Measurement of Spectral Radiance in the Japanese Cloud and Climate Study

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Introduction

The Japanese Cloud and Climate Study (JACCS) is a research program focusing on cloud-radiation interactions. The major scientific objectives of the JACCS program are 1) to advance our understanding of the relationship between the physical parameters and the radiative properties of clouds, 2) to develop advanced uses of satellite data in the cloud-climate study, and 3) to develop better parameterizations of cloud and radiation processes. To achieve these objectives, field observations of cloud and radiation have been planned and implemented since 1991. In this field observation project, two spectroradiometer systems have been developed. One is a grating spectroradiometer to measure the solar radiance of the sun or zenith direction in the range of 280- to 2500-nm wavelength. The other is an interferometer to measure solar and terrestrial radiance reflected, transmitted and emitted by clouds. The spectra data measured by these spectroradiometers can be used to understand the relationship between the physical parameters and radiative properties of clouds and to develop remote sensing techniques. The purpose of this paper is to describe the characteristics of the two spectroradiometer systems used in the JACCS program.

The Spectroradiometer in the Visible and Near Infrared Regions

The spectroradiometer system to measure radiance in the visible to near infrared wavelength range is composed of a multi-spectroradiometer, a sun tracker, a hood with 1.5 degree field of view (FOV), and two NEC personal computers. The multi-spectroradiometer is commercially available from OPTO RESEARCH Co. (MSR7000); the sun tracker is commercially available from PREDE Co., Ltd. (ASTX-1) with the automatic sun tracking option.

One computer is used to control the multi-spectroradiometer and to acquire and store the data digitized and transferred from the multi-spectroradiometer. The other computer controls the sun tracker. This sun tracker can be used with both automatic tracking mode and computer controlling mode. The hood is mounted on the sun tracker and an optical fiber is attached to the hood. The light is led to the multi-spectroradiometer through the optical fiber.

Table 1 shows the characteristics of the multi-spectroradiometer. The multi-spectroradiometer has three detectors. However, we use the silicon photodiode and the lead sulfide (PbS) in the wavelength range from 280 to

Table 1. Characteristics of the multi-spectroradiometer MSR7000.

Optical mount	Czerny Turner type	
Focal length	350 mm	
F number	9	
Grating	600 line/mm	
Spectral resolution	5nm	
Wavelength accuracy	±1 nm	
Wavelength region	280 - 2500 nm	
Detector	Photomultiplier (280-820nm),	
	Silicon photodiode (820-1100nm),	
	Lead Sulfide (1100-2500nm)	
Electric system	Amplifier	Lockinamp
	A/D converter	16bits
	Interface	RS232C

1100 nm and from 1100 to 2500 nm, respectively. A temperature-dependence test shows that the temperature dependence of the photomultiplier is large and that the system is very stable in the range of 20° to 30°C temperature. Therefore, we use the silicon photodiode in the whole visible region and operate the spectroradiometer in the box to keep the instrument in the proper temperature range.

Calibration of the Multi-Spectroradiometer

Calibrating the spectroradiometer is difficult. To calibrate it by the Langley plot method, we made measurements at the National Oceanic and Atmospheric Administration's (NOAA) Mauna Loa Observatory (MLO). Figures 1 and 2 are examples of the Langley plot and the calibration constant, respectively. The atmospheric transmittance in the molecular absorption band is estimated by a correlated k-distribution method we developed. Except for molecular absorption bands, the calibration constants are accurately determined. Figure 3 is an example of total aerosol optical (TAO) thickness measured at the MLO. The TAO in the water vapor absorption band could not be estimated due to the overestimate of absorption, but we can easily see the wavelength dependence of TAO in the region of weak molecular absorption.

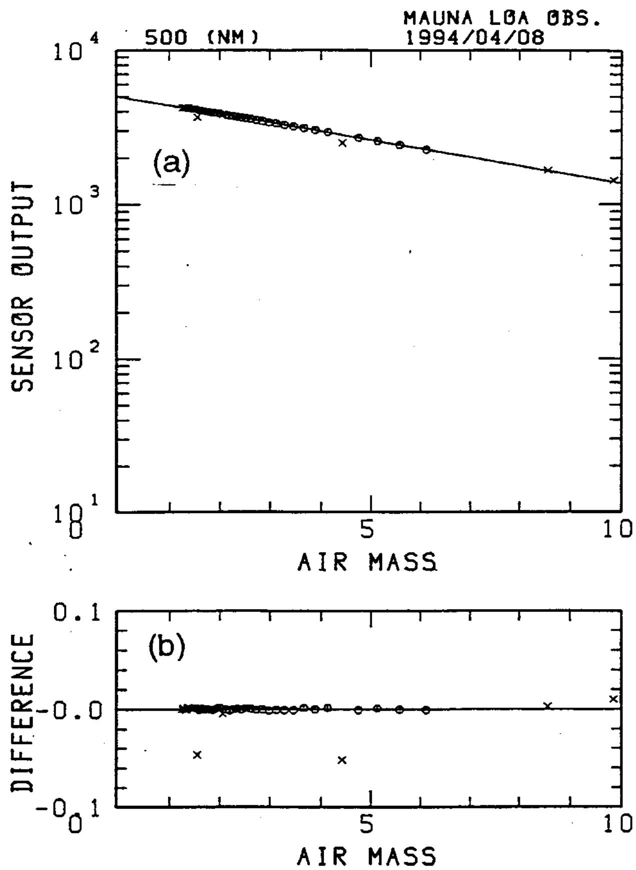

Figure 1. (a) An example of Langley plot at the 500-nm wavelength on April 8, 1994. The measurements were made every 4 minutes. (b) Difference between measurement values and linear regression line. There is no systematic tendency. Therefore, the atmosphere is very stable, and the calibration constant is accurately determined.

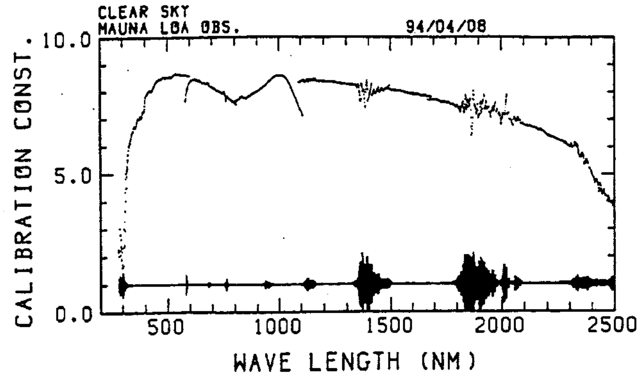

Figure 2. An example of calibration constants determined by the Langley plot and standard deviations.

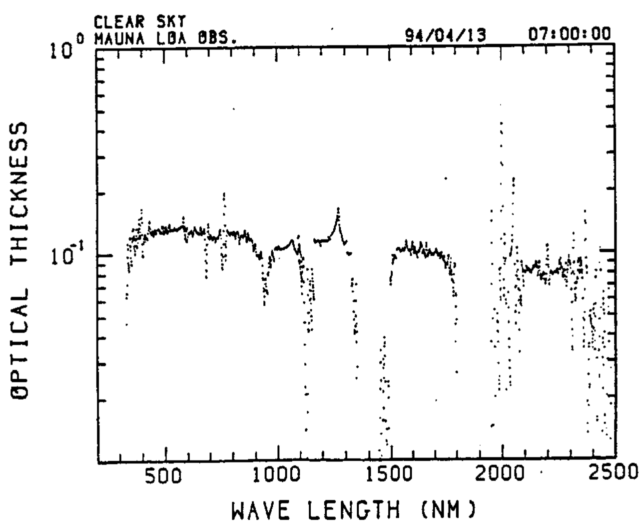

Figure 3. An example of total aerosol optical thickness observed at NOAA Mauna Loa Observatory on April 13, 1994, during a dust storm.

Cloud Radiation Fourier Transform Spectroradiometer (CRS)

An instrument for measuring the solar and terrestrial radiance reflected, transmitted, and emitted by clouds has been developed. The instrument is operated both from the ground and on the aircraft. The radiance from the cloud has no line structure as the atmospheric gaseous emission. Therefore, it operates at low spectral resolution: 16 cm^{-1} for the ground-based observation and 32 cm^{-1} for the aircraft one. This spectroradiometer system is composed of an interferometer, reference targets, a scan mirror, and an IBM personal computer (see Figure 4 and Table 2). The interferometer is a commercially available one from Bomem Inc. (MB155). The interferogram data are digitized and transferred to the personal computer, where they are Fourier-transformed and stored on the hard disk. A pair of detectors is used to cover the wide spectral range. One detector is MCT, which covers the spectral range from 500 to 5000 cm^{-1}. The other detector is InSb, which covers the spectral range from 2000 to 14000 cm^{-1}. The detectors are cooled in a dewar of LN_2. On the ground-based observation, three high emissivity black bodies are used as reference targets to calibrate the infrared radiance. One at ambient temperature, one is hotter than ambient temperature by 40° to 50°C, and one is cooled by LN_2. For the aircraft observation, the ambient-temperature and the hotter black bodies are used. To calibrate the radiance measured by the InSb detector, a near infrared source (NIS) is used. The NIS, which is also a product of Bomen Inc., is composed of a halogen lamp, a diffuse reflector, and a mirror. The radiances from the reference targets and the clouds are led to the interferometer by rotating the mirror. The reference black bodies are measured every 5 minutes. The near infrared source is measured at the beginning and end of the observation.

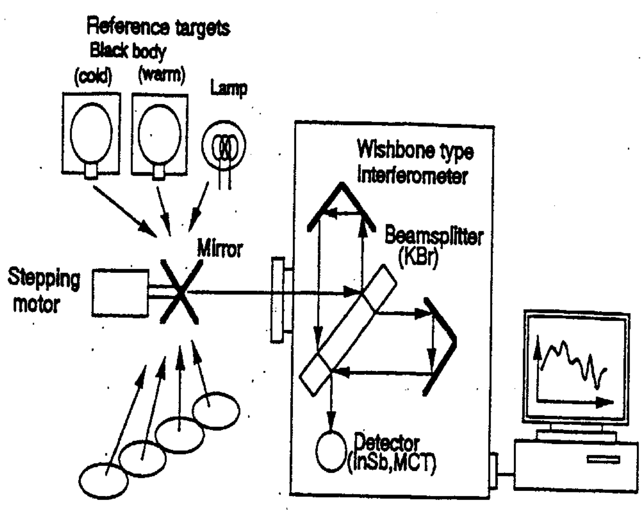

Figure 4. Schematic view of Cloud Radiation Fourier Transform Spectroradiometer (CRS).

Table 2. Characteristics of the cloud radiation Fourier transform spectroradiometer.

Model	Bomem MB155
Spectral range	500 to 14000 cm^{-1}
Detectors	InSb (2000 to 14000 cm^{-1})
	MCT(500 to 5000 cm^{-1})
Resolution	Near infrared 2,4,8,16,32,64,128 cm^{-1}
	Infrared 1,2,4,8,16,32,64,128 cm^{-1}
Scanning rate	40 scans/min (4 cm^{-1} resolution)
	5 scans/sec (32cm^{-1} resolution)
Wavenumber precision	0.01cm^{-1}
Interferometer	“Wishbone” type interferometer
Beamsplitters	KCl
Field of view	46mrad

Calibration of the CRS in the Infrared Region

To check the calibration method in the infrared region, the temperature variable black body (Micron: M340) and the ambient temperature black body are used. The temperature of the black body is set at 60°, 40°, 20°, 0°, and -12°C. The temperature of the ambient temperature black body is set at 25° - 26°C . The data of the black body at 40°, 20°, 0°, and -12°C are calibrated using the data of the black body at 60°C and that of the ambient black body. Figure 5 shows the ratio of the calibrated radiance to the radiance from the black body at 20°C. The radiance from the black body was estimated from the temperature and emissivity of the black body and ambient temperature. The calibration was performed by the method of Revercomb et al. (1988). Figure 6 is as same as Figure 5 except that the temperature is 0°C. At 20°C, both

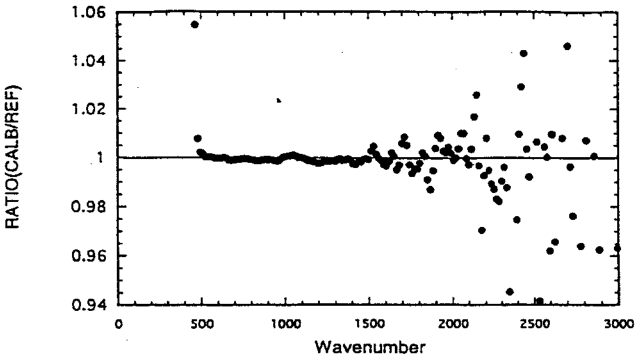

Figure 5. Ratio of the calibrated radiance to radiance from the reference target at 20°C.

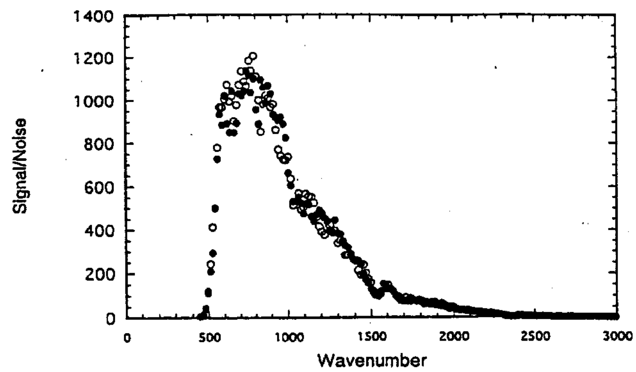

Figure 7. Signal to noise ratio (S/N) for the black body at 20°C.

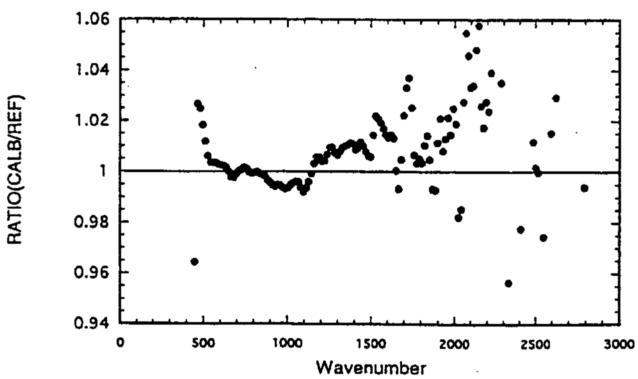

Figure 6. Same as Figure 4 but for a reference target temperature of 0°C.

radiances are coincident within ±0.3%. Though the figure in the case of 40°C is not shown, the same result was obtained. In the case of 0°C, the accuracy is ±1% in the range of 500 to 1500 cm^{-1}. This accuracy is slightly less than the 20° and 40°C case. Figure 7 shows signal-to-noise ratio (S/N) for the black body at 20°C. Here, S/N is defined as the ratio of mean value to standard deviation, which was calculated from 100 measurements. The S/N values are greater than 800 in the wavenumber region from 600 to 1000 cm^{-1}. As the wavenumber increases, S/N becomes smaller. These results indicate that the ground-based measurement of high-level clouds is possible by accumulating the data 10 times in the 800 to 1000 cm^{-1} atmospheric window.

In order to use reference targets more than 2 points, we extend the method developed by Revercomb et al. as follows:

$$
\begin{aligned}
L_v &= \mathrm{Re}\left\{\frac{C_v-\bar{C}}{\overline{CL}-\bar{C}\bar{L}}\right\}\left(\overline{L^2}-(\bar{L})^2\right)+\bar{L}\\
L_v &= \mathrm{Re}\left\{\frac{C_v-\bar{C}}{\overline{(C_v-\bar{C})(L_v-\bar{L})}}\right\}\overline{(L-\bar{L})^2}+\bar{L}\\
\bar{C} &= \frac{1}{N}\sum_j C_{vj},\\
\bar{L} &= \frac{1}{N}\sum_j L_{vj},\\
\overline{L^2} &= \frac{1}{N}\sum_j L_{vj}^2,\\
\overline{CL} &= \frac{1}{N}\sum_j C_{vj}L_{vj},\\
\overline{(C_v-\bar{C})(L_v-\bar{L})} &= \frac{1}{N}\sum_j (C_{vj}-\bar{C})(L_{vj}-\bar{L}),\\
\overline{(L-\bar{L})^2} &= \frac{1}{N}\sum_j (L_{vj}-\bar{L})^2
\end{aligned}
\qquad (1)
$$

where C_{vj} is the complex spectrum, L_{vj} is real radiance from the target, and *N* is the number of data.

Calibration of the CRS in the Near Infrared Region

The NIS is used as the secondary reference target to calibrate the radiance in the near infrared region. Therefore, we must calibrate the NIS itself by the more accurate reference. This problem is very difficult for the following reasons. First, since the Fourier transform spectrometer is used, the radiance in the wide wavenumber range enters the detector at a time. Second, the radiance that is of ~1000°C brightness temperature must be led to the spectrometer in order to calibrate the radiance in the region of less than 1000-nm wavelength, and it has the energy peak of radiance spectrum in the longer wavelength region. Third, as the wavelength increases, the sensitivity of the detector InSb becomes larger. Therefore, if we measured the black body at ~1000ºC by the Fourier transform spectrometer with the InSb detector so as not to saturate the output of the detector, we could obtain only a small signal in the shorter wavelength region. To solve this problem, we divide the spectral range and calibrate the NIS in each region. Figures 8 and 9 show the spectral radiance and brightness temperature of the calibrated near infrared source. Though the wavenumber region is noisy, the near infrared source can be calibrated. Once the near infrared source is calibrated, we can calibrate the radiance in the near infrared region.

Summary

The two spectroradiometer system has been developed in the JACCS project. Though the calibrations are difficult, most of them are solved. The grating spectroradiometer is calibrated by the Langley plot. A new method for calibrating data measured by the Fourier transform spectroradiometer in the infrared region has been developed. Reference data from more than two points can be easily used by this method. Furthermore, in the calibration procedure in the near infrared region, we have developed a new method for calibrating the secondary reference. In the future, we will improve the calibration method to obtain more accurate measurements and to accumulate the observation data in the JACCS observation program.

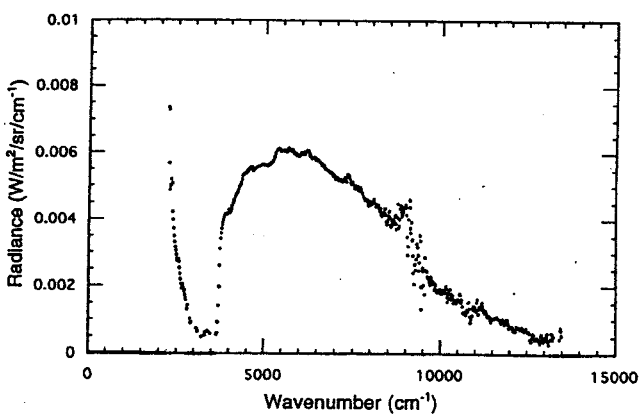

Figure 8. The calibrated spectral radiance of the secondary near infrared reference.

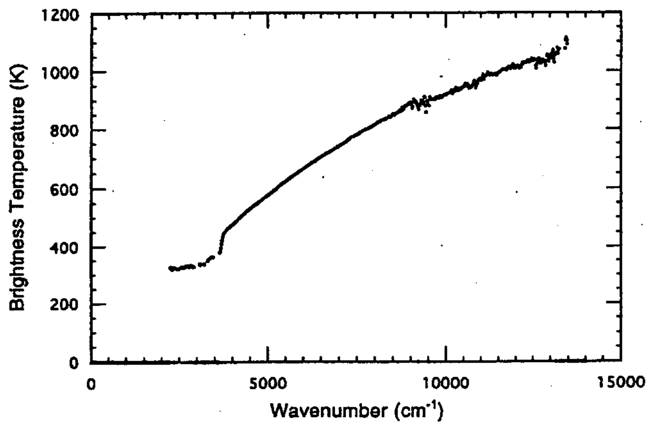

Figure 9. Same as Figure 8 but for brightness temperature.

Reference

Revercomb, H.E., H. Buijs, H.B. Howell, D.D. LaPorte, W.L. Smith, and L.A. Sromovsky, 1988: Radiometric calibration of IR Fourier transform spectrometers: solution to a problem with the High-Resolution Interferometer Sounder. *Appl. Opt.*, **27**, 3210-3218.