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The Developing Moderate Resolution Imaging Spectroradiometer (MODIS) Snow Cover Algorithm

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ABSTRACT

Elements of the snow cover algorithm to be implemented with the Earth Observing System (EOS) MODerate resolution Imaging Spectroradiometer (MODIS), scheduled for launch in 1998, are being developed and tested. The MODIS snow cover algorithm will generate global and regional snow cover data products weekly. The algorithm utilizes unique spectral and spatial characteristics of the MODIS to identify snow by reflectance characteristics. The algorithm implements a series of criteria tests and a Normalized Snow Difference Index (NSDI) to identify snow and to discriminate snow from many types of clouds. Landsat Thematic Mapper (TM) data, simulated MODIS data, and Advanced Very High Resolution Radiometer (AVHRR) data are used to prototype the algorithm. The snow cover algorithm has been tested on a variety of Landsat TM scenes with consistent snow identification results.

MODIS INSTRUMENT

The MODerate resolution Imaging Spectroradiometer (MODIS) is an Earth Observing System (EOS) instrument designed to measure biological and physical process on a global basis every one to two days. Slated for both the EOS-AM and -PM satellite series, MODIS will provide long-term observations of the Earth for study of global dynamics and processes occurring on the surface of the Earth and in the lower atmosphere. MODIS employs a conventional imaging radiometer concept, consisting of a cross-track scan mirror and collecting optics, and a set of linear detector arrays with spectral interference filters located on four focal planes. The optical arrangement will provide imagery in 36 discrete bands, selected for diagnostic significance in Earth sciences, between 0.4 μm and 15.0 μm. MODIS bands and spatial resolutions are given in Table 1 along with corresponding spectral coverage with TM and AVHRR bands. Each MODIS in the EOS series will provide daylight reflection and day/night emission spectral imaging of any point on Earth at least every two days, with a continuous duty cycle (Salomonson and Toll, 1991; NASA, 1993).

SNOW REFLECTANCE CHARACTERISTICS

Snow typically has high reflectance in the visible region of the spectrum. Nearly 80% of incident solar radiation may be reflected from fresh snow (O'Brien and Munis, 1975; Choudhury and Chang, 1981; Hall, et al., 1990a). Snow reflectance decreases as snow ages or becomes contaminated by deposition of aerosols, soot, pollen, etc. (Warren, 1982; Dozier, 1984); yet remains much brighter than most other surfaces. It is the high reflectance characteristics of snow in the visible portion of the spectrum that make it distinguishable from many other surface features. In the near infrared, snow and clouds have different reflectance characteristics; clouds have high reflectance, snow has low reflectance. It is

Table 1. MODIS band locations and corresponding TM and AVHRR bands.

MODIS Band	*Spatial Resolution (m)*	*Center Wavelength (μm)*	*Corresponding TM Band*	*Corresponding AVHRR Band*
1	250	0.645	1	
2	250	0.858	4	2
3	500	0.469	1	
4	500	0.555	2	
5	500	1.240		
6	500	1.640	5	
7	500	2.130	7	
8	1000	0.412		
9	1000	0.443		
10	1000	0.488		
11	1000	0.531		
12	1000	0.551		
13	1000	0.667	3	1
14	1000	0.678	3	1
15	1000	0.748		2
16	1000	0.869	4	2
17	1000	0.905		2
18	1000	0.936		2
19	1000	0.940		2
20	1000	3.750		3
21	1000	3.959		
22	1000	3.959		
23	1000	4.050		
24	1000	4.465		
25	1000	4.515		
26	1000	1.375		
27	1000	6.715		
28	1000	7.325		
29	1000	8.550		
30	1000	9.730		
31	1000	11.030	6	4/5
32	1000	12.020		5
33	1000	13.335		
34	1000	13.635		
35	1000	13.935		
36	1000	14.235		

this difference in reflectance between snow and clouds at 1.6 μm that makes it possible to distinguish between the two (Allen et al., 1990; Dozier, 1989). These reflectance characteristics of snow form the basis for the prototype MODIS snow algorithm.

MODIS SNOW COVER ALGORITHM

The purpose of the MODIS snow cover algorithm is to generate a snow cover data set useful in global change research, ecological research, hydrological models. The snow cover data set is to be generated in concert with a group of MODIS global survey data sets. This group of data sets will be generated using automated techniques. Segments and capabilities of the MODIS snow cover algorithm are developed with other sensors, i.e., Landsat Thematic Mapper (TM), AVHRR, and MODIS Airborne Simulator (MAS). Data from these sensors are used to develop and test segments of the algorithm for detecting snow cover, snow and cloud

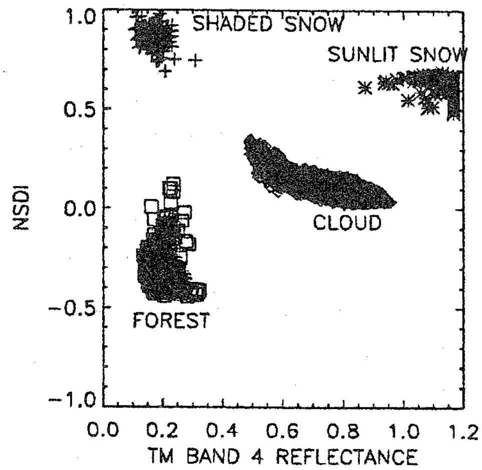

Figure 1. Relationship of NSDI to TM band 4 reflectances for four features sampled from a Landsat TM image of the Brooks Range, Alaska.

discrimination, and cloud screening before the launch of MODIS. Because no orbiting satellites have the capabilities of MODIS, components of the MODIS algorithm must be developed and tested with these other sensors. The components will merge into a MODIS algorithm that uses information from the visible, infrared and emitted wavelengths to identify snow and to discriminate snow from clouds.

The snow cover algorithm is a structured series of tests designed to identify snow by its reflectance characteristics, discriminate clouds from snow, and screen cirrus clouds. Cloud screening is based on differing characteristics of water vapor clouds and cirrus clouds across the visible, infrared, and emitted wavelengths (Riggs, et al., 1992). The tests are essentially threshold tests for reflectance or emittance characteristics of snow. A Normalized Snow Difference Index (NSDI) has been defined to help in identifying snow.

Normalized Snow Difference Index

The NSDI is based on the fact that snow is highly reflective of visible radiations and is a strong absorber of near infrared radiation. This relationship produces an index that is used to identify snow from other surface features. The NSDI identifies the characteristic change in snow reflectance between the visible and near infrared spectral regions. Snow should ideally have NSDI values near 1.0. For TM data the NSDI is calculated as:

NSDI = (TM band 2 - TM band 5) / (TM band 2 + TM band 5)

Snow has been found to have NSDI values typically $\geq$ 0.5. The NSDI alone could be used to identify snow cover, but using it in conjunction with other tests has increased accuracy of snow identification. Snow, sunlit and shaded, can be separated from clouds and non-snow covered surfaces when the NSDI is used in conjunction with a threshold test for TM band 4 reflectance (Figure 1).

Algorithm Structure

The decision logic of the algorithm for TM data (Figure 2) begins with a test for high visible reflectance this separates snow and other highly reflective features from those of low reflectivity. At the 30 m spatial resolution of the TM it is possible to identify snow shaded by clouds and terrain features. The NSDI value is then tested for both high and low reflectance pixels. If the NSDI value is 0.6 or greater then the pixel is considered to be either sunlit or shaded snow. A further check of reflectance in TM band 4 is done to separate snow from other possible features. Then a check is performed using thermal-infrared data to separate snow from other features. It is assumed that snow is always at a temperature of 273° K or less. One further check is done to separate water from shaded snow. It has been observed that water bodies such as lakes and rivers are sometimes confused with shaded snow, so a test to screen water was added to remove this confusion. Water is a strong absorber of radiation and typically has very low reflectance in the visible and infrared wavelengths, though characteristics of a water body may greatly change reflectance characteristics. The test for water screens pixels having reflectance $\leq$ 10% reflectance in the visible and near infrared as being water.

Values for the threshold reflectance tests and NSDI are based on published snow reflectances, and from sampling of snow, clouds, and other surface features from several different Landsat TM images. A reference set of threshold values has been adopted based on these samples. The adopted threshold values were determined after recursive testing and analysis with different values and combinations of threshold values on a variety of scenes.

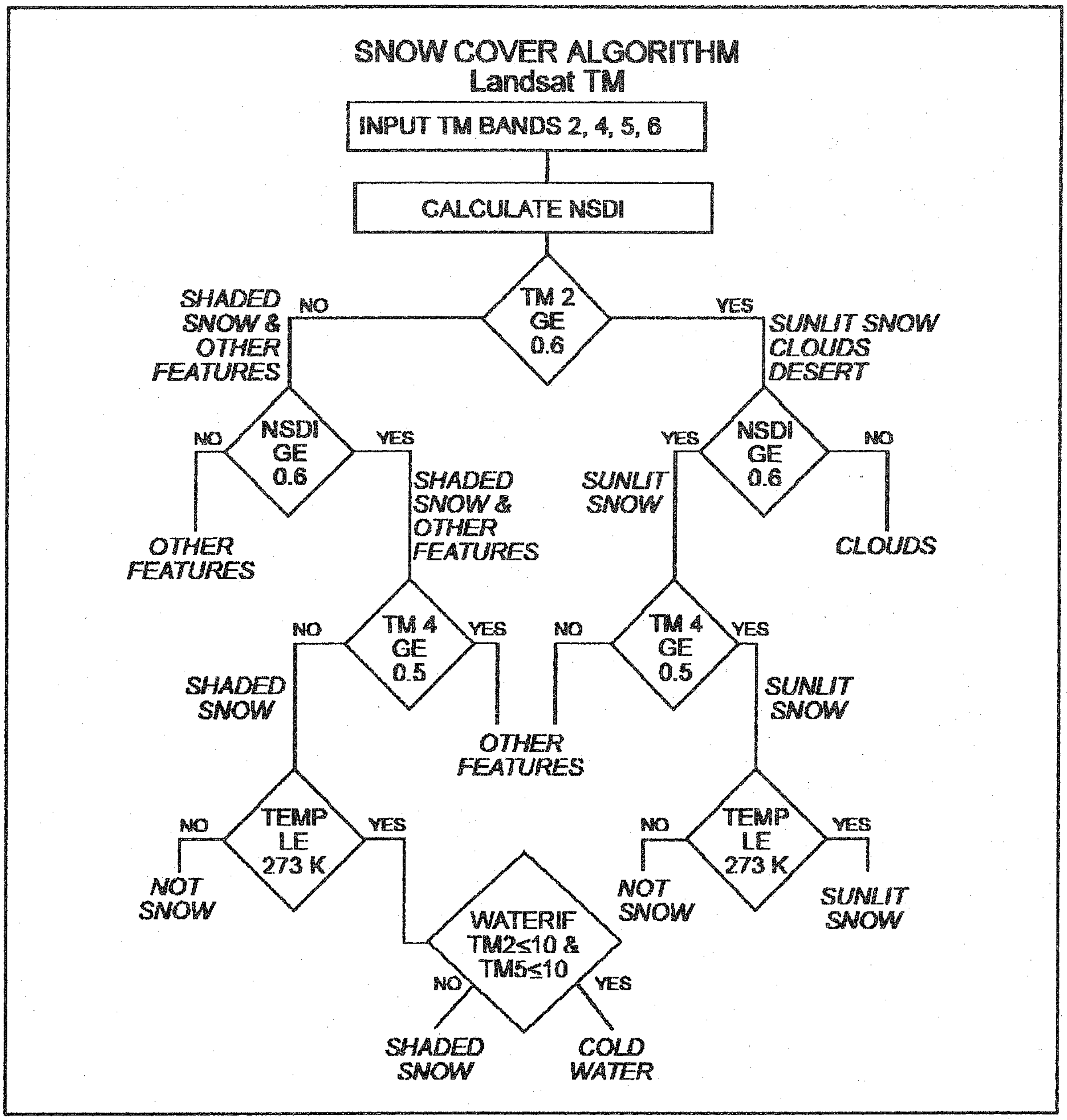

Figure 2. Decision tests of the snow cover algorithm for Landsat TM data.

These chosen reference thresholds are applied to any TM scene.

Because decisions are made on reflectance, TM data are converted to reflectance values. Conversion to reflectance is done separately from the algorithm using procedures, equations and constants given by Hall et al. (1990b), and Markham and Barker (1986). Each scene is unique because of the dependence on solar zenith angle. At present, corrections are not made for slope and aspect, but are these corrections are planned to be included in the future. For MODIS data the solar zenith angle is expected to be calculated for each pixel. Once the conversion to reflectance has been made, the algorithm may be implemented with the reflectance values.

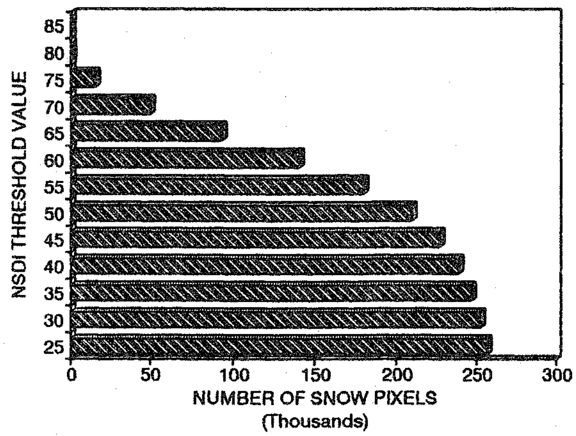

Figure 3. Change in number of identified snow pixels for a change in the NSDI acceptance threshold value.

RESULTS

The snow cover algorithm has been developed using Landsat TM scenes of mountainous regions in North America, and other areas. Results from a study of a scene of Glacier National Park, Montana, imaged on 14 March 1991, are the focus of this discussion. There was snow in the mountains and cloud cover over the mountains in Glacier National Park and to the west; much of the land far to the east of the mountains was not snow covered. Visual interpretation of the location and extent of snow cover in a false color composite agreed with snow cover location and extent identified by the algorithm. Without specific knowledge of conditions on the ground on that date, it is not possible to make a rigorous quantitative analysis. Snow, both sunlit and shaded, was identified for 31% of the image. No clouds were misidentified as snow. Errors of omission are the most likely source of error in the results. The reason for a bias toward errors of omission is that reflectance threshold values have been set at a high level to minimize errors of commission. The trade-off with high threshold acceptance values is to omit pixels that may be snow.

Sensitivity of Threshold Method

The effect of changing a threshold value is to change the amount of snow identified by the algorithm in a scene. It has been our experience that incremental stepping up or down of the threshold values results in 10% to 20% change in the amount of snow cover per step. The amount of change in snow cover is dependent upon the amount of snow in a particular scene. Changing thresholds results in an expansion or contraction of snow extent about the perimeters of snow areas identified with the previous threshold settings. This has been observed over a range of thresholds above and below what was considered the best threshold value result. An example of the change in amount of snow cover that occurs for stepping the NSDI threshold is shown in Figure 3. This type of analysis demonstrates the sensitivity of the thresholding technique. Near the highest and lowest threshold values, radical jumps in amount of snow cover mapped may be observed (Figure 3), but for a range of values between, changes in snow cover between threshold values are relatively small. Radical jumps in snow cover at lower threshold settings were not observed in this example, but have been observed with other scenes. There are not exact threshold settings, but there are ranges of acceptable thresholds that give relatively good qualitative results. The use of universal thresholds poses a problem in application because the thresholds have been selected independent of scene viewing conditions and may not be very applicable in some or many situations. It is planned to link threshold settings to empirically-derived scene reflectances calculated from viewing geometry. This approach does not use a universal threshold, but uses a universal rule to select thresholds. Threshold selection will possibly be linked to some percentage of the empirically-derived scene reflectances, with band specific linkage rules.

Other TM Scenes

The snow cover algorithm has been applied to several other TM scenes, some having snow cover and others having no snow cover. Testing with a variety of scenes has been done recursively to decide what threshold levels to adopt, and to find situations where the algorithm fails to yield satisfactory results. One finding of this testing is that cirrus clouds are very difficult to screen and distinguish from snow, unless they are specifically sampled in an image to determine the threshold that can be used to screen them out.

Simulated MODIS Data

Simulated MODIS data were generated for a subset of a TM image of the Chugach Mountains, Alaska using the technique described by Barker, et al., (1992). The area was selected for its view of mountain snow, glaciers, water, vegetated land, and cloud cover. Simulation of MODIS data was done by spatial filtering 30 m TM data in the frequency domain, and resampling to produce 250 m, 500 m, or 1000 m simulated MODIS imagery. The simulated data were also scaled to the dynamic range (12 bit data) expected for MODIS. TM radiance values were the starting data for the simulation procedure. The MODIS prototype TM snow algorithm was applied to both the original TM image and the simulated MODIS image. To apply the algorithm to the simulated MODIS data, the threshold values for the reflectance tests were adjusted to equivalent simulated MODIS (12 bit) data values.

The spatial degradation from 30 m TM to coarser resolution simulated MODIS data resulted in fewer pixels, and a blurred appearance in the simulated image. Fewer snow covered pixels were identified in the simulated MODIS image due to the combination of spatial degradation and lack of spatially extensive areas of snow in the image. When the snow algorithm was applied to the original TM image, approximately 21% of the image was identified as snow covered. When the snow algorithm was applied, with TM reference threshold values, to the simulated MODIS image only about 1% of the MODIS image was identified as snow. This difference may be attributable to the degraded resolution, conversion to dynamic range of simulated MODIS values, and different spatial resolutions of the MODIS bands. If the threshold value for only the NSDI test was changed in the algorithm, a snow cover extent that was visually similar to that identified in the original TM image could be achieved. At the best visual harmony between the images, approximately 8% snow cover was found for the simulated MODIS data. Analysis of these results suggest that modifications of the snow cover algorithm to adjust for the different dynamic range of MODIS and the differences in spatial resolutions (250 m, 500 m, and 1000 m) between MODIS bands expected to be utilized will be necessary.

AVHRR Data

A snow algorithm for AVHRR data is also being developed. AVHRR data will be used to prototype a weekly snow cover compositing technique to capture the dynamics of snow cover. A prototype algorithm for AVHRR data has been developed for AVHRR imagery covering Alaska. The prototype algorithm is based on the snow identification techniques used by the National Weather Service National Operational Hydrologic Remote Sensing Center (NOHRSC) in Minneapolis, Minnesota. The snow algorithm for AVHRR data is modeled on that used by NOHRSC and described by other researchers (Allen, et.al., 1990; Carroll, 1990; Holyroyd, et.al., 1989; Szeliga, et.al., 1990). Snow is identified by high reflectance in the visible (Channel 1, 0.58 - 0.68 μm) and snow/cloud discrimination is done with the difference of Channel 3 (3.55-3.93μm) - Channel 4 (10.30-11.30μm). The AVHRR snow algorithm is prototyping a temporal snow cover product for MODIS. An objective of using AVHRR data is to establish a time series of data to use in prototyping a temporal snow cover algorithm and product for MODIS. This will probably be a weekly snow cover data set that contains information on the extent and dynamics of snow cover.

FUTURE DIRECTION

The snow cover algorithm will continue to be modified in response to testing and analysis findings over the next several years. Because the project requirement is that the algorithm is executed automatically without an interpreter's intervention, the methods used must be able to be automated. It is our intention to continue pursuing the use of tests such as those described here for snow reflectance characteristics. Some initial comparisons with other methods of snow identification suggest that the results of this method generally agree with others. The importance of these initial comparisons of methods is that they generally agree; wildly divergent results have not been found. It is anticipated that threshold tests and decision rules for these tests will be based on snow reflectance characteristics and that selection of threshold and decision values will be empirically linked to viewing parameters at the time of acquisitions. Results using TM data and simulated MODIS data reinforce the idea that threshold values should be empirically linked to scene geometry and radiance. The infrared bands of MODIS should allow discrimination of many types of clouds from snow, and the 1.38 μm MODIS band should allow for reliable screening of cirrus clouds. According to Kaufman (1993) cirrus clouds can be detected at 1.38 μm.

Over the next four years the algorithm will evolve into an at-launch form and will be integrated with the group of MODIS Land Group algorithms for product generation in the EOS Data Information System (EOSDIS) before launch.

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