

AUTOMATED WHOLE SKY IMAGING SYSTEMS FOR CLOUD FIELD ASSESSMENT

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1. INTRODUCTION

An important requirement of the ARM Program Plan is to establish surface-based cloud imaging systems at research sites, to provide timely assessment of the directional characteristics of the cloud field. The relative placement and character of clouds can have a strong impact on both the total incoming radiation at the surface, and the reflected radiation above the cloud field.

The Marine Physical Lab's Optical Systems Group (OSG), has over a period of 8 years developed a family of automated Whole Sky Imagers (WSI) for use in high spatial and temporal resolution assessment of cloud fields. These WSI systems acquire digital imagery fully automatically; automated algorithms are used to radiometrically correct the raw data, and identify the cloud conditions at each "pixel" location. The Day WSI has operated at 7 sites over a 2 - 3 year period, acquiring imagery at 1/3 degree spatial resolution, at 1 minute intervals.

Since deployment of the Day WSI, a more sophisticated Day/Night WSI, capable of cloud field imagery under daylight, moonlight, and starlight conditions, has been developed and is currently fielded at military test sites. This system uses a slow-scan CCD sensor with a fiber optic taper. Full automation of this system, as well as development of moonlight cloud algorithms, is currently in progress.

2. OVERVIEW OF THE DAYTIME WSI SYSTEM

The Day Whole Sky Imager is a passive, ground-based sensor. It uses a fisheye lens to acquire images of the upper hemisphere down to an 80 degree zenith angle. A combination of spectral and neutral density filters, in conjunction with a Charge Injection Device (CID) solid state camera, enables acquisition of images which may be fully calibrated radiometrically. The sensor is controlled automatically, with four images acquired every minute, at 512 x 480 resolution. This yields 1/3 degree spatial resolution, for a footprint of roughly 17 meters for a cloud layer at 3 km altitude. The system is controlled by an IBM AT-clone with a resident 2.2 Gbyte tape system for data archival. In the field, the current system acquires data every minute, for 12 hours a day. A new tape must be inserted once a week for continuous operation. The system is further discussed in Shields, (1990), and Johnson, (1989).

The cloud determination sequence is illustrated in Fig. 1. The system acquires four images; a blue (450nm), a red (650nm), and a blue and a red trimmed with neutral density to acquire those regions which are offscale bright in the first two filters. A variety of additional neutral densities and aperture settings are used to bring the radiances to the proper onscale level. A number of calibrations are then applied to these four acquired radiance images. The most significant are the linearity calibration, which corrects for any non-linearity of the basic sensor, and the absolute calibration, which corrects for differences in the pass bands of the spectral filters, non-neutrality of the neutral density filters, and so on. (The resulting calibrated radiance images are not saved at this time, due to the extra processing time required.)

Ratios of red to blue radiance are then computed, including any correction for small differences in image size. The best red/blue pair to use is then selected on a pixel by pixel basis, to generate the composite ratio image. These ratios are then saved to tape in image format, for further processing.

Ratioing these images removes most of the directional and temporal variation in the background sky radiance. In the remaining ratio image, opaque clouds are identified by a fixed ratio threshold. Optically thin clouds are identified as a fixed perturbation with respect to the background sky ratio. This background sky ratio varies from pixel to pixel, as well as image to image, to allow for changes in aerosol load and changes in ratio due to different look angles and solar zenith angles. This process is further discussed in Koehler, (1991).

The Day systems have performed quite well in the field over the last three years. A data base of approximately 900 Gigabytes of raw image data (approximately 4600 data days) has been generated. Of this data, 14 months at each of 4 stations have been processed to the cloud decision image, Johnson, (1991), and Ciandro, (1991). The results compare quite well to the standard observer Shields (1990), and Koehler (1991).

There are several features of this cloud identification technique which should be noted. First, unlike schemes involving human evaluation of images, the technique is both fast and consistent. Secondly, through application of the calibration corrections, one is much less influenced by

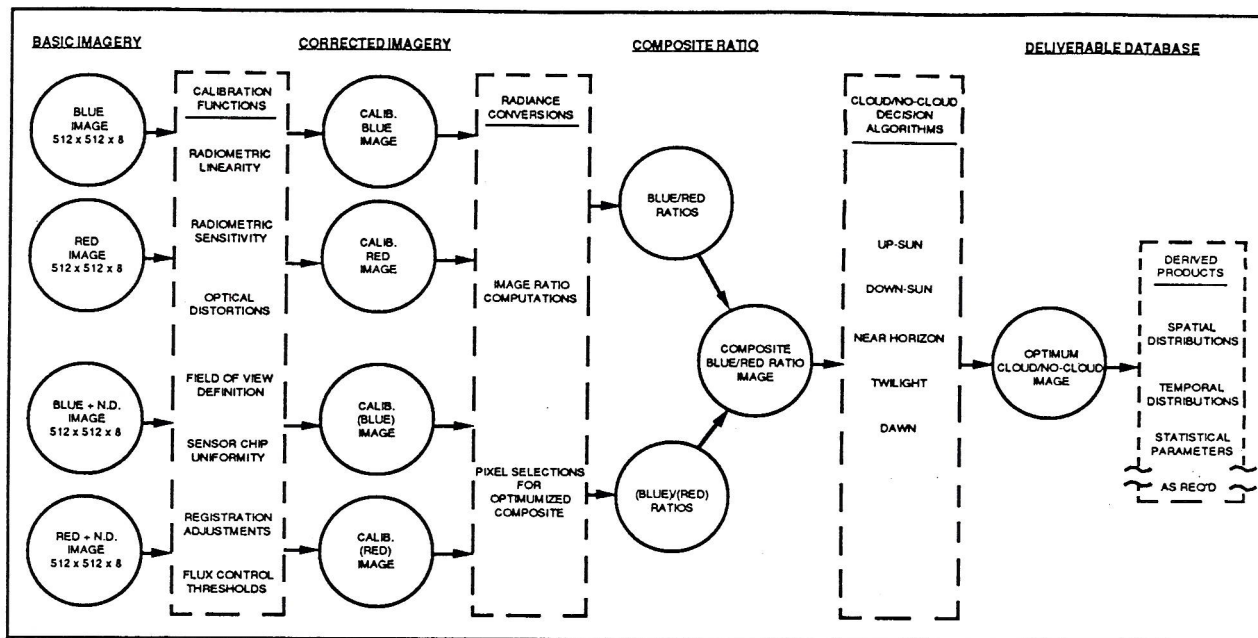


Figure 1. WSI Basic Image Processing Flow Chart

camera characteristics such as non-linearity. Third, through use of the ratio technique, as opposed to an identification based on radiative brightness, one correctly identifies even clouds which are darker than the sky background. Finally, through correction of the background sky ratio for aerosol load and directional variance, the system avoids the directional bias inherent in human assessment; for example, a cirrus streak from an aircraft is correctly identified both upsun and downsun.

3. COMPARISON WITH OBSERVER

The results of the WSI data processing are normally quite accurate. Fig. 2 shows the cloud cover distribution from 7 months of WSI data acquired at Columbia, Missouri, and processed with the first generation (fixed threshold) algorithm, in comparison with the values of total

sky cover reported on the National Weather Service Form 10's. The WSI values are from the image at the reported time of the weather observation. This plot is for the six hours surrounding local apparent noon. The comparison between WSI and observer is in general quite good. The cloud algorithm identifies some clear cases as 1/10 cover, but in all other cloud categories the match in frequency of observance is excellent.

Another indication of data quality is a direct case-by-case comparison between WSI and observer. For Fig. 3, the difference between WSI and observer has been computed for each case. That is, a WSI value of 7/10 and observer value of 5/10 would be a difference of 2 categories. The distribution of category differences is shown in Fig. 3. The majority of the cases show a category differ-

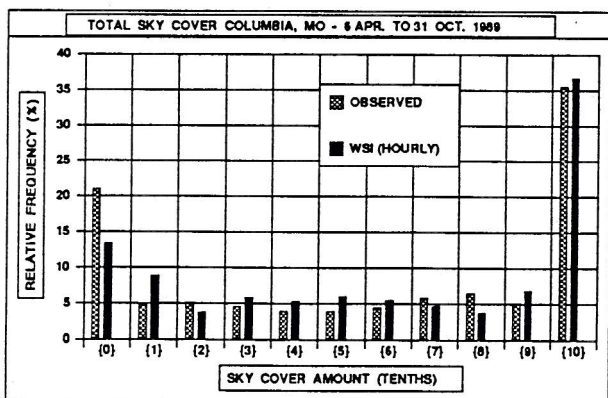


Figure 2. Distribution of Total Cloud Cover determinations, WSI and Weather Observer

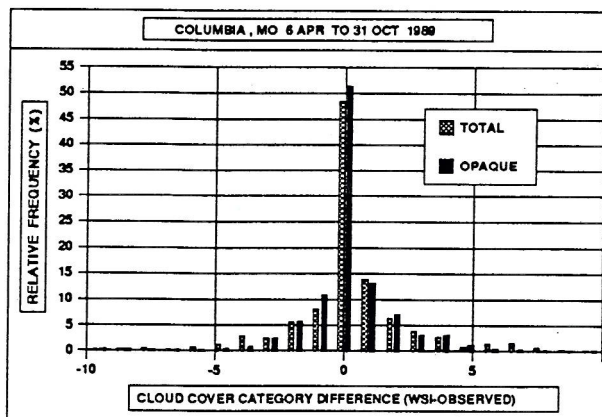


Figure 3. Total Cloud Cover determination difference for WSI minus observer

ence of 0. The average difference is less than half a category, i.e. much less than 1/10 cloud cover.

Although the observer to WSI comparison is generally good, the WSI data can show much more variance than the observer data, simply due to the limited temporal frequency of the observer values. One particularly dynamic day, 14 April at Columbia, MO, is illustrated in Fig. 4. In Fig. 4, which shows the cloud cover determinations for both the WSI and the observer, the observer values are consistent with the WSI, but they certainly do not show the true variability, due to their limited temporal frequency. For example, at 1350 and 1450, both WSI and observer show approximately 20% cloud cover, but during the intervening hour the cloud cover increased to nearly 80%. The fastest rate of change during this hour occurred between 1400 and 1413, when the cloud cover changed from 20 to 74%.

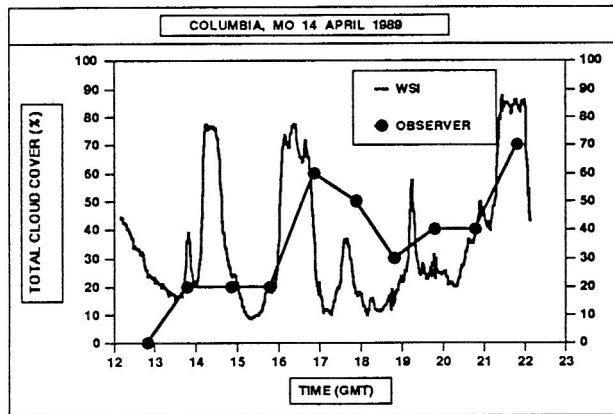


Figure 4. Total Cloud Cover Time series, WSI and Observer

4. THE DAY/NIGHT WSI

The new Day/Night WSI takes advantage of many of the technologies that have been used in the Day WSI. The sensor schematic is shown in Fig. 5. The new system includes a larger fisheye lens, for full upper hemisphere coverage down to 90 degrees zenith angle. This enables detection of the vertical buildup on the horizon, as well as providing full coverage for comparison with the meteorological observer.

The Day/Night WSI uses a slow scan Charge Coupled Device (CCD) sensor to yield the additional sensitivity required for night operation. Spectral filters are used, as with the Day WSI, generally down to quarter moon conditions. A fiber optic taper is used in place of the previously used lens relay system, to resize and relocate the image plane. The Day WSI's equatorially driven solar occulter is replaced in the Day/Night system with a zenith/azimuth dual drive occulter, in order to more readily transition from sun to moon occultation.

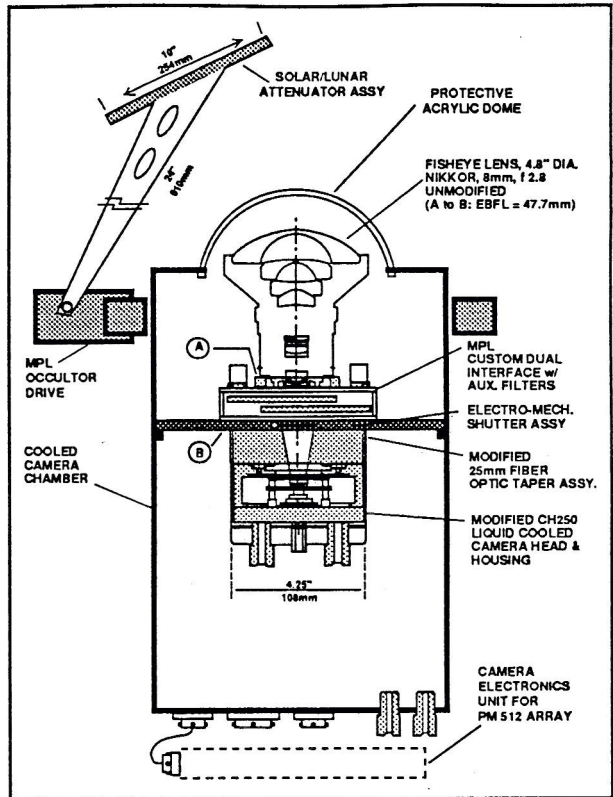


Figure 5. Day/Night WSI Imager Assembly. The system uses a 180 degree fisheye lens, slow scan camera, and custom filter and occulter assemblies.

One of the important design criteria is the large range of flux levels the system must be able to deal with. Figure 6 shows the naturally occurring illuminance levels under a variety of lighting conditions. These data are from the work of Brown (1952), and are consistent with irradiance measurements acquired by our group at the Visibility

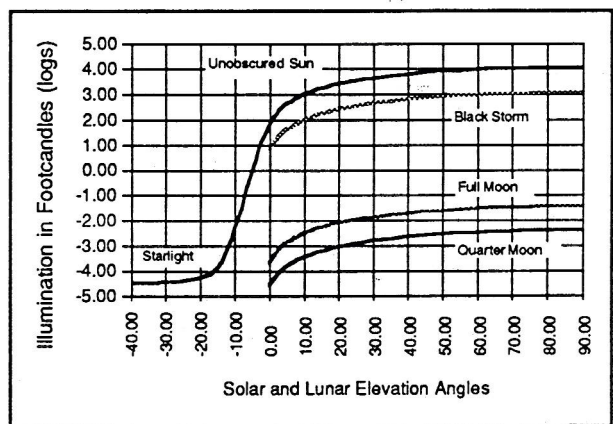


Figure 6. Natural Illumination Levels. These measurements, from Brown (1952), illustrate flux conditions the Day/Night WSI should encounter.

Lab over a period of several years. In Fig. 6, the daytime illuminance conditions the Day WSI has had to deal with are shown in the top two curves on the right side of the plot. These represent clear to dark storm conditions for sun zenith angles 0 to 90 degrees. The Day/Night WSI is operational for red/blue data acquisition at least down to quarter moon conditions shown on the bottom right curve and for urban starlight conditions. For rural starlight conditions, open-hole is used. This represents approximately a 9 log range of lighting conditions. The sensor is designed to obtain the necessary sensitivity range by using the approximately 3 log sensitivity of the camera chip, 3 logs range from exposure control, and 3 logs range through neutral density filter control.

For moonlit images, it should be possible to use a cloud decision algorithm which is conceptually similar to that used in the Day WSI. A study of night radiance distributions acquired by our group in 1968 and 1969 has been made to evaluate the red/blue ratios under a variety of conditions, Gordon, (1989). This study indicates that down to quarter moon, the red/blue ratio should be a reasonably good indicator of clouds, but for starlight conditions the spectral character of the sky is quite different, and a different algorithm will probably be required.

5. CONCLUSION

The current Whole Sky Imagers, developed by the Marine Physical Lab, acquire imagery appropriate for automated identification of cloud fields. Versions of these units exist which either yield a data archive for post processing, or yield near-real time results. The latest version of the WSI units acquires imagery not only during the daytime, but also down to starlight conditions.

In use by the military for nearly ten years, these systems can acquire not only cloud cover, but also measurements of cloud field spatial characteristics such as angular distribution. Statistical information such as the frequency of cloud obscuration of direct solar flux as a function of cloud cover and solar zenith angle are readily extracted (limited only by the mechanics of dealing with a large data base). Temporal studies such as evaluation of persistence and recurrence, as well as development vs.

translation studies become feasible. Finally, if full absolute radiometric calibrations are obtained prior to fielding the system, the upper hemisphere radiance distribution may be extracted from the data. As these systems continue to develop in capability, flexibility, and convenience, they should continue to have important applications in global warming studies.

6. REFERENCES

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