We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

6,900
Open access books available

186,000
International authors and editors

200M
Downloads

154
Countries delivered to

Our authors are among the

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Predictability of Water Sources Using Snow Maps Extracted from the Modis Imagery in Central Alborz, Iran

Seyed Kazem Alavipanah[*], Somayeh Talebi and Farshad Amiraslani
Faculty of Geography, Department of Cartography, University of Tehran, Tehran
Iran

1. Introduction

1.1 Snow reserves and remote sensing

Snow reserves in mountainous basins are important and reliable water resources in Iran. Identification of their quality is necessary because of an increasing value of freshwater and utilization of water recourses. About 60 percent of surface water and 57 percent of ground water sources in Iran flows in snowy regions (Rayegani, 2005). The water produced from snowmelt process provides soil water, ground water reserves and water in lakes and rivers. Since snow cover is one of the most important sources of provided water, an accurate prediction and timing of snow runoff is necessary for the efficient management and decision- making in water supply.

The science of snow hydrology, compared to other branches of hydrology science, has a relatively shorter history due to difficulties accompanied with snow measurement. The correct analysis of snow issues needs a set of observations and statistics in snow-gauging. Currently, however, there are no regular and comprehensive snow measurement procedures in most parts of Iran. Measurements are only limited to those snowy basins recharging important dams; even these measurements are carried out in scattered points rather than an entire dam catchment area.

The measurement range of these stations is limited to 2000-3000 m asl heights. Thus, in mountainous Iran, current distribution of stations would not seem to be adequate. In such conditions, study of snow reserves and identification of snow melting trend in most basins would be accompanied with limitations. Consequently, measuring snow cover using ground methods will be difficult and costly. Remote sensing technology has many applications in various environmental and earth resources studies including ice and snow research. These applications have been increased recently as a result of unique technical advantages such as multi-temporal imagery acquired in various wavelengths, extent of spatial coverage, and improvement of computer hardwares for interpretation and extraction of information. Regarding snow research, remote sensing technology can provide

---

[*] Corresponding Author

continuous information layers with higher accuracy and lower cost compared to the ground survey, so it can fill the information gaps in snow hydrological statistics. However, using ground data can increase the efficiency of remotely-sensed measurement of snow-gauging. Satellites are appropriate tools for gauging snow coverage, because of high reflection of snow that creates proper contrast to most of natural surfaces (with the exception of clouds). Therefore, using satellite imagery and GIS modeling one can produce snow-cover maps, assess the changes in snow cover area with various time series, discriminate snow from other features, and model it in a catchment area. These simplify decision-making process for engineers and hydrology managers.

One of the important issues in remotely-sensed snow-gauging is the selection of sensor. Some of optical sensors that have ever used in snow-measuring include sensors mounted to satellites namely TIROS-1 (1960), ESSA_3, NOAA (1996), LANDSAT (MSS and ETM), and MODIS (2000). Since each sensor has unique properties, a sensor with appropriate spectral, temporal and spatial resolution for snow-gauging must be selected. Since snow is a phenomenon with noticeable surface changes over time, it is necessary to select a sensor that produces proper multi-temporal series. Snow-gauging is done in vast areas, and snow surface is generally even; therefore, MODIS is an appropriate imagery for this purpose. From the view point of spectral resolution, MODIS is one of the best optical sensors for studying snow and discrimination of snow from phenomena such as cloud which has similar spectral reflectance.

One of the purposes of designing of MODIS is a global identification of various types of clouds; hence, several bands have been considered for it to identify various types of cloud cover, optical thickness, effective radius and thermal phase (King et al., 2004).

NASA (National Aeronautics and space administration) launched TERRA satellite to space on December 18th 1999, and MODIS as one of the five sensors mounted on TERRA transferred the first information to Earth on February 24th 2000. MODIS has 36 various bands in visible, infra-red and thermal parts of electromagnetic spectrum including 2 visible bands with 250 m resolution, 5 infra-red bands with 500 m resolution, and 29 thermal bands with 1000 m resolution (Hall et al., 2000).

1.2 A review on remotely-sensed snow measurement

Various methods have been used to estimate snow surface such as classification methods, threshold limit, decision-based methods, etc. One of the most applicable algorithms used to estimate snow surface is MODIS snow map algorithm. It was introduced in 1998 as a decision-based algorithm which uses group tests of threshold limit for detection of snow. This algorithm has very small volume from the calculation viewpoint and simple from the conceptual viewpoint, thus user can track how product has been created. In addition, this algorithm has an appropriate efficiency with global application (Hall et al., 1998).

Totally the properties of this algorithm include:

1. The precision of this method for various types of snow-covered surfaces for identification of snow surface is higher than other methods such as supervised classification, unsupervised classification and sub-pixel methods provided that atmospheric correction is considered (Dadashi Khaneghah, 2008).

2. This method is a completely automatic algorithm.
3. This algorithm is applicable for all regions in the globe.
4. This method is simple, accurate and easy to understand.

Snow Map algorithm uses normalized subtractive index (NDSI). Lee et al. (2001) compared MODIS snow maps created with NDSI index with maps prepared by National Operational Hydrologic Remote Sensing Center (NOHRSC, prepared automatically by GOES and NOAA images) in upper region of Rio Grande reservoir. In NOHRSC, the teta algorithm is used. In this algorithm, two classified images are subtracted to identify snow surface. In teta algorithm, two separate threshold limit is introduced for each image. Lee et al. (2001) concluded that both images are affected by cloudy condition and the main error is cloud coverage. They also mentioned that maps produced from MODIS were more accurate than the above-mentioned maps.

Ault et al. (2006) concluded that MOD10-L2 snow surface product, MODIS sensor, in clear sky condition had the highest accuracy. They showed that the highest error was associated with those conditions that snow depth was lower than 1 cm; thus the higher was the snow depth, the higher was the accuracy. Hall et al. (2000) also showed a low accuracy of low-mass and patchy snows in New England. Klein and Barnett (2003) carried out a snow cover study using MODIS in Rio Grande reservoir during the 2000-2001 period and compared their results to the ground-measuring methods such as snowpack telemetry (SNOTEL) and NOHRSC models. They ultimately concluded that the highest error associated with maps prepared by MODIS was related to the beginning and end of snowfall period. They showed that when the surface was completely covered by snow with no mixed cloud, ground survey or SNOTEL had the highest accuracy.

It can be mentioned that MODIS sensor and NDSI index are appropriate in snow map preparation, although cloud coverage and classification are regarded as constraints (Klein and Barnett, 2003; Zhou et al., 2005). In fact, in spite of various advantages, Snow Map algorithm has some limitations due to inseparability of snow cover from cloud and similarity of cloud behaviours to snow cover. This algorithm cannot completely distinguish clouds from snow (of course, this problem is relatively removable by using Cloud Mask algorithm). Also, this algorithm cannot detect coastal terrains which are similar to snow from viewpoint of whiteness and brightness. However, temperature can act as factor to discriminate snow from these terrains using MODIS bands 31 and 32. Since Cloud Mask and thermal Mask are used before applying algorithm, some error sources in snow map algorithm will be removed (Taghvakish, 2005; Adhami, 2005).

In snow-gauging using satellite imagery, the existence of cloud is problematic due to the following reasons (Riggs and Hall, 2002): first, clouds conceal Earth information; second, clouds create shades on area and change reflectance. Indeed, if clouds cannot be detected well, they will reduce the accuracy of snow map.

Clouds and snow have generally similar spectral reflectional properties in range of visible and infra-red spectra, so thermal properties is not enough for distinguishing them from each other as clouds may be cooler or hotter than snow (Singh and Singh, 2001). In order to detect clouds, a procedure called Cloud Mask algorithm is being used. Akerman et al. (1998) introduced MOD35 Cloud Mask algorithm. MOD35 algorithm is based on obstruction of Earth surface affected by cloud or dust particles that identifies water body, land and atmosphere (Strabala,

2003). In this process, based on land type, geographical position and available data, Cloud Mask algorithm uses 14 bands amongst 36 bands of MODIS to test 18 spectral and spatial features (Hall and Riggs, 2002). However, this procedure was modified by Hall and Riggs (2002) who presented a new version of Cloud Mask algorithm (Liberal). This algorithm can analyse the pixels located under thin and transparent clouds (Zhou et al., 2005; Ault et. al., 2006). This procedure identifies the darkness and if it faces to such darkness, it means that sun angle is higher than 85º. This algorithm is called Liberal Cloud Mask algorithm. In fact, Liberal Cloud Mask algorithm functions as subset of spectral tests of old Cloud Mask algorithm (MOD35) and uses 7 bands of MODIS and set 4 criteria (Hall and Riggs, 2002, 2004).

2. Material and methods

2.1 Study area

The Central Alborz mountainous range extends from 49º 5´- 53º 5´ longitude to 35º 5´- 37º 2´ latitude. Its area is about 40,000 km² and covers 64 sub-basins. The lowest, highest and average altitude of the basin is 48 m, 5671 m and 1870 m, respectively. The minimum, maximum and average slope is 5%, 25.4% and 23.56%, respectively. The main slope aspect of this region is directing towards north and south. Climatically, the region is classified to three classes as temperate in north, cold in center, and semi-arid in south. Geological structures mostly consist of mild outcrops that are inconsistent with general trend of east-west. In western part of Alborz, the structures have northwest-southeast trend, but in eastern part, the structures have northeast-southwest trend. These two inconsistent trends cross each other in Central Alborz.

2.2 Data

2.2.1 MODIS Data, TERRA satellite

MODIS encompasses noticeable number of spectral and thermal bands with narrow width, high radiometric resolution, proper width and collecting time, powerful and accurate calibration, and diverse land resolution (MODIS Home page) (http://modis.gsfc.nasa.gov).

In many cases, MODIS provides satellite snow-gauging requirements and therefore these data were used. In this research, images were provided from website (https://wist.echo.nasa.gov/wist) according to Table 1.

Year	2006	2006	2006	2006	2006	2006
Month	February	February	march	march	march	march
Day	21	25	4	8	13	15

Table 1. Temporal table applied images from MODIS sensor data

The imagery used in this research include MOD02 and MOD09. The MOD02 imagery include 36 bands while MOD09 include 6 bands. In MOD09GA imagery, atmospheric corrections have been done based on 6sv model, as one of the best models in atmospheric corrections with minimum error, suitable for measuring snow surface and detecting cloud from snow (Vermote and Kotchenova, 2008). In MOD09 imagery, corrections have been

implemented in way that atmospheric diffusion and reflection were minimum. Since data with higher wavelength are being less influenced by aerosols, suspended particles and non-selective diffusion phenomenon, thermal bands of MOD02 imagery were used.

2.2.2 Digital Elevation Model

Digital Elevation Model (DEM) obtained from SRTM Shuttle was used. These data that was in format of GeoTiff had Lambert image system. For transformation of this data to UTM coordinates system, PCI Geomatica software was used.

2.2.3 Ground stations data

Snow-gauge station data were obtained from Water Organization- Department of Surface Water. Snow-gauge stations of Central Alborz are located in five basins namely Lattian, Lar, Taleghan, Karaj and Golpayegan basins. In some cases, ground data survey time was not consistent with the time of image acquisition. For solving this problem, in those dates that no ground statistics were available, previous and next day's information were interpolated. Of course interpolation was carried out for those stations where sampling time was close to image acquisition date, and the station had snow cover during the period (February and March). Among sampled stations, 18 stations with above-mentioned conditions were selected.

It is necessary to mention that snow depth data has been used to examine the presence or absence of snow cover. Those gauging stations located far from human interfering features (e.g. buildings) were selected and their snow depth measured. The snow surface was defined an area where surface is regular and even, with the minimum wind blowing effect to increase measurement accuracy (Pfister and Schneebli, 1999). The output spatial resolution of snow map algorithm and Cloud Mask Algorithm is one kilometre. Around each station, up to two kilometres was regarded to include 9 to 13 pixels covering snow. The most repeated pixel shows snowy or not snowy condition. Finally, snow surface obtained from Snow Map Algorithm with and without Liberal Cloud Mask was compared to ground data. Figure 1 illustrates distribution pattern of snow-gauge stations within five basins in Central Alborz.
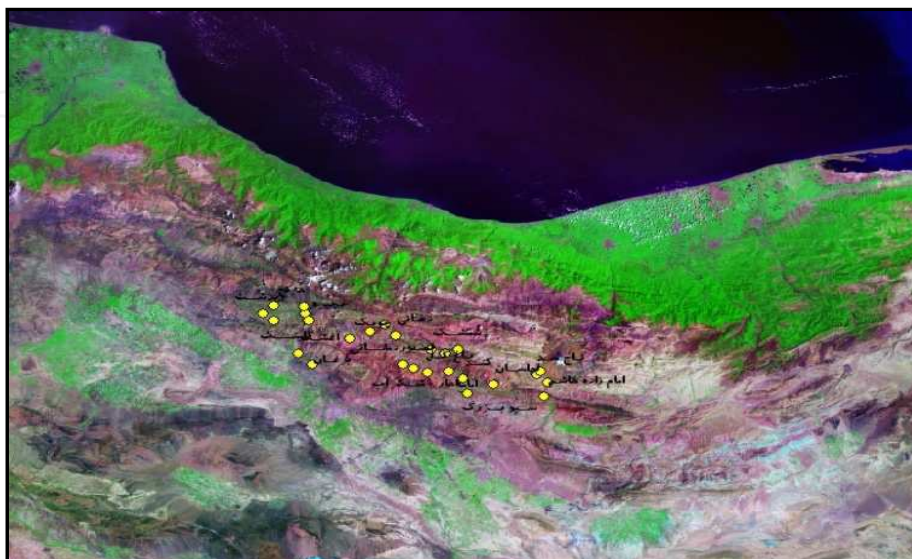

Fig. 1. The position Of snow gauge stations in Alborz-e-Markazi

2.3 Research method

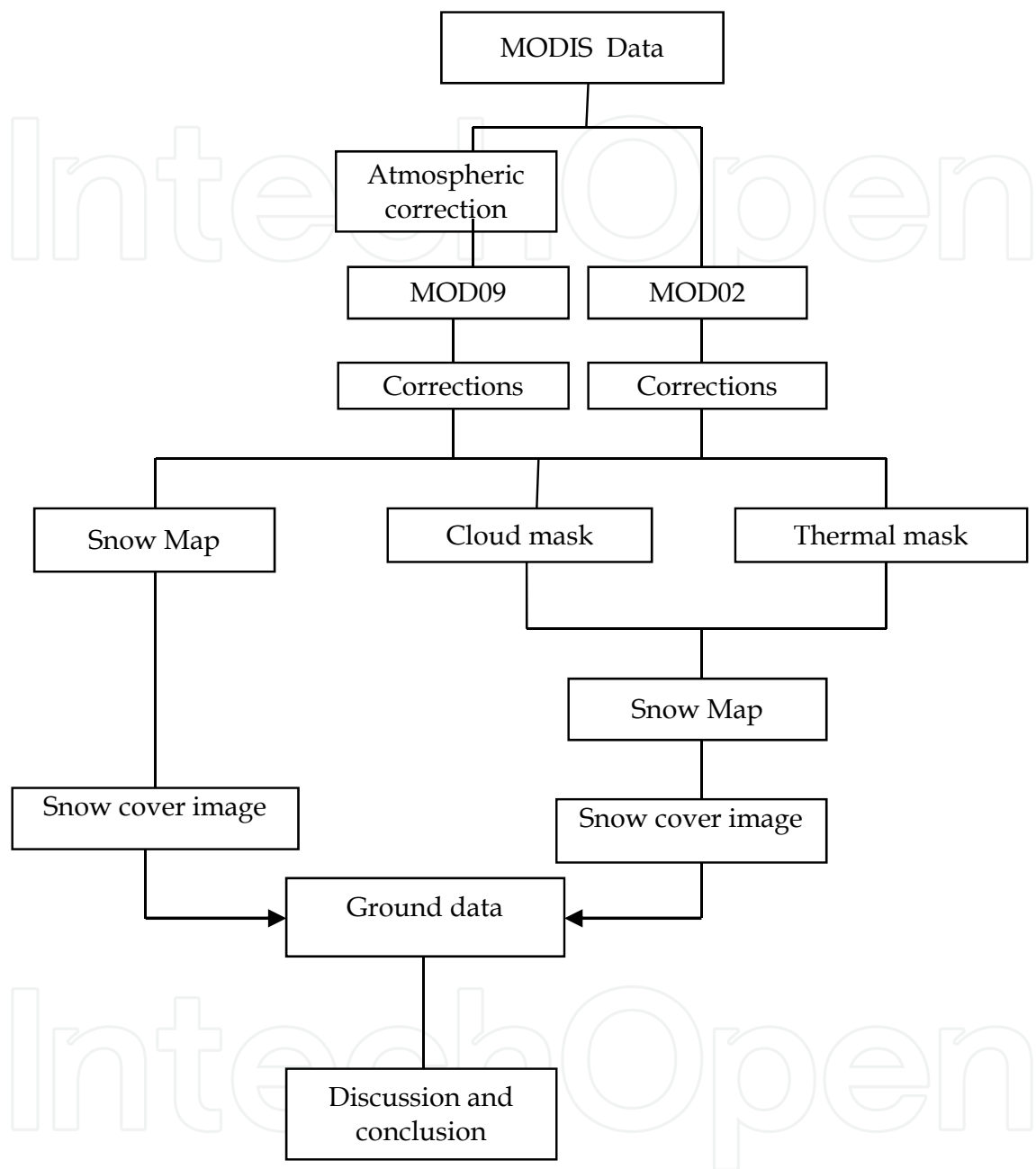Figure 2 illustrates overall flowchart of this research methodology.

Fig. 2. The flowchart of this research methodology

2.3.1 Snow map algorithm

Snow map algorithm benefits from Normalized Difference Snow Index (NDSI). Because of low reflection of snow in infrared bands and high reflection in visible bands, NDSI can be useful for discrimination of snow from other phenomena. NDSI is calculated by equation below (Hall et al., 1998):

NDSI = (band4-band6) / (band4+ band6)

Snow map algorithm includes following thresholds:

If NDSI ≥ 0.4; and MODIS band2 > 11%; and MODIS band 4 ≥ 0.4.

NDSI index is used to recognize snow and ice and also to differentiate between cumulus and ice or snow. In fact this index represents relative differential reflectance value of visible and short wave-infrared channels emitted from snow. Pure snow has a high NDSI value but other materials such as soil, smoke, etc cause a NDSI reduction. The mentioned threshold for band 4 of MODIS is a key tool to prevent identifying pixels with low reflection, for example dark Cypress, instead of snow. Water and cloud are separable using mentioned threshold for band 2 of MODIS and finally, NDSI has the key role in investigating snow (Hall et al., 1998).

Necessary eligibilities of pixels for applying snow map algorithm are as follows (Riggs et al., 2003):

- Pixels should have level1B reflection (geo-reference process and radiometric correction should be done),
- They should belong to terrestrial region or water bodies surrounded by lands,
- Imagery should be taken in day light,
- Imagery should not be covered by cloud (applying cloud mask),
- Their approximate temperature should be less than 283^0 K (applying temperature mask)

2.3.2 Cloud isolation

Liberal cloud masking just uses 7 out of 36 MODIS bands as well as 4 out of 18 old cloud masking algorithm criteria. Before performing snow map as one of the preprocessing steps, liberal cloud masking was applied. With regards to spectral resemblances between snow and cloud, applying mask on image is inevitable. In liberal cloud masking, a pixel will be considered as cloud provided that it covers one of the following criteria:

1. High cloud index introduces it as cloud
2. Heat difference index consider it as cloud
3. Visual bands reflection index proves the existence of cloud when reflection of band (1/625, 1/628, μm) is more than 20 percent and visual band threshold is applied.
4. NDSI ≥ 0.4 and reflection of band 6 is more than 20 percent (Riggs and Hall, 2002).

In this research, since the study area is located on terrestrial area and consequently discrimination of snow from cloud is very important and also all MODIS imagery were taken in day time, thresholds related to terrestrial region in day time were applied. Furthermore, water bodies were eliminated before image processing.

2.3.3 Heat masking

Heat masking is the final step before using snow map algorithm. This method was introduced on 3rd October 2001 and resulted in eliminating many of incorrect land cover classified as snow. In MODIS version 3, a threshold of 277^0 K was used whereas in version 4 this value increased to 283^0 K. Every individual pixel of band 31 with a temperature more than threshold of version 4 is not classified as snow (Kamanpoon, 2004). Heat masking is used to remove ambiguity between snow and other phenomena such as water bodies, sand

and cloud (Zhou et al., 2005). In this part using calculated apparent temperature for band 31 and applying 283^0K threshold, heat masking is performed after new cloud masking algorithm and before snow map algorithm.

3. Results

Images resulted from snow map algorithm before and after applying Liberal cloud mask related to February and March are illustrated in Figure 3. Right column shows images before liberal cloud masking and middle column show them after masking. Left column shows false color images which are made by combining visual and infrared channels of MODIS according to method introduced by Miller et al. (2004). Lands without snow cover, with snow cover, low height clouds and higher clouds appear as green, white, yellow and violet tones, respectively. False color image help to recognize cloudy regions on image as well as cloud height.
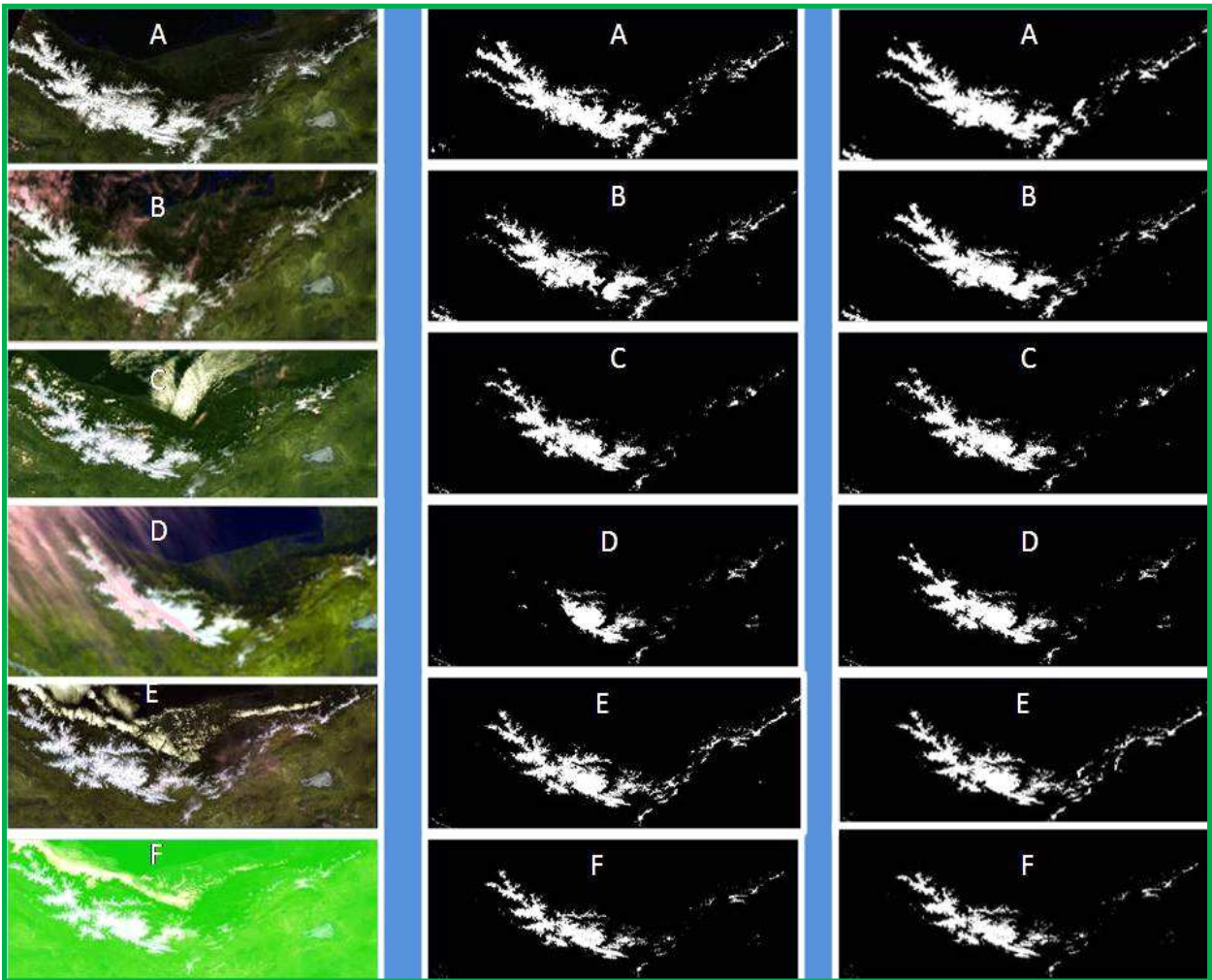

Fig. 3. Snow area before applying the liberal cloud mask (right column) and after applying the Liberal cloud mask (middle column) and false color composite (left column).

4. Discussion

In this part, using NDSI, topographic data and data gathered from snow measurement stations, snow map algorithm alone and together with Liberal cloud masking were separately interpreted. Ground-based snow measurement data and their corresponding points on images resulted from snow map algorithm as well as images resulted from snow map algorithm together with Liberal cloud masking in different dates are illustrated in table 2. In fact error matrix is drawn for each image and results have been surveyed.

Date of acquisition	Snow map	Snow	No snow	Total	Accuracy %	Snow map (masking)	Snow	No snow	Total	Accuracy %
13/3/2006	Snow	12	2	14	77	Snow	12	0	12	100
	No snow	0	4	4	100	No snow	0	6	6	100
	Total	12	6	18		Total	12	6	18	
	Accuracy %	100	66		88	Accuracy %	100	100		100
15/3/2006	Snow	12	2	14	85	Snow	12	0	12	100
	No snow	0	4	4	100	No snow	0	6	6	100
	Total	12	6	18		Total	12	6	18	
	Accuracy %	100	66		88	Accuracy %	100	100		100

Table 2. Evaluation of accuracy of snow gauge obtained from snow map algorithm and snow map algorithm with attending the Liberal cloud mask using earth data in 6th of February, 13th and 15th of March

Results demonstrate that in both images of 13th and 15th March in which snow map was applied, the number of points classified as snow is more than the time when applying snow map algorithm; adding cloud masking to snow map algorithm reduces this number. It means that regions which are incorrectly classified as snow by snow map algorithm can be categorized as cloud after adding cloud masking. Furthermore, no snow regions identified as snow in snow-gauging station and snow map algorithm with Liberal cloud masking are more than those no snow regions that are not classified as snow without applying Liberal cloud masking. So it can be concluded that snow map algorithm shows some regions as snow despite the fact that they are clouds. However, cloud masking can detect them and classify as cloud. Error matrix demonstrates that accuracy of snow map algorithm increases by applying cloud mask (Riggs and Hall, 2002; Ault et al., 2006; Hall and Riggs, 2007). Overall, results from snow map algorithm together with Liberal cloud masking are more compatible with data gathered from ground-based stations.

One of the factors affecting accuracy of snow detection is clouds which cover snow surface. These clouds are distinguishable by Liberal cloud masking provided that they are transparent and thin (Riggs and Hall, 2002; Ault et al., 2006). In images related to 21st February and 8th March, the observed cloud is thick and far from the Earth. False color images show that clouds are far from the Earth surface in both mentioned images so they can be detected and classified correctly by Liberal cloud masking. However, there is snow under these clouds and should be considered as snow. Data from ground-based snow

measurement and their corresponding points on images related to 21st February and 8th March resulted from snow map algorithm before and after applying Liberal cloud masking is shown in Table 3. As is shown in Table 3, field survey data are different from results obtained as a result of snow map algorithm together with Liberal cloud masking. In this situation, considering neighborhood effect, topographic factors and false color images, clouds over snow can be distinguishable and classify them as snow. Of course, neighborhood and topographic factors can be helpful when the cloud is smaller that total area of snow.

Date of acquisition	Snow map	Snow	No snow	Total	Accuracy %	Snow map (masking)	Snow	No snow	Total	Accuracy %
21/2/2006	Snow	15	2	17	77	Snow	12	0	12	100
	No snow	0	1	1	100	No snow	3	3	6	50
	Total	15	3	18		Total	15	3	18	
	Accuracy %	100	66		88	Accuracy %	83	16		83
8/3/2006	Snow	12	2	14	85	Snow	8	0	8	100
	No snow	0	4	4	100	No snow	4	6	10	55
	Total	12	6	18		Total	1	6	18	
	Accuracy %	100	66		88	Accuracy %	66	100		77

Table 3. Evaluation of accuracy of snow gauge obtained from snow map algorithm

There is a negligible difference before and after applying Liberal masking images covered by low height clouds (e.g. image of 4th March) (Table 4). It means that in this situation snow map algorithm with and without liberal cloud masking has the same result. So it can be concluded that snow map algorithm is able to detect low height clouds because the spectral diagram of low height clouds are different from that of snow in visual and infrared spectrum range. Data gathered from ground-based snow measurement and its corresponding points on images resulted from snow map algorithm as well as images resulted from snow map algorithm together with liberal cloud masking is shown in Table 4.

Date of acquisition	Snow map	Snow	No snow	Total	Accuracy %	Snow map (masking)	Snow	No snow	Total	Accuracy %
4/3/2006	Snow	11	0	11	100	Snow	11	0	11	100
	No snow	1	6	7	85	No snow	1	6	7	85
	Total	12	6	18		Total	12	6	18	
	Accuracy %	91	100		94	Accuracy %	91	100		94

Table 4. Evaluation of accuracy of snow gauge obtained from snow map algorithm and snow map algorithm with attending the Liberal cloud mask using earth data in 4th of March

In order to show NDSI ability in isolation of cloud from snow, variation range of NDSI in regions which are identified as cloud using new cloud masking is compared with variation in regions where classified as snow by use of snow map algorithm. As it can be found in diagram NDSI variation in regions where identified as cloud and regions where classified as snow has some overlaps so NDSI cannot distinguish between snow and cloud in these regions (Figure 4).
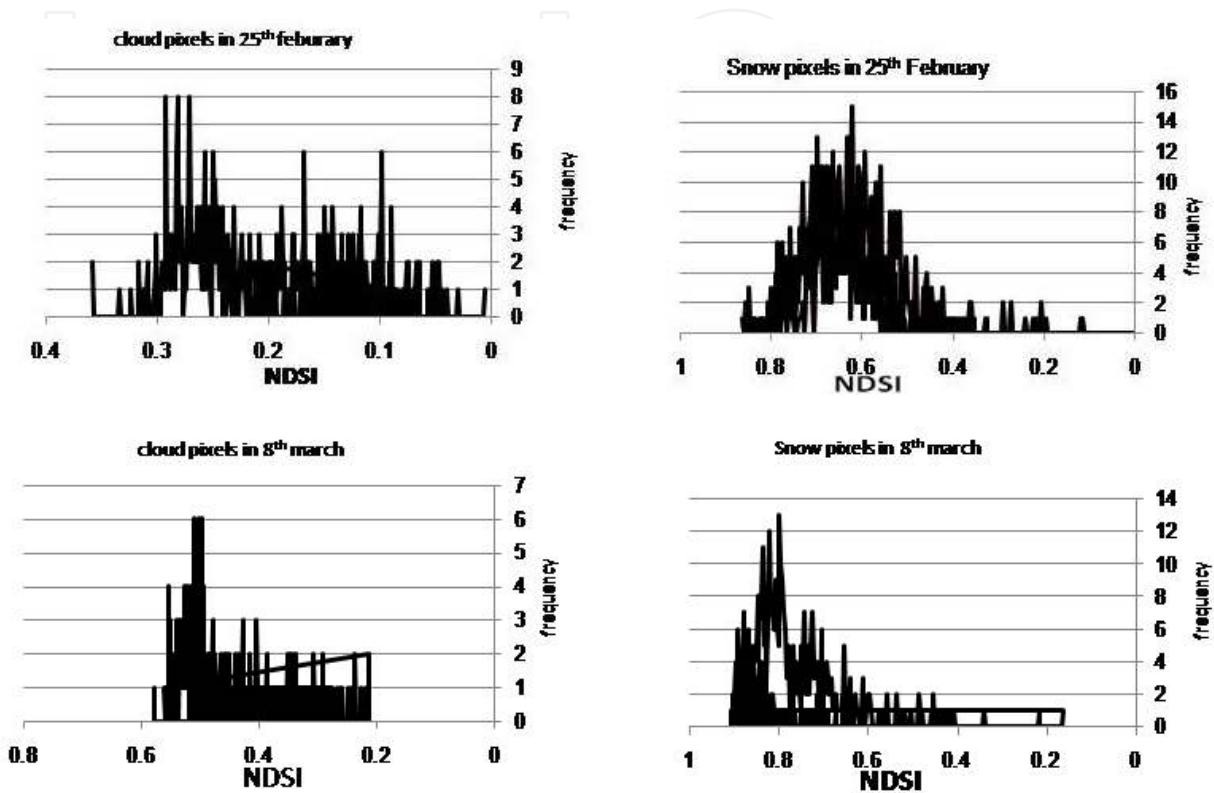

Fig. 4. The variation range of DSI in cloudy and snowy area on images of 25th February and 8th March

Figure 5 shows comparison of NDSI variation for image taken in 4th March which has only low height clouds in regions which are identified as cloud using new cloud masking with variation in regions where classified as snow using snow map algorithm. As it can be seen in diagram NDSI variation in regions where identified as cloud and regions where classified as snow are absolutely separable so NDSI can distinguish between snow and cloud in these regions and act similar to new cloud mask (Figure 5).

As a general rule, the amount of snow increases in higher elevations so if classification of snow and cloud is done perfectly, percentage of pixels related to snow should increase in higher elevation. This rule can be used to evaluate the accuracy of outputs resulted from snow map algorithm alone and together with Liberal mask algorithm. Figure 6 shows the relative frequency of snow pixels in each altitudinal zone. As it can be seen in this Figure, ascending trend occur whenever new cloud mask is applied together with snow map algorithm. In fact, cloud masking leads to the better identification of cloud pixels and prevents these pixels to be classified as snow. However ascending trend will not happen in mentioned diagram when snow map algorithm is used alone because some cloud pixels are categorized as snow incorrectly.

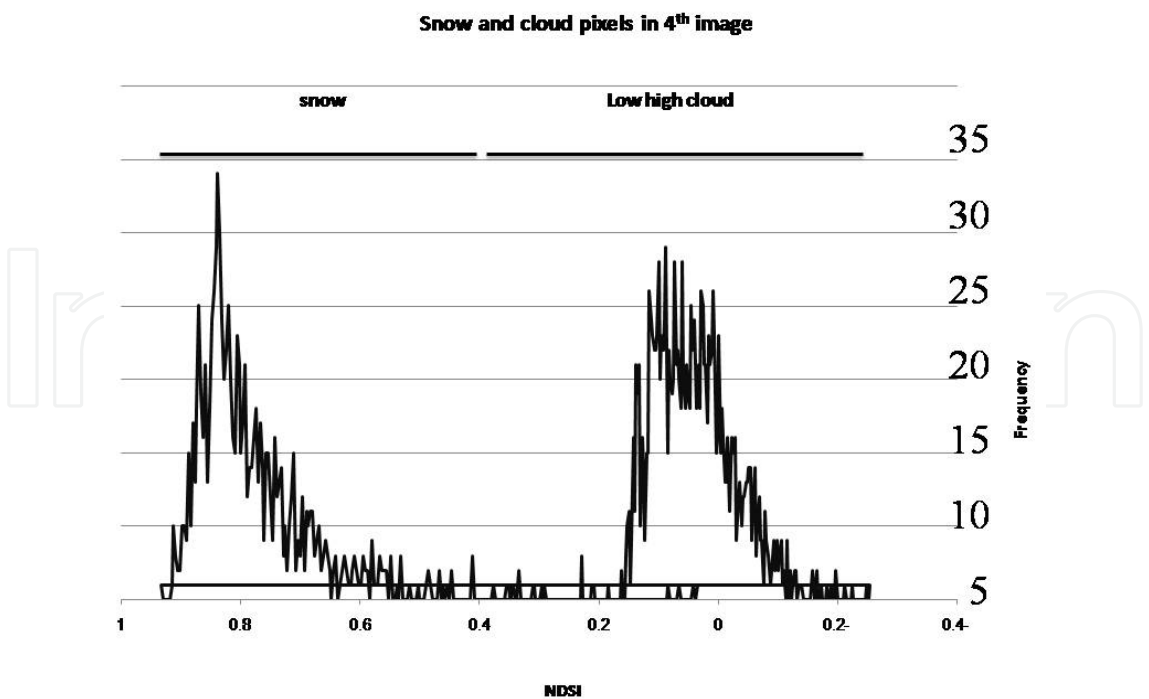**Snow and cloud pixels in 4th image**

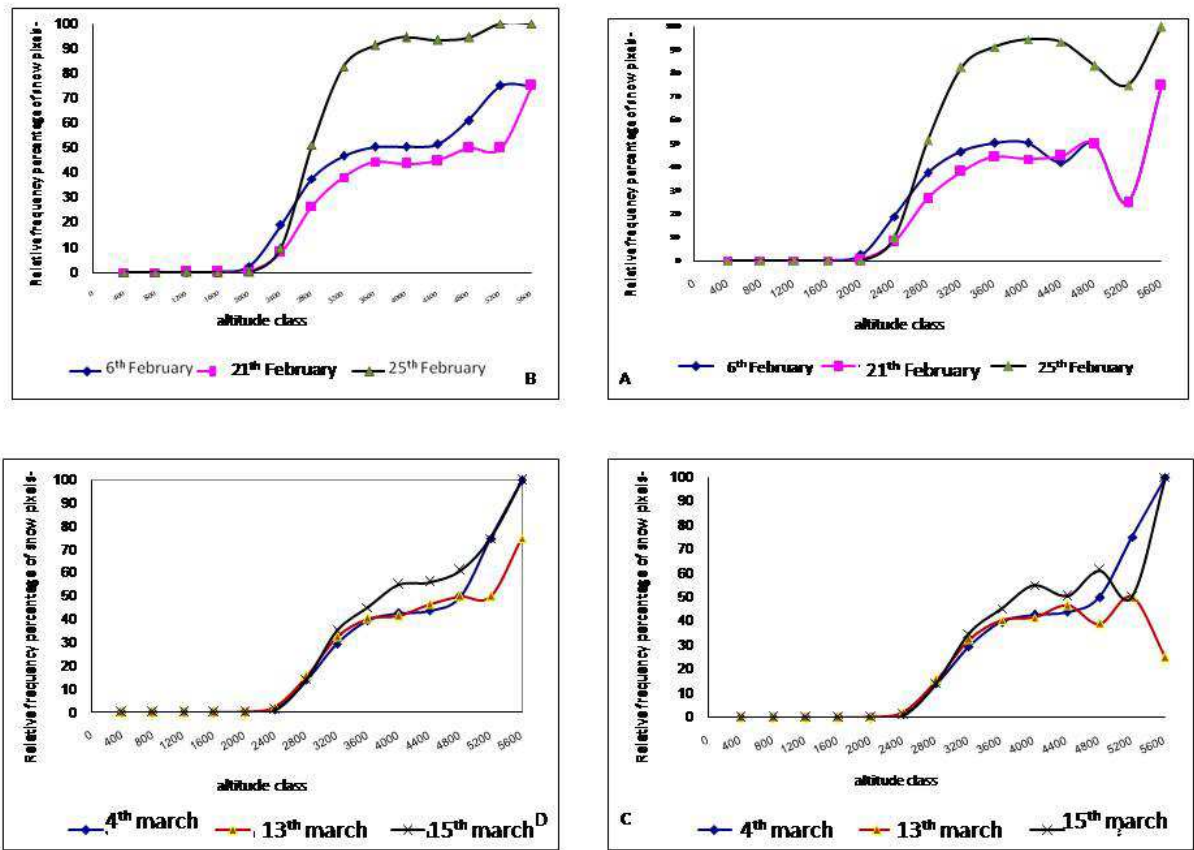Fig. 5. The variation range of NDSI in cloudy and snowy area on images of 4th March

Fig. 6. Relative frequency percentage of snow pixels in each altitude class; right: the obtained images of snow map algorithm; left: the obtained images of snow map algorithm accompanying the Liberal clod mask

5. Conclusion

Reviewing data resulted from ground-based snow measurements in addition to results from snow map algorithm and Liberal cloud mask, it can be concluded that snow map algorithm cannot detect some types of cloud and classify them as snow (Zhou et al., 2005; Riggs and Hall, 2002; Ault et al., 2006; Hall and Riggs, 2007), reducing the accuracy of maps produced for snow detection. Clouds which are not detected by snow map algorithm are those include ice particles in high elevations (Taghvakish, 2005). Using Liberal cloud masking can largely solve this problem and prevent some types of clouds to be categorized as snow. The accuracy of maps is increased approximately 10% in comparison with other methods. In images including only low elevation clouds, cloud masking cannot make better results; therefore it can be concluded that these kinds of clouds can be detected by snow map algorithm alone. Also, results from applying NDSI shows that some types of clouds are categorized in the same class as snow, so NDSI cannot distinguish between snow and cloud. However, those clouds in low elevation can be detected from snow.

Altitudinal parameter is another tool in order to evaluate the accuracy of snow map algorithm and Liberal cloud masking. An ascending trend in frequency of snow pixels is evident whenever cloud masking is used in addition to the snow map algorithm.

In summary, it can be said that although low height clouds are separable by snow map algorithm, some types of clouds cannot be detected by snow map algorithm alone and thus, application of cloud masking is inevitable. These are clouds which are in high elevation and include ice particles (Taghvakish, 2005). Finally, in some cases even cloud masking cannot distinguish between snow and ice particles (Ault et al., 2006, Riggs and Hall, 2002 , Taghvakish, 2005).

6. References

Ackerman S A, Strabala K I, Menzel P W P, Frey R A, Moeller C C and Gumley L E, 1998: Discriminating clear sky from clouds with MODIS, *Journal of Geophysical Research*, 103(D24):32,141-32,157.

Adhami S, 2005. Application of remote sensing and geographic information system in snow cover (Agichay). Unpublished MSc Thesis, University of Tabriz (In Persian).

Ault T W, Czajkowski K P, Benko T, et al., 2006. Validation of the MODIS snow product and cloud mask using student and NWS cooperative station observations in the Lower Great Lakes Region. *Remote sensing of Environment* 105: 341-353.

Dadashi Khanegha S, 2008. Appointment of snow cover using image processing techniques. Unpublished MSc Thesis. University of Shahid Beheshti (In Persian).

Hall D K, Tait A B, Riggs G A, Salomonson V V, Chien J, Andrew Y L, and Klein G. 1998. Algorithm Theoretical Basis Document (ATBD) for the MODIS Snow-, Lake Ice- and Sea Ice-Mapping Algorithms, MODIS Algorithm Theoretical Basis Document Number ATBD-MOD-10, NASA Goddard Space Flight Center, 1998.

Hall D K and Riggs G, 2007. Accuracy assessment of the MODIS snow products. *Hydrological Processes* 21:1534-154.

Hall D K, Tait A B, Foster J L, Change A T C, and Allen M, 2000. Intercomparison of satellite-derived snow-cover maps. *Annals of Glaciology* 31:396-376.

Kamanpoon S, 2004. Hydrological modelling using MODIS data for snow covered area in the Northern Boreal Forest of Manitoba, MSc Thesis.

King M D, Platnick S, Yang P, Arnold G T, Gray M A, Riedi J C, Ackerman S A, Liou K, 2004. Remote sensing of liquid water and ice cloud optical thickness and effective radius in the Arctic: Application of airborne multispectral MAS Data. *Journal of Atmospheric and Oceanic Technology* 21: 857-875.

Klein A G and Barnett A C, 2003. Validation of daily MODIS snow cover maps of the Upper Rio Grande River Basin for the 2000-2001 snow year. *Remote Sensing of Environment* 86:162-176.

Lee S, Klein A G and Over T M, 2001. A Comparison of MODIS and NOHRSC snow cover products for simulating streamflow using the Snowmelt RunOff Model in: http://www.modissnowice.gsfc.nasa.gov

Miller S D and Lee T F, 2004. Satellite-Based imagery techniques for daytime cloud/snow delineation from MODIS. *Journal of applied meteorology*. volume 44.

Pfister R and Schneebeli M, 1999. Snow accumulation on boards of different sizes and shapes. *Hydrological Processes* 13:2345-2355.

Hall D k, Foster J L, Robinson D A, Riggs G A, 2004. Merging the MODIS and RUCL monthly snow cover records. In Proceeding of IGARSS 04, Anchorage, AK, September 2004.

Rayegani B, 2005. Investigation on snow cover changes and estimation snowmelt runoff using MODIS data. Unpublished MSc Thesis. Isfahan University of Technology (In Persian).

Riggs G and Hall D K, 2002. Reduction of cloud obscuration in the MODIS snow data product, 59th Eastern Snow Conference, Stowe, Vermonte, USA.

Riggs G A , Haii D K and Salomonson V V, 2003. MODIS snow products users guide. Available at: http://www.modis-snow-ice.gsfc.nasa.gov/sug.pdf.

Strabala K, 1999. MODIS Cloud Mask User's Guide', *User's Guide.*

Singh P and Singh V P, 2001. *Snow and Glacier Hydrology*, Kluwer Academic Publishers, p742.

Taghvakish S, 2005. Supervision of snow cover using satellite images. Unpublished MSc Thesis, University Of Tehran (In Persian).

Vermote E F and Kotchenova S, 2008. Atmospheric correction for the monitoring of land surfaces. . *Journal of Geophysical Research -ATMOSPHERES*, 113(D23), D23S90.

Zhou X, Xie H and Hendrick J M H, 2005. Statistical evaluation of remotely sensed snow cover products with constraints from streamflow and SNOTEL measurements, *Remote Sensing of Environment* 94: 214–231.
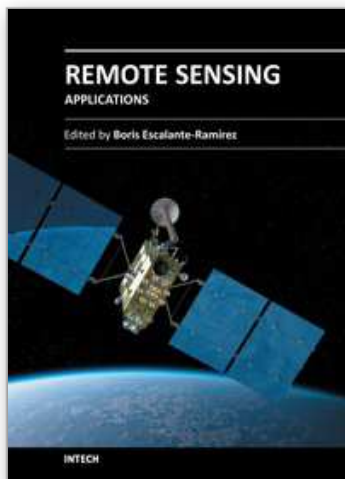
Remote Sensing - Applications

Edited by Dr. Boris Escalante

Nowadays it is hard to find areas of human activity and development that have not profited from or contributed to remote sensing. Natural, physical and social activities find in remote sensing a common ground for interaction and development. This book intends to show the reader how remote sensing impacts other areas of science, technology, and human activity, by displaying a selected number of high quality contributions dealing with different remote sensing applications.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

INTECH
open science | open minds