Validation of MODIS Snowcover Products in Romania. Methodology and conclusions

C. Flueraru, G. Stancalie, E. Savin, V. Craciunescu
National Meteorological Administration, Remote sensing & GIS Laboratory
Bucharest, Romania
cristian.flueraru@meteo.inmh.ro

SUMMARY

An accurate monitoring of snow cover extent (SCE) is an essential goal for the scientific research of the Earth Systems. The MODIS Snowcover product is one of the many geophysical products derived from MODIS data. The improved spatial resolution, snow/cloud discrimination capability and global coverage of the MODIS allow a significant improvement of the studies of snow. A validation of this product was conducted for the entire territory of Romania in order to derive our own quality assessment. This validation time interval was from 29th October 2004 to 1st May 2005 (due to an unexpectedly long winter season). The main part of the study consisted of a cross-validation between MODIS data and daily data from the meteorological network stations. The conclusions were detailed for elevation levels, types of landscape and percent of forest cover. Additionally, validations using ASTER high-resolution imagery and SPOT-VGT S10 mid-resolution imagery were performed.

KEYWORDS: *Remote sensing, snowcover, MODIS, earth observation systems*

INTRODUCTION

Alpine snowcover and its subsequent melting dominate mid-latitude climate and hydrology especially in mountainous regions, which in Romania represent approximately 30% of its territory. Due to recent changes in climate dynamics it is very important to understand and monitor the trends of this valuable resource – the alpine snowcover. In the recent research, scientists have investigated snow pack dynamics and snowmelt through spatially explicit models (Painter, 2001), which require both field observation and remote sensed data as inputs. Measurements of snow properties using in-situ observation provide direct determination, but at limited spatial and temporal extent or resolution. In Romania it a model that uses data from the meteorological station network and on-field measurements it is already functional (Flueraru, 2005). Nevertheless remote sensing techniques can regularly and safely provide a map of snow properties, under limitations imposed by instrument passes or cloud cover. The Snow Runoff Model (SRM) has already been used successfully for this purpose (Snow Runoff Model – developed by J. Martinec). It uses both ground observation and RS data and may be a good alternative for the existing methodology of estimating the amount of water stored in the snowpack.

DATA USED

A very efficient mean of monitoring the SCE is by remote observation from satellites. MODIS, medium resolution optical imagery is particularly useful for this task because of its possibility of performing frequent repeat observation (two sensors on-board of two different platforms) and possessing good radiometric capabilities (36 spectral intervals). These features recommend the use of RS techniques together with MODIS data as adequate for an accurate estimation of the SCE.

MODIS DATA

On December 18, 1999, the Earth Observing System (EOS) Terra spacecraft was launched with a complement of five instruments, one of which is Moderate Imaging

Spectroradiometer (MODIS). MODIS is a major instrument on the Earth Observing System. The MODIS instrument provides high radiometric sensitivity (12 bit) in 36 spectral bands ranging from 0.4 µm to 14.4 µm in wavelengths. It provides medium-to-coarse resolution imagery with a high temporal repeat cycle (1-2 days). The MODIS snowcover product is one of the many geophysical products derived from MODIS data. The improved spatial resolution (500m), the snow/cloud discrimination capability and the global coverage of the MODIS sensor enabled a significant improvement of the snow studies. MODIS snow mapping algorithm (Hall, 2002) is used be used to discriminate snow from other surface types. For this study, mainly MODIS 10A1 products, available from NSIDC (National Snow and Ice Data Center, Boulder –Colorado, USA), were used.

Research methodology – MODIS vs. meteorological data

For Eastern Europe's territory there was no accuracy study available for this imagery. References were found only for the northern part of Europe (references???). So, we had to derive our own quality assessment for the input data, before switching to a new methodology. The validation was conducted for the entire territory of Romania, with a special regard on the mountainous regions where the main reservoirs are located (should I point here all the 4 validation techniques that will be explained in the next part?). The validation time interval was from October 29. 2004 to April 1, 2005. The main part of the study consisted of a cross-validation between MODIS data and data from the meteorological network stations. Both imagery and text files containing meteorological information – such as cloud cover, snow depth and snow density –, were integrated into GIS environment using ArcGis 9 solutions, - see figure 1. MODIS imagery was first imported from the original "hdf" format in a more friendly "geo-tiff" format. This operation was carried out using HEGTool and MODIS Reprojection Tool provided freely by NASA Research Department. The meteorological data were stored in daily shapefiles, each point corresponding to a meteorological station, and overlaid on to the corresponding MODIS images. By linking the shapefiles with the ORACLE server, it was possible to perform a daily update of the information stored in these files. The information from 153 days was used for the validation, with 159 – 163 observation points/day (some of the high altitude stations had gaps in transmitting data during the winter season). A total of 24233 values from MODIS images were analyzed and checked with meteorological data from the meteorological station network. We found that the 68.24% (16539 values) from the initial set of data derived from MODIS images were useless because of high cloud-cover on MODIS imagery. The rest of 7293 values were compared with the ground truth data and divided into the five following categories: a) correct - snow or snow free land on both meteorological data and satellite imagery, coded as 0; b) error type 1 - snow on MODIS imagery but no snow in the meteorological observations - coded as 1; c) error type 2 - snow free land on MODIS imagery but presence of snow in the meteorological observations; snow depth has to be higher than 5 cm for this type of error - coded as 2; d) error type 3 - snow free land on MODIS imagery but presence of snow in the meteorological observations; snow depth has to be less than 5 cm for this type of error - coded as 3; e) error type 4 - clouds on MODIS imagery - coded as 4; f) error type 9 (NODATA either on MODIS imagery / meteorological data) – coded as 9. The errors coded as 4 (clouds on MODIS imagery) and 9 (NODATA in MODIS /meteorological data) were assumed as not useful data.

Only 33.5% of the initial set of data was used for the further cross-analysis, -since 66.5% of the data were classified as “not-useful”, due to errors type 4 and 9-. Following the report useful/not useful data along the study’s timeline, 4 major “peaks” were noticed – see figure 2: early November (100% of the data could be used for cross-validation at 05.11), early January (88.05% - 11.01), early February (74.21% - 09.02) and mid-March (94.34% - 23.03). It is observed that the most contributing results for this study were obtained the mid-winter cloud-free periods, i.e. -January and February-.

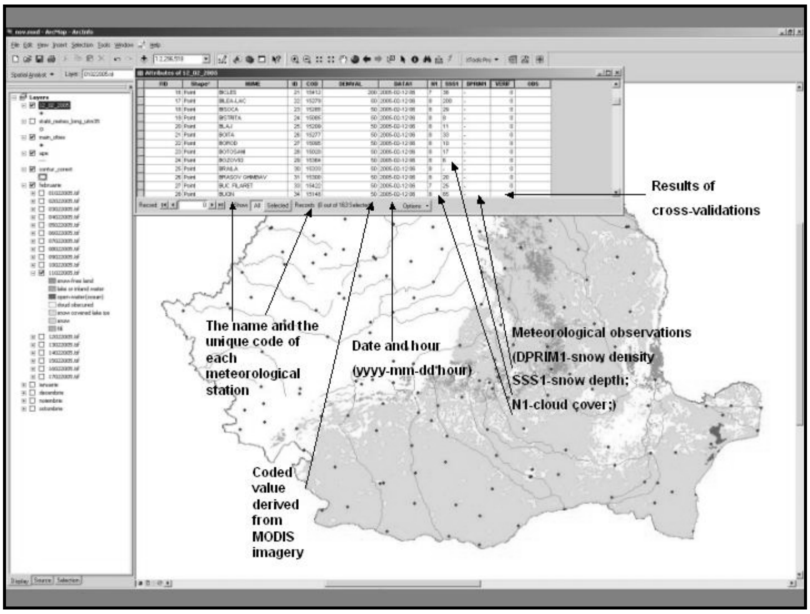

Figure 1: Snapshot of the cross-validation between MODIS MYD10A1 snow cover products and data from the meteorological station network stored as an element of geodatabase in a GIS environment.

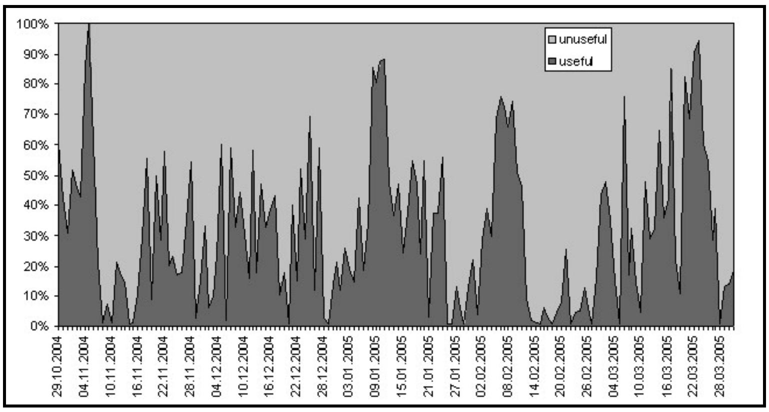

Figure 2: The distribution and the reports of the useful/not useful data over the study timeline.

The overall accuracy for the whole set of cloud-free useful data proved to be 95%. This includes all the common snow-situations: late-autumn fresh snow, winter "highly reflecting" snow and early-spring wet snow. The figure 3 summarizes the errors, which were calculated for each month the following, after the cross-validation:

#	Month	No. of obs.	% of not useful data (high-cloud cover, no data)	% of useful data	Results of the cross-analysis (% of total useful data)				No. of snow obs. on Modis imag. for meteo st.
					0	1	2	3	
1	Oct.	476	55.67	44.33	100.00	0.00	0.00	0.00	0
2	Nov.	4764	70.07	29.93	97.12	0.63	0.70	1.54	59
3	Dec.	4937	71.06	28.94	92.23	0.42	3.43	3.92	217
4	Jan.	4916	65.44	34.56	95.23	0.88	2.18	1.71	305
5	Feb.	4439	76.32	23.68	97.15	0.38	2.00	0.48	944
6	Mar.	4929	60.66	39.34	93.24	2.01	2.06	2.68	478
7	**Total**	**24461**	**66.54**	**33.46**	**95.83%**	**0.72%**	**1.73%**	**1.72%**	**2000**

Figure 3: Cross-validation of MODIS MYD10A1 snow cover products: the types of errors returned for each month of the studied period (October 2004 – March 2005)

The results show that for the months of February and March, an important number of snow observations (944 and 478) on the pixels corresponding the meteorological stations were recorded. This is due to the both clear sky conditions and long winter season. It turned out that the highest accuracy (>95%) was registered in the "real" winter months, January and February. During the "pre- / post- winter" seasons (months of December and March) the accuracy dropped to 93%.

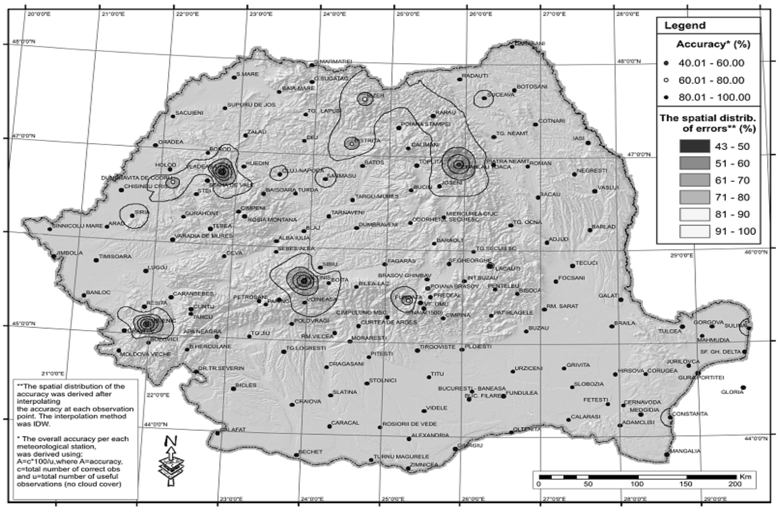

Figure 5: The spatial distribution of the accuracy for MODIS 10A1 products in regard with ground-truth data from the meteorological station network, over Romania's territory, during 29.10.2004 - 01.04.2005.

Out of 164 checkpoints of the initial data set, 7 were excluded after the cross-analysis due to the lack of the data or discontinuity in meteorological measurements. Figure 5 provides the spatial distribution of the accuracy for the MODIS products during the study's period. This information was derived interpolating the accuracy for each of the checkpoints (the remaining 157), which returned the general accuracy of 95.83%. The lowest values were recorder in mountainous areas at Vladeasa-1800 and Semenic meteorological stations (less than 50%).

As previously stated, the initial set of data used for validation originates from the 164 active meteorological stations located across Romania. All these stations are situated in locations characterized with different land cover and morphological attributes, parameters that significantly influence the quality of the validation results. All the 164 meteorological stations were classified based on their land cover (fig. 4), slope and elevation. This way the most important geographic attributes of the validation dataset were determined and stored as attributes of vector point themes. Two sets of land cover data were used in order to classify each meteorological station based on the land cover attribute: MOD12Q1 land cover dataset and CORINE 2000 land cover dataset. There were 46 errors between the two land cover datasets (28.9% of the total set of meteorological stations). The most frequent confusions were drawn where the meteorological stations are located near built-up areas/large water bodies, because of the different spatial resolution of the datasets (more than 50% of the errors). Since the purpose of the study did not require very detailed land cover information, only the MOD12Q1 land cover dataset was used (for its high temporal resolution, although the CORINE land cover dataset has more details). This way, the information could be structured in 5 classes instead of 11.

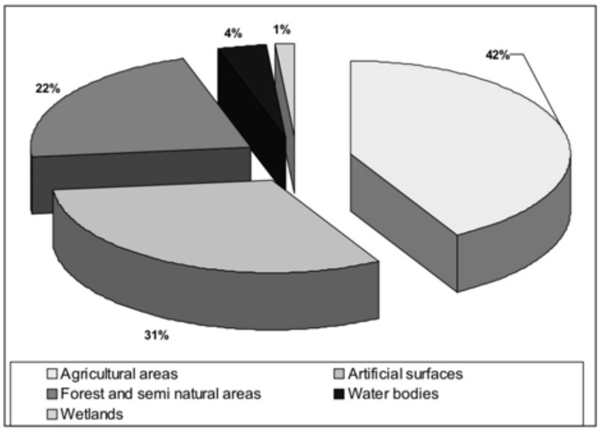

Figure 6: The distribution of land cover classes (source = MODIS MOD12Q1 land cover dataset) for the 164 meteorological stations used in this study.

Most of the validation information (>40%) comes from agricultural areas, which are particularly adequate for snow cover extent determination because their uniform landscape.

The morphometric information was derived from SRTM (Shuttle Radar Topography Mission) digital elevation model. According to the information provided by this set of elevation data, 71% of the meteorological stations are situated below 500m and 25% between 500 and 1500m, where snow cover has a major extent mostly during the months of January and February. Only 4% of the meteorological stations are located in mountainous areas (1500-2500m). This explains why in the months of November and December only 59 snow pixel observations in the corresponding meteorological stations were recorded. 60% of the meteorological stations are situated in locations favorable for snow accumulation with slope < 3^o. The rest of the meteorological stations are situated mostly between slope values of 3^o and 15^o (30%), only few meteorological stations over 15^o slope (10%).

#	Type of landcover	# of checkpoints	%of total checkpoints	# of obs.	%useful data	accuracy
1	Agricultural areas	66	42.04	10051	31.92%	96.79%
2	Artificial surfaces	49	31.21	7448	31.72%	95.41%
3	Forest and semi natural areas	34	21.66	5287	29.42%	89%
4	Water bodies	6	3.82	912	45.83%	98.27%
5	Wetlands	2	1.27	305	37.40%	98.18%

Figure 7: The accuracy of the MODIS for each landcover category (source for landcover – the MODIS MOD12Q1 land cover dataset)

Based on the information derived from the MODIS MOD12Q1 land cover dataset, the validation points were grouped and analyzed based on their type of landcover (see figure 7). The lowest accuracy was recorded over the forest and semi natural areas: 89% (only 29% of the total set of data was considered to be "useful" – no clouds). Values close to the overall average were derived for agricultural areas and artificial surfaces

MODIS VS. HIGH RESOLUTION ASTER DATA

Additionally, a validation using high-resolution imagery was performed over a 261000-km^2 ASTER mosaic from 31.01.2004. The use of imagery from 2004 was imposed by the lack of useful, cloud-free ASTER images for the period of the study. The mosaic covered, the plains and high-land in the eastern part of the country up to Ukraine's border, but also the mountainous area in the central-eastern part of Romania. Since only 25 meteorological stations are located in such areas, the aim of this validation was to check MODIS' snow detection algorithm performances for forested mountainous areas. The ASTER images were acquired between 9.26 and 9.40 AM. They were confronted with a MYD10A1 image from the same day, ~11.00 AM. Two validation were carried out on this mosaic, using 2 approaches. First, 107 randomly chosen points, covering all types of altitudes and ground cover, were chosen. The technique used for the validation was the one of visual interpretation (the high-spatial resolution of ASTER imagery allowed this). 81 checks (out of 107 checks, 6 of the observation points couldn't be used because of the presence of the clouds on one of the images) – 76% proved to be correct and 23 errors were recorded – 24%. The overall accuracy for this validation was 76%. Since 107 points wasn't enough for such a big area (an average of 1 point 243/km^2), another validation was carried out using 5000 random distributed points (an average of 1 point 5/km^2). This time, an automatic approach was tried using "classic" relevant indices: NDVI and NDSI - Normalized Difference Snow Index (Dozier, 1989). Four types of situations were encountered,: a) correct - snow or snow free land on both MODIS / ASTER data, coded as 0; b) error type 1 - snow on MODIS imagery but no snow on ASTER images - coded as 1; c) error type 2 - snow free land on MODIS imagery but presence of snow on ASTER images- coded as 2; d) error type 4 - clouds on MODIS or ASTER imagery - coded as 4. Out of the initial set of

5000 validation points 874 (17% of the whole set of check points) were classified as “clouds”. For the rest of the checking points an overall accuracy of 83.64% was derived – see figure 8.

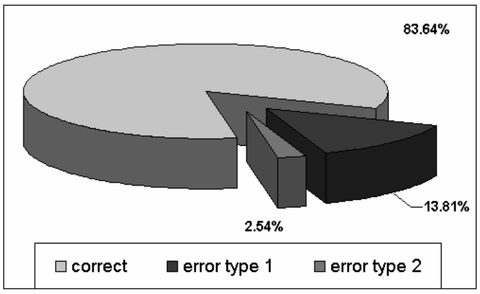

Figure 8: The accuracy for MODIS MY10A1 products in regard with ASTER data for 31.01.2004

MODIS VS. SPOT-VGT (VEGETATION) DATA

VGT products (e.g. Passot, 2000) consisting of red, near-infrared (NIR) and short wave infrared (SWIR) apparent surface reflectance channels, gridded at 1km resolution, formed the input to the snow cover mapping method used to produce the VGT snow cover maps (e.g. Simici). For this study S10 – ten-day synthesis – were available. The main method for the realization of snow cover maps is the thresholding of the NDSI index (Normalized Difference Snow Index). NDSI is useful for differentiating snow from other materials or elements having an intense reflectance, similar to that of snow. Jeff Dozier developed it mainly for LANDSAT imagery (e.g. Dozier, 1989). It is calculated using the information in visible (green) and medium infrared spectra. In order to compensate the spectral differences between LANDSAT and VGT sensor, a new index - Normalized Difference Snow and Ice Index – was developed, as revealed by Xiao, 2001. This new index was successfully used for snow mapping in Feno-scandia (e.g. Dankers).

MODIS images were down-sampled to 1km and 10-day syntheses were computed for the cross-analysis. However, for this study, the 1km spatial resolution and the 10 days temporal resolution of the VGT S10 products proved to be, in most of the cases, inadequate. Finally, considering also the fact that S10 SPOT-VGT products are not free resources (yet) and they can’t be implemented into operational tasks, the cross-validation MODIS – SPOT-VGT was performed only for testing the methodology.

MODIS VS. EXPEDITIONARY GROUND TRUTH DATA.

For the purpose of the qualitative analysis of the MODIS daily snowcover products, 6 field trips were made in the period from November 28, 2004 to December 19, 2004. The field trips were made mostly in mountainous areas of central Romania (Bucegi Mts., Fagaras Mts. and Baiului Mts.). For each field trip, GPS tracks and digital photos were acquired, where each photo had its localization marked by a GPS waypoint. Later, in a GIS environment, these information were overlaid onto the MODIS MYD10A1 image of the corresponding day. The overall qualitative conclusion was a positive one for high mountain plateaus or large clearages, with some question marks for the very dense coniferous forest.

CONCLUSIONS.

At the data when this study started (10.2004) these products were considered "provisional", meaning that the products were partially validated, with incremental improvements till occurring. They were considered early science validated products, useful for exploratory and process scientific studies. Since this study took place inside the main frame of a semi-operational project – "Estimation of snow water equivalent stored in the snow pack for the main Carpathians watersheds" (Flueraru, 2005), a realistic quality assessment for these products was needed. The results of the study encouraged the use of MODIS MYD10A1 products as new variable for this project. Additionally, the use of daily information about snow cover extent, allowed the use of SRM (Snow Runoff Model – developed by J. Martinec) for the above-mentioned project.

Based on the positive quality assessment obtained after this study, a cross validation started between MODIS daily snow cover maps and daily snow cover maps obtained by the interpolation of meteorological data. The study started early December 2005 and it is ongoing.

Correlations between albedo from MODIS imagery and forest cover or other various morphometric indexes are possible. For small test sites, (Flueraru, 2005) these analyses were already performed with high confidence coefficients. The new research efforts will move now towards correlations between MODIS albedo and density of snow (extracted from the meteorological dataset).

BIBLIOGRAPHY

R. Dankers, S. de Jong, "Monitoring snow cover dynamics in northern Fennoscandia with Spot Vegetation images," in press.

Dozier J., 1989, Spectral signature of Alpine snow cover from Landsat Thematic Mapper, Remote Sensing of Environment, 28, 9 – 22

D. Hall, G. Riggs, V. Salomonson, N. DiGirolamo, K. Bayr, "MODIS Snow-cover products," Remote Sensing of Environment, vol. 83, pp. 181-194, 2002.

C. Flueraru, G. Stancalie, S. Catana, E. Savin - " Estimation of snow cover extent in Carpathians Mountains using integrated GIS and remote sensing information ", « RAST 2005 – Proceedings of 2nd International Conference on Recent Advances in Space Technologies » IEEE Catalog number 05EX1011

C. Flueraru - Estimation of Snowcover Extent in Carpathian Mountains Using Fusioned GIS and Remote Sensing Information, On-line Magazine 'Sensors & Transducers' (S&T e-Digest) (ISSN 1726- 5479)

MODIS/Aqua Snow Cover Daily L3 Global 500m Grid – National Snow and Ice Data Center, Boulder-Colorado, USA http://nsidc.org/data/myd10a1.html

Martinec, J., Rango, A., Major, E: The Snowmelt-Runoff Model (SRM) User's Manualhttp://hydrolab.arsusda.gov/~rroberts/srmmanual/srmman.html

T. Painter, J. Dozier, D. Roberts, R. Davis and R. Green, "Retrieval of subpixel snow-covered area and grain size from imaging spectometer data", Remote Sensing of Environment, vol. 85, pp. 64-77, 2003.

X. Passot, "VEGETATION image processing methods in the CTIV," Proceedings of Vegetation-2000 Symposium, Lake Maggiore, Italy, 2000.

A.Simic, R. Fernandes, R.Brown, P.Romanov, W. Park, "Validation of VEGETATION, MODIS, and GOES+SSM/I Snow Cover Products over Canada Based on Surface Snow Depth Observations," unpublished.

X. Xiao, Z. Shen, X. Qin, "Assessing the potential of VEGETATION sensor data for mapping snow and ice cover: a Normalized Difference Snow and Ice Index," International Journal of Remote Sensing, vol. 22, pp. 2479-2487, 2001.