Journal of Geophysics & Remote Sensing

A COMBINED ACTIVE/PASSIVE MICROWAVE REMOTE SENSING APPROACH FOR ACTUAL PHYSICAL LAND-SURFACE TEMPERATURE

Prof. Dr. Mukesh Singh Boori

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Prof. Dr. Mukesh Singh Boori (Asst. Prof.)
Honorary/UK; Postdoc/USA; PhD/Brazil; Predoc/Belgium; MSc, BSc/India

Department of Geography, University of Leicester, England - UK.
Ph.:+01162523823(O), +01162523854(F)

Dept. of Geo-informatics, Section of Earth Science, Palacky University
Olomouc, Czech Republic - Europe
Ph.:+420585634519(O), +420732287744(M), +420585639196(R),
Email: mukesh.boori@upol.cz

Dept. of Environmental Science & Civil Engineering
School of Sciences, JECRC University, Jaipur, Rajasthan, India
Ph.:+91.141.2332358(R), Email: mukesh.boori@jecrcu.edu.in

Ex. Scientist JSAC/ISRO and NOAA/NASA
Email: msboori@gmail.com & boori_m@yahoo.com *Skype ID:* mukesh.singh.boori

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Summary

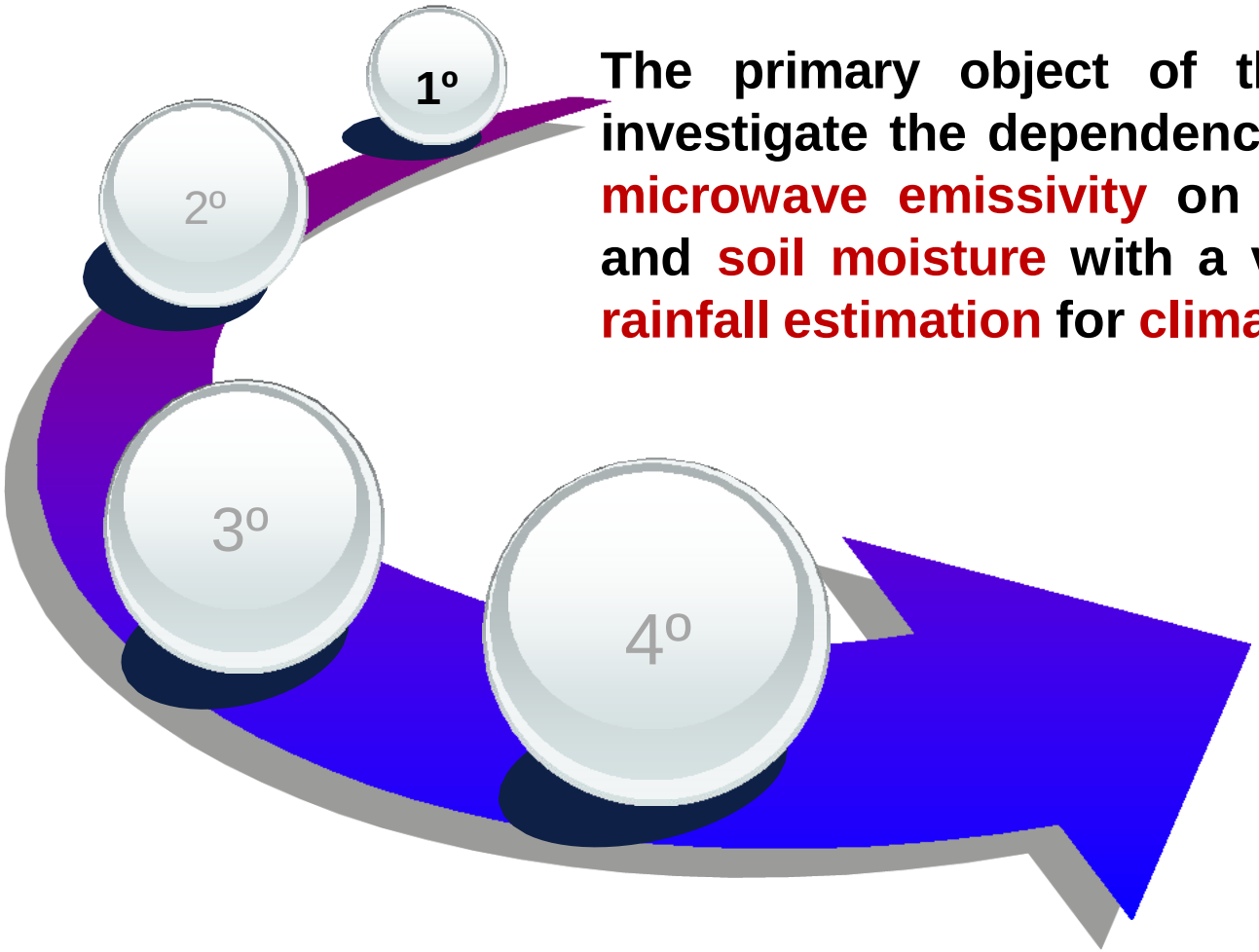
1. Introduction
2. Motivation & Objectives
3. Study Area
4. Data & Methodology
5. Results & Discussion
6. Conclusions & Perspectives

Introduction

WHAT`S THE IMPORTANCE OR NEED FOR HYDRO-GEOPHYSICAL STUDY THROUGH RS & GIS ?

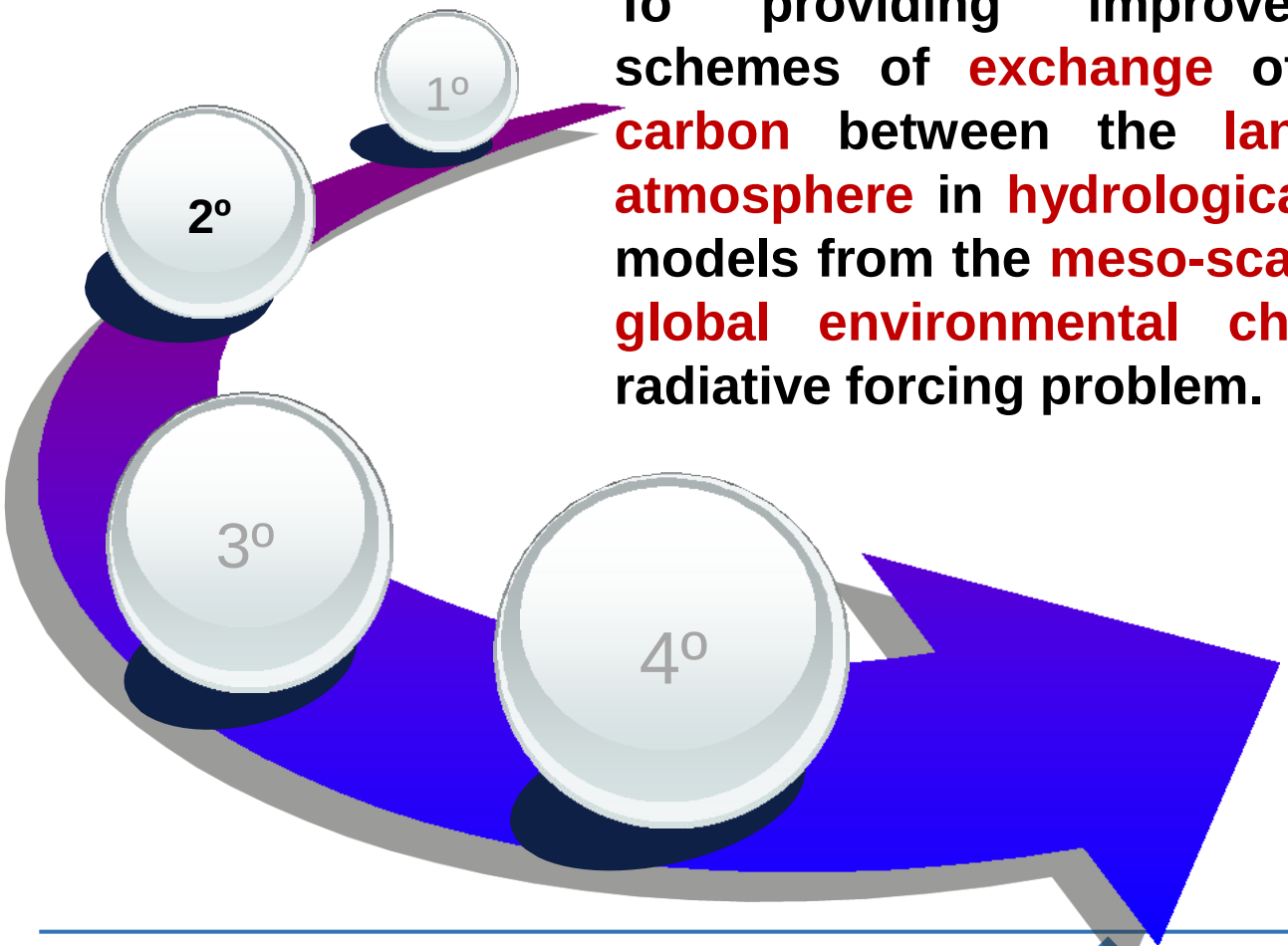
- These variables play an important role in quantifying water and energy fluxes at the land surface/atmosphere interface, which have direct implications in hydrological, climate and weather forecasting models.
- Significant influence on water and energy cycles (in terms of Earth radiative balance), as well as socioeconomic and environmental repercussions on the earth and these are significant indicators of climate change.
- It`s improve the satellite-based rainfall estimates for climate change.
- Real-time rainfall measurements are vital for crop monitoring, drought, famine warning and Indirect influence on other climate components such as snow cover, soil moisture and atmospheric circulation variability.
- Can benefit hydrological, meteorological, climatological, flood forecasting, food production, water use and control applications.

Objectives



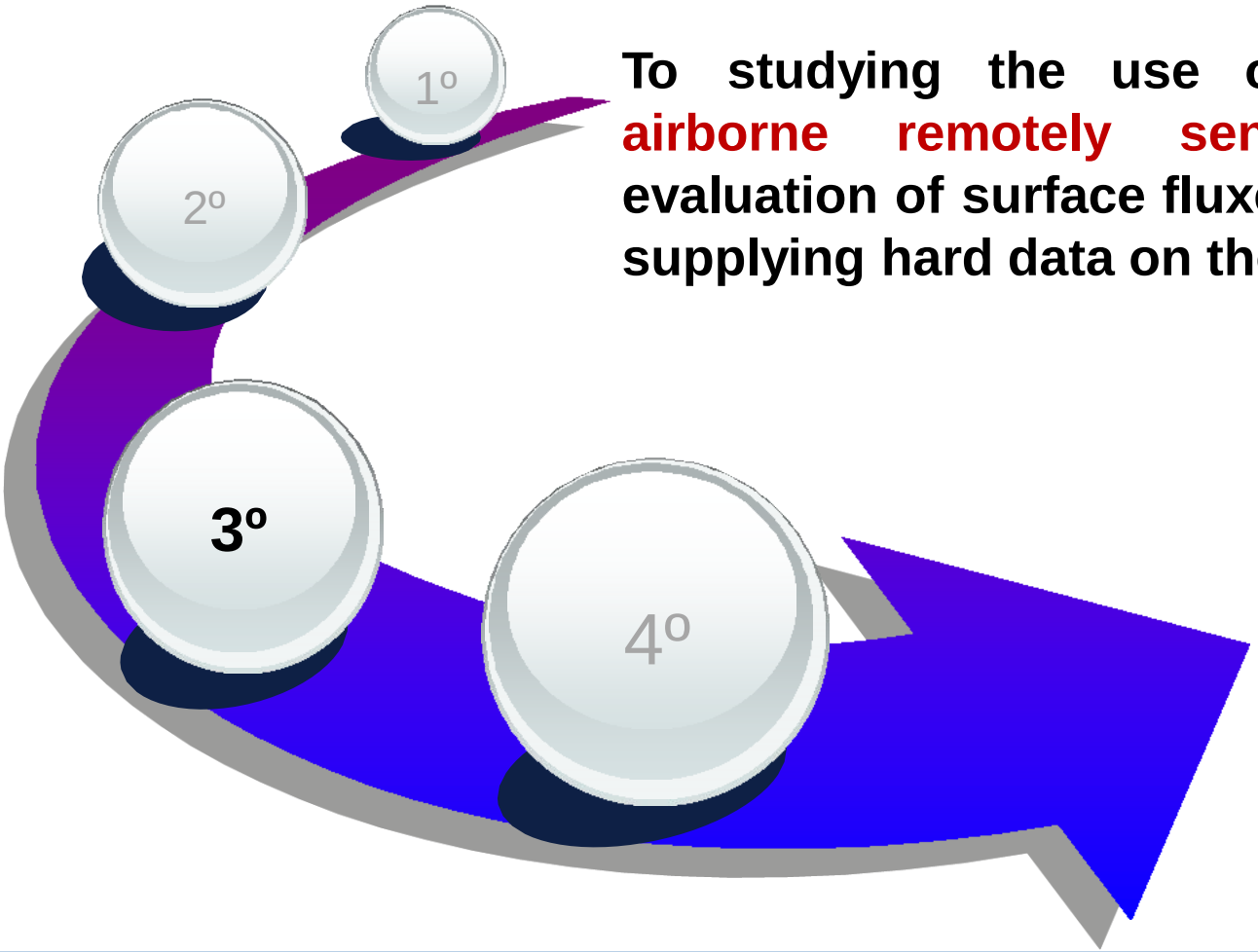
The primary object of this project is to investigate the dependence of land surface microwave emissivity on snow, vegetation and soil moisture with a view to improving rainfall estimation for climate change.

Objectives



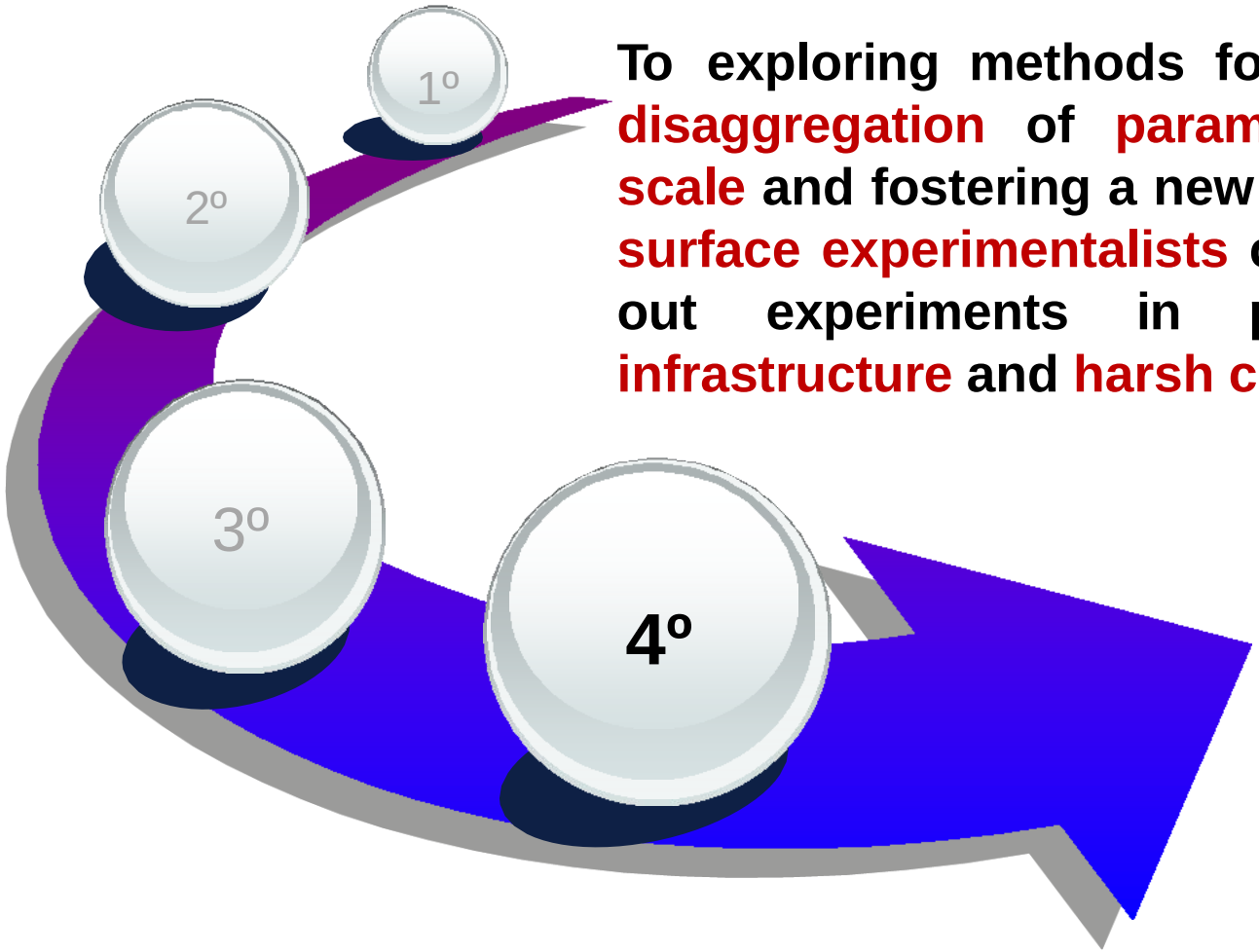
To providing improved parameterization schemes of exchange of water, energy and carbon between the land surface and the atmosphere in hydrological and meteorological models from the meso-scale to larger scales for global environmental change, including the radiative forcing problem.

Objectives



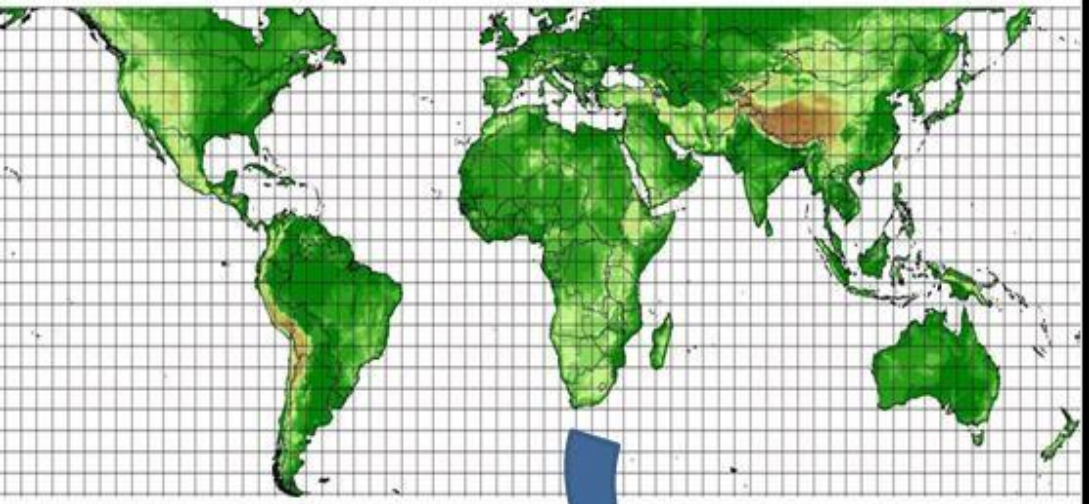
To studying the use of satellite and airborne remotely sensed data for evaluation of surface fluxes and states by supplying hard data on the ground truth.

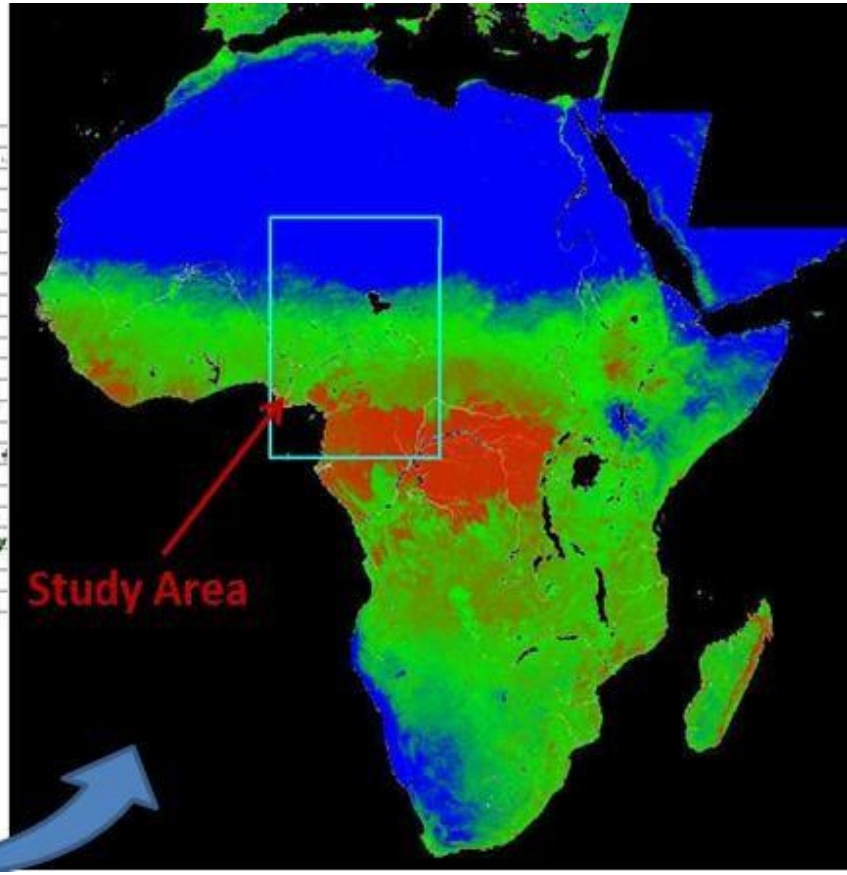
Objectives



To exploring methods for **aggregation** and **disaggregation** of **parameters** on **different scale** and fostering a new community of **land surface experimentalists** capable of carrying out experiments in places with **bad infrastructure** and **harsh climate**.

Study Area





Hapex Sahel Experimental Site

- **The area selected for this study is the Hapex Sahel experimental site and surrounding area (0°–5°E and 11°– 16°N).**
- **The EPSAT rain gauge network is located in this area.**
- **The study area is also interesting because of the change in vegetation cover from dense vegetation in the extreme south, and very little or no vegetation in the north, as desert.**

Data and Methodology

Database Products:

➢**Conventional data** are more accurate and site specific, but data collection is time consuming, expensive, requires more manpower and it may not be possible to extrapolate to a larger area.

➢**Remotely sensed data** on the other hand have got advantages due to repetitive and synoptic coverage of the large, inaccessible areas, quickly and economically.

In the present study, to take the dual advantages, both conventional and remotely sensed data were used.

✓**Primary Data:**

AMSR-E, SSMIS, TRMM, Landsat and SRTM data.

✓**Secondary Data:**

Topographic sheet, Socio-economic data, meteorological data.

Data and Methodology

- The accurate monitoring of hydro-geological parameters by optical imagery of high spatial resolution is seriously reduced by cloud cover due to the similar reflective nature of snow and clouds, while passive microwave remote sensing has advantage in penetration of cloud cover and all weather imaging.

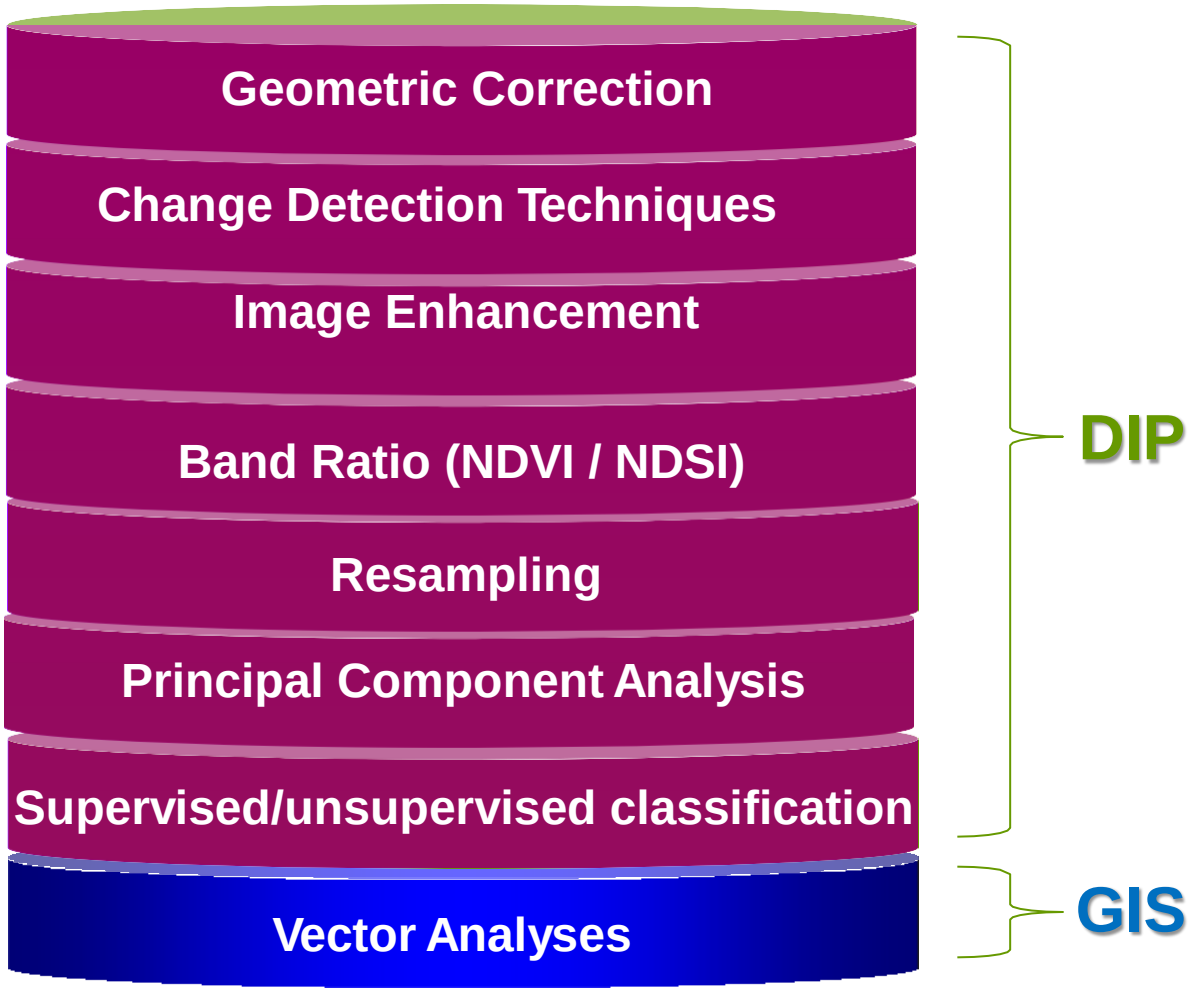
- A combination of the two products could provide a significant improvement with high spatial resolution from the optical imagery and cloud transparency from the microwave imagery.

Data and Methodology

- **WP1: Literature study on climate research through active/passive microwave remote sensing analysis and selection of proper models.**
- **WP2: Comprehension of the physics of climate change – influencing parameters, special attention on snow and vegetation cover (biomass) and soil moisture.**
- **WP3: Writing the correction algorithm and analysis of the interaction with other correction algorithms.**
- **WP4: Implementation the correction algorithms for specific applications such as rainfall, air temperature, humidity, radiation, sea ice, flood plain, soil moisture, surface roughness, sea surface salinity and temperature, aerosol properties, water vapors, gas molecules, global precipitation, clouds, haze, dust particles, LULC, total solar irradiance, seasonal changes of vegetation and snow cover, herbaceous and arboreous biomass etc. and in last publications & reporting.**

Data and Methodology

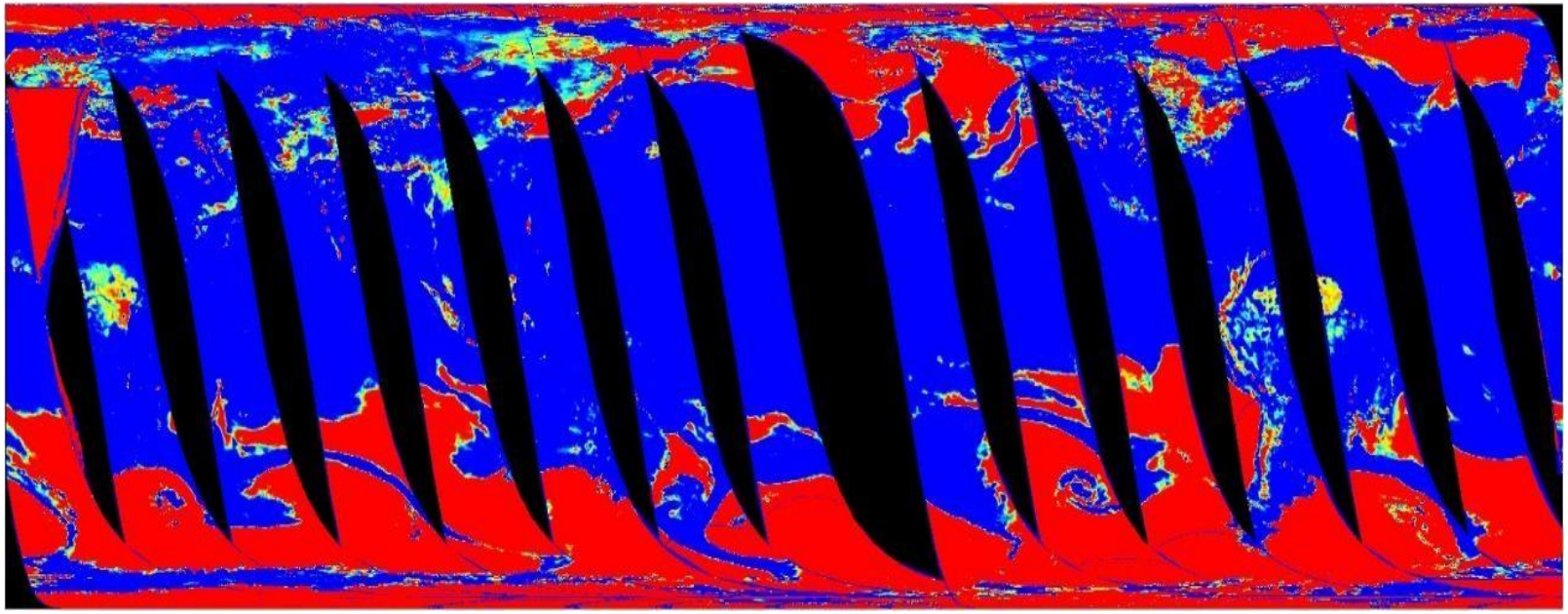
- **Methods to Building a Basic Geographic Database:**



Principal Component Analysis

- **Principal component analysis (PCA) involves a mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called *principal components*.**
- **The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible.**
- **PCA useful to discover or to reduce the dimensionality of the data set (For Landsat PCA1 = 91%, PCA2 = 4-5%, PCA3 = 2-3%.....).**

PCA-3



Polarization and Gradient Ratio

The PR/GR is an index that provides a standardized method of comparing surface features in satellite images. The formula to calculate PR/GR is:

$$PR = (XV - XH) / (XV + XH)$$

$$PR = (19V - 19H) / (19V + 19H)$$

$$GR = (XV - YV) / (XV + YV)$$

$$GR = (6V - 10V) / (6V + 10V)$$

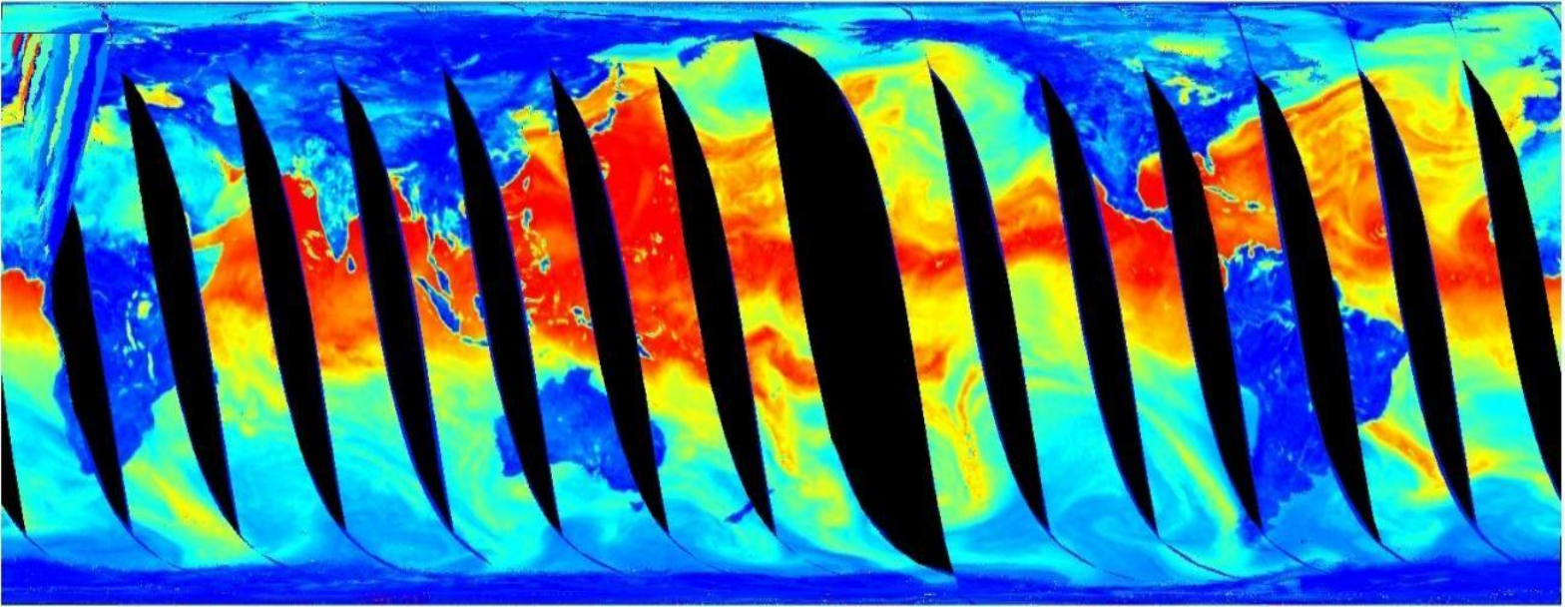
Normalized Difference Vegetation Index

Index values can range from -1.0 to 1.0, Higher index values are associated with higher levels of healthy vegetation cover, whereas clouds and snow will cause index values near zero, making it appear that the vegetation is less green.

$$NDVI = (\text{near IR band} - \text{red band}) / (\text{near IR band} + \text{red band})$$

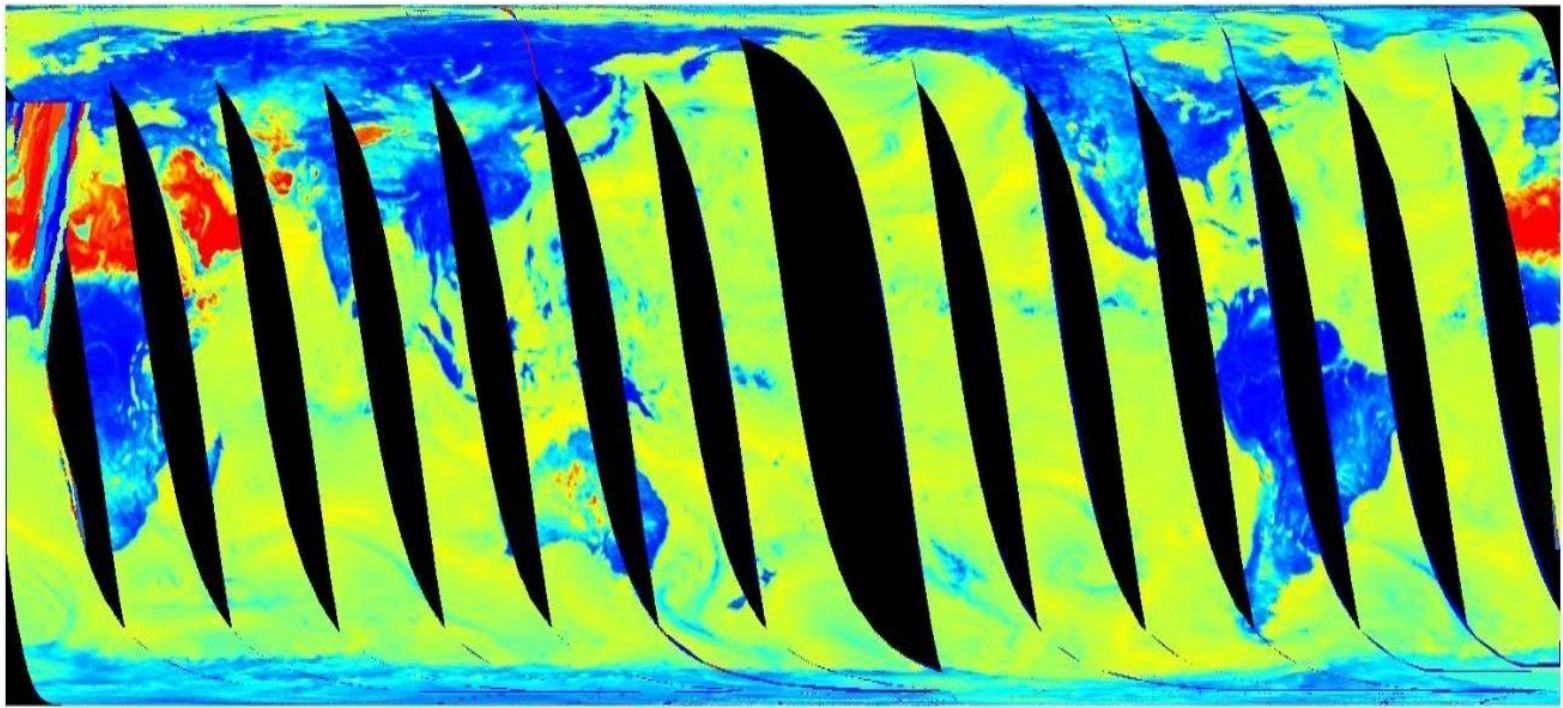
Bands from the following satellite sensors can be used to calculate NDVI:

- **Landsat TM -- bands 3 (0.63-0.69 µm) and 4 (0.76-0.90 µm)**
- **Landsat ETM -- bands 3 (0.63-0.69 µm) and 4 (0.75-0.90 µm)**
- **NOAA AVHRR -- bands 1 (0.58-0.68 µm) and 2 (0.72-1.0 µm)**
- **Terra MODIS -- bands 1 (0.62-0.67), 2 (0.841-0.876)**

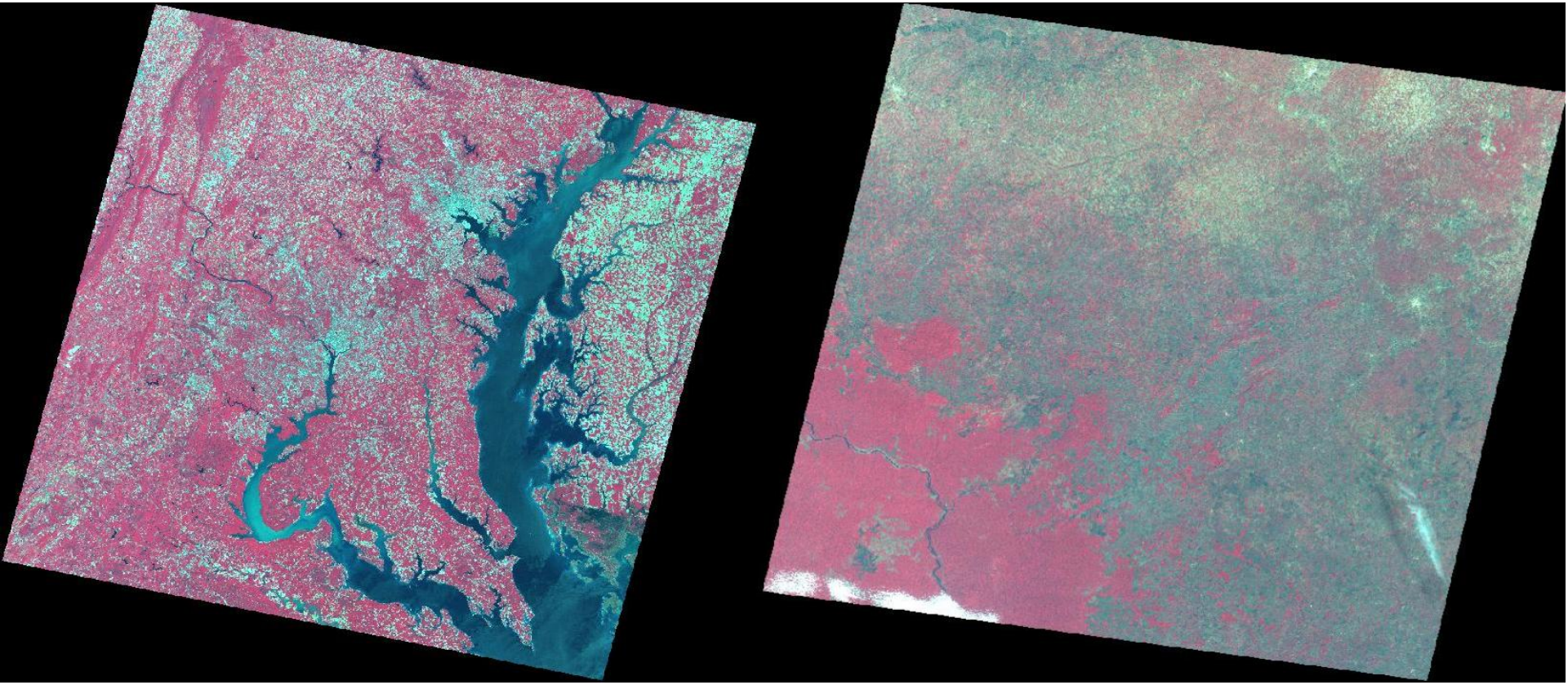


L2A20110831_H_GR_B34
GR=(18.7H-23.8H)/(18.7H+23.8H)

L2A20110831_PR_H5-V5
PR=(36.5H-36.5V)/(36.5H+36.5V



Landsat Images: Showing Vegetation / Forest condition, Settlements, River, Road, Drainage pattern, Hilly terrine, Clouds, Open Scrub/Westland, Wetland and water body.



Data and Methodology for Snow Work

- **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.**

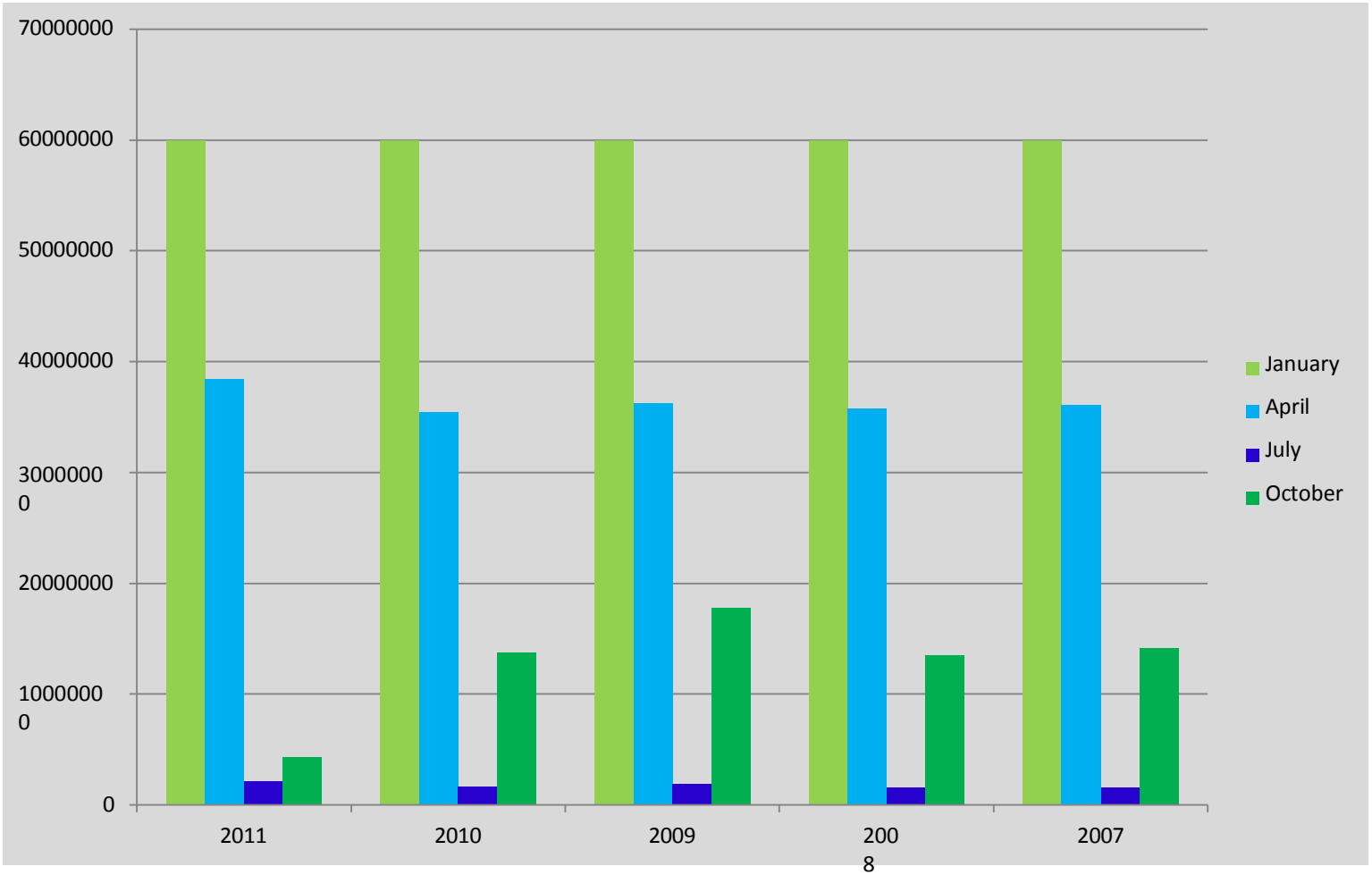
- ✓ **Unsupervised classification was performed here using 0 to 255 (8 bit) gray levels and digital topographic maps.**

- ✓ **The end gray levels 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.**

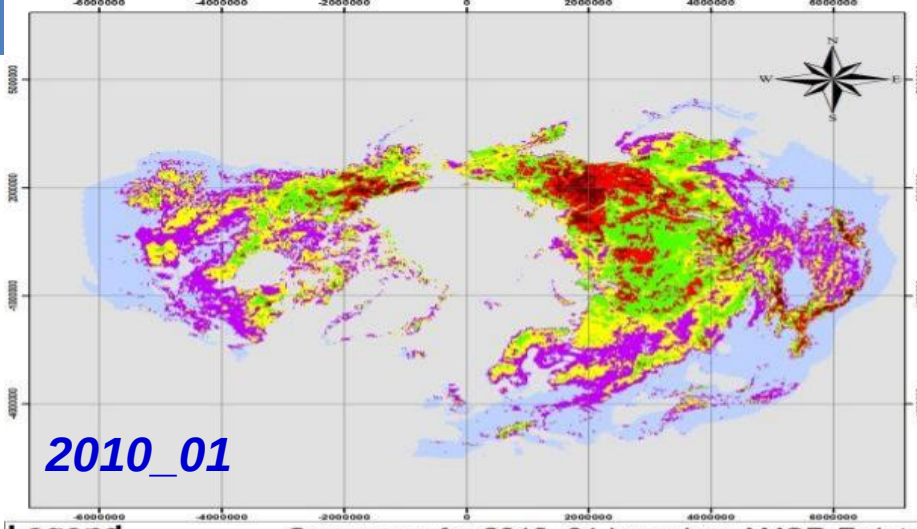
Result of Snow Work

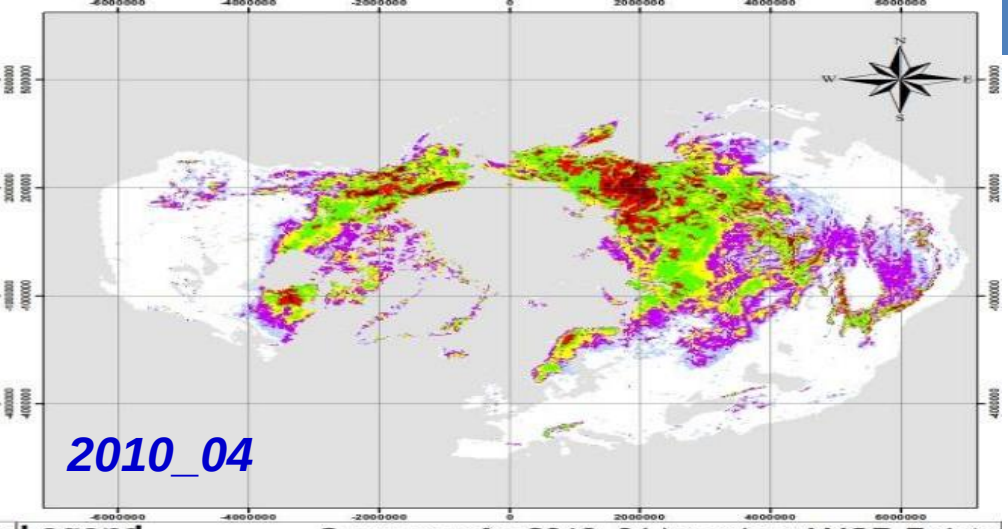
The presence of maximum snow is always detected in winter. In comparison of January total snow in April is 60%, July 3% and in October near to 25% snow covers.

1. Spatial-temporal variability of snow cover



Graphical representation of seasonal snow cover area.


2010_01
Legend
Snow map for 2010_01 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201001 Northern Hemisphere
Rest Part of Image
Snow classes
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro


2010_04
Legend
Snow map for 2010_04 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201004 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
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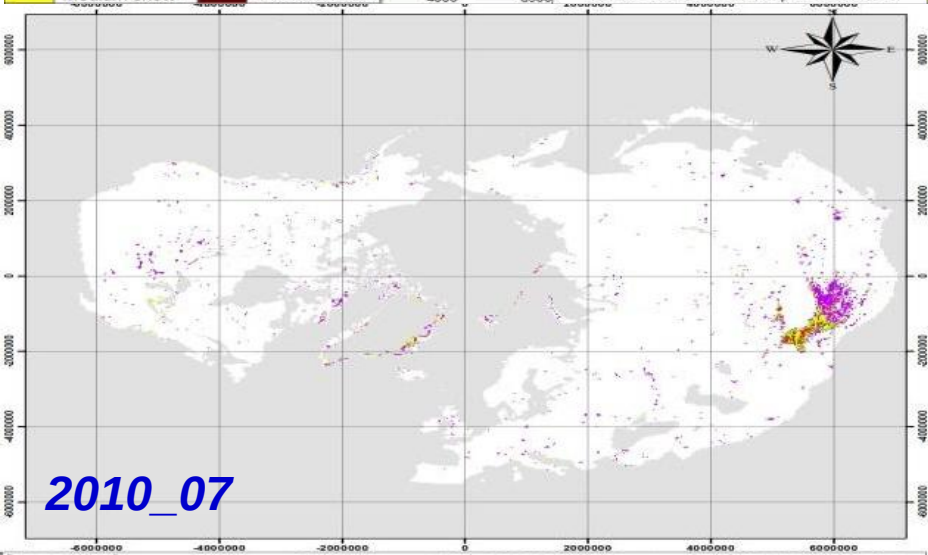
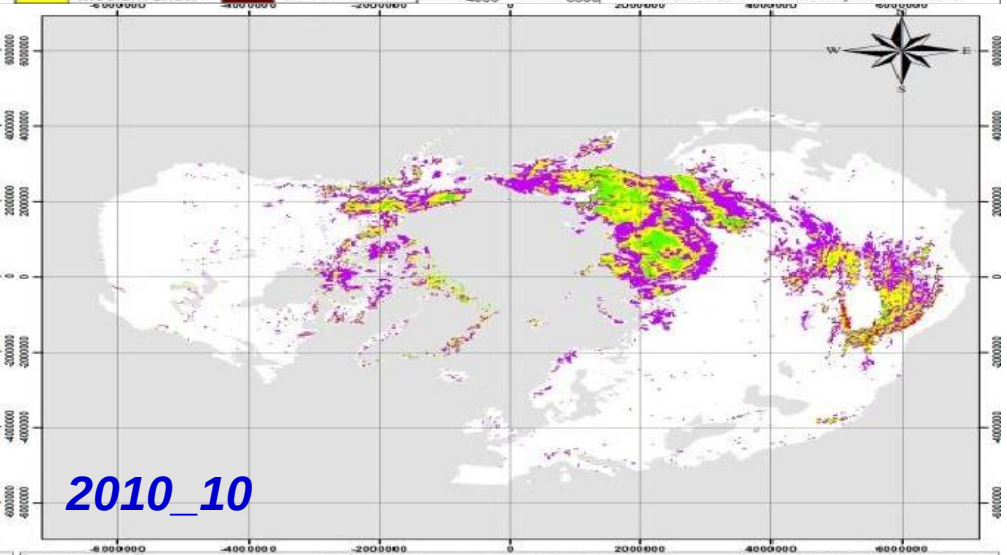
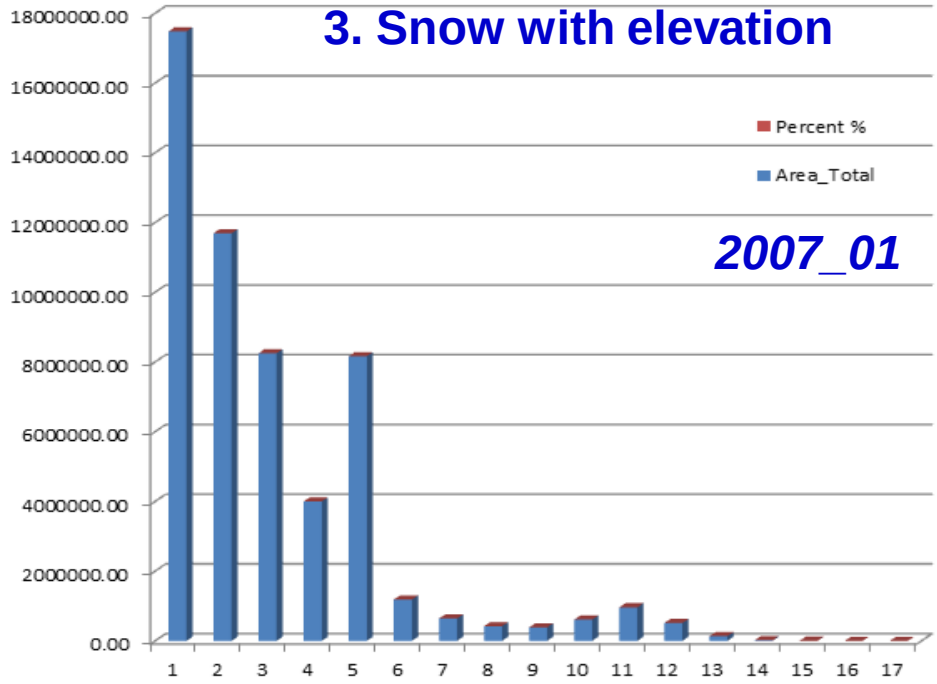
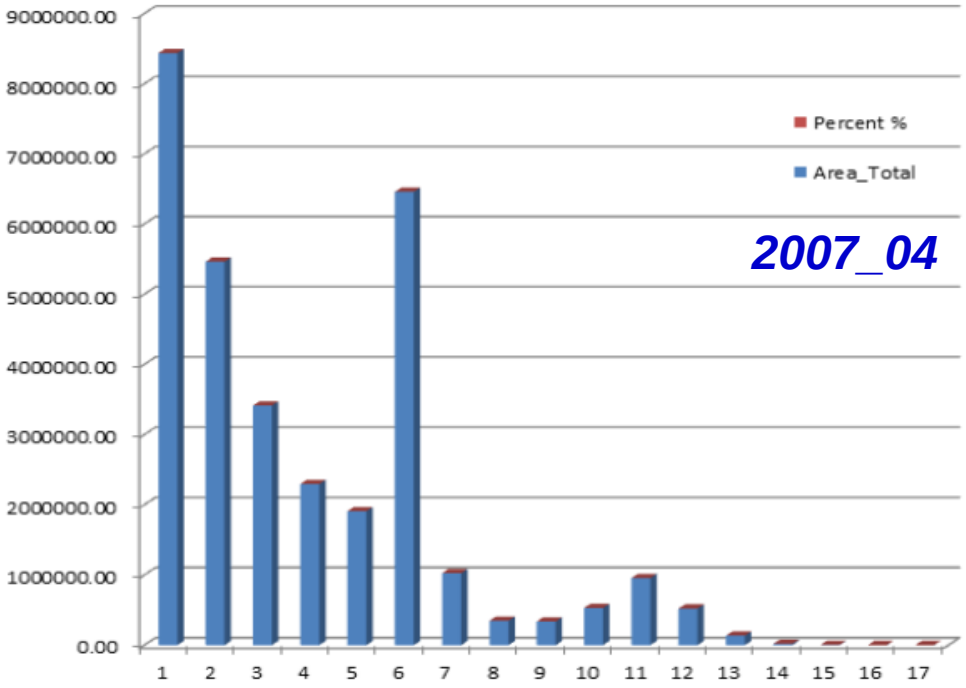
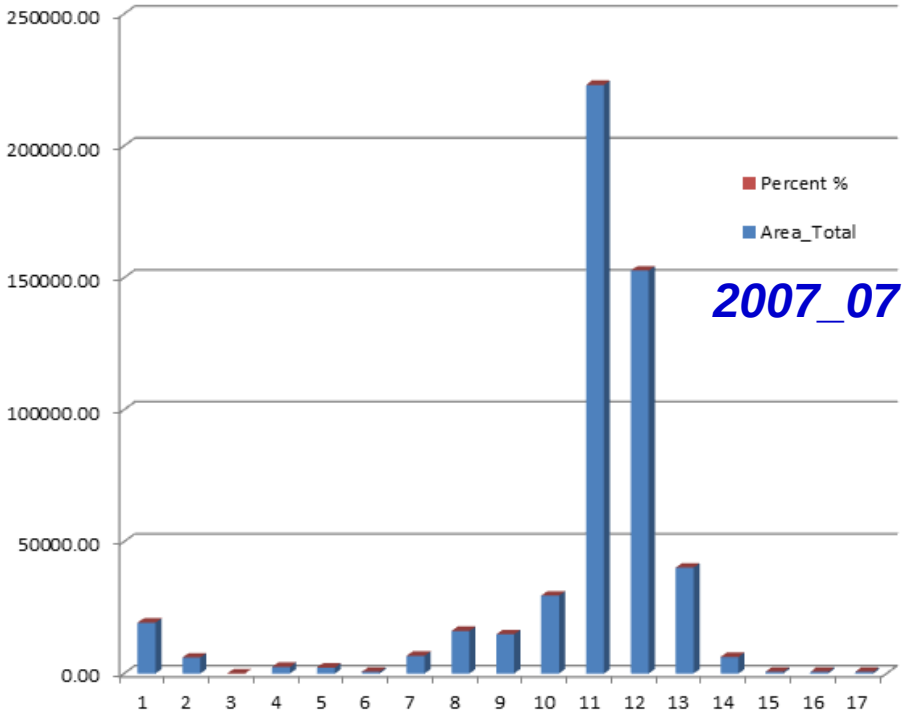

2010_07
Legend
Snow map for 2010_07 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201007 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Contour_500m
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

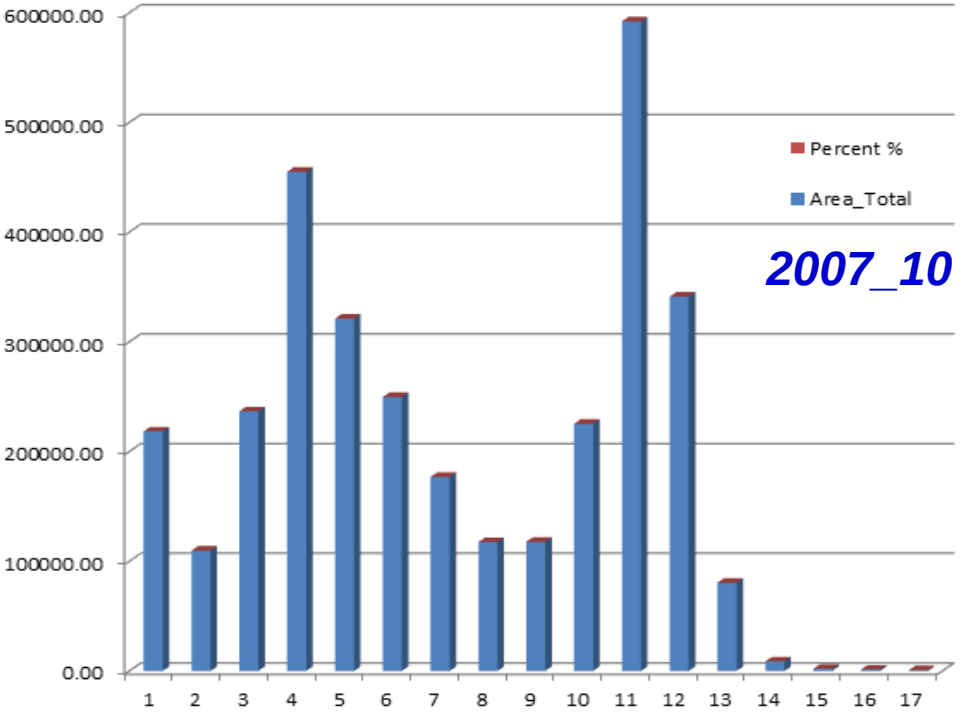

2010_10
Legend
Snow map for 2010_10 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201010 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Contour_500m
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

3. Snow with elevation









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 (59.96 million km^2) in January 2010.
- In January snow covered areas represent more than 70% of surfaces with altitudes in between 0 to 2000m, and in summer more than 70% for altitudes higher than 5000m and
- It`s totally constant at altitude from 7000m and above.
- Provide seasonal and inter-annual snow cover variations.

Looking forward

- ✓ **Mukesh Singh Boori**, Ralph R. Ferraro (2012), ***Northern Hemisphere snow variation with season and elevation using GIS and AMSR-E data.***

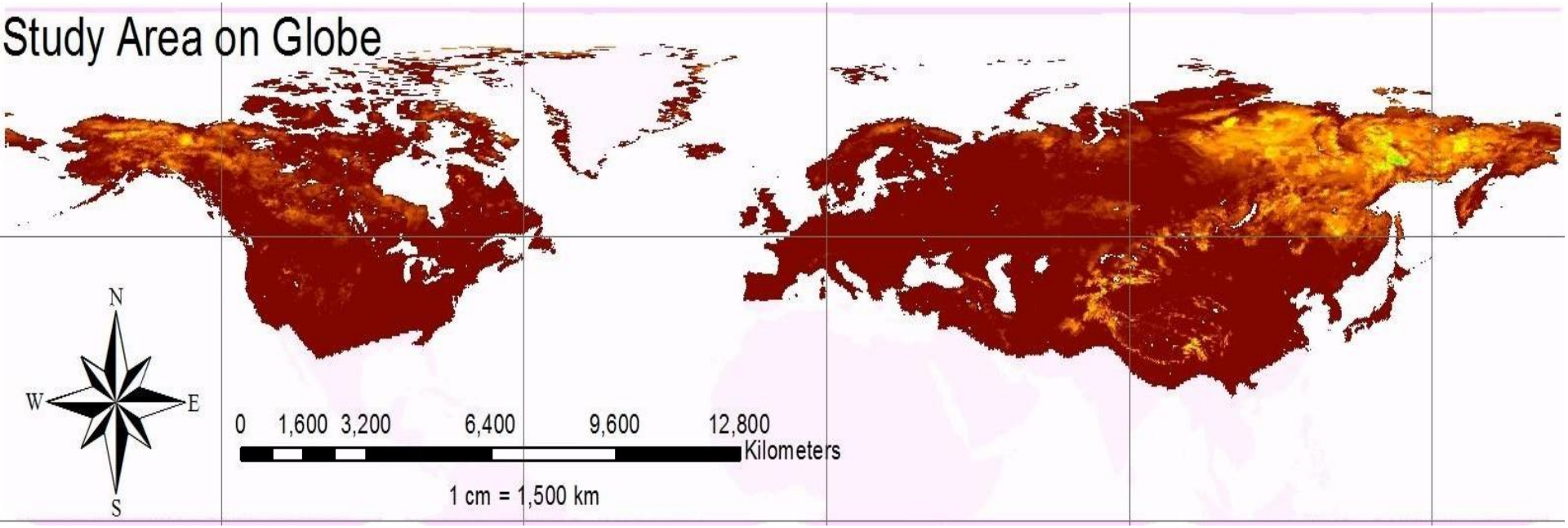
- ✓ **Mukesh Singh Boori**, Ralph R. Ferraro (2012), ***Seasonal snow type and snow cover change on different elevation in Northern Hemisphere using AMSR-E data from 2007 to 2011. "International Conference on Earth Science & Climate Change"*** Hilton Chicago Northbrook, USA, August 21-22, 2012.

- **Obviously, such information derived from remote sensing observations with a high repeatitivity 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, hydrological, meteorological, and climatological applications, etc).**

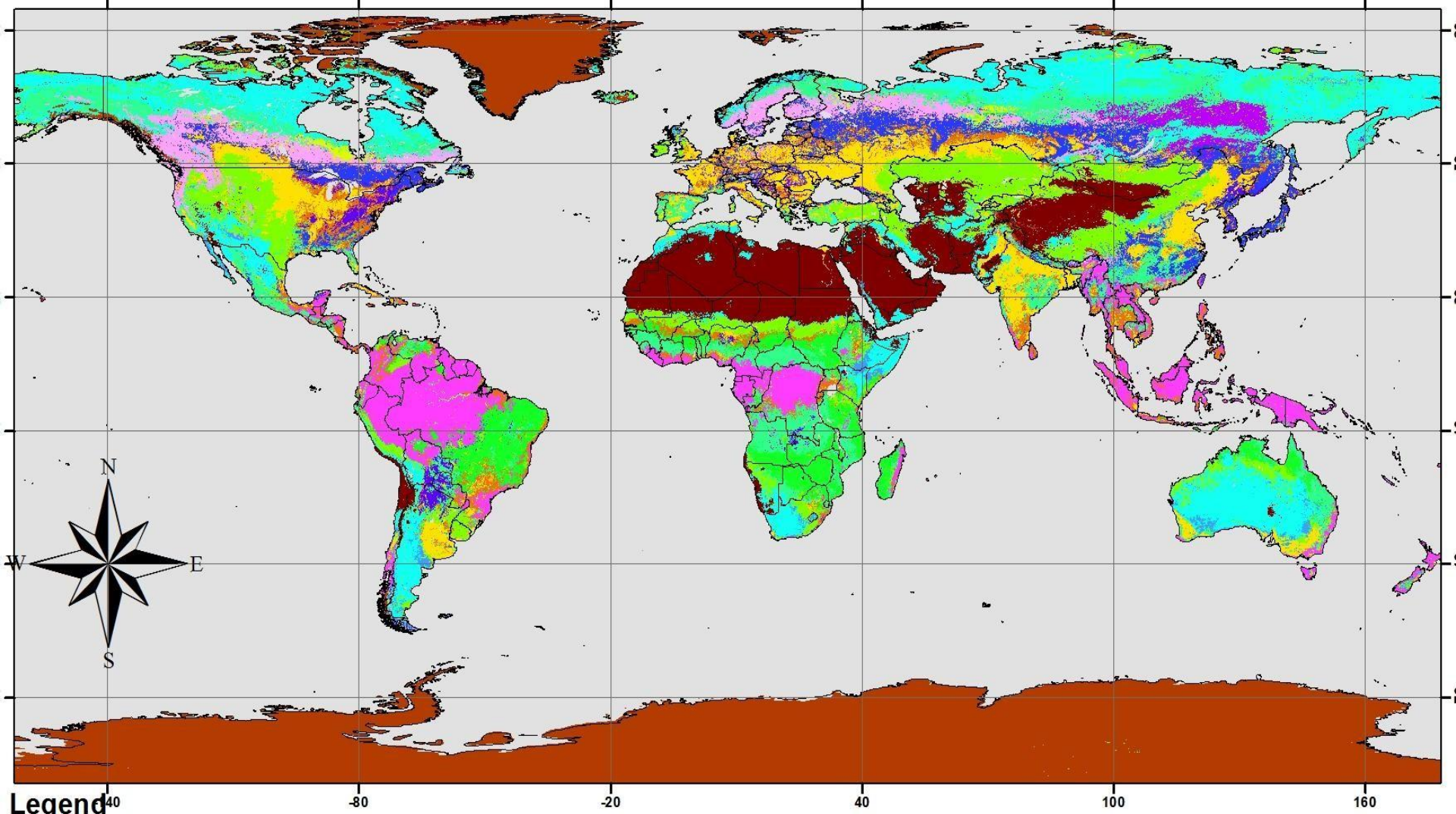
Thank you

BACKUP

Study Area



Northern Hemisphere (NH)



Legend

World Countries Boundary

MOD_Land Cover Classes_01/2009

- 0_Water
- 1_Evergreen Needleleaf Forest
- 2_Evergeen Broadleaf Forest
- 3_Deciduous Needleaf Forest
- 4_Deciduous Broadleaf Forest
- 5_Mixed Forest
- 6_Closed Shrublands
- 7_Open Shrublands
- 8_Woody Savannas
- 9_Savannas
- 10_Grasslands
- 11_Permanent Wetlands
- 12_Croplands
- 13_Urban Built-up
- 14_Cropland Natural Vegitation Mosaic
- 15_Snow Ice
- 16_Barren Sparsely Vegetated

NASA

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

STAR Center for Satellite Applications and Research
formerly ORA — Office of Research and Applications

NOAA Satellites and Information
National Environmental Satellite, Data, and Information Service

CORP

0 1,400 2,800 5,600 8,400 11,200 Kilometers

1:130,000,000

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Data and Methodology

- HDF-EOS to GeoTiff (HEG): File format, Resampling and Projection
- Hierarchical Data Format (HDF) and Earth Observing System (EOS)

  HDF => HDF-ESO {EOS = Grid, Point, Swath (Geo-location information)}

- 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 was performed here using 0 to 255 (8 bit) gray levels and digital topographic maps.
- ✓ The end gray levels 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.

2. Snow classification and changes

	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		
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**		

http://nsidc.org/data/docs/daac/ae_swe_ease-grids.gd.html

0-255 (0-240) * 2 = 0-480mm

0 – 10 – 22 – 35 – 55 – 75 - 240

Snow with elevation

	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

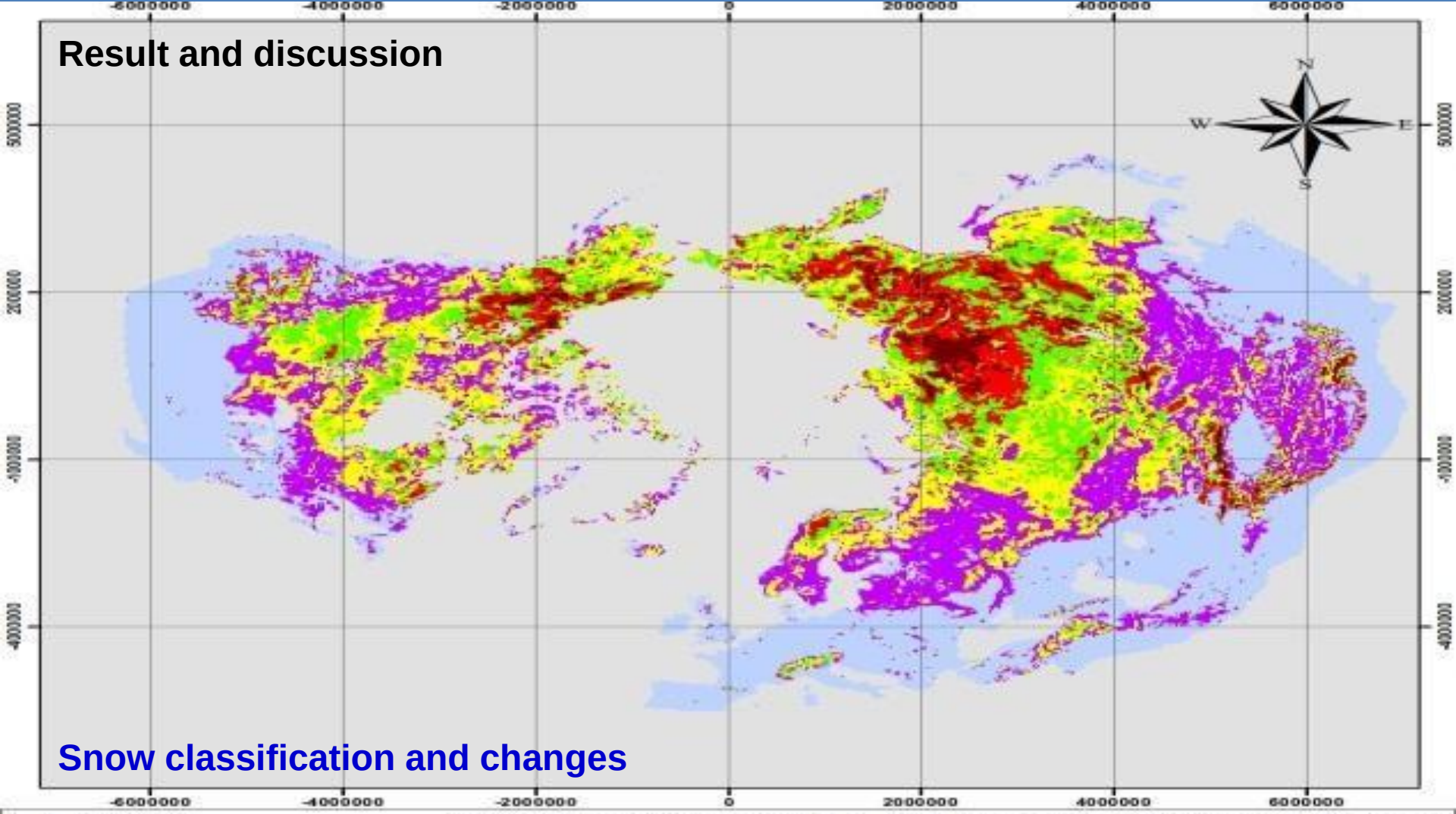
	2011_04		2010_04		2009_04		2008_04		2007_04	
Contour	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**
0	10999024.2	30.4	7878629.6	23.5	9080069.2	26.9	7997883.2	24.8	8436200.9	26.5
500	6764994.4	18.7	13234929.7	39.4	4685703.7	13.9	7064639.2	21.9	5465795.2	17.2
1000	3436179.6	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
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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**

Snow with elevation

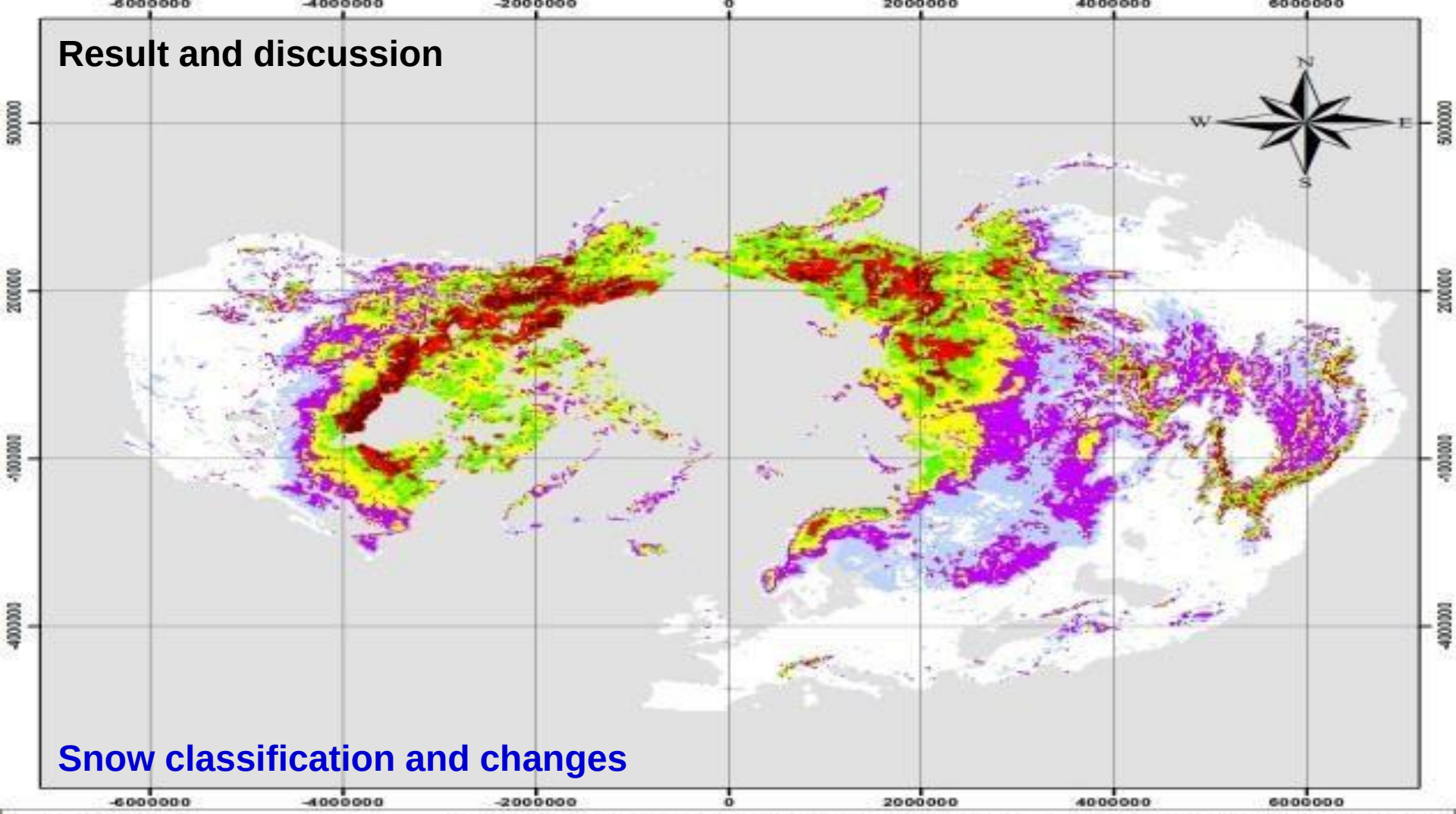
	2011_07		2010_07		2009_07		2008_07		2007_07	
Contour	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**
0	24977.1	5.1	16251.0	3.2	22070.7	3.6	17640.8	3.7	19238.2	3.7
500	9376.2	1.9	5903.8	1.2	4172.7	0.7	4828.9	1.0	6057.8	1.2
1000	3766.8	0.8	0.0	0.0	0.0	0.0	1486.4	0.3	0.0	0.0
1500	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
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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**

Result and discussion



Result and discussion



Snow classification and changes

Legend

Snow map for 2011_04 based on AMSR-E data

AMSR_E_L3_MonthlySnow
201104 Northern Hemisphere

Rest Part of Image

Snow classes

- No snow
- Very low snow
- High snow
- Low snow
- Very high snow
- Medium snow
- Extreme snow

Contour_500m

0	4500
500	5000
1000	5500
1500	6000
2000	6500
2500	7000
3000	7500
3500	8000
4000	8500

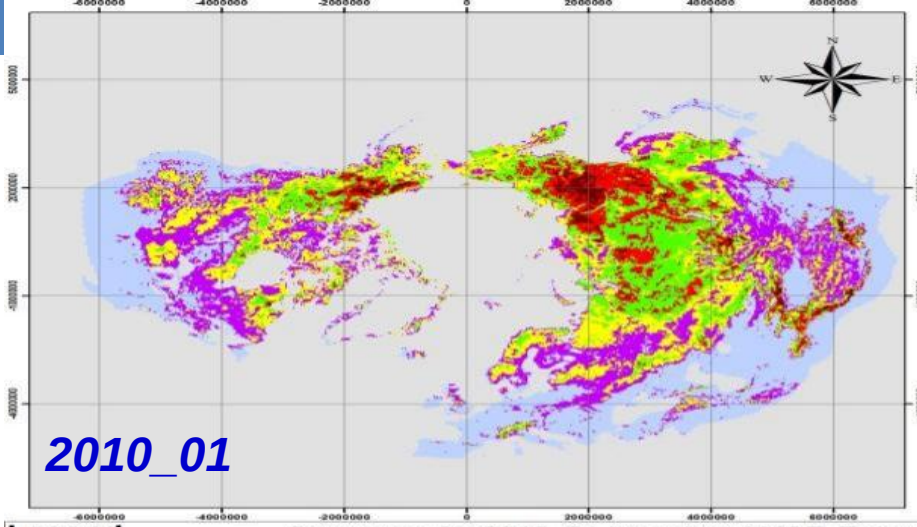
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

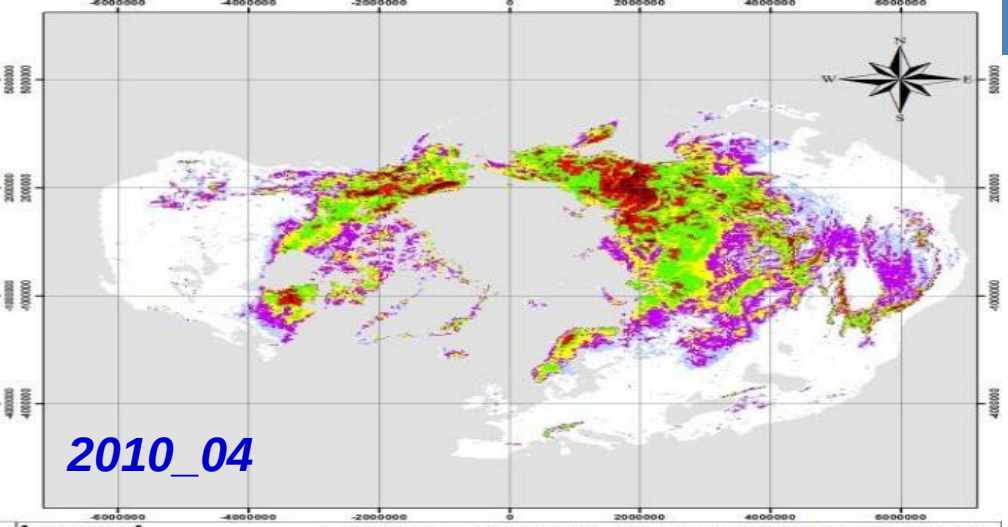
STAR Center for Satellite Applications and Research

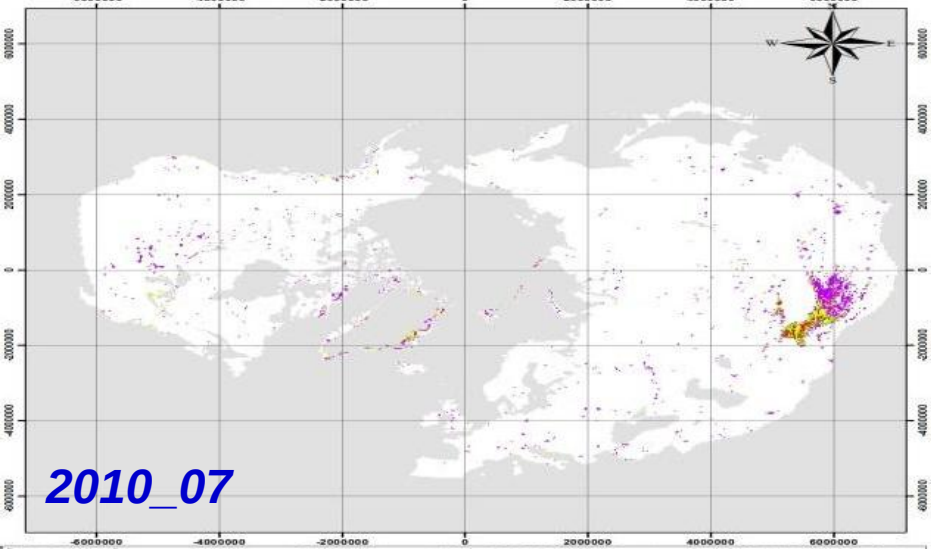
0 550 1,100 2,200 3,300 4,400 Kilometers

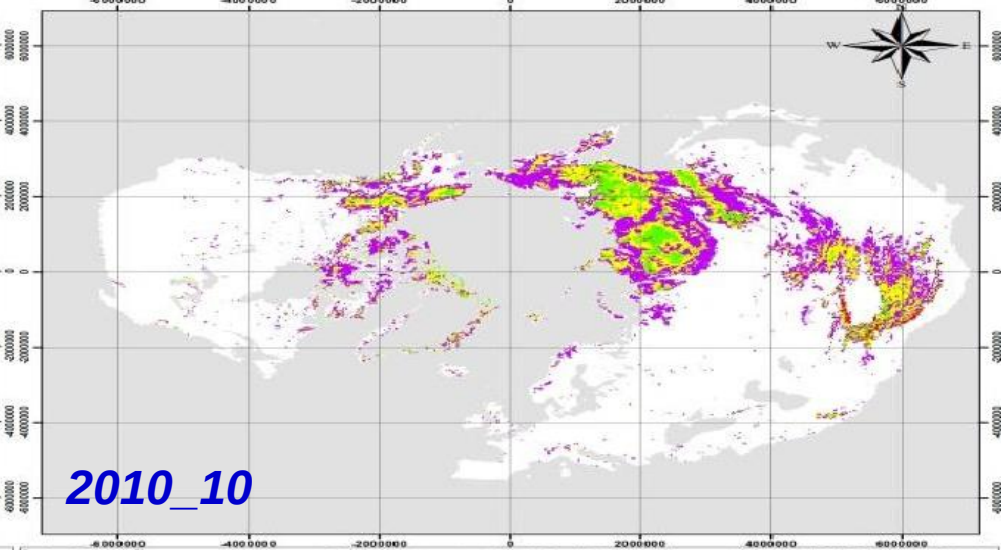
1 cm = 700 km

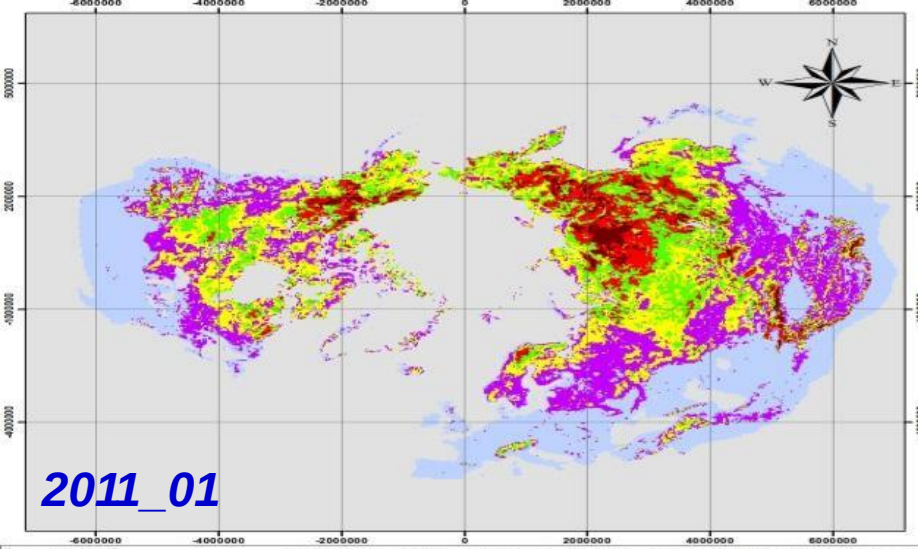
Mukesh S. Boori & Ralph R. Ferraro

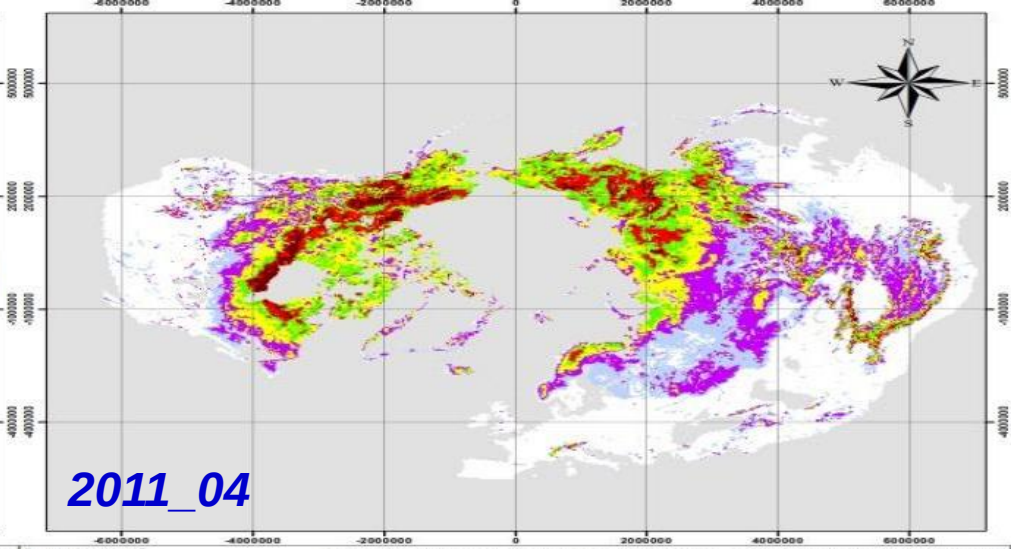

2010_01
Legend
Snow map for 2010_01 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201001 Northern Hemisphere
Rest Part of Image
Snow classes
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

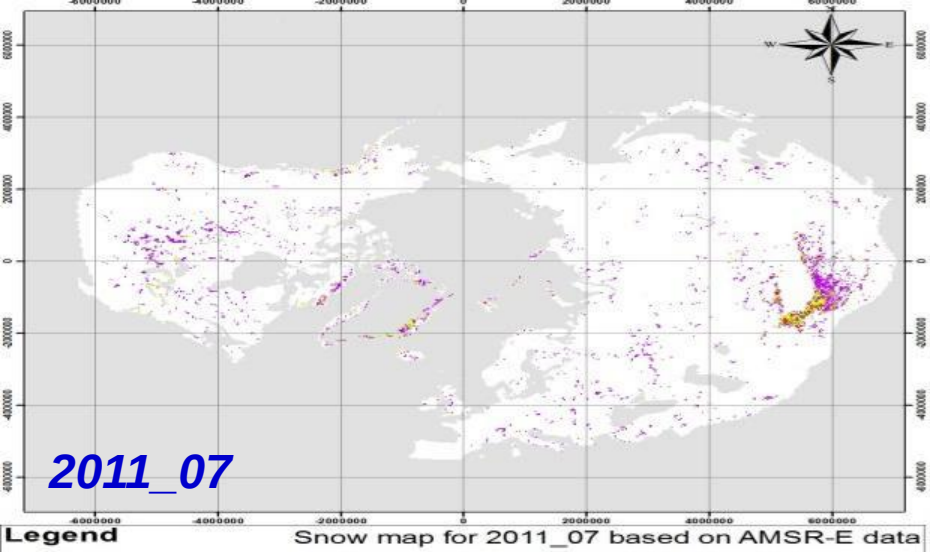

2010_04
Legend
Snow map for 2010_04 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201004 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

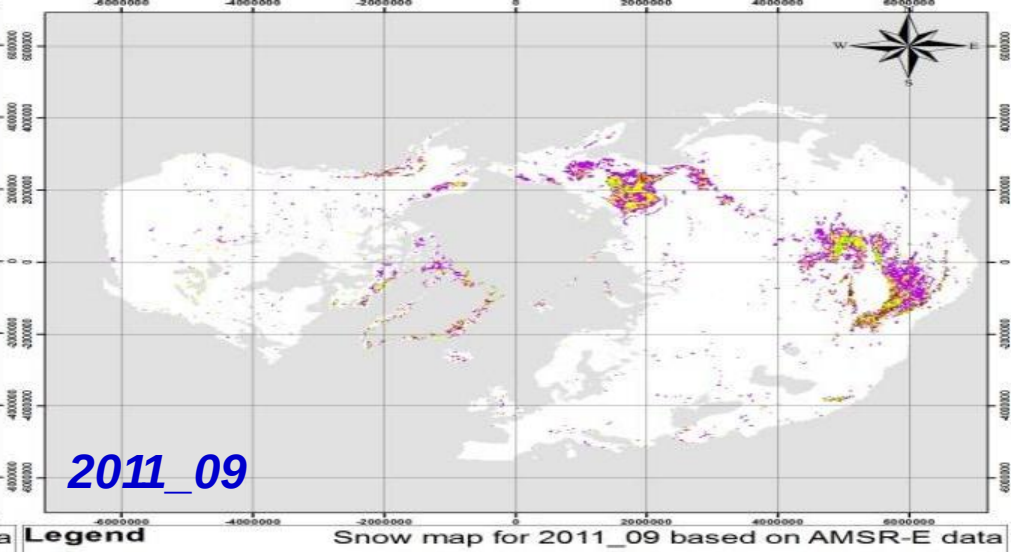

2010_07
Legend
Snow map for 2010_07 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201007 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Contour_500m
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

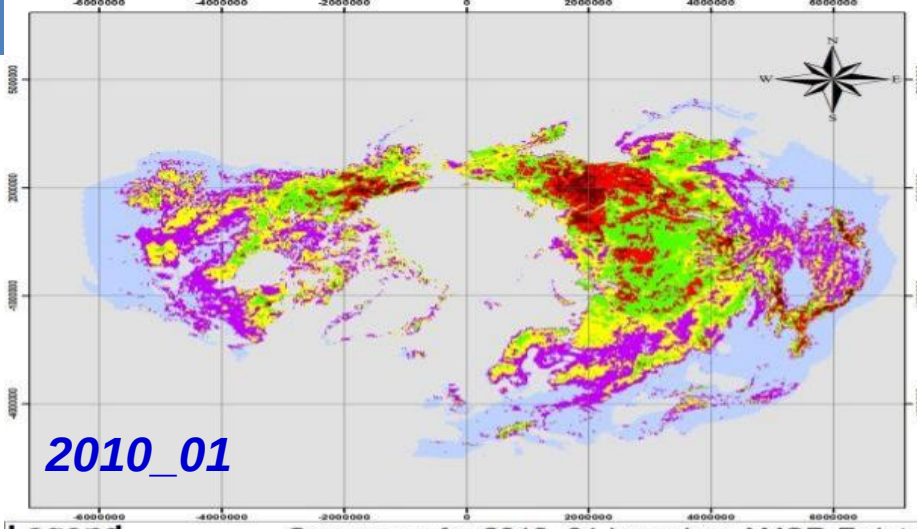

2010_10
Legend
Snow map for 2010_10 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201010 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Contour_500m
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

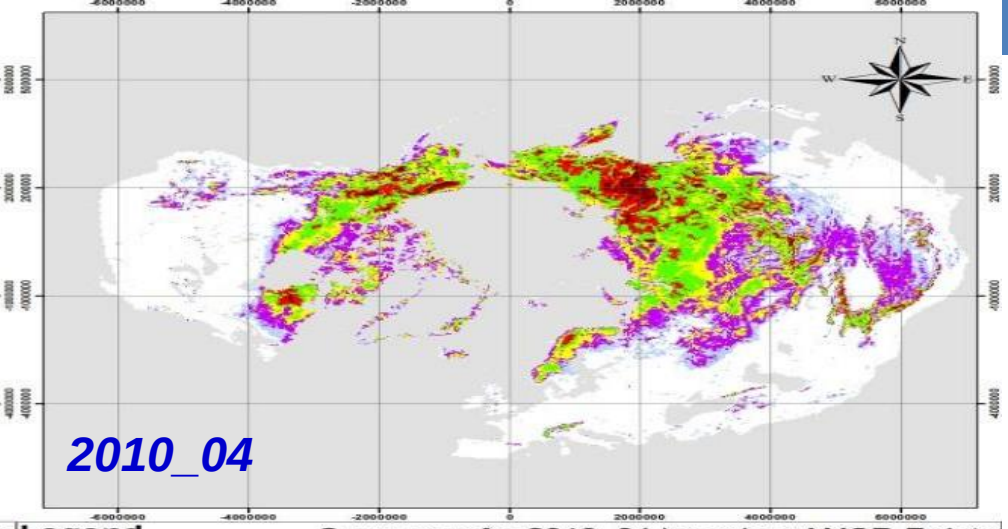

2011_01
Legend
Snow map for 2011_01 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201101 Northern Hemisphere
Rest Part of Image
Snow classes
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

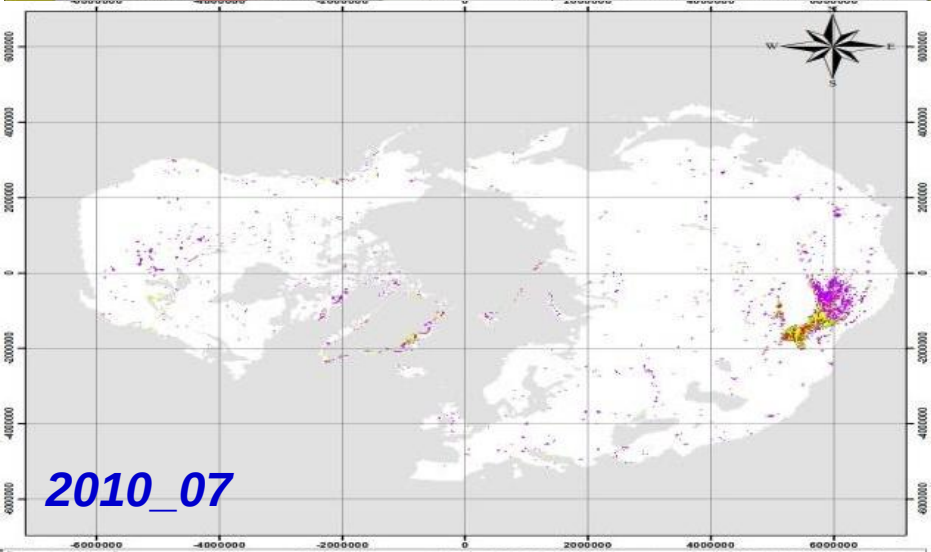

2011_04
Legend
Snow map for 2011_04 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201104 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

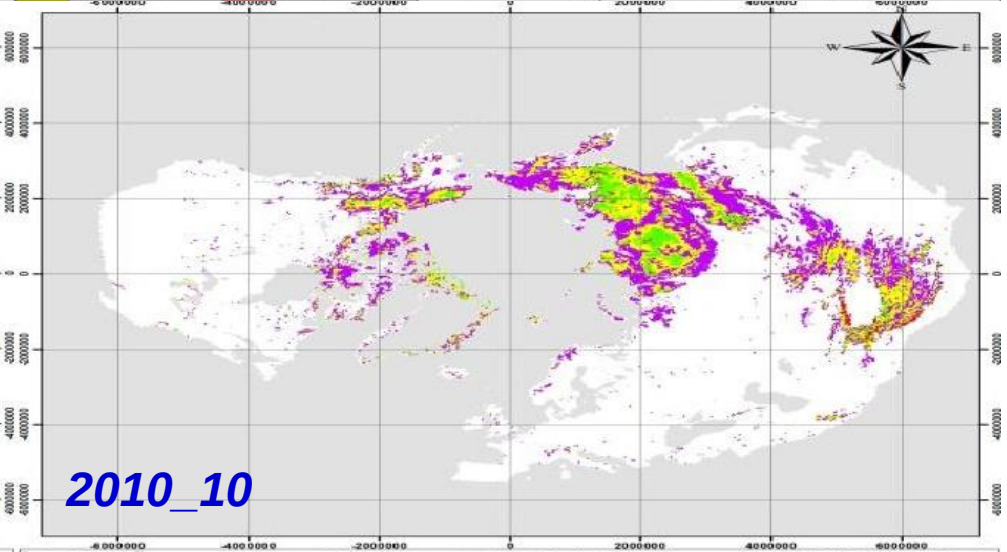

2011_07
Legend
Snow map for 2011_07 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201107 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Contour_500m
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

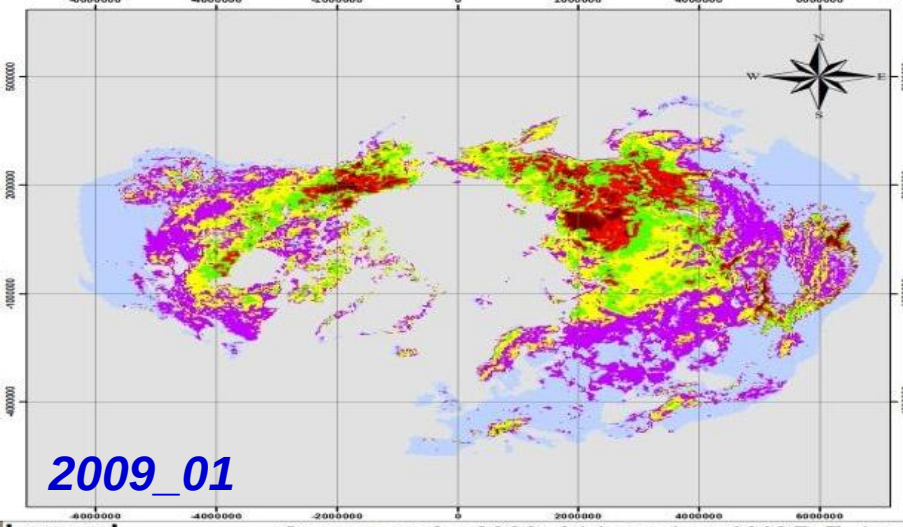

2011_09
Legend
Snow map for 2011_09 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201109 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro


2010_01
Legend
Snow map for 2010_01 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201001 Northern Hemisphere
Rest Part of Image
Snow classes
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

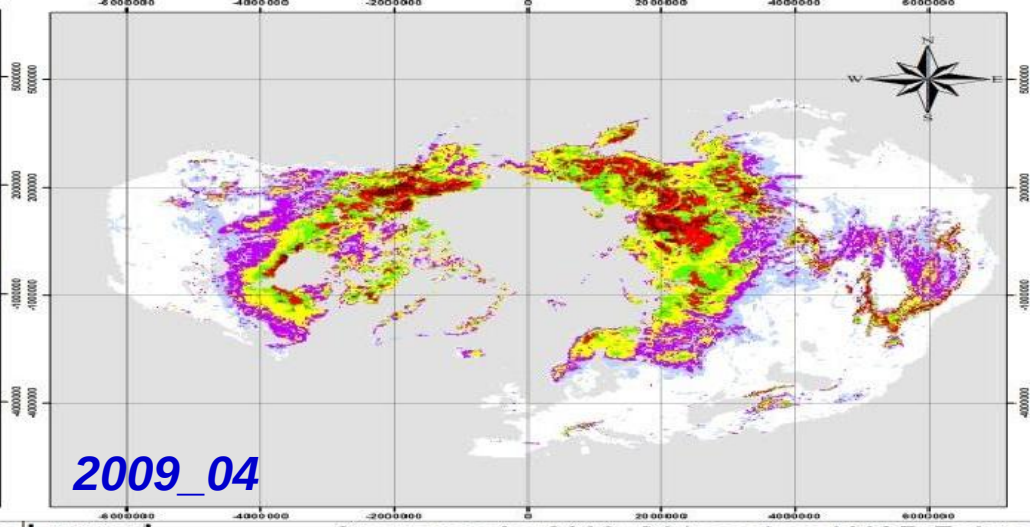

2010_04
Legend
Snow map for 2010_04 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201004 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro


2010_07
Legend
Snow map for 2010_07 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201007 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Contour_500m
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

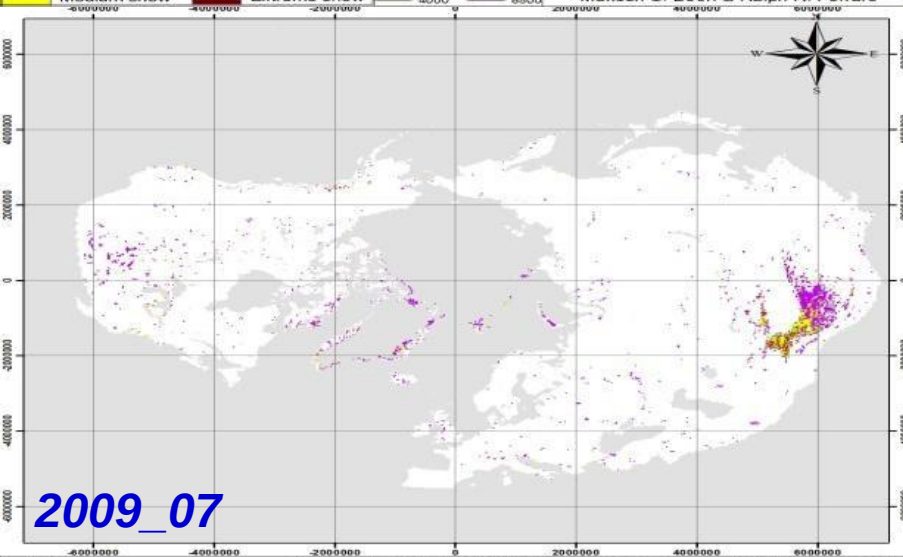

2010_10
Legend
Snow map for 2010_10 based on AMSR-E data
AMSR_E_L3_MonthlySnow
201010 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Contour_500m
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro


2009_01

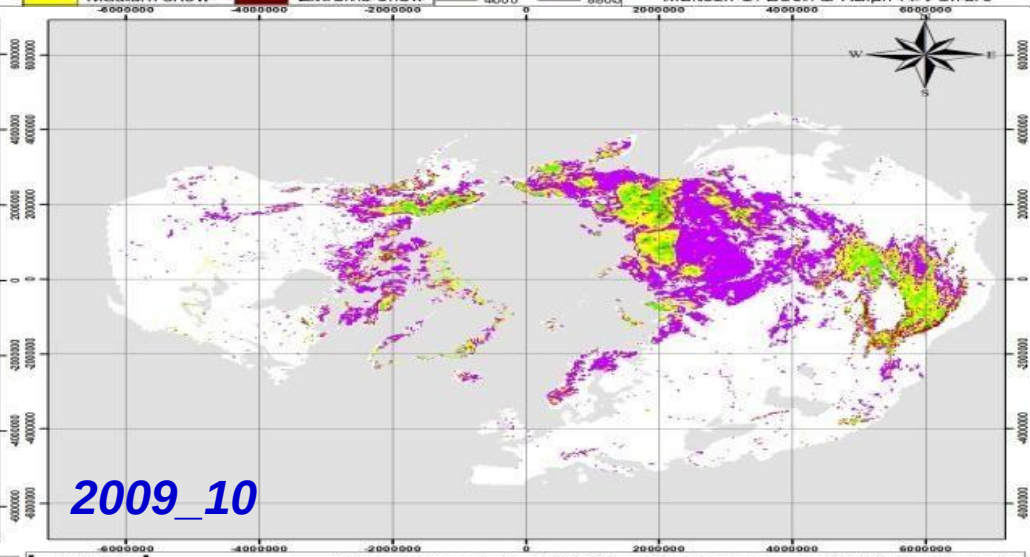

Legend
Snow map for 2009_01 based on AMSR-E data
AMSR_E_L3_MonthlySnow
200901 Northern Hemisphere
Rest Part of Image
Snow classes
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500 8000 8500
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

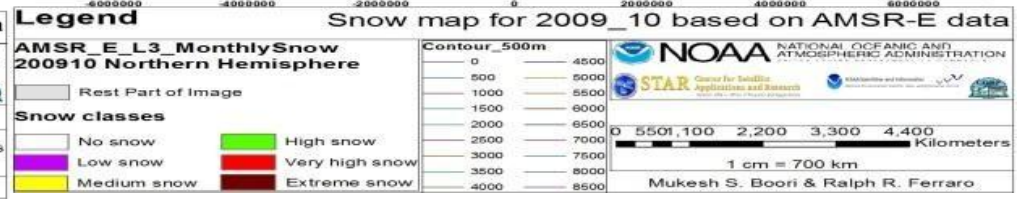

2009_04

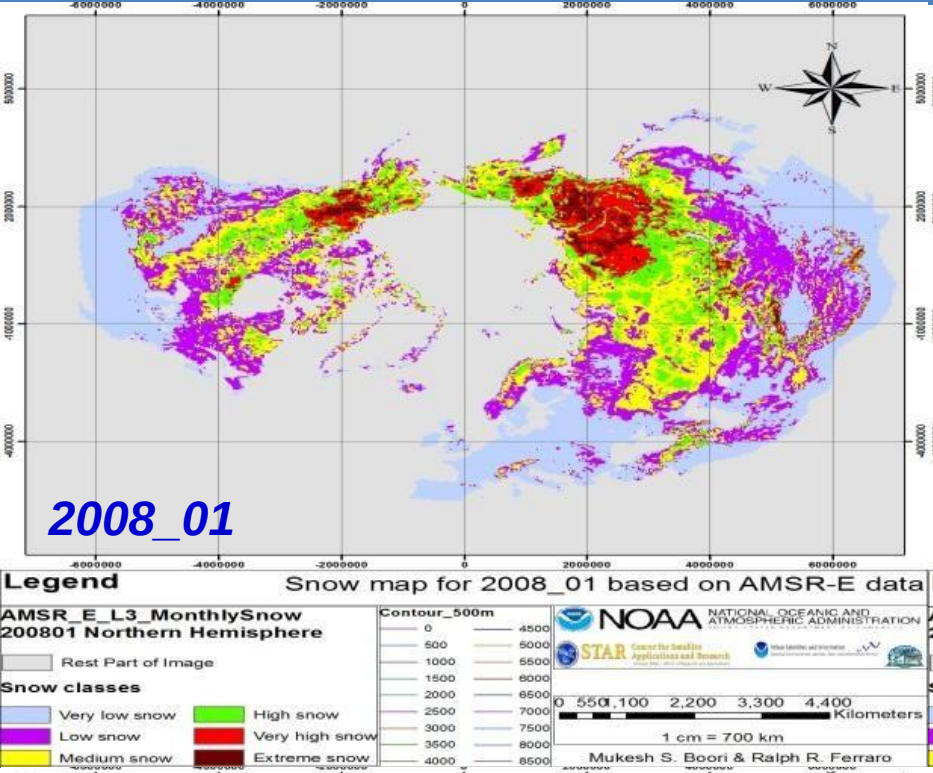

Legend
Snow map for 2009_04 based on AMSR-E data
AMSR_E_L3_MonthlySnow
200904 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500 8000 8500
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

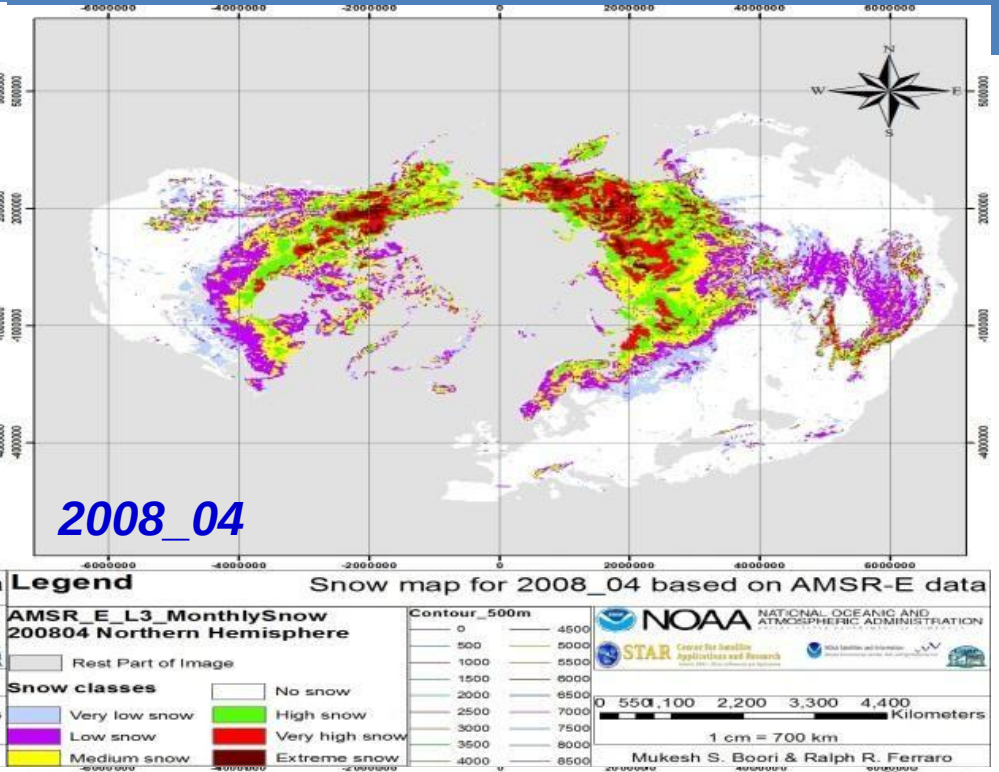

2009_07

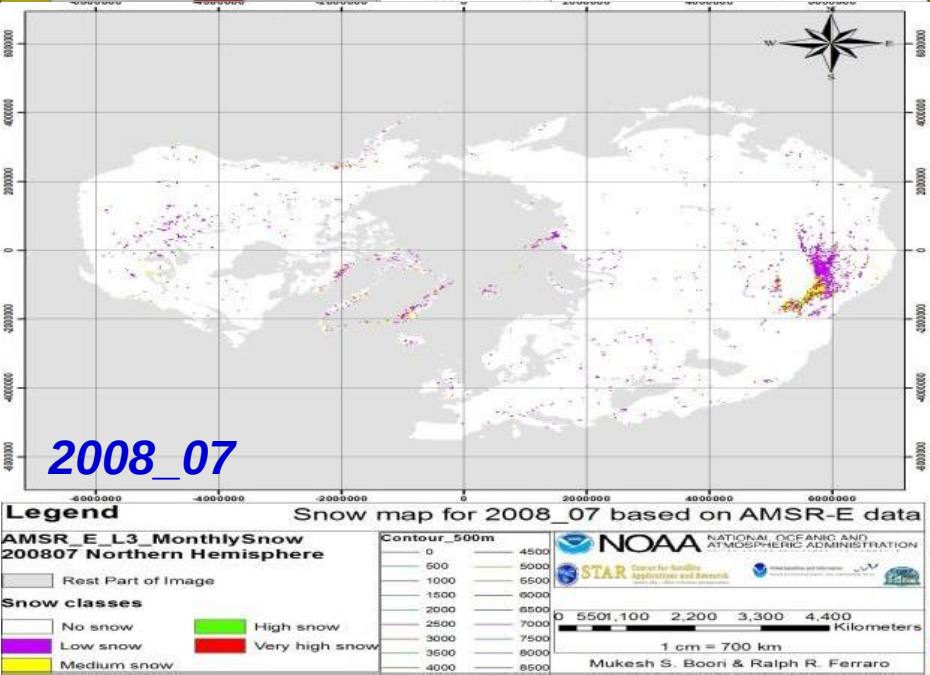

Legend
Snow map for 2009_07 based on AMSR-E data
AMSR_E_L3_MonthlySnow
200907 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Contour_500m
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500 8000 8500
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

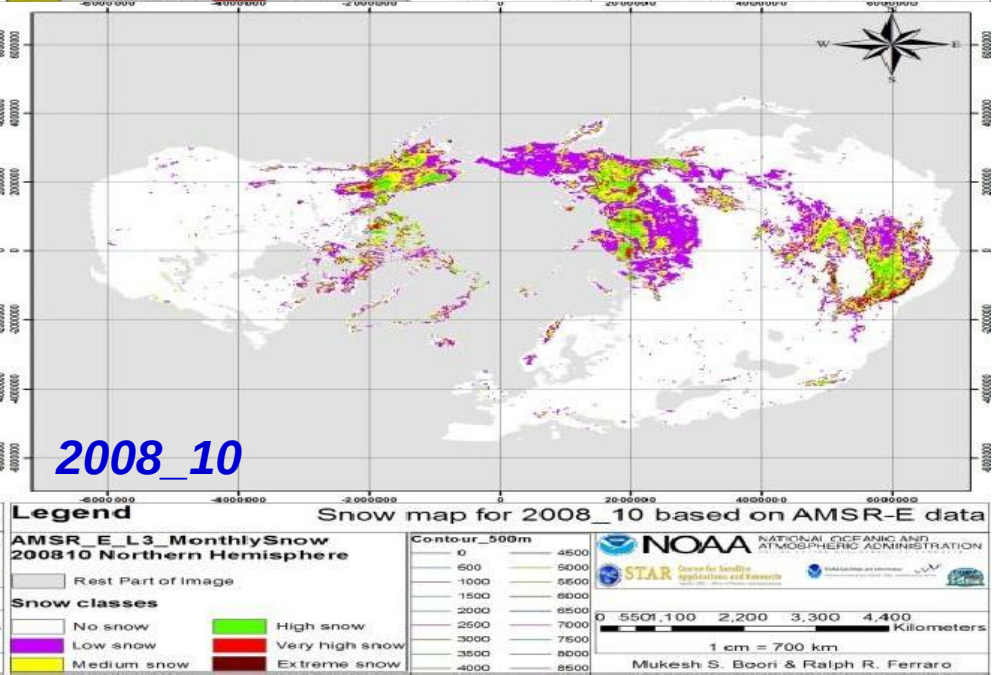

2009_10

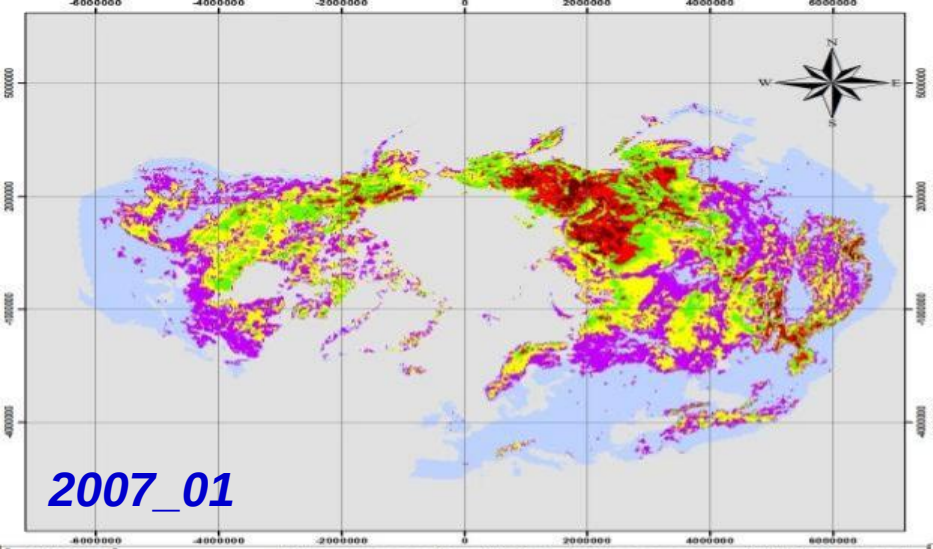

Legend
Snow map for 2009_10 based on AMSR-E data
AMSR_E_L3_MonthlySnow
200910 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500 8000 8500
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

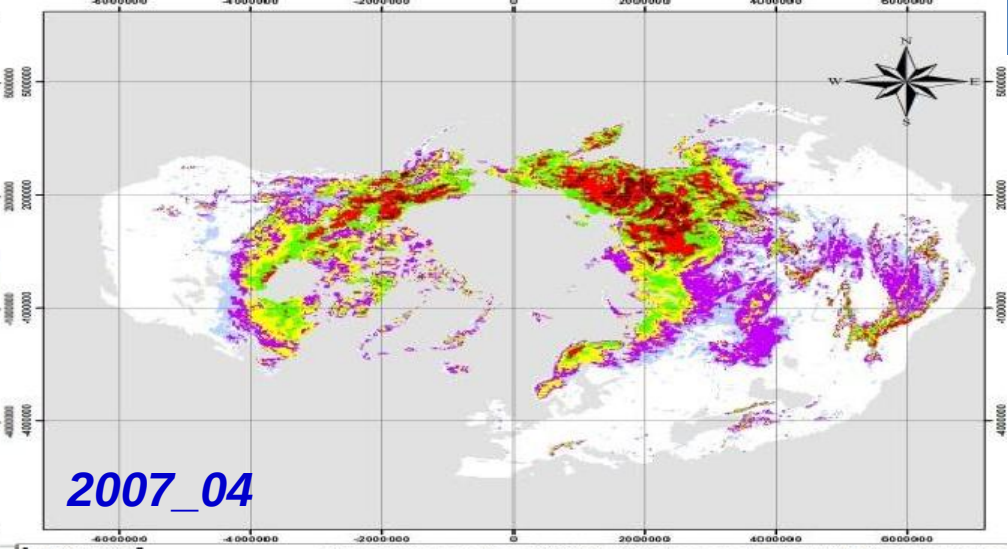

2008_01
Legend
Snow map for 2008_01 based on AMSR-E data
AMSR_E_L3_MonthlySnow
200801 Northern Hemisphere
Rest Part of Image
Snow classes
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

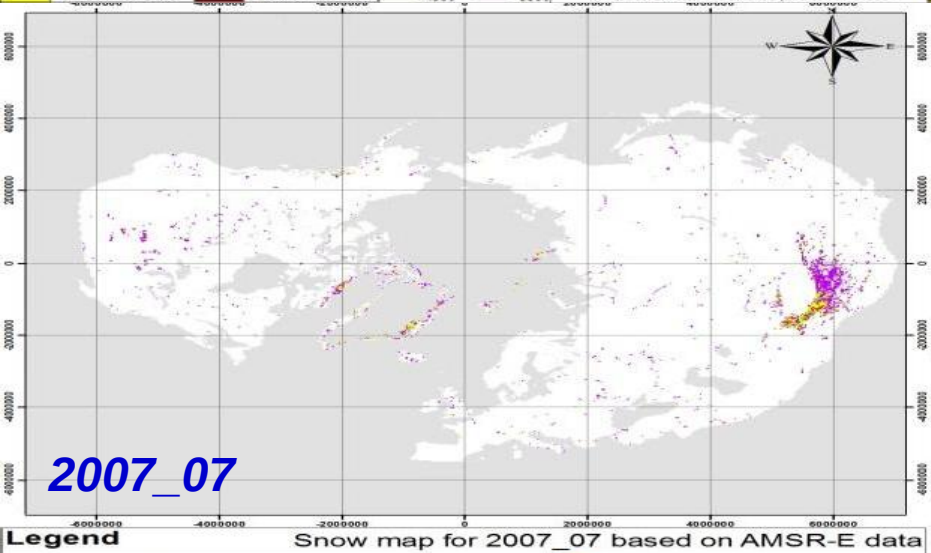

2008_04
Legend
Snow map for 2008_04 based on AMSR-E data
AMSR_E_L3_MonthlySnow
200804 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

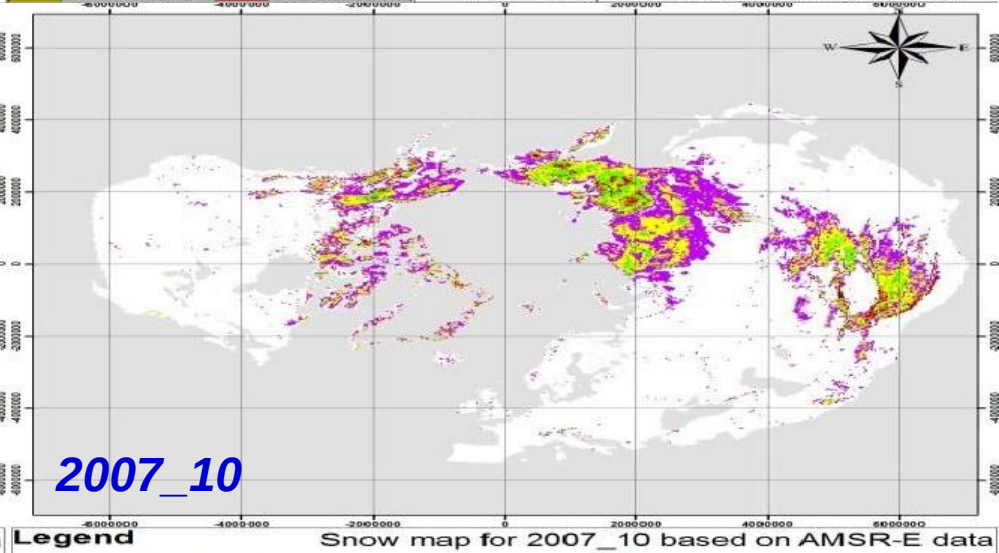

2008_07
Legend
Snow map for 2008_07 based on AMSR-E data
AMSR_E_L3_MonthlySnow
200807 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Contour_500m
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro


2008_10
Legend
Snow map for 2008_10 based on AMSR-E data
AMSR_E_L3_MonthlySnow
200810 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

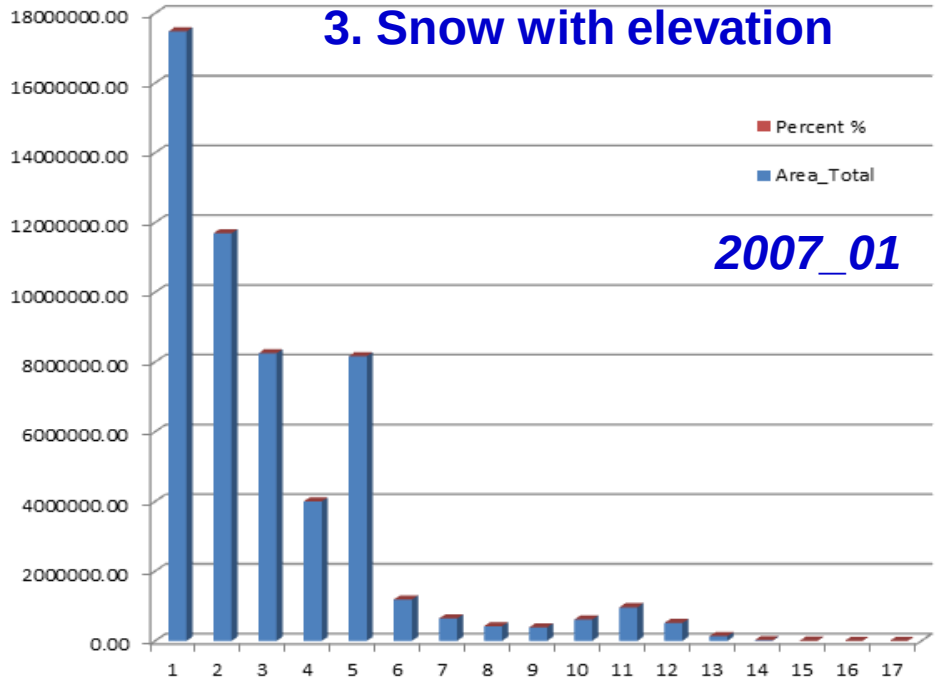

2007_01
Legend
Snow map for 2007_01 based on AMSR-E data
AMSR_E_L3_MonthlySnow
200701 Northern Hemisphere
Rest Part of Image
Snow classes
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

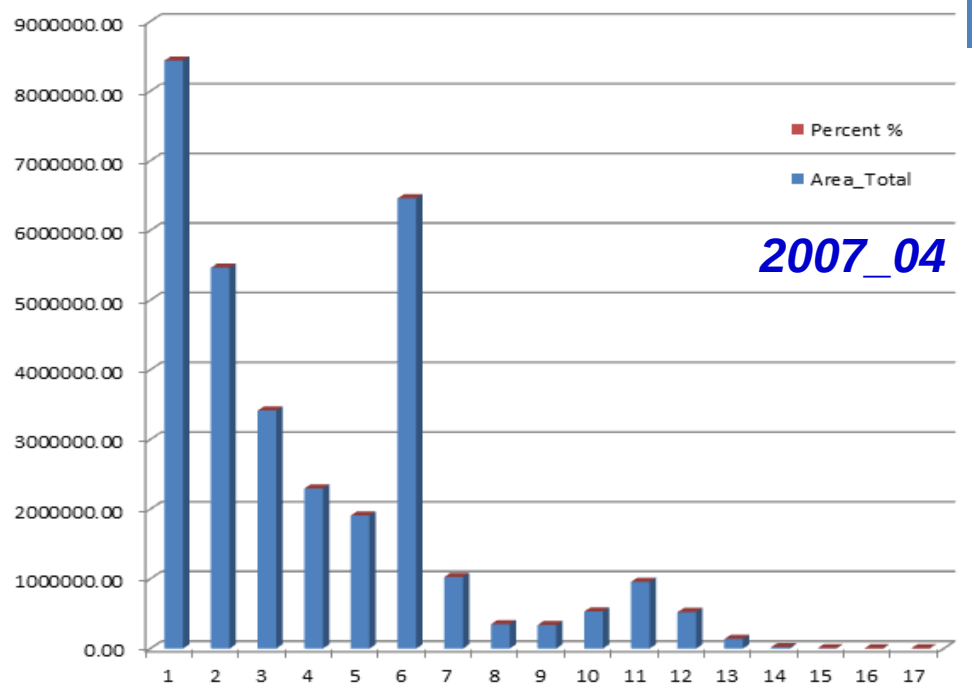

2007_04
Legend
Snow map for 2007_04 based on AMSR-E data
AMSR_E_L3_MonthlySnow
200704 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Very low snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

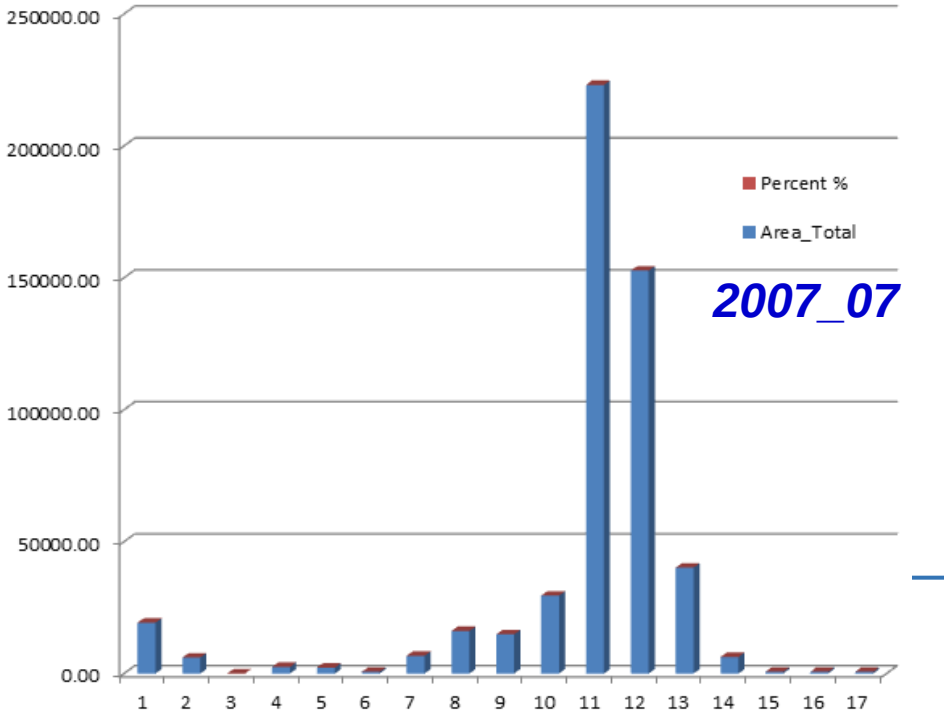

2007_07
Legend
Snow map for 2007_07 based on AMSR-E data
AMSR_E_L3_MonthlySnow
200707 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Contour_500m
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

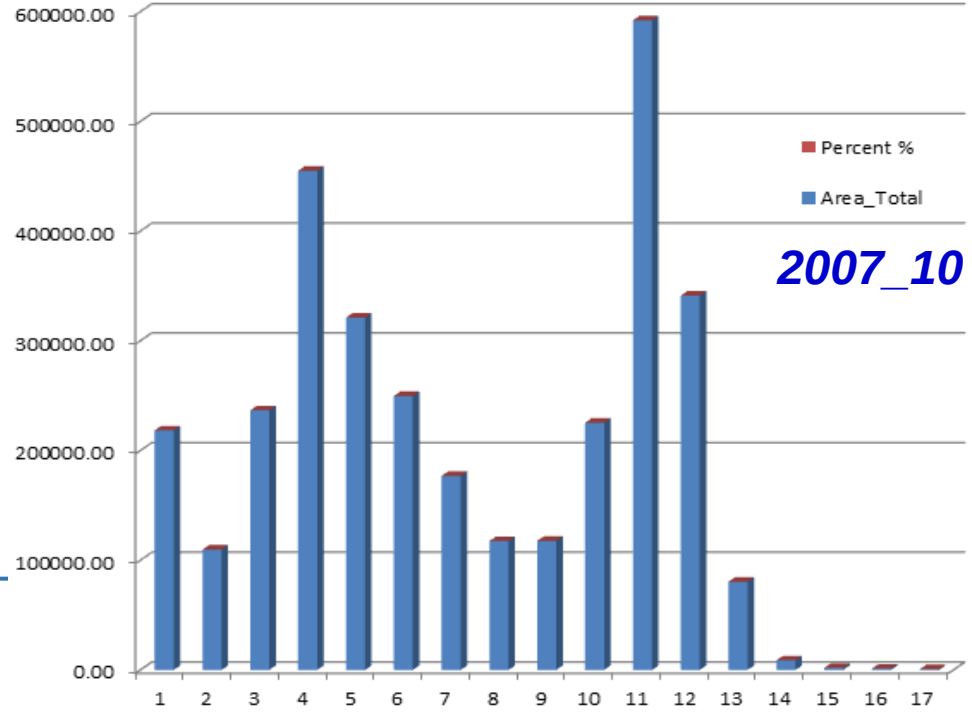

2007_10
Legend
Snow map for 2007_10 based on AMSR-E data
AMSR_E_L3_MonthlySnow
200710 Northern Hemisphere
Rest Part of Image
Snow classes
No snow
Low snow
Medium snow
High snow
Very high snow
Extreme snow
Contour_500m
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
STAR
0 550 1,100 2,200 3,300 4,400 Kilometers
1 cm = 700 km
Mukesh S. Boori & Ralph R. Ferraro

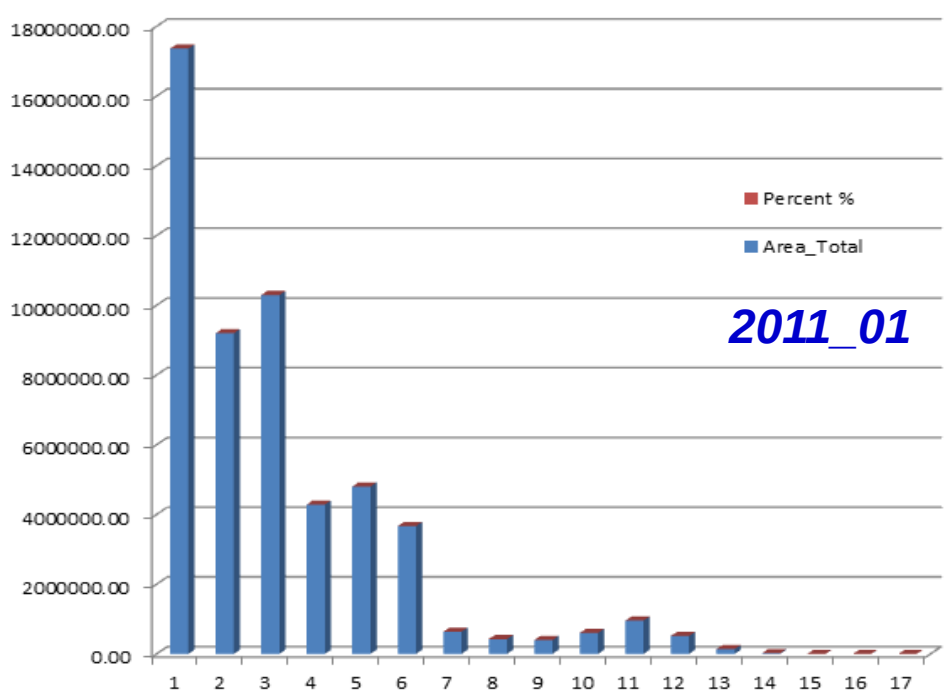
3. Snow with elevation







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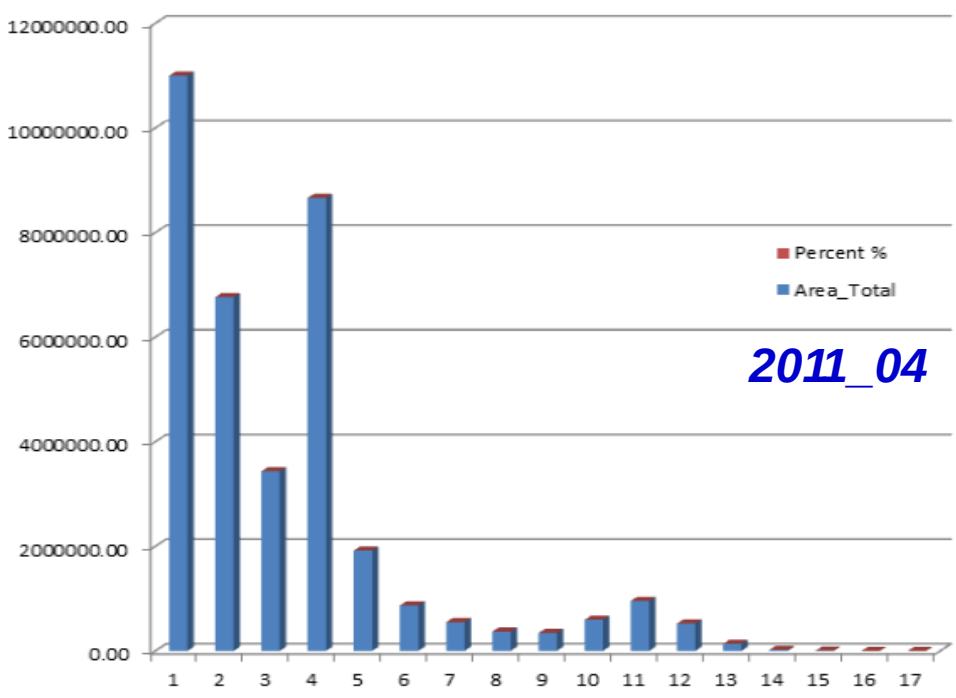
Percent %
Area_Total
2011_01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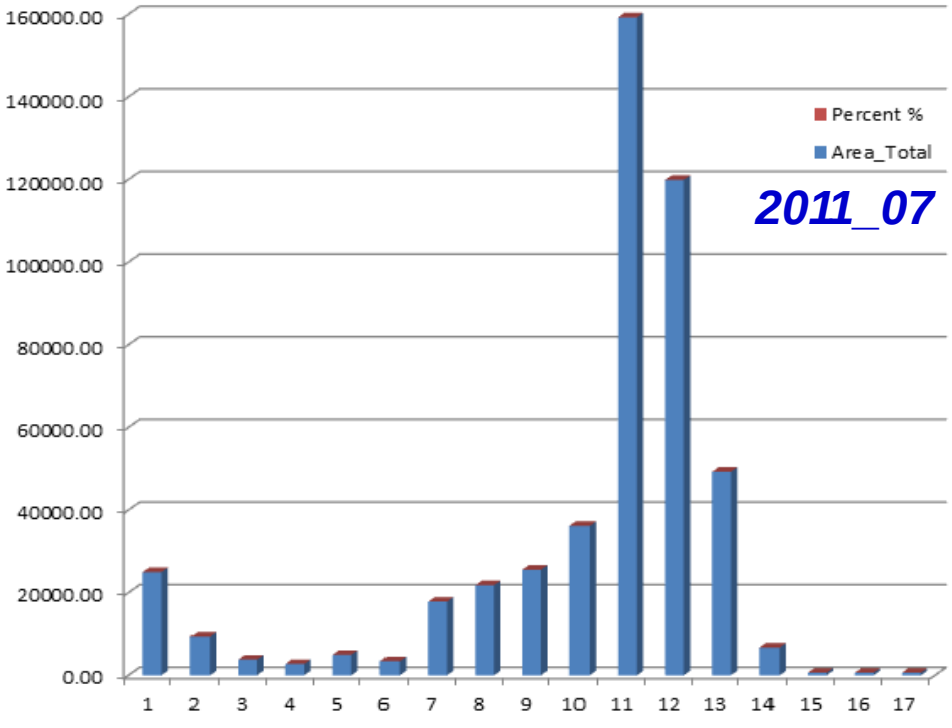
Percent %
Area_Total
2011_04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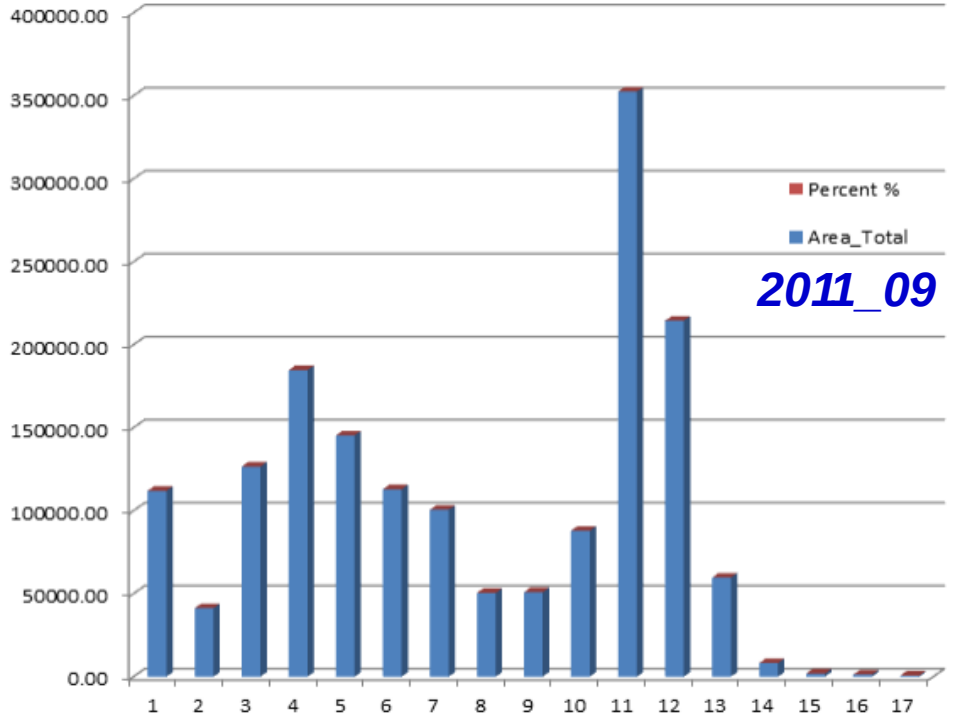
Percent %
Area_Total
2011_07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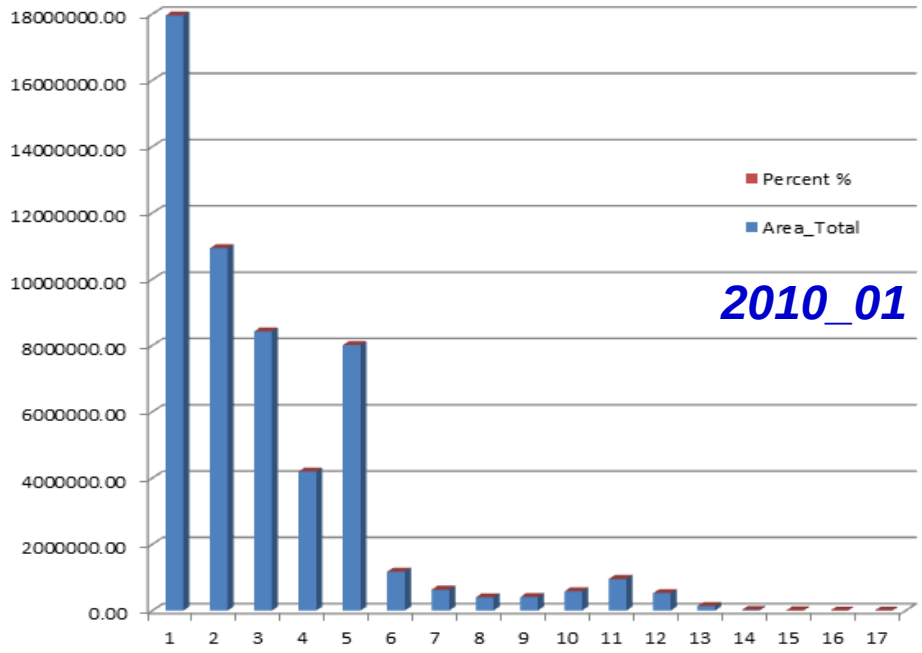
Percent %
Area_Total
2011_09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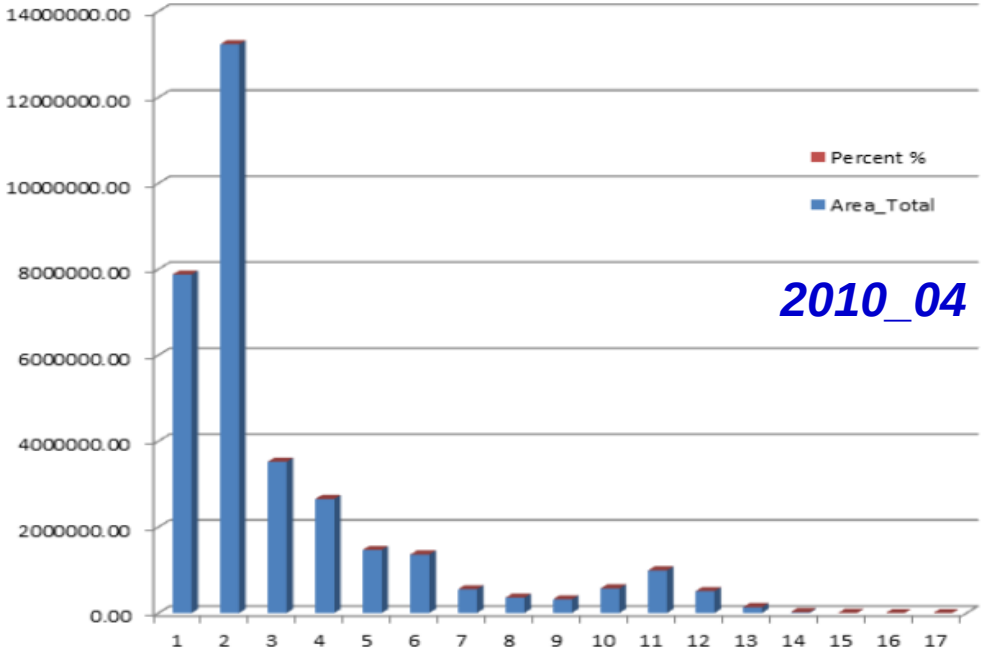
Percent %
Area_Total
2010_01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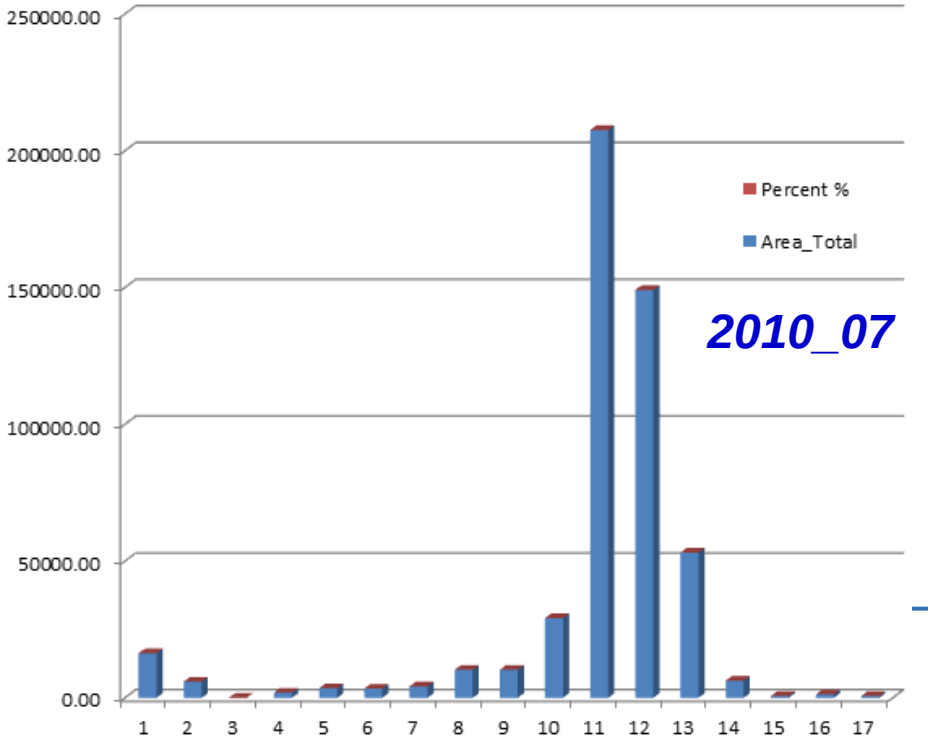
Percent %
Area_Total
2010_04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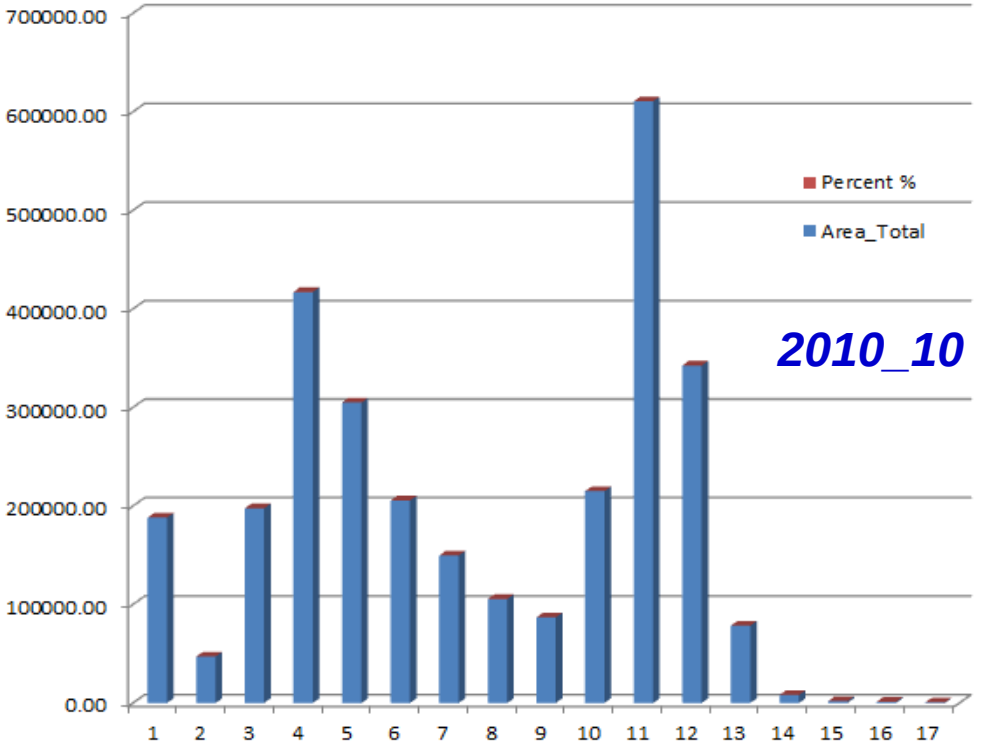
Area_Total
2010_07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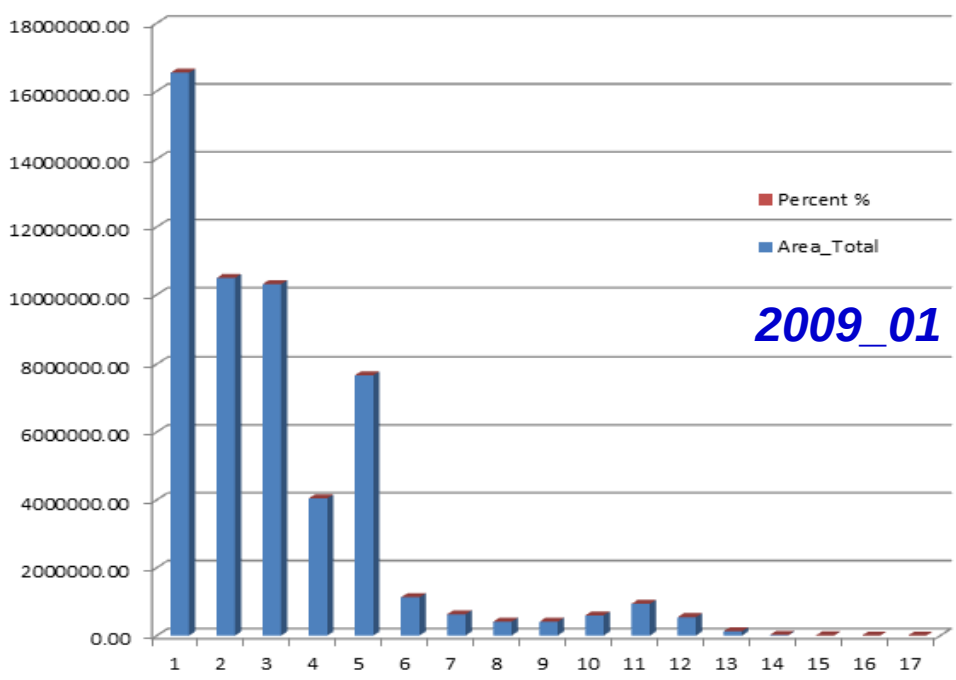
Percent %
Area_Total
2010_10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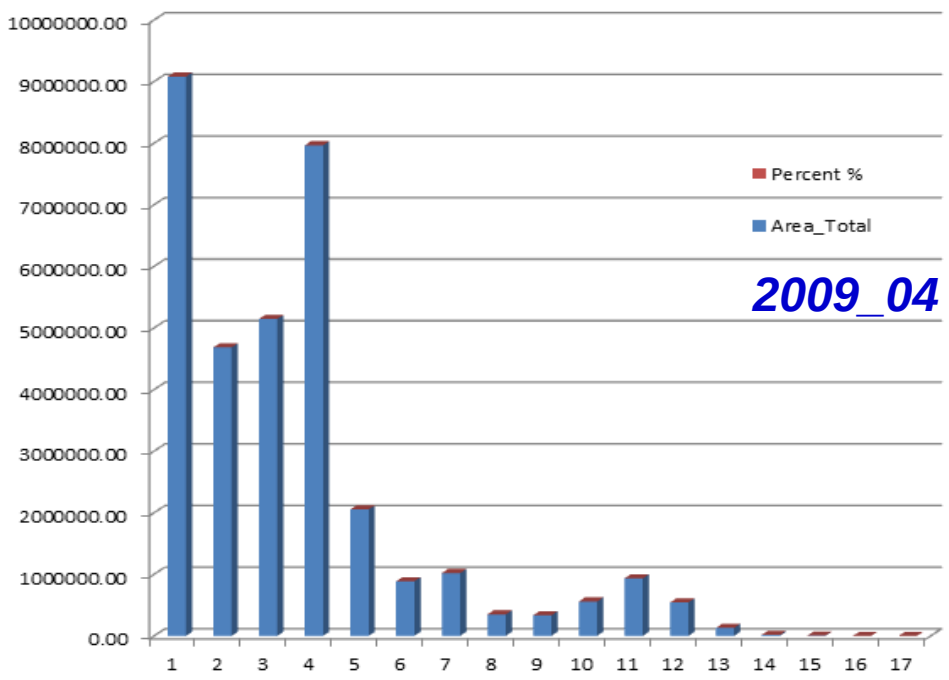
Percent %
Area_Total
2009_01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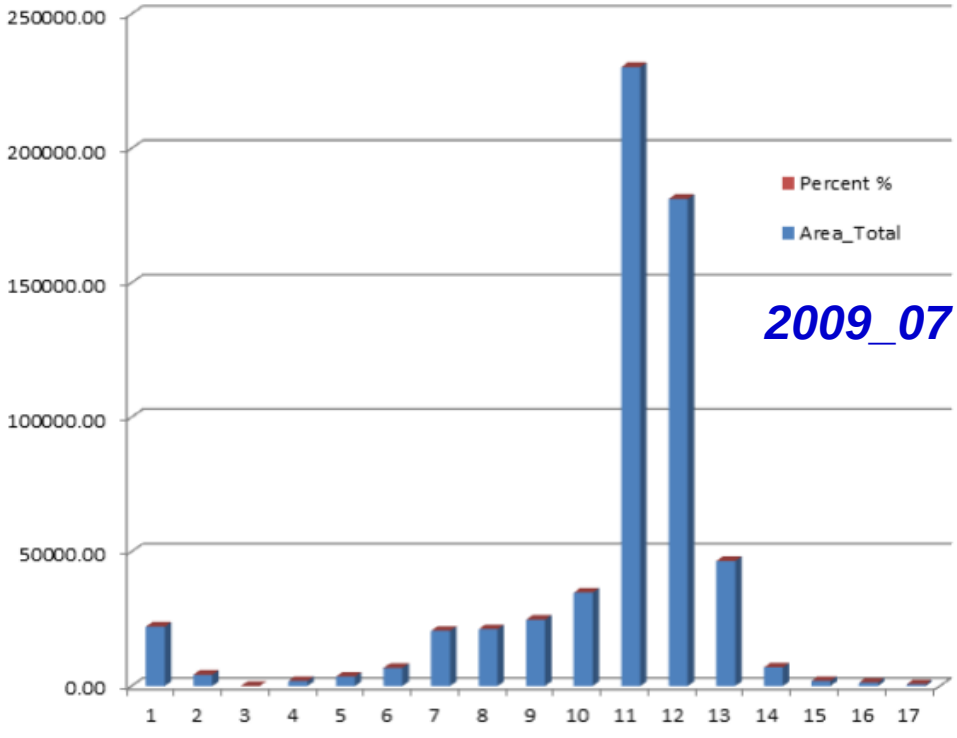
Percent %
Area_Total
2009_04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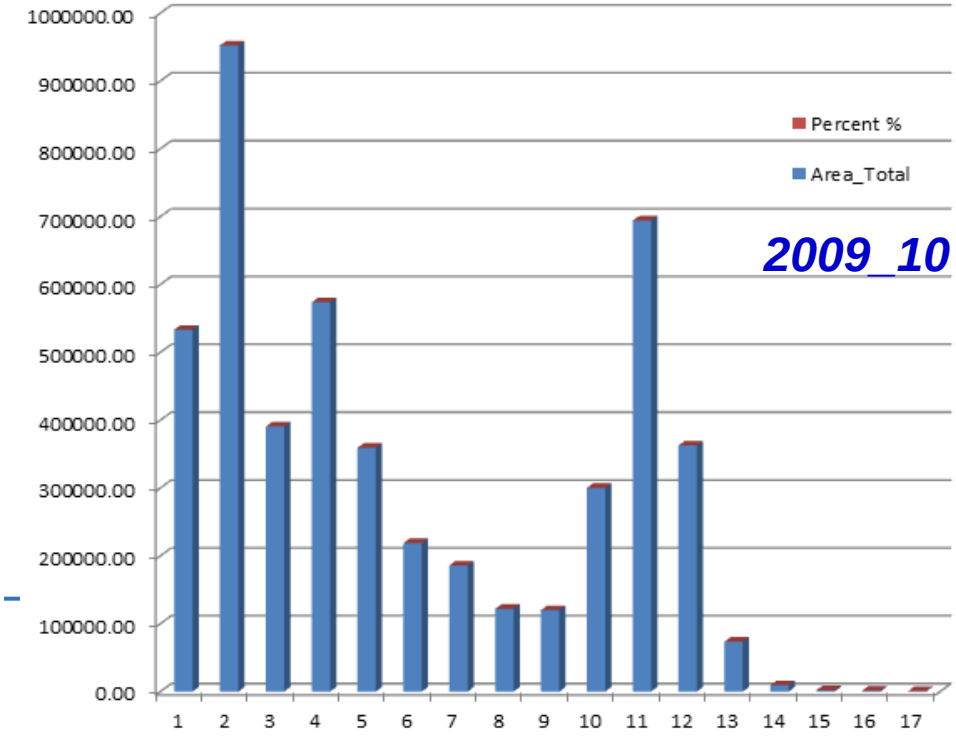
Percent %
Area_Total
2009_07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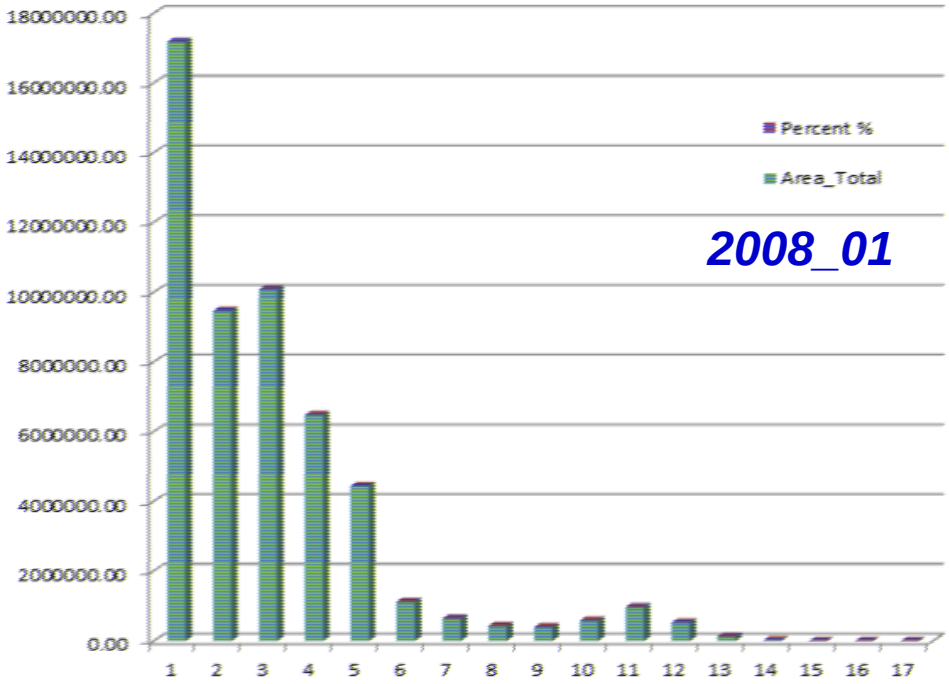
Percent %
Area_Total
2009_10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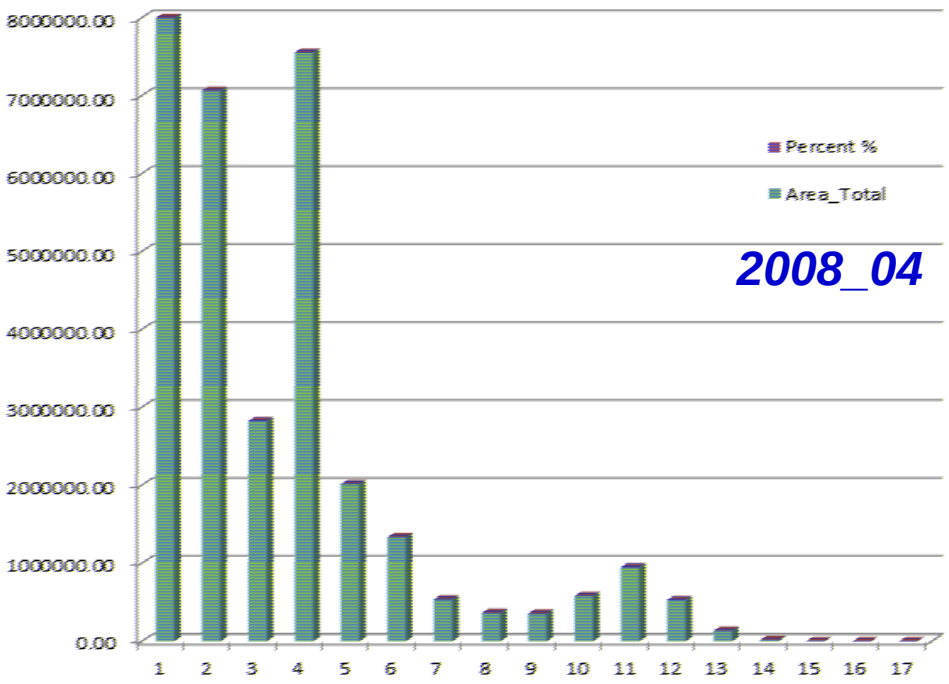
Percent %
Area_Total
2008_01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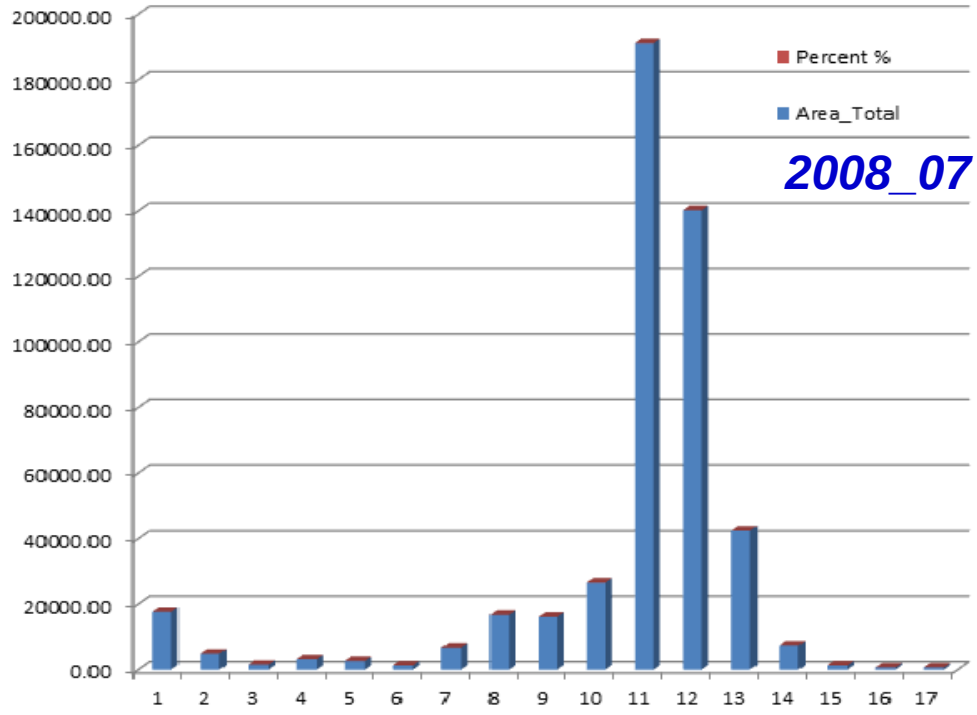
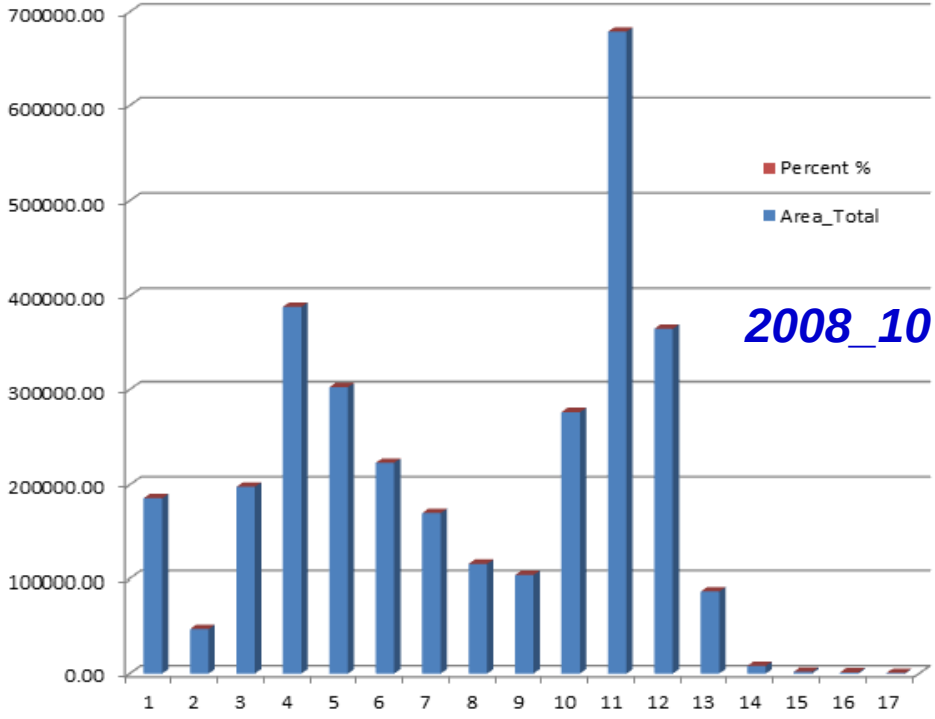
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Percent %
Area_Total
2008_04


200000.00
180000.00
160000.00
140000.00
120000.00
100000.00
80000.00
60000.00
40000.00
20000.00
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Percent %
Area_Total
2008_07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600000.00
500000.00
400000.00
300000.00
200000.00
100000.00
0.00
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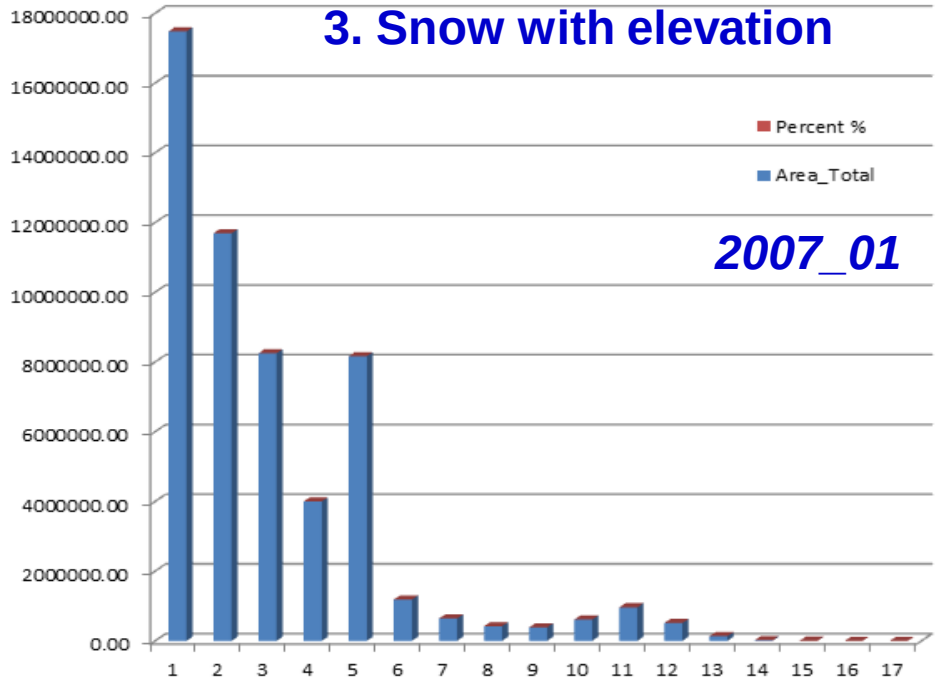
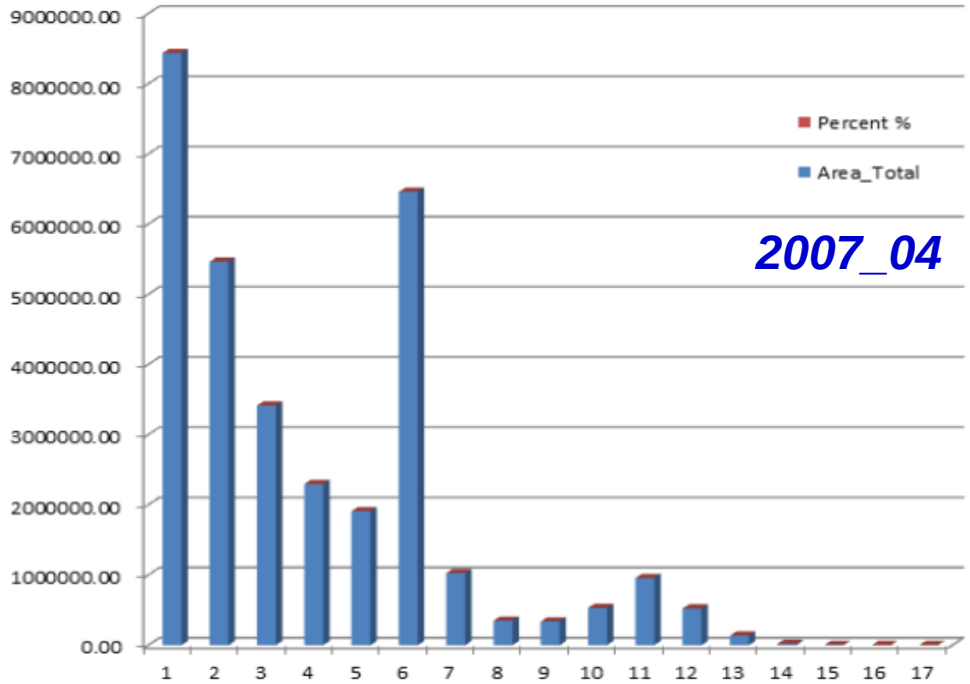
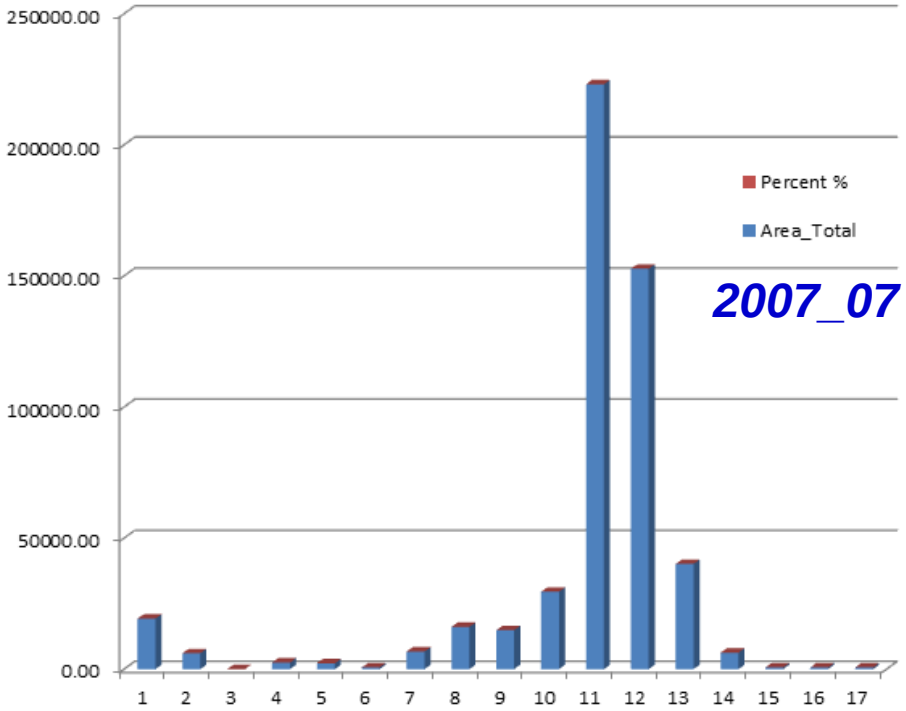
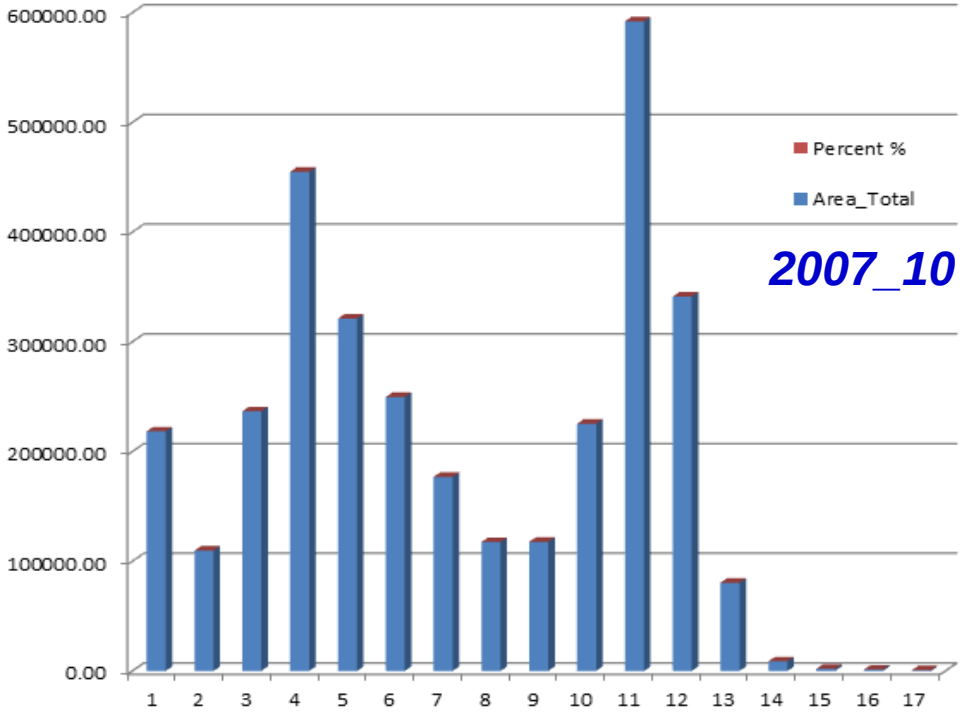
Percent %
Area_Total
2008_10

3. Snow with elevation









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