All-sky 10 μm cloud monitor on Mauna Kea.

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ABSTRACT

We report an infrared all sky cloud monitor operating at Subaru telescope at Mauna Kea, Hawaii. It consists of panoramic optics and a 10 μm infrared imager. Aspheric metal mirrors coated with gold (sapphire overcoated) are used in the panoramic optics, which is similar to the MAGNUM observatory's cloud monitor at Haleakala, Maui. The imager is a commercially available non-cooled bolometer array. The system is waterproof and (almost) maintenance-free. The video signals from the imager are captured, averaged over 50 frames, subtracted clear-sky frame and flat-fielded in two minutes interval. The processed cloud images are transferred to Subaru observational software system (SOSS) and displayed combined with telescope/targets information and also stored to Subaru Telescope data archive system (STARS). The processed images will be opened on Internet web site.

Keywords: Cloud monitor, metal mirror

1. INTRODUCTION

An all-sky cloud monitor is useful when observing in partially cloudy night. Observers usually go outside and look up the sky whether clouds cover the sky. However, it is hard to see the cloud in dark night even after the observer's eyes become sensitive in the dark. All-sky cloud monitor is also needed for remote observations. When using archived data, all-sky cloud data are useful to review the data quality.

An optical all-sky cloud monitor "CONCAM" is operating on Mauna Kea[1] and it is very useful during observation. Night sky is bright enough for CCD to image the silhouette of clouds, however, in the moon light, it is so strong to overflow CCD or make strong stray light and hard to distinguish from the cloud.

IR cloud monitor receives the emission form the cloud. Since the temperature of cirrus is about -20°C - -50°C, longer wavelength is preferred. The moon is not so bright in 10 μm. A scanning type all-sky monitor has been working at Apache Point Observatory and it seems to have enough sensitivity.[2] We have made an almost maintenance-free, waterproof IR camera system and testing at Mauna Kea. It is similar system to the IR cloud monitor at MAGNUM observatory on Haleakala.[3] In this paper we report our system description and some preliminary results.

2. SYSTEM OVERVIEW

The schematic view of our system is shown in Figure 1. The optics part of the system is located on the east edge of the roof of the control building of Subaru Telescope (Figure 2). The light emitted from the cloud is reflected by an aspheric primary and secondary mirrors and then refocused on the detector by camera lens. A thermal imager (AVIO TVS-610) is used as the camera. The output of the camera, that is analog video signal (NTCS), is captured video web-server (AXIS2400) and transferred to host computer using ftp. The images are sky subtracted, flat-fielded and averaged over 50 frames, then transferred to the Subaru observational software

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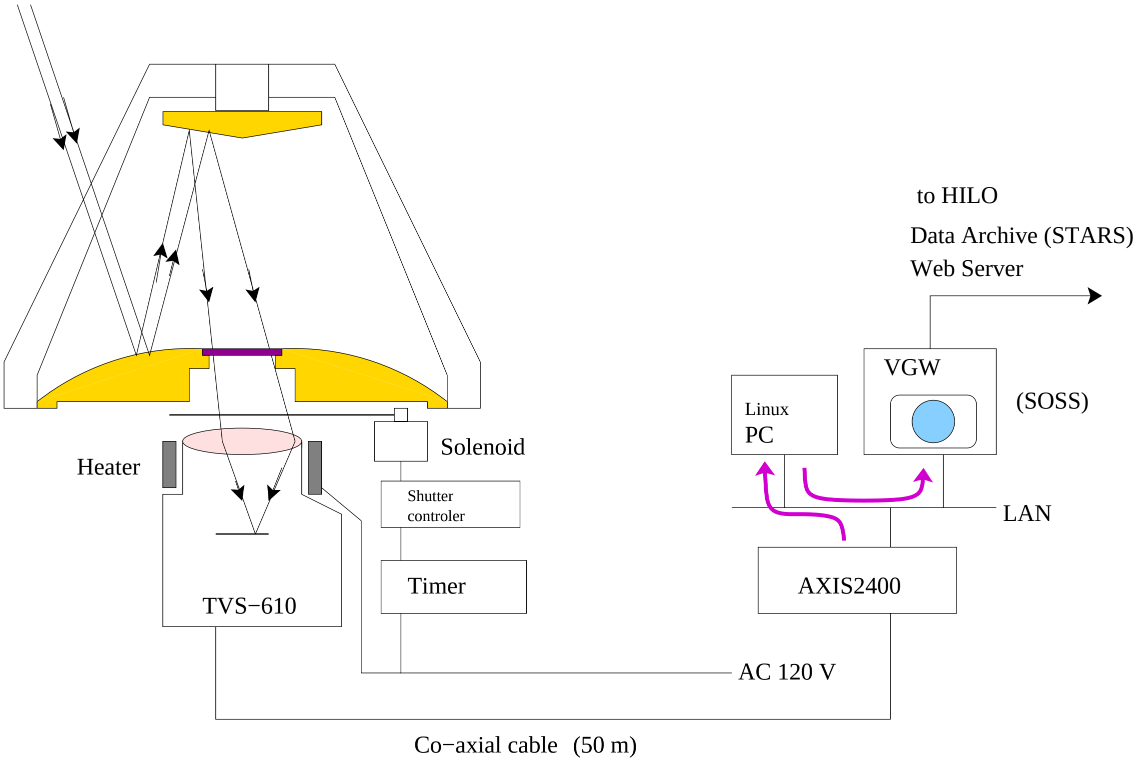

Figure 1. Block diagram of an all-sky cloud monitor at Subaru Telescope.

system (SOSS). The sky image is overlaid with marks of telescope current position, moon and object positions to be observed.

The sky images can be viewed form web site (currently Subaru internal only, it will be open soon). The data are also archived in the Subaru Telescope data archive system (STARS).[4]

2.1. Optics

The optical design is based on Chahl and Srinivasan (1997),[5] that is distortion-free optics (image scale is constant along with zenith distance). We modified it to reduce the astigmatism for optimizing to our small f-ratio camera (f/1).[3] The both mirrors are convex shape and primary surface is 6th order polynomial and the secondary is 4th order polynomial. The spot size is less than 1 pixel. This optics images zenith angle from 11° to 70°.

The mirrors are made of brass figured by diamond turning and polishing. The surface is coated by gold with sapphire protective layer. The central hole of the primary mirror is covered by 2 mm thick Ge window with anti-reflective coat on both sides and hard protective coat on outside. We tested thin diamond window (100 μm in thick) instead of Ge window, but it was broken by a hailstorm.

Three thin spider supports the secondary mirror. The spiders permit the rotation of the secondary about its optical axis, but those restrict the translation and tip/tilt motion. The optics has been exposed outside with no cover all the time (shine or rain) for one year, however, the surface looks no damaged. Dust is also not a big problem, we have not wiped the optics in one year and cannot observe the increase of the emissivity.

The Ge lens provided with the thermal imager is used as focusing lens. Its focal length is 35 mm and f-ratio is 1.0. Our system does not use full aperture of the focusing lens because if the diameter of primary mirror is fixed, the of view toward zenith is limited by the size of the center hole of the primary. This causes the increase of signal background level since the detector looks backside of the primary mirror.

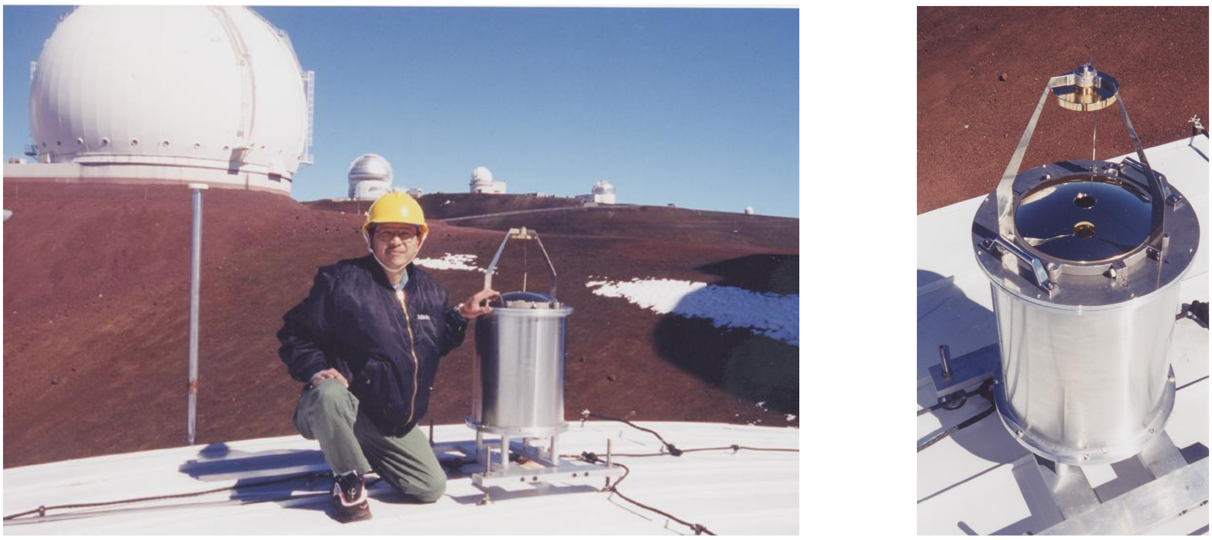

Figure 2. (*left*) All-sky cloud monitor is located on the east edge of the Subaru control building. The guy in the photo is N. Okada, who made the metal mirrors.
(*right*) Enlarged view of the cloud monitor. The Mirrors are coated by gold with sapphire protective layer, and the camera is waterproof.

2.2. Thermal Imager

The thermal imager TVS-610 (AVIO) is used for a imaging camera. The detector is an 320×240 pixel uncooled bolometer array sensitive at 8 - 14 μm wavelength. The Noise equivalent temperature (NEDT) is less than 0.15°C for black body of 30°C (catalog value).

The output format of the image is NTSC video (frame rate is 30 Hz). There is a calibration shutter inside the thermal imager and the imager can be calibrated itself automatically at the ambient temperature. But for low light level image, the calibrated signal is lower than the pedestal level of the video signal. The offset level of the signal can be adjustable inside the electric circuit of the imager, however, we warm up the focusing lens by using a heater and stop the calibration process. The temperature of the lens is controlled at 40°C.

2.3. Control System

The video frames from the thermal imager are captured by video web server AXIS2400, and each captured frame is converted to JPEG format file. The files are transferred to the Linux PC using ftp, and each frame is subtracted sky frame (taken at clear night), flat-fielded and averaged these processed images. Only 50 frames are captured in 2 minutes because of the limited speed of the AXIS2400 and the data processing.

The averaged image is stored as FITS format file. The Linux PC mounts a disk of SOSS workstation (VWG). The averaged file is written on the mounted disk with some "flag file," which include the valid processed file names. A process on the VGW is watching the flag-file and if it exists, the process get the averaged files listed in the flag-file and remove them. The SOSS overlies the current position of telescope, moon, and object positions listed in a operation file.

The processed images are transferred to data archive system at Hilo base facility (STARS). The images are also transferred to internal Web server.

To protect the detector from the sunlight, a mechanical shutter, driven by multi-stable solenoid, is equipped in front of the focusing lens. The shutter is controlled by electric timers.

Table 1. Specification of IR all-sky cloud monitor

Mirror diameter	Primary: ϕ240 mm
	Secondary: ϕ100 mm
Surface shape	Primary: 6th order polynomial
	Secondary: 4th order polynomial
Material	Brass
Coating	Gold with sapphire protective layer
Focusing lens	
Focal length	35 mm
F-ratio	1.0
Material	Ge
Field of view	$11^\circ - 70^\circ$ (zenith distance)
Detector	un-cooled bolometer array
	350×240 pixel
Effective wavelength	$8 - 12\ \mu$m
NEDT	$< 0.15^\circ$C for 30°C Black Body
Output signal	NTSC (30 Hz)

3. PERFORMANCES

The comparison with the CONCAM image and our IR all-sky cloud monitor are shown in Figure 3-5 for thick cumulus, and thick cirrus, and thin cloud, respectively. The straight beam from the Keck II Telescope seen in CONCAM image is a laser beam for laser guide star experiment. A circle overlaid on the CONCAM image indicates the field of view of IR all-sky cloud monitor.

We can see clouds on the images of IR all-sky cloud monitor in a same level as of CONCAM. However, our IR cloud monitor suffers the background variation. It may because the detector looks the backside of the primary mirror directly and the background level changes as mirror temperature changed. The cloud monitor does not detect cirrus that we can see by eyes in the dawn. Further sensitivity improvement is desired.

4. IMPROVEMENT PLAN

The main reason of degradation of cloud sensitivity is that the central hole of primary mirror is small and the detector looks the rear side of the primary mirror. If we enlarge the hole with keeping the field of view of the cloud monitor, the diameter of the primary mirror should be also enlarge. We are fabricating the larger primary (ϕ380 mm), which is limited by the capability of diamond turning machine. Enlarging the primary mirror is not only for reducing the background noise but also increasing the number of photon from the sky, which results in improvement of the sensitivity.

We use only 50 frames per 2 minutes, and 2 minutes refresh rate is slow compare with the time scale of the cloud variation. It can improve to use more frames and increase refresh rate, which also contributes to improving the cloud sensitivity.

We also planning to install a real-time visible II CCD camera with medium field of view at the telescope tube to monitor what going on around the telescope tube top and the sky which telescope is pointing. An auto guider outputs the intensity of the guiding star, which informs us about the real-time cloud passing. The real-time II CCD can also be used as the confirmation of these information.

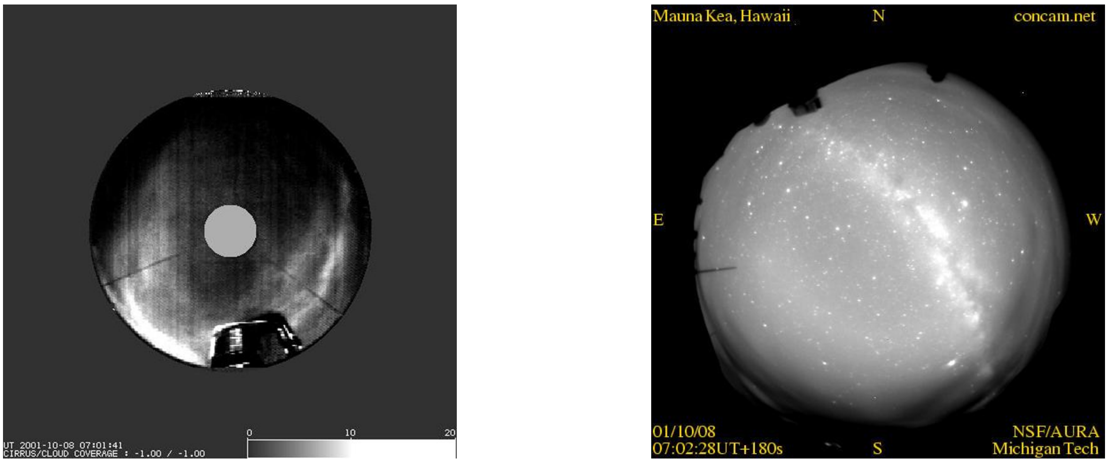

Figure 3. Comparison with CONCAM for partly thick cumulus. (*left*) IR all-sky cloud monitor, (*right*) CONCAM. The building seen at north in IR cloud monitor image is the enclosure of Subaru Telescope.

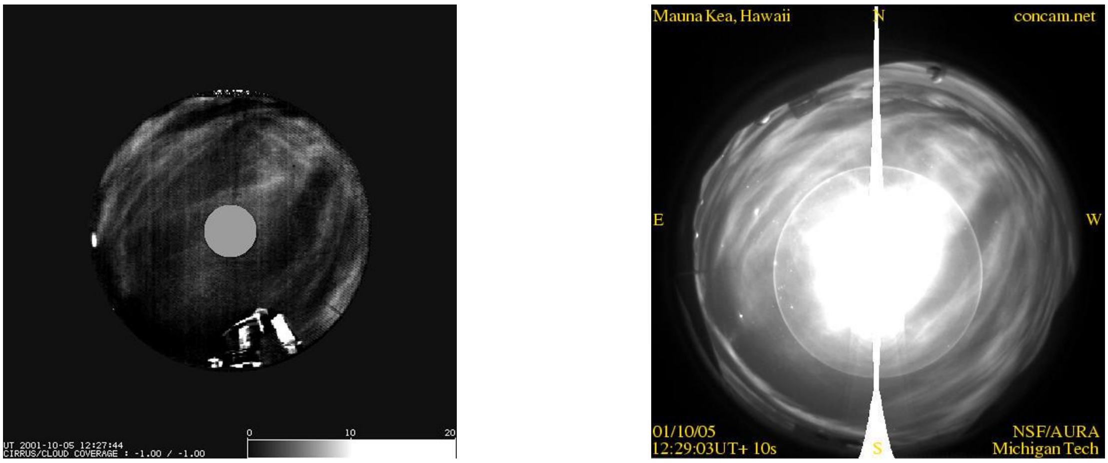

Figure 4. Same as Figure 4 but for thick cirrus.

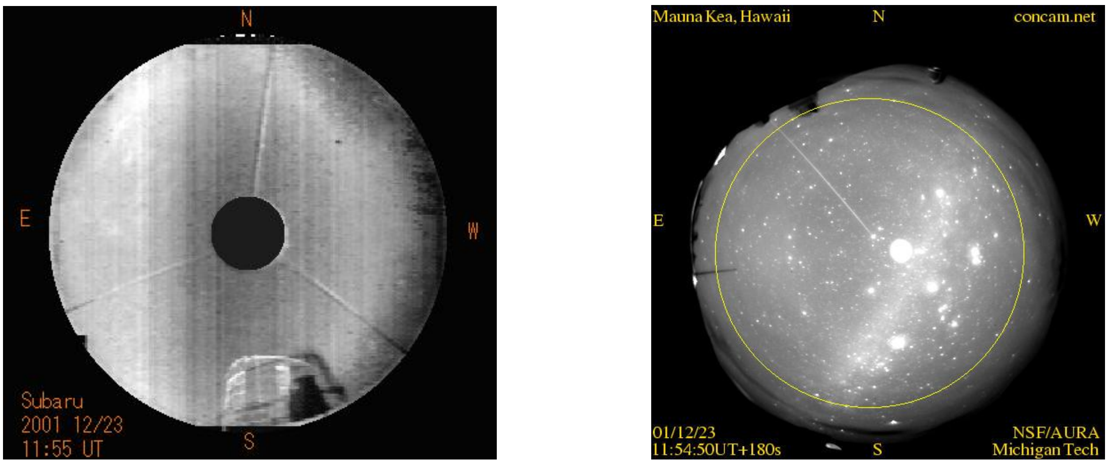

Figure 5. Same as Figure 4 but for thin cloud. The straight beam from the Keck II Telescope seen in CONCAM image is a laser beam for laser guide star experiment. A circle overlaid on the CONCAM image indicates the field of view of IR all-sky cloud monitor.

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