MODIS/Snow Project
Semi-Annual Report (January – June 1994)
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Summary

During the last 6 months, substantial progress was made on formulating the Algorithm Theoretical Basis Document (ATBD) and plans for the algorithm validation. The first round of the ATBD review process was completed. Six presentations were made dealing with the MODIS snow algorithm at scientific meetings, and 4 papers were either submitted for publication or/and completed.

A meeting was held at NOAA/NESDIS to discuss the current methods being used to map snow using NCAA data for development of the Northern Hemisphere weekly maps. MODIS investigators met with the Interactive Processes Branch at the World Weather 3uilding in Camp Springs, MD.

The prototype SNOMAP, the algorithm developed to map global snow cover using MODIS data, has been applied to scenes in Glacier National Park, Montana, along with digital elevation model (DEM) data. With the addition of DEM data, we found that there was up to 5 times more snow-covered area mapped than when satellite data were used alone. A model was developed to account for snow on the slopes of mountains. Topographic effects of snow-cover mapping on the global scale will be investigated as part of the error analysis of the SNOMAP algorithm. A global DEM has been acquired.

SNOMAP has been refined to map snow more accurately in the Sierra Nevadas (relative to a validated snow map) by using Landsat TM reflectances versus digital numbers.

ICEMAP, the algorithm under development to map sea ice, is mathematically very similar to SNOMAP at this time. ICEMAP has been tested on several Landsat TM scenes. However, validation of the ICEMAP algorithm has not yet been attempted. A search for additional TM scenes that contain sea ice is ongoing. Approximately 10 suitable scenes have been located and some of those will be ordered soon.

Simultaneously-acquired AVHRR and SSMI scenes of snow cover have been located of North America for the period 21-30 January 1988. Comparison allows determination of the snow line which compares well in the two data sets.

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 usinq 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

NOAA/NESDIS Meeting held on 30 June 1994. A meeting was held at the World Weather Building in Camp Springs, Maryland with MODIS investigators (D. Hall, J. Foster and G. Riggs/RDC) and the head of the Interactive Processes Branch (M. Matson) and some Interactive Processes Branch members. Thne purpose of the meeting was to discuss the current status and expected improvements of the Northern Hemisphere weekly snow charts product, and plans for MODIS/snow-cover algorithm development. Areas of collaboration were discussed. It was mentioned that our algorithm development may be useful for improving the NESDIS product when the next AVHRR sensor is launched because it will have a band capable of discriminating snow and clouds.

Error analysis of SNOMAP (D. Hall, G. Riggs/RDC). SNOMAP is the algorithm that is under development to map snow using thematic mapper (TM) and, eventually, MODIS data (Appendix I). Analysis of the results of the SNOMAP algorithm applied to a 14 March 1991 TM scene covering Glacier National Park, Montana reveals that the use of reflectances calculated from the TM digital numbers (DNs) increases the measured snow-covered area by about 10 percent, relative to when digital numbers were used as input to SNOMAP. Field work done at the time of acquisition of the 14 March 1991 TM scene reveals that the amount of snow mapped using the reflectances versus the DNs is more realistic. Accuracy was also found to increase when reflectances (versus digital numbers) were used to map snow on the 10 May 1992 TM scene, covering part of the Sierra Nevada Mountains, that has been validated previously by W. Rosenthal/UCSB. A paper that describes the SNOMAP algorithm and plans for future algorithm development and error analysis of SNOMAP in the pre-launch time frame has been prepared and will be submitted to Remote Sensing of Environment during August of 1994.

Analysis of Errors in Mapping Snow-Covered Area due to topography (D. Hall). Significant errors in mapping snow are inherent in mountainous areas if satellite data are used alone (i.e. without topographic data). This is because a

satellite image depicts any surface as being flat. Without topographic information, the TM data, used alone, are quite good at mapping snow in non-forested areas that are relatively flat. In areas of high relief, however, the actual amount of snow may be 5 times (or more) greater than the amount mapped using TM data alone. This was determined from analysis of TM/DEM registered data in a portion of Glacier National Park. A simple model was developed to describe the relationship between ruggedness of terrain and accuracy of SNOMAP results. A correction factor can be applied to areas of rugged terrain to improve the measurements of snow cover when using TM data alone. The results of this work were presented by D. Hall at the Third Circumpolar Conference on Remote Sensing of Arctic Environments, held in Fairbanks, Alaska, 15-20 May 1994; a paper was also prepared (Appendix II).

MODIS/BOREAS Experiment (A. Chang, D. Hall and J. Foster). During the week of February 6, 1994, the winter part of the BOREAS experiment was held in Saskatchewan. D. Hall, A. Chang, J. Foster of Code 974 and G. Liston/USRA went to the site to do snow measurements in support of the BOREAS/MODIS snow projects. Passive-microwave sensors were flown on a Canadian Twin Otter, and there was an ER-2 overflight with the MODIS Airborne Simulator (MAS). The snow conditions were good and temperatures were very cold (down to -40° C). Passive-microwave data are currently being processed. MAS data have been processed and at least 10 of the 22 flight lines are good. However, only 2 of those 10 flight lines were flown over the BOREAS test sites.

Preliminary results of the analysis of the BOREAS MAS data show that some snow can be mapped underneath thin, cirrus clouds. However, most of the snow, known to be continuous, is not mapped because the forest cover is so dense that the tree canopy obliterates the snow beneath the trees. Another interesting feature of the MAS data is that there are distinctly-different signatures from the snow on top of the frozen lakes. These signatures are only present in the short-wave infrared data. A preliminary explanation for the different signatures on the lakes is that the snow on the lakes in different parts of the lakes had different grain sizes. This is currently under investigation.

NDVI and forest density (J. Foster and D. Hall/974). In July in Eurasia, high NDVI values cover a much larger area than they do for North America. However, much more of the snow mass in the boreal forest of Eurasia is accounted for using microwave radiometry than is the case in the North American boreal forest. This is the converse of what is expected if NDVI were strictly a measure of vegetation density. Because of the above concerns, the NDVI for the month of October was also examined to see if this month's NDVI values were more closely related to forest density.

October is used as a surrogate for winter NDVI since at this time of year, and for boreal forest latitudes, deciduous plants have shed their leaves and chlorophyll production has virtually stopped.

In October as in July, the overall NDVI values are higher in the boreal forest of Eurasia than they are in the boreal forest of North America. While it is not yet clear if the higher NDVI values result from greater biomass, greater crown closure or more rigorous growth of the understory, it is evident that this index is not a useful indicator of fractional forest cover. Thus the NDVI, by itself, should not be used as an additional input to the Chang et al. snow/microwave algorithm (Appendix III).

The normalized difference vegetation index (NDVI) was calculated for the 14 March 1991 TM scene covering Glacier National Park. The results show that the areas having the highest NDVIs are areas where less snow is mapped by SNOMAP. These are areas known to be snow covered as determined from field work. The high tree canopy density obliterates the snow below. There is potentially >10 percent more snow cover (under the trees) in this scene than is mapped using SNOMAP. Invesyigation of various techniques to attempt to map more of the snow underneath the trees is being undertaken.

Global Snow Classification (G. Listen/US~). A global implementation of Matthew Sturm's (Cold Regions Research and Engineering Laboratory, Fairbanks, Alaska) snow-classification scheme is under development. The objective is to identify, based on common climatological variables and vegetation type, where the different snow types will be found around the world. To do this we are using the highest resolution global data sets available. This includes a $0.5^{\circ} \times 0.5^{\circ}$ gridded data set of observed precipitation and surface air temperature monthly mean climatologies (up to 60 years), and a $1^{\circ} \times 1^{\circ}$ gridded vegetation type data set. Of the 33 vegetation categories, the data were restructured into 4 general surface classes: (1) water; (2) forest and woodland (i.e., tall); (3) shrubland, grassland, and tundra (i.e., short); and (4) ice. These precipitation, air temperature, and vegetation data sets were cast on common grids. The concept of a cooling degree month was introduced and used to generate a general index of integrated winter temperatures and precipitation. The resulting temperature, precipitation, and vegetation data have been used in conjunction with Sturm's snow classification scheme to generate global distributions of various snow types, including tundra, alpine, taiga, prairie, maritime, and ephemeral.

Modeling Local Advection of Momentum, Heat, and moisture during the melt of Patchy Snow Covers (Glen Liston) . A numerical atmospheric boundary layer model, based on higher-order turbulence closure assumptions has been developed and used to simulate the local advection of momentum, heat, and moisture during the melt of patchy snow covers. The coupled model includes solution of the mass continuity equation, the horizontal and vertical momentum. equations, an E-epsilon turbulence model, an energy equation, and a water vapor conservation equation. Atmospheric buoyancy is accounted for, and a land-surface energy balance model is implemented at the lower boundary.

Model integrations indicate that snow-melt processes occurring at micro and local scales produce significant variations in local surface fluxes. The melt energy is found to increase in a largely-linear fashion as the fractional snow-covered area increases. The relationship between available melt energy and total snow-covered area is nearly invariant with the size of snow patches comprising the snow cover. The simulations suggest that, for the purposes of computing areally-averaged surface fluxes from grid-averaged atmospheric forcing, the subgrid-scale spatial variability of snow cover in regional and global land-atmosphere interaction models can be included with knowledge of the grid fraction covered by snow (Appendix IV) .

AVHRR and SSMI Comparison for Assessment of Snow-Covered area. Both AVHRR 4-km GAC and SSMI 30-km data were acquired for the time period 21-30 January 1988 for North America. The Chang et al. algorithm was applied to the SSMI data and the snow-covered area was determined on the SSMI data. It was very difficult to determine snow-covered area on the AVHRR data because of the similarity in spectral signature of clouds and snow. The only way that we could determine the position of a snow line was to develop a film loop of the AVHRR data; the film loop showed that the clouds moved and the snow line remained stationary over the 10-day period. The position of the snow line, thus determined, compared very well with the position of the snow line as seen on the SSMI data. The two data sets were registered and vu graphs were developed for up-coming presentations.

Future Plans

Snow/Sea Ice Mapping Mission - spring 1995. Plans are on-going for a joint snow/sea ice flight to be conducted in Alaska during the spring of 1995. The mission planning is being conducted with Don Cavalieri/Code 971. Flight hours have been secured from the NOAA P-3 in conjunction with their FOCI experiment. Arrangements are being made in an attempt to get passive-microwave sensors installed on the P-3 at Wallops. Extensive hardware testing, etc. must be performed on the passive-microwave sensors before they can

be considered to be ready for the mission. Determination of the feasibility of preparing the sensors for a mission is currently being undertaken jointly between Cede 974 (Dorothy Hall and Al Chang) and Code 971 (Don Cavalieri) and Code 972 (Dave Clem) .

MAS data have been requested to be acquired during the spring of 1995 as part of the above-mentioned snow and sea ice mission.

TM/DEM Analysis of Snow-Covered Areas. During the next few months, error analysis using DEM data will continue. We have begun collaborating with Dr. Tom Carroll of NOAA/NOHRSC. Initial studies are focusing on attempts to improve their measurements of snow-covered area using AVHRR and DEM data using the Hall et al. model that was developed using TM data of Glacier National Park.

ICEMAP. More work will be done to develop ICEMAP. About 10 suitable TM scenes of sea ice have been identified and will be ordered when an arrangement can be made to purchase them at a reasonable price. The cost of some of the TM data will drop dramatically in July and more in October 1994 and we plan to order the sea ice data after that time to take advantage of lower prices.

Spectral-mixture modeling may be a viable way to map sea ice. This is being investigated by G. Riggs/RDC.

AVHRR/SSMI Comparison. The comparison of simultaneously-acquired AVHRR and SSMI data will continue. Several vu-graphs have been developed that will be suitable for use in upcoming presentations. Also, a film loop has been made of a 10-day period in January (21-30) of 1988 which allows the separation of clouds and snow because the movement of the clouds is visible in the looped data, and the snow line remains stationary.

Presentations and Papers

Presentations.

1. Jim Foster/974 presented a paper entitled "Intercomparison of snow cover and snow mass in North America from General Circulation Models and remote sensing" at the American Meteorological Society meeting in Nashville, TN on January 26, 1994.

2. Dorothy Hall presented a seminar at the Byrd Polar Research Center in Columbus, Ohio on February 23, 1994, part of which dealt with snow mapping and the future role of MODIS.

3. Dorothy Hall gave a talk to GCIP, and GEWEX office managers (at GSFC) on the development of the MODIS snow-mapping algorithm on March 30, 1994.

4. Dorothy Hall made a presentation entitled "Development of the MODIS/Snow Mapping Algorithm and Error Analysis, at the MODIS Team Meeting May 4, 1994, in Greenbelt, Maryland.

5. Dorothy Hall gave a presentation on the MODIS Snow and Sea Ice Algorithms at the ATBD review May 10, 1994, in Landover, Maryland.

6. Dorothy Hall presented a paper entitled, "Determination of actual snow cover using Landsat TM and digital elevation model data in Glacier National Park, Montana," at the Third Circumpolar Conference on Remote Sensing of Arctic Environments," in Fairbanks, Alaska on May 18, 1994.

Abstracts/Papers.

1) A paper entitled, "Intercomparison of snow cover and snow mass in North America from general circulation models and remote sensing by Jim Foster et al. (see Appendix for authorship) was published in the Proceedings of the 6th Conference on Climate Variations (Appendix III) .

2) A paper entitled, "Determination of actual snow cover using Landsat TM and digital elevation model data in Glacier National Park, Montana," by D.K. Hall, J.L. Foster, J.Y.L. Chien and G. Riggs, was submitted to the Polar Record which will publish a special issue of papers from the Third Circumpolar Conference on Remote Sensing of Arctic Environments, after peer review (Appendix II).

3) A paper entitled "A snow index for the Landsat Thematic Mapper and Moderate Resolution Imaging Spectroradiometer," by G.A. Riggs, D.K. Hall and V.V. Salomonson, was submitted to the IGARSS '94 symposium to be held in August in Pasadena, CA (Appendix I).

4) G. Liston/USRA submitted an paper to the Tenth International Northern Basins Research Symposium and Workshop, Spitsbergen, Norway, 28 August - 3 September 1994. The paper entitled "A microclimate model for northern applications," will be presented by G. Liston at the meeting.