Validation of MODIS, VEGETATION, and GOES+SSM/I Snow Cover Products over Canada Based on Surface Snow Depth Observations

Anita Simic[1*], Richard Fernandes[2], Ross Brown[3], Peter Romanov[4], William Park[2], and Dorothy K. Hall[5]

[1]Noetix Research Inc. (under contract to CCRS), 588 Booth Street, Ottawa, Ontario, K1A 0Y7, CANADA
[2]Natural Resources Canada, Canada Centre for Remote Sensing, 588 Booth Street, Ottawa, Ontario, K1A 0Y7, CANADA
[3] Meteorological Service of Canada, Dorval, Quebec, CANADA
[4] Office of Research and Applications, NOAA/NESDIS, Camp Springs, MD, USA
[5] Hydrological Science Branch, NASA/Goddard Space Flight Centre, Greenbelt, MD, USA
*Tel: 613.947.1254, E-mail address: Anita.Simic@CCRS.NrCan.gc.ca

***Abstract* - The rate and pattern of snow melt control both hydrological and ecological factors. Snow cover maps derived by different satellite sensors can differ considerably from surface observations due to different spatial resolutions and snow cover classification algorithms. This article addresses issues related to the validation of three daily snow cover products over Canada: MODIS and GOES+SSM/I snow maps derived at 500m and 4km resolution, respectively for 2001, and VEGETATION snow maps derived at 1km resolution for 2000. The validation is based on surface snow depth observations from almost two thousand meteorological stations across Canada. The analysis is performed on a daily basis for the period of six months (January-June). A land cover map of Canada at 1km resolution is used to relate the differences within the validation to land cover types. The SPOT product shows an average agreement of 83% and considerably high percentage of omission error. The MODIS and GOES+SSM/I products have similar percentage average agreements, 93% and 92%, respectively. Generally, less agreement is seen within the evergreen forest cover types, earlier in the snow season and during snow melt. The MODIS product exhibits a high percentage commission error for evergreen forests. The GOES+SSM/I product shows relatively similar ratios of omission and commission errors for all land cover types except deciduous forest**.

I. Introduction

The snow ablation process is a crucial link variable concerning the hydrological cycle, terrestrial and water ecosystems, and climatologic processes. Snow ablation affects surface and subsurface soil moisture, runoff, ground water regime, and, ultimately, stream flow discharge. Sublimation of snow has an additional effect on the hydrological cycle. The transition between the snow melt and leaf appearance period is critical for the terrestrial ecosystem functioning and management of both understory and overstory vegetation. Furthermore, high albedo of snow cover may have an impact on global radiation budget and climate change, and vice versa.

The accuracy of snow cover maps is of particular importance in remote sensing applications to physical models. Numerous techniques are used in developing algorithms for snow detection. The cloud-snow confusion is one of the major impediments for the snow classification. Forest areas represent another obstacle to accurate snow cover mapping in remote sensing applications. Snowfall interception by conifer canopies and snow sublimation losses often result in underestimation of snow cover extent for forest areas. Moreover, the forest canopies obscure snow from the view of both visible and passive-microwave satellite sensors resulting in inaccurate snow cover distribution. Ultimately, less snow is detected when the sensors view at off-nadir angles than at nadir [2]. The scaling factor plays an important role in the validation process. Conifer canopies block understory snow cover from solar radiation during snow melt and, therefore, snow persists longer than in open land areas where the in-situ observations are commonly performed [1]. This effect may explain some of the observed differences we report in our study between satellite and in-situ snow cover.

The main intent of this study is to compare three daily snow cover satellite products:

- SPOT-4 VEGETATION (VGT) – S1
- MODIS MOD10A1
- NOAA GOESS+SSM/I

with surface snow observations during winter and spring season of 2000 (SPOT-4) and 2001 (MODIS and NOAA) over Canada. The validation is based on surface snow depth observations from almost two thousand meteorological stations across Canada. The assessment has been performed on a daily basis for the period of six months (January-June).

Satellite snow product and relevant algorithms

The VGT snow product used in this study was derived at 1km resolution. A three level cloud mask, a two level snow mask, and a two level cloud shadow mask are major steps undertaken in the producing the daily VGT snow imagery [4]. A genetic algorithm was developed to separate clear from cloudy pixels. To separate cloudy and snow pixels, a post-processing algorithm, which is based on neural network, is employed [4].

The MODIS product possesses high spatial (500m) and spectral (36 bands) resolutions, and the capability of the snow classification algorithm to separate most snow from clouds [3]. The fully automated, MODIS classification algorithm is based on the normalized difference snow index (NDSI) [2]. The process of classification involves a threshold to NDSI and to NIR band to separate snow from water. In order to increase snow cover extent within forest areas, where snow is commonly obscured by the canopies, both the NDSI and the normalized difference vegetation index (NDVI) are used to separate snow-free and snow-covered forest pixels. Since certain forest types might cause additional uncertainties, a threshold in green portion of the spectrum is used to overcome this problem [2][3].

The NOAA product is based on the combined employment of two satellite sensors: the Imager instrument onboard Geostationary Operational Environmental Satellite (GOES), and Special Sensor Microwave/Imager (SSM/I) aboard polar orbiting Defense Meteorological Satellite Program (DMSP) platform. The GOES snow algorithm incorporates the snow index (SI) threshold to separate snow-covered pixels. Visible reflectance threshold is set to eliminate cloud shadows and small water bodies. For mid-infrared reflectance the threshold is set to detect snow from most of clouds. To discriminate snow from clouds with ice tops and cirrus, two thresholds of temperature brightness of IR band are applied. Additional thresholds are employed to differentiate clouds from land. Snow cover maps, derived by SSM/I, are used to replace gaps within the GOES product [5].

Ground data is represented as vector points which values are then compared with the corresponding pixels of the satellite images. The comparison is based on agreement/disagreement of binary values of point and pixels data: snow and no-snow flags.

II. RESULTS AND DISCUSSION

Figure 1 indicates that the percentage agreement between the VGT snow cover product and surface measurements is 83% on average over all images from January to June 2000. Both deciduous and evergreen forests exhibit as low agreement as 41% in January. Herb dominant and lichen cover types show relatively high agreement for all months with the exception of March when the percentage agreement is slightly reduced for both types. It was found that the VGT product has considerably high percentage omission disagreement for all four land cover types.

The MODIS product exhibits an average percentage agreement of 93% (Figure 2). Evergreen forests demonstrate the lowest percentage agreement throughout the whole period with its minimum of 80% during snow melt. All cover types demonstrate lower percentage agreement during January and all, except lichen, exhibit the lowest agreement during snow melt (March-April). A better agreement was found in the study of [2] over the boreal forest of Central Alaska using MODIS Airborne Simulator (MAS) data;

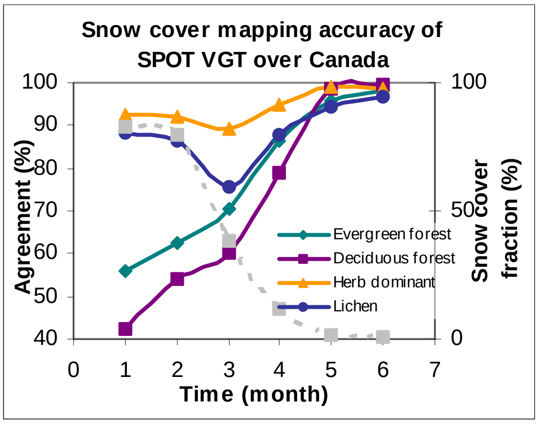

Fig.1. Agreement between snow cover mapping of VEGETATION and surface measurements over Canada (2000)

however, the assessment incorporated only the omission error since no snow-free land existed at the time. A relatively high ratio of commission disagreement was found within evergreen forests. Although the MODIS snow algorithm is effective in eliminating most clouds, high clouds that contain ice, are often confused for snow [3]. The error may be

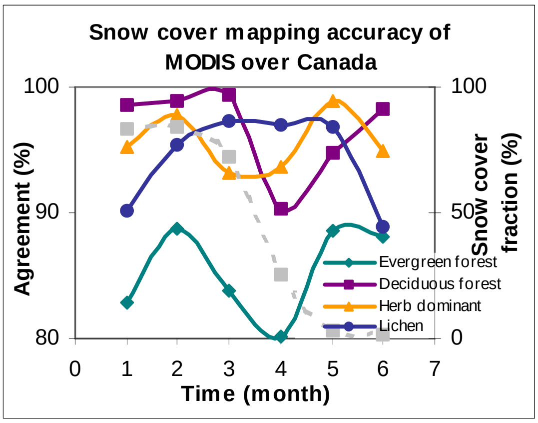

Fig.2. Agreement between snow cover mapping of MODIS and surface measurements over Canada (2001)

amplified within high-elevation regions. It was also found in this study that the BC mountainous region exhibits higher commission errors than the Boreal Region within the MODIS product. The scaling factor may also cause the commission errors.

Figure 3 shows the average percentage agreement of 92% for the NOAA product. The lowest agreement is seen within evergreen forests (81%). All land cover types show a similar trend, lower percentage agreement in January and during snow melt (March and April). A relatively similar ratio of omission and commission disagreement was found for all land cover types except deciduous forest, which shows higher omission disagreement. [5] found that GOES+SSM/I showed the agreement of 85% when compared with surface observations, and showed similar or higher agreement than the NOAA operational (non-automatized) product. Commission errors, often found within GOES snow maps, are mostly due to certain type of clouds, which may be confused with snow detection [5]. Although partly compensated by SSM/I data, high altitudes may cause additional errors for the GOES snow product due to low satellite and solar zenith angle and high viewing angle [5].

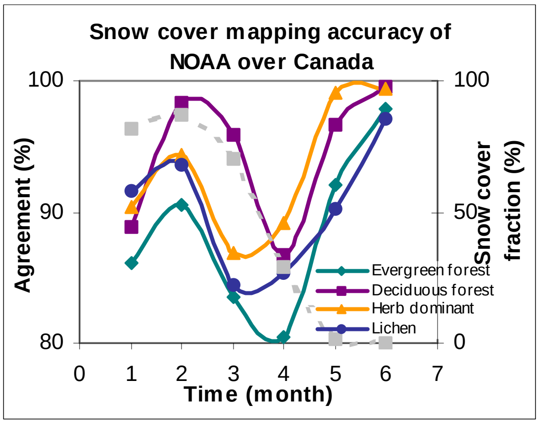

Figure.3. Agreement between snow cover mapping of GOES+SSM/I and surface measurements over Canada (2001).

Figures 4a and 4b show the snow cover maps derived from the MODIS and NOAA products for a selected day, respectively. When compared with the MODIS snow map more areas are snow covered within the GOES+SSM/I product for the same date. Most of the NOAA snow image is cloud-free and it is found that 100% of pixels used for the mapping in this study were cloud-free.

Based on the results of the assessment, the VGT product investigated in this study is not appropriate to use for snow mapping in Canada. The MODIS product exhibits high accuracy; however, the high ratio of the commission error suggests the need for the improvements with snow-cloud confusion. Both the sophisticated algorithm and hourly observations used in the NOAA product and the use of the microwave sensor are believed to be major factors in the high accuracy, relatively equal omission-commission ratio, and also high percentage of cloud-free pixels. Further progress involves the improvement of the clouds-snow confusion within the GOES product. Scaling is another major factor that may contribute towards observed differences during snow melt. Imagery from sensors such as Landsat or ASTER could be applied to refine our analysis during this period. However, an analysis of errors as a function of forest cover density suggests that the snow mapping method, rather than scaling differences, explains at least half of the observed differences, even with worse case scaling errors. Discriminating clouds from snow, and sheltering understory snow by forest canopies are believed to be main sources of limitations with current mapping algorithms.

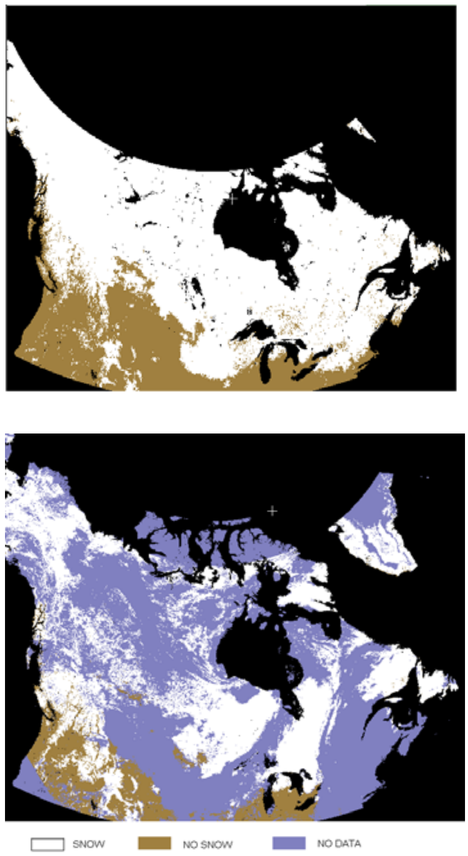

Figure.4. Snow cover extents by a) GOES+SSM/I and b) MODIS product (March 22/2001)

III. CONCLUSION

This study explores the accuracy of three daily snow cover products over Canada: SPOT VGT, MODIS and NOAA GOES+SSM/I. It was found that the VGT product is not applicable for the retrieval of snow cover in Canada. A high agreement between the satellite observations and surface measurements are seen with both the MODIS and NOAA products. The NOAA product shows the most prominent results due to the advantage of the microwave sensor.

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