Appendix I

Recent Progress in Development of the Moderate Resolution Imaging Spectroradiometer Snow Cover Algorithm and Product

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Abstract -- In preparation for the launch of the Moderate Resolution Imaging Spectroradiometer (MODIS) on the first NASA Earth Observing System platform in 1998, an algorithm to generate a global snow cover map is being developed. Status of the snow mapping algorithm and description of the data product is described in this paper.

INTRODUCTION

Monitoring the spatial and temporal extent of seasonal snow cover at synoptic, regional and local scales is important to the research, modelling and operational monitoring communities concerned with snow cover [1]. A snow algorithm and data product are being developed for the future Moderate Resolution Imaging Spectroradiometer (MODIS) instrument to be flown aboard the Earth Observing System (EOS), a part of NASA's Mission to Planet Earth (MTPE). Landsat Thematic Mapper (TM) and MODIS Airborne Simulator Data (MAS) are used as surrogates for MODIS data during development of the algorithm.

BACKGROUND

The objective for the MODIS snow algorithm, SNOMAP, is to generate a consistent, well described, global snow cover data product. The spatial resolution planned for the snow cover data product is 500 m with daily and ten day composites of the product generated and archived.

MODIS is an imaging radiometer consisting of a cross track scan mirror, collection optics and set of linear detector arrays with spectral interference filters in four focal planes. MODIS has 36 discrete bands between 0.4 and 15 μm selected for diagnostic significance in Earth science. The different spectral bands have spatial resolutions of 250 m, 500 m or 1 km at nadir. Complete description of the MODIS instrument can be found at the MODIS homepage http://ltpwww.gsfc.nasa.gov/MODIS/MODIS.html. Orbital characteristics of the EOS platform will allow MODIS to have near daily repeat coverage over much of the globe and in the mid to upper latitudes swath overlap will provide multiple daily views of some regions. Those multiple views open the option of the algorithm to select and analyze the "best" observation(s) of a location for the day.

Processing and generation of MODIS data products will be done at several levels. The levels are defined by temporal and spatial manipulations done on the data to arrive at a product. Information about the data processing system and these data levels can be found at the Earth Observation System and Data Information System (EOSDIS) home page http://spsosun.gsfc.nasa.gov/ESDIShome.html. The lowest level is a short segment of an orbital swath, while the next levels involve spatial and temporal manipulations, including gridding of data, to generate products covering larger spatial areas. Within the MODIS land group of investigators there is a gridding and tiling scheme to assemble MODIS swaths into geographically referenced and gridded tiles for common use among products.

The SNOMAP algorithm is composed of three algorithms for product generation at the swath level, daily composite, and ten day composite. Products from the swath flow to daily compositing, which flow to the ten day composite. Ten day compositing follows the compositing scheme laid out by the Science Working Group [EOS] AM Platform (SWAMP). The ten day compositing periods are defined as: first ten days of the month, days 11 - 21, then day 21 to end of month.

Other MODIS data products such as the cloud mask and static land/water mask are being integrated into SNOMAP to mask large water bodies and assist with discriminating snow from cloud. For information on other MODIS data products and the Earth Science Data Information System (ESDIS) in general begin at http://spsosun.gsfc.nasa.gov/ESDIShome.html.

The snow cover products are generated in HDF format composed of global attributes (metadata), product specific attributes (metadata and quality information) and the snow cover 'map' as a scientific data array.

TECHNIQUE

The SNOMAP algorithm at the swath level employs criteria tests and decision rules with universal threshold values, to identify snow by its reflectance features in the visible and near infrared wavelengths (NIR). Techniques are briefly described here; greater discussion is presented in [2]. A principle key to identification of snow is the Normalized Difference Snow Index (NDSI). The NDSI is defined as (visible reflectance - NIR reflectance) / (visible reflectance + NIR reflectance) or for TM (band 2 - band 5) / (band 2 + band 5). Snow and cloud discrimination is also achieved with the NDSI, though confusion with cirrus (ice clouds) is a problem. Water may also have a high NDSI and thus be confused with snow but, that confusion is largely eliminated by use of far red threshold test which discriminates water from snow because water absorbs whereas snow reflects through the red. If observation results lie in the snow decision region of the decision rule, the pixel is identified as snow covered.

TM data is converted to radiance then reflectance using methods described by [3] using pre-flight gains and offsets, or by using recorded gains and offsets [4] when available, prior to applying the snow decision tests. We have found that use of observed reflectances increases the accuracy of snow cover identification. MODIS data input will be at-sensor reflectances. Work is in progress to incorporate atmospheric correction.

In addition to the criteria tests and decision rules for snow, the full-up version of SNOMAP will contain internal checks for data integrity that will affect algorithm flow in cases of missing or out-of-range data. During execution of the algorithm, several pieces of metadata are accumulated to provide summary information with the snow cover map and serve as indicators of quality assessment (QA). Metadata such as counts of out-of-range data and total snow area are generated and written as attributes in the HDF output file. A general QA flag based on metadata and QA criteria rules is also written as an attribute.

SNOMAP at the second level composites the results of the swath outputs from overlapping orbits into a daily snow cover product. An intermediate algorithm assembles all the swaths into tiles of a grid, SNOMAP then employs a series of criterion tests to select the 'best' observation(s) of multiple observations. If there are multiple 'best' observations, the mode of the SNOMAP swath level result is used as the result for the day.

SNOMAP at the third level composites the level 2 results for a ten day period. The technique used is to sum the number of snow observations for that period to generate a snow cover summation product. That product contains the number of days that a cell was snow covered, along with summary metadata of snow cover.

RESULTS & DISCUSSION

Runs have been undertaken on over 25 TM scenes to generate snow cover maps. Snow cover extent identified by SNOMAP has agreed to within a few percent of snow cover identified with intensive classification methods (e.g. supervised classification and spectral mixture modelling [2]) on several TM scenes. Identified snow extent has also agreed with ground observations and with regional snow maps generated by the National Operational Hydrologic Remote Sensing Center (NOHRSC). SNOMAP continues to be validated against other techniques and data sources of snow cover.

The most commonly encountered error in SNOMAP is confusion of cirrus clouds with snow. No consistent trend has been observed in confusing snow with cirrus clouds. In some situations cirrus clouds over non-snow covered land may be identified as snow, while in other seemingly similar situations it will not; cirrus clouds over snow are also inconsistently confused. Means of sorting out this confusion are being explored. Much of the confusion may be alleviated with the integration of the MODIS cloud mask, developed by another MODIS investigator team, which has the capability of identifying cirrus clouds.

Solar zenith angle (SZA) has been observed to have an effect on identification of snow. A study is in progress to determine if there is a crucial SZA above which snow identification becomes erroneous. This appears to be an issue related to high SZA. If a crucial SZA is determined, then a bound on acceptable SZAs will be incorporated into SNOMAP.

A simulated weekly snow composite has been generated with SNOMAP from a pseudo time series of TM data to demonstrate the information content of the composited product. SNOMAP higher level products have been generated with simulated MODIS data. Simulated MODIS data are used to test the flow of SNOMAP through all levels of product generation. The higher level products exhibit consistent snow cover extent results among levels. Lack of validation data for composites precludes significant comment to be made for the composited snow covers.

SUMMARY

Results obtained with SNOMAP and review of products and techniques by the community [1,2] indicate that the snow identification technique and products being developed will be of general utility to sections of the community. Research is continuing to improve snow identification techniques, including conditional bounding of factors such as SZA, defining metadata and quality indicators for the SNOMAP products. Concurrent with research is the programming task of preparing the program code to be run in the production environment of EOSDIS. Expectations are that MODIS will be launched aboard the EOS AM platform in mid 1998, and that data product generation will begin shortly after MODIS is declared operational.

REFERENCES

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