MODIS/Snow Project
Semi-Annual Report (July - December 1994)

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Summary

Progress was made in several areas during the last 6 months. 4 presentations were made at scientific meetings, and one paper was accepted for journal publication, one is nearing completion for submittal to a journal, and 2 proceedings papers were published. Additionally, one abstract was submitted and accepted for presentation at an upcoming meeting. Plans for a snow/sea ice mission in Alaska have been formulated, and flight hours were approved. The ATBD Version 2.0 peer-review panel results were received and responses were prepared and submitted to the EOS Project in November along with the ATBD Version 2.0. The SDST Flathead Lake meeting on MODIS data simulation was attended as was the MODIS Team Meeting and the BOREAS workshop.

A comparison of Landsat TM data, mapped by conventional supervised-classification techniques, and by SNOMAP has been completed. MAS data acquired in February at the BOREAS test site have been analyzed in a preliminary manner. The SNOMAP algorithm was applied to the MAS data.

TM scenes of sea ice in Hudson Bay and near Antarctica have been acquired and classified. Results show that SNOMAP is a useful algorithm for mapping sea ice. SNOMAP is currently being modified to work for sea ice and the sea ice mapping algorithm will be called ICEMAP. No validation studies have been performed as yet.

Jim Foster/974 is completing work on his Ph.D. dissertation from the University of Reading, England. Some of the work relates directly to the MODIS project and results are reported herein.

Code for the snow mapping algorithm, SNOMAP, has been turned in to the SDST in accordance with requirements for the Beta Software Delivery.

Future plans include conducting the field and aircraft program in Alaska in April 1995, and holding a snow workshop to be held at Goddard in September 1995.

A. Task Objectives

The primary objective of the MODIS snow work is to develop, test and validate algorithms that will be used to map snow and sea ice cover globally, using MODIS calibrated radiances. Additionally, other snowpack properties will be studied in order to improve our understanding of snowpack energy balance. Concurrent with the development of an algorithm to map snow using MODIS data, algorithms to map snow globally using passive-microwave data are being validated and plans are being formulated to combine visible, near-infrared and passive-microwave data to optimize snow mapping and mapping of snow reflectance and water equivalent. A product combining visible, near-infrared and passive-microwave data is anticipated to be a post-launch product.

B. and C. Work Accomplished and Data Analysis

Supervised classification of Landsat TM data

Snow cover on TM scenes of the following areas has been mapped: Glacier Bay, Alaska, Vatnajokull ice cap area, Iceland, northern Minnesota, northern Montana including Glacier National Park and the Chugach Mountains. Results of the supervised classifications were compared with the results of the SNOMAP classification. Results of each were also compared interactively with a TM band 5, 4, 2 color composite, digital reflectance image of each scene.

Detailed analysis of each scene indicated that, overall, a better classification was achieved using SNOMAP than when superrvised classifications were performed. Additionally, SNOMAP did a more consistent job in the snow classifications than was done when supervised-classification techniques were used. In the 4 nearly-cloud-free images, supervised versus SNOMAP results compared to within about 6 percent (Table 1). Results of the 2 classification techniques compared less well in the 2 scenes where cloudcover was a significant factor.

In the case of the 14 March 1991 Glacier National Park scene comparison, because of extensive cloud cover, the supervised classification was poor. That is the reason for the large (12.4 percent) difference between the results of the SNOMAP- and supervised-classification approaches to mapping (Table 1). Using supervised classification, it was difficult to define pixels in cloud shadows that were snow-covered without inadvertently mapping non-snow pixels as well. In the case of the 29 September 1992 Chugach Mts. scene, a thick cirrus cloud in the northeastern part of the image was erroneously mapped as snow by SNOMAP, but not by the supervised-classification technique. The presence of this cloud caused the relatively large (9.5 percent) difference in results in the two classification techniques (Table 1).

The SNOMAP classification mapped areas of shadowed snow much better than did the supervised classification, while in some cases (e.g. the Glacier National Park scene acquired on 09 May 1994), the supervised classification mapped more snow at the edges of snow-covered areas. Both classification techniques generally did a good job of mapping snow under very thin cirrus clouds. Both techniques mapped a few, stray, non-snow pixels outside of the snow-covered areas. SNOMAP mapped more snow in dense forests (e.g. around Lake MacDonald on the 14 March 1991 Glacier National Park scene) than did the supervised classification. Interestingly, SNOMAP did not map very dark glacier ice as snow on the Iceland scene covering Vatnajokull ice cap, while the supervised-classification technique did. Using both techniques, it is concluded that, for pixels that are completely shadowed, or completely covered by tree canopy, there is insufficient signal from the snow, thus there is no means of determining ground cover using optical sensors.

Table 1. Snow-covered area (SCA) in km2 and percent of full TM scene determined using supervised versus SNOMAP classification techniques. GNP refers to Glacier National Park, Montana, Ch refers to the Chugach Mts., Alaska, Vat refers to Vatnajokull, Iceland and MN refers to northern Minnesota. Percent change refers to the difference in the amount of SCA mapped using the two different approaches for mapping snow cover.

	Supervised	SNOMAP	
	km2 (percent)	km2 (percent)	% change
GNP 14Mar91	6,450 (19.1%)	10,631 (31.5%)	12.4
GNP 06Mar94	10,253 (30.3%)	10,953 (32.4%)	2.1
GNP 09May94	4,126 (12.2%)	4,006 (11.9%)	0.3
Ch 29Sep92	12,841 (38.0%)	16,021 (47.5%)	9.5
Vat 19Oct92	12,020 (35.6%)	13,033 (38.6%)	3.0
MN 09Mar85	19,443 (57.6%)	21,534 (63.8%)	6.2

BOREAS/MODIS snow work

In connection with the MODLAND BOREAS project, some progress has been made. We found a problem in the original MAS data of the BOREAS site that was given to us. The reflectances were calculated improperly. RDC (Paul Hubanks and Liam Gumley) corrected the problem and issued us revised data. We ran SNOMAP on the MAS data of 2 flight lines. SNOMAP mapped a cirrus cloud in the scene as snow. We could easily correct this problem by changing the threshold level of the band ratio, but this is undesirable because, in the future, the algorithm has to be run automatically. With the 8 TM scenes mentioned above, we will further assess the seriousness of the cirrus cloud problem.

Another problem area in the mapping of snow using SNOMAP on the BOREAS MAS data is dense forest cover. Dense forests characterize the area and there was snow underneath the trees according to ground measurements. However, only about 60 percent of the scene was mapped by SNOMAP though we know that the entire area was snow covered.

Other BOREAS work includes the analysis of the passive-microwave data that were acquired. We have averaged the brightness temperatures in the flight lines and are beginning to compare results with ground measurements acquired by the Canadians. Preliminary results were reported by D. Hall at the AGU Fall meeting in San Francisco, and by A. Chang/974 at the recent BOREAS workshop in Williamsburg, VA.

Sea Ice

TM scenes of sea ice have been acquired and analysis has begun. Some TM quarter scenes were acquired from Ron Welch (ASTER team) of the South Dakota School of Mines and Technology. Another scene was purchased from the EROS Data Center of Hudson Bay. Preliminary analysis indicates that SNOMAP is useful for mapping sea ice. As analysis continues, it will be modified and called ICEMAP. Validation activities will be done in collaboration with Dr. Welch.

Code for the Beta Software Delivery for ICEMAP is nearly completed and should be submitted to SDST by the end of January 1995.

SNOW COVER AND SNOW MASS INTERCOMPARISONS IN THE BOREAL FORESTS FROM GENERAL CIRCULATION MODELS AND REMOTELY-SENSED DATA SETS

(From Chapter 4 of J. Foster's Ph.D. dissertation)

Introduction

Forests present the biggest challenge to microwave snow-retrieval algorithms. Algorithms need to be refined in order to reveal better what the forests conceal. Because much of the lands in Eurasia and North America are covered by forests, it is important that the passive microwave data and the models are evaluated for forested regions, as well as continentally. The boreal forest region is sufficiently large so that an adequate number of model grid cells are available for a quantitative comparison.

The boreal forests which stretch across the northern tier of North America and Eurasia are a mixture of evergreen needleleaf, deciduous needleleaf and deciduous broadleaf tree species which cover an area approximately 12 x 106 km2. This is the physiographic region where most of the difference seems to occur between the snow depth measurements based on climatological data and those based on microwave observations.

Snow is probably the most ephemeral resource in subarctic regions.

In the boreal forests snow covers the ground for at least half of the year, accumulates to deeper depths and melts later in the spring than in adjacent tundra or prairie areas. Since the boreal forests of the Northern Hemisphere constitutes approximately 15% of the lands normally covered by snow during the winter and upwards of 40% of the land surface normally snow covered during the autumn and spring, more reliable measures of the snow depth and snow-cover extent in boreal areas are needed for improved energy balance and water balance estimates.

Boreal Forest Physiography

The northern limits of the boreal forests or the treeline often serve as the boundary between the Arctic and subarctic. This treeline is generally rather gradual with the proportion of forest to tundra varying, but it closely corresponds to the 10oC monthly mean temperature for July. Factors such as the depth of the permafrost, drainage, exposure and aspect results in patches of forest on either side of this isotherm. In North America the tree line trends in a northwest to southeast direction largely due to the cooling effects of Hudson Bay during the summer months.

There are four subzones within the boreal forests. These are the wooded tundra, lichen woodland, closed boreal forest and forest parkland. The wooded tundra forms the northern border of the boreal forests.
Here spruce and larch are stunted and found in patches. The savannah-like lichen woodland consists of ground coverings of lichens and stands of spruce and pine growing together. The closed boreal forest is particularly dense with stands of pine, spruce and fir interspersed. Within this zone and also the lichen woodland zone in North America, the Canadian Shield rock is sometimes expressed at the surface which results in a rock-strewn landscape with scrawny conifers.

Muskeg and peat bogs are also part of the closed forest, and in this wet environment black spruce and larch are commonly found. Deciduous trees, especially aspen, poplar and birch are found towards the southern part of this zone. The most southerly-zone is the forest parkland which is the transition between the boreal forests and the prairies or steppes. Jack pine, aspen and grasslands coexist here.

The boreal forests in Eurasia and North America share many characteristics but there are some notable differences. Because of the greater continentality of Eurasia, the boreal forest there are more frequently underlain by permafrost than in North America. While coniferous trees dominate the northern latitudes of both North America and Eurasia, larches are especially abundant in Eurasia and are the most numerous conifer in Russia covering about 2.6 x 106 km2. Larches belong to a class of deciduous evergreens. They shed their needles in winter helping to resist the extremely dry as well as cold conditions which prevail across Siberia.

Larches are particularly dominant in central Siberia, where the continentality is greatest, and where the tundra meets the boreal forest. Most larches grow above permafrost areas. Due to a root system that spreads-out horizontally in search of the limited moisture available at the surface, the trees are prevented from growing too close together.

Some tree species in the boreal forest of both Eurasia and North America are shrub-like hugging the ground only a meter or so above the surface. For example, the Dwarf Japanese Stone Pine is common in the forests of far eastern Russia and China. These trees are covered by the insulating snow early in the winter protecting them from the freezing conditions.

In general, the tall stature, high leaf area index and high fractional cover of the boreal forest results leads to a considerable reduction of the snow covered surface albedo due to protruding vegetation. Tederer reported in 1968 that for a 50 cm snowpack at solar zenith angles between 62o and 74o, the albedo of a hardwood and pine forest was in the range from 0.14 - 0.25. For a nearby snow-covered field the albedo was 0.72. Robinson and Kukla (1984) obtained similar results.

Although the conical shape and short springy branches tends to help shed snow and thus prevent accumulation, coniferous forests may retain some snow in their canopy for extended periods during the winter.
This tends, at least locally, to increase the forest albedo slightly. The effects of the reduced albedo of the boreal forests increases hemispherically averaged surface air temperature by almost 2oC and the land surface temperature at 65o N latitude by more than 5oC, compared to treeless areas.

Results and Analysis

The GCMs used in this intercomparison are the same ones used in the continental study with the exception of the CCC model; namely the United Kingdom Meteorological Office GCM (HC), the University of Hamburg/Max Planck Institute GCM (ECHAM), the Goddard Laboratory for Atmospheres GCM (GLA) and the Goddard (ARIES) GCM. Each of these are run for the period from 1979-1988. In addition two models are included in this intercomparison and are run for a non-specified 5 year period. They are the Goddard Institute for Space Studies GCM (GISS), the National Center for Atmospheric Research GCM (GENESIS).

In this part of the intercomparison results are presented and analyzed for snow cover and snow mass in the boreal forest zones of North America and Eurasia. Forests in northeastern United States and in northeastern China, and also in northern Europe are included in these results, though they are not within the boreal forest province, since they are typically underlain by snow during at least a portion of the winter and are sufficiently dense to effect the microwave response. Whereas the area of the boreal forest is approximately 12 x 106 km2 for North America and Eurasia combined, the forested area here is given as approximately 17 x 106 km2. It should be noted that because of differences in the cell sizes used in the various data sets the areas, and therefore the mass, do not correspond that closely. For example, the forested area for Eurasia from the Canadian Climate Centre GCM is 12.86 x 106 km2 and from the MPI model is 10.35 x 106 km2, a difference of almost 20%. Using a grid size of 40 km2 (SDC data) the forested area for North America and Eurasia is given to be 6.47 x 106 km2 and 10.78 x 106 km2, respectively. Because the snowline is sometimes difficult to observe from NOAA satellites when within forested realms, it was decided that the surface-based SDC snow cover data would provide a better baseline against which to compare the passive microwave estimates and the model output. Unfortunately, using this static data set as the standard of reference precludes the use of significance tests since standard deviations cannot be computed. Tables 1 - 4 show average monthly snow cover extent for each of the models and the SDC and the SMMR data. These tables also show absolute and percentage differences for SMMR and the models when compared to the SDC.

From Table 1 it can be seen that snow covers the North American forested area about 50% of the time according to the SDC data, the SMMR data, the UKMO, ARIES, GEN and GISS models. For the GLA, MPI and CAN models snow covers the ground greater than 60% of the time.

The SMMR values show too little snow extent in November and December when compared to the SDC data. This is also the case for the UKMO model results, especially for November. The GEN model underestimates snow extent in November and May, and the ARIES model produces too little snow in November and April. With the GISS model the snow extent is too small in April and May, and probably too large in October. The MPI and CAN models both produce too much snow in September and October, and the CAN model also produces too great a snow cover in May and June.

For Eurasia, as can be seen in Table 3, SDC, SMMR and the UKMO ARIES, and GISS models covers the ground with snow between 56.0% and about 61.0% of the year. The GEN model keeps snow on the ground slightly less than 50% of the time. As was true in North America, the GLA, MPI and CAN models keep snow on the ground for a higher percentage of the time (about 68%). In comparison to the SDC data SMMR and all of the models show too great a snow cover in April and May. In June there is also too much snow for SMMR and each of the models except for the UKMO, GLA, ARIES and GEN models. The MPI and CAN models overestimate the snow cover in June as well. In October, SMMR and the UKMO, GLA, ARIES and GEN models underestimate snow extent.

When compared to the SDC data for North America SMMR underestimates snow mass by a considerable amount from November through March (Table 3). This was also the case when looking at results for the entire continent. As for the models the GLA, ARIES, GISS, CAN and GEN models also underestimate the snow mass during the coldest months. Most of the models overestimate snow mass from April through June. In addition, the UKMO model produces too much snow during the summer and fall. The average annual snow mass for the UKMO model is 47% greater than that from the SDC. In contrast snow mass from the ARIES model and SMMR data are less than that from the SDC by 46% and 49% respectively.

Boreal forest results from SMMR and the GCMs for Eurasia compare more favorably with the SDC than was observed for North America (Table 4). SMMR underestimates snow mass in the autumn months and overestimates snow mass during spring. The model results are similar to those from SMMR. Each of the models also produce too much snow in April and May and too little snow during the autumn. The average annual snow mass from SMMR is 13% less than measured with the SDC, and for the GCMs there is a 55% difference between the ARIES model and the SDC but only a 5% difference between the GISS model and the SDC. It should be noted though that the average annual snow mass values correspond rather closely with the SDC values only because excesses in some months tend to be counterbalanced by deficiencies in other months. For instance, even though there is only a 5% average annual difference between the SDC and the GISS snow mass, six of the twelve months have values that are considerably different. Nevertheless, in March when the maximum mass is typically observed, the SMMR and most of the model results agree with the SDC.

Discussion

In Eurasia at the time of maximum snow extent, the forested areas (boreal and northern transition) comprise about 37% of the total snow cover area. About 46% of the continental snow mass is stored in these forested areas. The average snow covered area in Eurasia during February from both SDC and SMMR data is approximately 29 x 106 km2. The forested area from SMMR is also nearly the same as the SDC (10.8 x 106 km2). In March the average continental snow mass from the SDC data is about 286 x 1013 kg and from SMMR the mass is about 242 x 1013 kg; a difference of 15.4%. The average snow mass in the forested areas of Eurasia at this time is approximately 139 x 1013 kg and 124 x 1013 kg from the SDC data and the SMMR data, respectively. So about 34% of the underestimation of the continental snow mass from the SMMR data can be attributed to underestimation of snow mass in the forested areas of Eurasia.

In North America the boreal forested area covers a larger percentage of the maximum continental snow extent than it does for Eurasia. The boreal forest comprises about 43% of the continental snow area, and nearly 54% of the snow mass in North America is stored in the boreal forest in late winter. The SMMR derived maximum snow cover for North America is about 9% less than that measured from the SDC data. Also, the SMMR derived boreal forest area is about 13% less than that measured from the SDC data. The continental snow mass in March is approximately 210 x 1013 kg from the SDC data and approximately 88 x 1013 kg from SMMR, and the boreal forest snow mass is about 113 x 1013 kg and 49 x 1013 kg from the SDC data and SMMR, respectively. Taking the above area differences into account, then as much as 56% of the underestimation of the continental snow mass in the winter can be attributed to the underestimation of snow mass in the boreal forest.

For each of the snow mass data sets in North America, the SDC data, SMMR and the GCMs, during the winter about 50% of the continental snow mass is stored in the boreal forest. Somewhat less is stored in the forests of Eurasia.

Both the model and SMMR results compare favorably to the winter SDC snow mass measurements in Eurasia for the continent as a whole and for the boreal forest. However, in North America the models compare reasonably to the SDC data, but SMMR estimates do not.

One reason for this, as alluded to earlier, is the higher continentality of Eurasia, the degree of influence land has on climate, which results in larger areas of permanently frozen soils. This permafrost favours the growth of species such as larch which generally grow in open stands and drop their needles during the winter. Both of these characteristics facilitate better remote sensing estimates of snow cover and volume.

In Eurasia SMMR estimates for about 80% of the snow mass as measured by the SDC data, during the winter and more than a third of the underestimation (about 7%) is due to the masking effect of the boreal vegetation. However, in North America, SMMR only accounts for about 42% of the SDC measured snow mass during the month of March; as previously mentioned, approximately 56% of the underestimation results from vegetation interfering with the scattering signal emanating from the underlying snow surface.

SMMR also underestimates the snow extent in North America by about 9% as compared to the SDC data during the winter. In the vicinity of the snowline the snow depth is usually shallow (< 5 cm), and the underestimation of this snow extent probably only results in an underestimation of a few percent of the continental snow mass. This means that, for the remaining non boreal portion of snow-covered North America (about 57%), nearly 40% of the underestimation is still unexplained.

As was observed on a continental basis, the models perform better in the boreal forests during the winter and summer months than during the transition months when compared to the SDC data. In the autumn (Oct.-Dec.) the snow mass from SMMR and from the models lags behind the snow mass values from the SDC by about one month . In some cases the smaller snow mass values may be partially explained by the smaller snow extent estimated by most of the models and derived from SMMR. However, even when the snow cover is the same or larger than the SDC snow cover, the models still underestimate snow mass at this time of year. For most of the models in both Eurasia and North America the temperatures are probably somewhat too high for these latitudes. Cyclonic systems following the storm track, which is normally positioned near or within the boreal forest during the autumn, are thus precipitating rain and not snow. The converse of this occurs in the spring; temperatures are too low and precipitation is all snow.

With SMMR the underestimation seems to result from the obscuration of the shallow but building snowpack by the dense vegetation, particularly by the under-store or sub-canopy. When smaller shrubs become cloaked in snow and the pack builds beneath the canopy and the canopy itself is retaining some snow, microwave sensors then receive a stronger scattering signal.

The Snow Depth Climatology data need to be discussed as well, for there are peculiarities in the monthly snow mass values which seem counterintuitive.

When looking at the SDC snow mass data it can be questioned whether the relatively few data points (meteorological stations) used to construct the isonivals are sufficient to represent snow depths realistically in the boreal forests. For instance, from March to April in Eurasia half of the snow mass is lost, but only about one quarter of the snow cover has melted.

This also happens in North America. Again the mass is decreased by half from March to April, but the snow extent decreases by only about 18%. In the northern reaches of the boreal forest the snowpack is still well established at this time and may even gain mass in some locations. Also, the density of the snowpack in northern latitudes is likely to increase in April even without additional accumulations. The Eurasian SDC data indicates that the snow mass is greater in the boreal forest in October than May (31.4 x 1013kg to 15.4 x 1013kg) and in November than April (68.7 x 1013kg to 64.6 x 1013kg). The opposite is true in the North American boreal forest and also for the Eurasian continent as a whole. The SMMR data and each of the models are all in agreement that for the boreal forest regions of Eurasia and North America snow mass in greater in May than October and greater in April than November.

Several questions are still left unresolved. With SMMR, even when the boreal forest masking effect is considered, why is there so much more unexplained, underestimated snow mass in North America than Eurasia? How can the microwave algorithms be refined to mitigate the influence of vegetation? Why do some of the models perform better in North America than Eurasia and vice versa? These questions will be looked at in the succeeding chapters.

<u>Aircraft and Field Campaign in Alaska</u> (D. Hall, J. Foster, A. Chang, D. Cavalieri/971 and J. Wang/975)

52 ER-2 flight hours have been approved for the MODIS/snow and sea ice project for a mission beginning April 3, 1995 in Alaska and in the Bering Sea. This mission is being planned jointly by D. Hall and Don Cavalieri. The objective of the mission is to acquire passive-microwave and MAS data, simultaneously when possible, of snow and sea ice to verify our SNOMAP and ICEMAP algorithms, and to determine the extent of the synergy expected by using both passive-microwave and MODIS sensors together in the future. Field measurements will be acquired in central and northern Alaska in collaboration with the University of Alaska (Dr. Carl Benson) and the U.S. Army Cold Regions Research and Engineering Laboratory (Dr. Matthew Sturm).

<u>Objectives for the Snow Part of the Field Mission</u> (D. Hall). The primary objective for the snow part of this study is to acquire data to permit improvement in the current algorithm that we are using to map snow cover. The current algorithm was developed using Landsat TM data. With the additional spectral bands available on the MAS, and MODIS in the future, we anticipate that improvements can be made to the current algorithm. The primary shortcoming of the current algorithm is that snow cover in dense forests is often not mapped. The utilization of additional bands in the visible, near-infrared and short-wave infrared parts of the spectrum may permit more accurate snow-cover mapping in forested areas. Because of the narrow spectral bands of the MAS and MODIS sensors, bands in the optical parts of the spectrum can be combined to map snow without mapping non-snow features.

While it is not expected that the use of the thermal-infrared bands will improve the mapping of snow, the thermal-infrared bands on the MAS will also be studied in the context of snow mapping and snow/cloud discrimination.

Additionally, the use of passive microwave data will allow us to test other algorithms that have been developed using satellite microwave data. These algorithms map snow extent and depth albeit at a coarser resolution than is available from the optical sensors. Even with the microwave data, the snow cover that is under trees in dense forests is often not mapped. Data from both the optical and microwave sensors from this mission will be used to determine if the synergistic use of these sensors provides improved mapping of snow cover under dense forests.

Analysis of Scanning Multichannel Microwave Radiometer (SMMR) and SSMI data has shown that there are areas just north of the Brooks Range in Alaska, that give anomalous passive microwave signatures. These signatures cannot be explained by snow conditions and may be related to atmospheric conditions. At any rate, these areas will be studied in more detail both in the field and with the resulting remotely-sensed data. It is important to develop an understanding of these anomalies, because until we do, our ability to derive reliable algorithms is compromised.

ERS-1 data will also be acquired of the study areas. While these data are not expected to relate to the primary objective of the mission, to improve the snow cover mapping algorithm, it will be interesting to study the radar signatures of snow (especially if there is wet snow). Very little work has been done to determine the utility of the SAR data for the snow mapping and water equivalent. Because the investigators (D. Hall and D. Cavalieri) are ERS-1 and ERS-2 investigators and can receive ERS-1/2 data at no cost, this data acquisition will enhance the mission without adding to the cost.

<u>Objectives for the Sea Ice Part of the Field Mission</u> (D. Cavalieri/971 and D. Hall). For the MODIS project, the primary objective for the data acquired of sea ice is to map the sea ice cover. The MAS data over the sea ice will be utilized to test the current algorithm that we have developed to map sea ice cover. The MAS data will also be used to test an algorithm to map sea ice based on spectral mixture modeling techniques. This technique is being developed for the MODIS project by Dr. Anne Nolin of the University of Colorado.

For the MIMR project, there are three objectives. The first objective is to test current sea ice algorithms that map sea ice concentration, ice type and ice temperature. The second objective is to explore the potential of using high-frequency (90 GHz) channels for improving these algorithms. Third, the aircraft data will be used to explore the feasibility of using the high-frequency channels to help with the problem of ice-weather discrimination.

Recently, a passive microwave algorithm, based on the 19 and 37 GHz dual-polarization channels of the DMSP SSM/I, has been developed for correcting low ice concentration biases in areas of new and young sea ice and for mapping these ice types in seasonal sea ice zones. While, preliminary comparisons with a few AVHRR images show that this algorithm provides a qualitatively correct distribution of thin ice types, the comparisons also show that the algorithm may still yield open water amounts that are too high. The MAS and passive microwave sensors on the ER2 aircraft will provide the requisite data needed for validating both the sea ice type distribution and the open water amount. In addition, the MAS will provide information on surface temperature which will be helpful in testing a new SSM/I sea ice temperature algorithm that utilizes output from the thin ice algorithm.

Little use has been made of the SSM/I 85.5 GHz channels for sea ice mapping. The reason for this is their greater sensitivity to atmospheric absorption and to their reduced dynamic range between open water and consolidated sea ice. Nevertheless, these channels may provide information with which to enhance algorithms based on lower-frequency channels. For example, at high frequencies (short-wavelengths) there is more volume scattering by snow on sea ice; thus, these data may provide the additional information needed to develop a snow cover algorithm. Analysis of the combined MAS and passive microwave aircraft data set may provide the insights needed to develop the physical basis of such an algorithm. A snow cover distribution on sea ice is important for estimating ice growth rates and surface heat fluxes.

The high-frequency channels may also provide information needed to help discriminate between atmospheric water vapor absorption and sea ice. Recently, an enhanced weather filter was recently developed for use with the SSM/I sea ice algorithm. This was necessitated by the much higher incidence of weather contamination over ice-free ocean on sea ice concentration maps derived from SSM/I radiances. This higher incidence resulted from the greater sensitivity of the 19.4 GHz channels to atmospheric water vapor than with the 18 GHz channels on the Nimbus 7 SMMR. The weather filter, which is based on the 22 GHz and 19 GHz vertical polarization channels, is generally quite effective, but under some circumstances the enhanced filter appears to remove low sea ice concentration information at the ice edge. The high-frequency data from the ER2 aircraft will be used to explore the potential of using these data for improving the discrimination between atmospheric water vapor absorption and sea ice in these instances.

Future Plans

As mentioned, in the near future (April 1995), the snow and sea ice mission will be undertaken in Alaska. Analysis of the resulting data will take place in conjunction with scientists at the University of Alaska and the U.S. Army Cold Regions Research and Engineering Laboratory in Fairbanks, AK.

The code for the Beta Software Delivery of ICEMAP will be delivered by the end of January 1995.

A snow workshop is being planned. Letters have been sent out to prospective attendees and most people indicated an interest in attending. The workshop will be held during the week of September 11, 1995 at Goddard.

Meetings attended

D. Hall attended the AVHRR Polar Science Workshop in Boulder, CO in July and gave a talk on the MODIS snow algorithm-development efforts.

V. Salomonson attended the IGARSS'94 symposium in Pasadena, CA in August and presented a paper on the MODIS snow-cover algorithm. The paper was published in the proceedings of the symposium.

G. Riggs/RDC attended the Flathead Lake, MT workshop on MODIS data simulation in September.

D. Hall attended the AGU Fall Meeting in San Francisco and gave a poster on preliminary results of the BOREAS MAS work.

Abstracts, papers and reports in preparation

A paper is being prepared for submission to Remote Sensing of Environment. This paper discusses results of the ATBD Version 2.

A paper is being prepared for submission to the Second Topical Symposium on Combined Optical and Microwave Earth and Atmosphere Sensing to be held in April 1995 in Atlanta, Georgia.

Abstracts, papers and reports completed during the last 6 months

Version 2 of the ATBD was revised according to comments by reviewers and comments by the peer-review committee that met last May, and submitted to the EOS Project Office.

A paper was written and a presentation made by J. Foster for the European Symposium on Satellite Remote Sensing, Conference on Microwave Sensing for Forestry and Hydrology, Rome, Italy, September 1994. The paper (Appendix A) is entitled, "Snow mass in boreal forests derived from a modified passive microwave algorithm," by J.L. Foster, A.T.C. Chang and D.K. Hall.

A paper (Appendix B) that was presented by D. Hall at the Third Circumpolar Conference on Remote Sensing of Arctic Environments, held in May, 1994 in Fairbanks, AK, was accepted for publication in a special issue of the Polar Record that will be devoted to results from the conference.

An abstract (Appendix C) was submitted by D. Hall et al. and accepted for presentation at the AGU Fall meeting held in December 1994 in San Francisco, CA. A poster was presented, and the abstract entitled, "Mapping snow cover during the BOREAS winter experiment," was published in EOS, V.75, pp. 283-284.

An abstract was accepted for the Second Topical Symposium on Combined Optical-Microwave Earth and Atmosphere Sensing, to be held on 3-6 April 1995. The title of the abstract is, "Use of passive microwave and optical data for large-scale snow-cover mapping," by V.V. Salomonson, D.K. Hall and J.Y.L. Chien. The presentation will be given by V. Salomonson.

Other internal reports have been written as required by the MODIS Project.

Table 1

Boreal Forest Snow Cover (10^6 km^2)
North America

	SDC	SMMR 1979-87	Abs. Dif.	Per. Dif.	HC 1979-88	Abs. Dif.	Per. Dif.	ECHAM 1979-88	Abs. Dif.	Per. Dif.	GLA 1979-88	Abs. Dif.	Per. Dif.	ARIES 1979-88	Abs. Dif.	Per Dif
Jan	6.26	5.28	-.98	15.7	6.1	-.16	2.6	5.9	-.62	9.9	5.8	-.46	7.3	5.01	-1.25	20.
Feb	6.45	5.58	-.87	13.5	6.1	-.35	5.4	5.9	-.55	8.5	5.8	-.65	10.1	4.90	-1.55	24.
Mar	6.47	5.62	-.85	13.1	5.7	-.77	11.9	5.9	-.57	8.8	5.8	-.67	10.4	4.53	-1.94	30.
Apr	5.32	5.18	-.14	2.6	4.6	-.72	13.5	5.3	-.02	0.4	5.5	.18	3.4	3.64	-1.68	31.
May	2.81	2.89	.22	7.8	2.4	-.41	14.6	3.3	.49	17.4	5.1	2.29	81.5	2.44	-0.37	13.
Jun	0.16	0.55			1.0			0.8			2.1			0.82		
Jul	0.00	0.11			0.4			0.0			0.0			0.10		
Aug	0.00	0.14			0.3			0.2			0.0			0.00		
Sep	0.39	0.36			0.6			1.3			0.0			0.02		
Oct	0.75	1.34	.62	82.1	1.4	.65	86.7	3.6	2.85	308	2.1	1.35	180	1.30	0.55	73.
Nov	5.65	2.49	-3.16	55.9	3.8	-1.85	32.7	5.7	.05	0.9	5.5	-.15	2.7	3.30	-2.35	41.
Dec	6.08	4.4	-1.68	27.6	5.1	-.98	16.1	5.9	-.18	3.0	5.8	-.28	4.6	4.82	-1.26	20.

Table 1 continued

Boreal Forest Snow Cover (10^6 km^2)
North America

	SDC	GISS yr. 1-5	Abs. Dif.	Per. Dif.	GEN yr. 1-5	Abs. Dif.	Per. Dif.
Jan	6.26	6.12	-.14	2.2	6.71	0.45	7.2
Feb	6.45	6.11	-.34	5.3	6.76	0.31	4.8
Mar	6.47	5.57	-.90	13.9	6.76	0.29	4.4
Apr	5.32	3.85	-1.47	27.6	5.80	0.48	9.0
May	2.81	1.58	-1.23	43.8	1.19	-1.62	5.8
Jun	0.16	0.23			0.00		
Jul	0.00	0.04			0.00		
Aug	0.00	0.10			0.00		
Sep	0.39	0.62			0.02		
Oct	0.75	2.71	1.96	261	0.93	0.18	24.0
Nov	5.65	5.20	-.45	8.7	4.16	-1.49	26.4
Dec	6.08	5.89	-.19	3.1	6.21	0.13	2.1

Table 2

Boreal Forest Snow Cover (10^6 km^2)
Eurasia (1979-88, AMIP period)

	SDC	SMMR 1979-87	Abs. Dif.	Per. Dif.	HC 1979-88	Abs. Dif.	Per. Dif.	ECHAM 1979-88	Abs. Dif.	Per. Dif.	GLA 1979-88	Abs. Dif.	Per. Dif.	ARIES 1979-88	Abs. Dif.	P D
Jan	10.69	10.64	-.05	0.5	11.05	.36	3.4	10.35	-.34	3.2	10.94	.25	2.3	10.95	0.26	2.
Feb	10.78	10.76	-.02	0.2	11.06	.28	2.6	10.35	-.43	4.0	10.94	.16	1.4	10.95	0.17	1.
Mar	10.79	10.84	.05	0.5	11.05	.26	2.4	10.36	-.43	4.0	10.94	.15	1.4	10.93	0.14	1.
Apr	7.98	10.18	2.8	35.1	10.43	2.5	30.7	10.27	2.29	28.7	10.88	2.9	36.3	10.74	2.76	34.
May	2.34	5.79	3.45	147	8.66	6.32	270	8.17	5.83	249	9.61	7.27	3.1	8.36	6.02	25
Jun	0.23	1.21			1.45			3.0			0.0			0.29		
Jul	0.00	0.09			0.0			0.2			0.0			0.00		
Aug	0.00	0.07			0.0			0.4			0.0			0.00		
Sep	0.17	1.22			0.7			3.22			0.0			0.34		
Oct	8.26	5.72	-2.54	30.8	3.8	-4.46	54.0	8.5	.24	2.9	4.35	-3.91	47.3	4.71	-3.55	43.
Nov	10.62	8.94	-1.68	15.8	9.38	-1.24	11.7	10.2	-.42	4.0	10.5	-.12	1.1	10.52	-0.10	0.
Dec	10.63	10.23	-.40	3.8	10.82	.19	1.8	10.34	-.29	2.7	10.94	.31	2.9	10.93	-0.30	2.

Table 2 continued

Boreal Forest Snow Cover (10^6 km^2)
Eurasia

	SDC	GISS yr. 1-5	Abs. Dif.	Per. Dif.	GEN yr. 1-5	Abs. Dif.	Per. Dif.
Jan	10.69	10.99	.30	2.8	6.95	-3.74	35.0
Feb	10.78	10.99	.21	1.9	7.36	-3.42	31.7
Mar	10.79	10.95	.16	1.5	7.39	-3.40	31.5
Apr	7.98	9.07	1.09	13.7	6.89	-1.09	13.7
May	2.34	4.45	2.11	50.2	3.52	0.91	38.9
Jun	0.23	0.77			0.32		
Jul	0.00	0.05			0.09		
Aug	0.00	0.37			0.01		
Sep	0.17	3.04			0.07		
Oct	8.26	7.85	-.41	5.0	0.72	-7.54	91.3
Nov	10.62	10.50	-.12	1.1	3.37	-7.25	68.3
Dec	10.63	10.91	.28	2.6	5.80	-4.83	45.4

Table 3

Boreal Forest Snow Mass (10^{13} kg)
North America (1979-88, AMIP period)

	SDC	SMMR 1979-87	Abs. Dif.	Per. Dif.	HC 1979-88	Abs. Dif.	Per. Dif.	ECHAM 1979-88	Abs. Dif.	Per. Dif.	GLA 1979-88	Abs. Dif.	Per. Dif.	ARIES 1979-88	Abs. Dif.	Pe Di
Jan	83.2	37.65	-45.6	54.7	92.6	9.4	11.3	74.2	-9.0	10.8	57.6	-25.6	30.8	30.4	-52.8	63.
Feb	107.5	47.88	-59.6	55.5	106.3	-1.2	1.1	97.3	-10.2	9.5	80.1	-27.4	25.5	40.8	-66.7	62.
Mar	112.6	48.55	-64.1	56.9	109.4	-3.2	2.8	111	-1.6	1.4	101.5	-11.1	9.9	44.4	-68.2	60.
Apr	57.7	40.17	-17.5	30.4	94.3	36.6	63.4	96.8	39.1	67.8	115.3	57.6	99.8	39.4	-18.3	31.
May	12.2	17.55	5.3	43.4	56.2	44.0	361	45.5	33.3	273	80.4	68.2	559	22.5	10.3	84.
Jun	0.4	1.9			34.5			4.1			11.0			4.2		
Jul	0.0	0.31			24.6			.01			0.0			0.2		
Aug	0.0	0.37			19.6			.05			0.0			0.0		
Sep	0.1	0.83			19.2			1.0			0.0			0.0		
Oct	2.0	3.46	1.5	75.0	22.3	20.3	1015	7.5	5.5	275	1.6	-0.4	20.0	0.9	-1.1	55.
Nov	22.6	9.03	-13.6	60.0	33.7	11.1	49.1	24.1	1.5	6.6	11.5	11.1	49.1	6.8	-15.8	69.
Dec	55.2	22.2	-33.0	59.8	52.4	-2.8	5.1	48.6	-6.6	12.0	34.2	21.0	38.0	17.2	-38.0	68.

Table 3 continued

Boreal Forest Snow Mass (10^{13} kg)
North America

	SDC	GISS yr. 1-5	Abs. Dif.	Per. Dif.	GEN yr. 1-5	Abs. Dif.	Per. Dif.
Jan	83.2	50.4	-32.8	39.4	56.2	-27.0	32.4
Feb	107.5	68.3	-39.2	36.5	71.3	-36.2	33.7
Mar	112.6	71.5	-41.1	36.5	83.6	-29.0	34.7
Apr	57.7	55.5	-2.2	3.8	63.2	-5.5	9.5
May	12.2	20.5	8.3	68.0	5.8	-6.4	52.5
Jun	0.4	0.8			0.0		
Jul	0.0	0.0			0.0		
Aug	0.0	0.0			0.0		
Sep	0.1	0.7			0.0		
Oct	2.0	2.2	0.2	10.0	3.0	1.0	50.0
Nov	22.6	13.3	-9.3	41.2	18.6	-4.0	17.7
Dec	55.2	31.4	-23.8	43.1	38.5	-16.7	30.3

Table 4

Boreal Forest Snow Mass (10^{13} kg)
Eurasia

	SDC	SMMR 1979-87	Abs. Dif.	Per. Dif.	HC 1979-88	Abs. Dif.	Per. Dif.	ECHAM 1979-88	Abs. Dif.	Per. Dif.	GLA 1979-88	Abs. Dif.	Per. Dif.	ARIES 1979-88	Abs. Dif.	Pe Di
Jan	120.0	104.7	-15.3	12.8	94.6	-25.4	21.2	108.2	-11.8	9.8	77.3	-42.7	35.6	57.8	-62.2	51.
Feb	137.5	121.4	-16.1	11.7	114.7	-22.8	16.6	134.2	-3.3	2.4	107.3	-30.2	22.0	75.6	-61.9	45.
Mar	138.8	124.4	-14.4	10.4	128.3	-10.5	7.6	157.3	18.5	13.3	134.5	-4.3	3.1	87.6	-51.2	36.
Apr	64.6	95.6	31.0	48.0	116.7	52.1	80.6	158.6	94.0	146	142.1	77.5	120	74.7	10.1	15.
May	15.1	43.0	27.9	185	72.9	57.8	383	92.7	77.6	514	51.0	35.9	238	22.5	7.4	49.
Jun	2.7	5.79			5.3			17.0			0.0			0.2		
Jul	0.0	0.3			0.0			0.2			0.0			0.0		
Aug	0.0	0.2			0.1			0.2			0.0			0.0		
Sep	0.2	3.0			2.5			2.8			0.0			0.1		
Oct	31.4	15.5	-15.9	50.6	12.3	-19.1	60.8	19.0	-12.4	39.5	1.7	-29.7	946	2.9	-28.5	90.
Nov	68.7	37.7	-31.0	45.1	32.8	-35.9	52.2	48.9	-19.8	28.8	17.6	-51.1	74.4	15.4	-53.3	77.
Dec	99.0	74.9	-24.1	24.3	57.4	-41.6	42.0	80.0	-19.0	19.2	46.8	-52.2	52.7	36.1	-62.9	63.

Table 4 continued

Boreal Forest Snow Mass (10^{13} kg)
Eurasia

	SDC	GISS yr. 1-5	Abs. Dif.	Per. Dif.	GEN yr. 1-5	Abs. Dif.	Per. Dif.
Jan	120.0	109.2	-10.8	9.0	73.4	-46.5	38.8
Feb	137.5	135.1	-2.4	1.7	104.7	-32.8	23.9
Mar	138.8	148.8	10.0	7.0	125.3	-13.5	9.7
Apr	64.6	116.9	52.3	61.0	109.7	45.1	69.8
May	15.1	52.1	37.0	245	38.7	23.8	158
Jun	2.7	3.85			6.1	3.4	126
Jul	0.0	0.0			0.9		
Aug	0.0	0.0			0.1		
Sep	0.2	2.0			0.2		
Oct	31.4	17.2	-14.2	45.2	2.6	-28.8	91.7
Nov	68.7	47.1	-21.6	31.4	16.0	-52.7	76.7
Dec	99.0	79.4	-19.6	19.8	42.7	-56.3	56.9