsolar region (the solar aureole) due to near-forward scattering by aerosols. Measurements of the sky brightness within several degrees of the sun are useful in relation to the problem of evaluating the aerosol scattering function (Eiden, 1968; Green *et al.*, 1971), and for deducing aerosol columnar mass loading. Deirmendjian (1970), for instance, has developed a technique that can be employed to derive the aerosol scattering function from measurements of sky brightness. This analysis involves a perturbation on a Rayleigh atmosphere (for which an exact evaluation of the radiation field is known including all orders of scattering), with an equivalent optical depth which can, of course, be easily derived from sun photometry. The Deirmendjian (1970) method reduces in complexity if measurements are carried out in the solar almucantar (an azimuth scan through the sun at constant elevation angle). We have used this technique successfully to derive the aerosol scattering function in pure atmospheres in Arctic Alaska (Shaw and Deehr, 1974).

From an observational standpoint, the quasi-monochromatic diffuse sky intensity in the almucantar

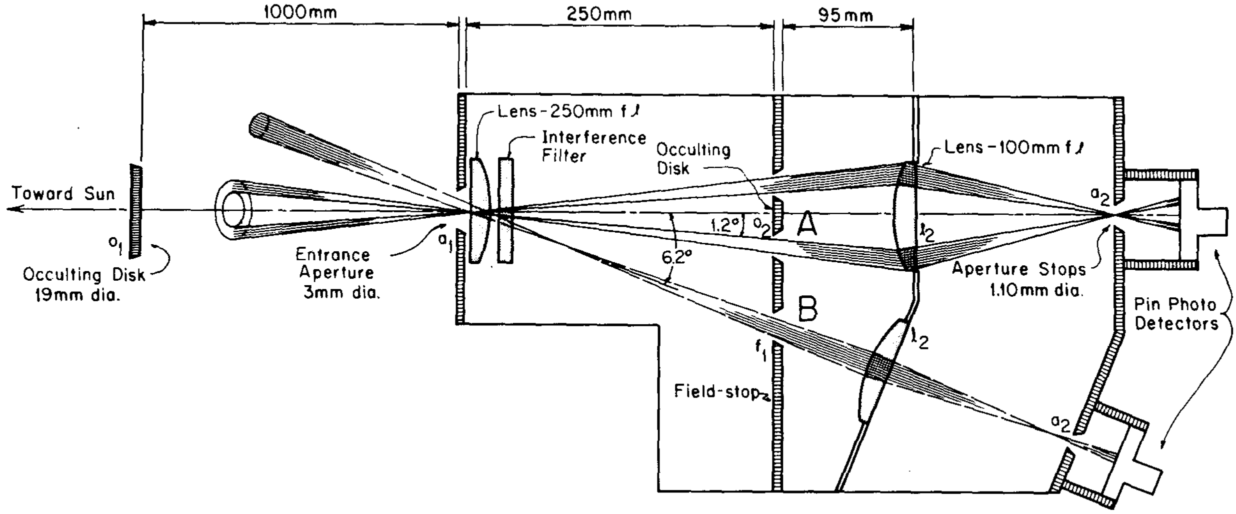

FIG. 1. Schematic diagram of photoelectric coronameter (not drawn to scale).

can be measured by making scans of the sky with a well-baffled photometer system including an optical interference filter to define a narrow wavelength interval. However, when an instrument of this type is used, one must be aware that light from the direct solar disk can enter into the photometer's field of view by scattering and diffraction from the various parts of the instrument. This effect, even for well-baffled instruments (~1° field of view), overrides the sky signal for angular distances of less than approximately 6° from the solar limb. Thus, even with the use of a well-baffled photometer system, it is almost impossible to make meaningful measurements of absolute diffuse sky brightness in the aureole region near the solar limb.

The instrument described below was designed to evaluate, quantitatively, the sky brightness and its gradient at angular distances of less than 6° from the solar limb. In practice, we measure sky brightness in the solar almucantar with a well-collimated (1° field of view) photometer of the usual design to within 10° of the sun. The photoelectric coronagraph or "coronameter" is then used to determine sky brightness at two additional points located around 2° and 6.5° from the solar limb. One can then draw a smooth curve through the data points to derive sky intensity up to approximately 1° from the solar limb.

2. The photoelectric coronameter

a. The instrument

The photoelectric coronameter has been developed to measure the diffuse-sky radiation field at small angular distances from the sun. Its design is based on the principles underlying a solar coronagraph, and it is similar in basic design to a visual-matching instrument described by Evans (1948), and a photographic coronagraph used by Eddy (1961). Formulas for calculating the size of various components can be found in the description of the visual instrument by Evans (1948).

Fig. 1 shows a schematic illustration of the photoelectric coronameter. In operation, the instrument is pointed toward the sun. Occulting disk O_1 shades the entrance aperture a_1 from the direct solar radiation, and diffuse skylight around O_1 enters through a_1 and is filtered by interference filter F. Lens ℓ_1 forms an image of the circumsolar region of the sky, and a slightly out-of-focus image of occulting disk O_1 on the second occulting disk O_2. The latter disk is made slightly larger than the blurred image of O_1 and serves to absorb diffracted light from the edge of O_1. This diffracted light is of the order of the circumsolar sky brightness and would introduce considerable error if only a single occulting disk (O_1) were used.

The field stop at f_1 is divided into two apertures. The first of these is circular and is centered around the occulting disk O_2 to provide an annular field of view of the region around the sun with a solid angle of 2×10^{-3} sr and located at a mean scattering distance from the sun's limb of 2°. This defines channel A.

The second aperture in plate f_1 (channel B) forms a segment of an annular field. It subtends the same solid angle as channel B, but it is located 6° horizontally from the sun's limb. Thus, the light passing through aperture A is the circumsolar sky flux at an angle of 2° from the sun while that passing through aperture B is from an equal area of sky to one side of the sun.

Lens elements ℓ_{2A} and ℓ_{2B} in conjunction with lens ℓ_1 form a 2.5 power telescope. Sky radiation passing through these lenses impinges on solid-state PIN-doped silicon photodetectors, PD_A and PD_B, to generate an electric current which is amplified and displayed on digital voltmeters.

As a final precaution to inhibit diffracted light from the edge of the entrance aperture a_1, a field stop a_2 (slightly smaller than the image of a_1) is placed coincident with the image of a_1 formed by lens ℓ_2. This refinement may not actually be necessary because the magnitude of diffracted light from a_1 is small in comparison to the sky radiation field. It should also be stated that the problems of alignment in the channel at 6° from the sun are not so critical as in the channel near the sun.

In principle, one could derive the near-sun circumsolar radiation at multiple wavelengths by replacing the single filter F by a filter turret arrangement. We have chosen to operate at a single wavelength of $\lambda = 580$ nm; the filter width is 10 nm.

b. *Calibration*

If the measurements of circumsolar radiation are to be used to obtain quantitative estimates of aerosols, the coronameter must be calibrated in terms of absolute units of intensity (μW cm^{-2} nm^{-1} sr^{-1}). There are several ways of doing this, but we have found that an accurate and highly convenient method consists of viewing with the coronameter a white Lambertian screen placed normal to the sun's direction and illuminated by the direct solar radiation. We measure the solar radiation flux incident on the screen at the coronameter wavelength with a small separate photometer (which can be calibrated either with a standard lamp or by using the Langley extrapolating procedure (Shaw *et al.*, 1973). The contribution of screen radiance arising from diffuse sky radiation is removed by shading the screen and subtracting the resultant coronameter voltage from the voltage corresponding to the total (diffuse and direct) screen radiance.

3. Discussion

The photoelectric coronameter can provide quantitative information on air turbidity. As an example, if one assumes that aerosols are distributed by size according to a Junge power law distribution, one can relate the ratio of $I(2°)/I(6°)$ to the Junge power law exponent. However, due to a number of possible errors inherent in this assumption, we recommend that sky brightness also be measured simultaneously over a large range of scattering angles using a standard well-baffled photometer. A physically more meaningful result is then obtained by considering the data from the entire range of angles and finding the aerosol scattering phase functions from a theory based on a perturbation (Deirmendjian, 1970; Shaw and Deehr, 1974) of an equivalent Rayleigh-scattering atmosphere.

We have found that numerical changes in optical depth of only a few thousandths give rise to readily detected changes in aureole brightness. In Arctic Alaska, for example, the sky brightness at 6° was found to be enhanced over a Rayleigh atmosphere usually by a factor of more than 2, and sometimes by as much as a factor of 10 or more during ice-crystal precipitation. We have also found interesting correlations between changes in circumsolar sky brightness fluctuation and mixing depth phenomena (Holmgren *et al.*, 1974) as deduced with an acoustic sounder. In short, we believe that the photoelectric coronameter provides a sensitive and useful supplemental tool for use in air turbidity studies.

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REFERENCES

Deirmendjian, D., 1970: Use of scattering techniques in cloud microphysics research 1. The aureole method. Rand Rept. R-590-PR.

Eddy, J. A., 1961: The stratospheric solar aureole. Ph.D. thesis, University of Colorado.

Eiden, R., 1968: Calculations and measurements of the spectral radiance of the solar aureole. *Tellus*, **20**, 380–398.

Evans, J. W., 1948: A photometer for measurement of sky brightness near the sun. *J. Opt. Soc. Amer.*, **38**, 1083–1085.

Green, A., A. Deepak and B. Lipofsky, 1971: Interpretation of the sun's aureole based on atmospheric aerosol models. *Appl. Opt.*, **10**, 1263–1279.

Holmgren, B., G. E. Shaw and G. Weller, 1974: Turbidity in the arctic atmosphere. AIDJEX Bull. No. 27, Div. Marine Sources, University of Washington.

Mitchell, J. M., Jr., 1971: The effect of atmospheric aerosols on climate with special reference to temperature near the earth's surface. *J. Appl. Meteor.*, **10**, 703–714.

Rasool, J. I., and S. H. Schneider, 1971: Atmospheric carbon dioxide and aerosols effects of large increases on global climate. *Science*, **173**, 138–141.

Shaw, G. E., and C. S. Deehr, 1974: On the relation between circumsolar sky brightness and atmospheric aerosols. Final Report EPA Grant R801113-01-2, Geophysical Institute, Fairbanks, Alaska.

——, J. A. Reagan and B. M. Herman, 1973: Investigation of atmospheric extinction using direct solar radiation measurements made with a multiple wavelength radiometer. *J. Appl. Meteor.*, **12**, 374–380.