
Marine Physical Laboratory

Continued Upgrade of the LIMDAS Day/ Night Whole Sky Imager for Night Cloud Monitoring

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Final Report

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Abstract

The Whole Sky Imager is a ground-based digital imaging system for assessment of cloud cover over the full upper hemisphere. Using a fisheye lens and a slow scan CCD sensor, it acquires imagery under daylight, moonlight, and starlight conditions. This contract funding enabled Marine Physical Lab to provide upgrades to the WSI at the White Sands Missile Range. The primary enhancements included adapting a cloud decision algorithm for this site, upgrading the WSI environmental housing for long-term use, characterizing the impact of lights on the moon algorithm, providing hardware for recording to video tape, and refurbishing an earlier version of the WSI used for daytime cloud sensing.

1. Introduction

The Atmospheric Optics Group at SIO's Marine Physical Laboratory (and formerly at SIO's Visibility Laboratory) has conducted research in atmospheric optics for several decades. The current generation of digital Day/Night Whole Sky Imagers were developed over many years by the Atmospheric Optics Group. The first digital WSI systems were developed by our group in the early 80's, with the first major field deployment in '84. This early development was based in part on experience by this group with fisheye systems and scanning radiometer systems developed for atmospheric research during research programs in the 50's, 60's, and 70's.

1. Introduction

A series of fully automated digital daytime WSI's was developed in the mid to late 80's, and these were fielded at several sites throughout the US in the late 80's, acquiring data at 1-minute intervals over periods of 2 years or more. These data were acquired in order to obtain a data archive large enough to provide statistically significant estimates of cloud free line of sight probabilities, as well as cloud free arc probabilities. The instruments operated autonomously, acquiring data under instrument control with occasional routine maintenance. The early development of these Day WSI's is documented in Johnson 1989.

In the early 90's, a Day/Night WSI capable of data acquisition under 24-hour operation was developed (Johnson 1991). Even though capability below quarter moon lighting conditions was not promised to sponsors, the group was successful in developing a digital imager which is fully operational down to starlight conditions. Like the Day WSI, it is fully automated, adjusting itself to the ambient lighting conditions and acquiring and archiving data at user-selected intervals. This instrument has been used for a variety of applications, including site support at the White Sands Missile Range (WSMR), where it is used to detect the presence of clouds which may affect other experiments. Other applications include monitoring of cloud cover, size, and distribution for use in climate research, and test site support for tracking missions. The first version of the Day/Night WSI is documented in Shields 1993.

Since the early instruments documented in Shields 1993 were developed, several advances have taken place (Shields 1996 a, b, c, and 1997). New WSI systems are now more robust, with a stronger occulter and safer environmental housing. Numerous self-checks have been added to the system, so that it now alerts the user if abnormal behavior occurs, such as difficulty changing filters, and it can also turn off the camera if system temperatures become dangerously high. The software has developed considerably, including ability to either archive images or send them over network, and hot key options which allow the user to interrupt the program and evaluate or save imagery. A real-time cloud algorithm is now integrated into the archival software and provides the cloud algorithm results (called the cloud decision image) as the data are acquired. At present, the real time algorithm is for daylight opaque clouds, and it is anticipated that work in the real-time daylight thin cloud algorithm will be progressing in the near future. Another addition to the capabilities is remote control via a Scramnet link. This allows a remote user to acquire images and status data from the WSI, and also send control instructions such as a change in acquisition interval. Networking via standard Ethernet links has also been developed.

At the time of the start of this contract, MPL had recently developed the first two Day/Night Whole Sky Imager (WSI) systems capable of opera-

2. Goals of the Contract

tion through daylight, moonlight, and starlight conditions. One of these units had been fielded at White Sands Missile Range (WSMR) HELSTF Site. This contract was for continued development of this system.

At this site, the WSI was being used to support Navy tracking missions. The WSI acquires imagery of the full sky, with a 180 degree field of view. Tracks of satellites or missiles may be input to the WSI system, which then superimposes these satellite tracks over the acquired and/or processed images. The WSI is used to assess the sky conditions along the track, as well as regions in which the background sky radiance increases substantially. Both the cloud elements and the enhanced path radiance have been related to trackers losing lock-on. The system is particularly valuable in this type of application because the unit can track the quickly changing positions of clouds, and precisely define their relation to the target track, even when the clouds are invisible to the human at night.

2. Goals of the Contract

One of the useful features of the WSI is a cloud algorithm, which determines the locations of clouds within the image on a pixel by pixel basis. While the basic algorithm had been developed under other contracts, it had not yet been applied to this site, because it requires a site-dependent characterization of the clear sky background. One of the goals of the contract was to provide this clear sky background and integrate it into the system.

A related goal was the evaluation of the ambient lights at night, and their impact on the moonlight algorithm. To a first approximation, the moonlight algorithm is very similar to the daylight algorithm, because the optical character of the moonlit sky is similar in many ways to the optical character of the sunlit sky. That is, in both cases, the primary source is a point source, and the primary mechanism for creation of the sky radiance and cloud radiance is scattering by the atmosphere. One primary difference is the presence of a background sky radiance which varies by location and direction partly due to anthropogenic sources, and this background sky radiance becomes increasingly important as the moon wanes. Thus a second goal was to evaluate the impact of this background light on the moonlight algorithm.

In the hardware arena, the primary task was to upgrade the environmental housing and to include a flow meter for camera protection, which would remove power from the camera in the event of unacceptably diminished coolant flow. We were also tasked to provide data conversion of the im-

3. Discussion of the Results

agery from VGA to NTSC format for recording the imagery to video tape, and evaluate methods to transfer the imagery to alternate sites for viewing by WSMR personnel.

Several optional tasks were included in an optional budget. One of these was funded at a later time; this was the refurbishment of the Day-only WSI, which was an earlier generation WSI used for daytime cloud assessment.

3. Discussion of the Results

The initial tasks were completed within a few months of the start of the contract. The system was delivered with the new housing and algorithms on 13 Sep 93 (following the start of the contract on 10 May 93). The day refurbishment option was funded some time later, and the work delayed at the request of the sponsor; most of the day refurbishment took place in 95 and 96, with delivery of the system on 9 Jun 96.

3.1 Software Algorithm Upgrades

The Day/Night WSI measures the sky radiance in approximately 1/3 degree increments over the entire sky dome. The measurements are made in two spectral regions centered at 650 nm and 450 nm, and through open-hole visible under starlight. The system provides 16-bit images. The images have low noise and large dynamic range. In combination with changes in filter and exposure selection, they provide sufficient dynamic range to cover full daylight to starlight. These raw data may be converted to 8 bit images for viewing by the user. These images are very useful for a variety of applications which involve sensing the cloud locations in the sky or in regions of interest.

Under daylight and moonlight, the red and blue images may be used to determine the presence of opaque clouds and thin clouds in the line of sight on a pixel-by-pixel basis. The output may be presented visually, as a cloud decision image in which areas assessed to be clear sky are colored blue, and opaque clouds are colored white. More importantly, at this point the numeric results in the cloud decision image may be used for numeric analysis, such as determination of cloud cover, and statistical studies such as cloud free line of sight analysis.

The cloud algorithm first applies calibration factors to the 16-bit data, and then ratios the red and blue images to provide a ratio image. The ratio is thresholded to identify the opaque clouds; thus opaque clouds are identi-

fied by their spectral character. For the thin clouds, the site-dependent spectral character of the clear sky is determined, as a function of zenith angle, azimuth with respect to the sun, solar zenith angle, and haze load. When field data are processed, the haze load for the image is determined from the imagery, and the ratio data are then ratioed with respect to the clear/hazy sky background. In this way, the algorithm identifies a pixel as thin cloud if the field image ratio exceeds the background clear sky ratio (for that pixel and time) by 20%. Thus a pixel is identified as thin if its spectral signature is not as high as that of an opaque cloud, but is significantly different from that of the clear or hazy sky at the same look angle and solar/lunar angle.

In order to apply this algorithm at the HELSTF site, it was necessary to process clear sky data to yield the clear sky background ratio library. This library consists of images of normalized ratios for the full sky at five degree solar zenith angle increments (i.e. an averaged normalized ratio image for each solar zenith angle). The clear sky background ratio library was successfully extracted for this field site, and applied to field data. It was found to work very well. It was installed on the system as an interactive program, which allows the user to adjust the opaque thresholds and the haze correction. It is intended for use with archived data. For a year or more after the algorithm was installed, it was used frequently, either at the WSMR site or at MPL, at the sponsor's request.

At this point in time, several improvements have been made to similar software in the interim, under funding from other sponsors. We recommend upgrading the algorithm program software at this site in similar ways for greater ease of user interaction.

The moonlight and non-moonlight data were evaluated using data acquired in the field at the WSMR site. It was found that the no-moon background data could be used effectively to correct the moonlight data for use with the daylight cloud algorithm. This program and its documentation were also delivered with the instrument in Sep 93.

3.2 Hardware Upgrades

The WSI was retrofit with a new metal housing, in place of an earlier temporary housing which was not large enough to hold the chiller. The flow mechanism was improved, both in order to provide better flow to the instrument, and in order to provide a flow sensor. This flow sensor allows the system to automatically shut off if the flow is reduced below an acceptable point. The CCD camera uses a 3-stage thermo-electric (TE) cooler on the back of the chip, and it requires constant flow of water to the back

3.3. Daytime WSI Refurbishment

of the chip to remove the heat from the hot side of the TE cooler. Since the camera is quite expensive to procure (due to its very low noise and large dynamic range and special adaptation to allow imaging of the full sky), a protection device to protect it in the event of interruption of the flow is vital. This flow device was installed and has been working well.

In addition, a VGA to NTSC converter was purchased, and installed with a VCR, in order to allow the user to create time lapse tapes of the image results during tracking missions. Also, preliminary tests were run of methods to transfer the image from the data acquisitions computer to a test computer. A standard Ethernet link was found to work successfully, with no loss in the image, and with sufficient speed. In fact, since this work was done, other WSI units built by MPL have had this feature installed, and are transmitting images over extended distances to operators removed from the site. While it has not yet been a funded priority at the WSMR site, the networking approach for bringing images into the observer room is clearly a reasonable technology to use.

3.3. Daytime WSI Refurbishment

The Day WSI was quite old, having been fielded in 1988, with a slave computer for near-real-time assessment added in 1989. The system was sent back for refurbishment in Feb 1995. At the sponsor's request, it was partially refurbished and deployed for a short test program at Ft. Hunter Liggett Army Base in May 95. Further refurbishment was then delayed at the sponsor's request, and then the refurbishment was completed and the system delivered in June 96. This refurbishment included replacing the camera, optical dome, lens housing, filter changer, occulter drive, environmental housing, and cables on the sensor. The master controller received a new monitor, CPU, hard drive and hard drive controller, tape drive, keyboard, and clock, and a newly repaired image board. The slave computer received a new monitor, SCSI board, hard drive and hard drive controller, modem, and tape drive. In addition, the software was upgraded for better handling of the RS232 timing and the track input. The system was reinstalled at the HELSTF site in June 96.

4. Conclusions

Both the Day/Night WSI and the Day WSI have continued to operate for many years. The Day/Night WSI was first fielded in Feb 1992, and is continuing to provide outstanding imagery. The Day WSI was fielded in 1988, and although it received significant refurbishment of parts, we con-

5. Acknowledgments

sider it remarkable that a system designed originally as a state-of-the-art research instrument should still be useful after so many years. We feel this is partly a result of the design of the instrument, but we also feel it is to the credit of the HELSTF personnel who have handled the instrument in a professional manner. This contract enabled MPL to complete upgrade of the Day/Night WSI in 93, and refurbish the Day WSI in 96.

Although the systems have continued to work well, both we and the HELSTF personnel feel that the system use is not at its optimal level, particularly in regard to the algorithms, primarily due to little contact during this period of low funding at the site. We are interested in remedying this situation with increased technical interaction with site personnel. In addition, since 93, the state of the art in Day/Night WSI sensors and software developed by MPL has continued to advance, and we feel that the site could benefit from upgrades in the software capabilities. Our understanding is that the instruments continue to provide very valuable monitoring of sky conditions, particularly for test support.

5. Acknowledgments

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