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Measurement of sky radiance using a CMOS camera for the retrieval of aerosol optical properties

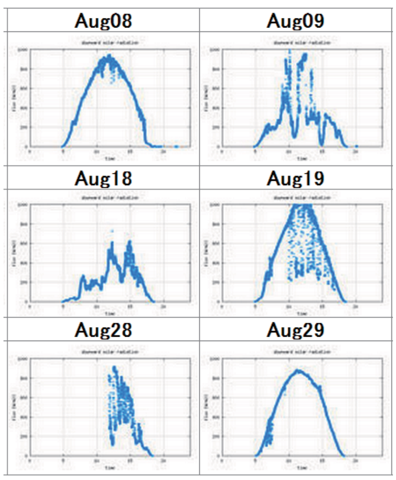
Hiroaki Iwanade[a]*, Hayato Saito[a], Ilham Alimuddin[a,b], Naohiro Manago[a], Hiroaki Kuze[a]

[a]Center for Environmental Remote Sensing (CEReS), Chiba University, Chiba 263-8522, Japan

[b]Faculty of Geography, Hasanuddin University, Makassar 90245, Indonesia

Organization of this presentation

1. Introduction
2. Instrumentation
   - CMOS camera
   - Spectroradiometer
   - Sunphotometer
3. Results and discussion
   - Conversion from DN to radiance
   - Elimination of blue shift
   - Flat-field and distortion corrections
4. Summary and future work



Downward shortwave flux (SKYNET)

1. Introduction

➢ Aerosol impacts the energy balance of the atmospheric system through the reflection and absorption of incident solar radiation.

➢ For the measurement of optical properties of aerosol particles, ground-based instruments such as a sunphotometer or a skyradiometer are employed.

➢ Aerosol parameters such as the aerosol optical thickness (AOT), size distribution, and complex refractive index can be retrieved from the measurements of the sky radiance and direct solar irradiance.

➢A sunphotometer is an instrument that measures the intensity of solar irradiance to obtain AOT and/or cloud optical thickness, while a skyradiometer is used to retrieve aerosol optical parameters by measuring the ratio between the scattered and direct intensities.

(cont'd)

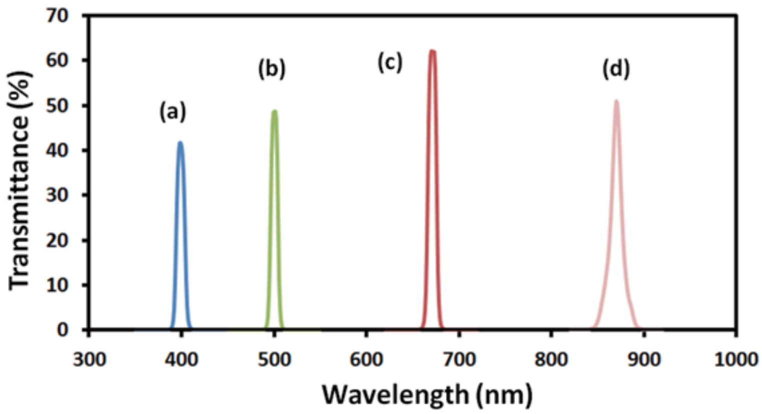
➢ The problems of these instruments are that they are expensive and bulky, mainly because of the sun-tracker.

➢ The present paper describes an attempt in which an imaging spectrometer is developed on the basis of a commercially available CMOS camera, with optical filters and a rotating stage.

➢ We hope that this approach makes it possible to retrieve aerosol optical characteristics without the need for precise tracking of the solar position, which can readily be determined in an image.

2. Instrument

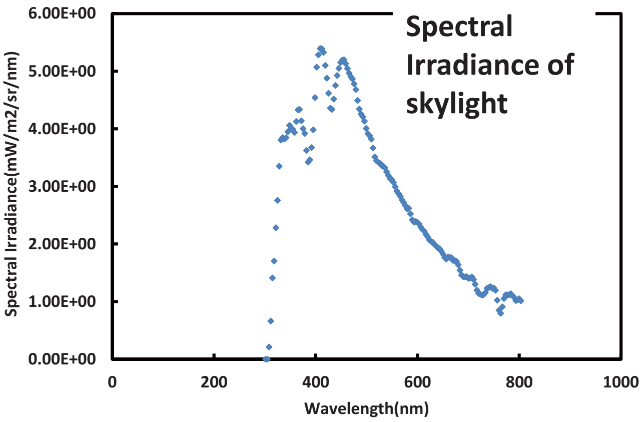
CMOS camera
(IDS, UI-3480CP-M)
➢black & white
➢2560(H) × 1920(V)
➢Radiance depth
12 bits



➢The camera and filter wheel are installed on a rotation stage, which enables the 360 degree observation around the vertical axis.

➢Transmission of narrow band-pass filters (400, 500, 670, and 870 nm)

Spectroradiometer (EKO, MS-720) used for the calibration of the CMOS camera



	Specification
Wavelength	350 - 1050 nm
Sampling Interval	3.3 nm
Optical Resolution	10 nm
Total Field of View	20° (with adopter)

➢The instrument was calibrated using the Langley plot method at the top of Mauna-Kea mountain in Hawaii.
➢Also, an integrating sphere (JAXA) has been used to check the stability of calibration.

Conversion of Digital Number (DN) to Radiance

CMOS Camera

Normalized DN

$$N = \frac{N_1}{t}\left(\frac{F}{F_0}\right)^2$$

MS-720

Spectral Irradiance

$$\overline{I} = \frac{\int I(\lambda)T(\lambda)\,\mathrm{d}\lambda}{\int T(\lambda)\,\mathrm{d}\lambda}$$

Conversion Equation

$$\overline{I} = kN$$

N: Normalized DN
N_1: DN (0~255)
t: Exposure Time
F: F-number
F_0: Maximum F Number

$I(\lambda)$: Spectral Radiance
$T(\lambda)$: Filter Transmission

k: Conversion factor for each filter

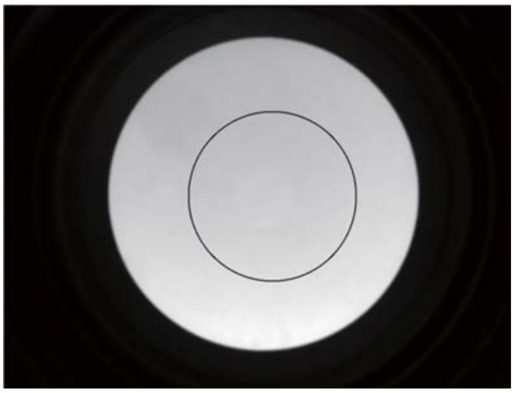
➢ Simultaneous observation of cloudless sky is made with the CMOS camera and MS-720 spectroradiometer.

➢In this way, we can determine the conversion factor *k*, which converts the DN values from the camera to spectral radiance for the wavelength range of each filter.

Calibration procedure

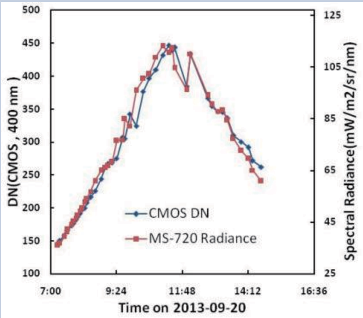
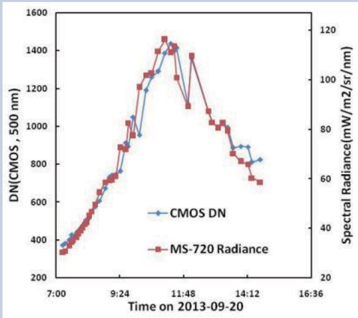
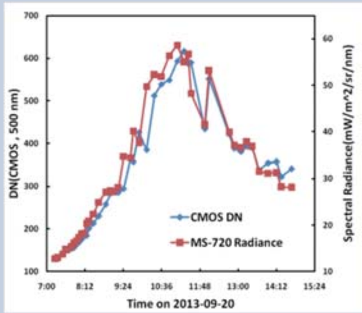
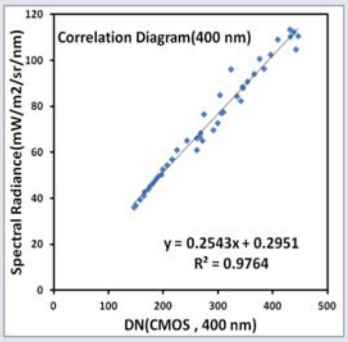
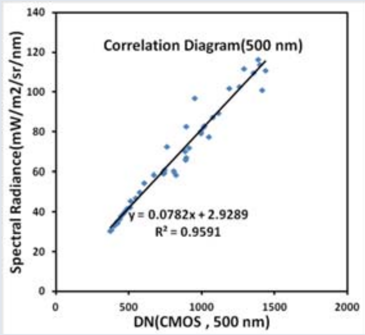
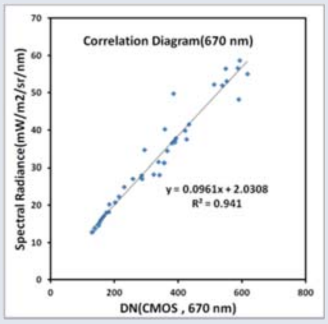
07:19 on September 20, 2013

Measurement of zenith sky



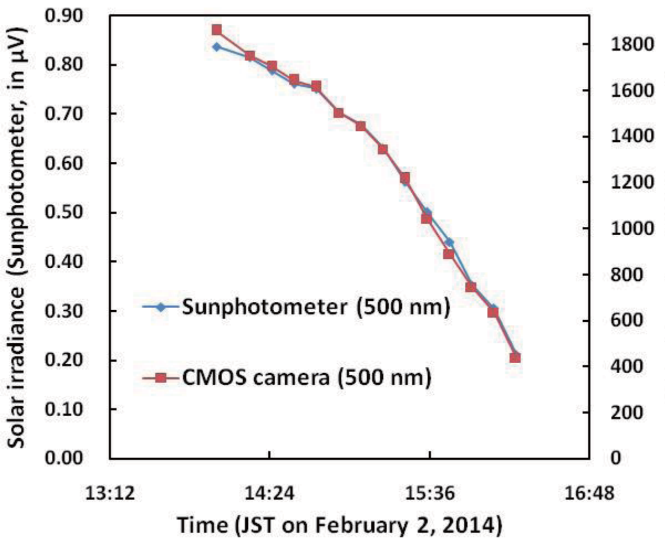
➢ The DN values are averaged for the pixels inside the viewing angle of less than 20 degrees. The resulting value can be directly compared with the spectral radiance derived from the MS-720 instrument.

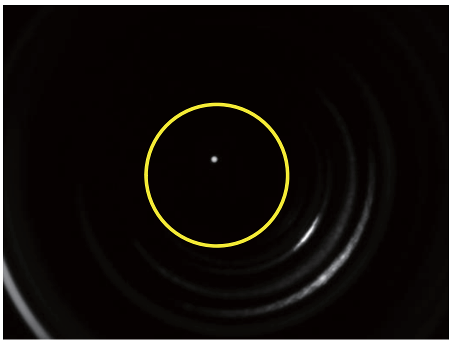
3. Results and discussion
Temporal variation and correlation plot for each wavelength

400 nm	500 nm	670 nm
		
		

k_{400}=0.255±0.008 k_{500}=0.082±0.004 k_{670}=0.099±0.006

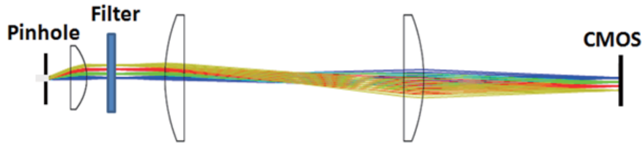
Comparison with sunphotometer
- measurement of direct solar radiation





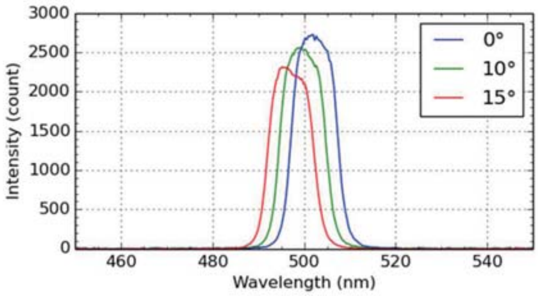
➢ The right panel shows the image of the Sun, taken with a combination of a band-pass and a neutral density (ND) filter.
➢ The agreement between the CMOS camera and the sunphotometer was quite reasonable, as shown in the left panel.

Removal of the blue-shift of narrow band-pass filters

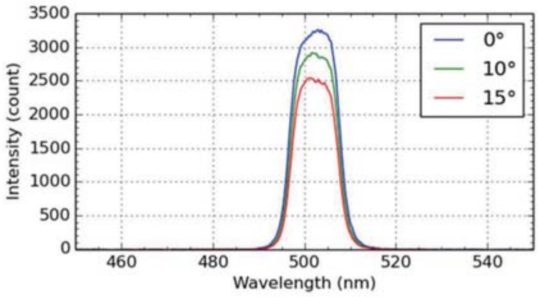


➢ The filter transmission shifts toward the shorter wavelength (blue shift) when the incident light is tilted.

➢ In order to eliminate this effect, a telecentric optical system has been constructed using a pin-hole and non-spherical lenses so that the vertical incidence is ensured.



Shift of transmission wavelength for tilted incidence (500 nm)



Blue-shift problem has been eliminated by introducing telecentric optical system.

Radiance measurement over the whole hemisphere - a skyradiometer based on a CMOS camera imager

Angular coverage of 26 deg

1280 pixels

0.02 deg/pixel

Angular coverage of 20 deg, 960 pixels

➢ The instrument was put on a rotating table. The elevation direction was covered with 3 different camera directions (25 deg step interval). The scanning time duration was about 20 min.

Flat-field and image distortion corrections

Flat-field correction based on a homogeneous illumination.

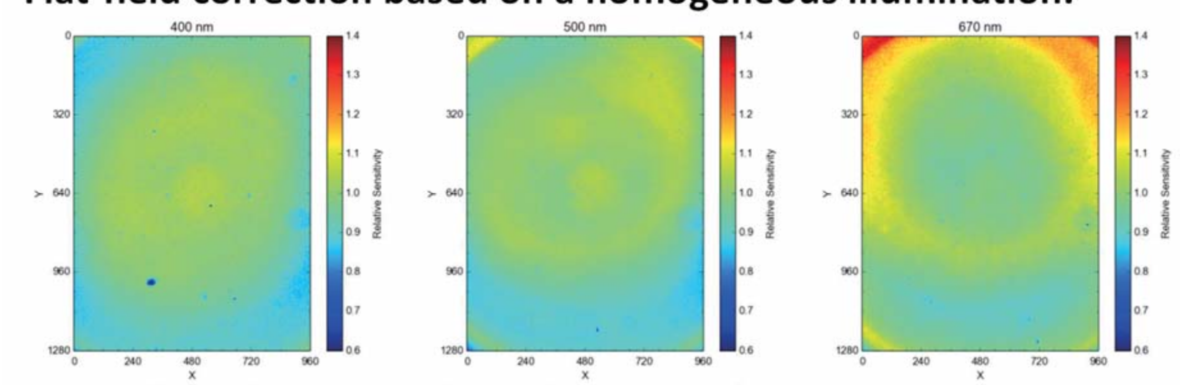
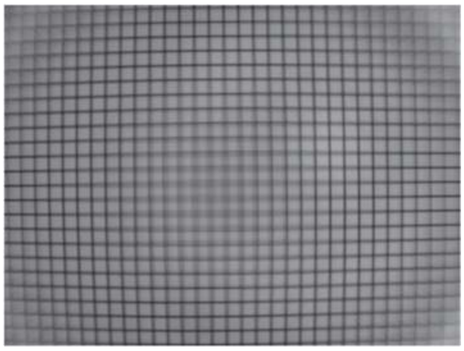
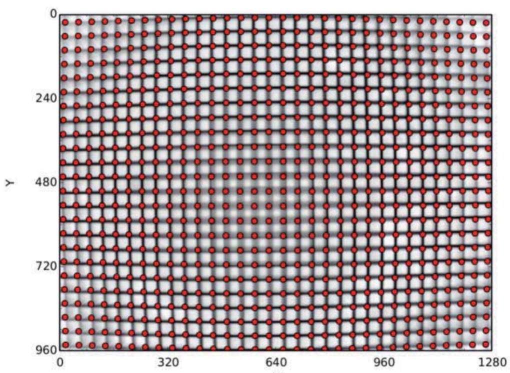


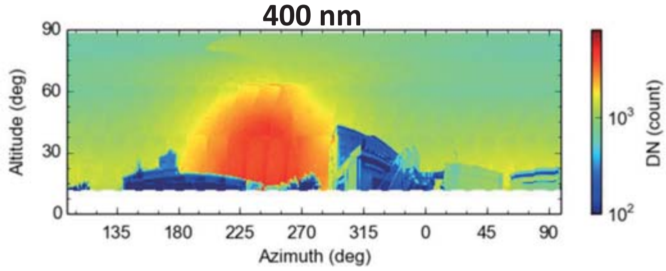
Image distortion correction using a test chart.



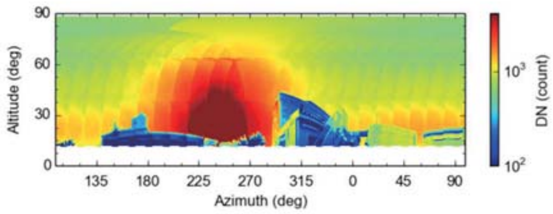


Hemispheric radiance distribution (September 29, 2014)- Composite image before smoothing

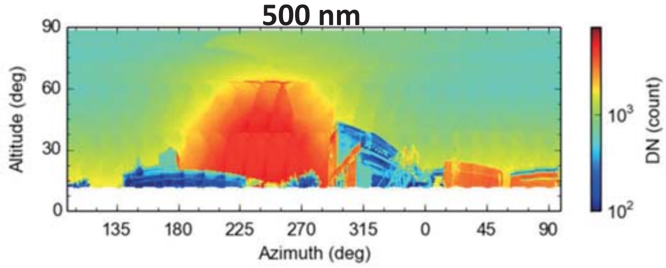
400 nm



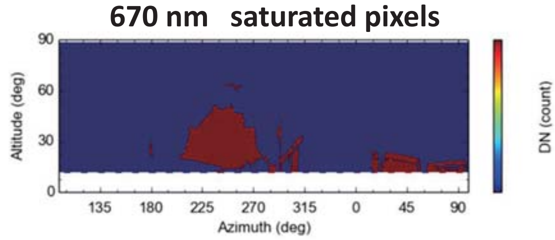
400 nm Before flat-field correction



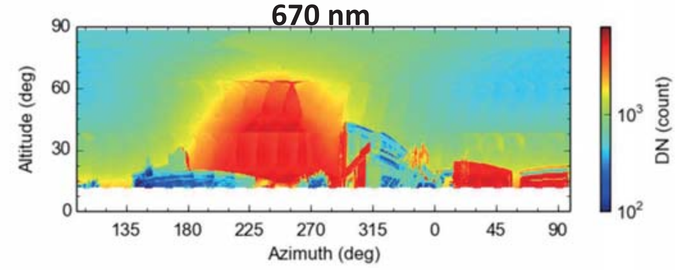
500 nm



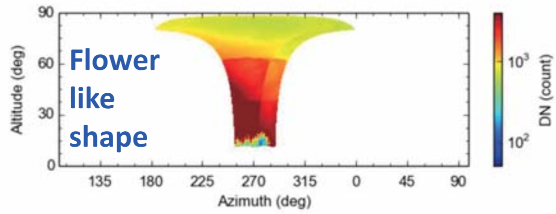
670 nm saturated pixels



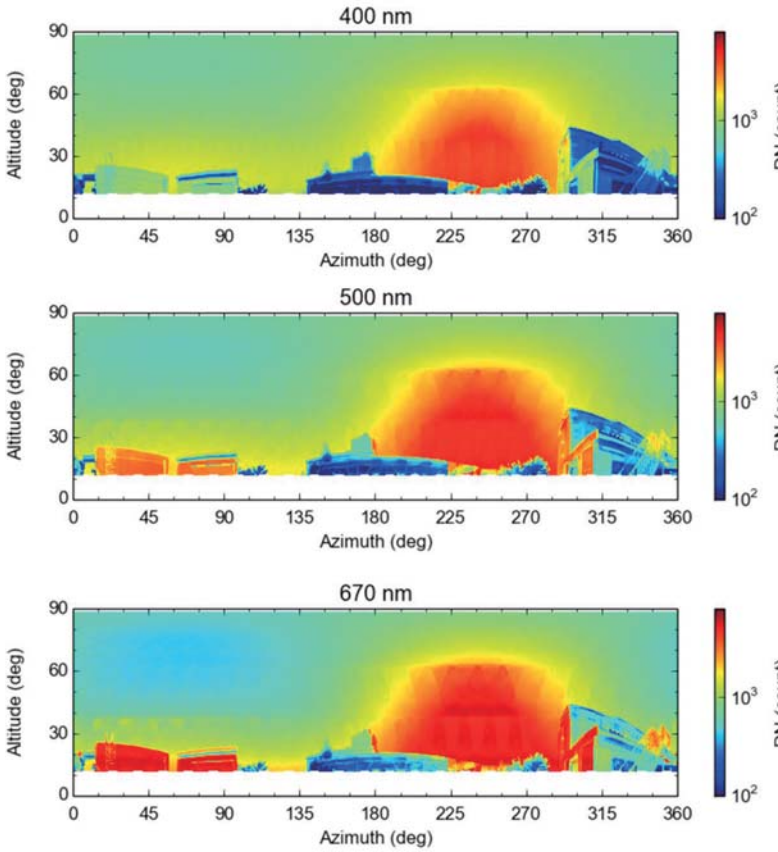
670 nm



670 nm Composition of 6 images



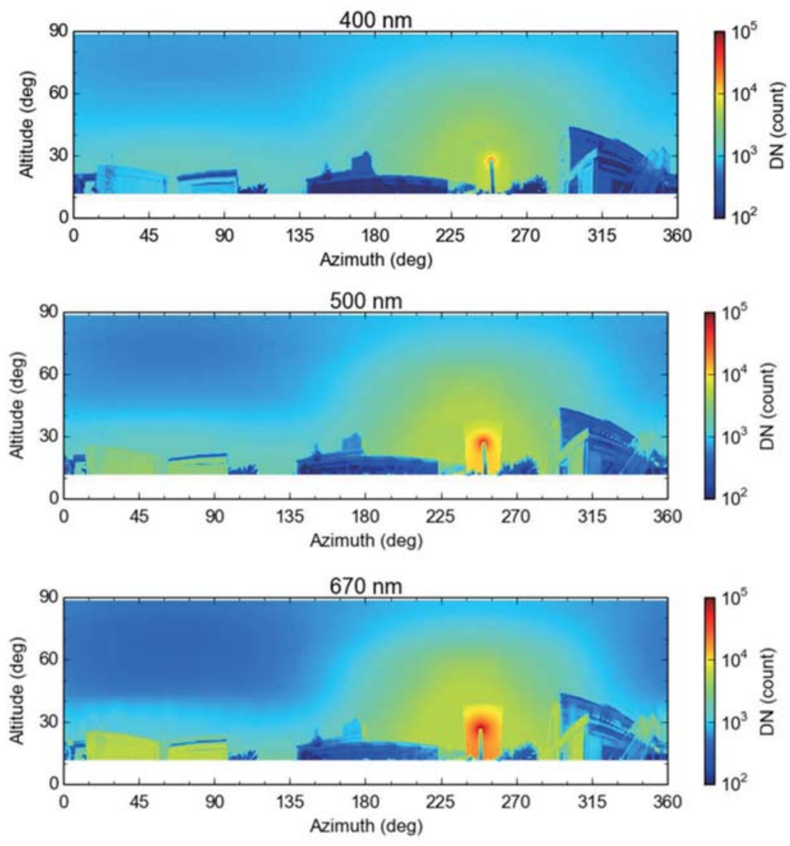
Hemispheric radiance distribution (September 29, 2014)- Resampling over a grid of 0.1 deg



➢ The composite image for each of the three bands (400, 500 and 670 nm) has been resampled over a grid of 0.1 deg.

➢In this way,
- the overlapping regions of neighboring images can be smoothly averaged
- the total image size can be reduced substantially, and
- the pixel information can be readily used for radiative analysis.

Hemispheric radiance distribution (September 29, 2014) - Composite image after smoothing

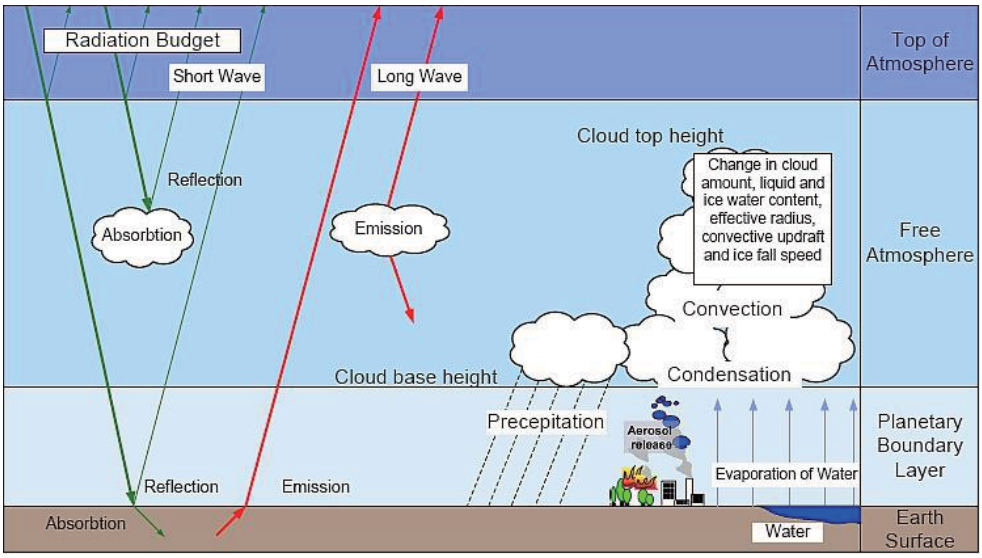


➢The combination of measurements with and without the ND filter will be useful for the radiance observation including the aureole (just around the Sun).

➢Here the aureole image taken with a rod-like shadow object is superposed on each of the camera images.

➢ The building images are overlaid without smoothing.

Radiative transfer calculation using the skyrad.pack



https://directory.eoportal.org/web/eoportal/satellite-missions/e/earthcare

➢ There are various processes in the atmosphere which determine the radiation environment on the Earth surface.
➢ The optical properties of aerosol particle are closely related with the radiation budget, the most important factor in the discussion of climate change.
➢ The CMOS camera approach can provide an inexpensive way for the implementation of the radiance analysis in many places of the world.

4. Summary and future work

➢The present observations have indicated that a commercially available CMOS camera can be applied to the image observation of direct and scattered solar radiation.

-(1) Quantitative comparison has been made with both a compact spectroradiometer and a sunphotometer.

-(2) Flat-field correction and distortion correction have successfully been applied.

-(3) The blue-shift problem associated with the oblique incidence on narrow band-pass filters has also been eliminated owing to the telecentric optical configuration.

➢ Further check on the temperature dependence of the calibration constant may be necessary. After that, the images can be subjected to the comparison with the radiative transfer calculations based on Skyrad.pack.

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http://helios.aori.u-tokyo.ac.jp/teedda/fs/en/about.html