Semi-Annual Report
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Task Objectives

The overall objectives of the MODIS/snow project are to: develop and test algorithms to map snow extent and reflectance using MODIS data, and to employ the snow data to analyze spatial and temporal variability in bidirectional, reflected solar and emitted thermal radiances over snow- and ice-covered areas to improve the current understanding of snow and ice cover as key components of the global energy balance.

Work Accomplished

There are three primary areas of research that have been on-going during 1992. The first is is the analysis of the results of field and aircraft measurements of bidirectional reflectance of snow in northern Montana. The second is the continued development of the algorithm to map snow extent. And the third is the evaluation and analysis of MODIS Airborne Simulator (MAS) data obtained over the snow-covered Sierra Nevada Mountains. Each will be discussed separately under the Data Analysis/Interpretation section.

Field work was undertaken in northern Montana in February of 1992 simultaneous with the acquisition of Advanced Solid-State Scanning Array Spectroradiometer (ASAS) data. The objective of the field program was to gain more information about the bidirectional reflectance properties of a variety of snow-covered surfaces. This was accomplished through acquisition of bidirectional reflectance data to compare reflectances with measurements made simultaneously on the ground using a portable spectrometer.

Relative to the snow extent algorithm development, George Riggs of Research and Data Systems Corporation has been investigating, in detail, the algorithms that are currently being used by the National Operational Hydrologic Remote Sensing Center (NOHRSC) to generate their satellite snow cover product. The NOHRSC product provides regional snow cover as compared to the NOAA product which covers the Northern Hemisphere. The NOHRSC satellite snow cover product consists of three classes: snow, not snow and cloud. AVHRR bands 1, 3 and 4 are used to identify snow. First the AVHRR data are normalized to reduce or eliminate solar illumination effects by taking into account viewing geometry. New data are created by subtracting band 4 from band 3. This allows for the classification of snow, no snow and cloud based on the separation between them. A geographic information system is then used to overlay the AVHRR classified image onto a digital elevation map and a map of basin boundaries in order to generate a map of snow cover by elevation zone. Our algorithm (under development) using the thematic mapper data as a surrogate for MODIS data, is essentially the same as the NOHRSC algorithm except that we use the TM band 6 (thermal band) to discriminate snow from clouds instead of creating a surrogate band 6 as is done with the NOHRSC algorithm.

A preliminary investigation has been undertaken to analyze the MODIS Airborne Simulator (MAS) data of snow-covered surfaces. During a test flight of the NASA ER-2, the MAS overflew the Sierra Nevada Mountains at our request and obtained some data of snow. The focus of our work so far has been to investigate the utility of the thermal-infrared data for snow mapping.

Data Analysis/Interpretation

Snow reflectance work. Bidirectional radiance measurements of various snow-covered surfaces were acquired using the Advanced Solid-State Array Spectroradiometer (ASAS) which was flown on the NASA C-130 aircraft over 4 snow-covered sites in Glacier National Park, Montana on 14 March 1991 simultaneous with a ground-truth campaign. Dorothy Hall, Jim Foster and Al Chang of the Hydrological Sciences Branch, Jim Irons of the Biospheric Sciences Branch, Phil Dabney of the Sensor Concepts and Development Branch and Janet Chien of General Sciences Corportation were directly involved in this project. A frozen lake, a meadow, a mixed coniferous/deciduous forest and a dense, coniferous forest were studied. Knowledge of the bidirectional reflectance characteristics of various snow-covered surfaces is key to calculation of albedo from satellite sensors in the future. While the reflectance characteristics of pure snow targets have been measured from the ground, aircraft and satellites, very little bidirectional reflectance data exist for surface covers of mixed snow and vegetation. This is important because much of the seasonally snow-covered parts of the Northern Hemisphere consist of mixed cover. Analysis of the 14 March 1991 ASAS data shows that the anisotropic reflectance of snow was strong over the frozen lake but slightly dampened over the meadow because of the presence of low vegetation. Over the coniferous forest, strong backscatter is observed while enhanced reflectance in both the forward and aftward sensor view-zenith directions was measured over the mixed forest. Snow that was known to be present beneath the coniferous forest canopy was not detected in our data.

Average ASAS-derived, at-sensor radiances for each of the 4 sites were calculated and are shown in Figure 1. Values were obtained when the data from each of the 7 view-zenith angles: -45o, -30o, -15o, 0o, +15o, +30o and +45o were averaged. Snow overlying the lake ice displays the highest average radiance and the coniferous forest has the lowest average radiance of the 4 study areas.

The addition of a neutral-density filter during acquisition of the data caused a low signal problem. This may have also affected the absolute accuracy of radiances. The radiances retrieved over snow did not decrease with wavelength at the rate expected on the basis of prior experience. The within-band precision of the radiance data, however, appears acceptable as the observed directional patterns, discussed in the following paragraphs, were consistent from band to band.

Figure 2 shows radiances from ASAS band 10 from the lake, meadow and forest sites when the flight line was parallel (Figs. 2A, 2C and 2E) and perpendicular (2B and 2D) to the principal plane of the Sun. The data of the meadow site, acquired when the flight line was perpendicular to the principal plane of the Sun, were incomplete and are thus not shown. Anisotropy of the surface cover reflectances is apparent in the data acquired when the flight line was parallel to the principal plane of the Sun, but is not apparent in data acquired perpendicular to the principal plane of the Sun.

The snow-covered lake displayed forward scattering (apparent in the ASAS forward view-zenith angles +15o, +30o and +45o) when the flight line was parallel to the principal plane of the Sun. When snow is mixed with vegetation in the meadow, the forward scattering was still apparent, but the across-field variation in radiance was greater than in the case of the snow over the lake. This is because of the presence of the vegetation and thus the greater heterogeneity of the meadow relative to the snow-covered lake (Figure 2E). A somewhat weaker forward-scattering component of reflected energy is evident in the data acquired over the meadow as compared to data acquired over the lake.

Data were also acquired over several sites in a mixed coniferous/deciduous forest. Results show a large amount of variability in the data and in the anisotropic reflectance patterns. Scattering was observed in both the forward and aftward sensor view-zenith angles indicating that both trees and snow were sensed. Radiance or reflectance curves for forests usually show a strong backscatter component due to shadowing from the trees (Irons et al., 1991; Li and Strahler, 1986). The radiances acquired over the coniferous forest in northern Montana displayed scattering characteristics of trees and anisotropy in the aftward view-zenith angles (-15o, -30o and -45o).

In forested areas and at view directions near the anti-solar direction, the sensor field-of-view consists primarily of directly illuminated canopy components. As the view direction changes to the forward-scattering direction, the field-of-view contains progressively greater proportions of shadowed and diffusely illuminated canopy components. The data shown here for the full conifer canopy with underlying snow resemble the ASAS data shown by Irons et al. (1991) for a coniferous canopy observed during the summer. Evidence of snow beneath the dense conifers is lacking in our data.

It is difficult to identify and measure snow under a dense forest using visible, near-infrared and even passive-microwave sensors from space (Foster et al., 1991). When using data from the reflective part of the spectrum, the scene reflectance may increase just after a snowfall when the newly-fallen snow is in the tree canopy, then reflectance decreases rapidly when the snow falls from the trees. In our data, the effect of the snow on the scene reflectance is evident in the meadow, and in the mixed forest but not at all evident in the coniferous forest. Even though the planetary albedo may be low (<30 percent) in densely forested areas, the snow cover is nevertheless important to the energy balance of the forest, and to the perpetuation of the forest itself.

Our data show distinctive anisotropy of a variety of snow covered surfaces: a snow-covered lake, a meadow, a mixed forest, and a coniferous forest. In future work, ASAS data will be corrected for the influence of the atmosphere, in order to compute the surface reflectance. Several atmospheric modeling studies have demonstrated that bidirectional reflectance patterns are preserved through a clear atmosphere (Tanre et al., 1979; Gerstl and Simmer, 1986) which prevailed during the March 1991 ASAS overflights. Knowledge of the bidirectional reflectance factors of mixed covers is important to development of algorithms to compute albedo using data that will be available from the MODIS and MISR sensors in the EOS era.

References

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Figure captions

1. Average ASAS-derived radiances for the lake, meadow, mixed forest, and coniferous forest study sites on 14 March 1991. Values were computed by taking an average of the radiances in each of 7 angles (-45o, -30o, -15o, 0o,+15o +30o, and +45o). The NASA C-130 flight line was parallel to the principal plane of the Sun. The Solar zenith angles at the time of the overflights were 55.26o for the lake, meadow and mixed forest sites, and 58.89o for the coniferous forest site.

2. ASAS Band 10 (center wavelength 573.4 nm) radiances for three snow-covered surfaces in Montanta on 14 March 1991. Curves show response at various sensor zenith angles. Mean values when a 25 X 25 pixel area was averaged are represented by the solid lines, and the dashed lines indicate plus-or-minus one standard deviation. When the flight line was parallel to the principal plane of the Sun, the solar zenith angles were 55.26o for the lake (2A), and meadow (2E) sites, and 58.89o for the coniferous forest site (2C). When the flight line was perpendicular to the principal plane of the Sun, the solar zenith angle was 56.06o for the lake site (2B), and 56.90o for the coniferous forest site (2D). Data acquired over the meadow when the flight line was perpendicular to the principal plane of the Sun were incomplete and therefore not shown.

Snow mapping algorithm development.

Landsat Thematic Mapper (TM) data have been utilized in development of a MODIS snow cover algorithm. TM data are used because because the TM has some spectral bands similar to those planned for MODIS (Table 1). Most importantly it has a 1.6 mm band that is useful for snow/cloud discrimination. TM is lacking the thermal bands of MODIS that may be utilized for cirrus cloud detection, thus those techniques will necessarily be developed with data from a different sensor in future work.

Table 1. Center wavelengths for TM and MODIS spectral bands.

MODIS Band	TM Band	Center Wavelength MODIS	Center Wavelength TM
1	3	.659	.66
2	4	.865	.83
4	2	.555	.56
6	5	1.640	1.65
7	7	2.130	2.22
31	6	11.030	11.45

Landsat 5 TM scenes of the Brooks Range in Alaska acquired on 13 September 1984 (solar zenith 67¯) and of the Chugach Mountains in Alaska analyzed on 1 August 1985 (solar zenith 47¯) have been acquired. Both scenes contain mountains with snow cover, glaciers, and clouds. These scenes were selected to develop techniques for snow identification and snow/cloud discrimination. A Landsat 4 TM scene of West Antarctica acquired 12 December 1988 (solar zenith 68¯) has also been used for snow/cloud discrimination technique development. This scene has thin cirrus clouds over snow. For initial tests of the algorithm for cases of no snow cover, a TM scene of Chernobyl taken 29 April 1986 was used. The image covers the nuclear reactor site, agricultural fields, forests, a river,

and a large lake. Image subsets, 512 x 512 or 1024 x 1024 pixels in size, were extracted from the scenes for analysis.

Landsat TM digital numbers were converted to either effective at-satellite reflectance, or at-satellite temperature. The use of physically-meaningful reflectances allows for reasonable comparison of results with other work, thus some atmospheric correction will be performed during the MODIS data processing thus providing surface reflectance measurements.

Algorithm Techniques

Our objective is to identify snow by its unique reflectance and emittance characteristics. The techniques developed must have consistency, accuracy, and be able to be automated. The operational algorithm must execute without the need for operator interpretation. Thresholding for reflectance or emittance characteristics is the dominant technique employed in the algorithm at present. Threshold techniques are currently employed by NOAA and NOHRSC for their snow cover products.

The technique of reflectance thresholding applies threshold or extrema that are not truly universal; many situations arise where they fail to perform satisfactorily. A common situation where snow is not consistently identified by threshold tests is shaded snow (where snow is shaded by mountains or clouds). Snow in those areas does not have the high visible band reflectance that is typical of sunlit snow. When the reflectance threshold is lowered to identify the shaded snow areas, the compromise is that non-snow features may then be identified as snow.

In order to evaluate the effect that changing the threshold had on the results of a reflectance test, the threshold was changed and the change in result was counted. This was done for each threshold test with acceptance criteria incremented in steps of 0.05 over the acceptance range of 0.0 to 1.0 for several images. There was about a 10% to 20% change in the number of pixels identified as snow for a 0.05 change in acceptance threshold from the previous threshold result.

The spatial result of changing thresholds was observed as an expansion or contraction of snow extent around the perimeters of the snow areas identified in the previous threshold levels, as reflectance threshold acceptance criteria were incremented or de-incremented. This was observed over a wide range of thresholds surrounding the threshold that we interpreted as producing the most acceptable result. At either the high or low ends of decision thresholds, radical jumps in identified snow area were observed as snow was either eliminated or other features were included in the result. It was observed that the amount of change in snow extent between increments was affected by the amount of snow cover observed in an image, with images having extensive areas of snow cover exhibiting smaller changes than those with lesser observed snow coverage. We observed that there was not an exact or critical threshold for these snow reflectance tests, but that there was a range of acceptable thresholds that corresponded to the best visual interpretations of snow cover. It has also been observed that a selected threshold value can be used with acceptable results in many different images. Further analysis of threshold selection is required.

To increase our ability to identify snow and decrease reliance on 'universal' thresholds we have defined a normalized snow difference index (NSDI). Snow reflects visible radiation and absorbs near-infrared radiation, thus the snow normalized difference is expressed as: NSDI=(reflected visible - absorbed near infrared) / (reflected visible + absorbed near infrared). For TM data we have used TM bands 2 and 5 because both closely correspond to MODIS bands 4 and 6 in spectral coverage, and both MODIS bands have the same spatial resolution (Table 1). The NSDI is then:

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

This NSDI is used to key on the characteristic change in snow reflectance between the visible and near-infrared spectral regions. Snow will have positive values; snow was commonly found to have NSDI values greater than approximately 0.6.

Snow Cover Algorithm Structure

Two algorithm structures have been developed and are being analyzed for snow identification. One form consists of two reflectance threshold tests for snow and the NSDI. The other form consists of the reflectance relationship between a single-band reflectance and NSDI. In brief the logic of Form 1 is to sequentially apply the tests and NSDI to each pixel, get a Boolean result (true=1, false=0), then use a set of decision rules to decide if a pixel is snow, not snow, or cloud. Form 2 uses spectral relationships, implemented as decision rules, between TM band 4 reflectance and NSDI of features to identify snow. Outlines for each form are given below:

FORM 1 OF THE ALGORITHM

REFLECTANCE TESTS

Test 1: IF reflectance at 0.56 mm, TM band 2, is >/= 0.6
THEN snow or cloud Test 1=1
ELSE not snow or cloud Test 1=0

Test 2: IF reflectance at 1.6 mm, TM band 5, is </= 0.3
THEN snow Test 2=1
ELSE not snow Test 2=0

Test 3: Calculate NSDI=(band 2 - band 5)/(band 2 + band 5)
IF NSDI >/= 0.6
THEN snow Test 3=1
ELSE not snow Test 3=0

APPLY DECISION RULES

Decision rules applied to test results are based on thresholds for snow and other features.

FORM 2 OF THE ALGORITHM

Calculate TM band 4 reflectance.

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

APPLY DECISION RULES

Decision rules based on relationships of TM band 4 reflectance to NSDI of features.

Reflectance threshold values used in the tests were derived from snow, cloud, and other feature samples extracted from the images, and from the literature. Selection of thresholds was decided on from analysis of the TM scenes of Alaska.

The NSDI has proved to be useful for the identification of sunlit snow, shaded snow, clouds, and surface. Discrimination of these four categories is possible because of the different locations in which they occur when NSDI is plotted against TM band 4 reflectance. Both sunlit and shaded snow have an NSDI greater than about 0.5, but sunlit snow has reflectance greater than 0.8 in TM band 4 where shaded snow has reflectance less than 0.3 (Figure 3). Clouds may be discriminated from snow by NSDI values less than about 0.4 and clouds may be discriminated from the surface by reflectances greater than 0.6 in TM band 4 where most surfaces have reflectance less than 0.4.

Both forms of the algorithm were developed from images containing predominately snow cover, but, have also been tested on several different TM image subsets of Alaska, Antarctica, and Chernobyl, USSR. Results from these tests demonstrate that the algorithm performs well in some situations, but not in others. These results indicate that more checking or screening for surface features other than snow will need to be incorporated into the algorithm to improve the accuracy.

The Alaska Kayak Island TM image is a case in which a large amount of sunlit snow did not have reflectance greater than 0.6, the threshold value. Possible solutions are: to tie the snow reflectance threshold value to the maximum reflectance measured in a scene, or to base the snow reflectance threshold on a percentage of the maximum amount of reflectance from a scene as determined from modelling reflectance from a Lambertian surface. Possible linking of threshold values to image parameters is a future activity.

The algorithm will need to be modified to mask water. Lakes, rivers, and bays may be identified as shaded snow surfaces by the algorithm. The confusion between water and snow begins with Test 2, where a low amount of reflectance is checked for, and continues in the NSDI. Water and snow both have a very low reflectance in TM band 5; the water sample had 0 reflectance in band 5. Both snow and water are identified as snow in Test 2 because both have very low reflectance. The very low reflectance characteristic of water at 1.6 mm also results in it having an NSDI very close to 1.0, thus it is again identified as snow, because the decision rules identify a pixel as snow if the NSDI is greater than or equal to 0.6. Masking of water is a future activity.

Cirrus clouds pose a special problem for detection and discrimination. A subset of the Antarctica scene was used as a test case for discrimination of cirrus clouds from snow. The cirrus clouds were not discriminated from snow by the algorithm; those cirrus present were identified as snow. It was possible in this case to discriminate the cirrus from snow with by implementing an at-satellite temperature (TM band 6 at 11.45 mm) check. This required sampling the cloud temperature to determine cloud temperature statistics for setting a threshold temperature value. This temperature check was not transferable from image to image. The lack of a consistent temperature check is because of the thermal variability of clouds between scenes. The algorithm was not able to distinguish some (suspected) thin cirrus clouds in the Alaska scenes. There are also other cloud situations such as fog over glaciers and snow cover that should be distinguishable by the algorithm. Because of the potential variable temperature differences between clouds and snow, and our ultimate goal of an automated snow cover algorithm, screening for cloud temperature with a single band will not be acceptable.

Thus far the snow algorithm has been developed and tested with a limited set of snow cover situations; more testing and development is required. Testing in snow cover situations discussed above is required in order to analyze the capabilities of the techniques employed to identify snow in various situations. More TM scenes covering a variety of snow cover situations to further test the snow algorithm need to be acquired. Some situations that are needed for testing are snow cover and cirrus clouds, snow cover and clouds, snow and ice covered lakes or ocean, open water, snow covered forest, snow covered forests and clouds, snow covered mountains in summer, desert (i.e. a surface with normally high visible reflectance), and grasslands in summer and in winter with and without snow. The algorithm needs to be tested for winter situations, seasonal transition periods, and summer situations, to evaluate its reliability in the different seasons.

Some of the potential capabilities of MODIS for distinguishing clouds need to be explored. In the future, techniques for distinguishing cirrus and other cloud types shall be integrated into the snow cover detection algorithm. The objective of identifying clouds is to avoid confusing them with snow. A current limitation to implementing cloud distinguishing techniques with TM data is the lack of data over the wavelengths required for these cloud distinguishing techniques and snow detection. Data from other sensors sensing in the thermal regions such as MODIS Airborne Simulator (MAS) will need to be studied for development of cloud detection techniques. Thermal data in the 3.7, 11, and 12 mm regions are required to test proposed cloud detection techniques employing temperature differences between these electromagnetic regions.

MODIS Airborne Simulator (MAS) study. The use of MAS data was examined in a preliminary way to determine the utility of the thermal infrared channels for mapping snow. Dorothy Hall, Jim Ormsby and Janet Chien were involved in this project. Data were acquired on 31 October 1991 in the snow-covered Sierra Nevada Mountains, California, from the NASA ER-2 aircraft with the MAS on board. MAS data from the visible (center wavelength 0.68 mm) and one of the thermal infrared (center wavelength 8.8 mm) channels have been studied.

Separate snow maps were produced uisng visible and thermal-infrared data. Results did not agree in terms of the amount of snow-covered area mapped. The snow-covered area mapped using visible data was produced by determining snow-covered area visually, while the snow-covered area mapped using the thermal infrared data was produced by assuming that all pixels having a temperature of 273 K or lower were snow covered.

While there were no coincident ground observations, the high contrast between snow covered and non-snow covered terrain permitted the mapping of snow-covered areas, visually. Areas of "pure" snow and snow-covered forests could also be distinguished, and radiances were computed using the channel 2 visible data. Using the MAS channel 10, in the thermal-infrared part of the spectrum, we were able to map snow-covered area and to compute "at-sensor" snow temperatures.

Atmospheric correction was not applied to any of the data, though this will be necessary in order to obtain physically-meaningful radiances and surface temperatures from the MAS data. Thus the radiances and temperatures reported herein are considered to be "at-sensor" values.

The areas that appear to be pure snow exhibited the highest radiances as computed from MAS channel 2 digital numbers (21.78-23.43 mW cm-2 sr-1 mm-1). These radiances correspond quite well to the highest radiances measured using Advanced Solid-State

Airborne Spectroradiometer (ASAS) data (Hall et al., in press) in northern Montana in March 1991. ASAS channel 18 (center wavelength 0.69 mm) radiances (acquired at nadir) for pure snow over lake ice were approximately 21 mW cm-2 sr-1 mm-1.

The snow-covered area, as delineated visually using visible data from MAS channel 2 in the Sierra Nevada, comprises approximately 53 percent of the entire scene. Using the thermal-infrared channel 10 data, 42 percent of the entire scene was considered snow covered. For this analysis, pixels with surface temperatures equal to or less than 273 K were considered snow covered since even melting snow should have a temperature no higher than 273 K. Within the snow-covered areas, at-sensor temperatures ranged from 263 K to 273 K. Mixed pixels may cause higher temperatures in snow-covered, vegetated areas because the non-snow material adjacent to, or protruding through, the snow may have a surface temperature greater than 273 K (Barnes et al., 1974). Many forested areas and areas of patchy snow were not classified as being snow covered, and thus misclassified, using the thermal infrared data because of the mixed pixels providing thermal infrared temperatures >273 K.

Within the snow-covered areas, there was some correspondence between the pure snow, as defined by the channel 2 (visible) data, and the coldest snow surface temperatures obtained from the channel 10 (thermal infrared) data. The areas that were coldest and displayed the highest radiances tended to be at high elevations.

MAS channel 10-derived temperatures in the range 263-268 K are found at elevations greater than about 2580 m (8500 feet). The slope and aspect is also important. A south-facing slope will have more direct solar radiation resulting in warmer snow temperatures. It is believed that the coldest snow was found on the north-facing slopes at high elevations. The use of a digital elevation map of the area combined with the MAS data will permit us, in the future, to study the relationship between slope, aspect and thermal infrared snow surface temperature in more detail. Digital elevation data of the areas have been ordered from the U.S. Geological Survey.

In conclusion, based on a preliminary analysis, the MAS thermal-infrared data are useful for delineating snow-covered area. The various snow temperatures, varied with elevation and, most probably, with orientation of the mountain slopes with respect to the Sun. Snow was present in areas that displayed channel 10 temperatures greater than 273 K. The effects of mixed pixels can cause pixels of snow mixed with vegetation to be greater than 273 K.

Analysis of diurnal change of snow surface temperature may be a viable method for improving snow-covered area measurement. The diurnal variation of the temperature of a dark surface is likely to be greater than the diurnal variation of the temperature of a bright or white surface like snow. So less diurnal variation in surface temperature would be expected over snow as compared to over adjacent non-snow-covered terrain (Barnes et al., 1974). Morning and afternoon MODIS thermal-infrared data could be used to determine diurnal temperature variations and thus to refine our ability to identify snow in problem areas where the identification of snow is difficult.

The use of the visible data alone resulted in assignment of about 11 percent more area as snow covered than did the use of the thermal-infrared data alone. A more in-depth study in which visible, near-infrared and thermal-infrared data are employed should help us to map the snow in this scene more accurately using a combination of several channels.

The thermal infrared data may prove useful for delineating snow in forests and for refining the measurement of the date of snowmelt. These and other applications of thermal-infrared data for the study of snow will be explored with additional MAS data, combined with digital elevation maps for this region.

References

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Barnes, J., 1981: The application of Heat Capacity Mapping Mission (HCMM) thermal data to snow hydrology, report for NASA, ERT Doc. P-2061-F, Environ. Res. and Technol. Inc., Concord, Mass.

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D. Anticipated Future Actions

Snow reflectance work. Plans are being formulated for the ASAS to overfly the Petawawa National Forest in Canada during the 1992-93 winter, simultaneous with a field measurement program conducted by the Hydrological and Biospheric Sciences Branches. Dorothy Hall, Jim Foster, Jim Irons and Don Deering (Biospheric Sciences Branch) are involved in the project. In addition to the SE-590 spectrometer which will be operated to obtain field measurements by D. Hall and J. Foster, D. Deering will obtain data from a boom-mounted PARABOLA instrument for comparison with the SE-590 and ASAS data. One specific objective of this field program is to undertake a comparison of nadir and hemispheric reflectance data to measure the difference in reflectance expected over different snow-covered types of vegetation and other (ie. lake ice) terrain, using nadir and bidirectional or hemispheric measurements.

Snow mapping work. The algorithm that has been developed using the Landsat TM data (similar to the NOHRSC algorithm) will be tested using AVHRR data and Landsat data, together over specific regions in order to analyze the accuracy of the algorithm.

Future analysis and algorithm development will focus on improving snow identification techniques, testing under diverse situations, and paramaterizing the algorithm to be capable of producing a global snow cover product. We will also be comparing our techniques and results to existing snow data sets.

Validation of results with other current snow cover products will be required. Study of existing snow data sets and their generation methods are used both for validation and development of the snow cover algorithm. Snow data sets from National Operational Hydrologic Remote Sensing Center have been ordered for this purpose. NOAA snow cover data sets may also be ordered. In about 1993 the NOAA snow mapping capabilities will become more relevant to our efforts because the new series of AVHRR instruments with a 1.6 mm band for snow/cloud discrimination should become operational.

MODIS Airborne Simulator (MAS) Study. When the digital elevation data are received from the U.S.G.S., they will be registered to the 31 October 1991 MAS data. The relationship of the snow temperatures as determined from the thermal-infrared bands, to the elevation, slope and aspect will be explored. Snow in the scene will be mapped using both thermal infrared and other available MAS bands. The objective will be to assess the improvement in accuracy of snow mapping with the addition of the digital elevation data. It is expected that additional digital elevation data of other areas will be studied in the future for algorithm development, in conjunction with AVHRR and Landsat data of snow covered areas.

E. Problems/Corrective Actions. No major problems are foreseen at this time. It is worth noting that the costs of the planned field work in the Petawawa National Forest in Canada are high and a reduction in our FY93 budget will preclude our ability to conduct the field work in the 1992-93 winter.

F. Publications (in chronological order)

Ormsby, J.P. and D.K. Hall, 1991: Spectral properties of fog over the Malaspina Glacier, Alaska, in comparison to snow, ice and clouds. Photogrammetric Engineering and Remote Sensing, V. 57, pp. 179-185.

Hall, D.K., J.L. Foster and A.T.C. Chang, 1992: Reflectance of snow as measured in situ and from space in sub-arctic areas in Canada and Alaska, IEEE Transactions on Geoscience and Remote Sensing, V.30, pp.634-637. (reprint attached)

Riggs, G.A., D.K. Hall, J.L. Barker and V.V. Salomonson, in press: Evolution of a snow cover algorithm for the Moderate Resolution Imaging Spectroradiometer (MODIS), Proceedings of the ASPRS/ACSM/RT92 Annual Convention, 3-8 August 1992, Washington, D.C.

Hall, D.K., J.L. Foster, J.R. Irons and P. Dabney, in press: Airborne bidirectional radiances of snow covered surfaces in northern Montana, U.S.A., Annals of Glaciology (accepted for publication).

Hall, D.K., J.P. Ormsby and J.Y.L. Chien, in press: Preliminary Evaluation of thermal infrared aircraft data for mapping snow cover in the Sierra Nevada Mountains, Proceedings of the 49th Annual Eastern Snow Conference, held 3-4 June 1992 in Oswego, NY.