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Snow-Cover Variability in North America in the 2000-2001 Winter as Determined from MODIS Snow Products

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ABSTRACT

Moderate Resolution Imaging Spectroradiometer (MODIS) snow-cover maps have been available since September 13, 2000. These products, at 500-m spatial resolution, are available through the National Snow and Ice Data Center Distributed Active Archive Center in Boulder, Colorado. By the 2001-02 winter, 5-km climate-modeling grid (CMG) products will be available for presentation of global views of snow cover and for use in climate models. All MODIS snow-cover products are produced from automated algorithms that map snow in an objective manner. In this paper, we describe the MODIS snow products, and show snow maps from the fall of 2000 in North America.

INTRODUCTION

Moderate Resolution Imaging Spectroradiometer (MODIS) snow-cover maps at 500-m spatial resolution are produced from automated algorithms, and have been available since September 13, 2000. The National Oceanic and Atmospheric Administration (NOAA) has operational snow maps that provide snow-cover information on a daily basis, but these maps, are not global and they rely on analysts to fine-tune the maps. For operational use, this is an advantage because both ground and satellite data can be used as available. But for long-term climate studies, a data set must be developed using an objective technique for snow mapping.

BACKGROUND

MODIS is an imaging spectroradiometer that provides imagery of the Earth's surface and clouds in 36 discrete spectral bands from approximately 0.4 to 14.0 µm [1]. The spatial resolution of the MODIS instrument varies with spectral band, and ranges from 250 m to 1 km at nadir.

Snow Maps. Operational snow maps are available from NOAA from the National Operational Remote Sensing Center (NOHRSC) and the National Environmental Satellite, Data, and Information Service (NESDIS). NOHRSC snow-cover maps are distributed electronically in near real time, to local, state and federal users at a spatial resolution of up to 1 km [2]. Since 1997, NESDIS has operated an Interactive Multi-Sensor Snow and Ice Mapping System (IMS) that produces daily snow products at a spatial resolution of about 25 km, and utilizes a variety of satellite data to produce the maps [3].

There are six MODIS snow products. The products are archived and distributed by the National Snow and Ice Data Center (NSIDC) in Boulder, CO [4].

Because cloudcover often precludes the acquisition of snow-cover information from visible and near-infrared sensors, the daily maps are composited into eight-day composite products. In the near future, 5-km resolution snow maps, gridded to a climate modeling grid (CMG), will be available. The CMG will provide a global view of the Earth's snow cover. Currently, to provide a global view, we use a ¼° x ¼° lat/long grid to produce special products of North America as seen in Figure 1.

The automated MODIS snow-mapping algorithm uses at-satellite reflectances in MODIS bands 4 (0.545-0.565 µm) and 6 (1.628-1.652 µm) to calculate the normalized difference snow index (NDSI), and MODIS bands 1 (0.620-0.670 µm)

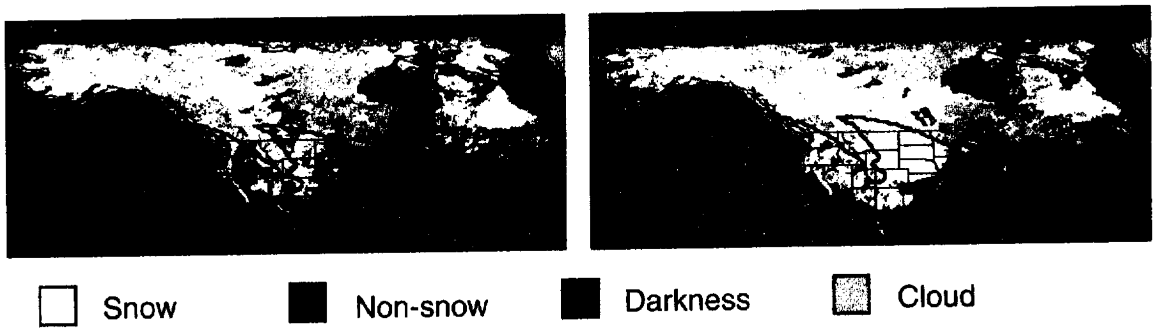

Figure 1. Seven or eight-day composite MODIS-derived snow maps from November 1 – 7 (left), and November 8-15, 2001. These special products are on a ¼ x ¼ deg lat/long grid. The line represents the average monthly snowline from NOAA/NESDIS data.

and 2 (0.841–0.876 μm) to calculate the normalized difference vegetation index (NDVI).

Used together, the NDVI and NDSI provide a strong signal that can be exploited to map snow cover even in forests [5]. Other tests are also employed to map snow and are discussed elsewhere [6].

Swath product. The snow data-product sequence begins as a swath (scene) at a nominal pixel spatial resolution of 500 m and a nominal swath coverage of 1354 km (cross track) by 2030 km (along track). Inputs to the swath snow-cover product are: the MODIS (Level 1B) radiance data [7] and the MODIS cloud mask [8], and a land/water mask.

Daily and eight-day composite tile products. The second product is created by mapping pixels from the swath product to their Earth locations on the integerized sinusoidal projection [9]. This daily product is an intermediate product in which all the observations (pixels) in the snow swath product are geolocated onto the projection. An eight-day composite maximum snow-cover product is produced for each tile by compositing eight days of the daily 500-m resolution products. If snow were present on any day in any location on the daily tile product, it will show up as snow covered on the eight-day composite. For a more complete description of the individual products, see [10].

Daily and 8-day composite climate-modeling grid products. The daily global snow-cover CMG product is planned be provided in a geographic projection, by assembling MODIS daily data tiles of the land areas at 500-m resolution, and binning the 500-m cell observations into 5-km spatial resolution cells. The compositing scheme for the CMG product will utilize the 8-day composite products at 500-m resolution. Those pixels will be binned into the coarser-resolution 5-km grid. Percentages of snow, cloud and other (non-snow) will be calculated thereby deriving sub-pixel snow cover at the 5-km resolution.

Quality assurance (QA) information is stored in each pixel of the products.

RESULTS AND DISCUSSION

Daily snow maps, while useful for local and regional purposes, are usually so cloud contaminated that it makes them difficult to use on a hemispheric or global scale. We use 8-day composite maps - only clouds that persisted for the entire 8-day period remain on the 8-day composite maps. We focus on the build-up of snow cover during the fall of 2000. The average monthly snowline (derived from the NOAA NESDIS snow maps) has been placed on the 7- or 8-day composite maps shown in Figure 1.

The snow cover was measured for the period November 1-7 and 8-15. These measurements are not an accurate depiction of the total snow cover for North America because the cloudcover is excluded, as is the area that is in darkness. However, the remaining areas show a 1.8 million km^2 increase from the first period (9.0 million km^2), to the second period (10.8 million km^2).

By mid-November 2000-01, the snow cover in the mid-western and western United States was much more extensive that normal, while the snow cover on the East Coast was not unusual. The snow cover, particularly in the mid-west, remained more extensive than average through the month of December. A video clip showing the changing snow conditions in the 2000-01 winter may be viewed on the MODIS snow and ice Web site: http://snowmelt.gsfc.nasa.gov/MODIS_Snow/modis.html

Spurious snow cover is detected along some coastlines (e.g., the west coast of Florida and the California coast and the northeastern coast of South America). These areas consist of a few pixels that are mapped as snow cover, however no snow exists there on the ground. Initial analysis indicates a mismatch between the 1-km resolution land/water mask, and the MODIS snow map. False detection of snow on perimeters of some may also be seen. Additional work is needed in order to characterize the misidentified snow and then to eradicate it in an objective way.

The snow-cover maps will be reprocessed in the future, using improved spectral tests for the MODIS cloud mask, and consistent Level 1B radiance data, and an improved land/water mask.

In conclusion, the MODIS snow maps are available, and special products have been made in order to make hemispheric-scale and global maps of the 2000-01 winter. A CMG at 5-km resolution will be available by the 2001-02 winter which should be useful for displaying the data as global products, and as input to climate models. These products, developed from automated algorithms, represent a consistent snow product, suitable for use in climate modeling.

ACKNOWLEDGMENT

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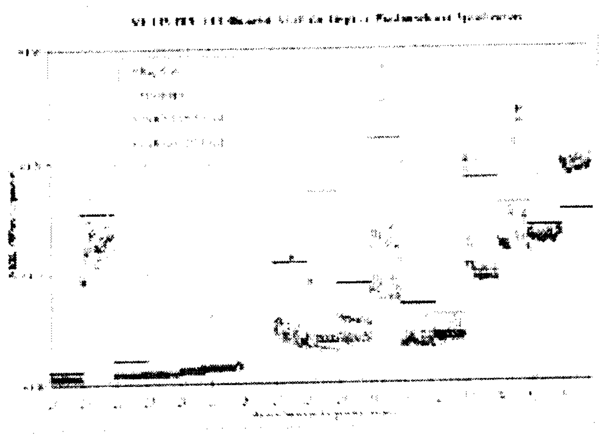

Fig. 2. NEdL Thermal Emissive Bands (TEB) (showing specifications, pre-launch and on-orbit values).

B. Geolocation Results

The specification of accuracy for geolocation of pixels from MODIS IS 300 meters (2 sigma) and the goal is 100 meters (2 sigma). The geolocation goal is driven by the need of the land community for land cover change or transformation to be able to have knowledge of pixel location to within one pixel accuracy. As of the beginning of 2001 the goals for geolocation have largely been attained. Products are still being examined to look for problem areas, but to-date the results look quite positive.

IV. MODIS PRODUCTS STATUS

Over 40 science products are being produced from MODIS data. Beginning in the late Fall of 2000 the data processing of MODIS data became relatively stable and since then has been providing complete days (288 granules) of MODIS data up to the present time. The science products are largely in "beta status" and a majority of products are expected to go to "provisional status" by mid-2001. Descriptions of the data products along with their availability are provided at: http://ltpwww.gsfc.nasa.gov/MODIS/MODIS.html.
Beginning in June of 2001 there are plans to produce a one-year data set extending from November 2000 to November 2001 that is consistently processed and uses the most up-to-date algorithms. Beyond that reprocessing of data will be dependent on the existence of updated algorithms and the availability of computing resources.

V. MODIS DATA PRODUCTION STATUS

In general the production of MODIS data is proceeding in a sustained fashion and products are regularly being produced. Early problems with getting Level 0 data have been reduced to where reorders are less that 1 percent. The Goddard Distributed Active Archive Center (DAAC) produces the Level 1 data for MODIS at a 2X rate using Origin 2000 computers. This production of Level 1 data will reach a 3X rate with upgraded equipment by mid-year. The production of Level 2 and above products is being accomplished on the MODIS Adaptive Processing System (MODAPS) striving to get to a 2X rate. So far 300GB/day of MODIS data are being sent to the relevant EOS DAAC's. Approximately 150 TB of Terra MODIS data has been archived at the GSFC, NSIDC, and EDC DAAC's by the end of December 2000.

VI. SUMMARY

The MODIS on-orbit performance demonstrates that key system parameters are within the sensor specification and are consistent with pre-launch values. The MODIS has considerable potential for obtaining powerful and insightful scientific results. Work continues to better understand the MODIS performance and to optimize its on-orbit performance.

ACKNOWLEDGMENTS

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