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HIGH SPATIAL RESOLUTION SURFACE AND CLOUD TYPE CLASSIFICATION FROM MODIS MULTI-SPECTRAL BAND MEASUREMENTS

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1. INTRODUCTION

A method was developed for automated classification of surface and cloud types using Moderate-Resolution Imaging Spectroradiometer (MODIS) radiance measurements. The MODIS cloud mask (Ackerman et al. 1998) is used to define the training sets. Surface and cloud type classification is based on the maximum likelihood (ML) classification method. Classified results then define training sets for another iteration. Iterations end when the number of pixels switching classes becomes smaller than a predetermined number or when other criteria are met. The final class mean gravity values in the spectral domain are used for class identification and a final 1 km resolution classification map is generated for a MODIS granules. This classification procedure refines the cloud mask algorithm, and enables further applications such as clear atmospheric profile or cloud parameter retrievals from MODIS radiance measurements or from the combination of MODIS and other sounder systems such as the Atmospheric Infrared Sounder (AIRS). The advantages of this method are the automated surface and cloud classification independent of radiance or brightness temperature threshold criteria, and interpretation of each class based on the radiative spectral characteristics of different classes. This paper describes the ML classification algorithm and presents daytime MODIS classification and identification results.

The classification results are compared with the cloud mask image, visible image, infrared window image and other sources of observations for the initial validation.

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2. MODIS CLASSIFICATION ALGORITHM

2.1 MODIS cloud mask algorithm

MODIS measures radiances in two visible bands at 250 m spatial resolution, in five more visible bands at 500 m resolution, and the remaining 29 visible and infrared bands at 1000 m resolution. Radiances from 14 spectral bands (bands 1 and 2, bands 5 and 6, bands 18-21, bands 26 and 27, band 29, bands 31 and 32, band 35) are used in the MODIS cloud mask algorithm (initial classification) to estimate whether a given view of the Earth surface is obstructed by clouds or optically thick aerosol and whether a clear scene is affected by cloud shadows (Ackerman et al. 1998).

The MODIS cloud mask provides fifteen classes. Those classes are the primary input as the initial classification of the iterative classification procedure. They are: Class 1: Confident clear water (bit fields 1~2 = 1 1, bit fields 6~7 = 0 0); Class 2: Confident clear coastal (bit fields 1~2 = 1 1, bit fields 6~7 = 0 1); Class 3: Confident clear desert or semi-arid ecosystems (bit fields

1~2 = 1 1, bit fields 6~7 = 1 0); Class 4: Confident clear land (bit fields 1~2 = 1 1, bit fields 6~7 = 1 1); Class 5: Confident clear snow or ice (bit fields 1~2 = 1 1, bit 5 = 0); Class 6: Shadow of cloud or other clear (bit fields 1~2 $\neq$ 1 1, bit 10 = 0); Class 7: Other confident clear; Class 8: Possible clear with cirrus detected by solar bands (bit fields 1~2 $\neq$ 1 1, bit 9 = 0); Class 9: Possible clear with cirrus detected by infrared bands (bit fields 1~2 $\neq$ 1 1, bit 11=0); Class 10: High clouds detected by CO_2 bands (bit fields 1~2 $\neq$ 1 1, bit 14 = 0); Class 11: High clouds detected by 6.7 micron band (bit fields 1~2 $\neq$ 1 1, bit 15 = 0); Class 12: High clouds detected by 1.38 micron band (bit fields 1~2 $\neq$ 1 1, bit 16 = 0); Class 13: High clouds detected by 3.7 micron and 12 micron bands (bit fields 1~2 $\neq$ 1 1, bit 17 = 0) at nighttime only; Class 14: Other clouds or possible clouds; and Class 15: Undecided (bit 0 = 0). The above classes will provide basic surface and cloud type information

2.2 Maximum likelihood classification algorithm based on the MODIS cloud mask

Data classification or clustering is an important part of data analysis and image segmentation; the method tries to analyze data and identify several groups or clusters. A group or cluster is a class of data that has similar appearances (i.e., for MODIS images, it can be a particular surface type or cloud cover). Basic data clustering does not need any external information for its completion. The clustering algorithm can be described by the following steps:

(1) Classify the MODIS measurements using the MODIS cloud mask, calculate the mean vector and covariance matrix of each class within the MODIS cloud mask;

(2) Calculate the distances between the vector of each pixel and all the class mean vectors and assign the pixel to the nearest class;

(3) Update the class mean vector and covariance matrix of each class after all pixels have been reassigned to the nearest classes;

(4) Analyze the separability of the classes produced and merge or split some classes if necessary. For example, if the distance between a pixel and its nearest class is too large, this pixel will form a new class in the remaining iterations; on the other hand, if the distance between two classes is too small, then these two classes will be merged into one class. In this paper, this procedure was not implemented in order to remain the surface and class type index of the MODIS cloud mask in the ML classification.

(5) Repeat steps 2 - 4 until convergence criteria are met. In this paper, if the summit of off-diagonal for each class in the classification matrix (Li et al. 2001) is less than 6%, the iterations end. In general, 6 ~ 7 iterations allow a final ML classification result.

3. FEATURE SELECTION FOR MODIS SURFACE AND CLOUD TYPE CLASSIFICATION

There are three types of features in the MODIS classification. All the features are determined for 1km resolution. More spectral bands are used for surface and cloud type classification than used for cloud masking.

(1) ***Spectral band radiances***

Radiances provide the primary spectral information of different scene and cloud types. MODIS visible bands 1-7, bands 17-29, and bands 31-35 are used in the daytime classification. The visible images are all mapped to the IR spatial resolution of 1km.

(2) ***Variance images***

A variance image is constructed for each of the visible images and infrared longwave window images. In the visible variance images, the value attributed to each 1km pixel is the local standard deviation (LSD) of FOVs within the 1km area (for example, the standard deviation is computed from 4 by 4 values (FOVs) for bands 1 and 2, and from 2 by 2 FOVs for bands 3-7). Visible variance images are used as the features in the ML classification procedure, this guarantees that all the information used in the classification is restricted in the 1km resolution pixel. In the associated visible images, edges of different classes still present large variances, low visible variances are associated with cirrus clouds and relatively high variances with low stratiform clouds.

(3) *Brightness temperature difference images*

Studies show that differences between two infrared spectral bands are very useful for detecting clouds. For example, large positive brightness temperature (BT) differences in 8 minus 11 microns indicate the presence of cirrus clouds, for clear conditions, the 8 minus 11 micron BT difference will usually be negative due to stronger atmospheric water vapor absorption at 8 microns than at 11 microns. Most clouds appear positive values in the BT difference (8.6 minus 11 micron) image.

In order to save computation time, the simple Euclidean distance is used in the ML classification procedure. A weighting factor for each feature is used to scale the magnitude in the distance calculation (Li et al. 2001).

4. RESULTS

Figure 1 shows the band 2 (left panel) and its variance (right panel) images of an African Sahel/desert scene at 0935UTC 05 November 2000, indicating the clouds in the southern part of the granule. The MODIS cloud mask algorithm sometimes has difficulties in desert area since the VIS reflectances are usually higher over the desert than over clear land, and sometimes clear desert is not well separated from low clouds in the cloud mask algorithm. Twelve classes are obtained from the cloud mask algorithm and the ML classification in this case. The details for each class can be found in a recent paper (Li et al. 2001).

Figure 2 shows the cloud mask map (left panel) and classification map (right panel) for this case. In the cloud mask algorithm, the drought lake mentioned above was mis-identified (classified as clouds) but is slightly recognized by the ML classification. Some striped lines existed in the cloud mask due to the use of band 36 in the cloud mask algorithm; band 36 was not used in the ML classification. The cloud coverage from the cloud mask is very close to that of classification results although there are significant cloud type changes (e.g., less high clouds in the classification than the cloud mask). However, the cloud mask has more clear desert than the classification.

The initial classification results from the cloud mask may be sensitive to the thresholds in some regions, especially when desert exists. In order to test the sensitivity of both the cloud mask and classification algorithms to the thresholds used in the cloud mask, the thresholds were changed in the cloud mask algorithm. Some arid and semi-arid zones were purposefully mis-identified vegetated land, where visible band thresholds are lowered. The cloud mask then misinterpreted the brighter than expected surface reflectances as clouds. Figure 3 is the cloud mask map (left panel) with altered thresholds and its corresponding classification map (right panel). In the cloud mask algorithm, many desert pixels are changed to lower clouds due to the change of thresholds; however, those low cloud pixels are correctly reclassified as desert after the classification. Although there are some differences for the desert/land separation between the two classifications (see figures 2 and 3), the clear/cloud separation is almost the same in both classifications. This offers some reassurance that the classification is relatively insensitive to the thresholds used in the cloud mask algorithm.

5. CONCLUSIONS

A maximum likelihood classification initialized from the cloud mask algorithm was used to classify the scenes and clouds. The VIS and IR 1km resolution spectral information and visible spatial information are used in the classification. Results of applying both radiances and local variances confirm the usefulness of these parameters for cloud/clear separation, as well as for separation between the cloud types or clear types. The 1 km resolution classification map improves the 1 km cloud mask derived from the MODIS cloud mask algorithm in some situations. Combined use of the cloud mask and cloud classification improves identification of clear skies in the MODIS imagery as well as cloud types.

6. REFERENCES

Ackerman, S. A., K. I. Strabala, W. P. Menzel, R. A. Frey, C. C. Moeller, and L. E. Gumley, 1998: Discriminating clear sky from clouds with MODIS. *J. Geophys. Res.,* 103, D24, 32141-32157.

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resolution surface and cloud type classification from MODIS multi-spectral band measurements, *J. Geophys. Res*. (submitted)

- Water (Black)
- Land (Blue)
- Desert (Green)
- Mid-low clouds (While)
- Mid-high clouds (Yellow)
- High clouds (Red)

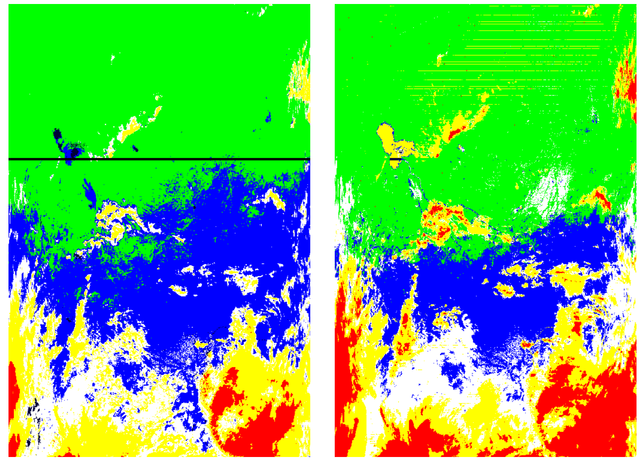

Figure 2 shows the cloud mask map (left panel) and classification map (right panel) for this case. In the cloud mask algorithm, the drought lake mentioned above was mis-identified (classified as clouds) but is slightly recognized by the ML classification (color image, see the left color bars)

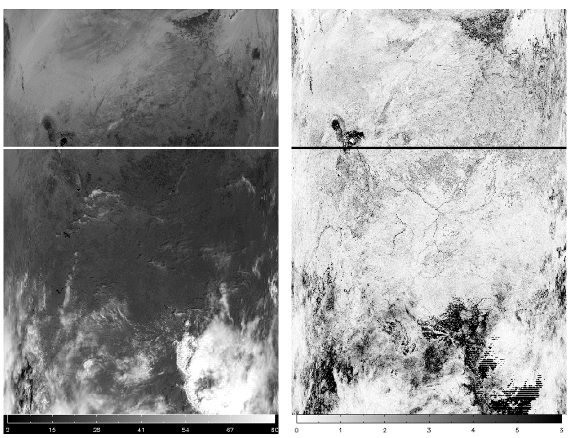

Figure 1,the MODIS band 2 (left panel) and its variance (right panel) images of an African Sahel/desert scene at 0935UTC 05 November 2000, indicating the clouds in the southern part of the granule.

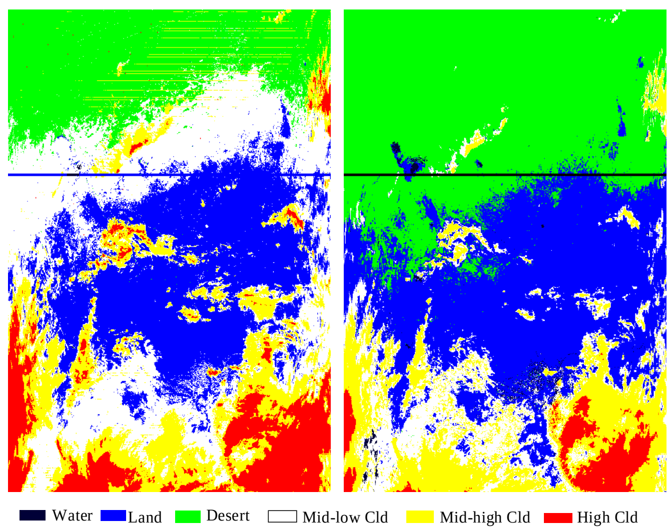

Figure 3, the cloud mask map (left panel) with altered thresholds and its corresponding classification map (right panel).