

# STATUS OF THE WHOLE SKY IMAGER DATABASE

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## ABSTRACT

Beginning in 1988, a seven site network of whole sky imagers was fabricated, fielded and maintained by the Marine Physical Laboratory. These imagers produced multispectral, digital imagery of the sky dome on a minute-by-minute basis during the daytime hours at each site. Data collection ended on 31 December 1990. The final status of the spectral image archive is summarized. A description of an improved cloud identification method is also presented.

## 1. INTRODUCTION

In response to a need of the Strategic Defense Initiative for information about the variability of cloudiness on short time scales and at high spatial resolution, a multi-site network of Whole Sky Imagers (WSI) was fielded and maintained by the Marine Physical Laboratory (MPL) of the Scripps Institution of Oceanography. Data collection took place from March 1988 through December 1990.

To aid in the cloud identification procedure, images were collected in both the blue (450 nm) and red (650 nm) parts of the visible spectrum. The cloud decision is performed on the red/blue ratio image. Two cloud decision algorithms have been developed and applied to a substantial subset (30%) of the WSI database. Both the fixed threshold and the directionally-dependent, variable threshold algorithms are briefly described. Examples are presented that illustrate the impact an improved cloud decision algorithm can have both on individual images, and on the overall agreement with a human observer.

## 2. RAW DATA ARCHIVE STATUS

Many of the details regarding placement of the WSI network, the format of the sky dome images, and the data processing procedures have been presented in previous CIDOS proceedings. (See, for example, Johnson et al., 1988, and Shields et al., 1989.) On each day at each site, a set of blue and red images were taken every minute during the 12 hour period centered on local apparent noon. Full resolution images were archived at every 10 minute interval, and subset images were archived every minute. Table 1 shows the deployment summary of the WSI network.

In all, about 765 gigabytes of image data were collected from over 4500 data days. More specific summaries of the database are available from MPL.

Table 1. WSI NETWORK DEPLOYMENT SUMMARY

| Site                | Placed in Service | Withdrawn from Service | Total Days | Data Days |
|---------------------|-------------------|------------------------|------------|-----------|
| C-Station, WSMR, NM | 30 Mar 88         | 19 Dec 90              | 995        | 768       |
| HELSTF, WSMR, NM    | 29 Mar 88         | 31 Dec 90              | 1008       | 819       |
| Kirtland AFB, NM    | 17 May 88         | 25 Dec 90              | 953        | 749       |
| China Lake NWC, CA  | 23 Jun 88         | 6 Dec 90               | 897        | 641       |
| Malmstrom AFB, MT   | 29 Aug 88         | 20 Dec 89              | 478        | 406       |
| Malabar, FL         | 18 Nov 88         | 19 Nov 90              | 735        | 602       |
| Columbia, MO        | 9 Feb 89          | 31 Dec 90              | 691        | 592       |

## 3. CLOUD DECISION PROCESSING

The WSI products of interest to most potential users are not the raw radiance data, but the processed cloud decision images. As noted in McGuffie and Henderson-Sellers (1989), most previous WSI cloud decisions have been performed directly from radiance imagery. In many circumstances, confusion can arise in regions of shaded cloud bases, where dark cloud can be confused with clear sky. To avoid this problem, our cloud discrimination technique is based on the ratio between the red and blue radiance values, where white objects, such as clouds, will have a larger ratio than a clear (blue) sky.

### 3.1 FIXED THRESHOLD ALGORITHMS

The simplest ratio cloud decision algorithm assigns a certain sky state to fixed ranges of ratio value. In our application, we want to discriminate between clear sky, thin cloud and opaque cloud. Two values, the thin and opaque thresholds, need to be defined. All pixels with a red/blue ratio exceeding the opaque threshold are then assumed opaque cloud. Those pixels with ratios between the thresholds are assumed thin cloud cover. Finally, those pixels with ratios below the thin threshold are assumed clear.

This fixed threshold technique was used in the first set of cloud decision processing runs from our WSI database. Fourteen months of one-minute data from February 1989 through March 1990 were run through ratio and cloud decision processing for three sites, C-Station, Kirtland, and Columbia, and

for a combination of Malmstrom (February through September 1989) and Malabar (October 1989 through March 1990).

The fixed threshold algorithm does a reasonable job in defining opaque cloud, but in many circumstances fails to properly distinguish the true thin-clear boundary. This problem is illustrated in the example shown in Fig. 1. Two contrails are evident in this image: a denser one oriented

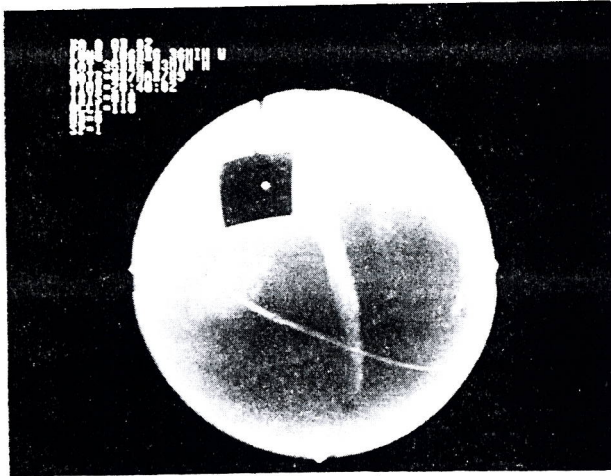


Figure 1. WSI 650 nm radiance image from Kirtland AFB, 8 March 1989

roughly from top to bottom, and a narrower one angling from the upper left to the lower right. The region just below the solar occulter is brighter than other parts of the image due to its proximity to the sun's aureole, but should probably be classified as clear. Figure 2 shows two different thin threshold slices through the same ratio image. The cloud decision with a thin threshold of 120, fails to identify significant parts of the contrails. When the thin threshold is brought down to 70 to bring out the remainder of the contrails, the clear regions near the occulter and the horizon are misidentified as thin cloud. This occurs because the clear sky ratio back-

ground is not constant. The sky appears lighter blue near the horizon and near the sun, than it appears in the downsun direction. Thus, a thin cloud in the downsun part of the sky may actually have a smaller ratio than clear sky near the sun or horizon. An improved algorithm would have to take this sky background variation into account.

### 3.2 VARIABLE THRESHOLD ALGORITHM

Several similar contrail cases were studied in an effort to determine the relationship between thin clouds and their background sky conditions. We found that the ratio of thin cloud red/blue radiance ratio to the clear sky background red/blue radiance ratio remains fairly constant along sections of contrails exhibiting uniform optical properties. If the clear sky background ratio were known, a thin cloud discrimination could then be based on whether the observed ratio exceeds the background ratio, and the degree of "thinness" could be estimated by the observed/background ratio. The thin cloud decision "problem" then becomes one of determining a reasonable estimate of the clear sky background ratio.

The red/blue clear sky ratio distribution is influenced by many factors the most important of which are the solar zenith angle, and the haze features of the atmospheric boundary layer. Figure 3 shows the variation of the ratio distribution as a function of solar zenith angle. Note how the clear sky background "whitens" as the sun approaches the horizon. Figure 4 illustrates the boundary layer haze influence, with the pristine February arctic air mass yielding "bluer" ratios than the haze laden air mass from July.

Our new cloud decision algorithm uses clear sky background fields derived from clear day observations. The haze effect is normalized by dividing the image by the reference red/blue ratio from the intersections between the 45° look zenith circle, and the locus of points separated by a 45° scattering angle from the sun. The effect of the normalization is shown in Figure 5. In practice, a set of normalized clear sky

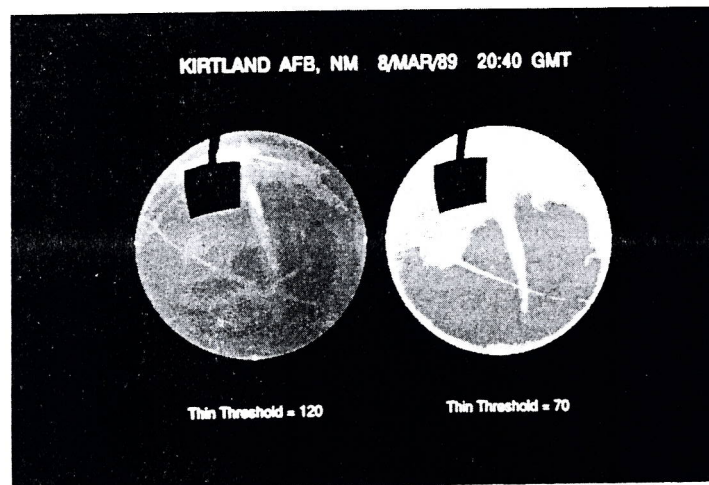


Figure 2. Fixed threshold cloud decisions with two different thin cloud thresholds. Lighter shades indicate cloud, darker indicate clear sky.

ratio tables are extracted from many clear days at a specified site for each 5° solar zenith angle. The table consists of normalized ratios at 5° look zenith intervals from 0 to 75°, and azimuths relative to the solar azimuth at 15° intervals. Tables for each solar zenith angle set are then averaged together to provide the best normalized clear sky estimate.

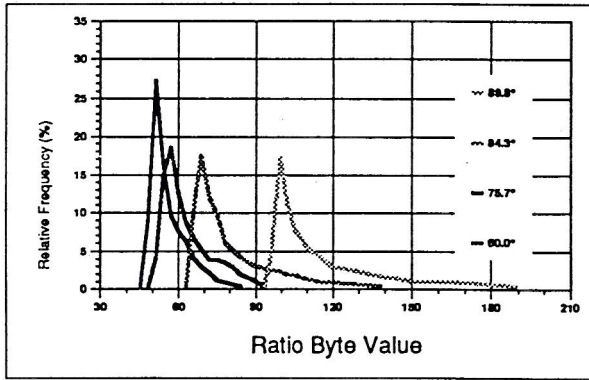


Figure 3. Clear Sky Solar Zenith Angle Dependence: 11/Feb/89 - Columbia, MO

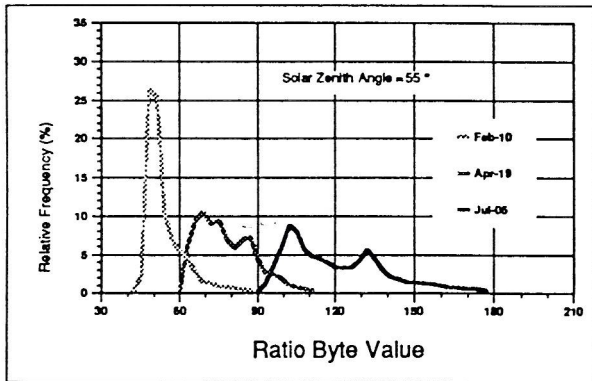


Figure 4. Clear Sky Haze Layer Dependence: Columbia, MO, 1989

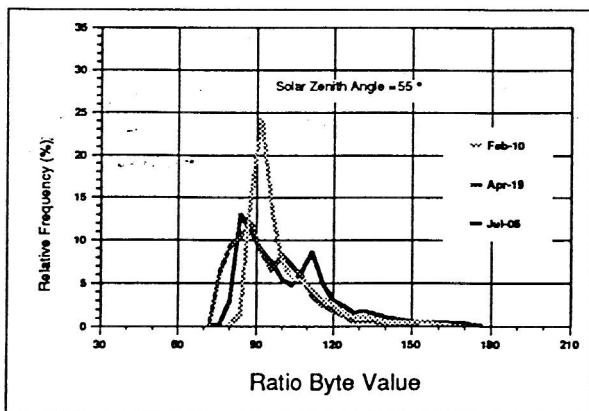


Figure 5. Normalized Clear Sky: Columbia, MO, 1989

In the cloud decision algorithm, the clear sky background for a particular image is determined as follows. First, the solar zenith angle is determined for the date, time and site location of the observation. A linear interpolation is then made

between the two closest solar zenith angle tables to estimate the normalized background table for the image. Given the zenith and relative azimuth of a particular pixel in the image, its normalized clear sky ratio estimate is then computed by bilinear interpolation of the table values. This normalized value is then multiplied by a reference ratio value determined from an interactive procedure that examines the reference value variation for that day and time.

The cloud decision is then made by comparing the observed ratio to the fixed opaque threshold, and the clear sky ratio estimate. The pixel is then given a numerical value that defines whether it is categorized as clear, thin cloud, opaque cloud, obscured from view, or indeterminate. This last category occurs when the clear sky ratio estimate exceeds the opaque cloud threshold. The cloud decision image from the new algorithm for the contrail case is shown in Figure 6. Note how the contrails are identified without misidentifying the points near the sun and horizon.

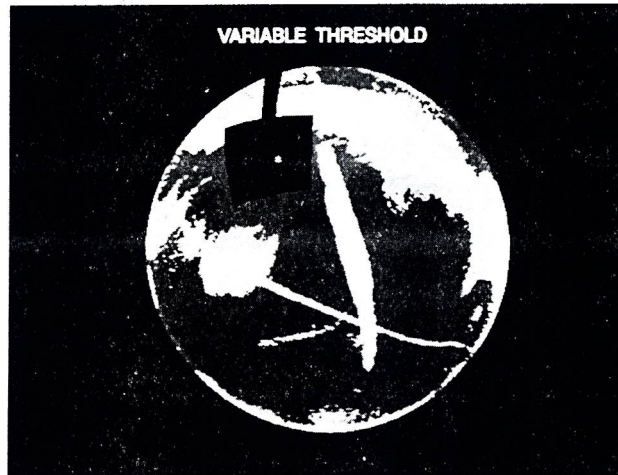


Figure 6. Variable threshold cloud decision image

### 3.3 DATA BASE PROCESSING WITH THE NEW ALGORITHM

The new variable threshold, directionally-dependent algorithm has been used to process the 10-minute, full resolution images from the same 14-month, 5 site subset processed earlier using the fixed threshold algorithm. The results are encouraging. The more reliable definition of thin cloud illustrated in the contrail example is the rule, not the exception. A measure of this improvement is shown in Figure 7. This figure, illustrates the tenths of total sky cover category differences between the WSI and the human observer at Columbia from the 14-month sample. Values from both the old, fixed threshold, and new, variable threshold algorithms are shown. The new algorithm shows better agreement with the human observer. This comparison only indicates cases where the improvement was due to changing the WSI total sky cover amount. In many cases, the total sky cover did not change but the spatial distribution of that percentage improved.

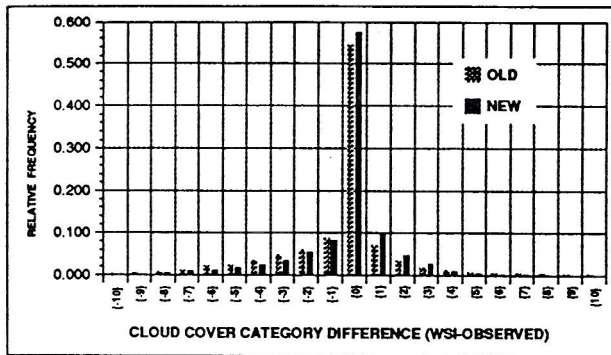


Figure 7. Total Cloud Cover: Columbia, MO  
9 Feb 89 - 28 Mar 90

#### 4. SUMMARY

A large digital image data base has been accumulated from the Whole Sky Imager network. A large fraction (roughly 30%) has been processed to the cloud-no cloud level, using both a simple, fixed threshold cloud decision algorithm, and a more sophisticated, variable threshold technique. Advantages of the newer algorithm include: more reliable thin cloud definition, adjustment of the clear sky background for changes in the haze layer characteristics, and most importantly, a reduction in the up sun and near horizon bias evident in previous WSI data sets.

Data of this type and quality could prove quite useful in several applications. These include cloud free line of sight

(CFLOS) and cloud free arc (CFARC) model parameter definitions, direct CFLOS and CFARC model validations, ground truthing of satellite cloud cover observations, determination of human observer biases, and many other applications requiring frequent, high spatial resolution cloud distributions.

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