ICIMOD Manual 2017/10

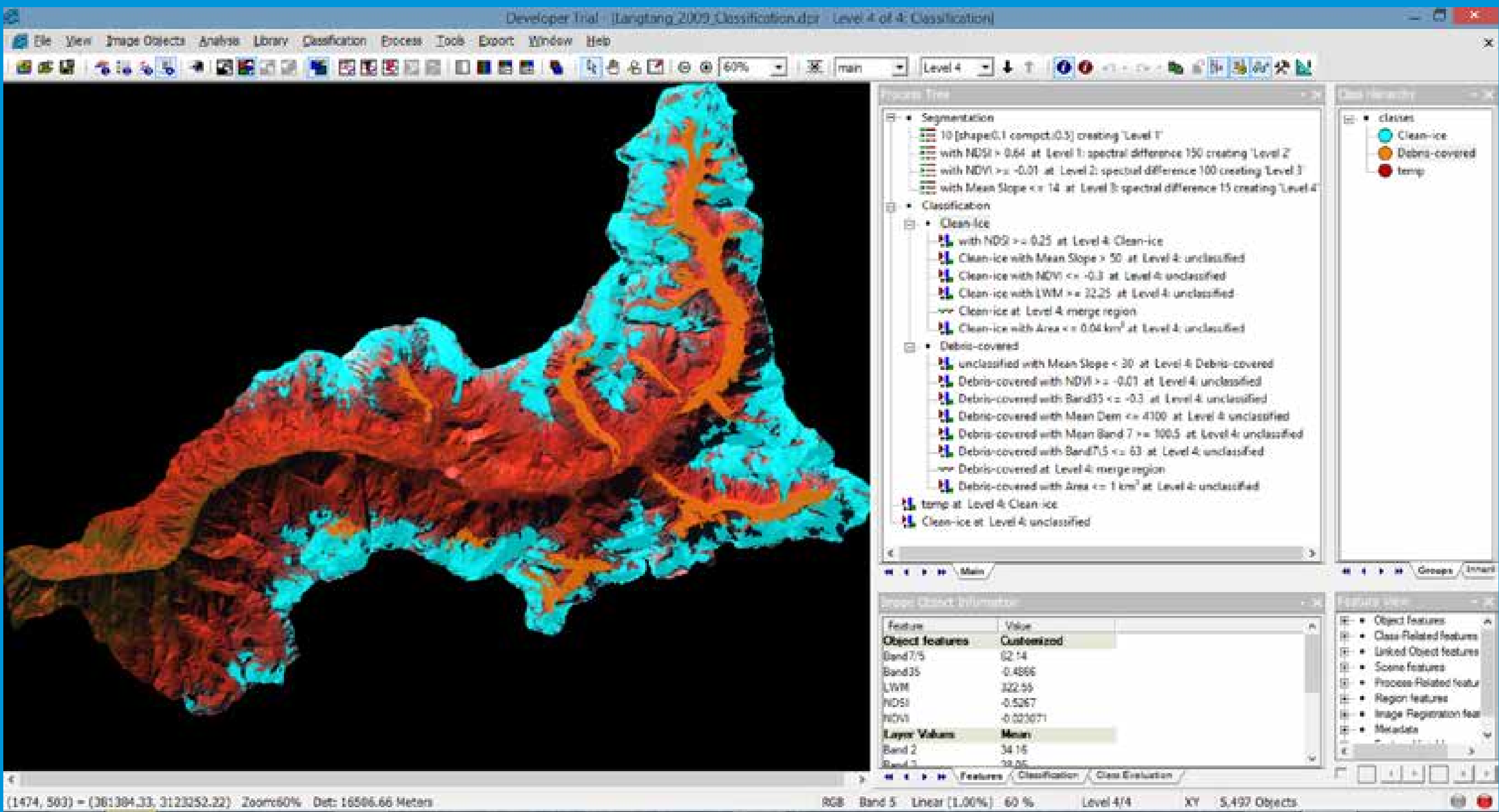
ICIMOD

FOR MOUNTAINS AND PEOPLE

Training Manual on

Application of Remote Sensing and Geographic Information Systems for Mapping and Monitoring of Glaciers

Part 1- Glacier Mapping Using eCognition



About ICIMOD

The International Centre for Integrated Mountain Development, ICIMOD, is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush Himalaya – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalisation and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

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Part 1 - Glacier Mapping Using eCognition

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The framework and draft manual were prepared in 2009, and used in several trainings on the Application of Remote Sensing and Geographic Information Systems in the Mapping and Monitoring of Glaciers since 2010. Representatives from the Department of Hydrology and Meteorology (DHM), the Water and Energy Commission Secretariat (WECS), Kathmandu University (KU), and Tribhuvan University (TU), Nepal, participated in these trainings. This manual was also used in regional training courses organized at the National Center for Remote Sensing and Geo-Informatics Institute of Space Technology, Karachi, India, in October 2014; Sherubtse College, the Royal University of Bhutan, in March 2015; the Department of Hydro-Met Services, the Royal Government of Bhutan, in November 2015; and the Department of Meteorology and Hydrology, Ministry of Transport and Communications, Myanmar, in July 2016. To date, 10 trainings have been conducted using this manual, including six in Nepal and four in the region. The manual has been updated continuously, incorporating feedback received from training participants and resource persons associated with each session, resulting in its considerable improvement. We thank everyone for their feedback and assistance.

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Acronyms and Abbreviations

APN	Asia Pacific Network
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometre
BHT	Bureau of Hydrology Tibet
C	Centigrade
CAREERI	Cold and Arid Region Environmental and Engineering Research Institute
CAS	Chinese Academy of Sciences
CGIAR	Consultative Group for International Agricultural Research
CI	clean ice
CSKHPAU	Chaudhary Sarwan Kumar Himachal Pradesh Agricultural University
C-Type	clean ice type
DC	debris cover
DGM	Department of Geology and Mines, Bhutan
DEM	digital elevation model
DHM	Department of Hydrology and Meteorology, Nepal
D-Type	debris covered type
DVI	differential vegetation Index
ECV	essential climate variables
ELA	equilibrium line altitude
ENVI	environment for visualizing images
EOS	Earth Observing System, NASA
ERTS	Earth Resources Technology Satellite
ERSDAC	Earth Remote Sensing Data Analysis Center, Japan
ESA	European Space Agency
ETM	enhanced thematic mapper
FCC	false colour composite
G	green
GDEM	Global Digital Elevation Model
GE	Google Earth
GIS	geographic information systems
GSI	Geological Survey of India
GLIMS	Global Land Ice Measurements from Space
GLOF	glacial lake outburst flood
HKH	Hindu Kush Himalaya
HP	Himachal Pradesh
HSI	hue, saturation, and intensity
ICIMOD	International Centre for Integrated Mountain Development
ICSI	International Commission on Snow and Ice
ID	identity
IDL	interactive data language
IPCC	Intergovernmental Panel for Climate Change
IR	Infrared
KU	Kathmandu University
km^2	square kilometre
km^3	cubic kilometre
Landsat	land resources satellite
LIGG	Lanzhou Institute of Glaciology and Geocryology

LWM	land and water mask
masl	metres above sea level
MENRIS	Mountain Environment Regional Information Systems
METI	Ministry of Economy, Trade and Industry, Japan
MIR	Middle Infra-Red
MSS	multi spectral scanner (Landsat)
NASA	National Aeronautics and Space Administration
NDSI	normalized difference snow index
NDVI	normalized difference vegetative index
NDWI	normalized difference water index
NEA	Nepal Electricity Authority
NIR	Near Infra-Red
NGA	National Geospatial-Intelligence Agency
NSIDC	National Snow and Ice Data Center
OBIC	object based image classification
PAN	panchromatic
PSFG	Permanent Service on Fluctuations of Glaciers
R	red
RGB	red green blue
RMC	regional member countries
RRC-AP	Regional Resource Centre for Asia and the Pacific
RVI	ratio vegetation index
SD	standard deviation
SLC	scan line corrector
SPOT	Système Probatoire d'Observation de la Terre /Satellite Pour l'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
START	Global Change Research, and Global Change System for Analysis Research and Training
SWIR	Short Wave Infra-Red
ThIR	Thermal Infra-Red
TM	Thematic Mapper
TTS	Temporary Technical Secretary
TU	Tribhuvan University
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UA	Uttarakhand
US	United States
USAID	United States Agency for International Development
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
μm	micrometre
VIS	visible
WECS	Water and Energy Commission Secretariat, Nepal
WIHG	Wadia Institute of Himalayan Geology
WGI	World Glacier Inventory
WGMS	World Glacier Monitoring Service
WGS	World Geodetic System
WRRI	Water Resource Research Institute, Pakistan

About the Manual

This manual provides detailed information on a customized methodology for glacier mapping using a remote sensing based semi-automatic technique for quick delivery. Based on this methodology, studies on the status of the glaciers of the Hindu Kush Himalaya and decadal glacier change since the 1980s have been carried out in selected areas and basins. The data and results derived from this methodology have been published in several journals, book chapters, and reports. A summary of the results and publications is presented here, and in global level glacier mapping initiatives. Reviews of the methodologies adopted by global initiatives like World Glacier Monitoring Service (WGMS), Global Land Ice Measurement from Space (GLIMS), and GlobGlacier are also presented in this manual. The methodology can be applied with little knowledge of remote sensing and geographic information systems. This is true not only for glacier mapping, but also for mapping the earth's physical features.

The methodology relies on the "eCognition" software, and post processing database management is done in an ArcGIS environment. A short introductory tour of the software is included here to facilitate the beginner's understanding of image processing and data handling.

We recommend that users read the manual carefully before moving on to hands-on exercises. Prepare the data in hand and proceed to semi-automatic mapping for the quick mapping and monitoring of glaciers.

Practice data for this manual are available at this link:
http://www.icimod.org/glacierdata/glacier_training_data.zip

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1. Introduction

Glaciers are solid fresh water reservoirs – lifelines for billions of people in the world. Glaciers in the Hindu Kush Himalaya (HKH) are important to global climate change studies, and impact biodiversity, agriculture, industry, and economic activities. Glaciers are one of the most sensitive indicators of global temperature change. Climate change is vivid and prominent, particularly in high mountains where warming has been much greater, 0.6°C per decade, than the global average of 0.74°C over the last 100 years (Shrestha et al., 1999, IPCC 2007, Bajracharya et al., 2007). Receding glaciers are an impact of rising temperature. These water reserves are rapidly dwindling. Settlements totally dependent on glacier melt are being abandoned. This threatens policies and actions that support sustainable water resources management. The bigger concern is a lack of long term information on the glaciers of the HKH for any kind of credible assessment. The International Centre for Integrated Mountain Development (ICIMOD) has been engaging with partner institutes in the region to build a glacier database of the HKH since late 1990s.

Though satellite images have been available since the 1970s, at the time, they were very costly. Even computers and software were expensive then. Hence, till the beginning of the 21st century, the mapping of glaciers and glacial lakes was mostly done through topographic maps with were manually digitized, consuming both time and resources. Using its resources and partners, ICIMOD mapped the glaciers and glacial lakes of the HKH from the topographic maps for Nepal, Bhutan, Pakistan, and selected basins in India, and China, from 1999 to 2004. It succeeded in mapping only half of the HKH then. The mapping of glaciers and glacial lakes from topographic maps stopped in 2004.

Glacier mapping from topographic maps was not only laborious work, it also presented limitations and resulted in errors in the database. The errors encountered in glacier and glacial lake databases include:

1. The projection parametres provided in the published topographic maps were incomplete, hence the data derived from topographic maps overlaid on Google Earth show some shifting and rotation.
2. The topographic maps of the HKH were mostly published from 1963 to 1982 on the basis of 1,957–1,959 aerial photographs. Topographic maps were published one/one – with one degree latitude and longitude extensions after the completion of survey. Furthermore, field surveys in the high Himalaya were limited, and hence not accurate.
3. Due to disputed country boundaries in the HKH, most topographic maps around these territories are restricted, and not available for public use.
4. The original eight-coloured 1inch to1mile topographic maps of all glaciated area are unavailable. Instead, sheets of ammonia print enlarged to a 1:50,000 scale are used. Such maps feature a lot of distortion which amplifies errors.
5. Photographs were mostly acquired during winter season. Most glaciated areas are snow covered, and it is difficult to differenciate glacier boundaries. Midland and low elevation topographic maps are more accurate than maps of snow covered Himalayan areas.
6. Satellite images from 1999 and 2000 were also used in some areas where topographic maps were unavailable. Thus, the data show a wide temporal range from 1963 to 2000, and are not useful in change assessments.
7. Human error affected the digitization of glacier and glacial lake polygons since many hands were used, depending on the load of glaicer and glacial lake digitization.

To get rid of all these errors, a semi-automatic delineation of glacier and glacial lake polygons were developed from Landsat satellite images. With this methodology, the glacier and glacial lake polygons derived from satellite image are properly fit onto Google Earth while being overlaid for validation. In 2011, ICIMOD published the first comprehensive inventory of glaciers for the entire HKH using a semi-automatic method based on Landsat7 ETM+ images from the years 2002 to 2008 (Bajracharya et al., 2011). This is the first report with details of glaciers of the entire HKH, including Myanmar. Based on the same methodology, four decades of glacier data from Nepal, Bhutan, and selected basins in other countries were also published (Bajracharya et al., 2014 a, b).

1.1 Objective

The objective of this manual is to provide an understanding of remote sensing tools and techniques for the semi-automatic delineation of clean ice and debris covered glaciers. An automatic method is used to delineate clean ice and debris covered glaciers separately from Landsat satellite images. Expert knowledge is used in editing the glacier outline for high accuracy. The methodology is efficient, and the glacier polygons derived are of short temporal range, and homogeneous. More specifically, this hands-on training manual aims to:

- Discuss remote sensing tools and techniques which can be used to carry out homogeneous and efficient mapping and monitoring of glaciers.
- Provide a description of mapping guidelines based on WGI (World Glacier Inventory), Global Land Ice Measurement from Space (GLIMS), and GlobGlacier consortium.
- Provide hands-on exercises for practising the semi-automatic delineation of clean ice and debris covered glaciers separately.
- Develop glacier boundary with high accuracy.

1.2 Users

The targeted users of this manual are professionals and researchers working in the HKH who are engaged in glacier mapping and monitoring for water resources management, modeling of snow and glacier melt, and climate change scenarios.

1.3 Expected Outcomes

With the use of this training manual, users will become familiar with remote sensing and geographic information system tools and techniques for mapping and monitoring, particularly in relation to glaciers and glacial lakes. It will also help foster better understanding of the status of glaciers in ICIMOD member countries, and facilitate joint actions and plans for a remote sensing based monitoring of glaciers in the region.

2. Review of Glacier Inventory

2.1 Glacier Inventory Initiatives

Global Level

A worldwide collection of information about ongoing glacier change was initiated in 1894 with the founding of the International Glacier Commission at the Sixth International Geological Congress in Zurich, Switzerland. Since then a valuable and increasingly important database on glacier change has been built up. In 1986 the World Glacier Monitoring Service (WGMS) began collecting and maintaining information on ongoing glacier change when two former International Commission on Snow and Ice (ICSI) services—the PSFG (Permanent Service on Fluctuations of Glaciers) and TTS/WGI (Temporal Technical Secretary/World Glacier Inventory)—were combined. Today, the WGMS (http://www.geo.uzh.ch/wgms/) collects standardized observations on changes in mass, volume, area and length of glaciers with time (glacier fluctuations), as well as statistical information on the distribution of perennial surface ice in space (glacier inventories).

The Global Land Ice Measurements from Space (GLIMS, http://www.glims.org/) is designed to monitor the world's glaciers primarily using data from optical satellite instruments, such as Advanced Spaceborne Thermal Emission and Reflection Radiometre (ASTER). Over 60 institutions across the globe are involved in GLIMS and ICIMOD serves as a regional coordinator for Bhutan, India, and Nepal.

Glaciers are monitored in a variety of manners, such as in-situ mass balance measurements, and air- and space borne imaging systems, such as the primary data source used by GLIMS, the ASTER instrument on the Terra spacecraft. Results from analysis conducted by the regional centers are sent for archiving at the National Snow and Ice Data Center (NSIDC, http://nsidc.org/) and made publicly available.

The GlobGlacier (http://globglacier.ch/) supported by European Space Agency (ESA) is yet another initiative to complement and strengthen the existing network for global glacier monitoring. The project will help to establish a global picture of glaciers and ice caps, and their role as essential climate variables (ECVs). In this respect, it is imperative to complete the world glacier inventory (WGI) from the 1970s by producing glacier outlines in regions that haven't yet been mapped and to complement the point information already stored in the WGI in 2D information to allow change assessment. Moreover, GlobGlacier will integrate satellite data from various sensors to create value-added products for a wide range of user communities. A close cooperation with major user groups (e.g., WGMS) and related projects (e.g., GLIMS) will ensure a maximum benefit of the generated products from a global perspective.

Regional Level

That Himalayan glaciers are sensitive to climate and receding rapidly in area and volume with irreversible long term consequences on population and environment is well established. However, a lack of regional coordination for long term regular mapping and monitoring hampers further progress on glacial research. Apart from ICIMOD's initiative to map all the glaciers and glacial lakes of the HKH, the Geological Survey of India (GSI) and Cold and Arid Region Environmental and Engineering Research Institute (CAREERI) of Chinese Academy of Science (CAS) are also turning their focus to glaciology. GSI has conducted advanced studies such glacier mass balance and flow hydrometry of Indian glaciers since 1978 (http://www.portal.gsi.gov.in). Similarly, the first national glacier inventory of China was carried out in 1979 for the World Glacier Inventory (WGI) and completed in 2002. A second national inventory on glaciers in China was completed in 2015 (Guo et al., 2015). Meanwhile, partner organizations in ICIMOD's eight regional member countries are developing their capacity to map glaciers by using a glacier inventory exercise provided by ICIMOD.

In view of the regional need to generate more data and knowledge on the cryosphere, glacial research is important not only for water resources and hazard management but also for global climate change research.

2.2 Glacier Inventory Approach

WGMS

In 1970, UNESCO first introduced a classification scheme for perennial snow and ice masses. They aimed to provide a useful database of glacial observations in a standardized digital form. The system was designed to characterize the morphology of glaciers rapidly and precisely. The major advantage of this system was that it allowed the assignment of six characteristics to a glacier. By applying a matrix-type classification based on specific glaciological characteristics, this work provides a defined number of values for each parametre. Since then, the World Glacier Monitoring Service (WGMS; http://www.geo.unizh.ch/wgms/) had adopted this system in a revised form, and applied it to 67,000 glaciers worldwide, of which most are terrestrial. Along with further relevant glacier data, the information is compiled in the World Glacier Inventory (WGI), located at the National Snow and Ice Data Center (NSIDC; http://nsidc.org).

GLIMS

Capitalizing on new developments in the field of remote sensing technologies, GLIMS was initiated to monitor the world's glaciers using data from optical satellite instruments, such as ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometre). Because of the enormous variety of glaciers around the world, it is often not easy to assign these glaciated forms one unambiguous expression. To ensure consistency and homogeneity in the GLIMS glacier database, guidelines for preparing glacier data has been implemented (http://www.glims.org/).

GlobGlacier

GlobGlacier is developing a guidelines for the compilation of glacier inventory data from digital sources. The structure of this document follows closely the original guidelines provided by Müller et al., (1977) for the former World Glacier Inventory (WGI). The main idea behind this document is to provide a selection of topographic glacier parametres and other attributes that can be calculated automatically from glacier outlines and a DEM. The glacier data should be provided when possible to the GLIMS database. A set of further parametres is also listed as 'nice-to have' but not mandatory.

GlobGlacier has been designed to help in the efficient compilation of glacier-inventory parametres from digital sources (vector outlines, digital elevation models or DEMs) and focuses on basic glacier parametres that are required in any compilation.

ICIMOD

Over the course of ICIMOD's work on glaciers starting in 1999, we categorize the work in terms of approaches – old and new.

Old Approach

The old methodology was based on the instructions for compilation and assemblage of data for the WGI, as developed by the Temporary Technical Secretary (TTS) at the Swiss Federal Institute of Technology, Zurich (Muller et al., 1977). It was based on the visual interpretation and manual digitization of glacier boundaries followed by the

Table 2.1: **The attributes used in old approach of the glacier inventory**

S.N.	Attributes	S.N.	Attributes	S.N.	Attributes
1	Glacier ID	7	Map code 1996's	13	Elevation highest
2	Glacier name	8	Aerial photo number	14	Mean elevation
3	Latitude	9	Image number	15	Elevation of tongue
4	Longitude	10	Max length (km)	16	Classification (TTS)
5	Total area (km^2)	11	Orientation accumulation	17	Mean thickness
6	Map code 1960's	12	Orientation ablation	18	Reserves of ice

integration of a non-spatial database. The inventory of glaciers has been systematically carried out for the drainage basins on the basis of topographic maps, which were published from 1963 to 1982, and satellite images from 1999 and 2000 to complement. The data represented a wide temporal range since it were derived from these different sources. As the method was completely manual it took nearly two years for three full-time professionals to compile the inventory for Nepal and Bhutan alone.

New Approach

There is a need for a glacier mapping method that can deliver glacier data quickly and is consistent with stablished international inventory systems to support global climate change research and adaptation studies. It is also important to compile glacier information from a single source representing a narrow temporal range to enable precise glacier change assessment in both spatial and temporal contexts. To achieve this objective, a customized approach using satellite images (Landsat) from a single source from 2005 ± 3 years has been developed. To expedite the process, delineation of glaciers is being carried out in semi-automatic fashion using an object-based classification approach. Since spectral characteristics of clean ice (CI) and debris covered (DC) ice are different and involve different algorithms for classification, each of these types (CI and DC) are catalogued differently and later merged into a single layer. Post-classification data management and parametreization are done in a GIS environment. This methods allows collection of additional attributes including glacier ID, name, location, area, elevation, slope, length, thickness, ice reserves, and classification. Table 2.2 presents each of the 19 columns.

Table 2.2: **List of attributes of the glacier used in new approach of the glacier inventory**

S.N.	Attributes	S.N.	Attributes	S.N.	Attributes
1	Local ID	7	Debris cover area (km^2)	13	Aspect
2	GLIMS ID	8	Glacier area (km^2)	14	Slope (°)
3	Latitude (°)	9	Max elev. of CI (masl)	15	Maximum length (km)
4	Longitude (°)	10	Min elev. CI (masl)	16	6 digit classification
5	Name	11	Max. elev. of DC (masl)	17	Morphological classification
6	CI area (km^2)	12	Min. elev. of DC (masl)	18	Average thickness (km)
				19	Reserves of ice (km^3)

3. Glacier Inventories

3.1 Glacier Inventory of the Hindu Kush Himalaya Based on Topographic Maps

Homogeneous and comprehensive glacier data from the HKH was not available till 2000. Only sporadic information on glaciers was available, based on which estimates regarding glaciers in the HKH were made. The result deviated from the facts and figures. ICIMOD initiated an inventory of the glaciers and glacial lakes of Nepal and Bhutan in 1999 with the support of the United Nations Environment Programme Regional Resource Centre for Asia and the Pacific (UNEP/RRC-AP). The first digital glacier database based on the topographic maps of Nepal and Bhutan was published in 2001. The inventory was further extended to include Himachal Pradesh (HP), Uttarakhand (UA), and Sikkim in India; the Indus basin in Pakistan, and the Ganges basin in China. The Asia Pacific Network (APN) for Global Change Research, and the Global Change System for Analysis Research and Training (START) supported the effort along with partner institutes in each country: Chaudhary Sarwan Kumar Himachal Pradesh Agricultural University (CSKHPAU), and Wadia Institute of Himalayan Geology (WIHG), India; Water Resource Research Institute (WRRI), Pakistan, and National Centre of Encellence Geology (NCEG), Pakistan; Department of Geology and Mines (DGM), Bhutan; Bureau of Hydrology Tibet (BHT), and Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI), China; and the Deaprtment of Hydrology and Meteorology (DHM), Kathmandu University (KU), Tribhuvan University (TU), and the Water and Energy Commission Secretarial (WECS), Nepal (Figure 3.1).

The database of glaciers and glacial lakes was derived from topographic maps from 1963 to 1982, and satellite images from 1999 and 2000 when topographic maps were not available. Before 2011, there were some regional gaps, particularly in Myanmar, Afghanistan, China, and some parts of India (Table 3.1).

Figure 3.1: **Regions where glacier inventories were carried out by ICIMOD along with national partners from 1999 to 2004**

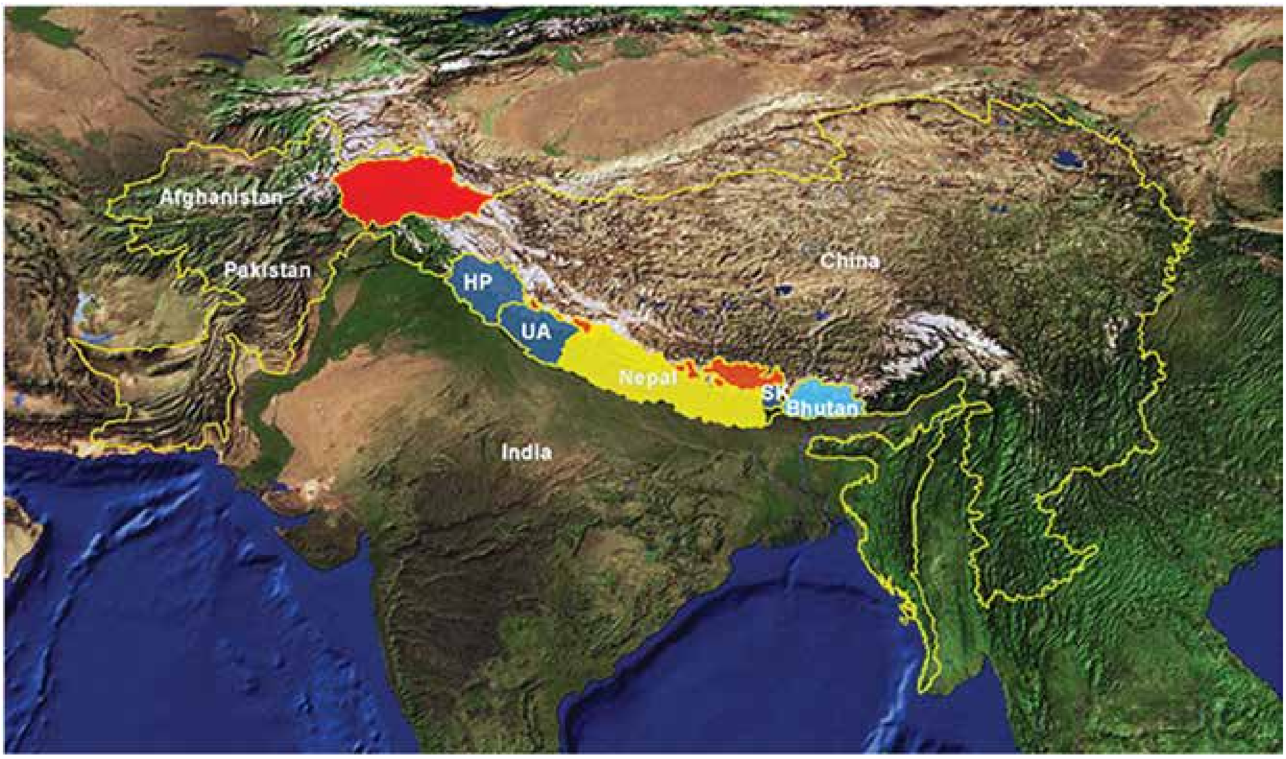


Table 3.1: **Summary of glaciers, glacial lakes, and potentially dangerous glacial lakes in the HKH studied by ICIMOD from 1999 to 2004 based on topographic maps**

River basins	Glaciers			Glacial lakes		
	Number	Area (km^2)	Ice reserve (km^3)	Number	Area (km^2)	Potential danger
Pakistan Indus River	5,218	15,041	2,738.51	2,420	126.35	52
India Sikkim	285	577	64.78	266	20.20	14
India Himachal Pradesh	2,554	4,161	387.35	156	385.22	16
India Uttarakhand	1,439	4,060	475.43	127	2.49	0
TAR China Ganges	1,578	2,864	NA	824	85.19	77
Nepal	3,252	5,324	481.23	2,323	75.70	20
Bhutan	677	1,317	127.25	2,674	106.87	24
Total	**15,003**	**33,344**	**4,274.55**	**8,790**	**796.52**	**203**

3.2 Glacier Inventory of Hindu Kush Himalayan Basins-based on Satellite Images

A glacier inventory of the HKH was started in 2010 using a semi-automatic mapping method delineating glaciers larger than 0.02 km^2 from Landsat satellite images taken between 2002 and 2008. A total of 54,252 individual glaciers were mapped with an overall area of 60,054 km^2, and estimated ice reserves of 6,100 km^3 (Bajracharya et al., 2011) (Figure 3.2, Table 3.2). The total estimated ice reserves are equal to roughly three times the annual precipitation over the entire HKH (Bookhagen and Burbank 2006; Immerzeel et al., 2009). In total, 1.4% of the HKH is glaciated. In terms of debris cover or clean-ice glacier type, altogether 28,500 glaciers were found with a glaciated area of 32,000 km^2 were found. The debris cover was estimated to be 9.3%, 11.06%, and 12.6% in the Indus, Brahmaputra, and Ganges basins respectively. Overall, 9.7% of the total glacier area in the HKH was debris-covered. Debris-covered glaciers are mostly valley glaciers with thick debris cover at the glacier tongue. The inventory found debris-covered glaicers had an average slope of around 12°, whereas clean-ice glaciers were much steeper with average slopes of around 25°. There was a large variation in glacier elevation range, with the lowest glacier terminus identified at 2,409 masl in the Indus basin, and the highest at 8,806 masl in the Koshi basin. Overall, the largest concentration of glaciated area in the HKH was found at altitudes between 5,000-6,000 masl.

Figure 3.2: **Distribution of glaciers in the Hindu Kush Himalayan basins**

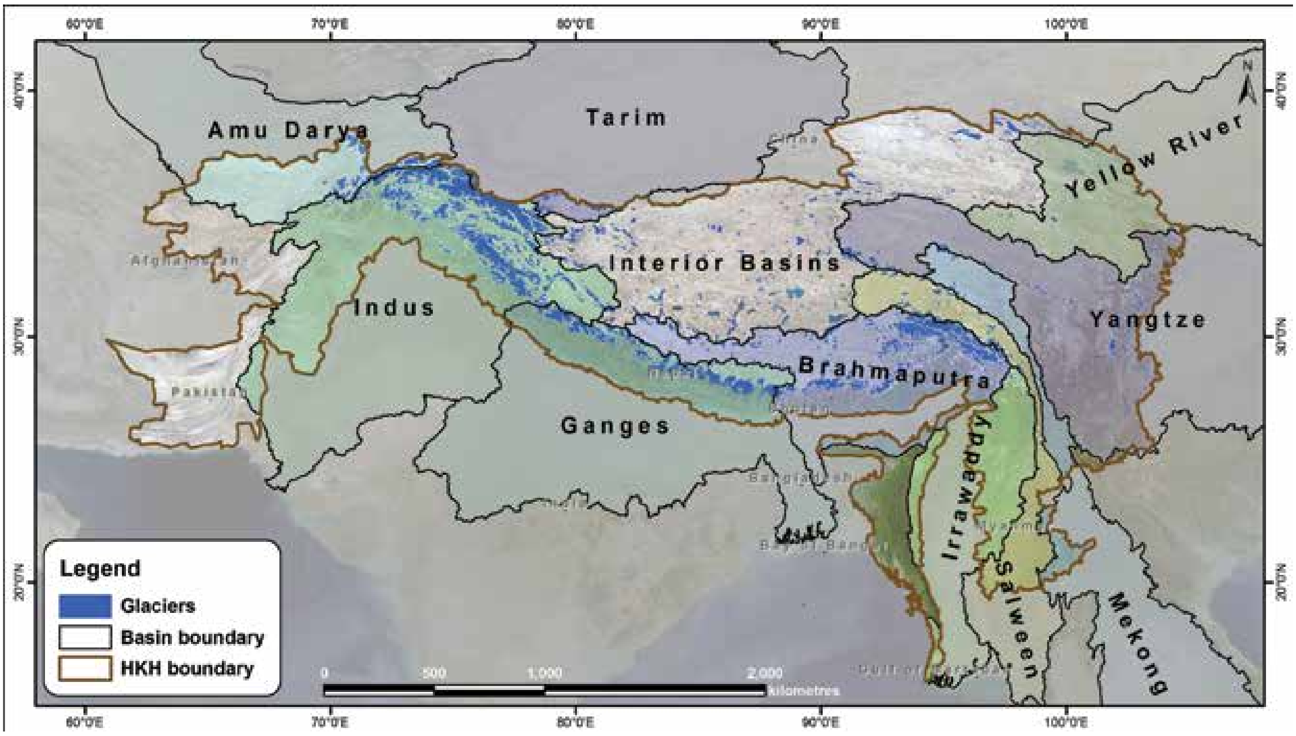


Table 3.2: **Status of glaciers in the Hindu Kush Himalaya by basins**

Basins	Basin area (km^2) in		Number	Area (km^2)	Estimated ice reserves (km^3)
	Total	HKH			
Amu Darya	645,726	166,686	3,277	2,566	162.61
Indus	1,116,086	555,450	18,495	21,193	2,696.05
Ganges	1,001,019	244,806	7,963	9,012	793.53
Brahmaputra	528,079	432,480	11,497	14,020	1,302.63
Irrawaddy	426,501	202,745	133	35	1.29
Salween	363,778	211,122	2,113	1,352	87.69
Mekong	841,322	138,876	482	235	10.68
Yangtze	2,065,763	565,102	1,661	1,660	121.40
Yellow	1,073,168	250,540	189	137	9.24
Tarim	929,003	26,729	1,091	2,310	378.64
Interior	NA	909,824	7,351	7,535	563.1
Total	**8,990,445**	**3,704,360**	**54,252**	**60,054**	**6,126.85**

Note: HKH basin area is 4,192,445 $km^2 \approx 4.2$ million km^2

The average size of individual glaciers was relatively small (1.1 km^2), but most of the ice reserves are found in larger glaciers as a result of the volume-area relationship. The largest individual glacier in the HKH is the Siachen Glacier in the Indus basin of Karakoram with a total area of 926 km^2. The distribution of glaciers across the region is shown in Figure 3.2, as is the level of glaciation in individual basins. There were large variations in glaciated areas found within each basin with the greatest proportions in the Indus (3.8% of the total basin area within the HKH), Brahmaputra (3.2% of the total basin area within the HKH), and Ganges basins (3.7% of the total basin area within the HKH).

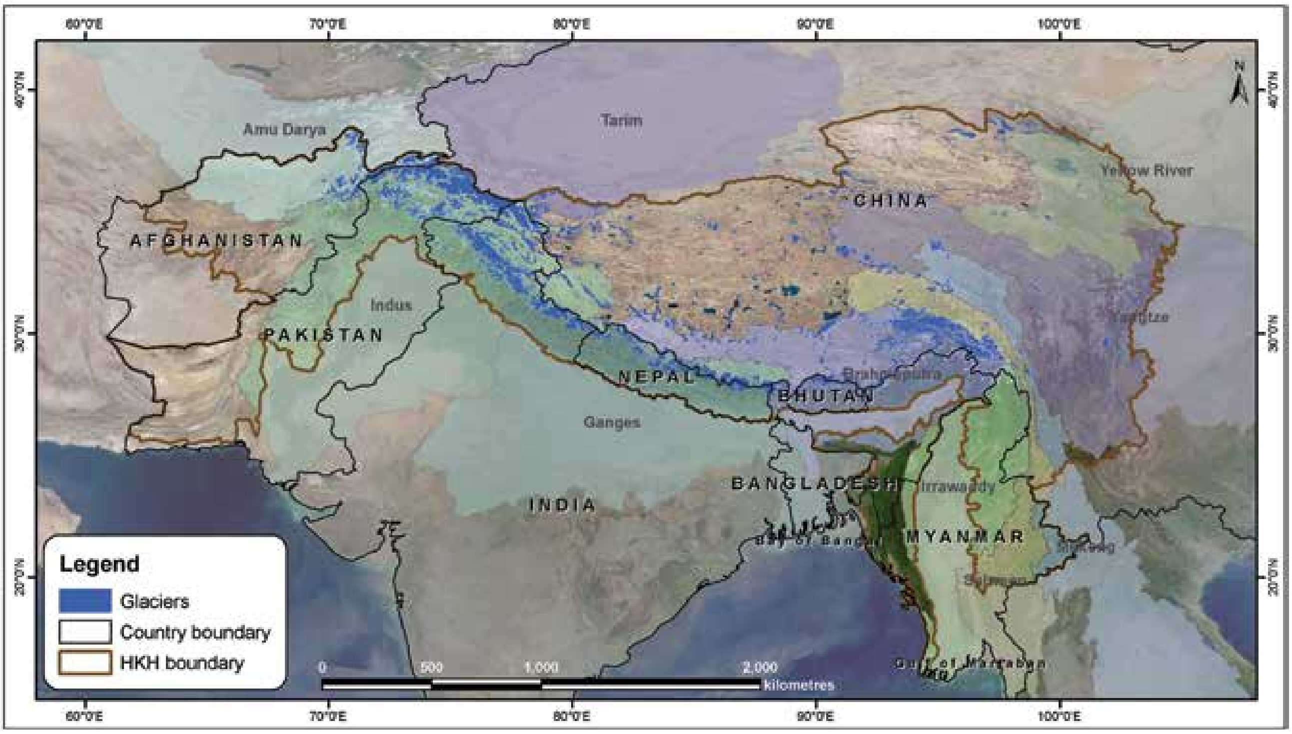
3.3 Glacier Inventory of Hindu Kush Himalayan Countries-based on Satellite Images

Glaciers are not bound by political borders separating countries. They are transboundary in nature. Because boundaries are disputed in some countries, glaciers that lie in such areas are listed under both countries. Hence the number and total area of glaciers when gauged based on HKH countries are slightly higher than HKH basins. However, such transboundary glaciers are presented here due to the importance of the status of these glaciers in each country (Figure 3.3). About 55% of China's glaciers lie within the territory of the HKH, which amounts to 26,347 glaciers with a 29,528 km^2 glacier area (Table 3.3). The number and area of glaciers in China are highest among the HKH countries (Table 3.3). The least number of glaciers were found in Myanmar, and this inventory is probably the first to report glaciers in the country.

Table 3.3: **Summary of glaciers in the HKH, based on country**

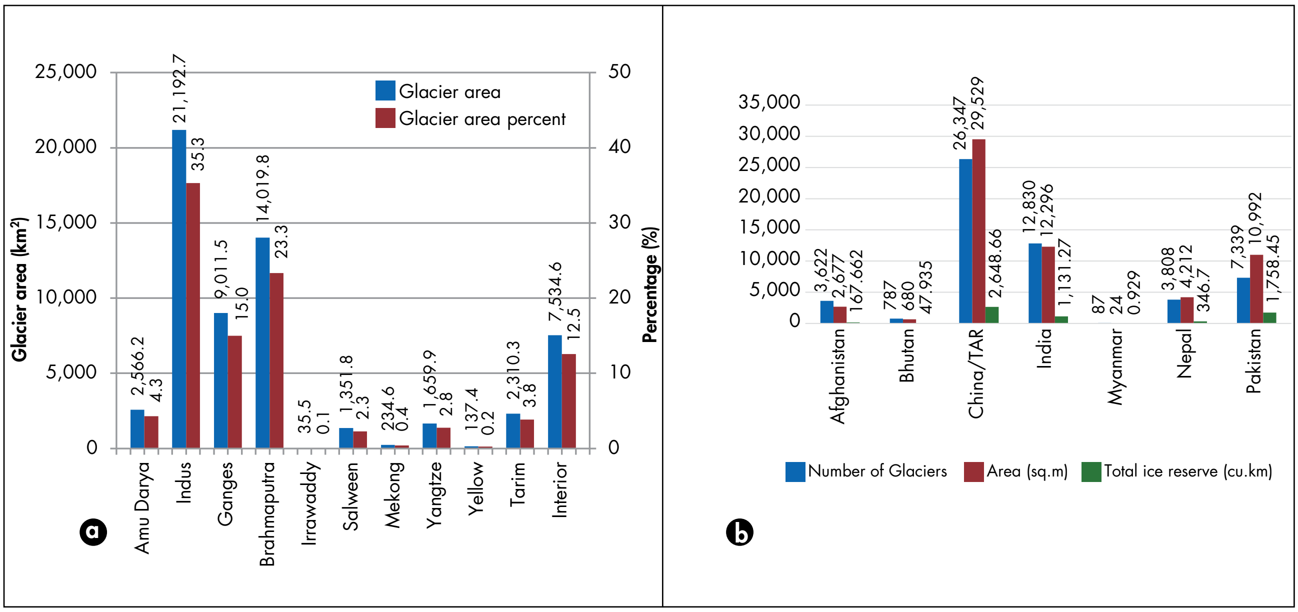
Countries	Glaciers					Remarks
	Number	Area (km^2)	Avg. area	Ice reserve (km^3)	Elevation range	
Afghanistan	3,622	2,677.34	0.739	167.662	3,131-7,256	
Bhutan	787	680.25	0.864	47.935	4,050-7,230	
China/HKH	26,347	29,528.6	1.121	2648.7	2,313-8,823	86% of total
China/all	42,370	43,087	1.017			
India	12,830	12,295.58	0.958	1,131.268	3,001-8,331	
Myanmar	87	23.99	0.276	0.929	4,256-5,695	
Nepal	3,808	4,213.03	1.106	346.70	3,273-8,437	
Pakistan	7,339	10,991.63	1.497	1,758.45	2,409-8,566	
Total	**54,820**	**60,410.42**	**1.102**	**6,101.644**	**2,313-8,566**	

Figure 3.3: **Glaciers in Hindu Kush Himalayan countries**



Note: Country boundary are unauthorized

Figure 3.4: **Percentage of glaciated area in the (a) HKH basins and (b) countries**



4. Decadal Glacier Change

Glaciers in the HKH are receding, some of them at a rate as high as over 70m/year, as in the case of Imja Glacier (Bajracharya et al., 2007). Elsewhere in the eastern Himalaya (Bhutan), reported glacier retreat can be as high as 160m/year, as in the case of the Luggye Glacier from 1988 to 1993 (Mool et al., 2001). Similarly, glacier area has decreased by 11.93 km^2 in 30 years (1963-1993) in Bhutan, as reported from the observation of 66 glaciers (Karma et al., 2003). In the western Himalaya, glacier area decreased from 84.41 km^2 to 77.29 km^2 from 1976 to 2003. Observed rates are 0.17, 0.19, and 0.77 km^2 per year, on average, during the periods 1976–90, 1990–99, and 1999–2003, respectively, suggesting that glacier retreat has accelerated in the most recent decade (Ye et al., 2006). Observers noted that smaller glaciers exhibit a higher retreat rate than larger glaciers.

The Chinese Academy of Sciences has reported that there has been a 5.5% shrinkage in volume of China's 46,928 glaciers during the last 24 years, equivalent to the loss of more than 3,000 km^2 of ice (Pradhan et al., 2007).

4.1 Decadal Glacier Change in Nepal from the 1980s to 2010

The report "Glacier status in Nepal and decadal change from 1980 to 2010 based on Landsat data", published in 2014, presents a comprehensive assessment of the status of Nepal's glaciers in 2010 and the changes since approximately 1980, 1990, 2000, and 2010 (Bajracharya et al., 2014a). A small case study in the Langtang and Imja sub-basins provided a more detailed snapshot view of the changes in individual glaciers and small sub-basins (Figure 4.1) and the possible changes in average temperatures over the past two decades.

Due to shrinking and fragmentation, the number of glaciers had increased by 11% (378) over the 30-year period, with the greatest increase between ~1980 and 1990. The glacier area decreased by 24% (1,266 km^2) and the estimated ice reserves by 29% (129 km^3), again with the greatest change between ~1980 and 1990. The overall glacier area decreased from 3.6% of the total land area of Nepal to 2.6%. Although the rate of loss of area was the same between 1990-2000 and 2000-2010, but the rate of loss of ice reserves increased over this period (Table 4.1).

Table 4.1: **Status and decadal change of glaciers in Nepal from 1980 to 2010**

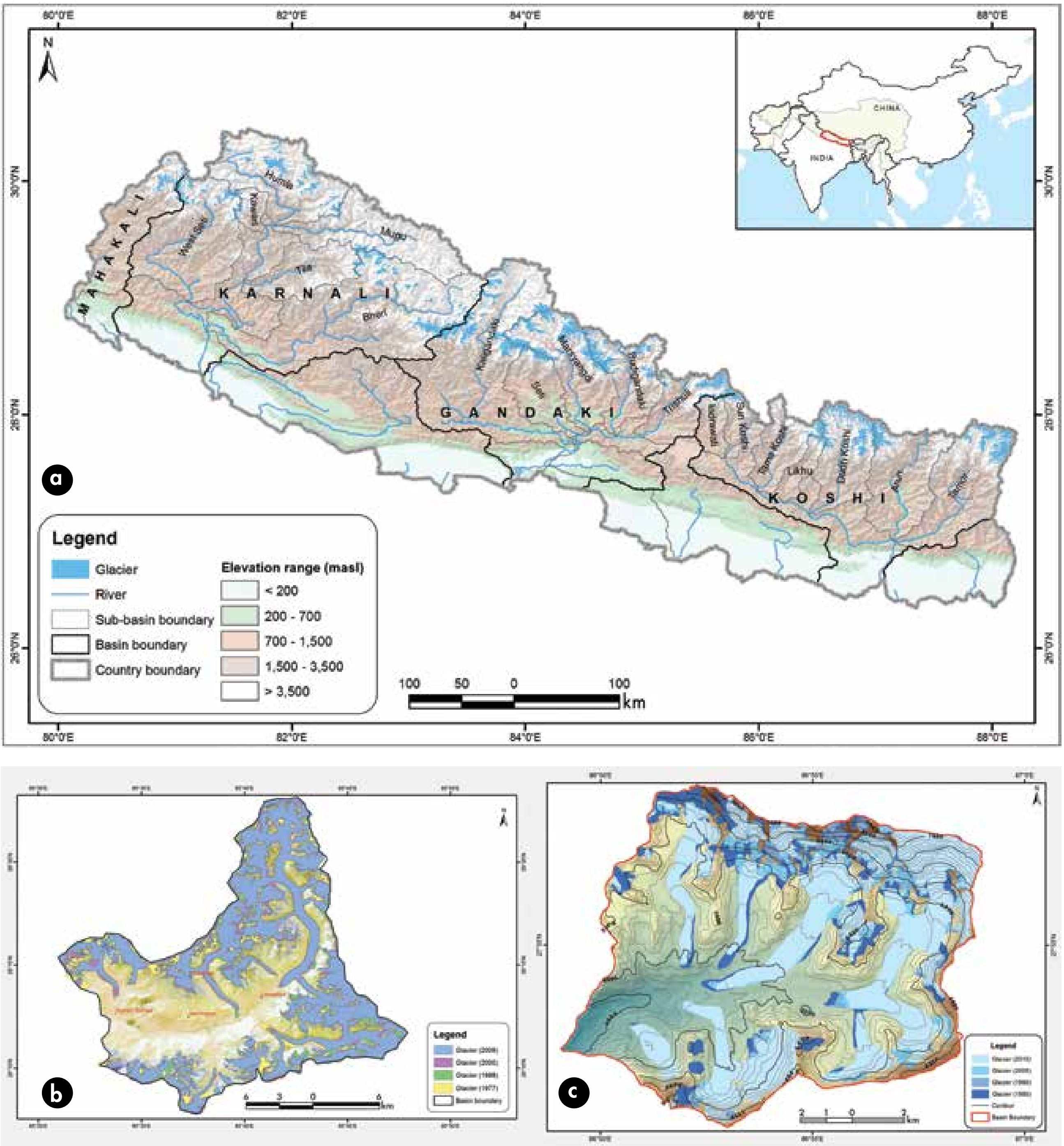
Glaciers	Decade (year)				Decadal change							
	~1980	1990	2000	2010	~1980 – 1990		1990 – 2000		2000 – 2010		~1980 – 2010	
Number	3,430	3,656	3,765	3,808	+226	+7%	+109	+3%	+43	+1%	+378	+11%
Area (km^2)	5,168	4,506	4,211	3,902	-662	-13%	-295	-7%	-308	-7%	-1,266	-24%
Estimated ice reserves (km^3)	441	370	343	312	-72	-16%	-27	-7%	-31	-9%	-129	-29%

4.2 Decadal Glacier Change in Bhutan from the 1980s to 2010

A total of 885 glaciers were mapped from the images of 2010, with an area of 642±16.1 km^2 (1.6% of Bhutan's total land) (Table 4.2 and Figure 4.2). The Punatsangchu basin has the highest number of glaciers (436) and glacier area (361.6±9.3 km^2), while the Wangchu basin has the lowest number of glaciers (56) and glacier area (32.8±0.7 km^2). The largest glacier was G090161E28125N in the Phochu sub-basin of Punatsangchu basin, with an area of 36 km^2. The glacier elevation ranged from 7,230 masl (in the Manaschu basin) to 4,050 masl (in the Punatsangchu basin) (Table 4.3).

Overall, the glacier number shows an increasing trend, whereas the glacier area shows a decreasing trend in the decades from ~1980 to 2010. The number of glaciers had increased by 7%, 5.3%, and 1.2% between ~1980-1990, 1990-2000, and 2000-2010, respectively, with an overall increase of 14.8% in 30 years (~1980 to 2010) (Table 4.4). The glacier area had decreased by 11.6±1.2%, 7.1±0.1%, and 6.7±0.1% between the decades ~1980-1990, 1990-2000, and 2000-2010, respectively, with an overall decrease of 23.3±0.9% in 30 years. The average glacier area in ~1980 was greater than 1 km^2 but decreased to less than 1 km^2 in

Figure 4.1: **(a) Distribution of glaciers in Nepal and decadal glacier change of Nepal. (b) Langtang valley (c) Imja valley**

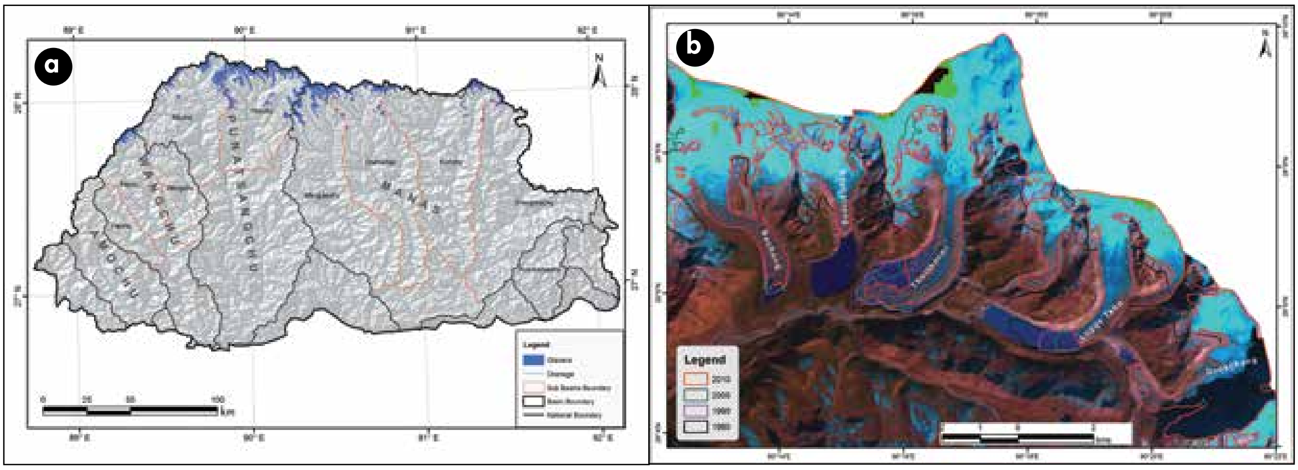


Note: Country boundary are unauthorized

Table 4.2: **Decadal clean-ice (CI) and debris-covered (DC) glacier area change from ~1980 to 2010**

Years	Glacier area (km²)			Change in glacier area (%)		
	CI	DC	Total	CI	DC	Total
~1980	757.4±26.05	80.2± 1.61	837.6± 28.81			
1990	654.6± 14.74	86.2± 0.96	740.7± 16.67	-13.6± 1.2	7.5 ± 0.9	-11.6± 1.2
2000	598.2 ± 14.3	90 ± 0.79	688.2± 16.45	-8.6 ± 0.1	4.4 ± 0.2	-7.1 ± 0.1
2010	550.7± 13.83	91.4± 0.71	642.1± 16.12	-7.9 ± 0.1	1.6 ± 0.1	-6.7 ± 0.1
~1980-2010				-27.3± 0.9	13.9± 1.2	-23.3± 0.9

Figure 4.2: **(a) Distribution of glaciers in Bhutan and (b) decadal change of glaciers in Lunana region from 1980s to 2010**



consecutive decades due to an increase in glacier number and decrease in glacier area. The increase in number with concomitant loss of glacier area indicates fragmentation of existing glaciers due to shrinking rather than the development of new glaciers. Nonetheless, glacier number had slightly decreased in 2010 due to the dissolution of glaciers on steep slopes.

In the context of global warming, with the rise of temperature, the glaciers are melting rapidly, resulting in the subsiding, shrinking, and retreating of glaciers. The observations of individual glaciers indicate that the annual retreat rates vary from basin to basin and in some instances, with a doubling of the rate in recent years compared to the early seventies. Given these contexts, the present status of glacier information is of utmost important, which requires regular updates in order to understand the dynamics of the cryosphere and its impact in the present context.

4.3 Decadal Glacier Change in Jhelum Basin from the 1980s to 2010

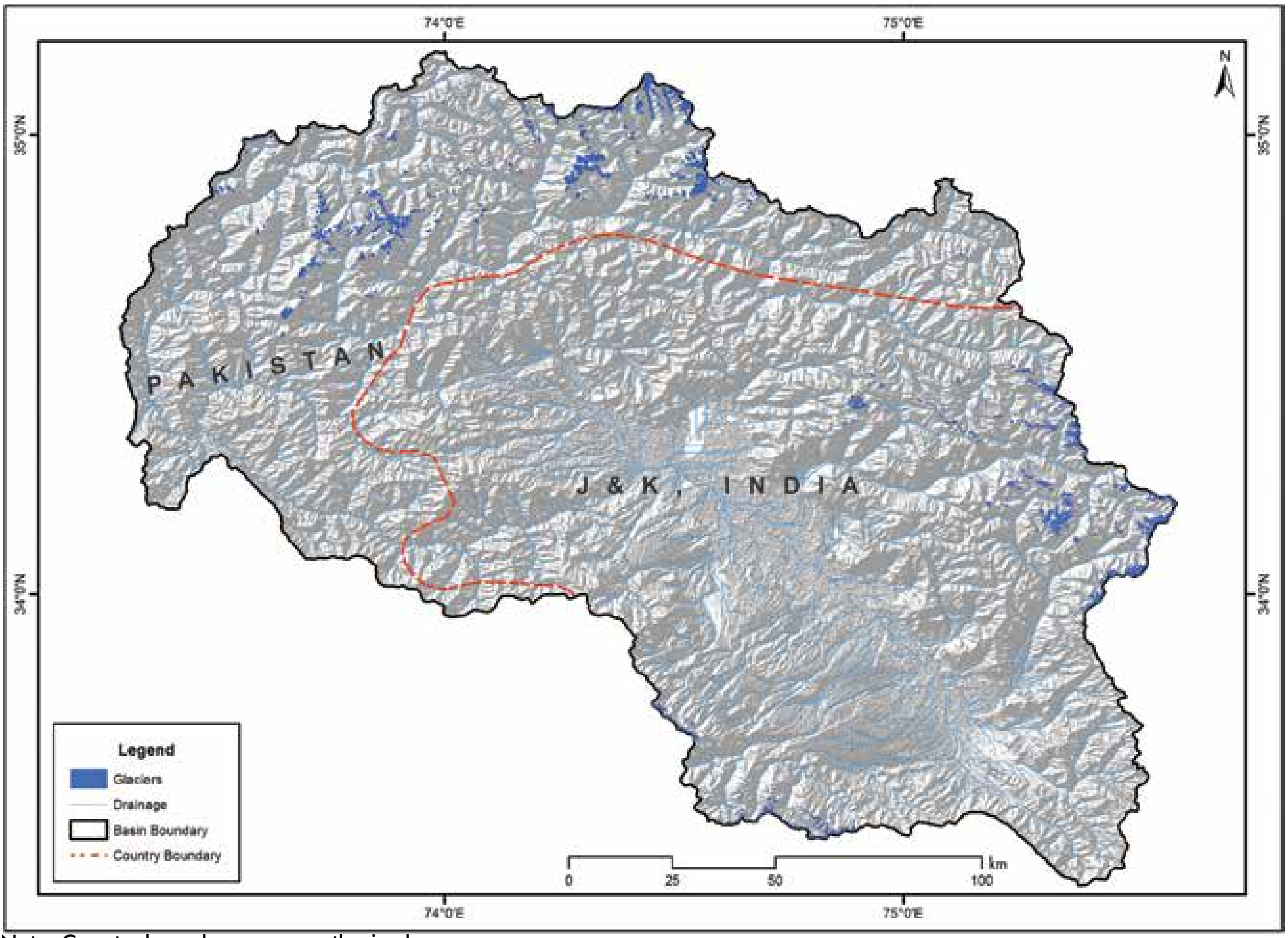
The Jhelum River catchment forms a transboundary basin extending into India and Pakistan. The basin extends from latitude 33.47° to 35.11° N and longitude 73.42° to 75.59°E (Figure 4.3). It is one of the major eastern tributaries of the Indus River. Most of the glaciers are distributed at the higher elevation of the northern sector (Table 4.3).

The glaciers in the Jhelum basin were mapped from the Landsat images of 1980s, 1990, 2000, and 2010 for the decadal glacier change. The results show that the basin contained 268.57 km^2 of glacier area in 1980, 248.15 km^2 in 1990, 220.83 km^2 in 2000, and 211.16 km^2 in 2010. There is a decrease of 21% in glacier area as compared from 1980 to 2010 data. The rapid melting of glaciers was observed between 1990-2000, during which the area decreased by 11%. The retreat rate of glaciers was found to be lowest (4.4%) during 2000-2010. The largest glacier (GLIMS ID G074442E35102N), which had an area of 6.86 km^2 in 1980, has reduced to 6.25 km^2 in 2010. The glacier does not show comparative change at the snout over these decades.

Table 4.3: **Decadal glacier area change in Jhelum basin**

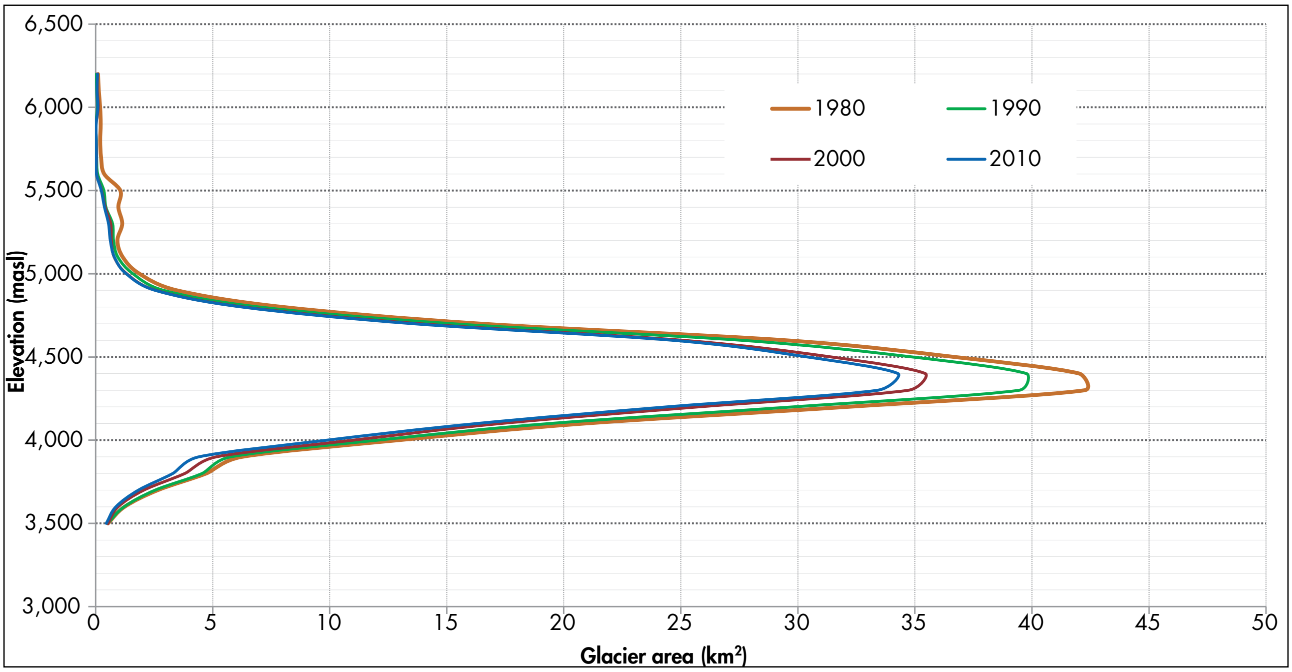
SN	Year	Glacier number	Glacier area (km^2)	Ice reserves (km^3)	Largest glacier area (km^2)	Elevation (masl)	
						Highest	Lowest
1	2010	846	211.16	8.36	6.25	6,285	3,520
2	2000	845	220.83	8.82	6.33	6,285	3,520
3	1990	823	248.15	10.04	6.53	6,285	3,520
4	1980	817	268.57	10.96	6.86	6,285	3,527

Figure 4.3: **Distribution of glaciers in 2010 in Jhelum basin**



Note: Country boundary are unauthorized

Figure 4.4: **100 m bin glacier area hypsographs of Jhelum basin from 1980s to 2010**



5. Data Sources for Glacier Inventory

Due to global warming, the rapid melting of glaciers has changed the glacial scenario significantly. To understand the behavior of individual glaciers, it is necessary to make the inventory of glacier such that the variation in each glacier can be monitored separately. The fast delivery of glacier inventory could be possible with the aid of satellite images, digital elevation models, and topographic maps.

5.1 Satellite Remote Sensing

Satellite data refers to images acquired by sensors (cameras) onboard satellite vehicles hovering in space. Since the launch of Sputnik by the former Soviet Union in 1957 there are various sensors that provide comprehensive pictures of the Earth's surface and processes a wide range of spatial, temporal and spectral resolutions. Figures 5.1 and 5.2 compare satellite images characteristics from different sensors.

Because glaciers are remote, satellite remote sensing is a key application in glacier mapping. Glaciers show different spectral reflectance parametres, which helps to identify them in satellite data and delineate their planimetric outline. Since the early 1970s, when the possibility of satellite data to map glaciers was first demonstrated, remote sensing has been used constantly in glacier mapping studies. The Landsat Multispectral Scanner (MSS) was one of the first satellites used for glacier mapping by the United States Geological Survey (USGS). Different sensors have been used for glacier mapping over time. Table 5.1 summarises some of the sensors commonly used for glacier mapping and their characteristics.

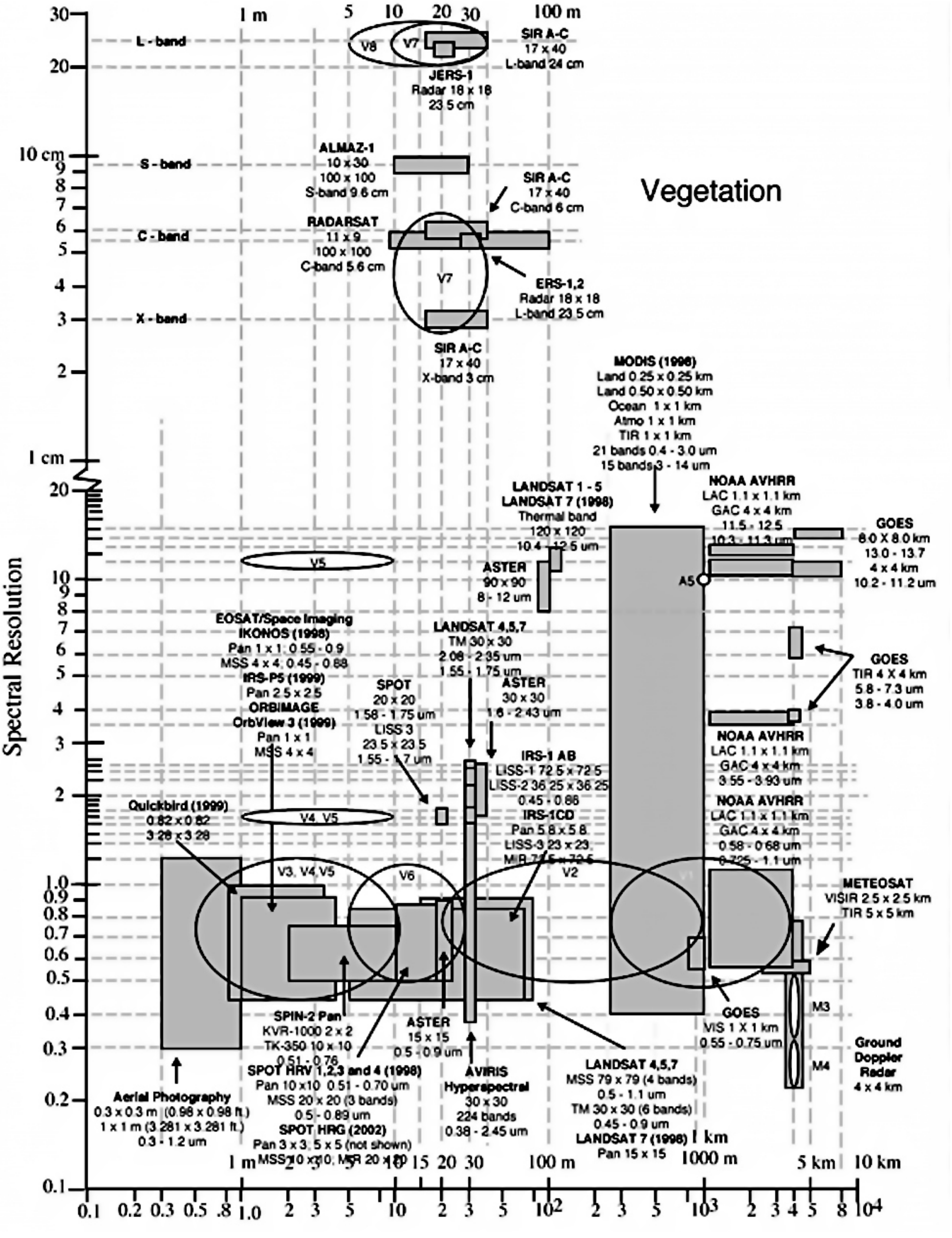
The most common characteristic of the various satellite remote sensing systems results from the spatial, temporal, and spectral resolutions. The spatial resolution specifies the pixel size of satellite images covering the earth surface. The temporal resolution specifies the revisiting frequency of a satellite sensor for a specific location. The spectral resolution specifies the number of spectral bands in which the sensor can collect reflected radiance. But the number of bands is not the only important aspect of spectral resolution; the position of bands in the electromagnetic spectrum is also important.

Remote sensing systems with spatial resolution of more than 1km are generally considered low resolution systems. MODIS and AVHRR are some of the very low resolution sensors. When the spatial resolution is 100m^{-1}km, it is considered a moderate resolution system. IRS WiFs (188m), band 6 (120m) of the Landsat TM, and bands 1-7 of MODIS (250-500m) are moderate resolution sensors. When the spatial resolution is in the range of 5-100m, the sensor is considered a high resolution system. Landsat ETM+(30m), IRS LISS-III (23MSS and 6m Panchromatic), AWiFS (56-70m), and SPOT 5 (2.5-5m Panchromatic) are some of the high resolution sensors. Very high resolution systems can provide spatial resolution of less than 5m. GeoEye, IKONOS, and QuickBird are a few examples of very high resolution systems (Figures 5.1 and 5.2).

Many remote sensing systems are multi-spectral; they record energy over separate wavelength ranges at various spectral resolutions. For example, IRS LISS-III uses four bands: 0.52-0.59 (green), 0.62-0.68 (red), 0.77-0.86 (near IR), and 1.55-1.70 (mid-IR). The Aqua/Terra MODIS instruments use 36 spectral bands, including three in the visible spectrum. A recent development is the hyper-spectral sensors – for instance, MODIS (36 bands) and AVIRIS (224 bands) – which detect hundreds of very narrow spectral bands. A range of features are identified from the image by comparing their responses over different distinct spectral bands. Water and vegetation can be easily separated using very broad wavelength ranges such as visible and near-infrared (Figure 5.1).

The higher the temporal resolution, the shorter the length of time between the acquisitions of images. Many satellites have a medial temporal resolution of about 14-16 days (IKONOS: 14 days, LANDSAT 7: 16 days). But there are also satellites with a very high temporal resolution capable of acquiring images of the same area every 15 minutes (meteorological satellites such as METEOSAT 8). Satellite sensors with a low temporal resolution (SPOT, IKONOS, QuickBird) are very useful for acquiring images of a certain area only once or twice a month and have a better spatial resolution than sensors with a resolution of, for instance, 1000m, providing images once an hour (Figure 5.2).

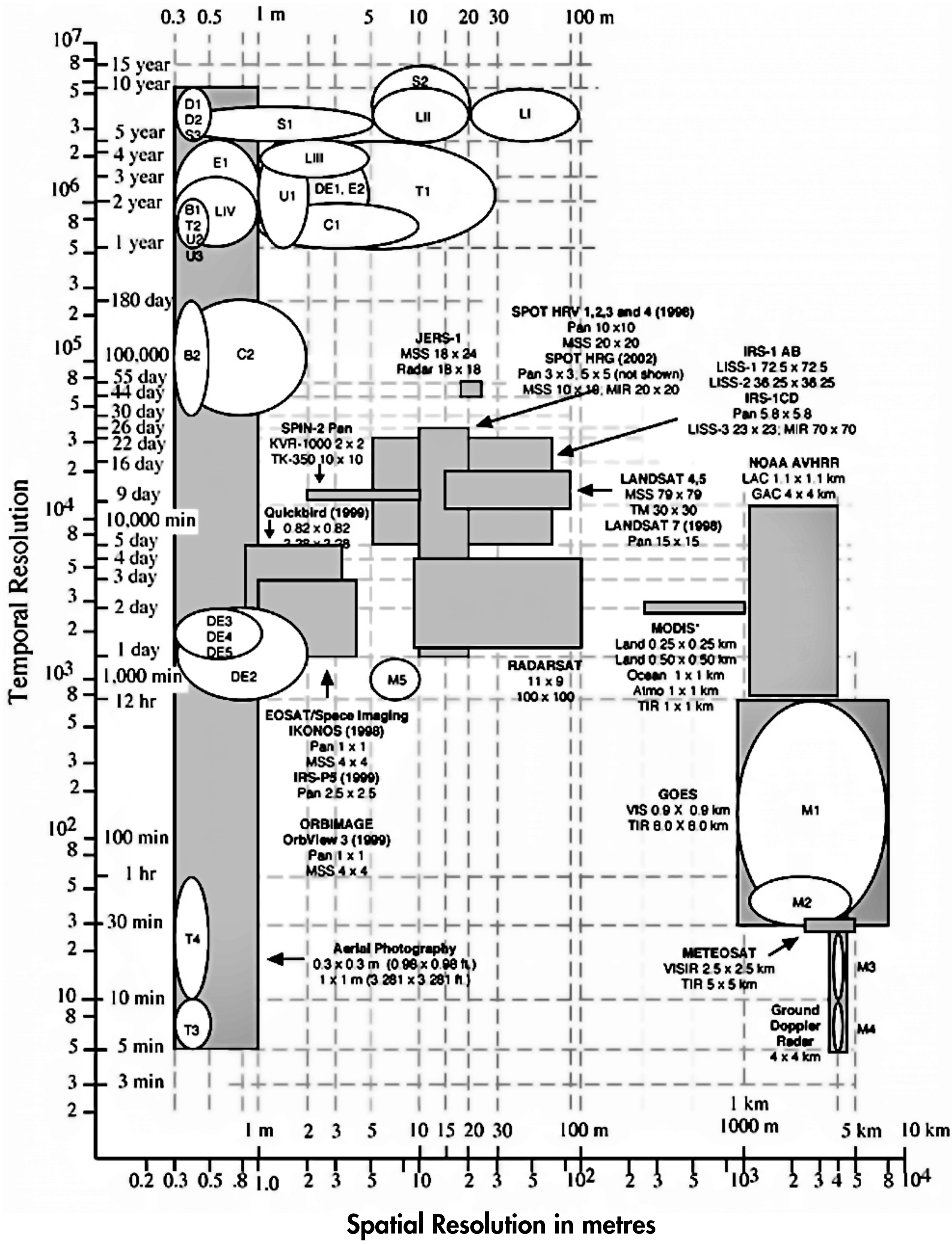
Figure 5.1: **Comprehensive picture of earth's surface and processes at wide range of spatial and spectral resolutions**



Spatial Resolution in metres

Source: Jensen J. et. al., (n.d.)

Figure 5.2: **Comprehensive picture of earth's surface and processes at wide range of spatial and temporal resolutions**



Source: Jensen, J.R. and Cowen, D.C. (1999)

Table 5.1: **Optical land imaging satellites with 56 metres or better resolution by launch date**

Satellite	Country	Launch date	Panchromatic resolution (m)	Multspectral resolution (m)	Swath (km)
Landsat 5	US	03/01/84		30.0	185
SPOT-2	France	01/22/90	10.0	20	120
IRS 1D	India	09/29/97	6.0	23	70; 142
Proba	ESA	10/21/97		18 Hyp	14
SPOT-4	France	03/24/98	10.0	20	120
Landsat 7	US	04/15/99	15.0	30	185
IKONOS-2	US	09/24/99	1.0	4	11
TERRA (ASTER)	Japan/US	12/15/99		15; 30; 90	60
KOMPSAT-1	Korea	12/20/99	6.6		17
EO-1	US	11/21/00	10.0	30	37
EROS A1	Israel	12/05/00	1.8		14
QuickBird-2	US	10/18/01	0.6	2.5	16
SPOT-5	France	05/04/02	2.5	10	120
DMC AlSat-1 (SSTL)	Algeria	11/28/02		32	600
DMC BilSat (SSTL)	Turkey	09/27/03	12.0	26	24; 52
DMC NigeriaSat-1 (SSTL)	Nigeria	09/27/03		32	600
DMC UK (SSTL)	UK	09/27/03		32	600
IRS ResourceSat-1	India	10/17/03	6.0	6; 23; 56	24; 140; 740
CBERS-2	China/Brazil	10/21/03	20.0	20	113
FORMOSAT-2	Taiwan	04/20/04	2.0	8	24
IRS Cartosat 1	India	05/04/05	2.5		30
MONITOR-E -1	Russia	08/26/05	8.0	20	94; 160
Beijing-1 (SSTL)	China	10/27/05	4.0	32	600
TopSat (SSTL)	UK	10/27/05	2.5	5	10; 15
ALOS	Japan	01/24/06	2.5	10	35; 70
EROS B1	Israel	04/25/06	0.7		7
Resurs DK-1 (01-N5)	Russia	06/15/06	1.0	3	28
KOMPSAT-2	Korea	07/28/06	1.0	4	15
IRS Cartosat 2	India	01/10/07	0.8		10
WorldView -1	US	09/18/07	0.5		16
CBERS-2B	China/Brazil	09/19/07	20.0	20	113
THOES	Thailand	02/27/08	2.0	15	22; 90
RazakSat*	Malaysia	03/01/08	2.5	5	?
HJ-1-A	China	04/01/08		30; 100 Hyp	720; 50
HJ-1-B	China	04/01/08		30; 150; 300	720
RapidEye-A	Germany	04/01/08		6.5	78
RapidEye-B	Germany	04/01/08		6.5	78
RapidEye-C	Germany	04/01/08		6.5	78
RapidEye-D	Germany	04/01/08		6.5	78
RapidEye-E	Germany	04/01/08		6.5	78
SumbandilaSat	South Africa	04/01/08		7.5	?
X-Sat	Singapore	04/16/08		10	50
Hi-res Stereo Imaging	China	07/01/08	2.5, 5	10	?
WorldView -2	US	07/01/08	0.5	1.8	16
Venus	Israel/France	08/01/08		10	28
GeoEye-1	US	08/23/08	0.4	1.64	15
DMC Deimos-1	Spain	11/15/08		22	660

Cont...

Table 5.1: **Optical land cont...**

Satellite	Country	Launch date	Panchromatic resolution (m)	Multspectral resolution (m)	Swath (km)
DubaiSat-1	UAE	11/15/08	?	?	?
DMC UK-2	UK	11/15/08		22	660
Alsat-2A	Algeria	12/01/08	2.5	10	?
IRS ResourceSat-2	India	12/15/08	6.0	6; 23; 56	24,140; 740
EROS C	Israel	04/01/09	0.7	2.8	11
CBERS-3	China/Brazil	05/01/09	5.0	20	60; 120
TWSAT	India	07/01/09		35	140
DMC NigeriaSat	Nigeria	07/01/09	2.5	5; 32	320
ARGO	Taiwan	07/01/09		6.5	78
KOMSAT-3	Korea	11/01/09	0.7	3.2	?
Alsat-2B	Algeria	12/01/09	2.5	10	?
Pleiades-1	France	03/01/10	0.7	2.8	20
CBERS-4	China/Brazil	07/01/10	5.0	20	60; 120
SeoSat	Spain	07/01/10	2.5		?
Pleiades-2	France	03/01/11	0.7	2.8	20
EnMap	Germany	07/01/11		30 Hyp	30
LDCM	US	07/01/11	10.0	30	177
SPOT	France	07/01/12	2.0	6	60
Sentinel 2 A	ESA	07/01/12		10; 20; 60	285
Sentinel 2 B	ESA	07/01/13		10; 20; 60	285
Landsat 8 OLI	US	02/11/13	15	30; 100	185
	Commercial	* Near Equatorial Orbit		Revised 1/21/08	

Note: Read 4/1 = 1st quarter, 7/1 = in that year, 11 & 12s = late in that year

5.2 Digital Elevation Model (DEM)

Digital elevation models (DEMs), which are digital representations of the Earth's relief, are one of the most important data structures used for geomatics and geoscientific analysis. Topographic information is required for geometric, radiometric, and atmospheric corrections of satellite data from optical and microwave instruments. When combined with a DEM, glacier outlines derive glacier parametres such as hypsometry, minimum/median elevations, and ELA. Recent studies incorporate slope information from DEM to study glacier dynamics. It can be generated using stereo satellite/photo pairs or by interpolating relief information like contour (line) and/or height (point) data.

Shuttle Radar Topography Mission (SRTM) DEM

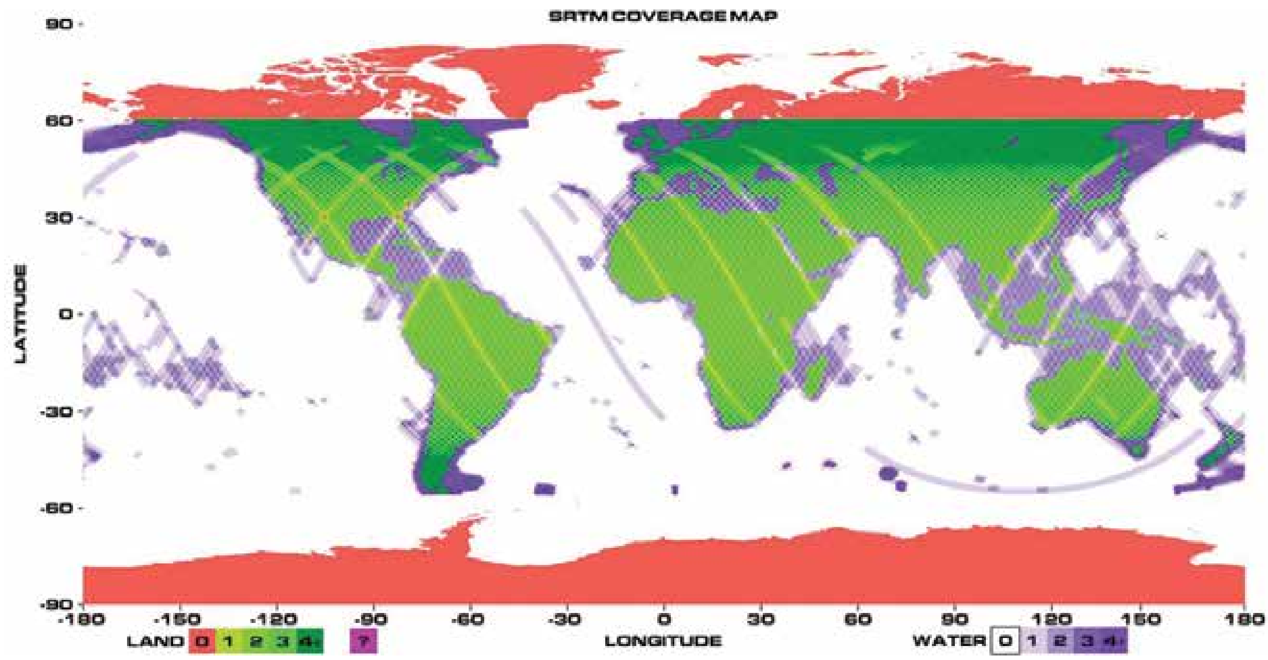
The Shuttle Radar Topography Mission (SRTM) is a joint project between the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). The SRTM obtained elevation data on a near-global (80%) scale to generate the most complete high-resolution digital topographic database of Earth. (Figure 5.3 shows the global coverage map of SRTM.) SRTM consists of a specially modified radar system that maps the earth's topography. A technique called Interferometric Synthetic Aperture Radar is used to send the signal to the ground, where it is picked up by radar, and then transformed to produce topographic data. (The SRTM index map used for the HKH is shown in Figure 5.4.)

The SRTM can map the earth's topography at a 30m spatial resolution, but data with such resolution have only been released over the United States territory and some isolated areas; for the rest of the world, 90m data are available. The elevation models are arranged into tiles, each covering one degree of latitude and one degree of longitude, named according to their southwestern corners. In 2005, NASA released version 2 of the SRTM digital topographic data (also known as the "finished" version), which has undergone substantial editing.

Advanced Spaceborne Thermal Emission and Reflection Radiometre (ASTER) DEM

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometre) is an imaging instrument flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS). ASTER is a cooperative effort between NASA, Japan's Ministry of Economy, Trade and Industry (METI), and Japan's Earth Remote Sensing Data Analysis Center (ERSDAC). ASTER, with its along-track stereo, has the capability to generate precise DEM. METI and NASA announced the release of the ASTER Global Digital Elevation Model (GDEM) on June 29, 2009. The GDEM was created by stereo-correlating the 1.3 million-scene ASTER VNIR archive, covering the Earth's land surface between 83°N and 83°S latitudes. The GDEM is produced with 30 metre postings, and is formatted in 1 x 1 degree tiles as GeoTIFF files. ASTER-DEM is suitable for terrain analysis in a GIS environment at 1:25,000 scale. Each GDEM file is accompanied by a Quality Assessment file, either giving the number of ASTER scenes used to calculate a pixel's value or indicating the source of external DEM data used to fill the ASTER voids. The GDEM is available for download from NASA's EOS data archive and Japan's Ground Data System. Global DEM like Shuttle Radar Topography Mission (SRTM) DEM and ASTER DEM are freely available in the public domain.

Figure 5.3: **Global coverage map of SRTM**

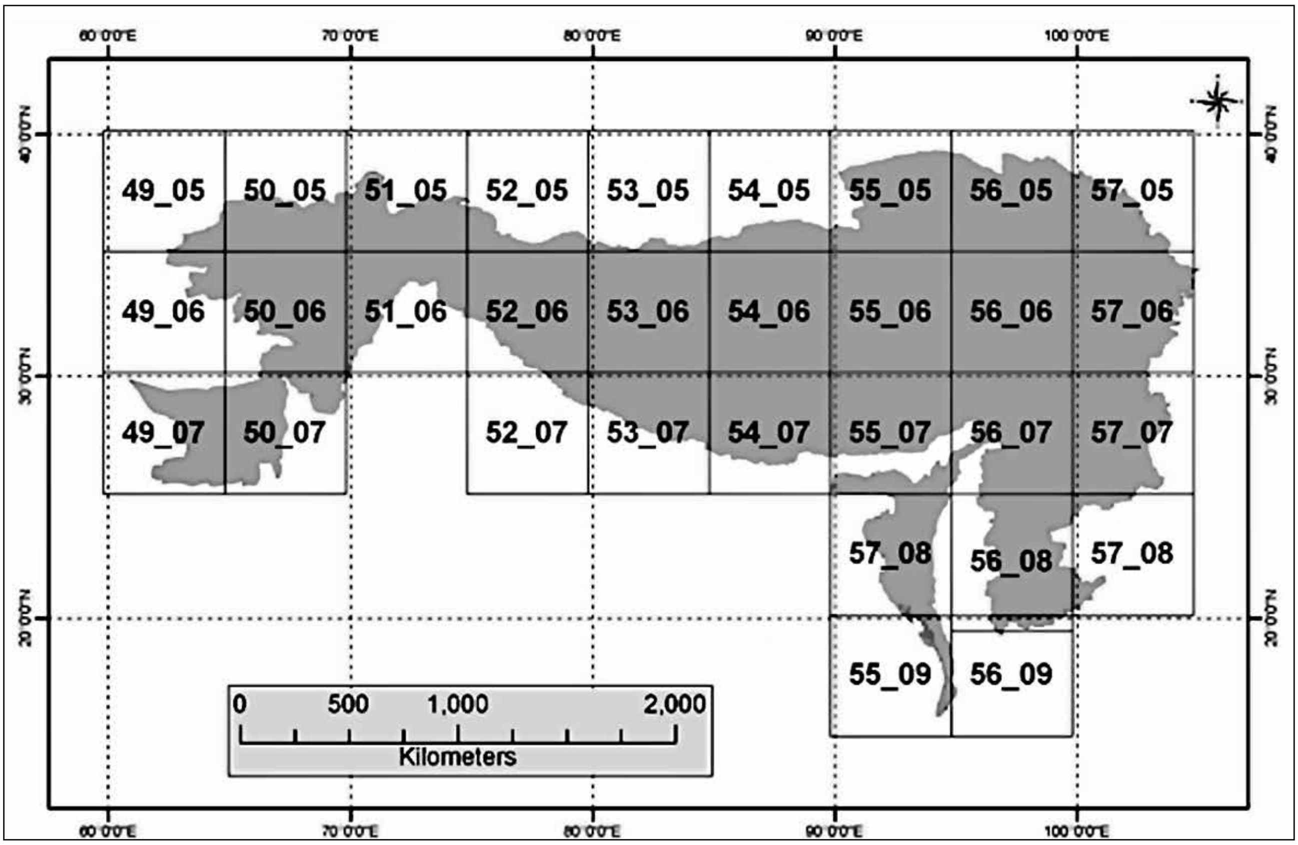


Source: NASA

Table 5.2: **Overview of DEM generation from satellite images (<15m)**

	IKONOS	QUICKBIRD	EROS-A1	SPOT-5/ HRG	SPOT-5/ HRS	IRS-PAN 1C/1D	ASTER-VNIR	PRISM
Bands	PAN, RGB, NIR	PAN, RGB, NIR	PAN	PAN	PAN	PAN	G, R, NIR	PAN
Ground resolution (m)	14	0.61, 2.44	2.6	2.5,5	10(5)	5	15	2.5
Stereo acquisition	Along/Across	Along/Across	Along/Across	Across	Along	Across	Along	
Scene size (km x km)	11 x 11	16.5 x 16.5	12.5 x 2.5	60 x 60	120 x 60	70 x 70	60 x 60	35 x 35/70

Figure 5.4: **SRTM index map of the HKH**



6. Glacier Inventory Methodology (New Approach)

The inventory of glaciers carried out by ICIMOD in 2001 was based on the topographic maps published from 1963 to 1982 and complemented by satellite images from 1999 and 2000. This information thus was captured from different sources with a wide temporal range. However, this work provided firsthand baseline information on glaciers and glacial lakes. But for scientific analysis of glaciers and glacial lakes, one must keep the source and date in the least diverse form possible. Keeping this in mind, a new quick inventory methodology has been developed to generate a glacier and glacial lake inventory database based on the single source of narrow temporal ranges. The readily available data sets are satellite images which are downloadable free of cost, such as Landsat 5, Landsat 7 TM, and Landsat 7ETM+. It is difficult to manage high quality images of one year covering the whole area of interest; thus, one has to use images covering a non-negligible temporal range. The satellite images (Landsat 5, 7, ETM+) of 2005 ±3 years are selected for the inventory of the glaciers, which will provide the status of glaciers in the region and baseline information for scientific analysis. The information will be purely based on the remote sensing approach, and management of the database will be done in a GIS environment; accordingly, the attribute information of the glaciers will be limited.

The glacier mapping and inventory will be carried out with a semi-automated approach and will map glacier outlines using multispectral (optical) satellite data using eCognition software (formerly known as Definion Developer). The attribute parametres will be based on the "Guidelines for the compilation of glacier inventory data from digital sources", which was reviewed and commented on by several members of the GlobGlacier working and user group, as well as the GLIMS community. The original structure of the inventory follows closely the original guidelines by Müller et al., (1977) for the former World Glacier Inventory (WGI).

All perennial snow and ice masses will be mapped for the glacier inventory using geo-referenced Landsat-5/7/ETM+ by implementing algorithms based on the semi-automatic approach. Semi-automatic object-based classification will be implemented in eCognition software and post- classification data management will be done in ArcGIS. Pre-classification preparatory processes, such as mosaicking different scenes of images and defining and clipping out areas of interest, will be done in Erdas Imagine.

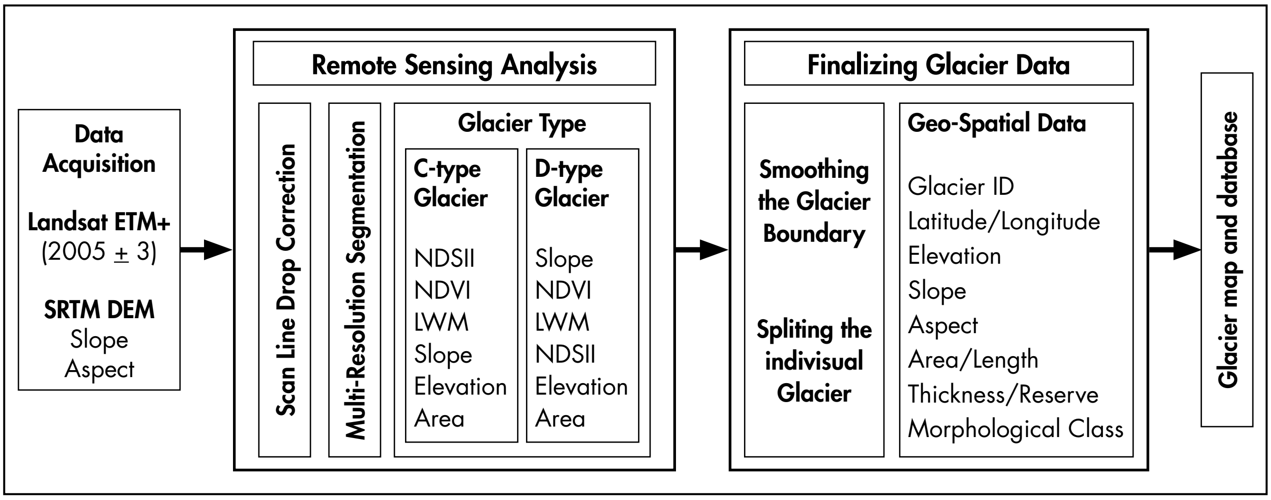
6.1 Semi-automatic Glacier Mapping

Spectral uniqueness of glacier ice in the visible and near-IR part of the electromagnetic spectrum enables algorithm-based semi-automatic mapping of glaciers, in contrast to the tedious manual approach. Of the two kinds, Clean Ice (C-type) and Debris covered (D-type) glaciers, the latter poses challenges in illuminating errors due to effects from surrounding materials in the semi-automatic mapping process. To minimize errors, the morphometric classification approach using morphological variables like slope should be employed.

Keeping in mind the spatial scalability of features, object-based multiresolution segmentation is possible in eCognition software, which enables the extraction of information in different resolutions. This multiresolution segmentation divides the image into object primitives. It is important to assign appropriate shape and compactness factors during segmentation. Segmentation is of major significance in the entire process since it influences the final quality of the classified data. In glacier mapping, visible and near infrared bands are used during segmenting.

As mentioned earlier, different approaches must be adopted for classifying C- and D-types of glaciers. From our experience, using a threshold value of Normalized Difference Snow Index (NDSI) for C-type and a mean slope for D-type have mapped all glacier pixels. Further filtering using different variables such as Normalized Difference Vegetation Index (NDVI) (for vegetation), land and water mask (water bodies), mean hue, mean slope, and mean altitude (glaciers) will eliminate any misclassified objects such as water bodies, shadows, rocks, and trees from the classified image of the glacier (Figure 6.1).

Figure 6.1: **Flow diagram on methodology for glacier mapping using satellite images**



6.2 Spectral Signatures

Glacier ice mapping relies on the spectral uniqueness of glacier ice in the visible and near-infrared part of the electromagnetic spectrum (Table 6.1). Snow and ice are characterized by: 1) high reflectivity (albedo) in the visible wavelengths (0.4-0.7 µm); 2) medium reflectivity in the near-infrared (0.8-2.5 µm); 3) low reflectivity and high emissivity in the thermal infrared (2.5-14 µm); and 4) low absorption and high scattering in the microwave (Rees et al., 2003).

Table 6.1: **Spectral bands (µm) details of Landsat ETM+ and its potential applications**

Band	Range (µm)	Spectral	Potential applications
1	0.45–0.52	Blue	Coastal water mapping; soil/vegetation differentiation; deciduous/coniferous differentiation (sensitive to chlorophyll concentration), etc.
2	0.52–0.62	Green	Green reflectance by healthy vegetation, etc.
3	0.63–0.69	Red	Chlorophyll absorption for plant species differentiation
4	0.78–0.90	NIR	Biomass surveys; water body delineation
5	1.55–1.75	Infrared (MIR)	Vegetation moisture measurement; snow/cloud differentiation; snow and ice study
6	10.4–12.5	ThIR	Plant heat stress management; other thermal mapping; soil moisture discrimination
7	2.08–2.35	IIR	Hydrothermal mapping; discrimination of mineral and rock types; snow/cloud differentiation; snow/ice study

For the delineation of clean and debris cover-type glaciers, the following variables are used:

Brightness: Sum of the mean values of the layers containing spectral information divided by their quantity computed for an image object (mean value of the spectral mean values of an image object).

NDSI: Normalized Difference Snow Index (NDSI) is analogous to the normalized difference ice index and is the normalized difference of spectral reflectance values between the visible (green) and short wave-infrared (SWIR). This is the ratio between the difference of spectral reflectance of band 3 and 5 to the sum of spectral reflectance of band 3 and 5 (Table 6.1). It is used to identify whether the pixel contains snow or ice.

NDSI = (VIS-MIR)/(VIS+MIR)

If you are using the Landsat 7etm+

NDSI = ([Mean Layer 2]-[Mean Layer 5])/([Mean Layer 2]+[Mean Layer 5])

NDVI: Normalized Difference Vegetation Index is the normalized difference between red and near infrared (NIR) and is used in the identification of vegetation in the pixel(s).

NDVI = ([Mean Layer 3]-[Mean Layer 4])/([Mean Layer 3]+[Mean Layer 4])

NDWI: Normalized Difference Water Index is analogous to NDVI but is related to the assessment of water content in a normalized way. It is the ratio of the difference of NIR and SWIR to the sum between the two.

DVI: Differential vegetation Index is the difference between near infrared and red bands and is ideal for biophysical properties of vegetation.

RVI: Ratio vegetation index is the ratio between near infrared and red bands and is used mostly for leaf area index characterization.

Red/Infrared: Normalized difference between red and infrared. This is the ratio between the difference of spectral reflectance of band 3 and band 4 to the sum of spectral reflectance of band 3 and 4.

Standard deviation (Layer 3): It is calculated from the image layer intensity values of all pixels forming an image object. It is preferable to use band 3 of Landsat 7ETM+.

HSI: Hue, the quality of a color as determined by its dominant wavelength. It is nothing but the color (blue, red, yellow, etc.) we describe; Saturation: the strength of a color with respect to its value or lightness; Intensity: the brightness or dullness of a hue (color).

The HSI color space is very useful for image processing because it separates the color information in ways that correspond to the human visual system's response. The hue value of the HSI color space represents the gradation of color.

Max. Diff.: Maximum Spectral Difference is defined as the amount of spectral difference between the mean intensity of image objects divided by the brightness of image objects.

Asymmetry: Asymmetry is the relative length of an image object compared to a regular polygon. The longer an image object, the more asymmetric it is. An ellipse is approximated around a given image object, which can be expressed by the ratio of the lengths of the minor and the major axis of this ellipse. The feature value increases with the asymmetry.

DEM: Topographic information such as elevation and slope play a crucial role in the identification of glaciers. This information is derived from a digital elevation model (DEM). A DEM is used to derive crucial glacier parametres such as minimum/median elevation, equilibrium line altitude (ELA), and hypsometry. The SRTM (Shuttle Radar Topography Mission) DEM at a spatial resolution of 90 metres is used for glacier study.

Slope: The general slope of the debris cover glacier in the mountain is less than 15 degrees, whereas the clean ice can remain at a slope of above 30 degrees.

Area: Surface area of the glaciers. The area of the clean ice less than 0.02 km^2 is not accounted here for the inventory of glaciers in the Himalaya.

6.3 Glacier Inventory Parametres

All polygons delineated for the present glacier inventory are coded, and attribute parametres are derived for each glacier polygon in ArcGIS. The coding system is based on the one used in the World Glacier Inventory. The descriptions of attributes for the inventory of glaciers are given below.

Glacier ID

Local ID: The Glacier ID is assigned by numbering the glaciers starting from the outlet of the major stream of a basin and proceeding clockwise around the basin through each significant small tributary (e.g., Ktrgr_123).

GLIMS ID: The Glacier ID is based on the latitude and longitude location of a "center point" on the glacier. The GLIMS ID is a 14-digit code including G for Global, E for East, and N for North. The latitude and longitude should be in degrees defined to three decimal places (e.g., G086700E28016N).

Latitude and Longitude

The location of the glacier is described using the central coordinates (latitude and longitude) of the glacier polygon. The latitude and longitude are stored in degrees defined to three decimal places.

Name

The name is inserted manually from the map or from an existing glacier inventory (if available).

Area of the Glacier

The area will be calculated separately for Clean Ice (CI) and Debris-covered (DC) glaciers, and the latter will be merged to make one glacier. Glaciers with an area of less than 0.2 sq.km. will be dropped out and the area will be presented in square kilometres with two digits after the decimal point.

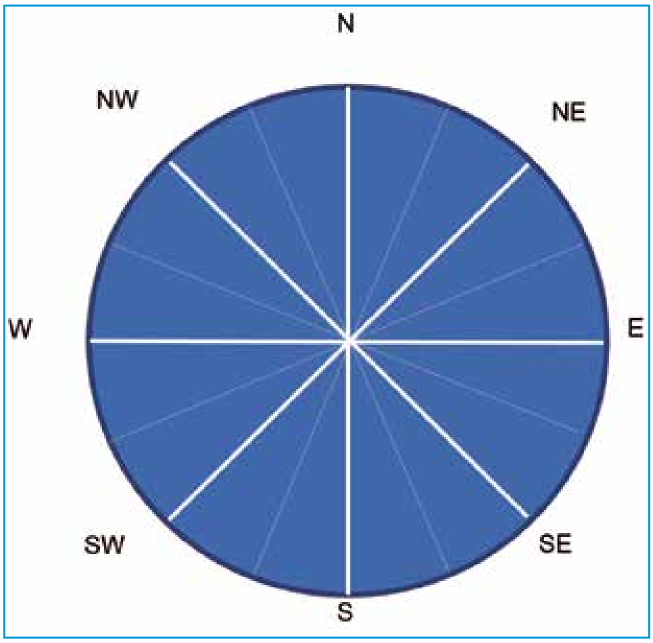
Elevation of the Glacier

Glacier elevation is divided into ***highest elevation*** (the highest elevation of the crown of the glacier) derived from the Clean Ice (CI), ***mean elevation*** (the arithmetic mean value of the highest glacier [CI] elevation and the lowest glacier [CI or DC] elevation), and ***lowest elevation*** (elevation of the tongue of the glacier) derived from the Debris-covered (DC) ice. If the glacier is not debris-covered, the tongue of the clean ice is considered the lowest elevation. It is measured in metres above sea level (masl).

Orientation of the Glacier

The orientation of Clean Ice (C type) and Debris-covered (D type) glaciers is represented in eight cardinal directions (N, NE, E, SE, S, SW, W, and NW) (Figure 6.2). Each cardinal direction has a range of 45 degrees, half to each side, as shown in Figure 6.2. Some glaciers are ice caps forming an apron around a peak and thus sloping in all directions; such glaciers were represented as "open." The orientations of C and D type glaciers in the compound basins can be different.

Figure 6.2: **Aspect quadrants**



Mean Slope

The mean slope was derived for each glacier from the DEM; it is independent of glacier length and refers to all individual cells of the DEM within the glacier boundary (cf. Manley 2008). The mean slope is a rough proxy for other parametres like mean thickness (cf. Haeberli and Hoelzle 1995) and also relates to other dynamic measures, such as surface flow speed.

Length of the Glacier

The length of the glacier is divided into three columns: *total length, length of Clean Ice*, and *length of Debris-covered ice*. The total (maximum) length refers to the longest distance of the glacier along the centerline. It is measured manually and presented in metres.

Mean Glacier Thickness and Ice Reserves

There are very few measurements of glacial ice thickness for the southern flank of the Himalaya. Measurements of glacial ice thickness in the northern flank (Tianshan Mountains, China) show that the glacial thickness increases with the increase of its area (LIGG/WECS/NEA 1988; CAREERI 2008). The relationship between ice thickness (H) and glacial area (F) was obtained by using the empirical formula

$$H = -11.32 + 53.21\ F^{0.3}$$

This scaling formula was used to estimate the mean ice thickness of the glaciers. However, the value is a tentative figure and highly uncertain, since surface slope, annual mass balance, and many other attributes affect ice thickness. The ice reserves were estimated from the mean ice thickness multiplied by the glacial area. The value is also highly uncertain, as it is derived from the already highly uncertain glacier thickness.

Morphological Classification

A morphological matrix-type classification and description was used in the study in line with the classification proposed by Muller et al., (1977) for the TTS to use in the WGI. Each glacier was coded as a six-digit number, one digit for each of six different morphological characteristics (Table 6.2). The individual numbers for each digit (horizontal row numbers) are read on the left-hand side. This scheme is a simple key for the classification of glaciers all over the world.

Table 6.2: **Classification and description of glaciers**

Digit 1	Digit 2	Digit 3	Digit 4	Digit 5	Digit 6
Primary classification	Form	Frontal characteristic	Longitudinal profile	Major source of nourishment	Activity of tongue
Uncertain or miscellaneous	Uncertain or miscellaneous	Normal or miscellaneous	Uncertain or miscellaneous	Uncertain or miscellaneous	Uncertain
Continental ice sheet	Compound basins	Piedmont	Even: regular	Snow and/or drift snow	Marked retreat
Ice field	Compound basin	Expanded foot	Hanging	Avalanche and/or snow	Slight retreat
Ice cap	Simple basin	Lobed	Cascading	Superimposed ice	Stationary
Outlet glacier	Cirque	Calving	Ice fall		Slight advance
Valley glacier	Niche	Confluent	Interrupted		Marked advance
Mountain glacier	Crater				Possible surge
Glacieret and snow field	Ice apron				Known surge
Ice shelf	Group				Oscillating
Rock glacier	Remnant				

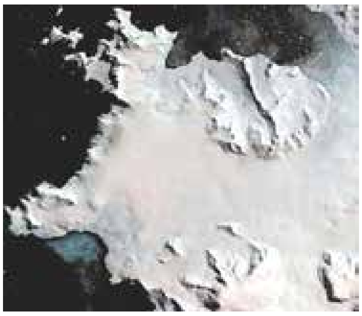
6-digit Classification

Digit 1: Primary classification

(Adopted from Illustrated GLIMS Glacier Classification Manual)

The six categories of the parametre group "Primary classification" attempt to classify glaciers into morphologically distinct units, which facilitate an identification of almost every type of glacier in the world (Table 6.3). Combining these primary classification values with those of other parametre groups, it becomes possible to typify commonly known glacier types of which the "primary types" seem to be cirque glaciers, tidewater glaciers, or hanging glaciers.

Table 6.3: **Primary classification**

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comments	Satellite Image/Photo/Graphics (if present: Primary classification – Form – Frontal Characteristics – Longitudinal Profile - Major source of nourishment)	GLIMS code
Uncertain or miscellaneous	• Any type not listed below	Any type not listed below			0
Continental ice sheet	• Unconstrained by topography • Continental size • Derive their morphological shape from ice flow properties, internal dynamics, and bedrock conditions	Inundates areas of continental size	• May incorporate individual ice domes		1
Ice-field	• Approximately horizontal, ice-covered area • Ice covering does not overwhelm surrounding topography • Occur in topographical depressions or plateaus • No dome-like shape (in contrast to ice cap) • Smaller than 50.000 km^2 (approx. 220 x 220 km)	Ice masses of sheet or blanket type of a thickness not sufficient to obscure the sub-surface topography	• In some cases no need to classify in "Frontal characteristic" (the frontal characteristic is described by the outreaching glaciers). • Might also be used to classify low lying areas where the ice divides and flow directions are not clearly detectable ("transectional glaciers") Excluded classification combinations: – Niche – Apron – Hanging – Cascading – Ice fall – Interrupted	 Figure 1 – Ice field  Figure 2 – Ice field  Figure 3 – Ice field – Uncertain or miscellaneous – Uncertain or miscellaneous – Even, regular– Snow  Figure 4 – Ice field – compound basins– Confluent – Even, regular– Snow  Figure 5 – Ice field	2

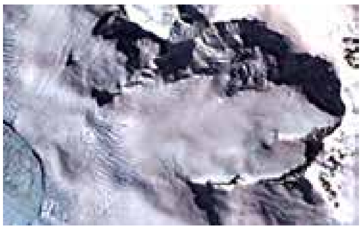
Cont...

Table 6.3 cont...

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comments	Satellite Image/Photo/Graphics (if present: Primary classification – Form – Frontal Characteristics – Longitudinal Profile - Major source of nourishment)	GLIMS code
				 Figure 6 – Ice field	
Ice cap	• Dome-shaped ice mass • Approximately radial ice flow • Upstanding ice mass over bedrock • Not to be interpreted as "mountain ice cap"	Dome-shaped ice mass with radial flow	• May incorporate ice domes • Longitudinal profile is in almost all cases "even/regular" (= 1). Excluded classification combinations: – not classifiable in "Form" at all – Therefore, it is set at "0" – Hanging – Interrupted	 Figure 7 – Ice cap  Figure 8 – Ice cap – Uncertain or miscellaneous – Lobed – Even, regular – Snow	3
Outlet glacier	• Flows down from an ice sheet, ice field, or ice cap beyond its margins • No clearly defined catchment area • Usually follows local topographic depressions	Drains an ice sheet, ice field, or ice cap, usually of valley glacier form; the catchment area may not be clearly delineated.	• The source ice sheet, ice field, or ice cap has the function of a "parent ice mass" in GLIMS. Excluded classification combinations: – Cirque – Niche – Crater – Apron – Group	 Figure 9 – Outlet glacier – Compound basin – Calving and expanded – Cascading – Snow  Figure 10 – Outlet glacier	4

Cont...

Table 6.3 cont...

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comments	Satellite Image/Photo/Graphics (if present: Primary classification – Form – Frontal Characteristics – Longitudinal Profile - Major source of nourishment)	GLIMS code
Valley glacier	• Accumulation area is clearly defined and limited by the topography • Ice-free slopes normally overlook glacier surface • Follows a preexisting valley	Flows down a valley; the catchment area is well defined.	Excluded classification combinations: – Cirque – Niche – Apron – Group	 Figure 11 – Valley glacier – Comp. basin – Normal – Cascading – Snow  Figure 12 – Valley glacier	5
Mountain glacier	• Glaciers adhering to mountain sides, and fitting in no other primary classification pattern, e.g., Cirque-, Niche-, and Crater-Glaciers, as well as Groups, Aprons, and Hanging glaciers and Glaciated flanks	Cirque, Niche or Crater type, Hanging glacier; includes Ice apron and groups of small units (WGMS 1970) Any shape; sometimes similar to a valley glacier, but much smaller; frequently located in Cirque or Niche (WGMS 1977) Cirque, Niche or Crater type, Hanging glacier; includes Ice apron and groups of small units (WGMS 1998)	• Must be distinguished from Valley glaciers where no valley has yet developed (often difficult to estimate from above ground) Excluded classification combinations: – Compound basins	 Figure 13 – Mountain glacier – Single basin – Calving – Cascading – Snow  Figure 14 – Mountain glacier	6
Glacieret and snowfield	• Very small ice or snow masses • Virtually no ice movement • Accumulation and ablation area not always clearly detectable	Small ice masses of indefinite shape in hollows, river beds, and on protected slopes, which have developed from snow drifting, avalanching, and/ or especially heavy accumulation in certain years; usually no marked flow pattern is visible; exist for at least two consecutive years	• Hard to detect by remote sensing analysis, due to size and short-term changes in the appearance Excluded classification combinations: – Compound basins – Piedmont – Expanded – Lobed	 Figure 15 – Glacieret	7

Cont...

Table 6.3 cont...

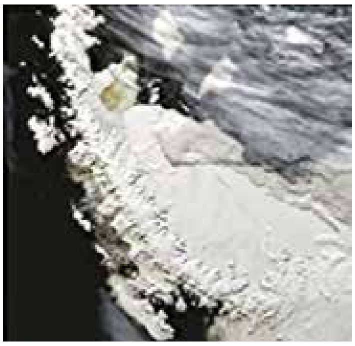
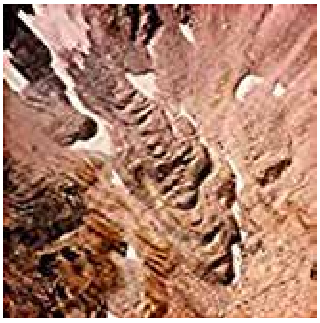
Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comments	Satellite Image/Photo/Graphics (if present: Primary classification – Form – Frontal Characteristics – Longitudinal Profile - Major source of nourishment)	GLIMS code
Ice shelf	• Floating ice masses • Attached to the coast • Seaward extension of terrestrial glaciers beyond the grounding line • Nourished by snow accumulation and bottom freezing, in addition to influx of glacier ice • The floating part is not affected by the dynamics of the nourishing glaciers.	Floating ice sheet of considerable thickness attached to a coast nourished by glacier(s); snow accumulation on its surface or bottom freezing	• Generic development of an Ice shelf starts with the confluence of several floating glaciers. Therefore, this classification combination should first be taken into account, before classifying an ice mass as Ice shelf. Excluded classification combinations: – Is not classifiable in "Form" – Longitudinal profile is always even/ regular	 Figure 16 – Ice shelf – Uncertain or miscellaneous – Floating – Even – Snow (MODIS)  Figure 17 – Ice shelf	8
Rock glacier	• Lava stream-like debris mass containing interstitial ice • Movement is primarily due to debris mass under the influence of gravity, and not due to ice flow patterns • Not a Debris-covered glacier, but permafrost phenomenon	A glacier-shaped mass of angular rock in a cirque or valley either with interstitial ice, firn, and snow or covering the remnants of a glacier, moving slowly downslope. (WGMS 1970) A glacier-shaped mass of angular rock in a cirque or valley either with interstitial ice, firn, and snow or covering the remnants of a glacier, moving slowly downslope. If in doubt about the ice content, the frequently present surface firn field should be classified as "Glacieret and snowfield". (WGMS 1977) Lava stream-like debris mass containing ice in several possible forms and moving slowly downslope (WGMS 1998)	• A Debris-covered glacier is not necessarily a Rock glacier. To distinguish between Rock glaciers and Debris-covered glaciers, the parametre group "Debris coverage of tongue" is offered. Excluded classification combinations: – Compound basins – Aprons	 Figure 18 – Rock glacier – remnant – normal – even – uncertain	9

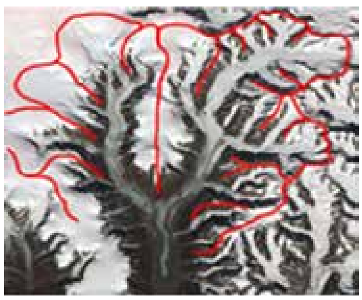
Table 6.3 cont...

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comments	Satellite Image/Photo/Graphics (if present: Primary classification – Form – Frontal Characteristics – Longitudinal Profile - Major source of nourishment)	GLIMS code
Ice stream	• Part of an Ice sheet • Ice flow of higher velocity than surrounding ice masses • Unrestricted by topographic features, which protrude out of the ice mass		The Primary Classification should be extended by the class "Ice stream" because they play an important role in the drainage of the Antarctic ice sheet. Although variable in time and space, they are well defined glaciological features and are of high importance for draining the continental ice sheets.		10

Digit 2: Form

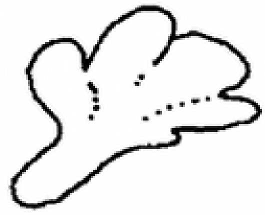
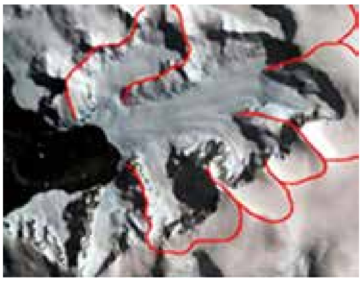
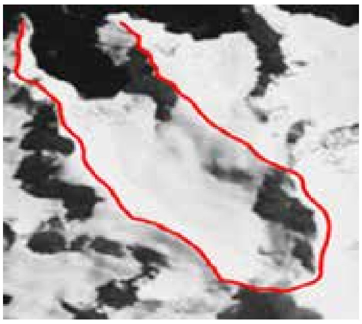
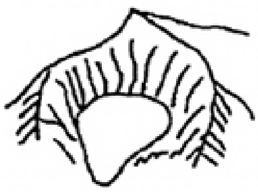
The parametre group "Form" essentially describes the outline of a glacier (Table 6.4). Most categories also correspond to the catchment area and therefore give important information on the extent and shape of a glacier. To get an impression of the whole accumulation basin, a DEM is very helpful in facilitating automatic delineation of glacier catchment areas. Because a precise DEM is not available for all regions, the outline can often be estimated only by optical means and has to be delineated by hand. The classification of "Form" should in most cases be possible, even though several ice masses are already described through the Primary Classification. As a consequence, these glaciers no longer have to be classified in "Form" and are set "0" (this includes, for example, "Ice shelf" and "Ice cap" or in some cases "Ice fields" and "Mountain glaciers").

Table 6.4: **Forms**

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image / Photo / Graphics (if present: Primary classification - Form - Frontal Characteristics - Longitudinal Profile - Major source of nourishment)	GLIMS Code
Uncertain or miscellaneous	• Any type not listed below	Any type not listed below			0
Compound basins	• Dendritic system of Outlet or Valley glaciers of more than one "compound basin" that merge together	Two or more individual Valley glaciers issuing from tributary valleys and coalescing		 Figure 19 – Compound basins  Figure 20 – Outlet glacier - Compound basins – Normal – Cascading – Snow	1

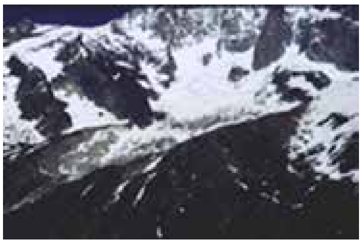
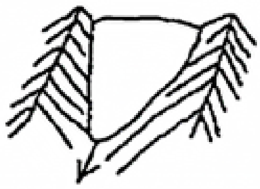
Cont...

Table 6.4 cont...

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image / Photo / Graphics (if present: Primary classification - Form - Frontal Characteristics - Longitudinal Profile - Major source of nourishment)	GLIMS code
Compound basin	• Several catchment areas of a simple basin type (see below) in a specific zone of accumulation feeding a glacier tongue	Two or more individual accumulation basins feeding one glacier system	• Can be used if a mountain glacier consists of several cirques, but has no valley developed	 Figure 21 – Compound basin  Figure 22 – Outlet glacier – Compound basin – Calving – Interrupted – Avalanche	2
Simple basin	• Glacier is fed from one single basin • Catchment area is detectable • Defined and limited by underlying or surface topographic features • Develops a glacier tongue out of one basin	Single accumulation area	• Does not need to be located in a valley (Mountain glacier)	 Figure 23 – Simple basin  Figure 24 – Outlet glacier – Simple basin – Calving – Even – Snow	3
Cirque	• Located in an armchair-shaped bedrock hollow • No tongue developed, in contrast to simple basin • As wide as, or even wider than, their length • Catchment area is created through the process of glacial erosion	Occupies a separate, rounded, steep-walled recess which it has formed on a mountainside	Excluded classification combinations: – Piedmont	 Figure 25 – Cirque	

Cont...

Table 6.4 cont...

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image / Photo / Graphics (if present: Primary classification - Form - Frontal Characteristics - Longitudinal Profile - Major source of nourishment)	GLIMS code
				 Figure 26 – Mountain glacier – Cirque – Normal – Even – Snow  Figure 27 – Cirque	4
Niche	• Small glaciers in v-shaped couloirs or depressions • Adhering to a mountain slope • genetically less developed in form than Cirque glacier	Small glacier in V-shaped gully or depression on a mountain slope; generally more common than the genetically further developed Cirque glacier (WGMS 1970, 1998) Small glacier in V-shaped gully or depression on a mountain slope (WGMS 1977)	Excluded classification combinations: – Piedmont – Expanded	 Figure 28 – Niche	5
Crater	• Glaciers in and/or on volcano craters • Network of glaciers encompassing the summit at the outward flanks	Occurring in extinct or dormant volcanic craters, which rise above the regional snow line (WGMS 1970) Occurring in and/or on volcanic craters (WGMS 1977) Occurring in extinct or dormant volcanic craters (WGMS 1998)		 Figure 29 – Crater (Photo: Peter Knight)  Figure 30 – Mountain glacier – Crater – Normal – Even – Snow	6

Cont...

Table 6.4 cont...

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image / Photo / Graphics (if present: Primary classification - Form - Frontal Characteristics - Longitudinal Profile - Major source of nourishment)	GLIMS code
Ice apron	• Steep, ice-covered mountain faces • Hanging glaciers • Thin ice flanks • See longitudinal characteristics for further differentiation	Irregular, usually thin, ice mass which adheres to a mountain slope or ridge	• Includes ice fringes • Thin ice and snow-overed mountain flank (ice flanks or steep "ice fields") Excluded classification combinations: – Piedmont – Expanded – Cascading	 Figure 31 – Ice apron  Figure 32 – Ice apron	7
Group	• Neighboring small glaciers • Slightly connected but too small to be treated separately	A number of similar small ice masses occurring in close proximity and too small to be assessed individually			8
Remnant	• Disconnected from accumulation area • Inactive	An inactive, usually small ice mass left by a receding glacier	Excluded classification combinations: – In "Dominant mass source" not classifiable		9

Digit 3: Frontal Characteristics

To make the frontal characteristic classification more precise, GLIMS proposed modifications to the WGMS system (Table 6.5). Several studies have shown the need for changing and expanding the classification values according to the various glacier fronts appearing all over the world (e.g., Weidick et al., 1992). The proposed changes in classification were kept to a minimum in order to maintain the compatibility with the WGMS database. Where the WGMS definitions correspond with the GLIMS definitions, they are listed in the "Definition WGMS" column. If there is no entry in the "Definition WGMS" column, GLIMS has redefined the value or added a totally new one.

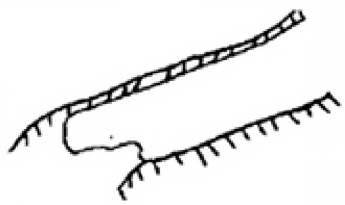
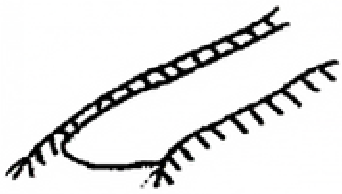
Further explanations:

Terrestrial glaciers: glaciers which rest their entire extent on bedrock and do not have any contact with the sea

Grounded glaciers: glaciers which rest on bedrock to a large extent but which may have parts reaching into lake or sea water (tidewater glaciers)

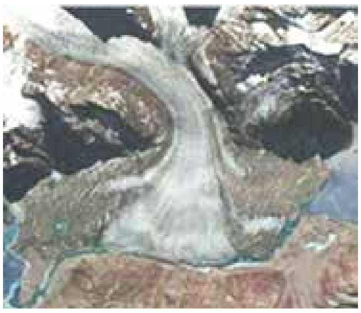
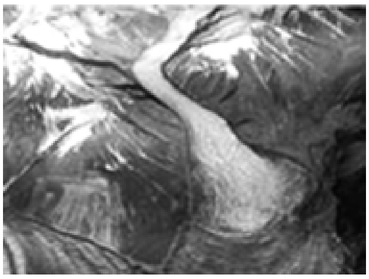
Floating glaciers: tidewater glaciers with floating tongues. Their lateral margins might be attached to the coastline; where there is no more topographic limitation, it might expand.

Table 6.5: **Frontal characteristics**

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image/Photo/Graphics (if present: Primary classification – Form - Frontal Characteristics – Longitudinal Profile – Major source of nourishment)	GLIMS code
Normal or miscellaneous	• The entire width of the tongue terminates on dry ground • Irregular or single lobe frontal line	Normal or miscellaneous		 Figure 33 – Outlet glacier – Simple basin – Normal – Cascading – Snow  Figure 34 – Normal; example of normal frontal characteristic with irregular tongue  Figure 35 – Normal; example of normal frontal characteristic with single-lobed tongue  Figure 36 – Normal, "single lobe"	0
Piedmont	• Occurs in unconstrained topographic areas (lowland) • Expanding glacial fronts • Radial frontal shape • "Terrestrial glaciers" • If it terminates into sea, use class "calving and piedmont"	Ice field formed on a lowland by lateral expansion of one glacier or coalescence of several glaciers		 Figure 37 – Piedmont	1

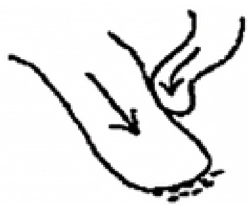
Cont…

Table 6.5 cont...

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image/Photo/Graphics (if present: Primary classification – Form - Frontal Characteristics – Longitudinal Profile – Major source of nourishment)	GLIMS code
				 Figure 38 – Piedmont  Figure 39 – Outlet glacier – Compound basin – Piedmont – Cascading – Snow  Figure 40 – Piedmont	1
Expanded	• Frontal expansion on a level surface (not necessary lowland) • Less restricted by topography • Widening of the tongue (lateral expansion is less than for Piedmont) • "Terrestrial glaciers" • If it terminates into sea, use class "calving and expanded"	Lobe or fan formed where the lower portion of the glacier leaves the confining wall of a valley and extends to a less restricted and more level surface (WGMS 1970, 1998) Lobe or fan formed where the lower portion of the glacier leaves the confining wall of a valley and extends to a less restricted and more level surface. Lateral extension markedly less than for Piedmont. (WGMS 1977)		 Figure 41 – Expanded  Figure 42 – Expanded	2

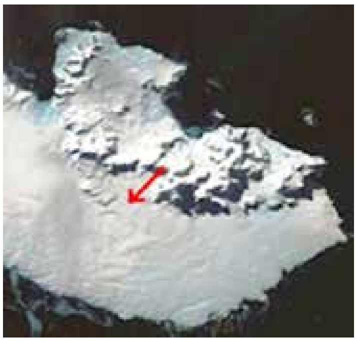
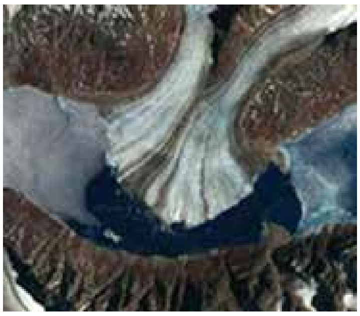
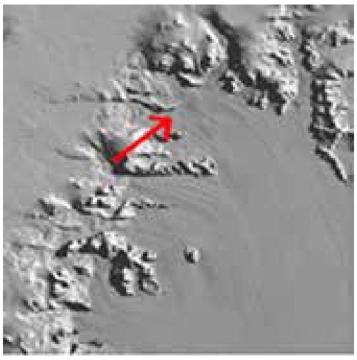
Cont...

Table 6.5 cont...

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image/Photo/Graphics (if present: Primary classification – Form - Frontal Characteristics – Longitudinal Profile – Major source of nourishment)	GLIMS code
Lobed	• Initial stage of tongue formation (occurs on both micro and macro scales) • In many cases, part of an ice sheet, cap, or field • Large or small scale radial ice margin • Is not an outlet or a Valley glacier • "Terrestrial glaciers" • If it terminates into sea, use class "calving and lobed"	Part of an ice sheet or ice cap, disqualified as an outlet glacier (WGMS 1970, 1998) Tongue-like form of an ice field or ice cap (WGMS 1977)		 Figure 43 – Lobed  Figure 44 – Ice cap – Uncertain – Lobed – Even – Snow	3
Calving	• Terminus extends into lake or sea (Tidewater glacier) • Produces icebergs • Any glacier that possesses "Normal" frontal characteristics and is calving • Not to be used for "Terrestrial calving" ("dry calving")	Terminus of a glacier sufficiently extending into sea or lake water to produce icebergs; includes – for this inventory – dry land calving which would be recognisable from the "lowest glacier elevation" (WGMS 1970, 1998) Terminus of a glacier sufficiently extending into sea or occasionally lake water to produce icebergs; includes – for this inventory – dry land calving (WGMS 1977)	If the frontal terminus is calving on dry land see classification for "Terrestrial calving"	 Figure 45 – Outlet glacier – Compound basin – Calving – Even – Snow  Figure 46 – Calving	4
Coalescing, non-contributing	• Glaciers whose tongues come together and flow in parallel without coalescing • No merging of ice masses	See Figure 47 (WGMS 1970, 1998) Glaciers whose tongues come together and flow in parallel without coalescing (WGMS 1977)		 Figure 47 – Coalescing, non-contributing	5

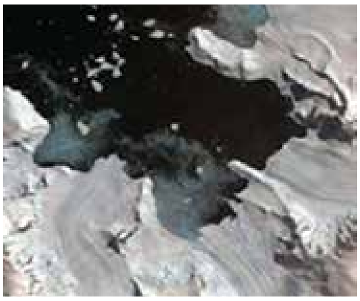
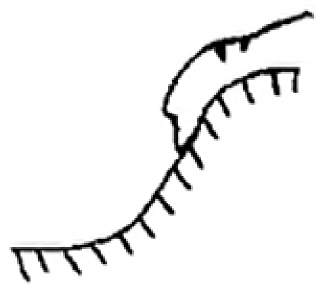
Cont...

Table 6.5 cont...

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image/Photo/Graphics (if present: Primary classification – Form - Frontal Characteristics – Longitudinal Profile – Major source of nourishment)	GLIMS code
Calving and Piedmont	• Combination of Calving and Piedmont			 Figure 48 – Outlet glacier – Compound basins – Calving and Piedmont – Even – Snow	10
Calving and Expanded	• Combination of Calving and Expanded			 Figure 49 – Outlet glacier – Compound basins – Calving and Expanded – Cascading – Snow	11
Calving and Lobed	• Combination of Calving and Lobed • "Grounded glaciers"			 Figure 50 – Ice cap – Uncertain – Calving and lobed – Even – Snow	12
Ice shelf nourishing	• Glaciers which are tributaries of an ice shelf • Approximate grounding line may be detectable		• This class has been introduced due to the necessity for classifying glaciers which are tributaries of an ice shelf.	 Figure 51 – Outlet glacier – Simple basin – Ice Shelf nourishing – Cascading – Snow	13

Cont...

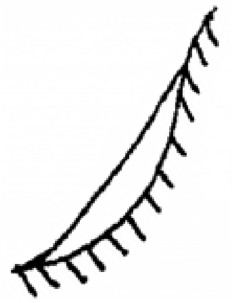
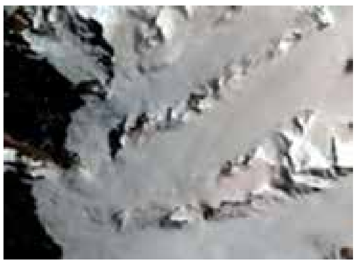
Table 6.5 cont...

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image/Photo/Graphics (if present: Primary classification – Form - Frontal Characteristics – Longitudinal Profile – Major source of nourishment)	GLIMS code
Floating	• Glacier terminus is floating in the sea • Approximate grounding line may be detectable • Tidewater glacier • Implies that the glacier is calving			 Figure 52 – Outlet glacier – Compound basin – Floating – Cascading – Snow	14
				 Figure 53 – Floating	
Terrestrial calving	• Dry calving • Ice front breaks off over cliffs or rock steps of different height		• This class has been introduced to facilitate a differentiation between calving into water (lakes, sea) and dry calving.	 Figure 54 – Terrestrial calving  Figure 55 – Terrestrial calving	15
Confluent	• Tributary glacier tongues that merge into other glaciers • Merging ice masses			 Figure 56 – <1> Outlet glacier – Compound basins – Normal– Cascading – Snow <2> Valley glacier – Compound basin – Confluent – Cascading – Snow	16

Digit 4: Longitudinal Characteristics

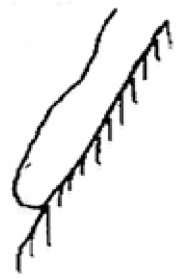
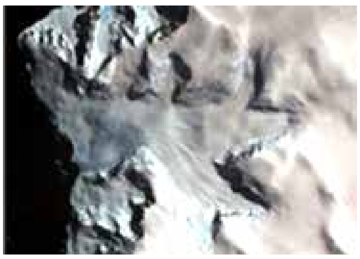
The Longitudinal characteristic encodes the description of the surface profile of a glacier (Table 6.6).

Table 6.6: **Longitudinal characteristics**

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image/Photo/Graphics (if present: Primary classification – Form - Frontal Characteristics – Longitudinal Profile - Major source of nourishment)	GLIMS code
Uncertain or miscellaneous	• Uncertain or miscellaneous	Uncertain or miscellaneous			0
Even, regular	• Regular • No striking changes in glacier surface profile • No crevasses • Can form on vertical slopes	Includes the regular or slightly irregular and stepped longitudinal profile (Not included in WGMS 1995)		 Figure 57 – Even  Figure 58 – Even  Figure 59 – Ice field – Uncertain or miscellaneous – Uncertain or miscellaneous – Even, regular – Snow	1
				 Figure 60 – Even	

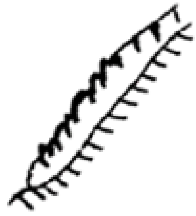
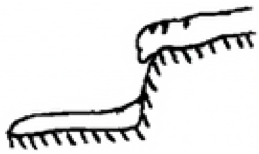
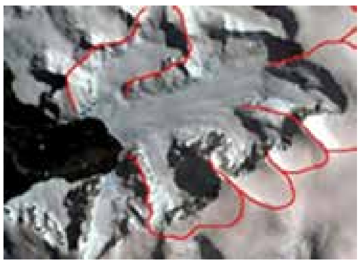
Cont…

Table 6.6 cont...

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image/Photo/Graphics (if present: Primary classification – Form - Frontal Characteristics – Longitudinal Profile - Major source of nourishment)	GLIMS code
Hanging	• Hanging only • No connection with mountain foot • Up to 60° slope	Perched on a steep mountain-side or issuing from a hanging valley (WGMS 1970) Perched on a steep mountain-side or issuing from a steep hanging valley (WGMS 1977) (Not included in WGMS 1995)		 Figure 61 – Hanging  Figure 62 – Hanging	2
Cascading	• Changes in the inclination of the glacier surface • Areas of crevasses and seracs are common	Descending in a series of marked steps with some crevasses and seracs. (Not included in WGMS 1995)		 Figure 63 – Cascading  Figure 64 – Cascading  Figure 65 – Outlet glacier – Compound basin – Calving – Cascading – Snow	3

Cont...

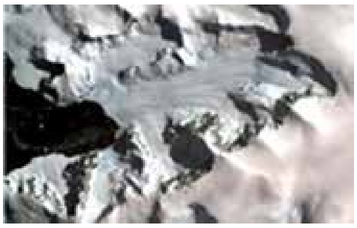
Table 6.6 cont...

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image/Photo/Graphics (if present: Primary classification – Form - Frontal Characteristics – Longitudinal Profile - Major source of nourishment)	GLIMS code
Ice-fall	• Closed ice cover over a steep mountainside • Entirely crevassed with many seracs	Break above a cliff, with reconstitution to a cohering ice mass below (WGMS 1970) A glacier with a considerable drop in the longitudinal profile at one point, causing heavily broken surface (WGMS 1977) (Not included in WGMS 1995)	• In this field the GLIMS Checklist definition differs from WGMS. What WGMS means is greatly covered by GLIMS field interrupted. Due to the proposed GLIMS definition, a distinction between these two fields should be made easier.	 Figure 66 – Ice-fall  Figure 67 – Ice-fall  Figure 68 – Ice-fall	4
Interrupted	• Glacier flow is interrupted by very steep cliff(s) • No dynamic connection • Reconstruct below the cliff	Not defined in (WGMS 1970) Glacier that breaks off over a cliff and reconstitutes below (WGMS 1977) Not included in (WGMS 1995)	• The entire catchment area of the glacier has to be looked at in order to identify if a glacier is interrupted or not.	 Figure 69 – Interrupted  Figure 70 – Outlet glacier – Compound basin – Calving – Interrupted – Avalanche  Figure 71 – Interrupted	5

Digit 5: Major Source of Nourishment

The dominant mass sources are not easy to detect. Often it is only possible to classify a glacier based on its major source of nourishment on a "best guess" decision.

Table 6.7: **Major source of nourishment**

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image/Photo/Graphics (if present: Primary classification - Form - Frontal Characteristics - Longitudinal Profile - Major source of nourishment)	Codes
Unknown	• Unknown	Unknown			0
Snow / Drift snow	• Snow • Wind transported snow and accumulation in lee sides • Hoar	Snow and/or drift snow		 Figure 72 – Drift snow	1
Avalanches	• Snow avalanches • Ice avalanches	Avalanche ice and/or avalanche snow		 Figure 73 – Outlet glacier – Compound basin – Calving – Interrupted – Avalanches	2
Super-imposed ice	• Superimposed ice	Superimposed ice			3

Digit 6: Tongue Activity

The classification of the tongue activity is affected by uncertainties in accuracy of the analyzed imagery (spatial resolution, geodetic accuracy, displacement errors, etc.) and data availability. In fact, the estimation of the extent of glacier change depends on the glacier size, as well as on the glacier type. Therefore, the suggested WGMS rates indicate the extent of change is only subjective (Table 6.8). The proposed rates should be regarded as a rough estimation, as, for example, a 20m recession of a glacieret of 150m length will be classified as a marked retreat, whereas, in contrast, a 30m retreat of an outlet glacier would be considered only as a slight retreat.

Table 6.8: **Tongue activity**

Name	GLIMS glacier parametre identification checklist for remote sensing observations	Definition WGMS	Comment	Code
Uncertain	• Uncertain, unknown, or not measured	Uncertain		0
Marked retreat	• Marked retreat	More than 20m per year retreat		1
Slight retreat	• Slight retreat	20m per year retreat		2
Stationary	• Stationary	Stationary		3
Slight advance	• Slight advance	20m per year advance		4
Marked advance	• Marked advance	More than 20m per year advance		5
Possible surge	• Possible surge	Possible surge		6
Known surge	• Known surge	Known surge		7
Oscillating	• Oscillating	Oscillating		8
Downwasting	• Downwasting	-	stationary but rapidly losing mass through melting	9

7. Hands-on Exercises

7.1 Hands-on Exercise I: Getting Started with eCognition Developer 8

Definiens eCognition Developer is a powerful integrated development environment for rapid image analysis solution development. Developers have unlimited access to the full functionality of the Definiens Cognition Network Language, along with development and workflow tools to aid in the rapid development of new image analysis solutions.

To start the Definiens eCognition Developer, click the Windows **Start** menus and go to **Programs**, then to **eCognition Developer Trial** and click on 

.

The Definiens eCognition Developer launching dialog box is opened.

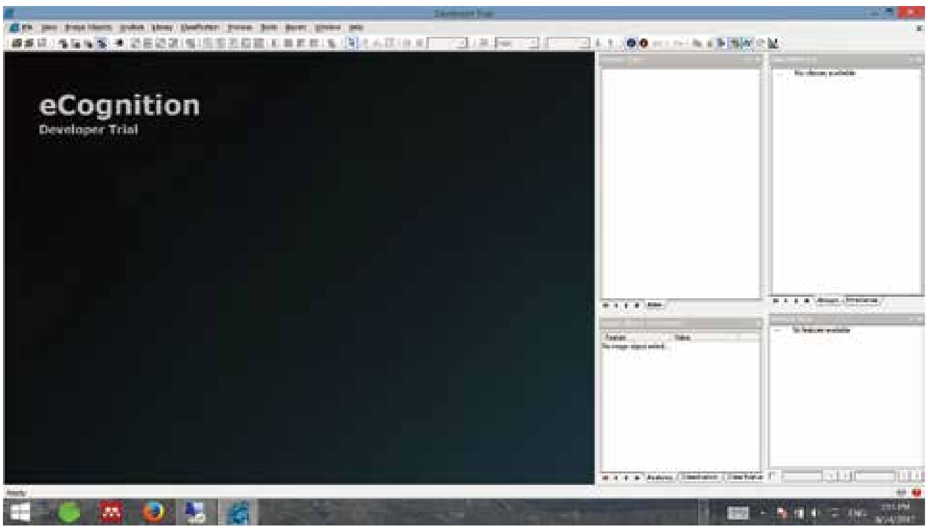
Now select the **Rule Set Mode** function in the launching dialog box and click on 

.

Then the Definiens eCognition Developer window is opened and it contains following features:

- Menu bar, Toolbars, and Status bar
- Map or Project View
- Process Tree, Class Hierarchy, Image Object Information, and Feature View

The view of the main window is shown in the figure below.

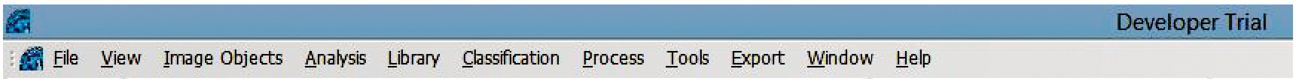


You can add additional windows to your layout and hide them again if you do not need them. Normally, additional windows find their place in the default layout. You can drag them to the desired position and size.

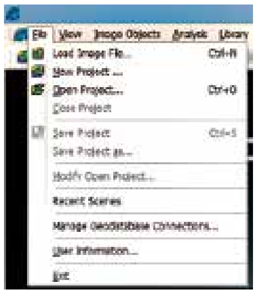
You can choose between different workflow views, which are preset layouts of the user interface. A workflow view displays all required windows for each of the major workflow steps.

a) Menu Bar

The menu bar is in the top row of the main window. It contains **File, View, Image Object, Analysis, Library, Classification, Process, Tools, Export, Window,** and **Help** options. Each option in the menu bar contains a drop-down menu. These menus are described below.

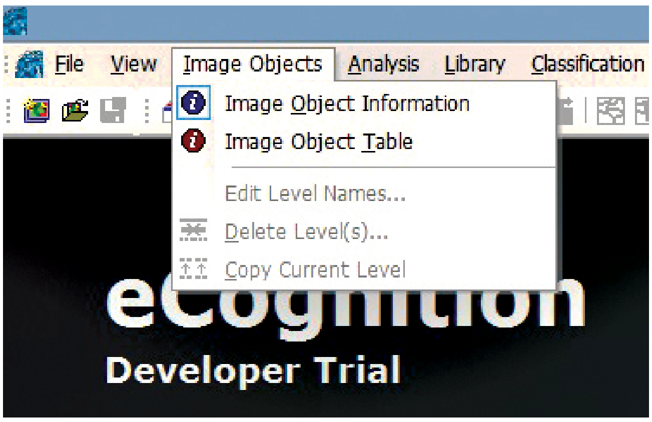


- Click on the **File** menu at the upper left corner of the eCognition Developer menu bar. The **File** drop-down menu opens, which contains the following sub-menus:

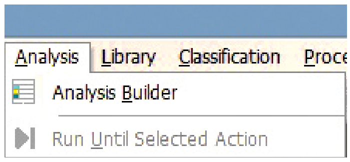


- Click on the **View** menu on the right side of the File menu in the menu bar. The **View** drop-down menu opens, which contains the following sub-menus:

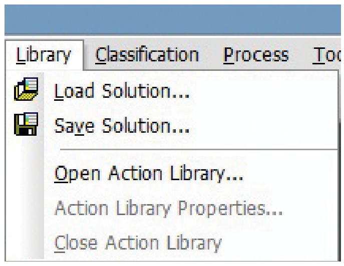
- Click on the **Image Objects** menu on the right side of the View menu in the menu bar. The **Image Objects** drop-down menu opens, which contains the following sub-menus:



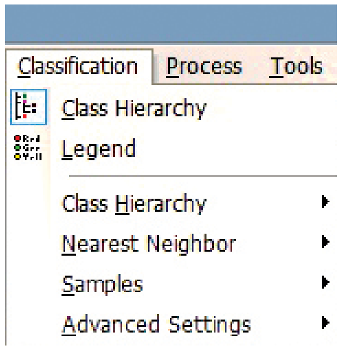
- Click on the **Analysis** menu on the right side of the Image Objects menu in the menu bar. The **Analysis** drop-down menu opens, which contains the following sub-menus:



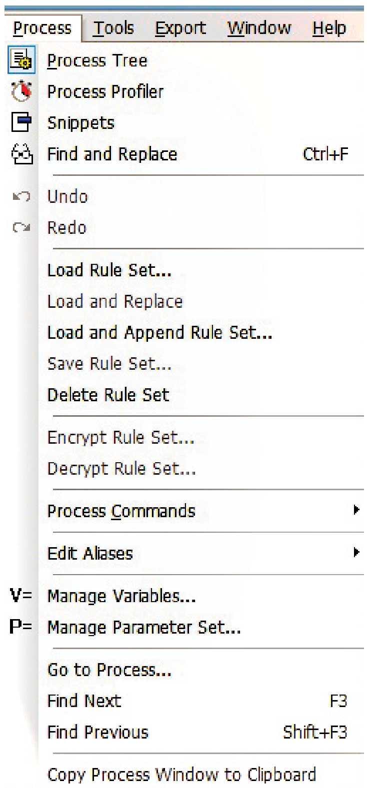
- Click on the **Library** menu on the right side of the Analysis menu in the menu bar. The **Library** drop-down menu opens, which contains the following sub-menus:



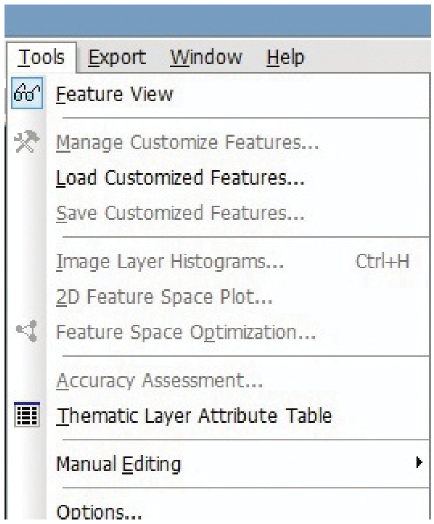
- Click on the **Classification** menu on the right side of the Library menu in the menu bar. The **Classification** drop-down menu opens, which contains the following sub-menus:



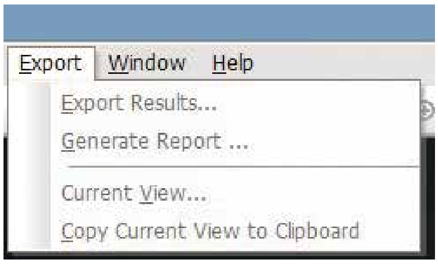
- Click on the **Process** menu on the right side of the Classification menu in the menu bar. The **Process** drop-down menu opens, which contains the following sub-menus:



- Click on the **Tools** menu on the right side of the Process menu in the menu bar. The **Tools** drop-down menu opens, which contains the following sub-menus:



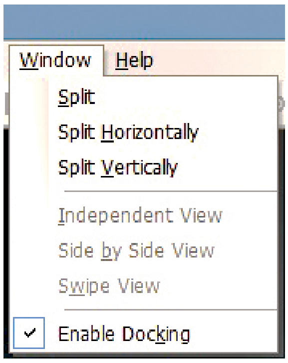
- Click on the **Export** menu on the right side of the Tools menu in the menu bar. The **Export** drop-down menu opens, which contains the following sub-menus:



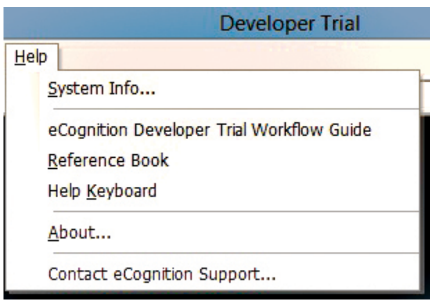
- Click on the **Window** menu on the right side of the Export menu in the menu bar. The **Window** drop-down menu opens, which contains the following sub-menus:

  Windows like Image Object Information facilitate the image analysis. They provide functions or controls for viewing and working with images.

  They can be opened using the appropriate menu items or by clicking the respective icons in the toolbars. Changes or selections in the windows are automatically shown in the project view. Windows can be moved to almost any position on your screen.



- Click on the **Help** menu on the right side of the Window menu in the menu bar. The **Help** drop-down menu opens, which contains the following sub-menus:



b) Toolbar

Toolbars contain buttons or list boxes to help you view or analyze your images. To check and modify the displayed toolbars, select View > Toolbars in the main menu bar. Alternatively, you can go to the Toolbars tab of the Customize dialog box.

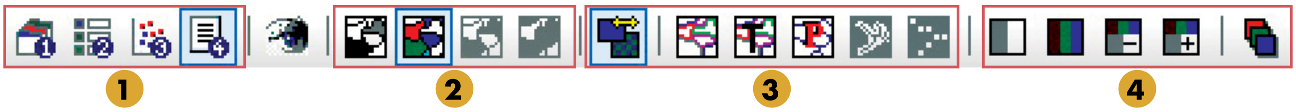
Toolbars may be docked at the edges of the main window. Also, they may be undocked as floating toolbars. Holding Ctrl while dragging deactivates the magnetic snapping, allowing you to place the toolbars anywhere on your screen. Right-clicking anywhere inside the menu bar and toolbar area allows you to access a context menu, which provides a selection of the View menu options.

According to the functionality of various tools in the Tool Bar menu in the main window, they are grouped into File, View Setting, Zoom Function, View Navigate, and Tools. The Tools icons and their functionalities are described below.

File Toolbar

The File toolbar allows loading image files, opening projects, saving projects, creating new workspaces, and importing predefined workspaces.

View Setting Toolbar



The first four buttons in group 1 , numbered from one to four, allow switching between the four window layouts. These four tools are Load and Manage Data, Configure Analysis, Review Results, and Develop Rule Sets.

The buttons in group 2 allow you to select image view options, offering views of layers, classifications, samples, and any features you wish to visualize.

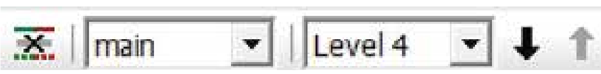
The buttons in group 3 are concerned with displaying outlines and borders of image objects and with views of pixels.

The buttons in group 4 allow you to visualize different layers in grayscale or in RGB. They also allow you to switch between layers and to mix them.

Zoom Toolbar

This toolbar offers direct selection and the ability to drag an image, along with several zoom options.

View Navigate Toolbar



This toolbar allows deleting levels , selecting maps main , and navigating the object hierarchy Level 4 .

Tools Toolbar

The buttons on the Tools toolbar launch the following dialog boxes and toolbars:

Image Object Information

Image Object Table

Redo and Undo Process Editing

Class Hierarchy

Process Tree

Feature View

Manage Customize Features

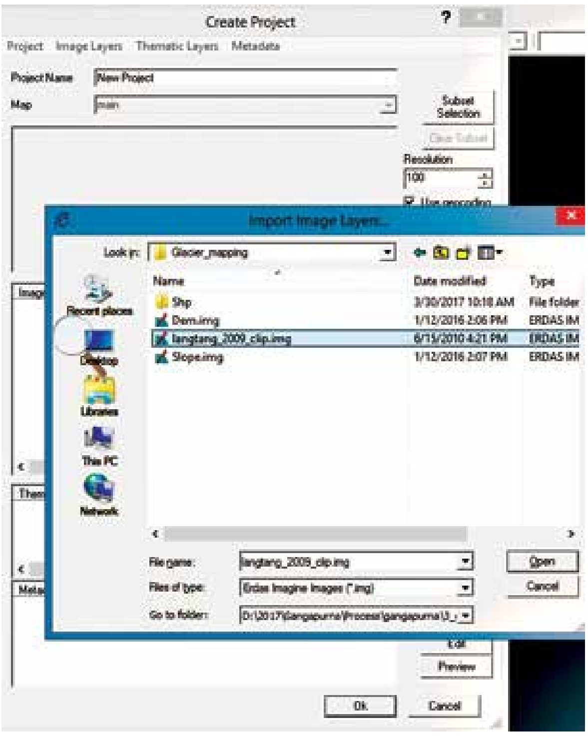
Manual Editing Toolbar

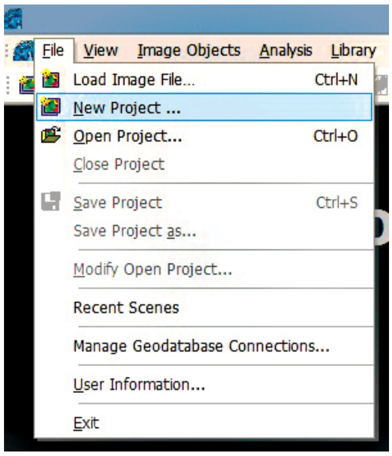
c) Creating a New Project

When creating a project, you import image layers and optionally thematic layers into a new project. You can rearrange the image layers, select a subset of the image, or modify the project default settings. In addition, you can add metadata.

An image file contains one or more image layers. For example, an RGB image file contains three image layers, which are displayed through the Red, Green, and Blue channels (layers).

- To Create a new project, go to the **File** menu in the menu bar and click on the **New Project** sub-menu in the dropdown File menu or directly click on **Create New Project** button on the **File** Toolbar.
- Then the **Create Project** and **Import Image Layers** window is opened.



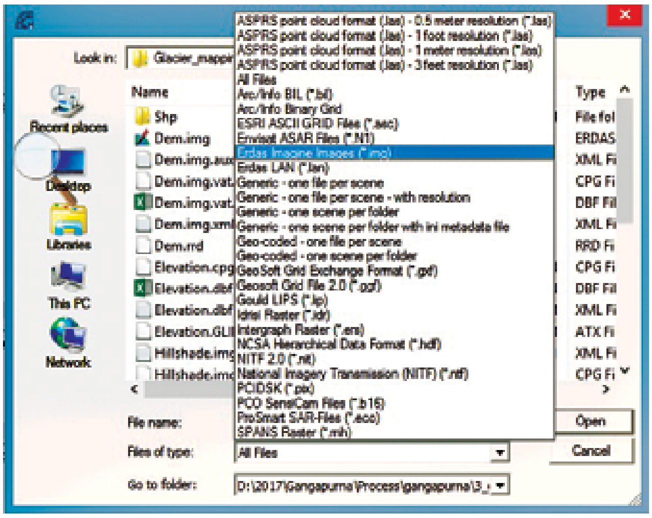


Now go to the location of the data. To locate the data:

- Click on the home icon on top of the **Import Image layers** window.
- Select the drive and folder location ("C:\TrainingData\Glacier_mapping") from the list in the box at the top left corner of the window just below the home icon.
- Select the files "*Langtang_2009_clip.img*", "*Dem.img*", and "*Slope.img*" in the file list box at the right side of the window.
- Click the "OK" button to add data.

To open some specific file formats or structures, you have to proceed as follows:

- First, select the correct driver in the **Files type** drop-down list box, or you can type "*.img" in the File Name Filter text box to view the "img" files.
- Then, select from the **main file** in the files list window.



The **Create Project** window has four Main sections.

General Settings

- The geocoding information is displayed if the "**Use geocoding**" check box is selected.
- The resolution is automatically detected and displayed in the "**Resolution**" field.
- The **unit** is detected automatically if **auto** is selected from the drop-down list.
- The **unit** is automatically set to metres, but can be changed by selecting another one from the drop-down list.

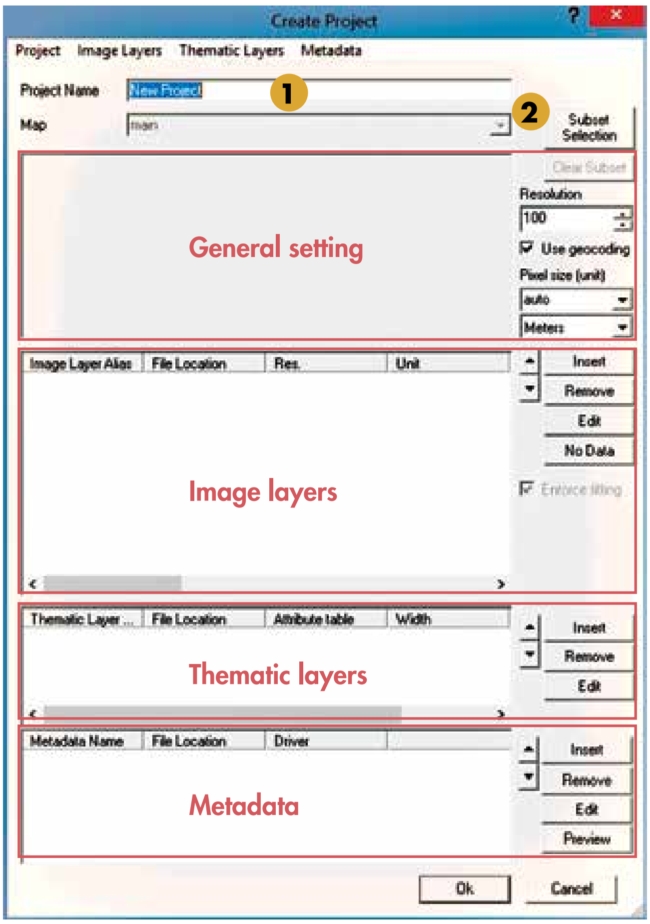


Image Layers

- All preloaded **image layers** are displayed, along with their properties. To select an image layer, click it. To select multiple image layers, press Ctrl or the Shift key and click on the image layers.
- To **edit a layer**, double-click or right-click an image layer and choose "**Edit**". The "**Layer Properties**" dialog box will open. Alternatively, you can click the "**Edit**" button.
- To **insert an additional image layer**, you can click the "**Insert**" button or **right-click** inside the image layer display window and choose "**Insert**" on the context menu.
- To **remove** one or more image layers, select the desired layer(s) and click "**Remove**".

- To change the order of the layers, select an image layer and use the up and down arrows.
- To set **No Data** values for those pixels not to be analyzed, click "**No Data**". The "**Assign No Data Values**" dialog box opens.

Thematic Layers

- To **insert** a thematic layer, you can click the "**Insert**" button or right-click inside the thematic layer display window and choose "**Insert**" from the context menu.
- **To edit, insert additional layer,** and **Remove** a thematic layer, follow the instructions for editing image layers described above.

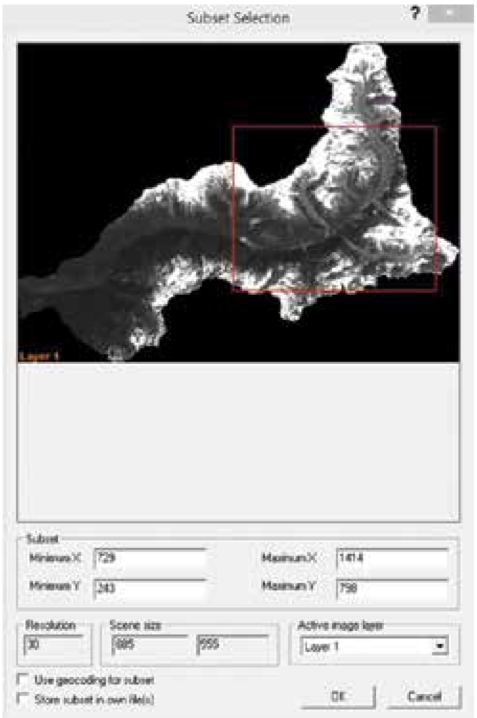
Metadata

- Can **add, remove, edit**, and **preview** additional information data as an .ini file, if available.

d) Subset Selection

To open the **Subset Selection** dialog box, do the following:

- After importing image layers, press the Subset Selection **2** button. The **Subset Selection** dialog box is opened.
- In the Subset Selection Dialog box, Click in the image and drag it to select a subset area.
- Alternatively, you may enter the subset coordinates. You can modify the coordinates by typing.
- Confirm with **OK** to return to the super ordinate dialog box.
- You can clear the subset selection by clicking **Clear Subset** in the super ordinate dialog box.



e) Define Layer Aliases

In order to generate Rule Sets that are transferable between different datasets, the loaded channels or layers of image have to have aliases assigned to them.

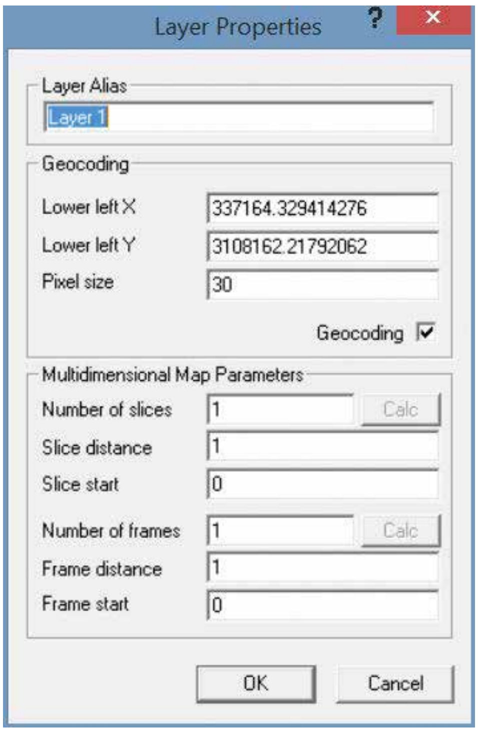
- To assign a layer alias, select the **layer** in the "**Create Project**" dialog box and **double-click** it.
- Then the **Layer Properties** dialog box is opened. Assign for **Layer 1** as "***Band 1***" in the **Layer Alias** section in the **Layer Properties** dialog box.
- Confirm the alias with "**OK**".
- Assign the following **aliases** to the other layers:

Layer 2 → Band 2

Layer 3 → Band 3

Layer 4 → Band 4

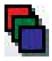
Layer 5 → Band 5, and so on

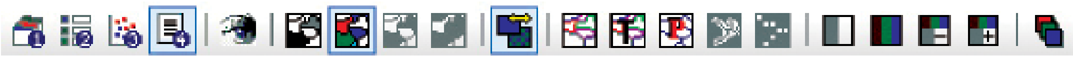


f) Displaying Image Layers

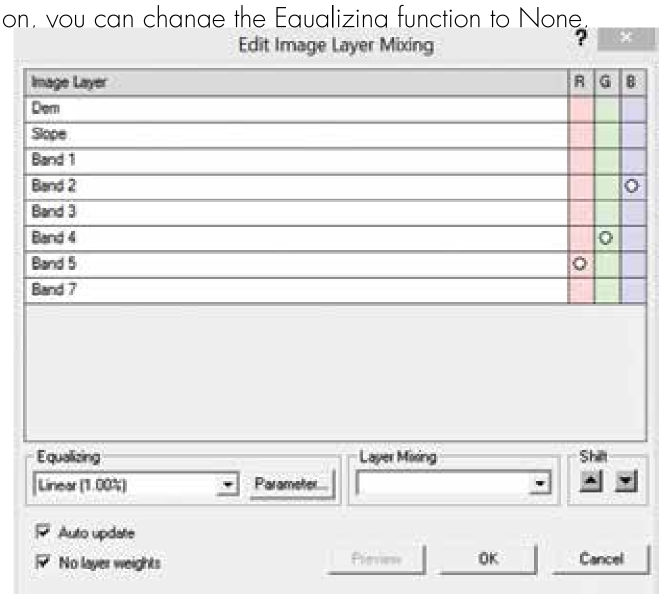
For better visualization of the image and to recognize the visual structures without actually changing them, the color composition of image layers can be defined to display in the map view. In addition, the different equalizing options can be chosen for better visualization.

While creating a new Project, the first three image layers are displayed in red, green, and blue; to change the layer mixing, open the **Edit Image Layer Mixing** dialog box.

- To open the layer mixing dialog box, go to **View** in the menu bar and select or click on the **Image Layer Mixing** from the drop-down menu, OR directly click on the **Image Layer Mixing** button  from the View Setting Toolbar.



- Click on the dots for the red, green, and blue layers to deactivate the default image layer view. Click on the red, green, and blue column of the respective image layer which you want to view in the respective channels to activate the image layers. Also, for better visualization, you can change the Equalizing function to None, Linear, Standard Deviation, Gamma Correction, Histogram, and Manual.
- At the bottom of the "**Edit Layer Mixing**" dialog box, click "**OK**".



g) Save a Project

Save the currently open project to a project file (extension **.dpr**). To save a project, do the following:

Choose **File > Save Project** on the main menu bar.

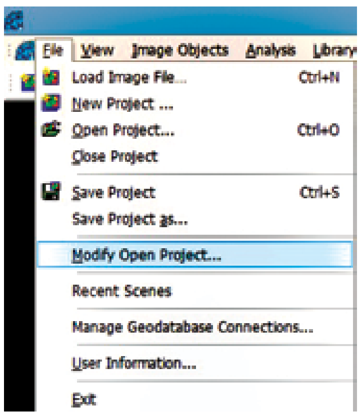
- Choose **File > Save Project As** on the main menu bar. The **Save Project** dialog box opens. Select a folder and enter a name for the project file (**.dpr**).
- Click the **Save** button to store the file.

h) Modify Project

Modify a selected project by exchanging or renaming image layers or through other operations.

To modify a project, do the following:

- Open a project and choose **File > Modify Open Project** on the main menu bar.
- The **Modify Project** dialog box opens.
- Modify as necessary.
- Click **OK** to modify the project.



i) Creating Image Objects Through Segmentation

The fundamental step of **eCognition** image analysis is to divide the image into defined areas or into image object primitives. This is called segmentation and creates undefined objects. Thus, initial segmentation is the subdivision of an image into separated regions represented by basic unclassified image objects called image object primitives. By definition, these objects will be relatively crude, but we can refine them later on with further rule sets. It is preferable to create fairly large objects, as smaller numbers are easier to work with.

For successful image analysis, defining object primitives of suitable size and shape is of utmost importance. As a rule of thumb, good object primitives are as large as possible, yet small enough to be used as building blocks for the objects to be detected in the image. Pixels are the smallest possible building block; however, pixels have limited information. To get larger building blocks, different segmentation methods are available to form contiguous clusters of pixels that have larger property space.

Commonly in image processing, segmentation is the subdivision of a digital image into smaller partitions according to given criteria. Within the **eCognition** technology, however, each operation that creates new image objects is called segmentation, regardless of whether the change is achieved by subdividing or by merging existing objects.

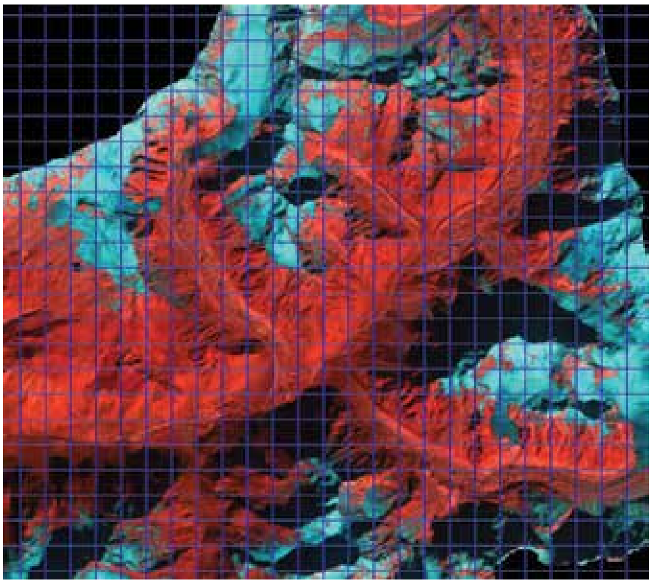
Different segmentation algorithms provide several methods for creating image object primitives. The new image objects created by segmentation are stored in what is called a new image object level. Each image object is defined by a contiguous set of pixels, where each pixel belongs to exactly one image object. Each of the subsequent image object-related operations, like classification, reshaping, re-segmentation, and information extraction, is done within an image object level. Simply said, image object levels serve as internal working areas of the image analysis.

Chessboard Segmentation: The Chessboard Segmentation algorithm splits the pixel domain or an image object domain into square image objects. A square grid aligned to the image left and top borders of fixed size is applied to all objects in the domain and each object is cut along these gridlines.

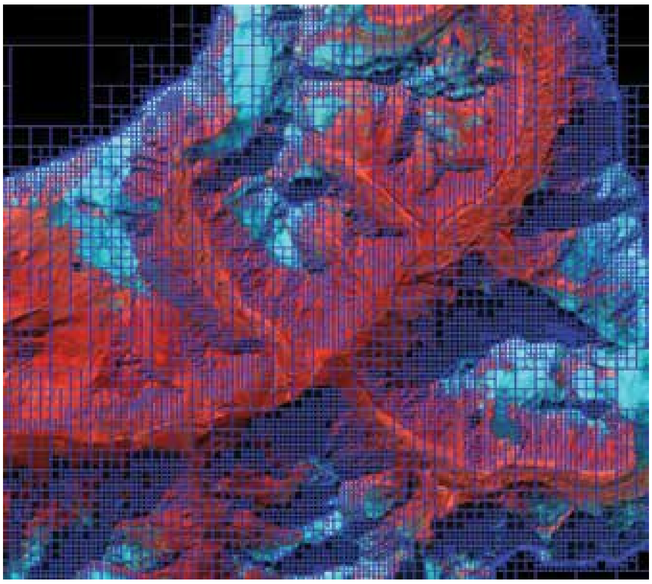
Quadtree-Based Segmentation: The Quadtree-Based Segmentation algorithm splits the pixel domain or an image object domain into a quadtree grid formed by square objects. The quadtree grid is built so that each square has a maximum possible size and fulfills the homogeneity criteria defined by the mode and scale parametres.

Multiresolution Segmentation: The Multiresolution Segmentation algorithm consecutively merges pixels or existing image objects. It is based on a pairwise region merging technique.

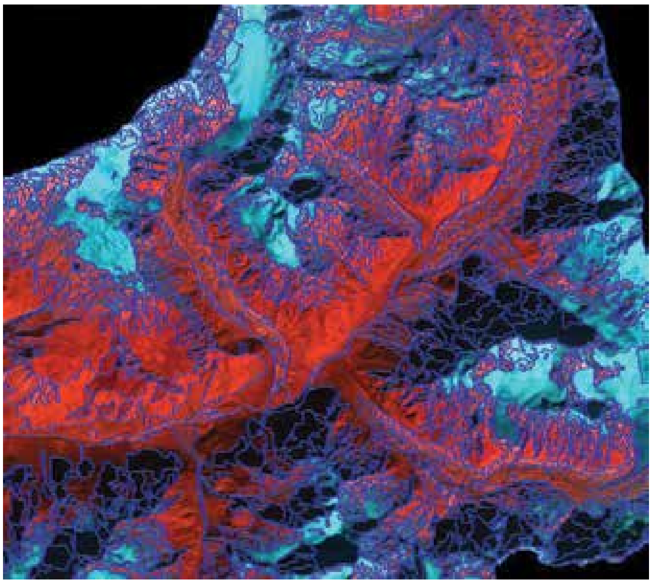
Spectral Difference Segmentation: The Spectral



Chessboard segmentation



Quad Tree Based Segmentations

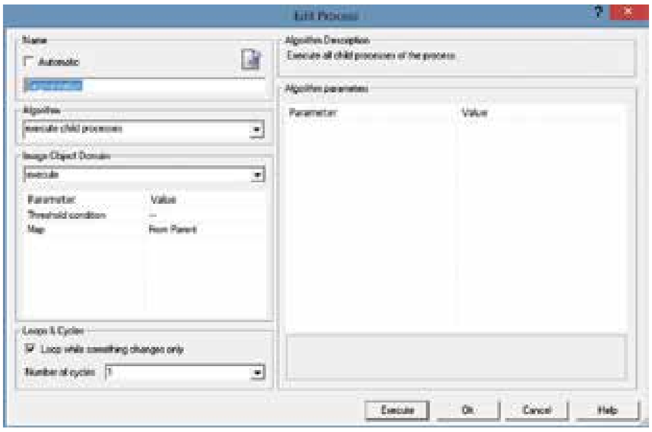


Multiresolution Segmentations

Difference Segmentation algorithm merges neighboring image objects according to their mean image layer intensity values. This algorithm is designed to refine existing segmentation results, by merging spectrally similar image objects produced by previous segmentation. It cannot be used to create new image object levels based on the pixel level domain.

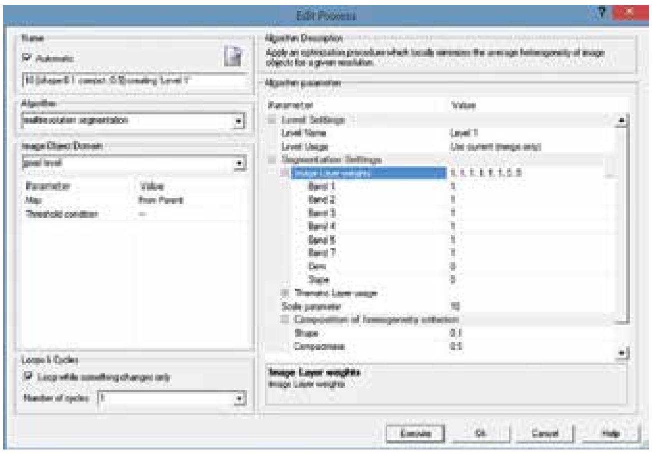
To create the new object level (Image Segmentation), use the following steps:

- Right-click in the **Process Tree** window and select **Append New** from the context menu. The **Edit Process** dialog appears. In the **Name** field, enter "Segmentation" and "remove background". Press **OK**. In the Edit Process box, you have the choice to run a process immediately (by pressing Execute) or to save it to the Process Tree window for later execution (by pressing OK).
- In the Process Tree window, right-click on this new rules (Segmentation) and select Insert Child. The **Edit Process** dialog box appears. In the **Algorithm** drop-down box of the **Edit Process** dialog box, select **Multiresolution Segmentation**. In the Segmentation Settings, which now appear on the right-hand side of the dialog box, change the **Level Name** to "**Level 1**", **Image Layer Weights** as **0** for false and **1** for true, S**cale Parametre**, and also set **Composition of homogeneity** if necessary. Then Press **OK** to save the rule in the Process Tree window for later execution, or if you want to run the rule set, immediately press the **Execute** button.
- After execution of the segmentation rule sets, it creates a new **Image Objects Level** named as ***Level 1*** are stored which can be viewed in the **View Navigation** toolbar in the drop-down menu of the **object hierarchy** menu.

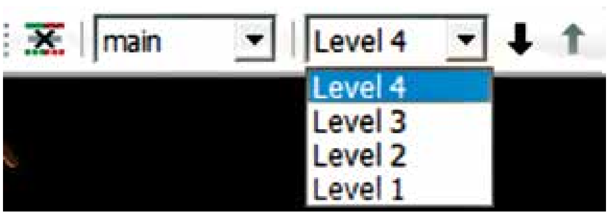


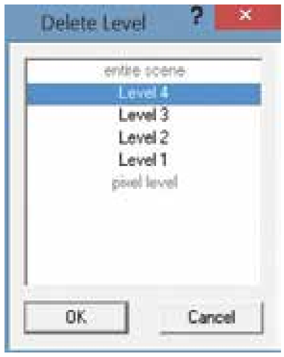
j) Deleting Image Objects Level

Deleting an image object level enables you to work with image object levels that are temporary, or that might be required for testing processes while developing rule sets.



- To delete an image objects level which is created temporarily for testing processes, go to the **Image Objects** menu in the menu bar in the top row of the Project window. Select the **Delete Levels** sub menu from the drop-down menu of Image Objects. You can also do this by directly clicking on the **Delete Level**  button in the **View Navigation** Toolbar. Then the Delete Level dialog box appears.





In the **Delete Level** dialog box, all the image object levels are displayed according to the hierarchy of the image objects. To delete the image object level, select it and click the **OK** button in the dialog box to confirm that you want to remove the selected image object level.

k) Classify Image Object Level

After image objects have been created in your scenes, you need to classify them to give them both a meaning and a label. Information contained in image objects is used as a filter for classification.

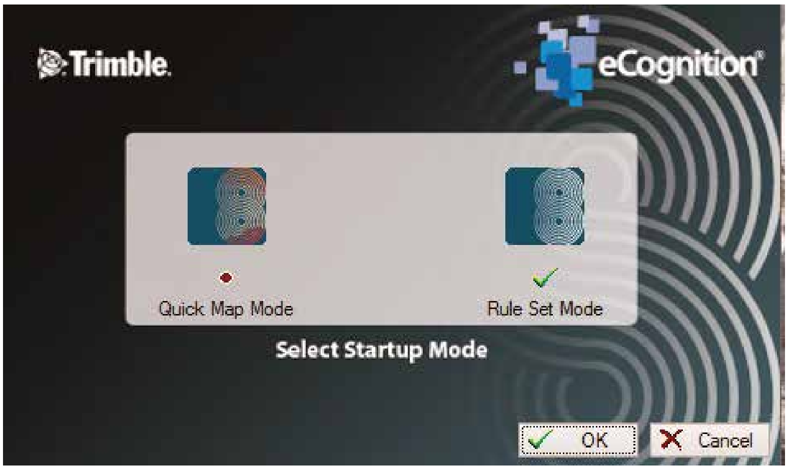
- Based on a classification of image objects, you can analyze and interpret complete images. To perform a classification, appropriate classes need to be defined. During classification, the image objects are analyzed according to defined criteria and assigned to classes that best meet the defined criteria.

7.2 Hands on Exercise II: Clean-ice Glacier Mapping

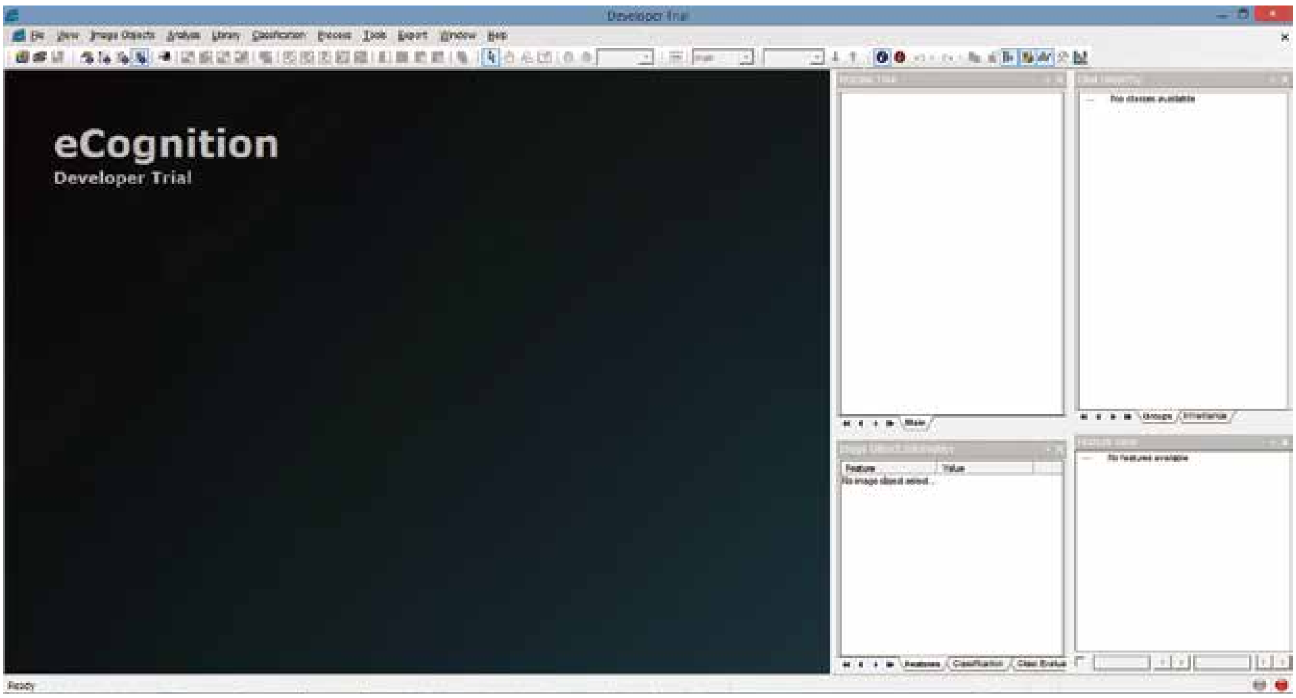
If the Program is not open, go to the Windows Start menu and Click Start > Programs > eCognition Developer Trial 8.0> 

Then Definiens eCognition Developer launching dialog box is opened. Select the Rule Set mode function in the launching dialog box and click on 

.

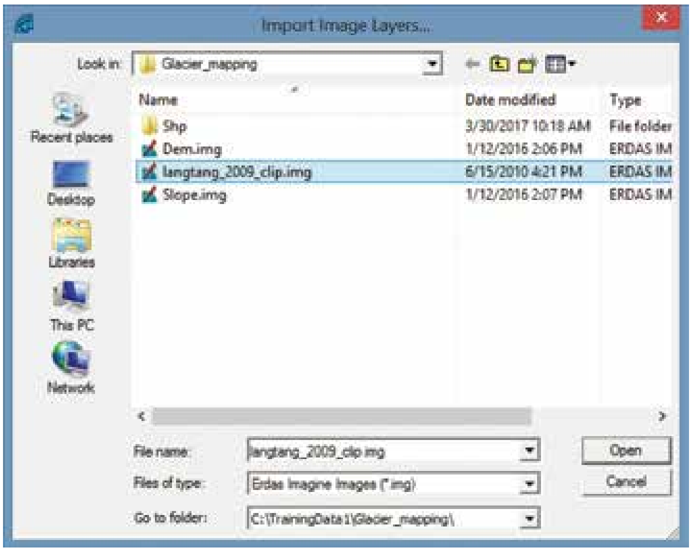


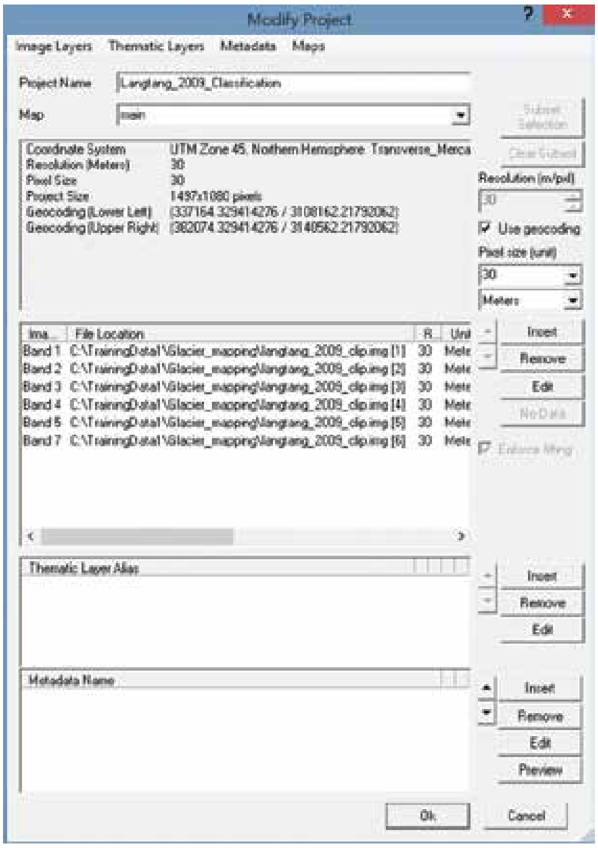
The Definiens eCognition Developer window will now be open.



Create New Project for Glacier Mapping

- To Create a New Project, go to File menu in the menu bar and click on the **New Project** menu in the drop-down File menu, or alternatively, directly click on the **New Project** button in the File toolbar.
- Then the Create Project sub-window and **Import Image Layers** dialog box is opened.
- Now go to the location of the data (C:\TrainingData\Glacier_mapping) from the **Look in** drop-down menu in the top of the **Import Image Layers** dialogue box and select image file ('Langtang_2009_clip.img') and click on the **OK** button.

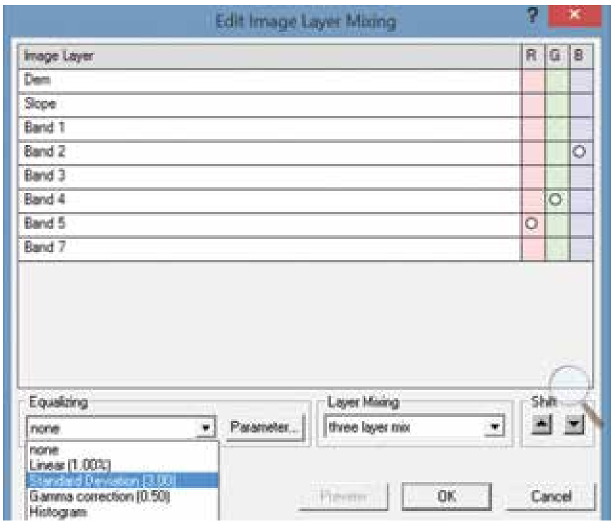




- Double click on each Image Layer Alias and Rename all the Image Layers Aliases in each Image **Layer Properties** dialog box (Layer 1 → *Band 1*; Layer 2 → *Band 2*; Layer 3 → *Band 3*; Layer 4 → *Band 4*; Layer 5 → *Band 5*; Layer 6 → *Band 7*) and confirm each renamed Layers alias by clicking the **OK** button in each **Layer Properties** dialog box.
- Again, add **DEM** and **Slope** Raster layers. To insert a DEM Layer, click on the **Insert** button in the Image Layer section of the **Create Project** dialog box and go to the location of the data (C:\TrainingData\Glacier_mapping) and open the DEM raster file (Dem.img). Similarly, add the Slope raster file (Slope.img).
- Rename the DEM and Slope raster layer alias as *Dem* and *Slope* by double clicking the respective layers.
- After adding all the data in the image layer section, click the **OK** button in the **Create Project** dialog box.
- Save the Project as '*LangtangGr_mapping.dpr*' by clicking on the **Save Project** button in the File toolbar, or go to the File menu and click on the **Save Project** menu.

Displaying Image Layers

The color composition of the image layers is set to display in map view for better visualization and to recognize the visual structures without actually changing them. In default view, the first three image layers are displayed in red, green, and blue. To change the display of the image layer for better visualization in glacier mapping, use the following steps:



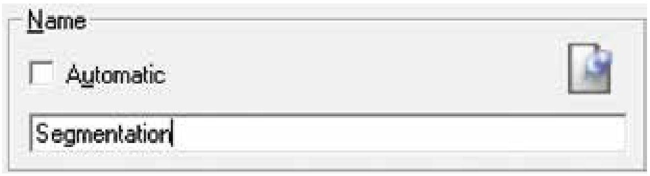
- Click on the **Image Layer Mixing** button in the **View Setting** Toolbar or, alternatively, go to **View** in the Menu bar and click on the **Image Layer Mixing** in the drop-down **View** Menu. Then the **Edit Image Layer Mixing** dialog box is opened.

- Change the Default band combinations Band 3, Band 2, and Band 1 as Red, Green, and Blue to Band 4, Band 3, and Band 2, or Band 5, Band 4, and Band 2 as Red, Green, and Blue.
- Then change **Histogram** in Equalizing.
- Click on the **OK** button to confirm the changes in band combination.

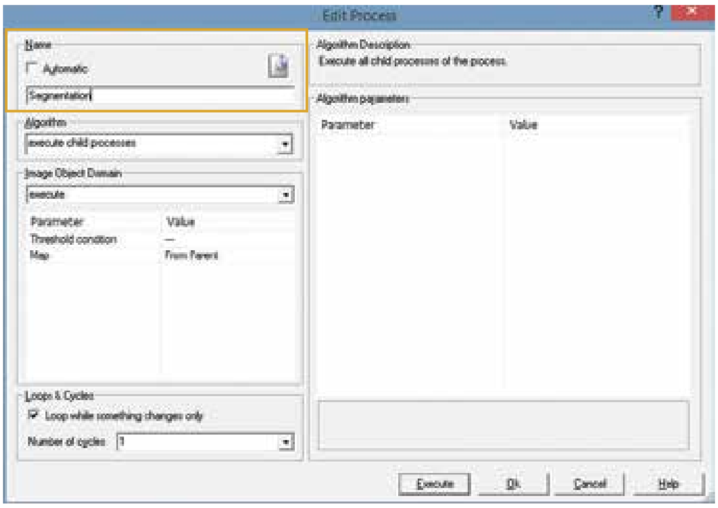
Creating Image Object Levels (Segmentation)

Inserting Parent Process

- If the Process Tree window is not opened, go to the **Process** menu on the Menu toolbar and click on the **Process Tree** in the drop-down **Process** menu.
- Right-click inside the **Process Tree** window and click on the **Append New** from the Right-click menu. The Edit Process dialog appears.

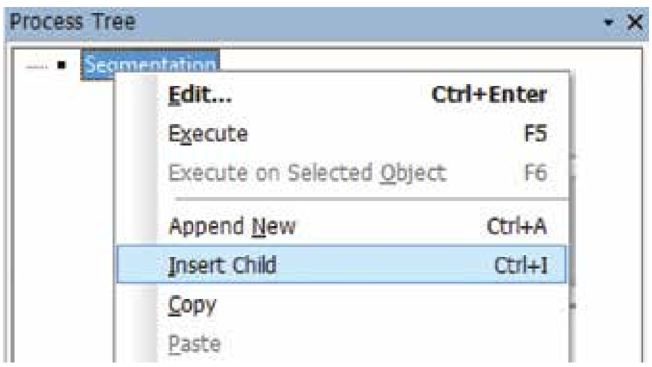


- Type "**Segmentation**" (name of the Parent process, which serves as a wrapper for the underlying processes and can execute the whole sequence of underlying processes) in the **Name** field of the **Edit Process** dialog box and Click **OK**.

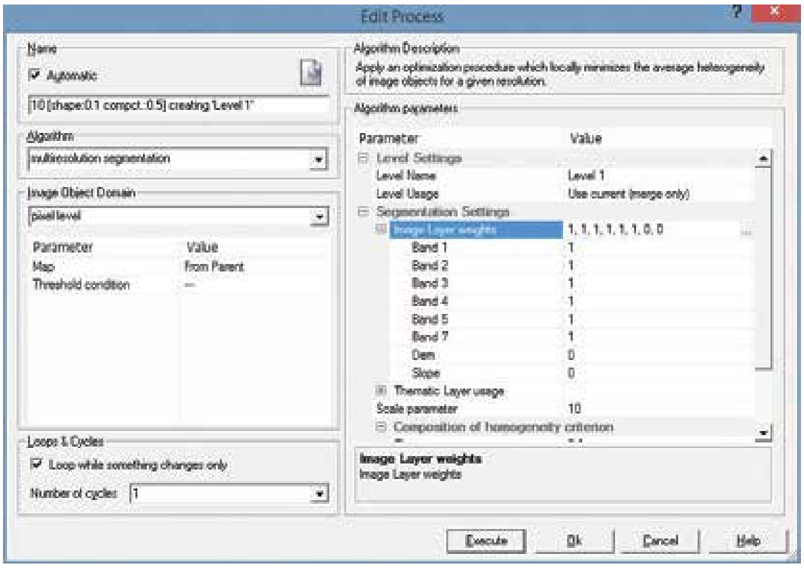


Inserting Child Process (Multi-resolution Segmentation Process)

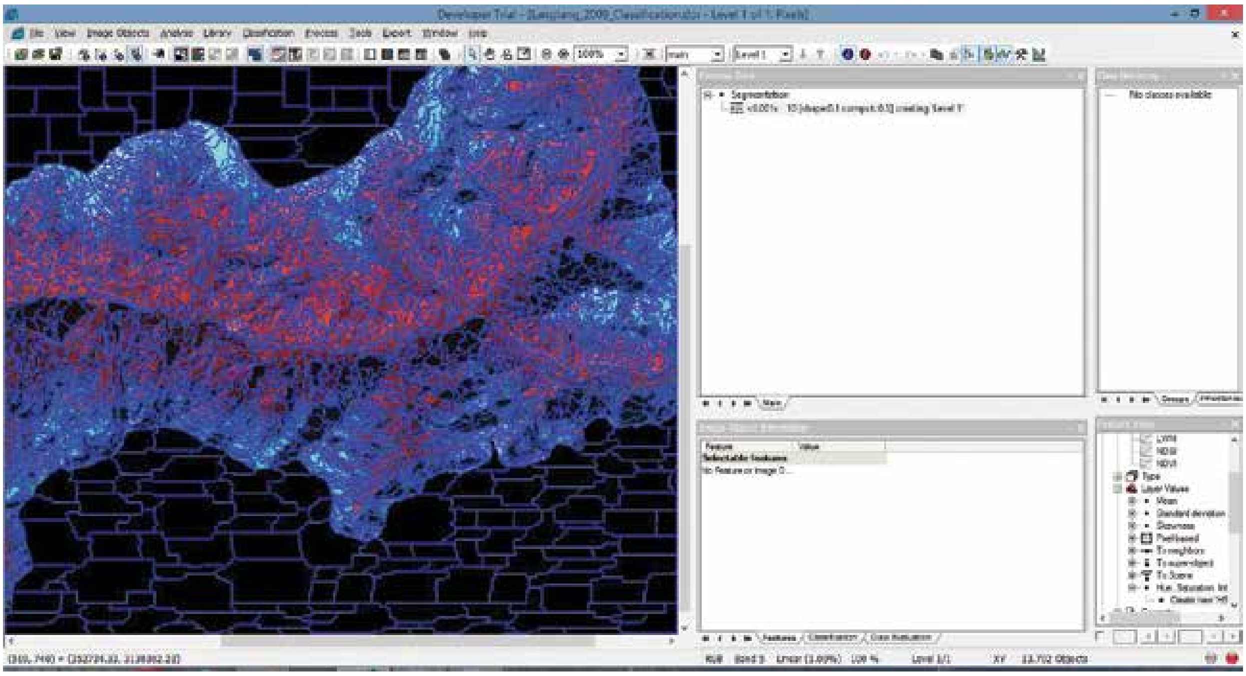
- Again in the **Process Tree** window, select the "**Segmentation**" Parent Process and right-click on it. Click on **Insert Child** from the context menu. The **Edit Process** dialog box appears.
- In the **Algorithm** drop-down box of the **Edit Process** dialog box, select **Multiresolution Segmentation** from the lists.
- Keep the **Pixel Level** in the **Image Object Domain** drop-down menu box.
- In the Algorithms Parametres for Segmentation, which now appear on the right-hand side of the dialog box, change the **Level Name** to Level 1 (name of the image object level to be created), **Image Layer Weights** as 0 for Dem and Slope, and 1 for Band 1 to Band 7, **Scale Parametre as 10**, and set **Composition of Homogeneity** as default.



- Then press **Execute** to process the rule and save the rule in the Process Tree window.

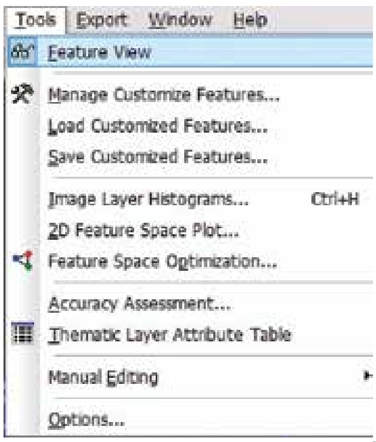


- The New Image Layer will appear as **Layer 1** in the **Object Hierarchy** drop-down menu of the **View Navigation** toolbar.



Multi-resolution segmentation of Image at Scale factor 10 and image object level as "Level 1"

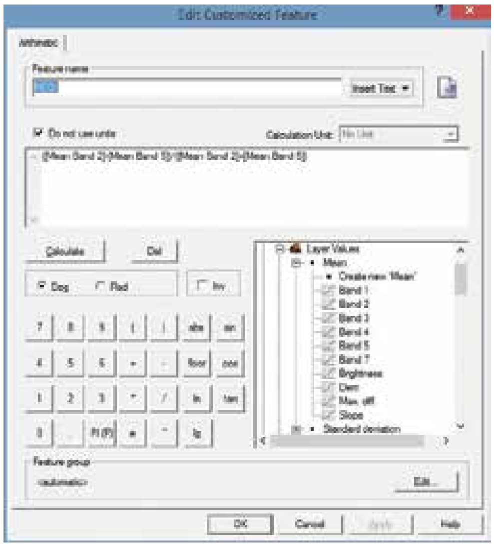
Creating New Arithmetic Features



The most crucial part in Definiens eCognition Developer software is finding the optimal features and values for classifying image objects in one of the classes. The "Feature View" is a tool that helps to find the **Optimal Features** and to determine **Threshold Values** for **classification**. With the "Feature View" the values for all objects are displayed in the viewer in **Grey Values**. There are also functions or options to create your one new feature from the arithmetic and relational calculation of the available features. To create **New Arithmetic Features**, use the following steps:

- If the Feature View window is not already open, go to the Tools menu in the menu bar and click on **Feature View** from the lists; alternatively, select the "Feature View" button from the "**Tool**" toolbar. The Feature View window will appear.
- In the **Feature View** window, expand the **Object Features** menu by clicking on the **Plus** sign of the Object Features menu and similarly expand the **Customized** menu.
- Double click on the **Create New** "**Arithmetic Features**". The **Edit Customized Features** window will appear.

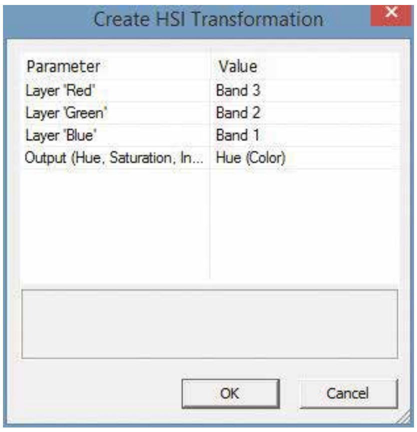
- Assign the feature name as **NDSI** in the **Feature Name** textbox of the **Edit Customized Feature** window.
- Assign the arithmetic expression "([*Mean Band 2*] - [*Mean Band 5*])/ ([*Mean Band 2*] + [*Mean Band 5*])" in the Feature Calculator text box. To assign an arithmetic expression, use the calculator and select features "[*Mean Band 2*]" from the **Feature Tree** on the right side of the calculator.
- Click the **OK** button to confirm the process. The newly created Features will appear in the **Customized** sub-menu of the **Object Features** in the Feature Tree menu in the **Feature View** window.
- Similarly, assign the following features, which are useful for glacier mapping:



S.N.	Feature name	Arithmetic expression
1	NDVI	*([Mean Band 4] - [Mean Band 3])/ ([Mean Band 4] + [Mean Band 3])*
2	LWM	*([Mean Band 5])/ ([Mean Band 2] + 0.0001) *100*
3	NDWI	*([Mean Band 4] - [Mean Band 5])/ ([Mean Band 4] + [Mean Band 5])*
4	Band35	*([Mean Band 3] - [Mean Band 5])/ ([Mean Band 3] + [Mean Band 5])*
5	Band7/5	*([Mean Band 7])/ ([Mean Band 5] + 0.0001) *100*

Create New Hue and Intensity Layers

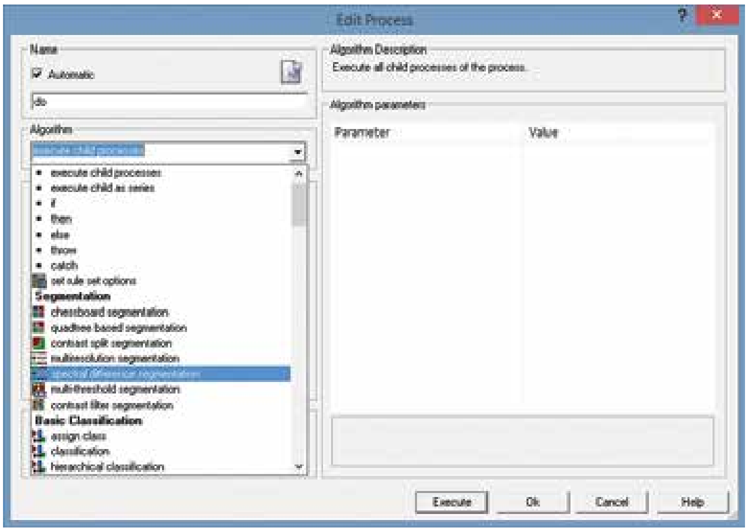
- In the **Feature View** window, expand the **Object Features** menu by clicking on the **Plus** sign of the **Object Features** menu and similarly expand the **Layer Values** and **Hue, Saturation, Intensity** menu.
- Double click on the **Create New** "**HIS Transformation**". The **Create HSI Transformation** window will appear.
- Assign the **Value** of the **Layer** "**Red**" Parametre as "**Band 3**" from the drop-down list. Follow the same procedure for **Layer** "**Green**" as "**Band 2**" and **Layer** "**Blue**" as "**Band 1**".
- Select **Hue** (**color**) from the drop-down list as **Output** and then click on the **OK** button to create the **Hue** Layer.
- Now you can see the Hue layer added in the menu under the "Hue, Saturation, Intensity" tree menu.
- Create the Intensity layer in the same manner.

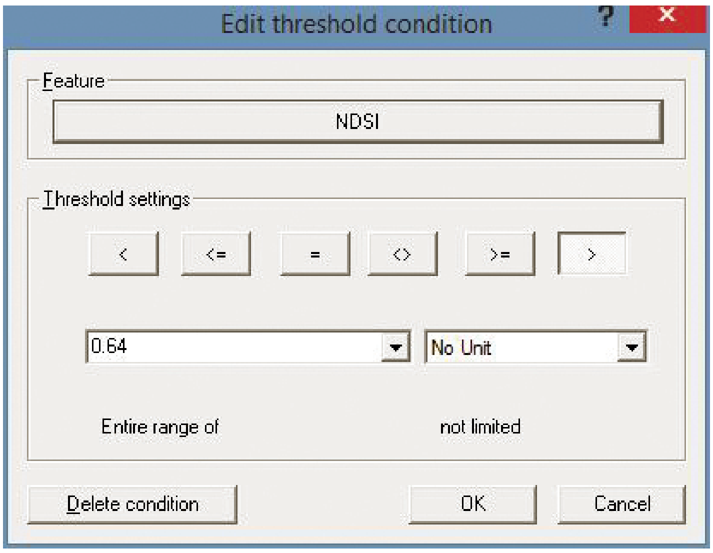


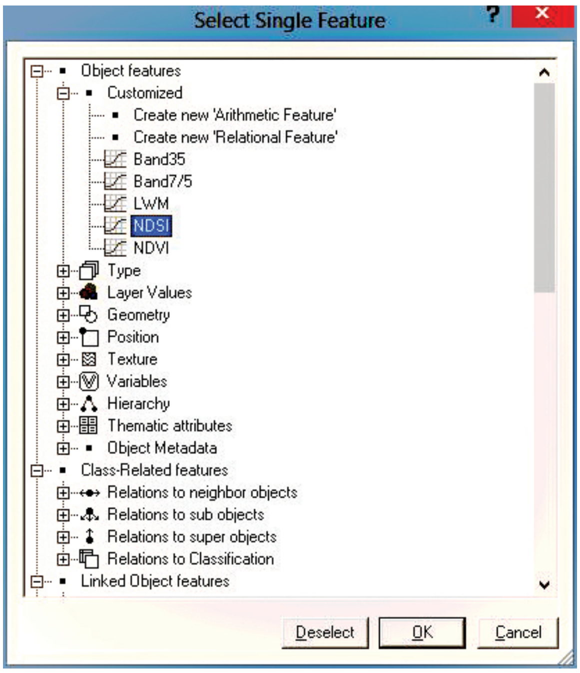
Modify the Image Object Level ("Level 1")

To make the classification of the image simpler and easier, the image object level is modified using the Spectral Difference Segmentation process, which merges the neighboring objects according to their mean layer intensity values. To modify the image objects level using Spectral Difference Segmentation, take the following steps:

- Select and right-click on the "**Segmentation**" parent process that is already created during segmentation. Click on the **Insert Child** from the context menu. The **Edit Process** dialog box appears.
- In the **Algorithm** drop-down box of the **Edit Process** dialog box, select **Spectral Difference Segmentation** from the lists.
- Select the **Image Object Level** in the **Image Object Domain** drop-down menu box.
- Select **Level** as "**Level 1**" to be modified.
- Click on '…' next to the **Threshold Condition** field and the **Select Single Feature** dialog box will open.
- Browse to "**Object features > Customized > NDSI**" and double-click on it. **The Edit Threshold Condition** dialog box opens.







- Choose **Greater than** or **Equal to** as operator from the **Threshold settings** in the dialog box and enter the value **0.64** in the text box.
- Click on **OK** to confirm.
- In the Algorithms Parametres for Segmentation, which now appear on the right-hand side of the dialog box, select the **Level Usage** as "**Create Above**" and change the **Level Name** to "**Level 2**" (name of the image object level to be created),

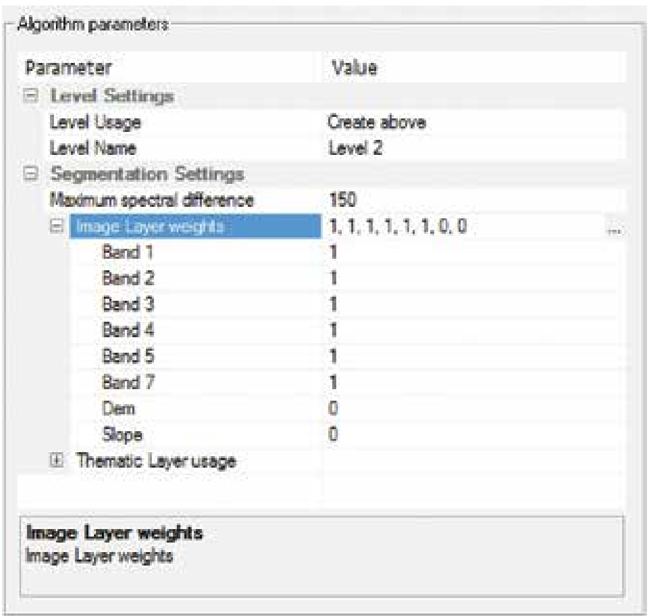
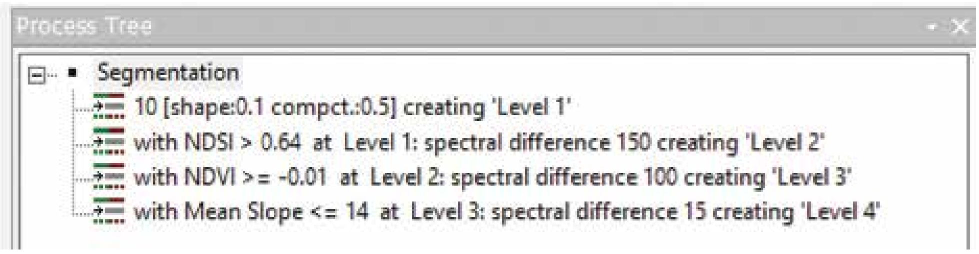


Image Layer Weights as **0** for Dem and Slope; and 1 for Band 1 to Band 7 and Maximum Spectral Difference as **150**.

- Then Press **Execute** to process the rule and save the rule in the Process Tree window. This modifiy the image object of Clean-ice glacier parts by merging smaller objects to the larger image objects
- Again, modify the Image object level "**Level 2**" by applying the same steps using threshold Condition as **NDVI >= -0.01** and a **Maximum Spectral Difference** of **100** and save the **image object level** as "**Level 3**". This modifies the non-glacier objects.
- Also, modify the Image object level "**Level 3**" by applying the same steps using threshold Condition as **Mean Slope <= 14** and **Maximum Spectral Difference** of **15** and save the image object level as "**Level 4**". This modifies the Debris-covered glaciers into bigger objects.



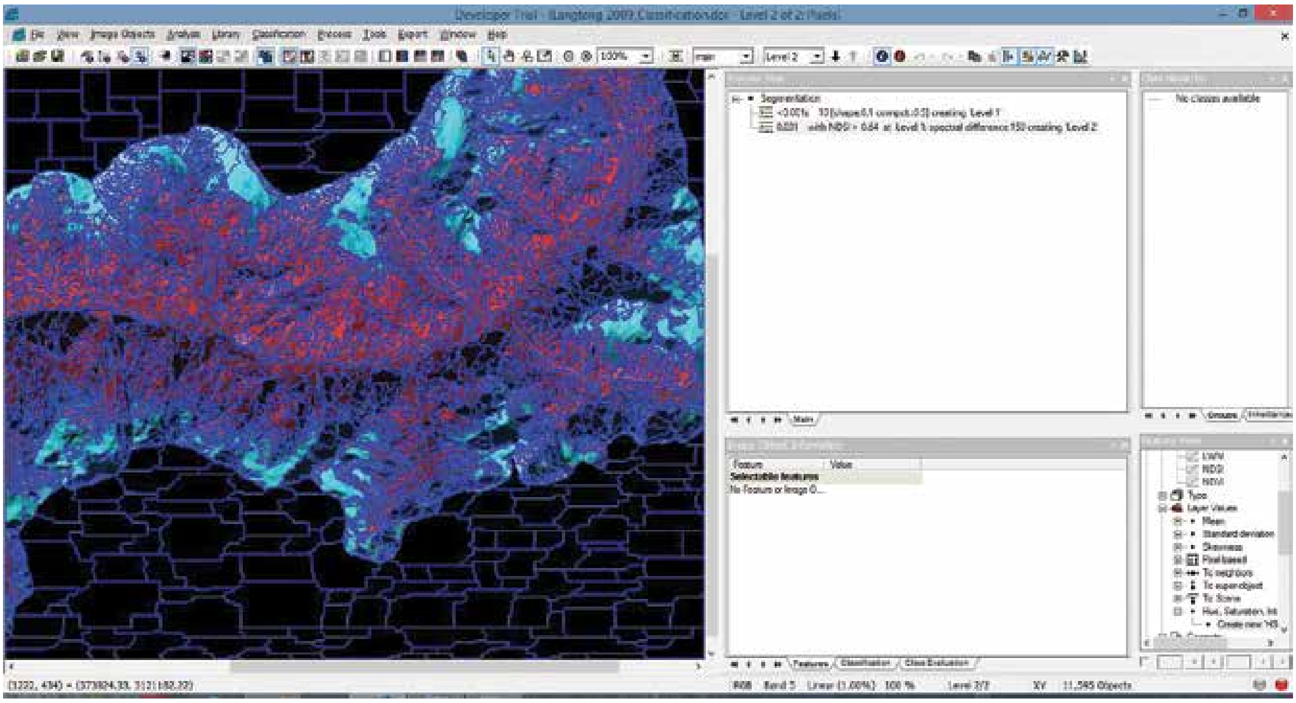


Image Object Level – "Level 2": Modifying objects level 1 using Spectral Difference Segmentation with threshold setting NDSI >= 0.64 and spectral difference 150

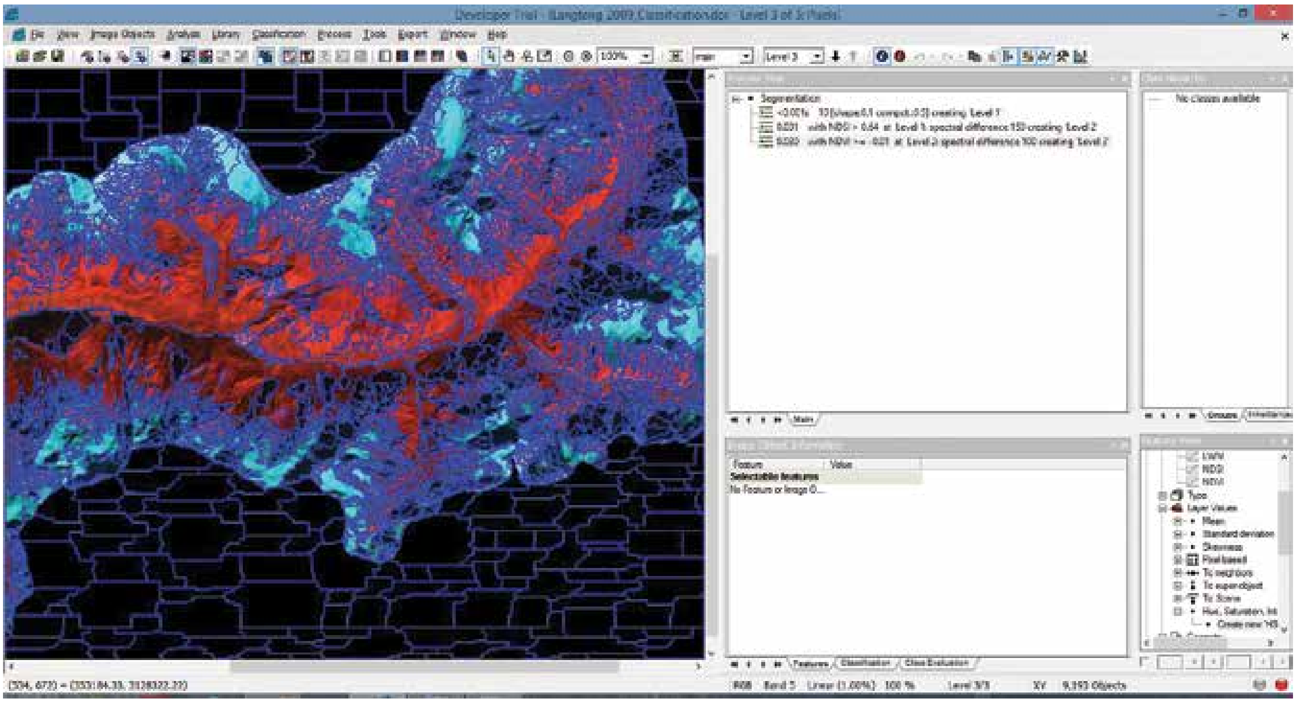


Image Object Level – "Level 3'": Modifying objects level 2 using Spectral Difference Segmentation with threshold setting NDVI >= -0.01 and spectral difference 100

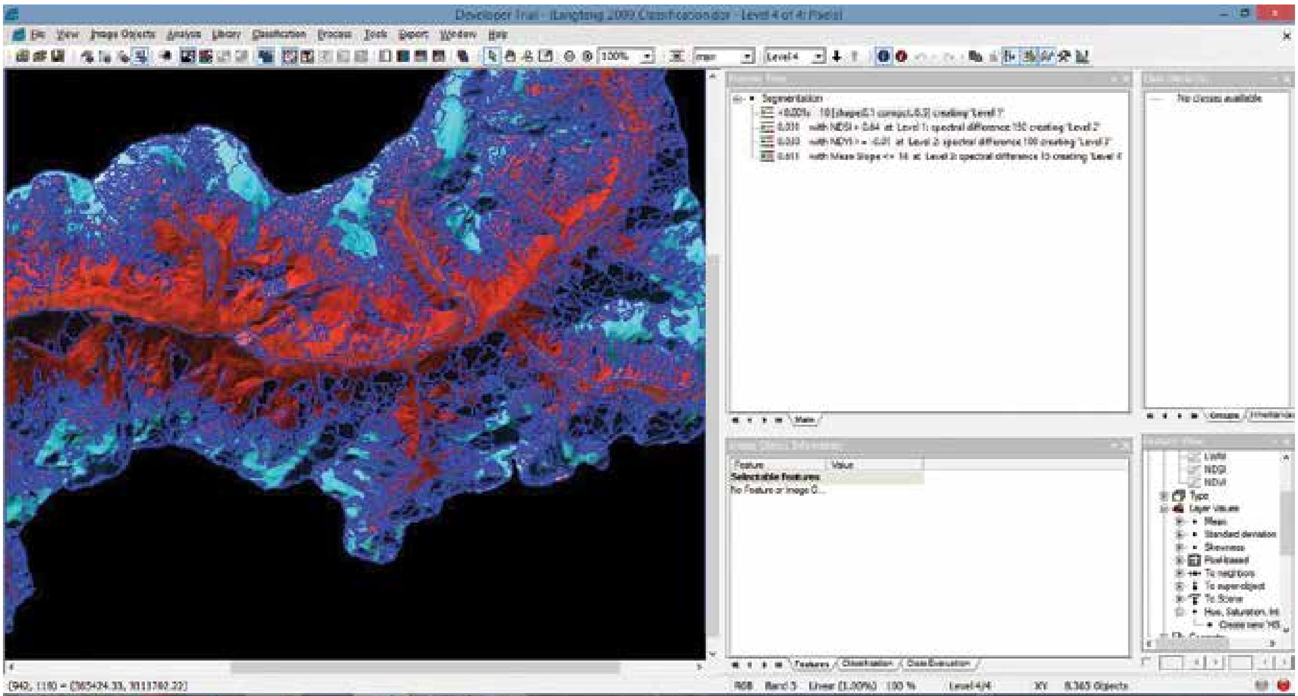
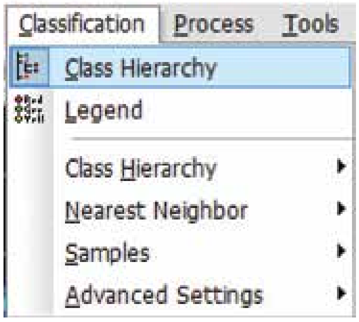


Image Object Level – "Level 4": Modifying objects level 3 using Spectral Difference Segmentation with threshold setting Mean Slope <= 14 and spectral difference 15

Create a Class in the "Class Hierarchy" window

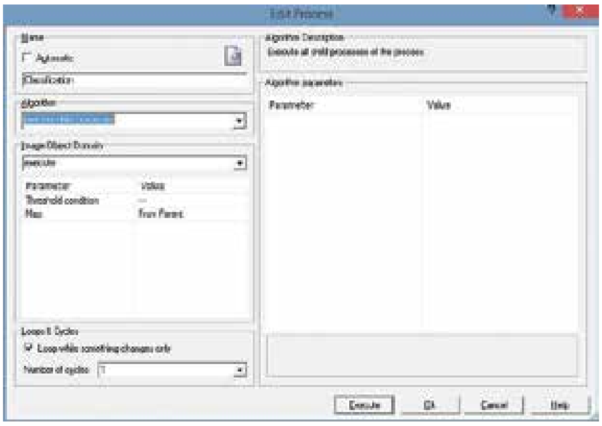


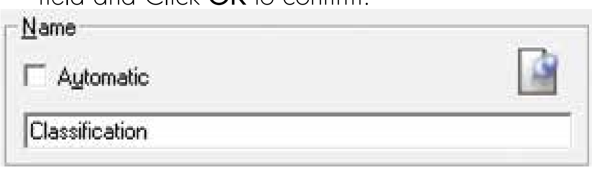
- If the **Class Hierarchy** window is not already open, go to the **Classification** menu in the **Menu** bar and click on the **Class Hierarchy** from the lists; alternatively, select the "**Class Hierarchy**" button from the "**Tool**" toolbar. The Feature View window appears.
- **Right-click** in the "**Class Hierarchy**" window and select "**Insert Class**" from the context menu. The "Class Description" dialog box opens.
- Enter "**Clean-ice**" in the "**Name**" field. Keep the default color or change the color from the color drop-down box.
- Click on **OK** to confirm.
- Again, follow the same process to create "**Debris-covered**" class.

Classify the Glacier (Clean-ice)

Inserting Parent Process

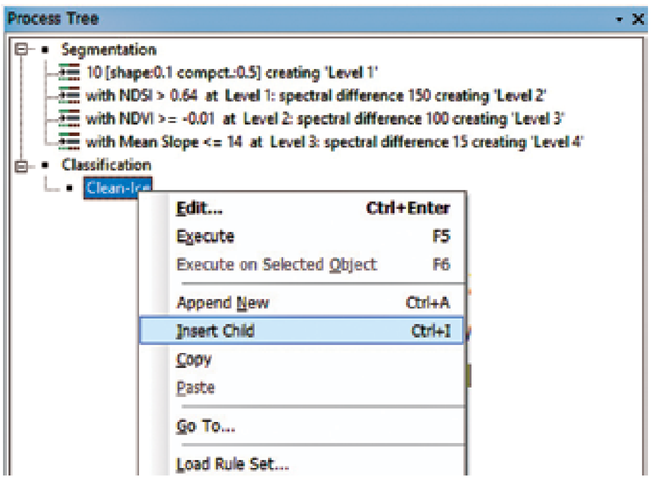
- If the Process Tree window is not opened, go to the **Process** menu in the Menu bar and click on the **Process Tree** Process Tree in the drop-down **Process** menu; alternatively, select the **Process Tree** button from the **Tool** toolbar. The Process Tree window will open.
- Right-click inside the **Process Tree** window and click on **Append New** from the context menu. The **Edit Process** dialog appears.
- Type "**Classification**" (name of the Parent Process which serves as a wrapper for the underlying processes and can execute the whole sequence of underlying processes) in the **Name** field of the **Edit Process** dialog box and Click **OK**.
- Now select **Classification** in the **Process Tree** window and right-click on it. Select **Insert Child** from the context menu. The **Edit Process** dialog box appears.
- Assign "**Clean-ice**" (as sub-parent process) in the **Name** field and Click **OK** to confirm.



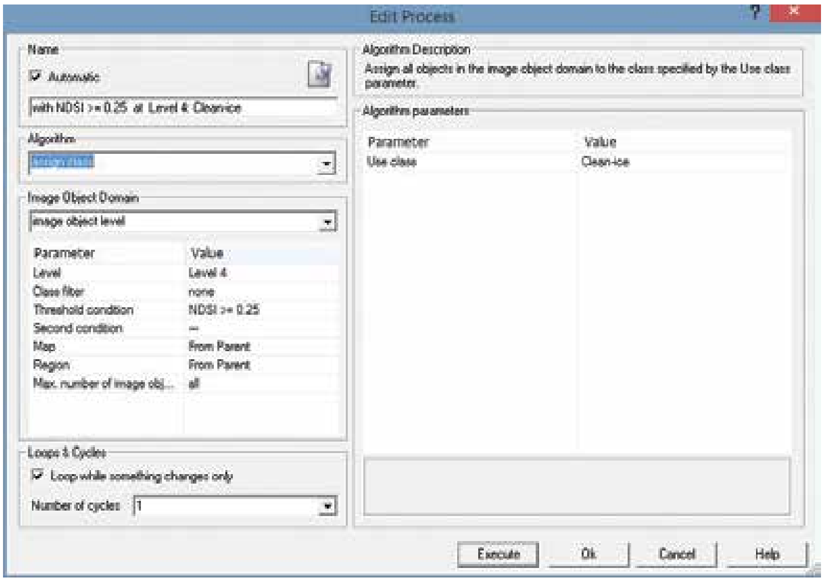


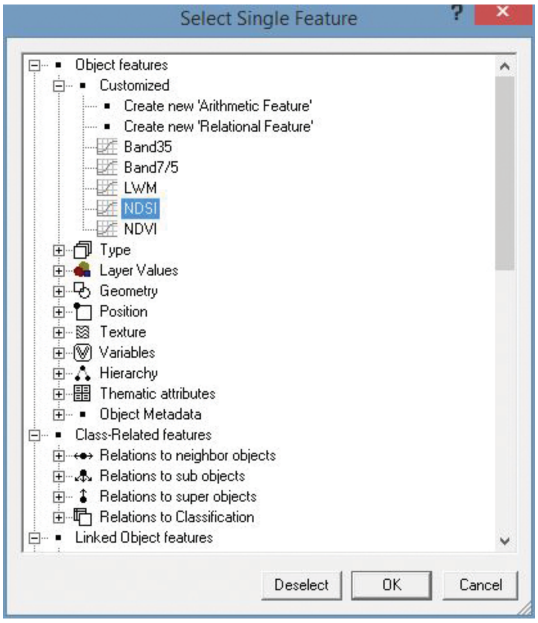
Inserting Child Process (Rules for Classification of Clean-ice)

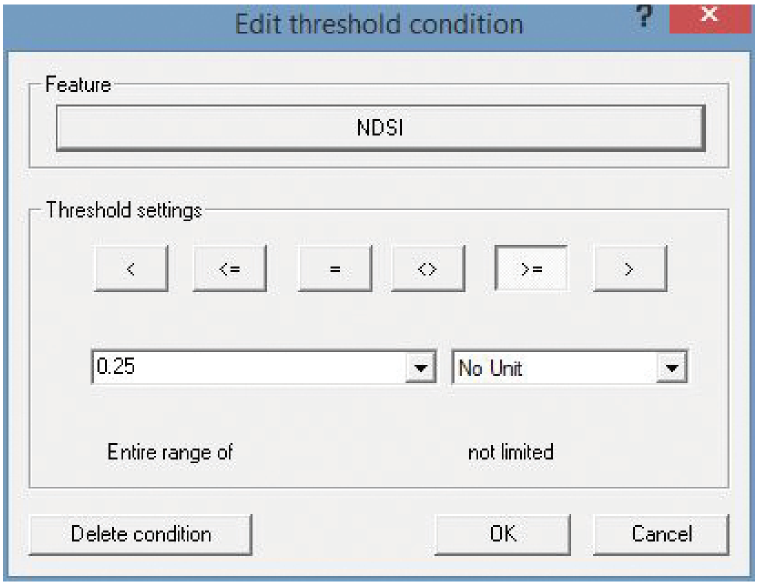
- Select the "**Clean-ice**" sub-Parent Process and right-click on it. Click on **Insert Child** from the context menu. The **Edit Process** dialog box appears.
- In the **Algorithm** drop-down box of the **Edit Process** dialog box, select **assign class** from the lists.
- Select the **Image Object Level** in the **Image Object Domain** drop-down menu box.
- Select **Level** as "**Level 4**" to set as the level domain.
- In the Class Filter field keep **none**.



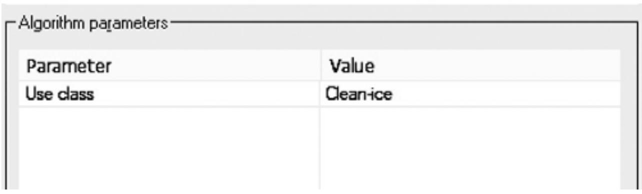
- Click on '…' next to the **Threshold Condition** field and the **Select Single Feature** dialog box will open.
- Browse to "**Object features > Customized > NDSI**" and double-click on it. The **Edit threshold condition** dialog box opens.
- Choose **greater than** as operator from the **Threshold settings** in the dialog box and enter the value **0.25** in the text box.
- Click on **OK** to confirm.
- In the Algorithms Parametres section





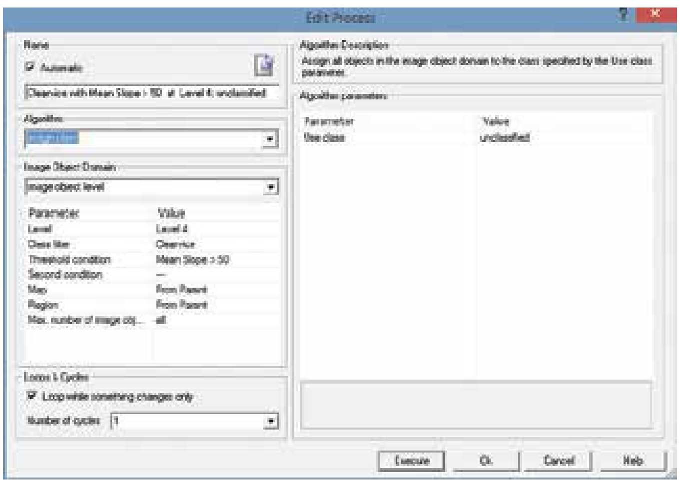


in the right pane, select **Clean-ice** from the drop-down list in the **Use Class** field to define the target class.



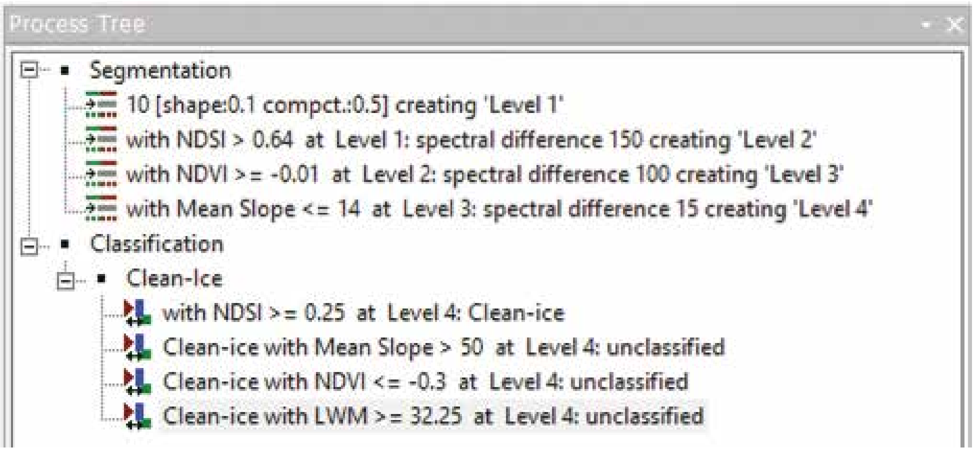
- Then confirm the process setting with the **OK** button.
- Right-click on the saved process and click on **Execute** from the context menu. The classified image objects level is seen in the **Map** window.

Removing Misclassified Image Objects from the Clean-ice Glacier



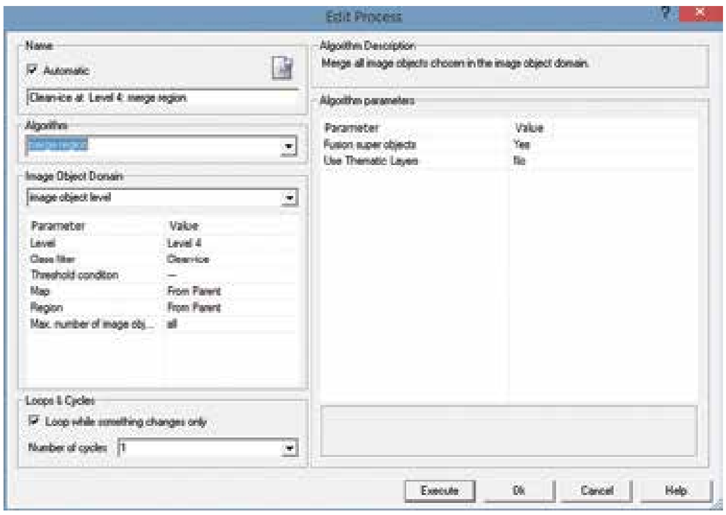
- Select the "**Clean-ice**" sub-Parent Process and right-click on it. Click on **Insert Child** from the context menu. The **Edit Process** dialog box appears.
- In the **Algorithm** drop-down box of the **Edit Process** dialog box, select **assign class** from the lists.
- Select the **Image Object Level** in the **Image Object Domain** drop-down menu box.

- Select **Level** as "**Level 4**" to set as the level domain.
- In the field **Class Filter,** select the **Clean-ice** class from drop-down list.
- Click on '…' next to the **Threshold Condition** field and the **Select Single Feature** dialog box will open.
- Browse to "**Object features > Layer Values > Mean > Slope**" and double-click on it. The **Edit threshold condition** dialog box opens.
- Choose **greater than** as operator from the **Threshold settings** in the dialog box and enter the value **50** in the text box.
- Click on **OK** to confirm.
- In the **Algorithms Parametres** section in the right pane, select **unclassified** from the drop-down list of the **Use Class** field to define the target class.
- Then confirm the process setting with the **OK** button.
- Select the rule in the Process Tree window. Arrange it by dragging and placing it one step down from the previously created rules.
- Right-click on the rule set and click on **Execute** from the context menu.
- Repeat the same process, defining Threshold Setting as **NDVI <= -0.3** and **LWM > 32.25**, to remove other misclassified objects from the Clean-ice class.



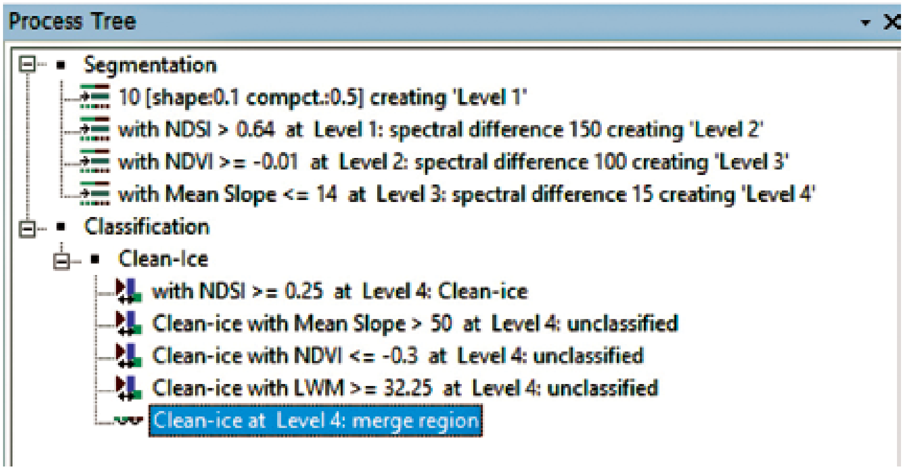
Note: To refine the classification of the Clean-ice glacier, you can also use other parametres or features such as DVI, RVI, NDWI, DEM, Hue, Brightness, Mean Bands, etc.

Merging Classified Clean-ice Objects.



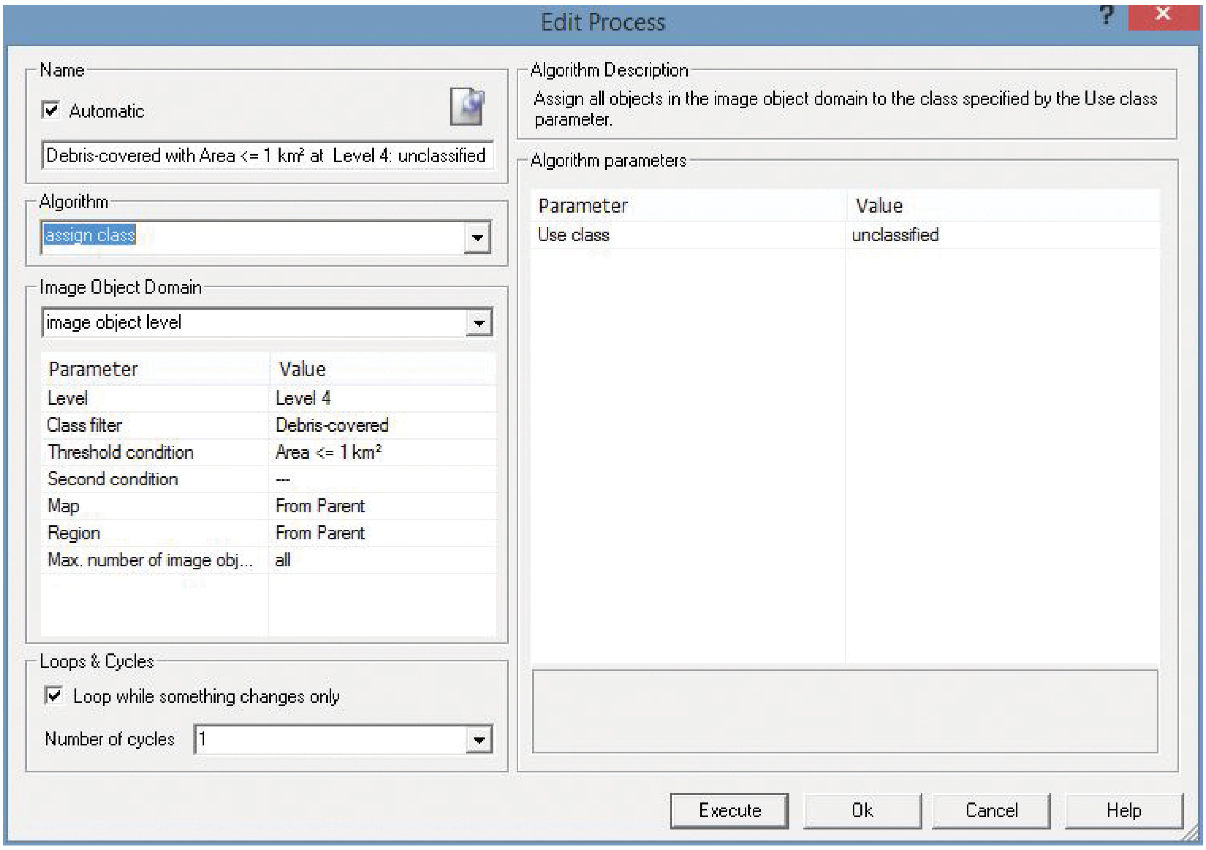
- Select the "**Clean Ice**" sub-Parent Process and right-click on it. Click on **Insert Child** from the context menu. The **Edit Process** dialog box appears.
- In the **Algorithm** drop-down box of the **Edit Process** dialog box, select **Merge Region** from the lists.
- Select the **Image Object Level** in the **Image Object Domain** drop-down menu box.
- Select **Level** as "**Level 4**" to set as the level domain.
- In the field **Class Filter**, select the **Clean Ice** class from the drop-down list.
- In the **Algorithms Parametres** section in the right pane, select **Yes** from the drop-down list of **Fusion Super Objects** field and set it as the default on the **Use Thematic Layers** field.
- Then confirm the process setting with **OK** button
- Select the rule in the **Process Tree** window. Arrange it by dragging and placing it one step down from the previously created rules.

- Right-click on the rule set and click on **Execute** from the context menu. Then the classified object Clean-ice is merged and viewed in the Map window.

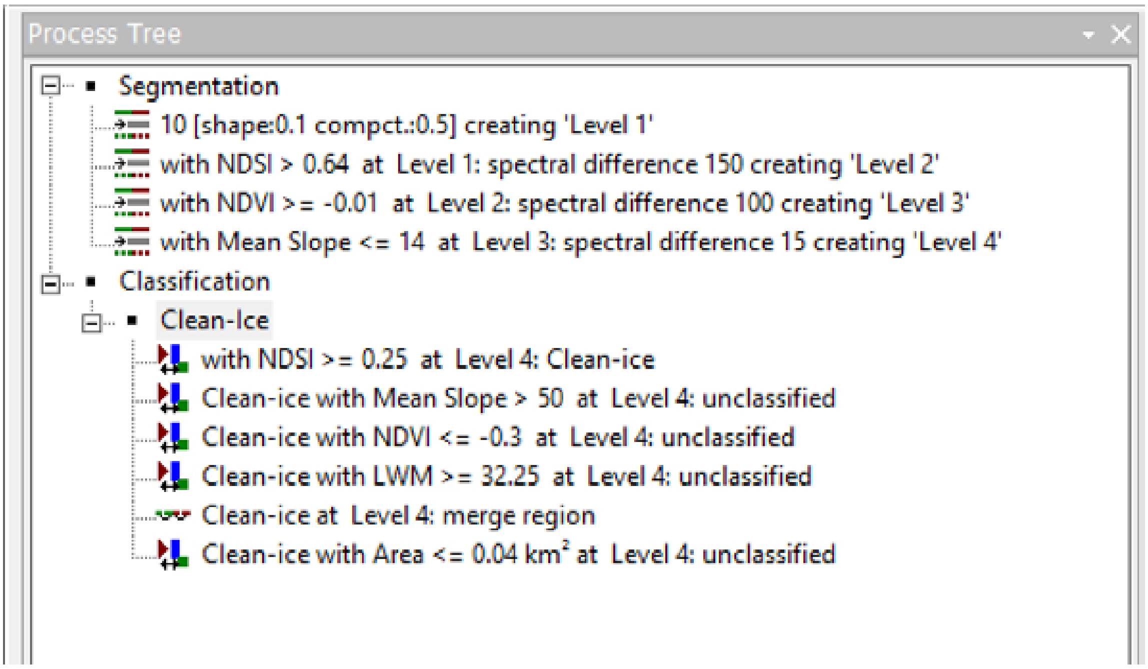


Removing Misclassified Smaller Image Objects by Using Area Class from the Clean-ice Glacier

- Select the "**Clean-ice**" sub-Parent Process and right-click on it. Click on **Insert Child** from the context menu. The **Edit Process** dialog box appears.
- In the **Algorithm** drop-down box of the **Edit Process** dialog box, select **assign class** from the lists.
- Select the **Image Object Level** in the **Image Object Domain** drop-down menu box.
- Select **Level** as "**Level 4**" to set as the level domain.
- In the field **Class Filter**, select the **Clean-ice** class from the drop-down list.
- Click on '…' next to the **Threshold Condition** field and the **Select Single Feature** dialog box will open.
- Browse to "**Object features > Geometry > Extent > Area**" and right-click on the "**Area**", then select "**Edit unit**" from the list.



- Choose "**Square Kilometres**" from the drop-down menu list of "**Feature unit**" in the Select Unit window and close the window.
- Double-click on "**Area**" in the list "**Object features > Geometry > Extent >**". The **Edit threshold condition** window will open.
- Choose **less than** as operator from the **Threshold settings** in the window and enter the value **0.04** in the text box.
- Click on **OK** to confirm.
- In the **Algorithms Parametres** section in the right pane, select **Unclassified** from the drop-down list of the **Use Class** field to define the target class.
- Then confirm the process setting with the **OK**" button.
- Select the rule in the Process Tree window. Arrange it by dragging and placing it one step down from the previously created rules.



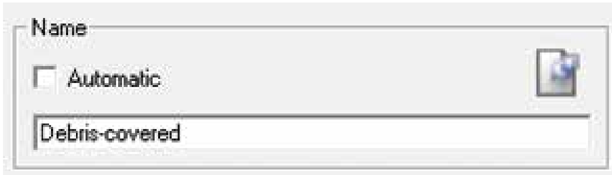
After completion of the process, do not forget to save the project.

7.3 Hands-on Exercise III: Debris-covered Glacier Mapping

Classify the Glacier (Debris-covererd)

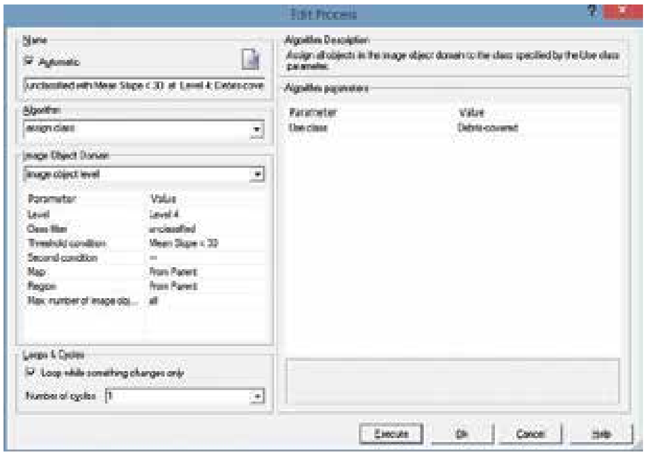
Inserting Parent Process for Debris-covered

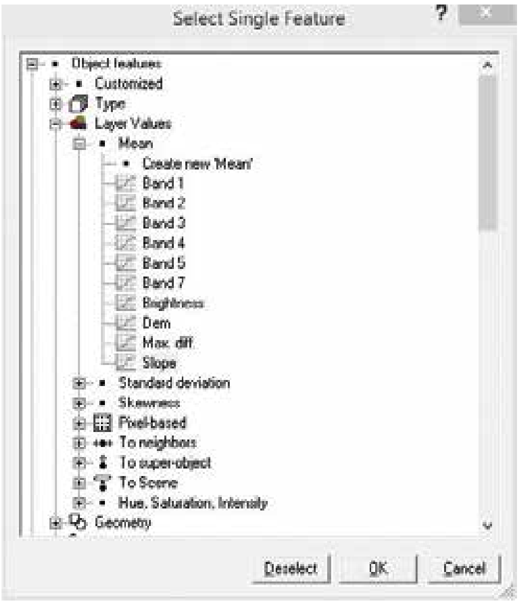
- Select **Classification** parent process in the Process Tree window and right-click on it. Select Insert Child from the context menu. The **Edit Process** dialog box appears.
- Assign "**Debris-covered**" (as sub-parent process) in the **Name** field and Click **OK** to confirm.

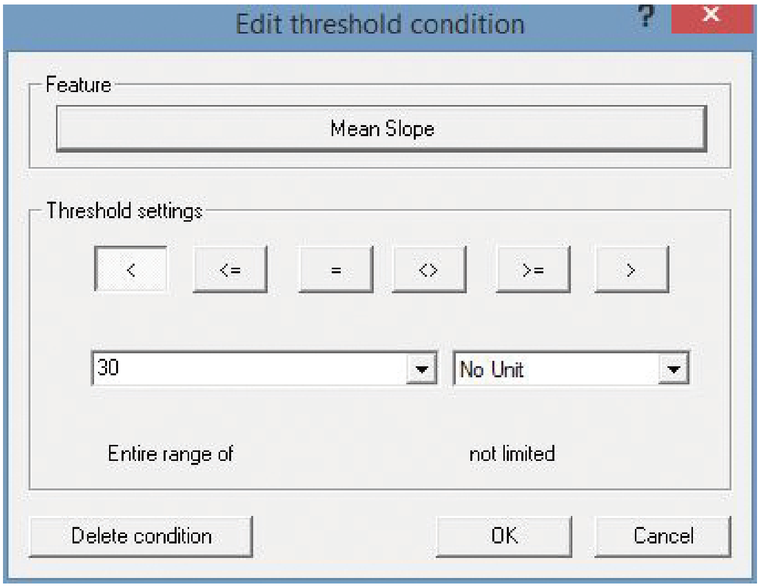


Inserting Child Process (Rules for Classification of Debris Cover)

- Select the "**Debris-covered**" sub-Parent Process and right-click on it. Click on **Insert Child** from the context menu. The **Edit Process** dialog box appears.
- In the **Algorithm** drop-down box of the **Edit Process** dialog box, select **assign class** from the lists.
- Select the **Image Object Level** in the **Image Object Domain** drop-down menu box.
- Select **Level** as "**Level 4**" to set as the level domain.
- In the Class Filter field, select the **unclassified** class from drop-down list.
- Click on '…' next to the **Threshold Condition** field and the Select Single Feature dialog box will open.



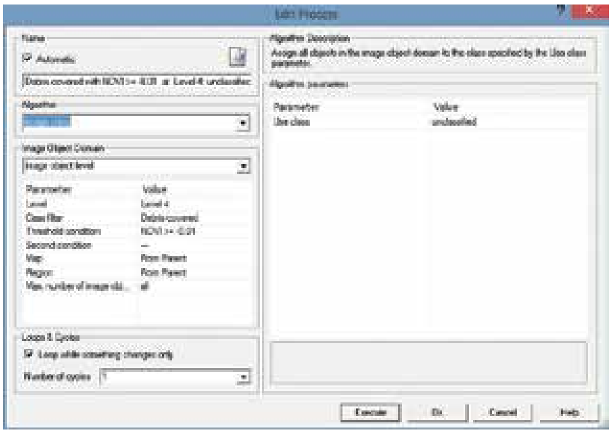


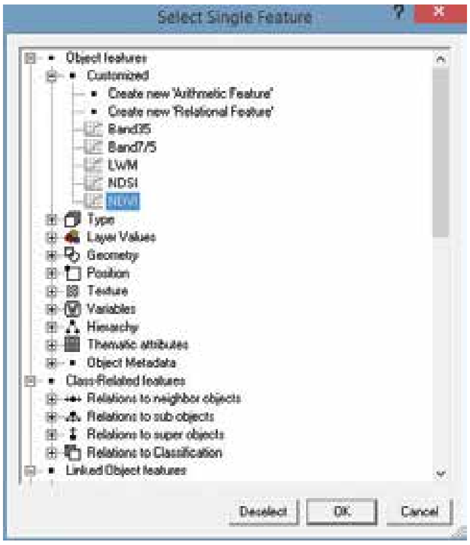


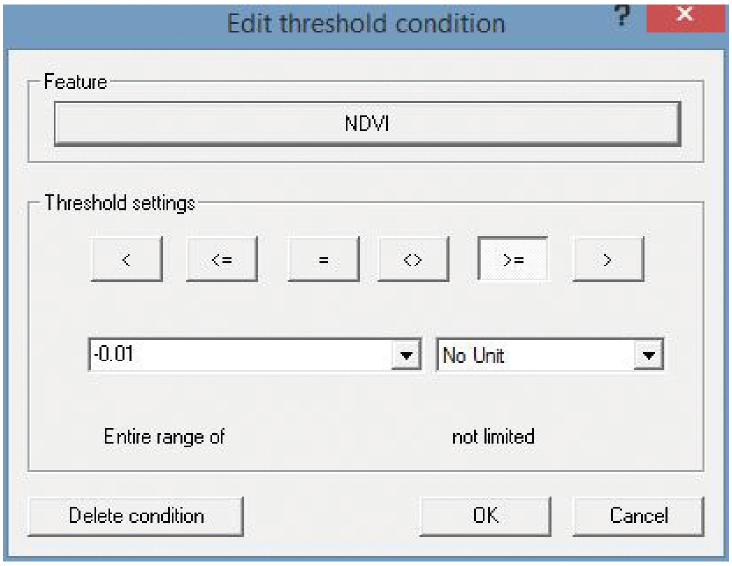
- Browse to "**Object features > Layer Values > Mean > Slope**" and double-click on it. The **Edit threshold condition** dialog box opens.
- Choose less-than or equal-to as operator from the Threshold settings in the dialog box and enter the value **30** in the text box.
- Click on **OK** to confirm.
- In the **Algorithms Parametres** section in the right pane, select **Debris-covered** from the drop-down list of the **Use Class** field to define the target class.
- Then confirm the process setting with the **OK** button
- Right-click on the saved process and click on **Execute** from the context menu. The classified image objects level is seen in the **Map** window.

Removing Misclassified Image Objects from the Debris-covered Glacier

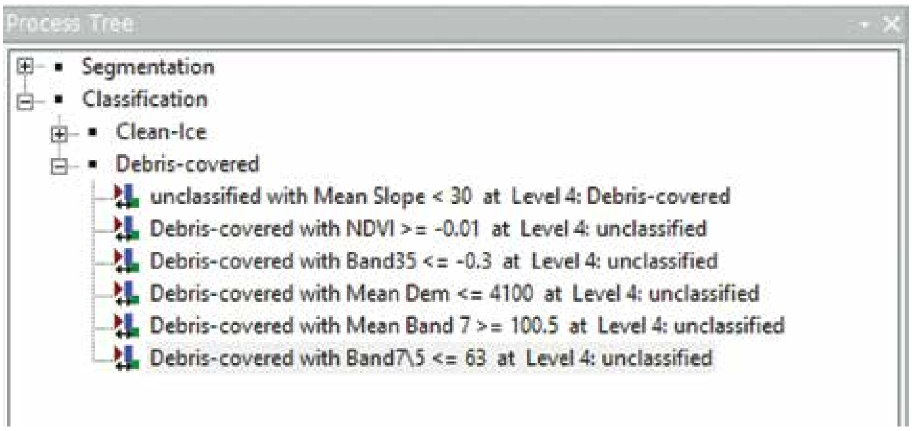
- Select the '**Debris-covered**' sub Parent Process and right-click on it. Click on **Insert Child** from the context menu. The **Edit Process** dialog box appears.
- In the **Algorithm** drop-down box of the **Edit Process** dialog box, select **assign class** from the lists.
- Select the **Image Object Level** in the **Image Object Domain** drop-down menu box.
- Select **Level** as "**Level 4**" to set as the level domain.
- In the field **Class Filter,** select the **Debris-covered** class from the drop-down list.
- Click on '…' next to the **Threshold Condition** field and the **Select Single Feature** dialog box opens.
- Browse to "**Object features > Customized > NDVI**'" and double-click on it. The **Edit threshold condition** dialog box opens.
- Choose **greater than** or **equal** to as operator from the **Threshold settings** in the dialog box and enter the value **-0.01** in the text box.







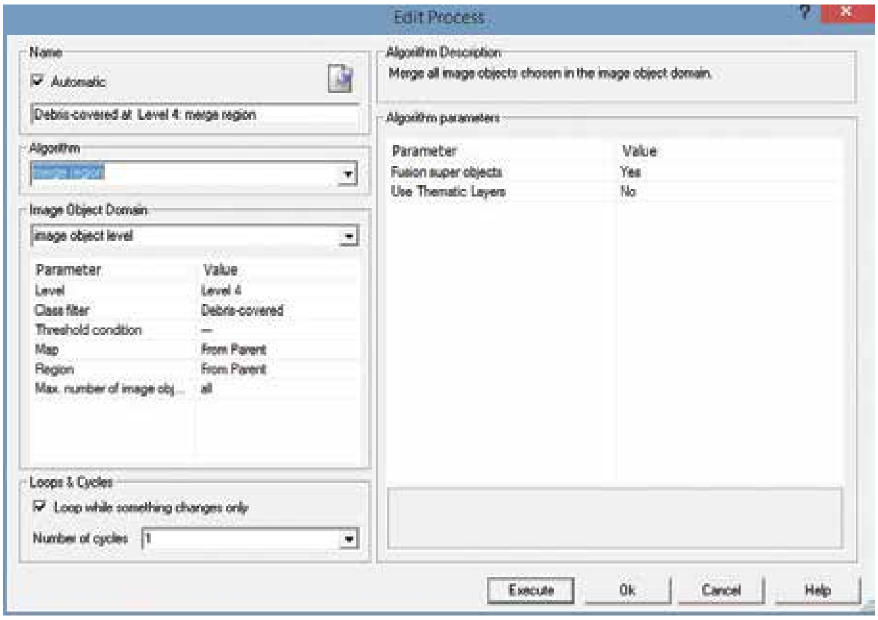
- Click on **OK** to confirm.
- In the **Algorithms Parametres** section in the right pane, select **Unclassified** from the drop-down list of the **Use Class** field to define the target class.
- Then confirm the process setting with the **OK**" button.
- Select the rule in the Process Tree window. Arrange it by dragging and placing it one step down from the previously created rules.
- Right-click on the rule set and click on **Execute** from the context menu.
- Repeat the same process, defining the Threshold Setting as **Band35 <= -0.3, Mean Dem <= 4100, Mean Band 7 >= 100.5, Band7/5 <= 63** sequentially to remove other misclassified objects from the Debris-covered class.



Note: To refine the classification of the Debris-covered glacier, you can also use other parametres or features such as DVI, RVI, Hue, Brightness, other Mean Bands, etc.

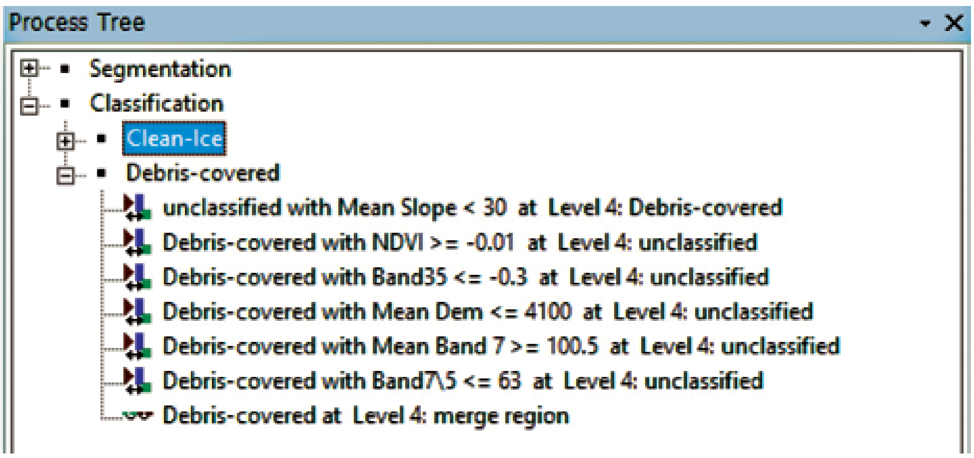
Merging Classified Debris-covered Objects

- Select the "**Debris-covered**" sub-Parent Process and right-click on it. Click on **Insert Child** from the context menu. The **Edit Process** dialog box appears.
- In the **Algorithm** drop-down box of the **Edit Process** dialog box, select **Merge Region** from the lists.
- Select the **Image Object Level** in the **Image Object Domain** drop-down menu box.
- Select **Level** as "**Level 4**" to set as the level domain.
- In the **Class Filter** field, select the **Debris-covered** class from the drop-down list.
- In the **Algorithms Parametres** section in the right pane, select **Yes** from the drop-down list of the **Fusion super objects** field and set it as the default in the **Use Thematic Layers** field.
- Then confirm the process setting with the "**OK**" button



- Select the rule in the Process Tree window. Arrange it by dragging and placing it one step down from the previously created rules.
- Right-click on the rule set and click on **Execute** from the context menu. Then the classified objects Clean Ice is merged and viewed in the **Map** window.

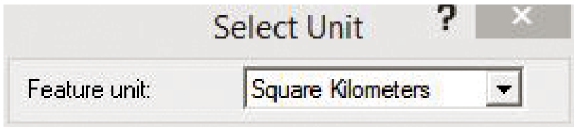
In the same way set the following steps and run the process.

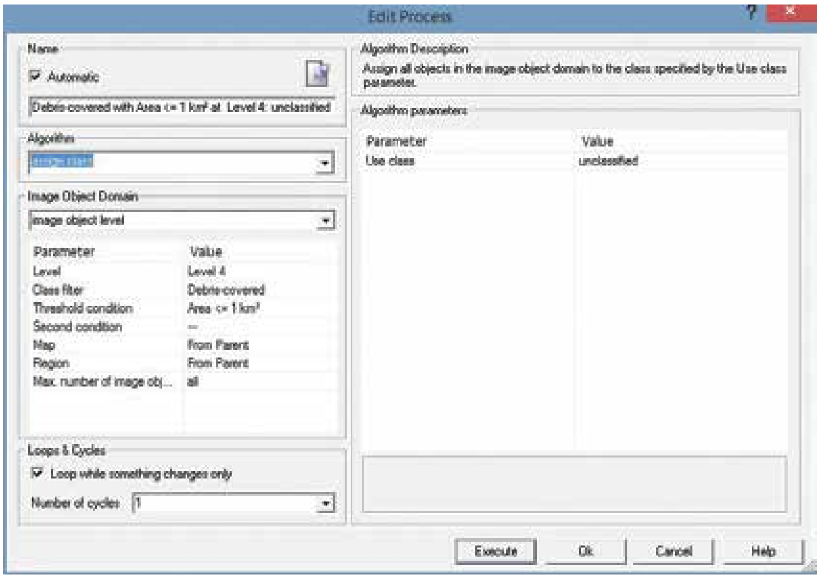


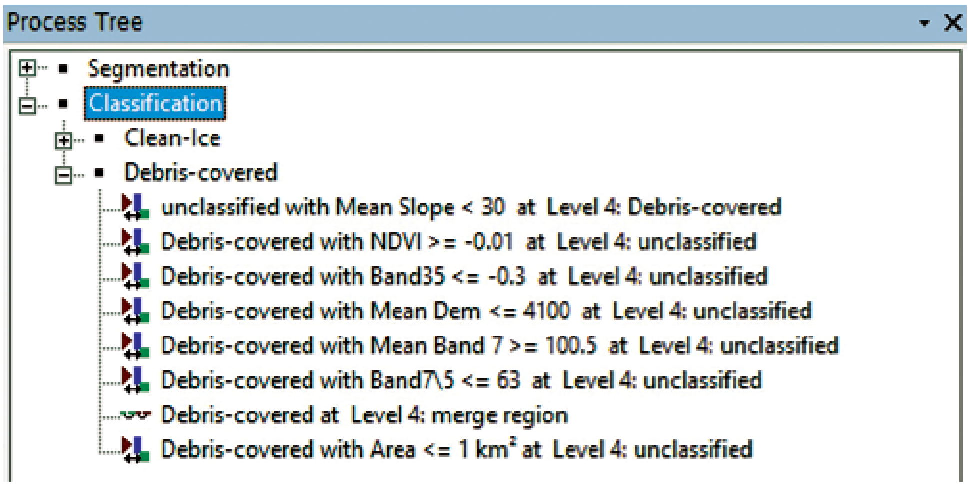
Removing Misclassified Image Objects by using Area Class from the Debris-covered Glacier

- Select the "**Debris-covered**" sub-Parent Process and right-click on it. Click on **Insert Child** from the context menu. The **Edit Process** dialog box appears.
- In the **Algorithm** drop-down box of the **Edit Process** dialog box, select **assign class** from the lists.

- Select the **Image Object Level** in the **Image Object Domain** drop-down menu box.
- Select **Level** as "**Level 4**" to set as the level domain.
- In the **Class Filter** field, select **Debris-covered** class from the drop-down list.
- Click on '…' next to the **Threshold Condition** field and the **Select Single Feature** dialog box will open.
- Browse to "**Object features > Geometry > Extent > Area**" and right-click on the "**Area**". Then change the unit of the Area if it is different from the "**Square Kilometres**" by right-clicking on it and selecting "**Edit unit**" from the list.
- Double click on "**Area**" in the list "**Object features > Geometry > Extent >**". The Edit threshold condition window opens.
- Choose **less than** as operator from the **Threshold settings** in the window and enter the value **1** in the text box.
- Click on **OK** to confirm.
- In the **Algorithms Parametres** section in the right pane, select **Unclassified** from the drop-down list of the **Use Class** field to define the target class.
- Then confirm the process setting with **OK** button
- Select the rule in the Process Tree window. Arrange it by dragging and placing it one step down from the previously created rules and click on **Execute**.

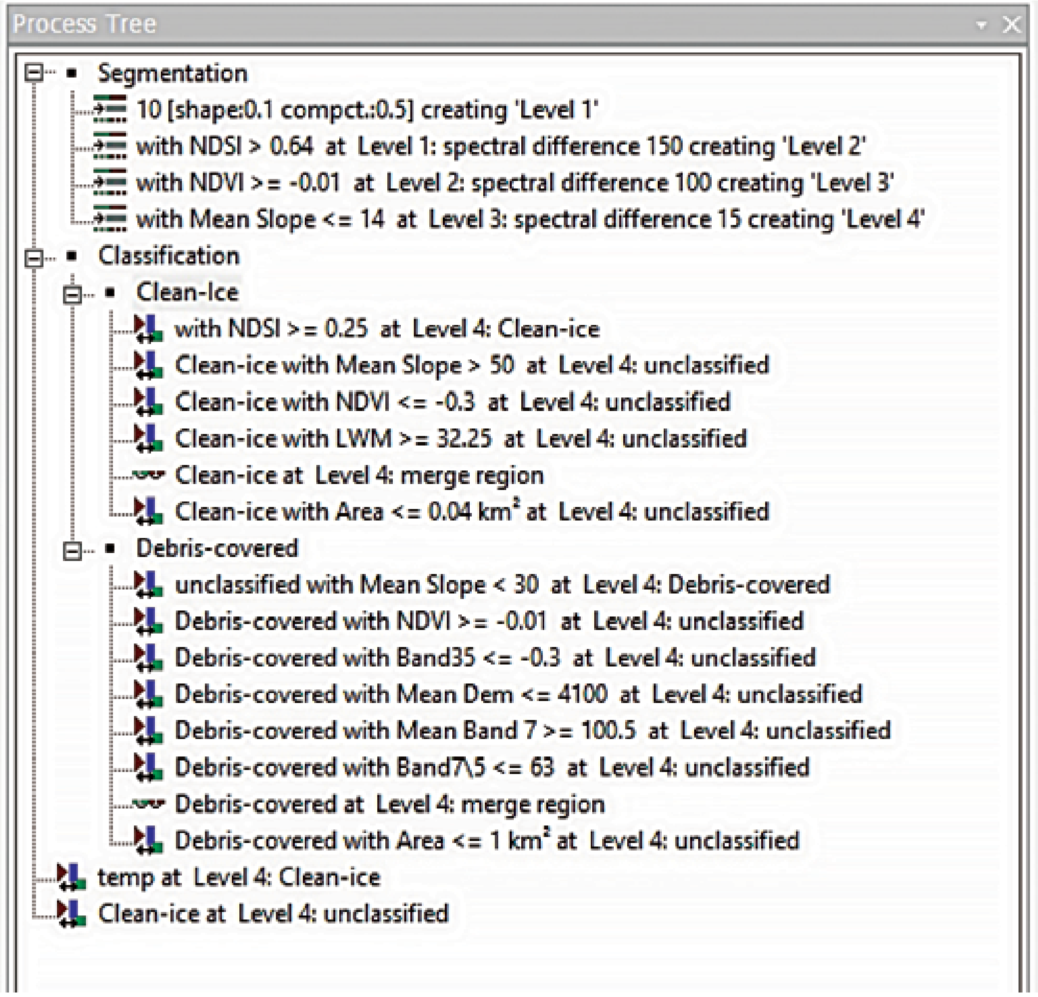






After completion of the process, do not forget to save the project.

7.4 Complete the Rule Sets of this Exercise

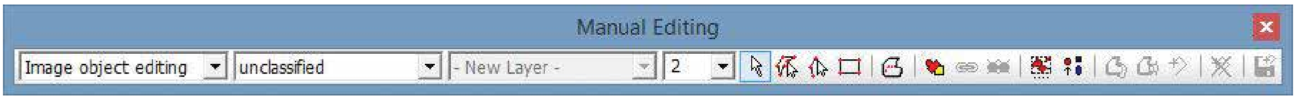


7.5 Manual Editing of Objects

Manual editing of image objects and thematic objects allows you to manually influence the result of an image analysis. The main manual editing tools are **Merge Objects Manually, Classify Image Objects Manually,** and **Cut an Object Manually.**

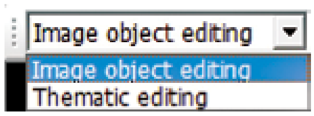
While manual editing is not commonly used in automated image analysis, it can be applied to highlight or reclassify certain objects or to quickly improve the analysis result without adjusting the applied rule set.

To open the **Manual Editing** toolbar, choose **View > Toolbars > Manual Editing** on the **Main** menu; alternatively, click on the **Manual Editing Toolbar** button in the **Tools** toolbar. The **Manual Editing Toolbar** appears.



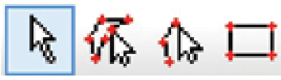
Change Editing Mode

The **Change Editing Mode** drop-down list on the **Manual Editing** toolbar is set to **Image Object Editing** by default. If you work with thematic layers and want to edit them by hand, choose **Thematic editing** from the drop-down list.



Selection Tools

Objects to be fused or classified can be selected from the **Manual Editing** toolbar in one of the following ways:



1 2 3 4

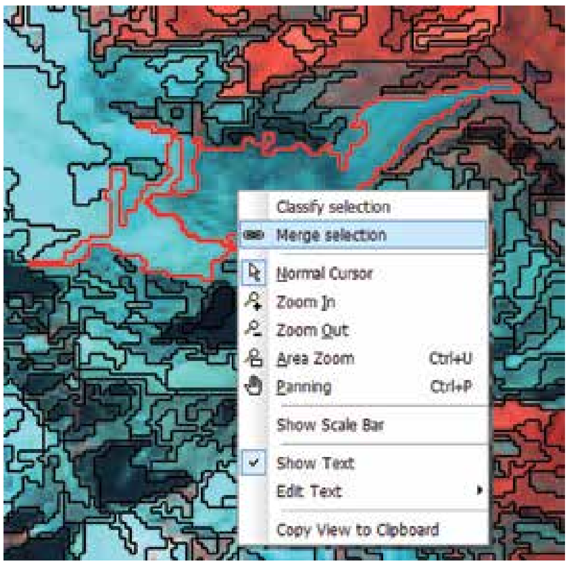
1. **Single Selection Mode** selects one object. Select the object with a single click.
2. **Polygon Selection** selects all objects that lie within or touch the border of a polygon. Set vertices of the polygon with a single click. Right-click and choose **Close Polygon** to close the polygon.
3. **Line Selection** selects all objects along a line. Set vertices of the line with a single click. A line can also be closed to form a polygon by right-clicking and choosing **Close Polygon**. All objects that touch the line are selected.
4. **Rectangle Selection** selects all objects within or touching the border of a rectangle. Drag a rectangle to select the image objects.

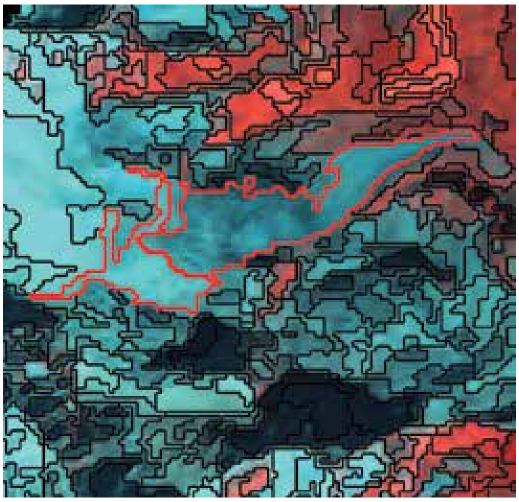
Merge Objects Manually

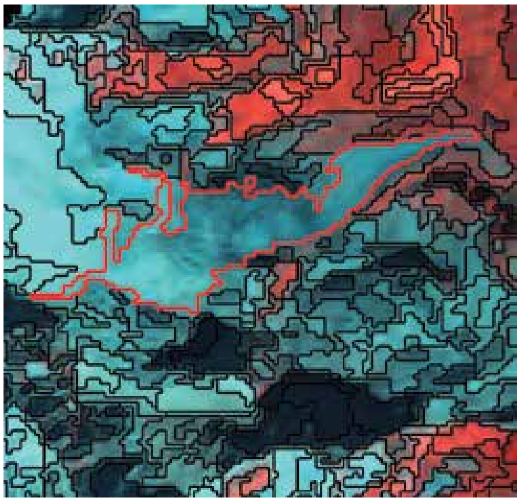
The manual editing tool **Merge Objects** is used to manually merge selected neighboring images or thematic objects.

Note: Manual object merging operates only on the current image object level.

Choose Tools > Manual Editing > Merge Objects from the main menu bar or press the **Merge Objects Manually** button on the **Manual Editing** toolbar to activate the input mode. Or you can use **right-click**.







Note: You should have at least two objects.

Classify Image Objects Manually

The manual editing tool **Classify Image Objects** allows easy class assignment of selected image objects.

Manual image object classification can be used for the following purposes:

- Manual correction of previous classification results, including classification of previously unclassified objects.
- Classification without rule sets (in case the creation of an appropriate rule set is more time-consuming), using the initial segmentation run for automated digitizing. Precondition: To classify image objects manually, the project has to contain at least one image object level and one class in the **Class Hierarchy**.

To perform a manual classification, do one of the following:

- Choose **Tools > Manual Editing > Classify Image Objects** from the menu bar or click on the **Classify Image Objects** button in the **Manual Editing Toolbar**.
- Click the **Classify Image Objects** button on the **Manual Editing** toolbar to activate the manual classification input mode.
- In the **Select Class for Manual Classification** drop-down list box, select the class to which you want to manually assign objects. Note that selecting a class in the **Legend** window or in the **Class Hierarchy** window (if available) will not determine the class for manual editing; the class has to be selected from the before-mentioned drop-down list.

Now objects can be classified manually with a single mouse-click. To classify objects, do one of the following:

- Select the **Classify Image Objects** button and the **Class for Manual Classification**. Click the image objects to be classified.
- Select the image object(s) you want to classify first. Select the **Class for Manual Classification** and press the **Classify Image Objects** button to classify all selected objects.
- Select one or more image objects, right-click into the image object(s), and select **Classify Selection** from the context menu.

When the object is classified, it is painted in the color of the respective class.

If no class is selected, a mouse-click deletes the previous class assignment; the image object becomes unclassified.

To undo a manual classification on a previously unclassified object, simply click the object a second time. If the object was previously classified, then clicking again does not restore the former classification; instead, the object becomes unclassified.

8. Online Resources for Glacier Database

ICIMOD

The International Centre for Integrated Mountain Development (www.icimod.org) attaches great importance to the Himalayan glaciers for climate change research and ecosystem services and has been involved in building a long-term database on Himalayan glaciers since the late 1990s. The database is being disseminated through "Mountain Portal", an interactive web service through the Google Earth (GE) interface. Also part of the information are additional parametres, such as

- Physical condition - Orientation, drainage condition;
- Type – moraine dam, supra glacier, erosion, block, cirque, valley;
- Spatial - latitude, longitude, area, length, elevation values;
- Estimated - ice thickness, ice reserve;
- Orientation - accumulation, ablation;
- Classification - 6 digit WGMS standard.

The data layers are divided into the 19 sub-basins of Nepal. However, data (glaciers polygon dataset) layers presented in this GE are generalized to the actual database to reduce the size of the KML. (http://geoportal.icimod.org/)

NSIDC

The National Snow and Ice Data Center offers more than 500 data products to researchers, commercial applications users, and others worldwide. Their data are disseminated through the NSIDC Distributed Active Archive Center (DAAC). (http://nsidc.org/)

GLIMS

The Global Land and Ice Measurement System (http://www.glims.org/) project is currently creating a unique glacier inventory, storing information about the extent and rates of change of the entire world's glacial resources. The GLIMS Glacier Database provides students, educators, scientists, and the public with reliable glacier data from research. Through the GLIMS Glacier Viewer Web Mapping Service (WMS), one can gain access to the GLIMS Glacier Database. This WMS allows users to view and query several thematic layers, including glacier outlines, ASTER footprints, Regional Center locations, and the World Glacier Inventory. Query results can be downloaded into a number of GIS-compatible formats, including ESRI Shape files, MapInfo tables, and Geographic Mark-up Language (GML). (http://glims.colorado.edu/cgi-bin/mapserv)

Randolph Glacier Inventory (RGI)

The Randolph Glacier Inventory (RGI) is a globally complete inventory of glacier outlines. It is supplemental to the Global Land Ice Measurements from Space initiative (GLIMS). Production of the RGI was motivated by the preparation of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The RGI was released initially during 2012 with little documentation in view of the IPCC's tight deadlines. In due course, the content of the RGI will be merged into the database of GLIMS. The RGI will, however, evolve into a downloadable subset of the extensive and diverse holdings of GLIMS, offering complete one-time coverage, version control, and a standard set of attributes. (http://www.glims.org/RGI/)

WGMS

Since 1986, the World Glacier Monitoring Service has maintained and continued the collection of information about ongoing glacier changes to support climate change research. Today, the WGMS collects standardized observations on changes in mass, volume, area, and length of glaciers with time (glacier fluctuations), as well as statistical information on the distribution of perennial surface ice in space (glacier inventories). Such glacier fluctuation and inventory data are high priority key variables in climate system monitoring; they form a basis for hydrological modelling with respect to possible effects of atmospheric warming, and provide fundamental information in glaciology, glacial geomorphology, and quaternary geology. The highest information density is found for the Alps and Scandinavia, where long and uninterrupted records are available. (http://www.geo.unizh.ch/wgms/)

GlobGlacier

The GlobGlacier supported by the European Space Agency (ESA) is yet another initiative that complements and strengthens the existing network for global glacier monitoring. The project will help to establish a global picture of glaciers and ice caps, and their role as Essential Climate Variables (ECVs). In this respect, the most requested issue is to complete the world glacier inventory (WGI) from the 1970s by producing glacier outlines in regions and to complement the point information already stored in the WGI by 2D information to allow change assessment. Moreover, GlobGlacier will integrate satellite data from various sensors to create value-added products for a wide range of user communities. A close cooperation with major user groups (e.g., WGMS) and related projects (e.g., GLIMS) will ensure the maximum benefit of the generated products from a global perspective. (http://globglacier.ch/)

WDC

The World Data Center for Glaciology and Geocryology, Lanzhou is a part of the World Data Center and is committed to the collection, saving, management, and analysis of the Chinese Cryosphere Database, which includes the Polar Regions and high Asia Regions. The collection of the glacier data is intended to contribute to the research on global climate change. (http://wdcdgg.westgis.ac.cn/)

GSI

The Geologic Survey of India has conducted advance studies like glacier mass balance and flow hydrometry of the Indian Himalayan glacier since 1978. (http://www.portal.gsi.gov.in)

For glacier data analysis, please use the companion manual: Training Manual on Application of Remote Sensing and Geographic Information Systems or Mapping and Monitoring of Glaciers, Part 2 (ICIMOD Manual 2017/11)

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