Annual Progress Report: Validation of AMSR-E Snow Products (NAG5-11107)

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Northern Hemisphere Snow Cover
January 1-23, 2003

SSM/I MODIS AMSR-E

I. Objectives

A. Background and Legacy Data

The extent of the seasonal snow cover, which may include as much as 50 percent of the Northern Hemisphere land surface, is an extremely important parameter in global climate and hydrologic systems due to significant effects on energy and moisture budgets. Realistic simulation of snow cover in climate models is essential for correct representation of the surface energy balance, as well as for understanding winter water storage and predicting year-round runoff. Passive microwave signatures of seasonal snow cover are clearly characterized by a strong dielectric contrast between snow-covered and snow-free ground, by decreasing emissivity (dry snow) with increasing microwave frequency (negative spectral gradient) and by decreasing emissivity with increasing snow mass. Because of this clear capability, a microwave snow cover algorithm is included in the suite of algorithms supported by the AMSR-E Science Team.

The AMSR-E snow products will contribute to one of the longest time series of any environmental product derived from satellite remote sensing. The National Snow and Ice Data Center (NSIDC) has produced a 24 year, consistently processed, time series of gridded satellite passive microwave data in a common format called the Equal-Area Scalable Earth Grid (EASE-Grid). This data set was developed using SMMR (Scanning Multichannel Microwave Radiometer) data for the period 1978 to 1987 and SSM/I (Special Sensor Microwave Imager) data for 1987 to 2002 and has been used to derive a series of snow and ice products. Figure 1 shows this time series for Northern Hemisphere snow cover and includes data from the NOAA visible satellites for the same period for comparison.

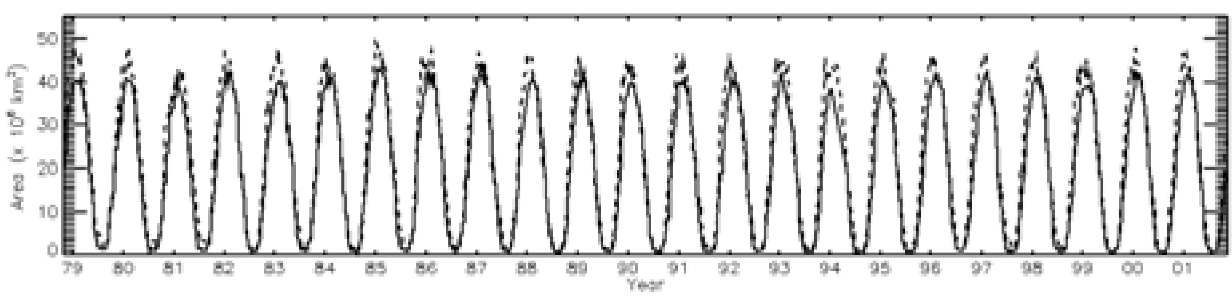

Fig.1. Northern Hemisphere snow-covered area (x 10^6 km^2) derived from visible (NOAA) (dashed line) and passive microwave (SMMR and SSM/I) (solid line) satellite data, 1978-2002 (Armstrong and Brodzik, 2001).

Snow depth and water equivalent can vary greatly with weather conditions and land surface characteristics. Given the large footprint of passive microwave sensors (> 500 km^2), snow storage within a footprint is seldom uniformly distributed. Therefore, large differences between station or gauge measurements (a point) and satellite estimates (an area integration) are to be expected. Where these differences are small, this apparent success could merely be fortuitous and we cannot always assume that such results represent true validation of a given algorithm. Comparisons of point observations with satellite estimated snow storage at best provide an order of magnitude check on the temporal patterns and spatial distribution. It is necessary to design schemes to compare areal snow storage with satellite derived snow storage. In the first phase of our validation of AMSR-E snow products we provide comparisons with snow extent derived from MODIS and snow extent and water equivalent derived from SSM/I as described in Section C. below.

II. Progress and Accomplishments

A. Interaction with the AMSR-E Science Team

Interaction with the AMSR-E Science Team and the developers of the snow algorithm has been continuous and effective. At various times during 2001 and 2002 we obtained copies of the algorithm software and ancillary data (various masks indicating land/ocean, forest cover, ice sheet locations, etc.) for the AMSR-E team snow algorithm. Prior to the launch of Aqua we evaluated the various versions of the software implementation and sent comments to Al Chang and his programming staff. Some examples of this interaction included:

1) We evaluated the existing masks and supplied comments regarding additional masks that we thought would be more useful (e.g. monthly snow climatologies rather than a fixed climatology for the whole year).

2) Using SSM/I input data we implemented a copy of the prototype AMSR-E algorithm and a modified version with our recommended changes to generate examples and explain the differences.

3) We met with Al Chang and discussed the problems we had found and the changes we proposed. We followed up afterward by e-mail and provided the latest tests for precipitation that we received from Alan Basist (NOAA/NESDIS) which differed from the last versions Al Chang had obtained.

4) We reviewed the sample Level 2A data produced by Remote Sensing Systems (RSS) during June and July of 2002. This review resulted in a few questions regarding the processing which were answered by Peter Ashcroft of RSS and which lead to an improved understanding at NSIDC of the processing routines for the Level 2A data. One of these questions identified a problem with the amount of overlap trimmed from the half orbit segments which had been leaving 12 second gaps at the poles. This problem was acknowledged by RSS with the result that the gaps were removed in subsequent and re-processed Level 2A data.

B. Summary of data flow following the May 4, 2002 launch.

Following launch, a limited amount of Level 2A and Level 3 data were made available by NASDA. Dates covered were June 1-3, June 19-20, July 17-23, August 8-9, September 3-12 and 20-30 and October 1-15. Except for the October dates (example for October 10 shown below) these time periods did not provide significant amounts of snow cover in the Northern Hemisphere for algorithm validation. No additional AMSR-E data have been provided by NASDA up to the date of this report. Therefore, the AMSR-E snow product evaluated in the following examples was produced using Level 2A brightness temperature data (Figure 2.) provided by RSS and are unofficially referred to as the “X1” version of the RSS calibration. It is anticipated that following approximately May of 2003 we will be using the official data stream provided by NASDA for this validation study.

C. Comparison of AMSR-E with other satellite-derived snow products

1. Early evaluation of AMSR-E snow product

As a baseline check on the early accuracy of the AMSR-E snow algorithm we compared output using brightness temperatures from both AMSR-E and SSM/I. This comparison was done using the earliest AMSR-E data available following the establishment of substantial continental-scale snow cover. This opportunity first occurred in October of 2002 and the results of the direct comparison are shown in Figure 3. We felt that the results, given the preliminary calibration, indicated that algorithm output using AMSR-E TBs was reasonable.

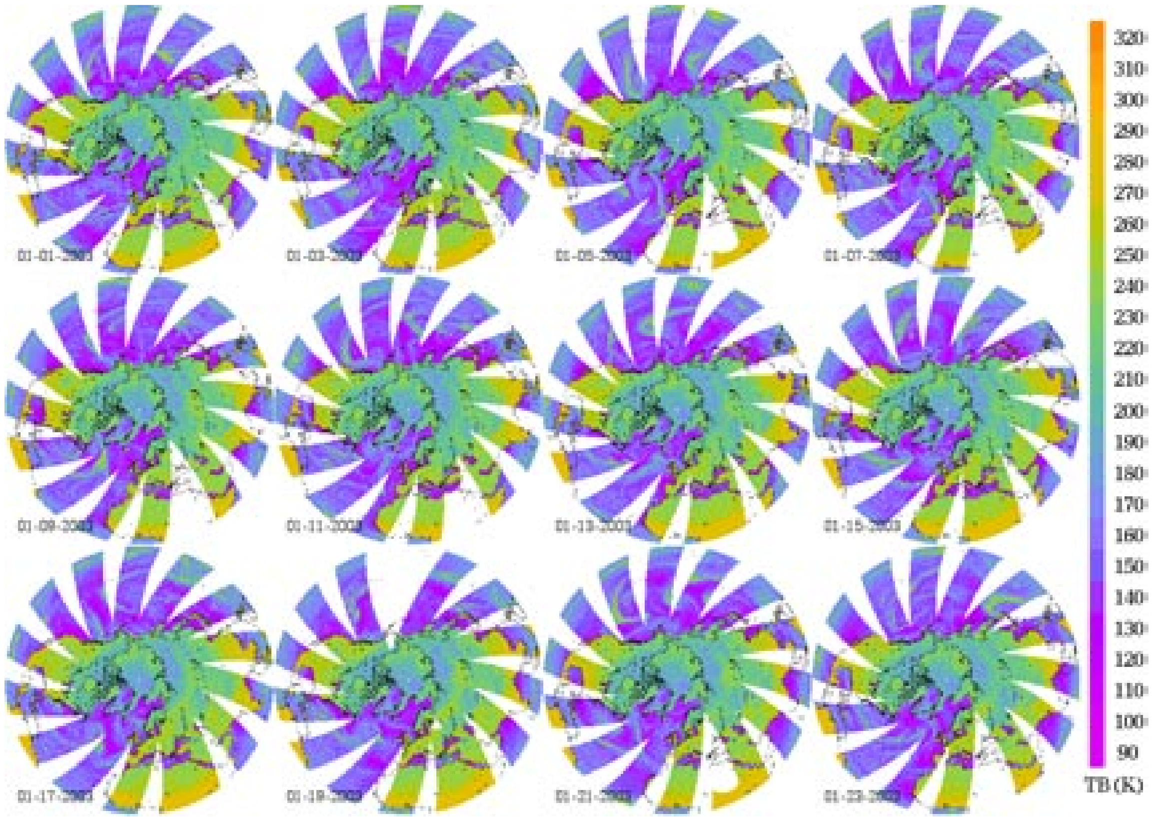

Figure 2. Northern Hemisphere AMSR-E 36 GHz Horizontal brightness temperatures (descending orbits only) from January 1, every second day, to January 23, 2003.

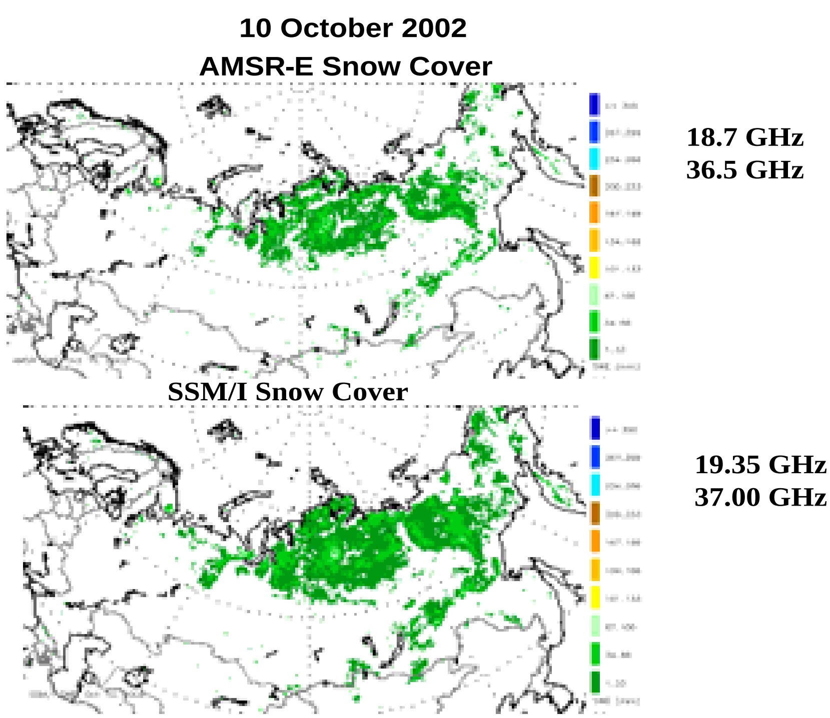

Figure 3. Preliminary comparison of snow extent and SWE across northern Asia returned by the same algorithm using AMSR-E and SSM/I brightness temperatures.

2. Comparison of AMSR-E with MODIS and SSM/I.

For this first Northern Hemisphere winter season with available AMSR-E data, we are comparing the Terra MODIS 8-day snow product with the AMSR-E SWE (snow water equivalent) product and SWE derived from SSM/I. The MODIS product represents a maximum extent for a given 8-day period, and minimizes the likelihood that any given area will be obscured by cloud for the entire time. In order to make the least ambiguous comparison, we compare to a maximum SWE composite of the daily AMSR-E snow product for the same dates. An example of this comparison for January 1-8, 2003, including a maximum composite SWE derived from SSM/I, is shown in Figure 4. This result is typical of subsequent comparisons during later January and February. Of course, the optimal comparison of AMSR-E snow extent with MODIS would include daily data from both sensors on the Aqua platform. However, because of current problems (failed detectors) with the 1.6 micron channel used in the MODIS algorithm, we have not yet included data from the Aqua MODIS in the comparison. Eventual modification of the MODIS snow algorithm by the MODIS science team should allow application of the Aqua MODIS data in the future.

a. Comparison with MODIS

In Figure 4, AMSR-E and SSM/I snow extent are represented by SWE values up to and exceeding 300 mm. Locations where the passive microwave sensors do not detect snow but MODIS does detect snow are shown in red. The spatial resolution of the MODIS data used in this example is approximately 5 km (MODIS 0.05 deg. “climate modelers grid”) and the areas shown in red represent locations where MODIS snow extent is 50 percent or more within the 625 km^2 passive microwave grid cell. One area of significant disagreement between MODIS and AMSR-E snow extent is seen across northern Europe. AMSR-E grid values in this region show flags indicating wet snow or rain. As the SSM/I data show closer correspondence with MODIS in this same region, it would appear that adjustments could be made to the AMSR-E flags to bring results into closer agreement with the MODIS data. Although we cannot always be certain that MODIS represents actual “truth”, as an independent check, the output from the NOAA Northern Hemisphere IMS (Interactive Multisensor Snow and Ice Mapping System) daily snow product also indicated snow across Europe at this time. It should be noted that snow mapping using passive microwave at the lower elevations of Europe has often been problematic, most likely due to the prevalence of wet snow and, in some locations, dense forest. In other locations the snow extent from AMSR-E shows reasonable agreement with MODIS.

b. Comparison with SSM/I snow extent and snow water equivalent (SWE).

The SWE from SSM/I is derived using the current NSIDC research algorithm (NSIDC6). Areas of significant difference between results from AMSR-E and SSM/I are apparent in central and eastern Siberia and northern Scandinavia where maximum SWE values for AMSR-E are considerably less than for SSM/I. One clear reason for this difference in Siberia is the fact that the current version of the AMSR-E algorithm is limited to a maximum value of 240 mm SWE. An explanation of the differences in northern Scandinavia is uncertain at this time.

Significant differences also appear in the desert regions of east-central Asia (Gobi desert and surrounding area east of the obvious snow free region of the Taklamakan Desert). Here the SSM/I appears to slightly underestimate snow extent compared to the MODIS and the AMSR-E algorithm is likely overestimating snow extent. The AMSR-E algorithm uses vertical polarizations only, which has been shown to provide false positives for snow cover in cold deserts (Armstrong and Brodzik, 2002).

The current implementation of the AMSR-E daily snow algorithm includes both ascending (warm) and descending (cold) pass TBs. Previous studies have clearly shown that only cold passes should be used in a snow algorithm (Armstrong and Brodzik, 2001) in order to minimize measurements made in the presence of melting snow. The AMSR-E Science Team and the SIPS are aware of this problem and the change to descending-only TBs will be made soon.

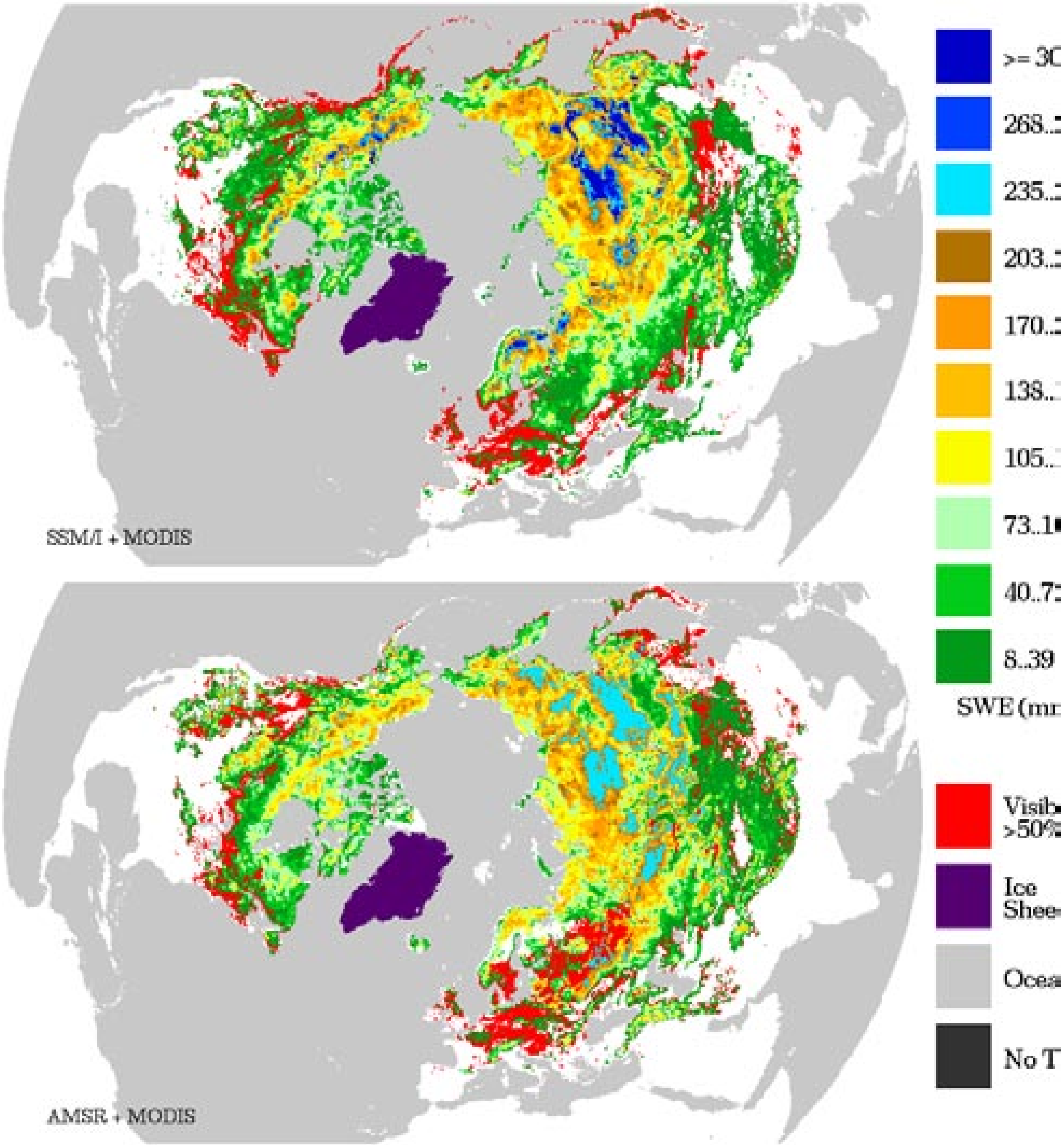

Figure 4. Comparison of AMSR-E snow product with the NSIDC SSM/I snow product and the MODIS snow product – maximum values for the period January 1-8, 2003.

The preceding comparisons have been limited to a qualitative analysis and a more detailed quantitative evaluation of the AMSR-E algorithm using MODIS and SSM/I data will be undertaken during year two. This work will be undertaken as soon as the final calibration for the AMSR-E brightness temperatures has been completed and the official data stream identified.

III. Plans for Year Two

A. Local or grid scale validation

These studies are being accomplished through direct participation in the NASA Cold Land Processes Experiment (CLPX) taking place during both mid-February and late March 2003 in northwestern Colorado (Cline, 2001). The CLPX is designed to improve our knowledge of the terrestrial cryosphere by providing a more compete understanding of the fluxes, storage and transformations of water and energy in cold land areas. Details of the CLPX experiment plan can be found in Cline et al. (2001) and on-line at http://www.nohrsc.nws.gov/~cline/clp.html. Prior snow validation efforts have primarily relied on what might be termed “data sets of opportunity” - data sets which typically were not entirely appropriate for passive microwave algorithm validation and often introduced as many questions as answers to the process. The optimal sampling scheme comprising spatially nested sampling areas (Figure 5.) offered by the CLPX represents a major advancement over previous efforts to validate passive microwave snow algorithms.

The CLPX will provide this study with unique validation data sets which will include a wide range of measurements from the ground-based and airborne components of this field experiment. The ground based measurements will provide a spatial density that is unprecedented and will include 9,000 snow depth measurements and 144 snow pit profiles (snow water equivalent, snow density, grain size type and size and temperature) per winter season to characterize the snow cover over three 25 x 25 km Meso-cell Study Areas (MSAs) providing data at the spatial scale of the AMSR-E footprint.

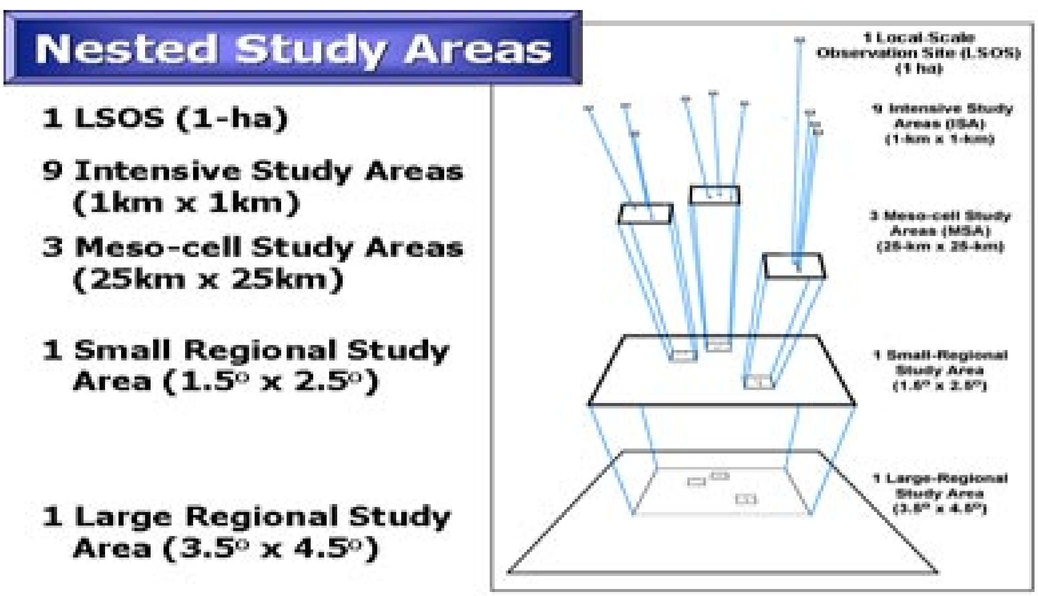

Figure 5. Cold Land Processes Field Experiment Nested Study Area Concept (Cline, 2001).

Although this validation study is limited to three land cover types (grassland, coniferous forest and alpine) these regions are typical of many other locations world-wide where seasonal snow cover is the prevalent land cover during the winter season. Therefore, the algorithms validated in this experiment can be applied and tested over comparable land cover types throughout the world.

In conjunction with the CLPX we are operating the University of Tokyo Ground Based

Microwave Radiometer (GBMR-7), an AMSR-E simulator for the higher frequency channels (18.7, 23.8, 36.5 and 89.0 GHz) during 2003 at the Fraser Experimental Forest study site near Fraser, Colorado. University of Colorado personnel are operating the GBMR-7 at 10 day intervals during the 2002-2003 winter season making measurements over bare soil (frozen and unfrozen) and snow (dry and wet). In developing the snow algorithm it has been found that the grain size distribution is one of the most critical parameters. With a priori grain size profiles built into the algorithm, snow retrieval accuracy can be improved. Field experiments associated with the operation of the GBMR-7 will measure snow grain size distribution, variation with time and influence on microwave emission. The GBMR-7 was successfully operated during the CLPX Intensive Observation Period 2003 (IOP3, February 18 to 25, 2003) with data being collected over a range of snow depths, grain sizes and surface conditions. These data will again be collected during IOP4 (March 25 to 30) and will be analyzed early in year two of this study.

An additional data set acquired by NSIDC during CLPX IOP3 (February 26, 2003) included GPR (ground penetrating radar) at 800 MHz which allowed snow thickness measurements to the ground surface with the prevailing snow depths of less than 3 m. Nine transects were run connecting CLPX snow pits and depth measurements in the Walton Creek ISA of the Rabbit Ears Pass MSA. In total, 1,800 m of transect data were collected. These data will be analyzed in the next few months and will provide validation data representing intermediate sampling densities between the point measurements and the area integration represented by the AMSR-E footprint.

B. Large river basin scale validation

Output from the AMSR-E snow algorithm will be compared with river discharge data as well as with modeled values of distributed winter precipitation. The Arctic Basin with its relatively non-forested and non-complex terrain and long persisting subfreezing snow cover is an excellent location for the validation of passive microwave snow algorithms. In addition, a number of the rivers draining into the Arctic Ocean are underlain by permafrost which reduces the amount of runoff going into ground water thus making the relationship between total seasonal SWE on the ground and total snow-melt river discharge more direct.

C. Regional to hemispheric scale validation

We will continue to evaluate the AMSR-E snow algorithms by comparison with MODIS and NOAA IMS snow extent maps and SSM/I-derived SWE data. Within the United States, additional sources for SWE data will include NOAA/NESDIS, NOHRSC and USDA as well as possible surface station data obtained through ongoing collaboration with colleagues in Canada, Russia and China.

IV. Data Management and Archival

All pertinent data resulting from this validation study will be archived at the National Snow and Ice Data Center (NSIDC), University of Colorado, Boulder. Selected data sets will be available to the wider scientific community through NSIDC's User Services Office (nsidc@nsidcorg).

V. References:

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