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Research Article

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Northern Hemisphere Snow Variations with Season and Elevation Using GIS and AMSR-E Data

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Abstract

Seasonal snow cover and properties in the Northern Hemisphere(NH) was examined in this study using AMSR-E multispectral passive microwave satellite derived Snow Water Equivalent (SWE) and the Digital Elevation Model (DEM) for the different seasons (January, April, July and October months) from 2007 to 2011. The methodology involves conversion of satellite SWE data into 6 snow classes, computation of NDSI, determination of the boundary between snow classes from spectral response data and threshold slicing of the image data. Accuracy assessment of AMSR-E snow products was accomplished using Geographic Information System (GIS) techniques. The coldest month has all six snow type classes due to snow pack growth whereas the summer months only contain residual snow at the highest elevations. Sharp season-to-season differences were noted. The final results show the greatest snow cover extent in January whereas total snow in April is 60%, July 3% and in October near to 25%. In terms of inter-seasonal variations during the study period, the minimum (1.53 million km^2) snow cover extent was observed in July 2008 and the maximum (60.0 km^2) in January 2010. In terms of elevation, the maximum snow extent exists between 0 to 2000 m in winter and near to 5000 m in summer. Finally, this study shows how satellite remote sensing can be useful for the long-term observation of the intra and inter-annual variability of snowpacks in rather inaccessible regions and providing useful information on a critical component of the hydrological cycle, where the network of meteorological stations is deficient.

Keywords: Northern hemisphere; Snow cover variation; DEM; GIS; AMSR-E

Introduction

Variability in terrestrial Snow Cover Area (SCA) has a significant influence on water and energy cycles, as well as socioeconomic and environmental repercussions Wulder et al. [1] and Groisman et al. [2] on the earth. An important property of snow and ice is their reflective power (albedo). Snow cover variability shows an indirect influence on other climate components such as soil moisture and the atmospheric circulation variability both at the seasonal time scale [3] and the interannual-to-interdecadel oscillations [4]. A general reduction of snow cover is responsible for the higher accumulation of planet energy due to failed albedo effect. Seasonal snow cover also plays an important role in hydrological processes and climate, specifically hydro-power production, avalanche activity/forecasting and for its potential in shaping the mountain ecosystem. Therefore, monitoring of the seasonal snow cover is important for several purposes such as climatology, hydrometeorology, water use and control and hydrology, including flood forecasting and food production.

Snow cover monitoring through conventional methods have limitations in high altitude because of highly rugged terrain and harsh weather conditions. In this perspective, satellite remote sensing has a great value as it can provide repetitive data on snow cover area at regular intervals of time. In addition to in situ network of snow cover measurements, various snow cover products are operationally produced from satellite data by numerous government agencies using both optical and passive microwave imagery [5]. Snow cover mapping is one field where satellite remote sensing has reached an operational status. The potential for operational satellite based snow cover mapping has grown with the availability of higher spatial, spectral and temporal resolution satellite sensors over the years. The first data used to compute the snow cover spatial distribution on a synoptic scale were remotely sensed images of the NOAA satellite in 1966 covering the NH [6,7]. Optical remote sensing (e.g., Landsat, Advanced Very High Resolution Radiometer- AVHRR, Moderate Resolution Imaging Spectroradiometer-MODIS) for SCA mapping has been studied for many years [8-13]. The space-borne passive microwave snow time series of hemispheric or global perspective are provided by the Scanning Multichannel Microwave Radiometer (SMMR, 1978-1987), Special Sensor Microwave/Imager (SSM/I, 1987-present), and the Advanced Microwave Scanning Radiometer- Earth Observing System (AMSR-E) on board the Aqua satellite (2002- present) [1,14]. Efforts to map snow cover using passive microwave data have enabled the development of a long time series (since 1978 to present) of spatially continuous data of SCA, snow depth, and Snow Water Equivalent (SWE). However, the accurate monitoring of SCA using optical imagery of high spatial resolution is seriously reduced by cloud cover due to the similar reflective nature of snow and clouds [5,15], while passive microwave remote sensing has advantage in penetration of cloud cover. A combination of the two products could provide a significant improvement of SCA product with high spatial resolution from the optical imagery and cloud transparency from the microwave imagery.

The objective of this study was to analyze the seasonal snow type and

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snow cover changes on the NH and its relations with different elevation. Such information is urgently need for the satellite precipitation community to better delineate snow covered regions to minimize the impact of falsely classifying raining areas from snow on the ground Sudradjat et al. [16]. This paper describes an approach to assemble a consistent 5-year record of seasonal snow covered area of NH. There are, however, very limited data that can be used to corroborate our findings (satellite data, secondary data or otherwise), making extensive quantitative validation of the snow estimates extremely challenging.

Data and Methodology

The intensity of microwave radiation emitted from a snowpack is determined by several factors, including freeze/thaw states of the underlying soil, crystal size, and temperature and density profiles and layering structure [17]. Space borne passive microwave data are significantly useful in monitoring SCA due to its all-weather imaging and wide swath width with frequent overpass times. This is an important characteristic, which greatly complement the deficiency of optical space-borne imagery due to the cloud blockage, especially for snow product on a daily basis.

There are many techniques available for detecting and recording differences, such as image differencing, ratios and correlation [18-20]. However, the simple detection of change is rarely sufficient in itself: information is generally required about the initial and final snow cover analysis as described by Khorram et al. [21].

Furthermore, detection of image differences may be confused with problems in penology and cropping and such problems may be exacerbated by limited image availability, poor quality in temperate zones and difficulties in calibrating poor images. Post-classification comparisons of derived, thematic maps go beyond simple change detection because they attempt to quantify the different types of change. Their degree of success depends upon the reliability of the maps that have been made by image classification. Broadly speaking, both large scale changes such as very low snow class, and small scale changes like extreme snow, might be mapped reasonably easily.

AMSR-E snow data and DEM

The AMSR-E instrument on NASA's EOS Aqua satellite provides global passive microwave measurements of terrestrial, oceanic and atmospheric variables for the investigation of water and energy cycles. The Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) is a twelve-channel, six-frequency, passive-microwave radiometer system. It measures horizontally and vertically polarized brightness temperatures at 6.9 GHz, 10.7 GHz, 18.7 GHz, 23.8 GHz, 36.5 GHz, and 89.0 GHz. Spatial resolutions of the individual measurements varies from 5.4 km at 89 GHz to 56 km at 6.9 GHz. AMSR-E improves upon past microwave radiometers. The spatial resolution of AMSR-E data doubles that of Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave/Imager (SSM/I) data. Also, AMSR-E combines into one sensor all the channels that SMMR and SSM/I had individually.

The monthly level-3 AMSR-E Snow Water Equivalent (SWE) data AE_MoSno (AMSR-E/Aqua monthly L3 Global Snow Water Equivalent EASE-Grids) in Northern Hemisphere were obtained from the NSIDC website [17,22]. These data are stored in Hierarchical Data Format–Earth Observing System (HDF–EOS) format and contain SWE data and quality assurance flags mapped to 25 km Equal-Area Scalable Earth Grids (EASE-Grids). Actual SWE values are scaled down by a factor of 2 for storing in the HDF-EOS file, resulting in a stored data range of 0-240. Users must multiply the SWE values in the file by a factor of 2 to scale the snow depth data up to the correct range of 0-480mm. Finally Shuttle Radar Topography Mission (SRTM) data of approximately 90 m resolution were downloaded from the website and used to prepare the Digital Elevation Map (DEM).

Image classification

Snow cover classes are typically mapped from digital remotely sensed data using some sort of unsupervised digital image classification [23,24]. The overall objective of the image classification procedure is to automatically categorize all pixels in an image into snow cover classes or themes on the basis of pixel value/gray levels. Unsupervised classification quantitatively evaluates both the variance and covariance of the category`s spectral response patterns whenever it classifies an unknown pixel. This is why it is considered to be one of the useful classifiers - it is based on statistical parameters.

Unsupervised classification was performed here using 0 to 255 gray levels and digital topographic maps. All AMSR-E monthly SWE images were transformed into ESRI grid format files with Lambert Azimuthal equal area projection and the grid was resampled by binary approach. The end gray levels from 240 to 255 of AMSR-E data indicates a snow free surface (or land surface), off-earth, land or snow impossible, ice sheet, water and data missing, respectively. In terms of snow depth each gray level need to multiply by factor 2 so this data show snow depth from 0 to 480 mm.

To convert AMSR-E data into GeoTif file format, we used binary method for resampling. In binary method resampled new pixel value is based on four pixels. Another method for resampling is nearest neighborhood and cubic method but nearest neighborhood is less accurate in compare of binary method because in this method resampled new pixel value is based on nearest pixel. In cubic method, new resampled pixel value is based on sixteen pixels and more accurate than binary method but cubic method is too much complicated and time consuming. That`s why here we used binary method for resampling AMSR-E data.

Snow cover classification was computed from 2007 to 2011 for the months of January, April, July and October. Separate analyses were done for 500 m elevation ranges. The snow was classified into six main classes based on SWE values: Very low snow, low snow, medium snow, high snow, very high snow and extreme snow and land which was covered by snow in winter but not in other seasons is classified as "No Snow" class.

Result and Discussion

Spatial-temporal variability of snow cover

Figure1 show the seasonal variations of the snow cover area (SCA) accumulated over the whole study area for January, April, July and

	2011	2010	2009	2008	2007
January	59963980.23	59968143.60	59966076.21	59965533.25	59962652.62
April	28270185.08	35397344.56	36254101.96	35759056.74	36067128.24
July	2076815.60	1628064.12	1851118.32	1527946.80	1590047.16
October	4339296.33	13732860.49	17790316.77	13517734.62	14186854.78

Table 1: Snow cover area in km^2 for January, April, July and October months from 2007 to 2011.

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October months from 2007 to 2011. The minimum (1.53 million km^2) snow cover extent was observed in July 2008 and the maximum (60.0 million km^2) in January 2010 (Figure 1). Table 1 summarizes the main features of the snow cover from the satellite observations. These results highlight the strong seasonal and inter-annual variability of snow packs in the region. The presence of maximum snow is always detected in winter. In comparison of January total snow in April is 60%, July 3% and in October near to 25% snow covers.

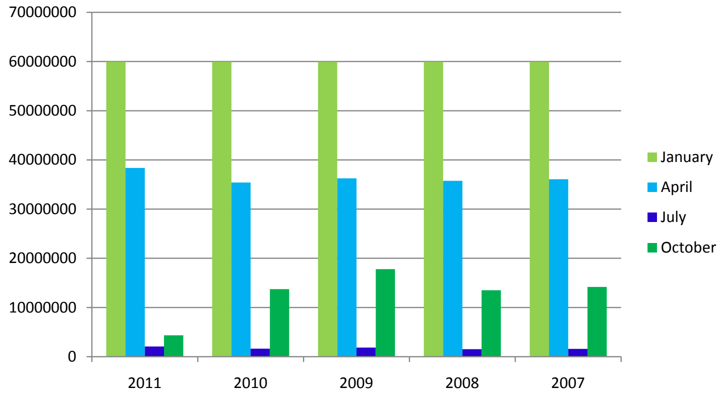

Figure 1: Graphical representation of snow cover area of table 1.

	2011_01			2010_01			2009_01			2008_01			2007_01		
Class	**Area**	**%**		**Area**	**%**		**Area**	**%**		**Area**	**%**		**Area**	**%**	
Very low snow	21.9	36.4		21.4	35.7		22.2	37.0		21.7	36.2		24.3	40.6	
Low snow	13.4	22.3		13.2	21.9		15.1	25.1		14.8	24.7		13.2	22.1	
Medium snow	11.5	19.1		11.2	18.7		11.2	18.7		11.9	19.9		11.4	19.0	
High snow	7.5	12.5		8.6	14.4		6.7	11.1		6.7	11.2		6.3	10.5	
Very high snow	4.3	7.2		4.4	7.3		3.7	6.1		3.5	5.8		3.6	5.9	
Extreme snow	1.5	2.5		1.2	2.0		1.2	1.9		1.3	2.2		1.2	1.9	
Total snow	**60.0**	**100.0**		**60.0**	**100.0**		**60.0**	**100.0**		**60.0**	**100.0**		**60.0**	**100.0**	
RPI	264.9			264.9			264.9			264.9			264.9		
Total	**324.8**			**324.8**			**324.8**			**324.8**			**324.8**		
	2011_04			**2010_04**			**2009_04**			**2008_04**			**2007_04**		
Class	**Area**	**%**	**%**	**Area**	**%**	**%**	**Area**	**%**	**%**	**Area**	**%**	**%**	**Area**	**%**	**%**
Very low snow	10.7	27.8	17.8	8.6	24.2	14.3	8.8	24.3	14.7	9.5	26.6	15.9	9.6	26.7	16.0
Low snow	9.8	25.6	16.4	8.9	25.1	14.8	8.9	24.5	14.8	8.8	24.6	14.6	9.3	25.8	15.5
Medium snow	7.7	20.0	12.8	8.3	23.5	13.9	8.2	22.6	13.7	7.4	20.6	12.3	7.5	20.9	12.6
High snow	5.5	14.4	9.2	6.0	16.8	9.9	5.9	16.3	9.9	5.9	16.5	9.8	5.3	14.6	8.8
Very high snow	3.5	9.1	5.8	2.9	8.1	4.8	3.3	9.2	5.6	3.2	9.0	5.4	3.3	9.1	5.5
Extreme snow	1.1	3.0	1.9	0.8	2.2	1.3	1.1	3.1	1.9	0.9	2.6	1.6	1.1	2.9	1.8
Total snow	**38.4**	**100.0**	**64.0**	**35.4**	**100.0**	**59.0**	**36.2**	**100.0**	**60.5**	**35.8**	**100.0**	**59.6**	**36.1**	**100.0**	**60.1**
No snow	21.6		36.0	24.6		41.0	23.7		39.5	24.2		40.4	23.9		39.9
Total classes	**60.0**		**100.0**	**60.0**		**100.0**	**60.0**		**100.0**	**60.0**		**100.0**	**60.0**		**100.0**
RPI	264.9			264.9			264.9			264.9			264.9		
Total	**324.8**			**324.8**			**324.8**			**324.8**			**324.8**		
	2011_07			**2010_07**			**2009_07**			**2008_07**			**2007_07**		
Class	**Area**	**%**	**%**	**Area**	**%**	**%**	**Area**	**%**	**%**	**Area**	**%**	**%**	**Area**	**%**	**%**
Low snow	1.5	73.4	2.5	1.1	66.2	1.8	1.3	69.9	2.2	1.1	72.4	1.8	1.1	70.9	1.9
Medium snow	0.4	18.8	0.7	0.3	20.3	0.5	0.3	18.3	0.6	0.3	19.7	0.5	0.3	21.5	0.6
High snow	0.1	5.8	0.2	0.2	9.2	0.2	0.2	8.1	0.2	0.1	5.9	0.1	0.1	5.1	0.1
Very high snow	0.0	1.9	0.1	0.1	4.3	0.1	0.1	3.8	0.1	0.0	2.0	0.0	0.0	2.5	0.1
Total snow	**2.1**	**100.0**	**3.5**	**1.6**	**100.0**	**2.7**	**1.9**	**100.0**	**3.1**	**1.5**	**100.0**	**2.5**	**1.6**	**100.0**	**2.6**
No snow	57.9		96.6	58.4		97.3	58.2		96.9	58.5		97.5	58.4		97.4
Total classes	**60.0**		**100.0**	**60.0**		**100.0**	**60.0**		**100.0**	**60.0**		**100.0**	**60.0**		**100.0**
RPI	264.8			264.8			264.8			264.8			264.8		
Total	**324.8**			**324.8**			**324.8**			**324.8**			**324.8**		
	2011_09			**2010_10**			**2009_10**			**2008_10**			**2007_10**		

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Class	Area	%	%	Area	%	%	Area	%	%	Area	%	%	Area	%	%
Low snow	2.6	59.6	4.3	7.4	54.0	12.4	11.0	62.0	18.4	7.3	54.1	12.2	7.4	52.2	12.3
Medium snow	1.2	28.4	2.1	4.4	31.7	7.3	4.4	24.8	7.4	3.5	26.2	5.9	4.4	31.1	7.3
High snow	0.4	8.1	0.6	1.7	12.5	2.9	1.9	10.9	3.2	2.0	15.0	3.4	1.8	12.6	3.0
Very high snow	0.1	2.8	0.2	0.3	1.8	0.4	0.4	2.0	0.6	0.6	4.1	0.9	0.5	3.5	0.8
Extreme snow	0.1	1.2	0.1	0.0	0.0	0.0	0.1	0.3	0.1	0.1	0.5	0.1	0.1	0.6	0.2
Total snow	**4.3**	**100.0**	**7.2**	**13.7**	**100.0**	**22.9**	**17.8**	**100.0**	**29.7**	**13.5**	**100.0**	**22.5**	**14.2**	**100.0**	**23.6**
No snow	55.7		92.8	46.2		77.1	42.2		70.3	46.5		77.5	45.8		76.4
Total classes	**60.0**		**100.0**	**60.0**		**100.0**	**60.0**		**100.0**	**60.0**		**100.0**	**59.9**		**100.0**
RPI	264.9			264.9			264.9			264.9			264.9		
Total	**324.8**			**324.8**			**324.8**			**324.8**			**324.8**		

Table 2: Snow classes and snow cover area in million km² for January, April, July and October months from 2007 to 2011.

	2011_01		**2010_01**		**2009_01**		**2008_01**		**2007_01**	
Contour	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**
0	17362649.6	32.6	17959009.5	33.0	16539754.7	30.7	17177288.2	32.7	17481910.7	32.1
500	9197864.9	17.3	10935393.3	20.1	10494707.4	19.5	9463614.5	18.0	11692291.3	21.5
1000	10294087.4	19.3	8425619.9	15.5	10313948.1	19.1	10085143.7	19.2	8252253.1	15.1
1500	4284155.9	8.0	4197795.3	7.7	4046441.8	7.5	6478086.7	12.3	4001756.6	7.3
2000	4800833.2	9.0	8012046.2	14.7	7669374.4	14.2	4443398.8	8.5	8167279.0	15.0
2500	3665846.9	6.9	1174627.0	2.2	1126771.6	2.1	1123920.2	2.1	1188233.3	2.2
3000	637913.4	1.2	628591.2	1.2	627988.2	1.2	645518.8	1.2	641266.3	1.2
3500	426450.2	0.8	400986.6	0.7	411614.3	0.8	430249.4	0.8	422342.9	0.8
4000	400835.7	0.8	405413.7	0.7	406438.4	0.8	393439.4	0.7	389942.0	0.7
4500	604524.6	1.1	580856.0	1.1	595727.4	1.1	581812.2	1.1	609286.1	1.1
5000	955138.9	1.8	951997.0	1.8	937544.2	1.7	971476.8	1.9	962679.4	1.8
5500	516529.0	1.0	524896.1	1.0	542921.1	1.0	525954.8	1.0	513200.8	0.9
6000	136987.0	0.3	138872.2	0.3	128189.7	0.2	131331.6	0.3	134473.5	0.2
6500	19479.8	0.0	17594.7	0.0	17594.7	0.0	19479.8	0.0	16966.3	0.0
7000	3141.9	0.0	3141.9	0.0	3141.9	0.0	2513.5	0.0	3141.9	0.0
7500	1256.8	0.0	1256.8	0.0	1256.8	0.0	1256.8	0.0	1256.8	0.0
8000	628.4	0.0	628.4	0.0	628.4	0.0	628.4	0.0	628.4	0.0
Total	**53308323.6**	**100.0**	**54358725.6**	**100.0**	**53864042.9**	**100.0**	**52475113.4**	**100.0**	**54478908.3**	100.0
	2011_04		**2010_04**		**2009_04**		**2008_04**		**2007_04**	
Contour	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**
0	10999024.2	30.4	7878629.6	23.5	9080069.2	26.9	7997883.2	24.8	8436200.9	26.5
500	6764994.4	18.7	13234929.7	39.4	4685703.7	13.9	7064639.2	21.9	5465795.2	17.2
1000	3436179.6	9.5	3521242.5	10.5	5145792.3	15.3	2824878.9	8.8	3415148.5	10.7
1500	8661662.3	24.0	2653021.0	7.9	7965703.4	23.6	7551817.1	23.4	2296278.4	7.2
2000	1919586.5	5.3	1469056.9	4.4	2054501.5	6.1	2015961.6	6.2	1909271.0	6.0
2500	869231.9	2.4	1361802.1	4.1	886655.9	2.6	1335973.3	4.1	6460291.5	20.3
3000	548500.3	1.5	552940.8	1.6	1021159.8	3.0	536248.4	1.7	1026730.1	3.2
3500	368967.9	1.0	355960.5	1.1	349032.5	1.0	363113.1	1.1	348273.2	1.1
4000	342367.1	0.9	319343.4	1.0	335367.3	1.0	354689.3	1.1	337351.4	1.1
4500	594704.9	1.6	573096.7	1.7	559153.8	1.7	580175.6	1.8	531475.6	1.7
5000	956298.9	2.6	993456.0	3.0	935009.0	2.8	947195.9	2.9	957132.0	3.0
5500	521782.1	1.4	508988.5	1.5	543753.1	1.6	528694.3	1.6	522184.5	1.6
6000	135730.3	0.4	136987.0	0.4	128818.1	0.4	135730.3	0.4	136358.6	0.4
6500	17594.7	0.0	18851.4	0.1	16966.3	0.1	18223.0	0.1	17594.7	0.1
7000	3141.9	0.0	3141.9	0.0	3141.9	0.0	3141.9	0.0	3770.3	0.0
7500	1256.8	0.0	1256.8	0.0	1256.8	0.0	628.4	0.0	1256.8	0.0
8000	628.4	0.0	628.4	0.0	628.4	0.0	628.4	0.0	628.4	0.0
Total	**36141652.0**	**100.0**	**33583333.0**	**100.0**	**33712712.8**	**100.0**	**32259621.6**	**100.0**	**31865740.9**	**100.0**
	2011_07		**2010_07**		**2009_07**		**2008_07**		**2007_07**	
Contour	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**
0	24977.1	5.1	16251.0	3.2	22070.7	3.6	17640.8	3.7	19238.2	3.7
500	9376.2	1.9	5903.8	1.2	4172.7	0.7	4828.9	1.0	6057.8	1.2
1000	3766.8	0.8	0.0	0.0	0.0	0.0	1486.4	0.3	0.0	0.0
1500	2717.8	0.6	1885.1	0.4	1885.1	0.3	3164.3	0.7	2513.5	0.5
2000	4927.9	1.0	3494.8	0.7	3494.8	0.6	2640.4	0.5	2238.0	0.4

2500	3374.0	0.7	3374.0	0.7	6714.0	1.1	1256.8	0.3	628.4	0.1
3000	17821.4	3.7	4172.7	0.8	20510.6	3.4	6686.2	1.4	6686.2	1.3
3500	21783.6	4.5	10230.5	2.0	21139.0	3.5	16740.3	3.5	16111.9	3.1
4000	25537.6	5.2	10230.5	2.0	24683.3	4.1	16111.9	3.4	14855.2	2.8
4500	36174.2	7.4	29109.8	5.8	34737.4	5.7	26568.4	5.5	29533.9	5.7
5000	159247.9	32.7	207542.1	41.2	230191.7	37.9	191164.9	39.8	223048.0	42.7
5500	119869.5	24.6	149102.7	29.6	181150.1	29.8	140140.4	29.2	152697.2	29.3
6000	49246.4	10.1	53054.7	10.5	46500.2	7.6	42377.8	8.8	40100.9	7.7
6500	6686.2	1.4	6283.8	1.2	6912.2	1.1	7314.6	1.5	6283.8	1.2
7000	628.4	0.1	628.4	0.1	1885.1	0.3	1256.8	0.3	628.4	0.1
7500	628.4	0.1	1285.1	0.3	1256.8	0.2	628.4	0.1	628.4	0.1
8000	628.4	0.1	628.4	0.1	628.4	0.1	628.4	0.1	628.4	0.1
Total	**487391.7**	**100.0**	**503177.3**	**100.0**	**607931.9**	**100.0**	**480635.6**	**100.0**	**521878.2**	**100.0**
	2011_09		**2010_10**		**2009_10**		**2008_10**		**2007_10**	
Contour	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**
0	111976.6	6.8	188062.3	6.4	533296.6	10.9	185548.8	5.9	218392.8	6.7
500	41247.1	2.5	47128.6	1.6	952328.4	19.4	47531.0	1.5	109753.1	3.4
1000	126556.5	7.7	197488.0	6.7	390727.4	8.0	197714.0	6.3	236673.6	7.3
1500	184694.4	11.2	417068.5	14.1	573907.7	11.7	388305.3	12.3	454947.7	14.0
2000	145332.4	8.8	304891.6	10.3	359504.6	7.3	302405.9	9.6	321080.9	9.9
2500	112882.6	6.8	205480.5	6.9	218952.8	4.5	223351.5	7.1	249665.3	7.7
3000	100544.6	6.1	149656.5	5.1	185774.7	3.8	169803.2	5.4	176804.6	5.4
3500	50474.8	3.1	105568.0	3.6	121933.7	2.5	115423.9	3.7	117507.2	3.6
4000	50877.1	3.1	86920.8	2.9	120108.8	2.5	103484.7	3.3	117683.6	3.6
4500	87929.9	5.3	214935.6	7.3	300326.2	6.1	275859.2	8.8	225362.6	6.9
5000	352463.8	21.3	610560.2	20.6	694321.3	14.2	678827.7	21.5	592111.2	18.2
5500	214404.7	13.0	342467.6	11.6	362801.7	7.4	364863.3	11.6	341210.8	10.5
6000	59696.2	3.6	78547.6	2.7	73520.6	1.5	87570.9	2.8	80432.7	2.5
6500	8169.0	0.5	8169.0	0.3	9425.7	0.2	8169.0	0.3	8797.3	0.3
7000	1885.1	0.1	1885.1	0.1	1885.1	0.0	1885.1	0.1	1885.1	0.1
7500	1256.8	0.1	1256.8	0.0	1256.8	0.0	1256.8	0.0	1256.8	0.0
8000	628.4	0.0	628.4	0.0	628.4	0.0	628.4	0.0	628.4	0.0
Total	**1651019.9**	**100.0**	**2960714.9**	**100.0**	**4900700.4**	**100.0**	**3152628.5**	**100.0**	**3254193.8**	**100.0**

Table 3: Snow cover area in km^2 on 500m elevation intervals from 0 to 8500m for January, April, July and October months from 2007 to 2011.

Snow classification and changes

Classification maps were generated for all of the five years for January, April, July and October months shown in figure 2 (included as supplementary deta) and individual class area summarized in table 2 (included as supplementary deta). We find six main snow classes (Very low, Low, Medium, High, Very high and Extreme snow) and land where snow is present in January but not in other months shown as a “no snow” class.

Very low snow class present by 0 to 10 gray levels means its snow depth is variant 0 to 20 mm. Low snow from 20 to 44 mm, medium snow class from 44 to 70 mm and high snow present from 70 to 110 mm snow depth. Very high snow show by 55 to 75 gray levels so snow depth is 110 to 150 mm and extreme snow variant from 150 to 480 mm snow depth (http://nsidc.org/data/docs/daac/ae_swe_ease-grids.gd.html). In January 2007 extreme snow was 1.93% and it was 2.46% in January 2011. It was stable during these years except January 2008 (2.16%). For April it`s variant in between1.32 to 1.90% but it`s always less than January month.

Here is no extreme snow class was present in July month for all years. It`s again shown in October but in very less area. In all years for January and April months maximum area was covered by very low snow class and it`s more than 35% in January and more than 25% for April. In unsupervised classification we didn`t find very low snow class for July and October months because it`s goes in no snow class. Low snow class cover near to 25% area in January and April but in July it`s cover maximum area approximately 70% and in October more than 50%. High snow class cover near to 12% area in January and near to 15% in April but in July it`s cover approximately 6% area which is very less in comparison of January (0.20%) and for October near to 3%. No snow class was 40% in April, 97% in July and more than 75% in October so this area was covered by snow in January but not in other seasons.

Snow with elevation

Figure3 (included as supplementary deta) and table 3 shows a more detailed analysis of snow covered areas during the 2007 to 2011 seasons, for which the dynamics of SCA was the most important. We note, very logically, that in winter (January) the rate of snow coverage increases with low altitude in between 0 to 2000 m, as well as the non-permanent character of the snowpack. But during summer (July) it`s increase on high altitude near to 5000 m and again in beginning of winter (October) it`s start to come down side or low altitudes. In January snow covered areas represent more than 70% of surfaces with altitudes in between 0 to 2000 m and in summer more than 70% for altitudes higher than 5000 m and it`s totally constant at altitude from 7000 m and above (Table 3).

Conclusion and Perspectives

The seasonal snow cover extent changes from 2007 to 2011 were successfully monitored by AMSR-E images. The results showed a seasonal variation in snow cover extent, in comparison of January total snow in April is 60%, July 3% and in October near to 25%, in addition to its seasonal behavior. The minimum (1.53 million km^2) snow cover extent was observed in July 2008 and the maximum (60.0 million km^2) in January 2010. In January snow covered area represent more than 70% of surfaces with altitudes in between 0 to 2000 m, and in summer more than 70% for altitudes higher than 5000m and it`s totally constant at altitude from 7000 m and above.

In addition, preliminary studies of the linkages between inter and intra-annual variability of snow cover, snow type, elevation and climate has been carried out. So long term observation of snow covered areas by means of remote sensing can thus (1) provide seasonal and inter-annual snow cover variations and (2) provide a better understanding on the dynamic of SCA over this region and in particular. Obviously, such information derived from remote sensing observations with a high repeativity can be of great interest for operational planning of water use (reinforcement of the monitoring of precipitations, identification of the dry and wet years, relation between snowfall and flow rates, etc.).

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