



Estimation of Snowcover Extent in Carpathian Mountains Using Fused GIS and Remote Sensing Information

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Abstract: The alpine snowcover in the mid-latitudes is important in risk management, climatic and hydrologic context. An accurate mapping of snowcover and estimation of snow characteristics requires snow to be distinguished from other surface cover and from clouds. In order to become useful, the information about snow characteristics, have to be available for large areas and to be provided on regular bases for various types of users. MODIS sensors together with GIS data can provide this kind of information but their joint use require a long-time validation. This validation was carried out fusing meteorological data together with satellite observation and GIS information.

Keywords: GIS, remote sensing, meteorological data

1. Introduction

The management of the water resources in Romania represents a major issue considering the fact that the natural potential of the watercourses is rather reduced and altered by over-use. An efficient and rational management of water resources involves also the estimation of water resources stored in the snow pack in Carpathian basins [1]. Mapping of snow and estimation of snow characteristics from remote sensed data requires the performance of an accurate distinction between snow and other high reflective surface and compensate for the effects of the atmosphere and rugged terrain. Over the last two decades satellite remote sensing has opened the possibility of data acquisition at regular intervals and operational modes. Remote sensing of the seasonal snow cover has been used to improve the monitoring

of existing conditions and has been incorporated into several runoff forecasting and management systems such as Snow Runoff Model [2]. The test areas used for the evaluation of the snowcover resources are located in the upper stream of the main Romanian hydrographical basins associated with reservoirs like: Arges, Lotru, Ialomita, Dambovita, Somes, Bistrita, etc.

2. Data Used

The data used in the assessment and monitoring of the snow pack characteristics are provided by satellite and ground information as shown in Figure 1:

Input data	Spatial resolution	Temporal resolution
High resolution satellite imagery	14.5 m	~ 15 days *2
Topographic maps scale - 1:25.000	2 m *1	1981 maps are available
Digital elevation model	90 m	2000 SRTM DEM *3
Field observations	GPS located	2-3 field campaigns/year
MODIS MYD10A1	463.3 m	Daily data
MODIS MYD10A2	463.3 m	8 day synthesis
SPOT VEGETATION	1 Km	10 day synthesis
Data provided by the meteo station network	GPS located	Daily data
*1 – resolution obtained after scanning/geocoding of the 1:25.000 naps *2 – despite Landsat’s 15 days temporal resolution, for this project were available images from 1989, 2000 and 2002. *3 – for small test areas 5m DEMs were derived from 1:25.000 maps		

Fig. 1. *Data used as input for the GIS database creation and for operational purposes – spatial and temporal resolution.*

This approach is required by:

1. The complex physiographical particularities of the Carpathian watershed and their relatively restricted area, which requires the use of the large-scale imageries;
2. The necessity of determining both the extent of the snow cover and its condition, which requires the use of multispectral image-data;
3. The maximum stored amount of snow and the snowmelt process have a great instability in time. A continuous surveillance of the snow cover will be required, especially during the winter-spring season. This will impose the use of daily satellite imageries together with the data from the meteorological station network.

The snow cover water resources evaluation is based on geocoded spatial information organized in a GIS database as shown in Figure 2. The geo-referenced information may be used as separate layers or interconnected in order to extract useful information for a correct and accurate estimation of snow pack conditions and snow water resources, during the winter-spring period.

Input	Output
Landsat 7ETM+ imagery	- land cover update - deriving specific indexes such as NDVI, NDSI etc.
1:25.000 topographic sheets	- sub-basin delineation - hydrographic network
SRTM 90 DEM	- morphometric information such as elevation, slope, aspect etc.
MODIS MYD10A1	- daily information about snow cover extent and albedo
On field measurements	- on-field mapping - AOI for classifications

Fig. 2. GIS database creation: input information and the derived products using GIS/remote sensing techniques.

3. Remotely Sensed Data

As shown in the first part of this study, an accurate monitoring of snow cover extent (SCE) is itself a goal for the scientific research of the Earth Systems. The most efficient mean of monitoring the SCE is the remote observation from satellites. Fortunately, the physical properties of snow make this purpose highly adequate. Medium resolution optical imageries are particularly useful for this task because of frequent repeat observation and good radiometric capabilities.

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 in wavelength from 0.4 μm to 14.4 μm . It provides medium-to-coarse resolution imagery with a high temporal repeat cycle (1-2 days). Bands 1 and 2 provide 250 m resolution images in the red and near-infrared regions. Bands 3-7 provide 500 m resolution multi-spectral images in the visible and infrared region. Finally, bands 8-36 provide hyper-spectral coverage in the visible, reflected infrared, and thermal infrared regions, with a 1km resolution. The 36 bands are grouped in three band segments in which band segment 1 (bands 1-7) observes the land cover features, as well as the clouds and aerosol properties. The purpose of MODIS is to measure the surface temperature, ocean color, global vegetation and deforestation, cloud and aerosols, and snow cover. The MODIS snow cover products are one of the many geophysical products derived from MODIS data. The improved spatial resolution, snow/cloud discrimination capability and global coverage of the MODIS made a significant improvement for the snow study. MODIS snow mapping algorithm [3] will be used to discriminate snow from other surface types. The MODIS snow product classification is based on the normalized difference snow index (NDSI), which is utilized in the fully automated algorithm through a series of thresholds [4]. The process of classification starts with mapping snow covered pixels by applying a threshold to the normalized difference snow index (NDSI), and separating the snow from water, applying a threshold to NIR band. In order to increase snow cover extent within forest areas, where the canopies commonly obscure snow, both NDSI and the normalized vegetation index (NDVI) are used for forest-designated pixels. This differentiates the snow-free and snow-covered forest pixels. Since many snow-covered forests have $\text{NDSI} < 0.4$, a higher NDVI value for the forest areas covered by snow is used to separate these areas from surrounding snow cover open land areas. An additional

threshold of 10% green spectral band reflectance is used to reduce commission errors over forests. Additionally, a thermal mask using infrared bands 31 (10.78-11.28um) and 32 (11.77-12.27um) is used to further differentiate snow from clouds [8]. For this study, MODIS 10A1 products available from NSIDC (National Snow and Ice Data Center, Boulder – Colorado, USA) appeared to be the most useful. But these products are considered "provisional", as in [5], meaning that the products are partially validated; incremental improvements are still occurring. These are early science validated products and are useful for exploratory and process scientific studies.

4. Validation of MODIS Products Using Fused Meteorological/Remote Sensed Observations

A validation of these products was conducted for the entire territory of Romania in order to derive our own quality assessment for these products. This validation began on 29 October and is still ongoing (May 2005) at this time due to an unexpectedly long winter season. The main part consisted in a cross-validation between MODIS data and data from the meteorological network stations. Both imagery and text files containing meteorological information (cloud cover, snow depth and snow density) were integrated and fused into GIS environment using ArcGIS 9 solutions, as in Figure 3. This way it is possible to add a spatial component to the qualitative information provided by the meteorological station network.

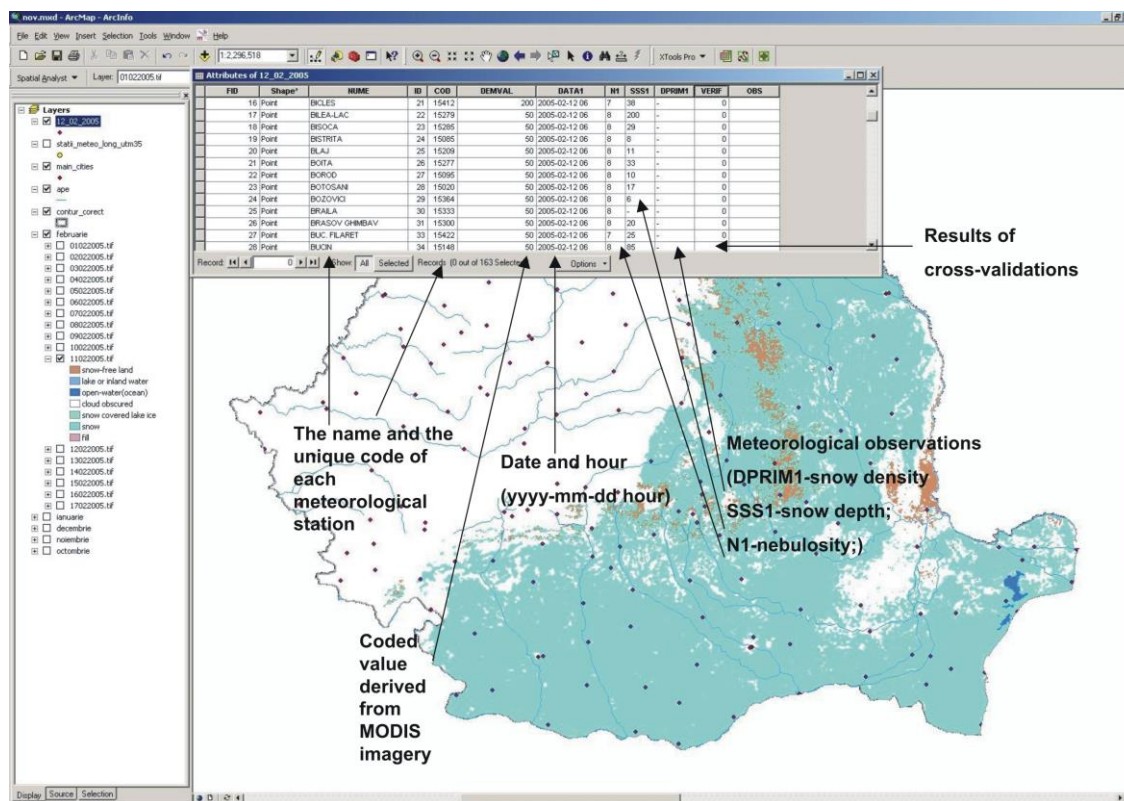


Fig. 3. Cross-validation of MODIS MYD10A1 snow cover products: MODIS values vs. data from the meteorological station network.

Considering the fact that the validation is not over, it is not possible yet to classify in any way MODIS' products accuracy in snow mapping over Romania's territory. So far the main problem that we deal with was an often presence of dense cloud cover. This allowed only about 30-40% of the in-situ observation

to be used for the validation. Additionally, a validation using high-resolution imagery was performed over a 35000-km² ASTER mosaic from 31.01.2004. 213 randomly chosen points, covering all types of altitudes and ground cover were overlaid. 75% accuracy was obtained for this validation. During December 2004 weekly field trips were done in the most important mountainous areas for ground truth evaluations of the quality / accuracy of MODIS snow cover maps. According to other researcher's experiences with this type of information in northern latitudes [6, 7], the preliminary results encouraged the use of this kind of data.

5. Results Based on the Fused Data

The achievement of snow cover maps on daily bases was possible for the test areas. Using the information available from the GIS database, pixels classified as "snow" were classified in various classes of confidence as in Figure 4 based on their forest cover derived from LANDSAT 7 ETM+ 10.02.2002 supervised classification. A high degree of confidence will be assigned to the pixels in the northern part of the test site, corresponding to high-mountain areas, based on this association.

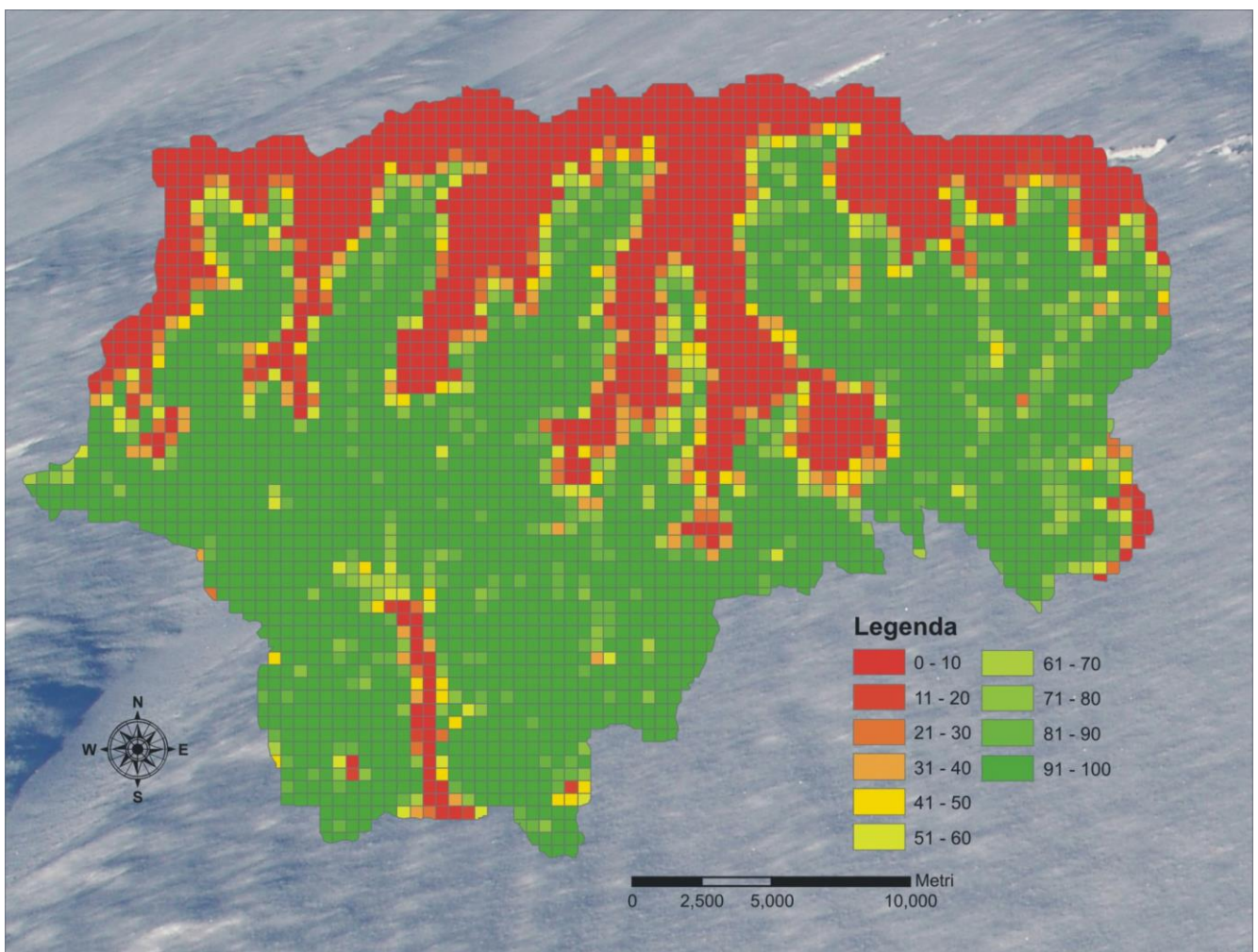


Fig. 4. Classification of the MODIS pixels considering their forest cover derived from LANDSAT 7 ETM+ 10.05.2004 supervised classification.

A morphometric index (Surface Area Ratio - SAR) was computed based on the same SRTM 90 DEM. SAR represents the relation between real surface and the plan projection of the surface and will have always values higher than 1, because real surface will always be bigger than its plan projection. Again, MODIS pixels were classified based on this index as shown in Figure 5.

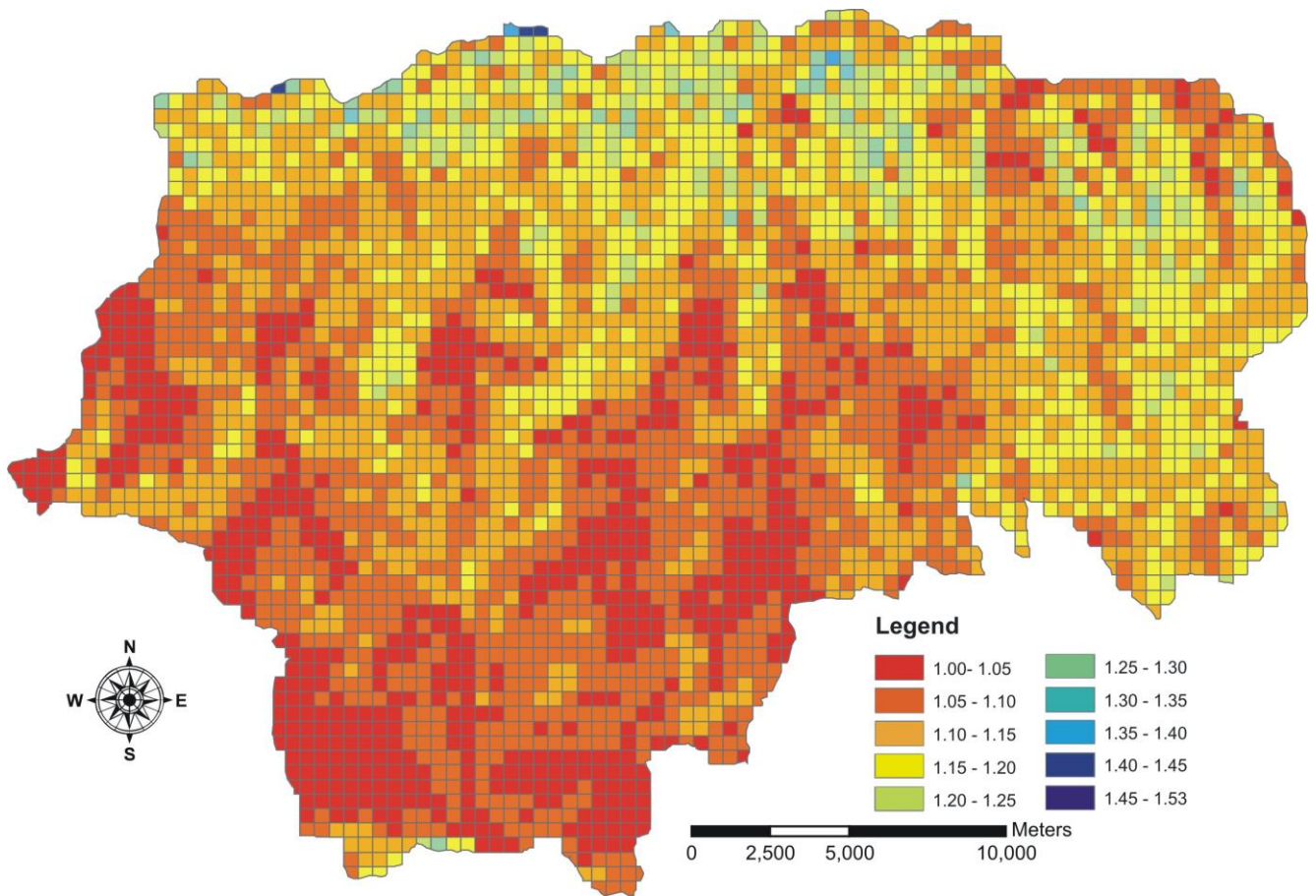


Fig. 5. Classification of the MODIS pixels considering their Surface Area Ratio derived from SRTM 90 digital elevation model.

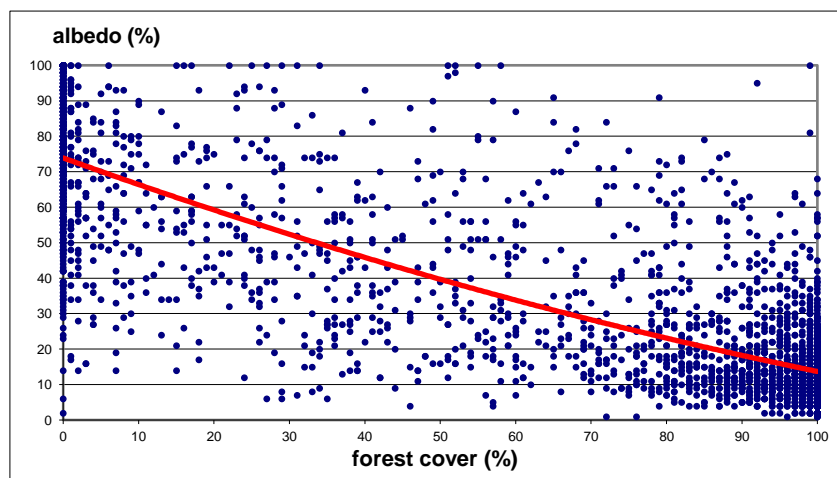


Fig. 6. Correlation between snow albedo and forest cover for Arges test site, based on MODIS MYD10A1 image from 31.01.2004 and forest cover derived from LANDSAT 7 ETM+ 10.05.2004 supervised classification.

Using the MODIS MYD10A1 data available for the Arges test site on 31.01.2004 a correlation between snow albedo and forest cover was realized (Figure 6). Only the pixels classified as “snow” were selected (2198 pixels). The number of pixels can be afterwards reduced based on various degrees of confidence (forest cover < 50% & SAR < 1.25 etc.). Forest cover was derived from LANDSAT 7 ETM+ 10.02.2002 supervised classification.

6. Conclusions

In this paper were presented some facts and early conclusions about fusing MODIS remotely sensed data with ground-truth meteorological observation and GIS layers. The fused data can be used under GIS environment for cross-validation purposes or for identifying particular areas (such as avalanche trigger areas with height > 1600m, slope > 30°, forest cover – pastures or bare soil). Those areas can be marked for future remote sensed monitoring (on long time series of data) or for on-field measurements.

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