MODIS Semi-Annual Report
Snow and Ice Project
Reporting Period: July - December 1996
Submitted by: Dorothy K. Hall/974

SUMMARY

During this reporting period several major events have taken place. The ATBD was updated and submitted to the Project by the 1 November 1996 deadline. The first meeting of the Ad-hoc Committee on MODIS Snow and Ice Products was held on 25 November. All MODIS Airborne Simulator (MAS) data were obtained in the fall of 1996 and analysis has begun. We have estimated the errors in using SNOMAP to map snow in North America with future MODIS data. Preliminary calculations indicate that the accuracy of snow mapping in North America will be from 91-95%. Dr. Alex Moore/Hartwick College spent the summer working on analysis of the spectral-mixture modeling approach to mapping global snow cover. Andrew Klein has recently joined the group as a post-doc at USRA. Plans have been finalized for the field experiments to be held in January and February 1997 in New Hampshire and Wisconsin. Version 1 of the MODIS data product codes for MOD10 and MOD29 has been delivered to the Project. MODIS-related meetings were attended, abstracts were submitted, and presentations were given during the reporting period and are all listed at the end of this report.

ATBD

The ATBD was updated and submitted to the EOS Project by 1 November. It was sent out for review. Four reviews of the ATBD were received and transmitted to the authors. With one exception, the reviews were favorable.

AD-HOC COMMITTEE MEETING ON MODIS SNOW AND ICE PRODUCTS

An all-day meeting was held at Goddard on 25 November 1996 of the Ad-Hoc Committee on MODIS Snow and Ice Products. The advisory group consisted of 6 people: Dr. Steve Ackerman/Univ. of Wisconsin, Dr. Roger Barry/Univ. of Colorado, Dr. Tom Carroll/NOAA/NOHRSC, Dr. Jeff Key/Boston Univ., Bruce Ramsay/NOAA/NESDIS and Dr. Dave Robinson/Rutgers University. Drs. Dorothy Hall, George Riggs and Andrew Klein gave presentations on the status and plans of the MODIS snow and ice project. There was a good amount of discussion about the MODIS snow and sea ice products. In the afternoon, the committee met in a closed-door session and identified a series of recommendations. These recommendations are contained in their report (see below). The recommendations are all very constructive and are being studied in detail by the snow and ice group. A detailed follow-up on each recommendation will be presented to the Ad-Hoc Committee either in writing and/or verbally at the next meeting.

First Report of the MODIS Snow and Ice Adhoc Advisory Committee*

The global extent of land snow cover and sea ice are significant parameters of global climate in view of their role in ice-albedo feedback, surface energy and moisture balance, the hydrological cycle and ocean deep-water formation. As identified in numerous GCCP and WCRP documents, snow and ice extent are also key indicators of changes in the global climate system. Moreover, near real-time MODIS snow and ice products have potential application in operational hydrometeorological programs.

The snow and ice products to be produced under the MODIS program will represent a significant advance on currently available information. In particular the SNOMAP product will be unique in terms of its 500 meter spatial resolution, its global coverage, and its temporal frequency. It is also a fully automated technique and employs 1.6 μm information and a broad array of cloud information. The ICEMAP product is unique in providing global one kilometer information about ice extent, surface temperature and, indirectly, ice thickness/age classes. The availability of a daily combined snow and ice product is a further new feature. Another new element will be the availability of data ice for 19 large lakes.

We are confident that the current algorithms will be ready to be implemented at launch. It is important in the pre-launch time frame to maintain the planned simplicity of these products. Some techniques (e.g. spectral-mixture modeling, neural net classifications) that are potentially useful in the post-launch time frame cannot be implemented now, because it would likely preclude having an algorithm ready at launch.

Version 3.0 of the Algorithm Theoretical Basis Document shows significant progress over earlier versions. Here we will address the positive direction in which the project is headed, mention several concerns that remain and make a number of recommendations regarding future directions.

The positive steps taken to date include:

1. Error analysis (absolute and relative) is being actively planned.
2. The concerns of various communities (e.g. observational, modeling) are being addressed.
3. The effect of forest cover on snow identification is being addressed rigorously and systematically.
4. A flexible systems environment is being maintained, particularly as it applies to post-launch enhancements.

Our present concerns include:

1. The SNOMAP and ICEMAP algorithms should be independent of atmospherically corrected surface reflectances, which may unnecessarily complicate the cryospheric retrievals.
2. These products will only be available ca. 3 days after data collection. Operational users require such products within 24 hours of overpass.
3. The proposed sinusoidal projection is not sufficient for the cryospheric community.
4. Sea ice algorithm testing is not being conducted for the melt season.

Recommendations:

The Adhoc Advisory Committee wishes to make the following recommendations which we feel warrant attention by the MODIS team. The recommendations deal primarily with the pre-launch interval, at least work on them should continue or commence during this period. However, efforts on most will likely follow on into the post-launch domain.

1. Tune the SNOMAP algorithm for land cover differences amongst major biomes.
2. Evaluate the feasibility of assessing forest cover density using scatterometer data (e.g. approach of Chris Neale at Utah State University)
3. Continue evaluating the utility of employing MODIS band 7 (2.1 µm) to better assess snow cover under vegetation canopies.
4. The following ice products should be generated: a) ice extent derived from reflectance data, b) ice surface temperature, and c) a combined extent product using reflectances and surface temperature.
5. Explore implementing the AVHRR sea ice motion technique using MODIS sea ice retrievals.
6. In the pre-launch interval, utilize TM, AVHRR and ERS data in combination with field programs such as SIMMS (Seasonal Sea Ice Monitoring and Modeling Site) for ice algorithm testing. If launch occurs on schedule, utilize Surface Heat Budget of the Arctic Ocean (SHEBA) experiment data.
7. Assess the sign and magnitude of the SNOMAP and ICEMAP biases seasonally.
8. Quantify differences between algorithm products generated with and without atmospheric surface reflection correction.
9. Continue working with the MODIS cloud mask team to define when and where to map snow and ice parameters.
10. Address issues of mapping snow and ice under cloud shadows.
11. Develop in conjunction with the DAACs a plan for post-launch quality control of daily and composite products. This should include operator review and comparison of MODIS products with products from alternative data sources.
12. Snow and ice products should be made available within 24 hours of satellite overpass to be of maximum value to the operational community.
13. Level 3 products should be generated and archived in EASE grid (Equal Area SSM/I Earth-grid).

14. The option for user specified temporal composite intervals should be implemented at NSIDC.
15. Continue exploring strategies for post launch enhancements in the products. This includes evaluating other approaches (e.g. spectral and textural mixture analysis, fuzzy logic, neural networks) and multi-sensor/multi-platform data fusion.

In closing, the Committee would like to thank Dorothy Hall and her research team and Vincent Salomonson for the opportunity to review and learn more about the interesting and ambitious plans for snow and ice in the MODIS program. We hope that our recommendations will help the program achieve its cryospheric goals, and look forward to seeing the program progress through the pre and post launch intervals.

Committee members include:

David A. Robinson, Rutgers University (chair)
Stephen Ackerman , University of Wisconsin
Roger Barry, University of Colorado
Thomas Carroll, NOAA/NOHRSC
Jeffrey Key, Boston University
Bruce Ramsay, NOAA/NESDIS

APRIL 1995 ALASKA MISSION/ANALYSIS OF MAS SNOR DATA

Preliminary data suggest that the MAS data in the 25 reflective bands are good. Results show reflectances from snow on the North Slope of Alaska, acquired on 3 April 1996, vary from about 85 percent to about 5 percent. Reflectances of snow in forested areas vary from about 35 percent down to about 0 percent. No observed, significant change in reflectance across the scan (±43°) has been observed in preliminary analysis of the reflectance data from the North Slope. No data covering the entire scan has yet been found of the forested areas in order to determine the change in reflectance across the scan in the forested areas.

Preliminary analysis of MODIS Airborne Simulator (MAS) data acquired over central Alaska in April 1995 show that MODIS band 7 (2.105-2.155 μm) improves the performance of SNOMAP under some forested conditions. An abstract on this topic has been submitted by A. Klein, D. Hall and G. Riggs to the IGARSS ‘97 Symposium in Singapore to be held 3-8 August 1997.

SEA ICE ALGORITHM DEVELOPMENT

Major advances in development of the MODIS sea ice algorithm were; the selection of an ice surface temperature (IST) technique for integration into the MODIS sea ice algorithm and inclusion of IST as part of the data product, development of a prototype of the MODIS sea ice algorithm with MODIS Airborne Simulator (MAS) data from the MAS Alaska campaign of 1995, initial integration and analysis of the cloud mask product (MOD35) with the sea ice algorithm, and presentation of status of the algorithm and product to the MODIS snow and ice ad-hoc committee.

The MAS version of the MODIS cloud mask algorithm was implemented and analysis was begun on the integration of the cloud mask with the sea ice algorithm. The objective is to determine what information in the cloud mask product is relevant to masking of clouds over sea ice then integrate that information into the sea ice algorithm to mask clouds from analysis.

The sea ice algorithm, MOD_PR29, Version 1 code was delivered to SDST. That code used MODIS simulated data as input and created a data product file according to product specification. Prototype code was developed for read and analysis of the MODIS cloud mask (MOD35) data product for use in next version of the sea ice algorithm to mask clouds.

Preliminary results of integrating cloud mask results into the sea ice algorithm have shown that the MAS cloud mask makes few errors of cloud omission over sea ice, however; commission errors of masking some types of new sea ice as cloud have often been found. These preliminary results are based on the use of three bits of information of the 48 bits available in the cloud mask. Investigation of the use of other bits of information in the cloud mask to determine if the commission errors can be reduced has been initiated.

Developed a MAS sea ice algorithm for analysis of the MAS data obtained during the 1995 MAS Alaska campaign. This algorithm serves as a functional prototype of the MODIS sea ice algorithm and facilitates scientific inquiry and analysis of the algorithm, both processes which are not possible using MODIS simulated data. Note that algorithm deliveries are made with simulated MODIS data which is not scientifically valid but serves to build and test the data product production system.

Global Error Estimation of SNOMAP

We have been working on estimating the expected accuracy of the SNOMAP algorithm over North America. Depending on the method we use, the estimated accuracy of the MODIS SNOMAP algorithm for North America for an average February (when the snowline is at its most southerly position) is between 91% and 95%. Because we won't have the global land-cover map from EDC until spring, we can only do North America at this time. However, the estimated accuracy for global snow-cover mapping should be higher. We calculated the estimated accuracy in the following ways.

First, we determined the percentage of land cover in North Anerica in each of 7 general categories: agricultural (8.23%), alpine (0.31%), forest (35.99%), glaciers (14.92%), prairie (14.92%), tundra (25.42%)and urban (0.21%). We make the assumption that 100% snow cover is mapped everywhere except in the forested areas. We can back this up quite well. Using TM scenes from the Sierra Nevadas (alpine) and southern Saskatchewan (agricultural) we find 98% and 99% accuracy in snow-cover mapping using SNOMAP, respectively (for pixels that are 50% or greater covered by snow). MODIS Airborne Simulator (MAS) data are 100% accurate in mapping continuous snow using SNOMAP in tundra areas on the North Slope of Alaska. We're disregarding urban areas, and for now, assuming 100% accuracy in snow mapping in the prairie areas. Therefore, 64.01% of the snow-covered land areas of North America can be mapped with nearly 100% accuracy according to the above logic. The remaining 34.99% of land is forested.

We've estimated the accuracy in the forested areas by two methods. In one method that provides 95% accuracy for North America, we used Jim Foster's estimate of accuracy in snow-cover mapping using SMMR data. He shows in his Ph.D. thesis that in February the SMMR is 85% accurate in mapping the snow cover in the boreal forest during the month of February, as compared to climatological data. Jim looked at the average of the SMMR-derived snow cover from 1979-1987 for February and compared these values to the climatological snow cover data as computed by the U.S.A.F. which he is using as the baseline for comparison. The SMMR snow cover extent is 15% less in the boreal forest of North America using this approach. Using this information, and performing a simple weighted average, we calculate that the average accuracy for North America is 95%.

In the other method, the accuracy computed for North America is somewhat lower, 91%. In this case, we used a TM scene of the BOREAS study area in southern Saskatchewan. We calculated the accuracy of the SNOMAP algorithm in a dense mixed forest. The accuracy of mapping snow there was about 75%. Again performing a weighted average, we find that the average accuracy for North America is 91% using this method.

The conclusion is that the accuracy for snow mapping in February for North America using MODIS data is likely to be between 91% and 95%. Clearly this is an oversimplification. We will refine the estimated accuracy as we obtain better estimates of the accuracy of snow mapping using SNOMAP using MAS data from our aircraft experiments. Also, when we get the global land-cover map from EDC which is due out in the spring, we will calculate an estimate for the entire Northern Hemisphere.

ALEXANDRE C. MOORE/JOVE FELLOW/HARTWICK COLLEGE

Dr. Alexandre Moore, a professor in the geology department of Hartwick College, NY spent the summer working on validation of the SNOMAP algorithm. She employed results obtained from Walter Rosenthal/UCSB to validate a TM scene of the Sierra Nevada Mountains. Her results show that the spectral mixture modeling-based approach of Rosenthal agrees with SNOMAP with an accuracy of >95%. An abbreviated version of her final report is given below.

GLOBAL SNOW COVER MAPPING WITH THE MODERATE RESOLUTION IMAGING SPECTRORADIOMETER:

VALIDATION & TESTING OF THE SNOMAP ALGORITHM

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I. ABSTRACT

The objective of this research project is to test the SNOMAP algorithm, developed for the Moderate Resolution Imaging Spectroradiometer (MODIS). The algorithm uses MODIS data to accurately map global snow-covered area on a daily basis. In addition to the daily snow cover product, a weekly map of maximum snow extent will also be produced. These products will provide information on the spatial distribution of snow and its persistence, and will be used as inputs to general circulation models and snowmelt runoff models. The prototype SNOMAP algorithm is currently designed for use with Landsat TM data.

The SNOMAP algorithm has been compared to an independently produced snow mapping algorithm (SCA). These two algorithms apply different techniques to the problem of snow mapping with remotely sensed data. SNOMAP is a threshold-based binomial classification, whereas SCA is based on spectral mixture modeling. The SCA algorithm has been verified with high-resolution aerial photography and ground-based measurements, thus it provides a good test for SNOMAP. This report presents results from three validation projects: (1) results of SNOMAP compared directly with those of SCA, (2) NDSI values compared to SCA, and (3) SCA and SNOMAP degraded to a resolution of 500 meters and compared.

SNOMAP compares extremely well to the results of SCA for pixels that are 60% or more snow-covered. Agreement between the two techniques is >98%. For pixels less than 60% snow-covered the threshold cutoff for SNOMAP prevents it from identifying any of these lower snow cover fractions as snow. SNOMAP thresholds are based on NDSI values and TM band 4 reflectance. NDSI values for a Landsat TM scene of the Sierra Nevada mountains were compared with the results of the SCA classification. NDSI appears to be an excellent predictor of snow covered area for pixels that are moderately

(30-60%) or heavily (>60%) snow covered. For moderately snow-covered pixels NDSI values map fractional snow cover with an accuracy of 80%. NDSI values may be used to produce a second data product of fractional snow cover from MODIS data.

SNOMAP was modified to run on data at 500 meter resolution. The Sierra TM scene and the SCA results were degraded to 500 m. Results of comparisons at 500 m resolution are not as good as those for the original data set. Agreement between SNOMAP and SCA is excellent for high snow cover fractions (70-100%) but decreases with decreasing snow fraction. Pixels that are 31-60% snow-covered can be mapped with an accuracy of 75%.

The results of this study suggest that fractional snow cover maps for moderate and heavy snow cover can be produced easily from MODIS data. This work should be continued on additional TM scenes, and with other MODIS-related data sets in order to corroborate the findings presented here.

II. Introduction

Algorithms for mapping global snow and sea ice cover are currently being developed in preparation for the launch of the EOS-AM1 satellite in 1998. The EOS platform will carry a suite of instruments, among them the Moderate Resolution Imaging Spectroradiometer (MODIS). MODIS is designed to study a variety of continental, oceanic and atmospheric processes (Salomonson and Toll, 1991). Snow and ice are of particular interest as they are important components of the Earth's hydrologic cycle, they play a key role in the global energy budget, they influence seasonal weather patterns, and they comprise an important water resource for human populations and natural ecosystems (*e.g.* Foster & Chang, 1993). Thus it is desirable to have a good understanding of interannual and long-term variations in the extent of global snow and ice cover. The snow and ice mapping algorithms need to be tested and validated in the pre-launch time frame, and revised once the MODIS sensor is operational. Maps of global snow and sea ice cover will be generated on a daily and weekly basis. It is anticipated that MODIS snow products will be used as input to general circulation models and to models of snowmelt runoff, among other applications (Hall *et al.*, 1995).

The current prototype snowmapping algorithm is SNOMAP. It is presently configured to identify snow in Landsat thematic mapper scenes. The Landsat TM sensor currently provides 7 bands of data in the visible and near IR part of the spectrum. MODIS will provide 36 bands, some of which are similar to the TM bands, thus making Landsat scenes useful testing grounds for MODIS algorithm development. Landsat TM bands **5** (1.55-1.75 μm), **4** (0.76-0.90 μm) and **2** (0.52-0.60 μm) have proven to be especially useful in the identification of snow (Hall *et al.*, 1995).

The difficulty in testing the SNOMAP algorithm is in identifying a suitable standard against which the results can be compared. There are essentially three methods currently employed to map snow cover: ground-based measurements, low-altitude aerial photography, and satellite observation. Each is best-suited to a specific purpose, and has drawbacks when applied more broadly. Ground-based observation is essential, but can only be accomplished at point-localities, so spatial coverage is extremely limited. Long term coverage requires a dedicated, staffed site. Low-altitude aerial photography is also limited in its spatial extent, and cost dictates that flights are of limited duration. Satellite remote sensing provides excellent spatial and temporal coverage, but the identification of ground surface materials is complex, owing to the fact that pixels on the ground are typically composed of more than one type of surface, and some surface materials have similar spectral characteristics. Independent satellite observation, in combination with low-altitude aerial photography and ground validation provides the best means by which to validate any satellite snow mapping technique. However, there are very few sites for which all three types of information are available. The best-studied region is the Sierra Nevada mountains of California. This region is of great interest because of the importance of seasonal snowmelt runoff to the water supply of the state of California.

A Landsat TM scene of the Sierra Nevada acquired on May 10, 1992 was used to judge the accuracy of the SNOMAP algorithm. An independently derived algorithm (SCA) based on spectral mixture modeling has been produced and run on this scene (Rosenthal, 1993; Rosenthal & Dozier, 1996). The accuracy of the SCA algorithm was verified through ground-based observations and analysis of simultaneously acquired aerial photography. These data are assumed to be the closest available approximation of the actual distribution of snow cover. The SNOMAP algorithm was run on the same Sierra Nevada scene, and results were compared with those of the SCA algorithm.

III. Overview of the SNOMAP Algorithm

The SNOMAP algorithm is currently under development for use with future MODIS data. A prototype of the SNOMAP algorithm developed for Landsat TM imagery was used in this study. At present, SNOMAP is a binary classification system in which each pixel of data is mapped as either "snow," or "not snow." Two criteria determine pixel classification. The first is energy reflectance in TM band 4. Band 4 reflectance allows snow to be distinguished from other surface materials that are highly reflective in the visible spectrum, such as liquid water. It has been determined that a TM4 reflectance greater than 11% is a valid threshold for snow classification (Hall *et al.*, 1995). The second criteria is the value of the Normalized Difference Snow Index (NDSI). This is a parameter analogous to the commonly-used NDVI, the Normalized Difference Vegetation Index (*e.g.* Tucker, 1979). The NDSI is defined as the difference in reflectance between TM bands 2 and 5, normalized by the sum of reflectances.

Observation shows that NDSI values greater than 0.4 accurately distinguish snow from other land surface materials. The combination of these two threshold values is used by SNOMAP to map the distribution of snow in TM scenes.

The prototype SNOMAP algorithm has been compared with supervised classification techniques for six TM scenes (Montana, Minnesota, Alaska and Iceland), and with the results of an independent snow mapping algorithm (SCA) applied to an additional TM scene of the Sierra Nevada mountains in California (Hall *et al.*, 1995). SNOMAP has proved superior to supervised classification techniques. Comparison with the SCA algorithm is described below.

IV. Overview of the SCA Algorithm

Unlike SNOMAP, the SCA algorithm is not a binary classification system. SCA uses spectral mixture modeling to identify not only those pixels that are snow covered, but to estimate the faction of each pixel that is covered with snow. This technique is based on the assumption that most pixels contain a mixture of surface materials, each with unique spectral properties. Several end member materials are chosen and a spectral model is created for each. For the Sierra Nevada TM scene the end members are pure snow, rock and vegetation. All pixels are assumed to be some combination of these three end members. A "learning sample" of several thousand pixels is selected in order to create a decision tree algorithm that will eventually classify the scene. The final decision tree algorithm is optimized, representing a balance between speed (simplicity) and accuracy in identifying snow. Snow-free pixels are identified and masked, then the decision tree algorithm estimates the fraction of each remaining pixel covered by snow. The SCA algorithm assigns pixels containing snow to one of eight fractional snow cover categories: 96%, 84%, 72%, 60%, 50%, 38%, 22% and 9% snow-covered (Rosenthal & Dozier, 1996). The results of SCA have been verified with low-altitude, high-resolution aerial photography and with ground measurements for sub-regions within the TM scene.

V. Preliminary Activities and Results

Following Rosenthal's (1993) work on spectral mixture modeling, the SNOMAP algorithm has been compared several times against the SCA model results. Repetition of these comparisons was the first project that I undertook. This served as an introduction to the image analysis software and the techniques of snow mapping, and provided a check on the results of previous work. The SCA data set consists of the results of the SCA algorithm run on the Sierra Nevada TM scene, acquired on May 10, 1992 (scene ID#5299217572). The resolution of this image is 28.8m. These results were compared with those of the SNOMAP algorithm run on the same scene. Three comparisons were made: (1) pixels mapped as snow by both SCA and SNOMAP, (2) pixels mapped as snow by SCA but not by SNOMAP, and (3) pixels mapped as snow by SNOMAP but not by SCA. The first two comparisons were made for each of the eight snow cover classes produced by the SCA algorithm. In the third comparison the SNOMAP result is compared against the entire SCA data set. Visual inspection shows that SNOMAP classifies significantly fewer pixels and snow than SCA, however when compared only with SCA snow cover categories >60% agreement is quite good. This is also well-illustrated by a histogram plot of agreement between the two algorithms for snow-covered pixels in each snow cover category. For pixels covered by >72% snow the agreement between the two techniques is >98%. Agreement is only about 50% for pixels that are 60% snow covered, and agreement is very poor for the lower snow cover fractions. SNOMAP identifies 51% of the total number of snow-covered pixels that SCA does. The total snow-covered area mapped by SNOMAP is 2.67 million km^2, compared with a total snow covered area of 2.97 million km^2 mapped by SCA, an agreement of 91%. A small number of pixels are mapped as snow by SNOMAP but not by SCA.

VI. NDSI as an Indicator of Snow-Covered Area

Since the NDSI value is an important criterion for distinguishing snow-covered pixels from those that are not snow-covered, the NDSI values for the Sierra TM scene have been compared with their corresponding SCA snow cover classes. The SNOMAP algorithm produces data files of NDSI values and TM4 reflectances. These data were used to create a new image of the Sierra scene. First pixels with TM4 reflectance ≤11% were masked. Then 3000 pixels from a mountainous part of the scene were selected from both the SCA and new NDSI images. From this group, non-snow pixels (those with SCA=0) were removed and the remaining 1483 snow-covered pixels were used for comparison (Figure 5). Since there is some scatter in the data, particularly in the lower snow cover fractions, the mean NDSI values for each SCA category were calculated. These average values were then plotted, with error bars of two standard deviations from the mean. A linear regression was fitted to these data. The curve fit to the mean values rather than the whole data set reduces the influence of outlying data points. It is evident that NDSI is an excellent predictor of snow cover fraction.

These data illuminate the relationships. There is good agreement between the SNOMAP and SCA results in SCA categories 72, 84 and 96 because all of these pixels have NDSI≥40 and are thus mapped as snow by SNOMAP. For SCA category 60, only about half of the pixels have NDSI≥40, thus the agreement between the two techniques is only about 50%. For the lower snow cover categories, none of the pixels have NDSI≥40, thus none are mapped as snow by SNOMAP. It is also interesting to note that SCA categories 72, 84 and 96 do not have overlapping NDSI values, while those in the lower snow cover classes overlap by as much as 50%. This suggests that NDSI values can be used with a great deal of confidence for pixels that are mostly snow covered, while reliability decreases with decreasing fractional snow cover.

The regression line was used to define new fractional snow cover categories based on NDSI values. The Sierra TM scene was then re-analyzed using the 10 new snow cover categories (10% increments from 1-100% snow-covered). Pixels mapped as snow based on NDSI are plotted as a histogram along with the SCA snow-covered pixels. Although the two charts are not directly comparable (due to the different number of snow cover categories and their differing values), it can be seen that the same general pattern is present in both data sets. More pixels are mapped as snow at high and low snow cover fractions, and fewer are mapped as snow in the intermediate categories. The NDSI value is not a good predictor of the presence/absence of snow for pixels with small fractional snow covers. Images of the NDSI results overlain on the TM scene show that highways, rivers, talus slopes, desert playas and some lake shorelines all have low NDSI values and are thus mistaken for snow.

Since there may be a need for some fractional snow cover products (but perhaps not for 10% classes), the NDSI data were grouped into three categories: 1-30%, 31-60% and 61-100% snow cover. The SCA data were grouped similarly. For the highest fractional snow cover category (61-100%) there is excellent agreement between the NDSI and SCA snow maps. At 31-60% snow cover the agreement is 80%. For snow cover less than 30% the agreement is terrible, and the NDSI technique clearly cannot be applied in this situation. However, since NDSI values and TM4 reflectances are generated as a part of the SNOMAP algorithm, the addition of a new 31-60% snow cover category to the SNOMAP data product seems entirely feasible.

VII. 500 meter Resolution Data

The Sierra Nevada TM scene was degraded to 500 meter resolution in an attempt to better simulate future MODIS data. TM bands 5,4 and 2 were re-sampled using a cubic-convolution technique, reducing each scene to 415 pixels and 358 lines of data. The SNOMAP algorithm was modified to accommodate the new data structure, and was compiled and run on the new data set. The *results* of the SCA algorithm were also resampled using the cubic-convolution technique. The resampling technique smoothed the eight original SCA snow cover categories in such a way as to produce a continuum of snow cover fractions. The SCA and SNOMAP data were both grouped into 10% snow cover fractions These two data sets were then compared using similar techniques and criteria to those applied to the 28.5 m data set. One difficulty arose, in that the SNOMAP result appeared to be offset from the SCA result by one line of pixels. The SNOMAP scene was adjusted accordingly prior to comparison.

The SCA and SNOMAP data were again examined on a pixel-by pixel basis, and the same three comparisons were made: (1) pixels mapped as snow by both SCA and SNOMAP, (2) pixels mapped as snow by SCA but not by SNOMAP, and (3) pixels mapped as snow by SNOMAP but not by SCA (Table II). The agreement between SCA and SNOMAP is equally good (98%) for categories with the most snow cover (70-100%). Agreement was 90% for pixels that are 61-70% snow covered, 30% for pixels 51-60% snow covered, and very poor for pixels <50% snow covered.

SCA values were again plotted as a function of the Normalized Difference Snow Index. Two thousand pixels were selected for comparison, of those, 865 were snow-covered. A linear regression was applied to these data, also with an excellent fit (r^2=0.941). However, a number of outlying data points are observed with high NDSI values and low snow cover fractions. The regression line was used to calculate the fractional snow cover of each pixel based on its NDSI value. These snow cover fractions were compared to the SCA data.

The results of the 500 m NDSI comparison are somewhat difficult to interpret. In general, agreement between SCA and NDSI snow-covered areas is not as good at 500 m resolution as it was in the original 28.5 m TM scene. In some categories (e.g. 91-100% snow cover) the agreement is excellent (99%). The agreement becomes poorer at lower snow cover fractions. The variance (+/-) as a fraction from perfect agreement is plotted. When the snow cover fractions are grouped into thirds, variance averages appx. 10% for the 61-100% snow class and 25% for the 31-60% snow class. As before, agreement is extremely poor for snow cover fractions less than 30%.

VIII. Discussion and Conclusions

It is not clear why the results of the 500 m data comparison are not as good as those from the original 28.5 m data set. One explanation may be the different ways in which the 500 m data for NDSI and SCA were derived. In the case of the NDSI values, these were calculated when SNOMAP was run on the degraded TM scene. It was not possible to run SCA on the 500 m scene, thus the SCA result produced from the original 28.5 m data was degraded, rather than being regenerated at 500 m resolution. This may be the cause of some error, but it is not clear why this should be the case. The outlying data points observed certainly account for a small amount of disagreement, on the order of 2-3%.

If the SNOMAP thresholds of TM4 reflectance >11% and NDSI ≥40 are maintained for the 500 m data set, then the agreement between SNOMAP and SCA is excellent for pixels that are >70% snow-covered. The NDSI technique can be applied to pixels that are 31-70% snow-covered with appx. 75% confidence. The NDSI technique is not robust for pixels <30% snow-covered.

For both the original TM scene and the 500 m degraded image the NDSI technique appears very promising in its ability to add an additional category of snow-covered pixels to the MODIS data products. If one is willing to accept an uncertainty of 75-80%, then pixels that are 31-60% snow-covered can also be easily mapped with SNOMAP. At this time there appears to be no simple way to map pixels that are <30% snow-covered.

The results of this study must be considered to be preliminary. The merit of NDSI as a predictor of snow-covered area was demonstrated for a single Landsat TM scene. The regressions used to calculate snow cover fractions were derived from a small subset of the data from this scene. Before the NDSI technique is applied more broadly it should be verified on additional data sets.

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ANDREW G. KLEIN

Andrew G. Klein joined the group in Code 974 in September 1996 as an employee of GSC. He will complete requirements for the Ph.D. degree in Geology from Cornell University in January 1997. Beginning on January 2, 1997 he has been employed by USRA as a post-doc fellow. He has undertaken several projects so far. His first project was a follow-on from the summer work of Alex Moore/JOVE/Hartwick College. His results show that, using the newest version of the Rosenthal and Dozier (1996) SCA spectral-mixture modeling based algorithm, agreement between the SCA and SNOMAP methods of snow mapping on a 10 May 1992 TM scene of the Sierra Nevada Mountains is 95% for pixels that are 50% or greater snow covered. The estimates of total snow-covered area determined by the two algorithms (SCA and SNOMAP) differed by <1.3%. He also showed that, when the TM data were degraded to 500-m resolution to simulate the MODIS pixel size, comparison of results in the 2 algorithms was equally good.

FIELD EXPERIMENT - FEBRUARY 1997

Plans for the February 1997 field experiment, to be held in connection with the WINCE Experiment, are currently being finalized. The draft Experiment Plan follows. This covers the field experiment planned for the New Hampshire study site. Additional field measurements will be conducted at sites in Wisconsin.

Experiment Plan
February 1997

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Introduction

A one-day field and aircraft mission is being planned in conjunction with the mission lead by the University of Wisconsin MODIS cloud-masking project called Wisconsin Ice and Cloud Experiment (WINCE). One overflight of New Hampshire and New York study sites is tentaitvely scheduled. Field measurements will be acquired on the ground by D. Hall, A. Klein/USRA, G. Riggs/RDC and K. Bayr and students at Keene State College, and A. Moore and students at Hartwick College. Field and low-level aircraft flights are required in order to validate the algorithm, called SNOMAP, that has been developed to map snow using future Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) data following the launch of the EOS-AM platform in 1998. Results of the mission will be analyzed at GSFC, and jointly with Drs. Bayr and Moore at Keene State and Hartwick College, respectively.

The ER-2 aircraft will be equipped with the following instruments: the MODIS Airborne Simulator (MAS), the Millimeter-Wave Radiometer (MIR), as well as a camera to acquire air photos.

There is a Landsat-5 overpass scheduled for the Keene, NH study area on Thursday, 6 February 1997. The ER-2 should occur on a day in which there is minimal cloudcover over the sites. The decision to fly will be made by Dorothy Hall in conjunction with the Wisconsin cloud-masking group and the Ames flight crew and Drs. Bayr and Moore.

Objective

The objective of the mission is to validate the SNOMAP algorithm in different land covers, and to determine the errors in using SNOMAP to map snow in different land covers. Specifically, snow conditions will be measured simultaneous with an overflight of the NASA ER-2 aircraft in order to validate and refine SNOMAP. The Landsat-5 spacecraft will acquire data on 6 February 1997 at the Keene, NH site.

A small airplane will acquire air photos concurrent with the ER-2 overflight. One of two methods will be used to compare the air photo-derived snow maps with the MAS-derived snow maps. One method involves drawing snow maps onto topographic maps from the aerial photographs. This snow map will be digitized and compared quantitatively with snow maps derived from MAS using the SNOMAP algorithm. Or, air photos will be first digitized, mosaicked and then compared digitally with snow maps derived from MAS using the SNOMAP algorithm. Errors in mapping snow will be determined in each land cover in each area: deciduous forest, coniferous forest, mixed forest, agricultural, and barren/lake areas. As a first-order approximation of global-scale errors of mapping snow with SNOMAP from MODIS, errors in the various land covers will be extrapolated to the global scale in the pre-launch time frame. Following launch, global errors using SNOMAP will be re-calculated using the MODIS-derived snow- and land-cover maps.

A secondary objective is to determine the correlation between snow depth and passive-microwave brightness temperature as measured using the MIR data. The snow depth and grain size measurements are important because snow depth and crystal size influence the amount of radiation scattered and thus received by the sensors on the MIR. Reflectivity in the visible and near infrared is also a function of grain size.

Field Measurements

Near Keene, NH, there will be 3 sites. Sites will be located in a forest (site 1), an agricultural area (site 2), on a frozen, snow-covered lake (site 3). There will be 3 field teams consisting of 2 Keene State students each, supervised by Drs. Bayr and Hall. If possible, measurements will be made simultaneous with the ER-2 and/or Landsat-5 overpasses. At each site, there will be two transects. Snow depth and density measurements will be made every 100 m for a length of 2 km. Also at each 100-m site, information about the ground cover should be recorded, e.g. information about vegetation type (coniferous versus deciduous trees), and, in the case of coniferous trees, it should be noted how much snow (if any) is in the tree canopy. A photograph should be taken of the site. Another photograph should be taken looking straight up at the sky. The resulting picture can be digitized and then canopy density will be calculated.

Three snow pits will be dug - near the beginning, middle and end of each transect. At each snow depth measurement, the air and snow temperature will be recorded. Cloudcover information should be recorded at each snow pit. Measurements of the snow pit should include snow temperature at the surface and at various depths, information on what conditions are beneath the snow (vegetation, and whether or not the ground is frozen). Snow crystal size throughout the snowpack should be measured and recorded. Time of day (local time) should be recorded at each 100-m site.

Measurements (100-m sites)

Name and site #:____

Local time: ____

Air temperature: ____

Snow temperature (10-cm depth): ____

Snow depth (take 5 measurements and record each measurement and the average):
____

Crystal size near surface ____

Take a photograph of the ground site, and straight up of the sky.

Describe setting. Forest type? ______________________________ Snow in the tree canopy? ________________________ If yes, how much? _________________________ Is there an understory? ____ If yes, does it have snow on the canopy? ____
Please note any other information that may be relevant.
____
____
____
____

Snow Pit Sites

Perform all measurements required for the 100-m sites (see above).

Sun photometer. ____

____

Crystal size in mid-pack (how deep?): ____

Crystal size near the bottom of the snow pack (how deep?): ________________________

Describe ground condition beneath the snow. ____________________________________
____
____

Describe sky condition. ____
Is there any cloudcover, and if so, where and what kind of clouds? __________________
____

SOFTWARE DELIVERY

George Riggs and Hugh Powell delivered the MODIS snow cover algorithm MOD_PR10 Version 1 code and supporting data files and documentation to SDST. This was a re-delivery of the code after interaction with STIG on some coding and metadata issues, and included integration of product required metadata that was not in the previous delivery. That code used MODIS simulated data as input and created a data product, and included project required metadata, per product specification.

Riggs and Powell delivered the MODIS sea ice algorithm, MOD_PR29 Version 1 code and supporting data files and documentation to SDST. That code used MODIS simulated data as input and created a data product, and included project required metadata, per product specification.

Riggs and Powell delivered the MODIS level 3 daily snow cover algorithm MOD_PR10A Version 1 code and supporting data files and documentation to SDST. That code used MOD_PR10G, the daily gridded and tiled snow cover product from MOD_PR10, as input and generated a data product per product specification.

PUBLICATIONS, MEETINGS AND CONFERENCES

Meetings attended

19 July 1996 Cloud-masking workshop, Langley, VA (D. Hall, G. Riggs)

9-11 October 1996 MODIS Team Meeting (D. Hall, G. Riggs)

Alex Moore and Dorothy Hall attended the AGU meeting in San Francisco where Dr. Moore presented a poster entitled, “Enhancements to the MODIS Snow-Cover Mapping Algorithm,” by A. C. Moore and D. K. Hall.

Abstracts submitted

Hall, D.K., J.L. Foster, A.T.C. Chang and C.S. Benson, "Analysis of changing albedo in snow-covered terrain in Alaska as determined from aircraft data," submitted to the International Glaciological Society meeting on Snow and Avalanches, 26-30 May 1997, Chamonix, France.

Klein, A., D. Hall and G. Riggs, "Improving the MODIS Snow-Mapping Algorithm," submitted to the IGARSS '97 Symposium, 3-8 August 1997, Singapore.

Presentations

George Riggs presented a talk at the MODIS Algorithm Developer's Forum on October 9, 1996, entitled, "Version 1: Lessons Learned."

Dorothy Hall presented a talk at the Ad-hoc Committee on MODIS Snow and Ice Products meeting on 25 November 1996 entitled, "SNOMAP algorithm development: progress and plans."

Andrew Klein presented a talk at the Ad-hoc Committee on MODIS Snow and Ice Products meeting on 25 November 1996 entitled, "SNOMAP validation activities."

George Riggs presented a talk at the Ad-hoc Committee on MODIS Snow and Ice Products meeting on 25 November 1996 entitled, "ICEMAP algorithm development: progress and plans."

Dorothy Hall gave a Goddard DAAC training seminar entitled, "The MODIS snow and ice project," on 10 December 1996.