DEVELOPMENT OF A SWIR SOLAR SPECTRAL RADIOMETER FOR THE ARM PROGRAM

Final Report

Grant Number: DE-FG02-92ER61360

DOER/61360-2

Submitted to

Department of Energy
Acquisition and Assistance Management

by

Department of Physics
University of Denver
Denver, CO 80208-0202

July 1995

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Original
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *[Signature]*

MASTER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

Solar radiation is the major source of energy input to the earth's atmospheric system. The majority of the energy in this radiation is contained in the region between $0.35\mu\text{m}$ and $1.0\mu\text{m}$ where the earth's atmosphere is relatively transparent. About one third of the energy occurs in the region from $1\mu\text{m}$ to $5\mu\text{m}$. The atmosphere has a number of strong absorption bands in this spectral region and as a result, significant amounts of this radiation is deposited into the atmosphere. A knowledge of the absolute spectral intensity of the radiation reaching the earth's surface in this spectral region is important in our understanding of radiation exchange in the earth-atmosphere system. Absolute solar spectral measurements in this spectral region are difficult, and it is only recently that the absolute spectral radiometric sources for this region have become available. The availability of such sources, coupled with development of reliable interferometers and associated small computers, appeared to make it possible to develop an absolute solar spectrometer system for field use. The object of this program was to investigate the feasibility of constructing such a system. There were three areas of particular concern about achieving the desired absolute accuracy. There were: 1) linearity; 2) sensitivity, and 3) stability.

A system was assembled using a small commercial interferometer system, a solar tracking system and NIST traceable standard radiance source. This system was used to investigate these areas of concern. The results showed a system based on this design could be constructed that would be suitable for field operation by ARM site personnel.

INTRODUCTION

The solar radiation input to the Earth has a significant component in the near infrared. The atmosphere has a number of strong molecular absorption bands in this spectral region and a large amount of this radiation is deposited in the atmosphere and does not reach the earth's surface. In view of this it is important that the solar spectrum received on the ground be accurately measured. Spectrometers are generally calibrated by measuring the spectrum they produce when viewing a blackbody with a temperature close to the object to be measured. Since the sun is such a high temperature object the availability of suitable sources has limited the capability of accurately calibrating spectrometers in this wavelength region. Recent developments in small, stable interferometer systems and the availability of NIST traceable standard sources has led to the feasibility of constructing an absolute spectral radiometer capable of measuring the solar spectrum in this spectral region. The object of this grant was to investigate the feasibility of constructing an absolute spectrometer system for measuring the infrared solar spectra from the ground. A system was constructed consisting of a small commercial interferometer (BOMEM MB160), solar tracking system and NIST traceable standard radiance source. An optical system was constructed that allowed the spectrometer to view the calibration standard and the sun through the same optics. There were three areas of particular concern about achieving the desired absolute accuracy. These were: 1) linearity, 2) sensitivity and, 3) stability. The research instrument was used to investigate all three of these areas of concern. The results showed the system satisfied all of the requirements in these areas and the research system was capable of measuring the absolute solar spectral intensity with an error of less than 2% over most of the spectral region between $1\mu\text{m}$ and $5\mu\text{m}$.

SPECTROMETER SYSTEM

Optical Design

The interferometer used for this study is a Bomem MB160-2E with no additional optics. This interferometer has a CaF_2 beamsplitter for operation

from the visible to $6\mu\text{m}$, and is capable of spectral resolution of 1 cm^{-1} . Most of the work in the feasibility study was done at 4 cm^{-1} .

In order to do radiometric calibration, the calibration source and the unknown source must both fill the instrument field of view. This requirement complicates the design, because the sun is at an effectively infinite distance with a $\frac{1}{2}^\circ$ angular size, while the calibration lamp is close with a filament size of 2 by 7 mm (1.4 mm by 5 mm is calibrated). The optical system is arranged to accept light from a $\frac{1}{4}^\circ$ angular field (this minimizes solar limb darkening effects) that passes through a 1.4 by 5 mm area 0.5 m in front of the interferometer. This ensures that both the sun and the source completely fill the field of view. The radiation is re-imaged onto a 1 mm diameter detector (either InSb for 1.4 to $5\mu\text{m}$ or Ge for 0.9 to $1.4\mu\text{m}$). An optical filter is positioned in front of the detector to select the desired bandpass.

The instrument uses three bandpasses: 0.95 to $1.45\mu\text{m}$ (10500 to 6800 cm^{-1}), 1.4 to $2.2\mu\text{m}$ (7100 to 4500 cm^{-1}) and 2.0 to $5.0\mu\text{m}$ (5000 to 2000 cm^{-1}). These cover approximately equal intervals (in frequency), with similar total intensity from the sun. Figure 1 shows the raw solar spectrum observed in the three channels. The calibration issue is more severe at 0.95 to 1.45, where the source intensity is about 1% of the solar. The interferometer alignment is also most sensitive at the short wavelength end. Therefore, much of the work was done with the Ge detector. The test system we constructed can mechanically accommodate only one detector at a time, so changing bandpasses requires some realignment.

The instrument is mounted on a solar tracking base. The entire system is oriented in azimuth so the input mirror is in the direction on the sun. The input mirror is mounted at 45° to the interferometer optical axis, on the shaft of a servo controlled torque motor. This mirror is used to set the elevation so solar radiation is directed into the interferometer (fine control is based on error signals derived from a photosensor). For calibration, the mirror is set to 0° elevation, and the calibration lamp is in the proper position.

Figure 1. Raw (uncalibrated) solar spectrum. The three bandpasses have been combined onto one plot. The system noise is not visible, all wiggles are real atmospheric absorptions.

Electrical Design

Both detectors are photovoltaic, i.e. they produce current that is proportional to the number of photons arriving on their surface. The detector signal is converted to a voltage by a transimpedance amplifier. The output is then the interferogram on a DC background. This signal is then AC coupled to the data collection channel or to another gain stage.

In order to accommodate the large dynamic range, the interferograms have a x1 channel and a x64 channel. In our test instrument, the data collection system is only a single channel, so the gain is switched when the source is used instead of the sun.

The interferogram is sampled with a 16 bit analog to digital converter and transferred to a personal computer for storage and transformation to a spectrum. The PC has display software for monitoring performance of the interferometer and examining the spectra.

Linearity

The system linearity was checked by observing the sun, and transforming the interferogram into a spectrum. Any linearity error causes signal to appear in regions where no signal is possible (i.e. where the detector has no response). An example of this is shown in Figure 2, on an interferometer system in Hawaii that exhibits significant non linearity (due to the detector itself). The spectrum observed with the test instrument is shown in Figure 3, along with a simulation of the effect of a 1% non linearity. It is clear that the signal chain is good to better than 1%.

Sensitivity and Stability

The instrument was set up in the laboratory and calibrated occasionally for several weeks. Results are shown in Figure 4. The variation is close to the accuracy requirement over the 2 week period. Each spectrum and the reference were 2 minute integrations, so the signal-to-noise ratio on the calibration source is better than 0.25% (RMS) throughout the region. It was our intention to develop a high temperature source for calibration, as the NIST traceable lamps have only a 50 hour useful life. Since it appears that calibration will be necessary only every few days, the lamps will have adequate life and the high temperature source was not developed.

Figure 2. Spectrum from an interferometer at Mauna Loa, Hawaii which exhibits significant non linearity. The original spectrum is shown, along with a 10 times vertical expansion. The apparent signals at low frequency and near 2000 cm^{-1} are a result of the detector non linearity.

Figure 3. Spectrum from the test instrument with the Ge detector. The solar spectrum from 6000 to 10000 cm^{-1} is shown, along with a times 100 expansion (noisy curve) and a simulated 1% non linearity (smooth curve).

Figure 4. Multiple runs of the calibration source. All spectra are divided by the reference spectrum of January 19. Jan 31A and Jan 31B are runs from the morning and evening of the same day. The $\approx 2\%$ change was the largest observed, and may be due to the temperature changing in the laboratory. Each spectrum and the reference were 2 minute integrations on the calibration source.

CONCLUSIONS

The objective of this research was to investigate the possibility of constructing an absolute solar spectrometer system for operation in the $1\mu\text{m}$ to $5\mu\text{m}$ spectral region. The result of the investigation was to show that it is possible to construct a system with sufficient linearity, sensitivity and stability to make the desired measurement. The investigation also demonstrated that it is possible to construct such a system for operation by site personnel at the ARM sites.