Solar Infrared Photometer

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26 June 1984 and 26 December 1984

ABSTRACT

A sun photometer which operates at five wavelengths in the near infrared between 1.0 and 4.0 μm has been developed. The instrument is a manually operated, filter wheel design and has principal applications for atmospheric aerosol studies. The wavelength filters were selected at bands with minimal gaseous absorption. A modified Langley analysis which accounts for residual gaseous absorption is employed for the instrument calibration. Calibration and stability results for the instrument are presented.

1. Introduction

Sun photometry is a standard technique for measuring transmission through the atmosphere. The observation of spectral turbidity has basic applications for studies of the magnitude and influence of particulate loading in the atmosphere. Most current sun photometer instruments are based on silicon or germanium photodiode detectors and operate at wavelengths less than 1.1 μm for silicon or 1.7 μm for germanium detectors (Shaw, 1983; Volz, 1974). However, there are a number of applications for which aerosol optical thickness measurements at longer wavelengths are desirable. The scattering, and particularly the absorption, of IR wavelength radiation is important to the climate influence of aerosol particles. Also, the scattering of solar radiation in the atmosphere is an important problem for interpretation of satellite earth resource imaging. With the advent of the thematic mapper instrument, measurements have been extended into the 2 μm wavelength region, and knowledge of optical thickness at these wavelengths is desirable. In addition, measurements into the IR region should improve the retrieval of aerosol size distributions from spectral extinction measurement. The inversion of spectral sun photometer measurements to derive the columnar aerosol size distribution has been demonstrated and applied (King *et al.*, 1978; Michalsky *et al.*, 1984). For extinction measurements which are limited to visible wavelengths, substantial errors can arise in the inversion results for larger particle sizes due to lack of information in the inversion kernel. An extension of observations to longer wavelengths will improve the inversion information at larger particle sizes.

In this note we will describe a sun photometer which operates at five bands in the 1–4 μm wavelength region. The instrument is a basic design which requires manual operation in a manner similar to most simple visible wavelength sun photometers. In order to measure aerosol optical thickness in the near IR region, wavelength bands were carefully selected to minimize gaseous absorption, and as will be described, corrections must be applied to account for any residual gaseous attentuation.

2. Instrument

The solar infrared photometer (SIP) is a filter wheel design whereby wavelengths are selected through a sequence of narrow band interference filters. The instrument characteristics are listed in Table 1, and a simplified functional diagram of the SIP is shown in Fig. 1. On the particular instrument described here, wavelengths are selected by manually rotating the filter wheel. The filter wavelengths were chosen in order to minimize gaseous absorption, with primary consideration given to minimization of absorption by variable gases such as water vapor. The 1.032 μm wavelength allows for overlap with and comparison to measurements by silicon detector type photometers. Filter bandwidths were selected in order to maintain the relative instrument response within an order of magnitude over the range of wavelengths and in addition avoid gaseous absorption. Just as for visible wavelength photometers, a critical factor for the SIP filters was out-of-band rejection over the response range of the detector. The filters were specified and tested for 10^{-5} out-of-band rejection.

The instrument detector is a 3 mm square PbSe element mounted to a two stage thermoelectric cooler. The detector is controlled to a constant −10°C operating temperature. A passivation type coating of the PbSe element provides for good detector stability. Since the detector responds to beyond 5 μm wavelength, it is necessary to chop the incoming radiation

TABLE 1. Instrument characteristics.

Characteristic	Value
Filter wavelength, bandwidth (FWHM)	1.032, 0.01 1.225, 0.01 1.550, 0.01 2.233, 0.024 3.956, 0.046 μm
Field definition	Baffled cone
Field of view	1.5° Clear field
Detector	PbSe (IR Industries #5767)
Detector temperature	−10°C
Chopping rate	430 Hz (nominal)
Demodulator bandwidth	2 Hz
Readout	4 Digit panel meter

in order to prevent offset drifts due to emitted thermal radiation within the instrument. A PbSe detector was chosen over a thermopile detector in order to obtain a fast time constant response and avoid slow chopping frequencies. The DC motor-driven chopper is mounted at the front aperture of the instrument entrance barrel. The field of view is defined by a baffled Gershun cone arrangement which gives a 1.5° clear field and a partially obscured field to 2.7°.

The modulated signal from the detector is first amplified by a preamplifier in the photometer head. With use of a pick off signal from the chopper, the detector signal is then demodulated by a full wave, synchronous demodulation circuit. The filtered output of the demodulator is a DC voltage which is linear with the solar radiance. The signal voltage is displayed by a four digit panel meter. The only additional electronics necessary for the photometer are circuits which control the detector cooling. The instrument is portable but is most conveniently operated from a tripod mount. For hand-held use, a commercial peak-hold meter can be connected to an external signal output and readings obtained from momentary alignments with the sun.

3. Calibration

The critical factors which allow accurate sun photometer measurements of atmospheric optical thickness are a band limited, stable and linear instrument response and a precise knowledge of the instrument calibration. The observation equation for sun photometer measurements may be written as

$$V(\lambda, m) = V_0(\lambda) \exp[-\tau_{a,r}(\lambda)m] T_g(\lambda, m) \qquad (1)$$

where V is the instrument signal at a given wavelength λ and airmass m. The molecular (Rayleigh) scattering optical thickness plus aerosol optical thickness $\tau_{a,r}$ is the quantity to be measured, and any gaseous attenuation is represented by the term $T_g(\lambda, m)$. The quantity $V_0(\lambda)$ is the instrument calibration and represents the relative signal reading in the absence of an intervening atmosphere for a given earth to sun distance factor. In order to measure $\tau_{a,r}$ both V_0 and T_g must be known.

The standard technique for sun photometer calibration is the Langley method, whereby measurements are acquired as a function of solar zenith angle and then extrapolated to zero airmass. The method assumes a linear relationship between the airmass and total optical thickness. If gaseous absorption is a significant fraction of the total optical thickness, the nonlinearities which may be introduced will lead to possibly inaccurate zero airmass calibrations. Calculations of the ln T_g versus airmass relationship for the SIP wavelength bands are shown in Fig. 2. The values were calculated by means of the Lowtran computer program for atmospheric transmission (Robertson, *et al.*, 1981), and the calculations shown are for an altitude of 3.4 km which would correspond to observations from a mountain observatory. Absorption in the instrument bands was due to water vapor or mixed gases, as defined for Lowtran. For the wavelengths shorter than 1.55 μm the gaseous attenuation is negligible. At the 1.55 μm wavelength the absorption is due to mixed gases and is small. For 2.22 μm, absorption is also relatively small and is due primarily to water vapor. The absorption at 3.96 μm, mostly due to the nitrogen continuum, is much more pronounced than for the other wave-

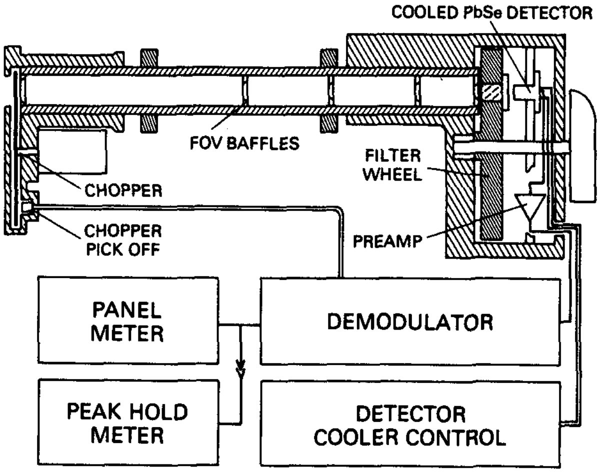

FIG. 1. Functional diagram of the infrared solar photometer. The instrument FOV is defined by an open baffled cone arrangement. Radiation is chopped at the front aperture by a DC motor driven chopper. Wavelengths are selected by a manually rotated filter wheel, and the signal is detected by a thermoelectrically cooled PbSe element. The chopped signal is demodulated by a full wave, synchonous demodulation circuit. An external peak-hold meter has been used in some instances for signal acquisition.

lengths and would significantly bias Langley analysis results.

However, if gaseous absorption can be calculated, the Langley method may be readily modified to give correct calibration results. The sun photometer equation can be written as

$$V'(\lambda, m) = V(\lambda, m)/T_g(\lambda, m)$$
$$= V_0(\lambda) \exp[-\tau_{a,r}(\lambda)m]; \qquad (2)$$

then if V' rather than V is applied for the Langley analysis, correct results for V_0 should be obtained. Just as for visible sun photometer measurements, a reliable Langley calibration requires a stable aerosol optical thickness and accurate airmass calculations (Shaw, 1976). For the modified Langley analysis, $T_g(\lambda, m)$ must be adequately known. Whereas the calculation of T_g as shown in Fig. 2 would not be expected to be fully accurate, the accuracy would be adequate to judge the importance and errors associated with the gaseous absorption correction. For the case of measurements from a high altitude observatory, the Langely calibration errors associated with the T_g correction would not be significant. However, the errors could be significant at the two longest instrument wavelengths for lower altitude measurements where water vapor amount would be greater. Even if instrument calibration values are correctly known, an error in the optical thickness retrieval at the two longest wavelengths would be expected from uncertainties in the water vapor amount. For sea level measurements, calculations of the water vapor transmittance similar to those shown in Fig. 2 indicate that with the water vapor amount known to 10%, the typical error in the optical thickness determination would be of the order of 0.005 or less due to the water vapor uncertainty.

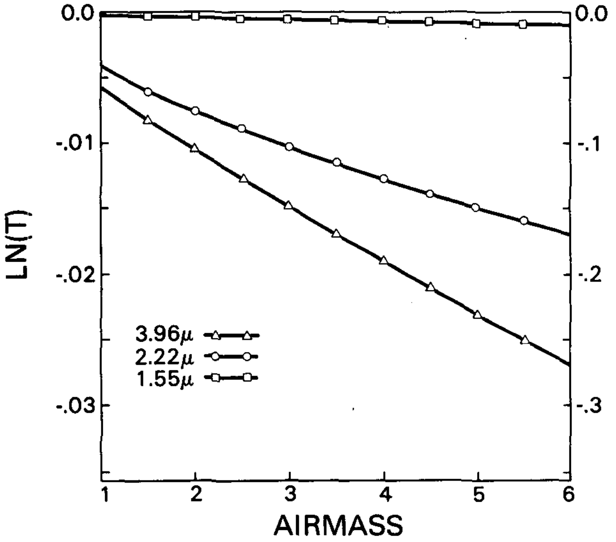

FIG. 2. Calculation of the log of the gaseous transmission versus airmass for the SIP wavelength bands. The scale on the left applies for the 2.2 μm and 1.55 μm wavelengths. The scale on the right applies to the 3.96 μm wavelength. At the shorter instrument wavelengths, the calculated gaseous absorption was negligible. The calculations are modeled for an instrument operating altitude of 3.4 km.

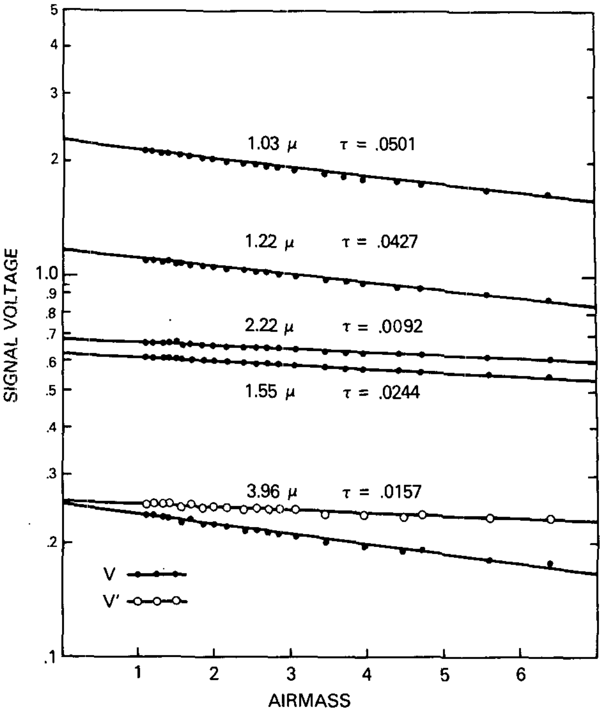

FIG. 3. Observations of the instrument signal voltage versus airmass for 9 July 1983 at Mauna Loa observatory. The data points are indicated as dots and the calculated Langley intercept lines are also shown. Also shown for the 3.96 μm wavelength are the results for the modified Langley analysis. At other wavelengths the difference between V and V' is too small to usefully depict. The log slope result for the total scattering optical thickness for each of the wavelengths is listed.

4. Results

An example of measurements obtained with the SIP instrument is shown in Fig. 3. The observations were acquired at Mauna Loa observatory from an altitude of 3.4 km on July 9, 1983 and are plotted in a form to indicate the results from a Langley calibraton analysis of the data. Linear regression lines are shown extrapolated to zero airmass. The regression for values of both V and V' were considered. For the wavelengths other than 3.96 μm the values and regression results for V' were essentially the same as the values which are shown for V. The modified Langley analysis, however, gives a significant correction at the 3.96 μm wavelength and results in a 2 percent change for the instrument calibration.

Measurements were obtained at Mauna Loa observatory on six days in July 1983. The calibration intercepts for the six days were within 0.7 percent for the instruments wavelengths other than 3.96 μm. For the 3.96 μm wavelength, the intercepts for the six days were within 1.5 percent. The greater variability at the 3.96 μm wavelength is partially due to a decreased instrument response at that wavelength, but also reflects some uncertainty in the gaseous absorption correction. Values of $\tau_{a,r}$ derived for the 9 July case are listed in Fig. 3. The optical thickness values reflect the unusually high aerosol loading of the stratosphere that was injected by the El Chichon volcanic eruption. The increase in aerosol optical thickness from 2.22 μm to 3.96 μm is consistent with the absorption characteristics for sulfuric acid droplets.

A critical factor for the utilization of solar photometer measurements is the long term stability of the instrument calibration. Langley calibration values for the instrument were also derived for measurements obtained near Tucson, Arizona in December 1982 and March 1983. The calibration values derived for these cases were within one percent of the results from July 1983 for all but two of the instrument wavelengths. At the other two wavlengths the calibration values were within two percent. These results indicate that the instrument stability is sufficient for useful photometric measurements.

Measurements with the SIP instrument have been obtained for a number of surface-based field programs and the results have proven to be a useful extension of visible wavelength photometer measurements. In addition, the instrument has been successfully used from an aircraft in an experiment similar to that reported by Spinhirne (1983) for visible wavelength measurements. The results of these applications of solar infrared photometer measurements will be reported in future contributions.

Acknowledgments. The authors gratefully acknowledge the assistance they received from the Institute of Atmospheric Physics, University of Arizona, and Geophysical Monitoring for Climatic Change, NOAA-ERL, for use of facilities during instrument calibration measurements.

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