Title: PERFORMANCE OF THE MTI DENSE-CLOUD MASK ALGORITHM, AND ITS REFINEMENT WITH A GENETIC LEARNING PROGRAM

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Performance of the MTI Dense-Cloud Mask Algorithm, and its Refinement with a Genetic Learning Program

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ABSTRACT
In support of its dual mission in environmental studies and nuclear nonproliferation, the Multispectral Thermal Imager (MTI) has enhanced spatial and radiometric resolutions and state-of-the-art calibration capabilities. These instrumental developments put a new burden on retrieval algorithm developers to pass this accuracy on to the inferred geophysical parameters. In particular, current atmospheric correction schemes assume the intervening atmosphere is adequately modeled as a plane-parallel horizontally-homogeneous medium. A single dense-enough cloud in view of the ground target can easily offset reality from the calculations, hence the need for a reliable cloud-masking algorithm. Pixel-scale cloud detection relies on the simple facts that clouds are generally whiter, brighter, and colder than the ground below; spatially, dense clouds are generally large, by some standard. This is a good basis for searching multispectral datacubes for cloud signatures. However, the resulting cloud mask can be very sensitive to the choice of thresholds in whiteness, brightness, and temperature. In view of the nature of MTI’s mission, a false positive is preferable to a miss and this helps the threshold setting. We have used the outcome of a genetic algorithm trained on several (MAS-based) simulated MTI images to help refine an operational cloud-mask. Its performance will be compared to EOS/Terra cloud mask algorithms.

Keywords: MTI, Multispectral Imaging, Cloud Masks, Genetic Algorithms

1. INTRODUCTION
The dual primary missions of the Multispectral Thermal Imager (MTI) spacecraft are environmental studies and nuclear non-proliferation. In order to study the images from the spacecraft, atmospheric effects such as water vapor absorption or aerosol scattering must be removed. Also, clouds, which limit seeing of the ground, routinely must be removed from the images. For the MTI spacecraft, efforts have been made to limit analyst requirements. Most software is automated to some degree.

Thus, using the simple definition that clouds are white, bright, and cold, analysts are required to determine three thresholds explicitly for each image: an upper limit on temperature, a lower limit on whiteness, and a lower limit on brightness (as determined by a classic NDVI scheme). While fundamentally there is a lot more science to clouds, for the primary purpose of the MTI mission, clouds are noise that must be removed. Therefore it is important to quickly sort data into “cloud” and “not cloud” categories, rather than to classify the types of clouds. The classification of clouds is important as a scientific topic and will be a focus for future work with the MTI data.

The MTI spacecraft1 was launched on March 12, 2000. A collaborative project between Los Alamos National Laboratory, Sandia National Laboratory and Savannah River Technology Center, MTI’s mission objectives are to advance the state of the art in multispectral and thermal imaging, image processing, and to better understand the usefulness of these data. MTI has 15 multispectral channels (see Figure 1), including three visible channels, five very near infrared, two short-wave infrared, two mid-wave infrared and three longwave infrared.2

The MODIS Airborne Simulator (MAS)3 is a high resolution scanning spectrometer that is carried on-board a NASA ER–2 high-altitude aircraft. Its primary objective was to help create and assess algorithms for the MODerate resolution Imaging Spectroradiometer (MODIS) on board the TERRA spacecraft. In this work, resampled MAS...
Figure 1. MTI channels shown above a model atmospheric transmission profile from Clodius, et al.
data is used as a proxy for the MTI spacecraft data. The data is from the Smoke, Clouds, And Radiation - Brazil (SCARB) campaign to study tropospheric aerosol radiative forcing in August of 1995.

The MODIS cloud mask was developed for use on MAS data. Ackerman et al.\textsuperscript{4} clearly describe this physics based algorithm. Their method involves categorizing the scene into night, day and type of background (e.g. desert), then they classify the types of clouds based on thresholds and adjacency requirements for the specific type of cloud being assessed.

GENIE\textsuperscript{5} is an evolutionary computation software system, using a genetic algorithm to assemble image-processing tools (retrieval algorithms) from a collection of low-level image operators (e.g., texture measures, spectral band math, edge detectors, various morphological filters). A population of candidate tools is generated, ranked according to a fitness metric measuring their performance on some user-provided training data, and fit members of the population permitted to reproduce. Each tool generates a number of intermediate feature planes, which are then combined using a supervised classifier (currently a Fisher discriminant and threshold function) to generate a final result mask. This process cycles until the population converges to a solution; or the user decides to accept the current best solution or to change the training data. GENIE is free to ignore the spatial information in the image and rely wholly on spectral band math and the supervised classifier, but in practice GENIE will construct integrated spatio-spectral algorithms. These have been shown to be effective in looking for complex terrain features, such as golf courses.\textsuperscript{6}

As with all machine learning systems, performance depends crucially on the provision of a sufficient quantity of training data, supplying this data is typically a major challenge. For GENIE, training data is provided via a graphical user interface. The user is able to influence the evolution of algorithms by providing additional information, and by interactively providing additional training data.

While this method has been applied to many different remote-sensing problems, we started this investigation to explore its usefulness for the important task of cloud-finding.

2. ALGORITHMS

2.1. Simple Thresholds

For the MTI cloud masking algorithm, we use three basic descriptive criteria about clouds to determine the cloud mask. In order for the mask to work well, we need data from at least a visible, a near infrared band, and a thermal band. This empirically driven algorithm works poorly over snow and ice (where most cloud masks do less well) and at night.

Observationally, clouds are usually much brighter than their background. They can be considered to be lambertian. Their brightness is caused by refraction by the ice and water droplets that primarily make up the cloud. Clouds usually appear white when viewed from above. Due to the altitude of the clouds, they are cold. Often, they appear much colder than their background, when viewed from above - ranging from perhaps greater than 20°C to -60°C depending on their opacity and altitude.

For MTI we developed a very simple routine that uses user-defined thresholds for the brightness, as derived from NDVI; whiteness; and coldness. This routine is part of the Level 2 data processing for regular data retrievals for MTI. While these codes are mostly automated, this routine requires that the thresholds be determined by hand. Figure 2 illustrates this simple algorithm. We use a normalized dense vegetation index (NDVI) to determine whiteness, the red band to determine brightness, and the thermal band to determine a relative temperature, using simple thresholds on each of these.

2.2. MODIS Method

Ackerman et al.,\textsuperscript{4} exhaustively describe the cloud mask developed for the MODIS spacecraft. Here we summarize their methods. Their automated masking routines specify pixels that are optically thick aerosol, clouds or shadow. It returns a 48 bit cloud mask that includes much information, for example the likelihood that the pixel is cloudy. This cloud mask is based on radiance values in seventeen bands plus ancillary data: spacecraft viewing geometry, land/water map, topography, etc.

Their method is based on the fact that different types of clouds have different physical signatures. These physical signatures are a function of the time of day and the background that they are viewed against.
Determine 3 thresholds: NIR, Red, TIR Observationally

Is pixel value greater than Red threshold?

Yes

Create NDVI image
Create NDVI threshold
Is NDVI pixel less than NDVI threshold?

Yes

Is thermal pixel value less than TIR threshold?

Yes

Cloud

No

Not Cloud

No

Create NDVI image
Create NDVI threshold
Is NDVI pixel less than NDVI threshold?

Yes

Is thermal pixel value less than TIR threshold?

No

Figure 2. A flow chart of the MTI simple thresholding algorithm.
Here is a brief description of the mask implementation. The pixel is set to either land or water. Next its ecosystem is determined. Adjust for whether it is in a sun glint region. Assign day or night status. A special adjustment is necessary if snow or ice is in the image. Apply appropriate masking test based on all of the attributes that have now been assigned to the pixel. This last step assigns a value to the pixel, each pixel will then be either clear (with high confidence), probably clear, maybe clear and likely cloudy with those designations defined via use of a threshold. Any pixel not labeled clear with high confidence will be considered cloudy for our cloud mask comparison.

We use the cloud mask determined with this method as a training set for the genetic algorithm to evolve on.

2.3. GENIE

The MODIS cloud mask was run on several scenes from the MAS SCAR-B flight series (95-162, 95-163). This required several minutes of computation per scene. The 2-bit cloud cover classification was used as training data for GENIE. We chose to use the most conservative cloud finding setting, so any pixels classified as even possibly cloudy were marked as true for GENIE’s training data.

A population of 100 candidate tools, each consisting of 20 primitive image processing steps, was evolved for 100 generations. This evolution required a few hours compute time on a fast Linux/Intel workstation. The evolved solution produced a good match to the training data, and compared to the MODIS cloud mask we achieved a detection rate of 95% and a false alarm rate of 6.1%, as shown in Table 1.

Each candidate tool generates five feature planes. We use the contents of these planes to derive the Fisher discriminant, which is the linear combination of the feature planes that maximizes the mean separation in spectral terms between those pixels marked up as “true” and those pixels marked up as “false”, normalized by the “total variance” in the projection defined by the linear combination. See7 for details of this discriminant. The output of the discriminant-finding phase is a gray-scale image. This is reduced to a binary image by using Brent’s method8 to find the threshold value that minimizes the total number of misclassifications (false positives plus false negatives) on the training data.

It is possible to analyze the evolved algorithm to determine if all the features contribute to the final answer. In the present case, we found that only two features planes were significant, and we present a flow chart of the reduced algorithm in Figure 3.

The algorithm consists of two independent blocks:

(A) MAS band 2, 0.653 μm visible red, 1km spatial resolution, spectrally equivalent to MODIS band 13 and MTI band C, undergoes a linear contrast stretch, but is otherwise passed raw to the Fisher discriminant.

(B) MAS band 35, 4.465 μm MWIR, equivalent to MODIS band 24 and similar to MTI band J, undergoes local gradient spatial processing, equivalent to the difference of the standard morphological filtering operations of grey scale dilate and erode. A scalar constant is subtracted from the output, and the result is clipped at the 95% level. An NDVI-like ratio is formed of this processed result and the MAS band 1, 0.659 μm visible red, 250m spatial resolution.

To test generalization of the evolved algorithm, we ran our algorithm without modification on two other scenes from the SCAR-B flight series, the results of which are also shown in Table 1. Generalization is quantitatively good, and is in fact equal or superior to performance on the training image because of the generally reduced complexity of types of clouds present in other flight tracks in the SCAR-B sequence.

3. METHOD COMPARISON

Each cloud detection method mentioned above has positives and negatives associated with it. Here several of these aspects are described.

The simple threshold method requires a user to interface and determine the thresholds for each image. The computation time for this method is minimal (on the order of seconds). The mask is usually quite accurate, with the possible exception of images that contain both snow and clouds.
Figure 3. Two contributing feature planes evolved for a cloud mask on SCAR-B data.

Table 1. The quantitative results from the evolved GENIE algorithm on SCAR-B data

<table>
<thead>
<tr>
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<th>Training scene (007) result:</th>
<th>Test scene (001) result:</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>FITNESS</td>
<td>FALSEALARMRATE</td>
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<tr>
<td></td>
<td>942</td>
<td>0.061</td>
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</table>
The MODIS cloud mask uses a great deal of ancillary data. This is instead of having user determined thresholds. It does better over snow and ice than the simple threshold method. However, it is computationally intensive, taking minutes to run, and a great deal of memory.

GENIE again requires a user to interface and determine some truth. A limited amount of training data (i.e. a portion of the image marked with 'truth') is generally sufficient. Yet, once it has evolved an algorithm, it can be generalized to many images in contrast to the simple thresholds which require user intervention for each image. The evolution process takes a few hours running on the same platform, but after it has evolved a solution, it takes seconds to run on any particular image. It is not as memory intensive as the MODIS cloud mask. Finally, unlike either of the other methods, it has a quantifiable error rate (on the training data). This instills more confidence (assuming the error rate is low) on the user end, though in principle generalization of the algorithm needs to be shown on a case by case basis. In practice, we find that the evolved algorithm does tend to generalize well.

The algorithm evolved from GENIE is dependant on a thermal infrared band and a red band. This is similar to the method used with the simple thresholds. Though the band choices are not identical.

Figure 4 shows a portion of the cloud image from the SCAR-B data set. It is from flight 95–163. Panel a shows the clouds in the image using a near infrared band (similar to MTI band E) from the MAS data. Panel b shows the clouds determined using a simple threshold mask. Panel c shows the MODIS cloud mask for this image. Panel d shows the GENIE results for this data. Here it is important to note that GENIE discovered some false positive pixels in the MODIS cloud mask. The GENIE cloud mask and the cloud mask determined from simple thresholds are quite similar. This leads to greater confidence in the simple threshold applicability to this particular data set. Note also that the false positives in the lower left edge of the image in the cloud mask from MODIS are not replicated with the simple threshold routine. Caution is necessary, however, as the similarities and differences between the cloud masks should not be generalized to snowy or night scenes.

4. SUMMARY

We have created a cloud mask using simple, user defined thresholds. This mask compares quite favorably to the MODIS cloud mask. While it does require user intervention, it does not require large amounts of processing time or disk space. We have also compared our results to an evolved solution for masking clouds. Again, the simple method compares favorably to the genetic algorithm derived mask.

All three methods have strong points and drawbacks. We plan to continue the comparison between the GENIE cloud masks and the MODIS cloud mask more quantitatively in future work. Also, we plan to use both GENIE and the MTI cloud mask on a regular basis in masking clouds for the MTI spacecraft. For the time being, though, our level 2 masking algorithm will remain the simple thresholding routine.

ACKNOWLEDGMENTS

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REFERENCES

Figure 4. The original data is compared with the three cloud masking algorithm results. (a) Shows the actual scene, a portion of flight 95-163 shown in a near infrared band. (b) The MTI cloud masking algorithm results. (c) The MODIS cloud mask results. (d) The GENIE cloud mask results.
