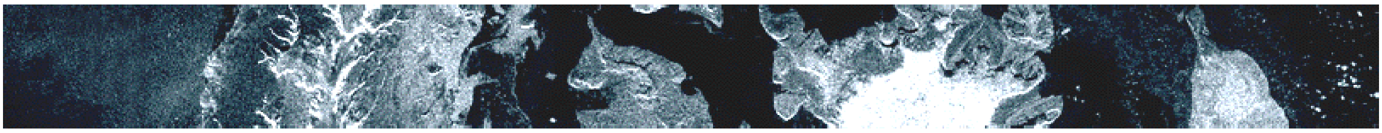

GLIMS Regional Center 'Antarctic Peninsula'

Illustrated GLIMS Glacier Classification Manual

Glacier Classification Guidance for the GLIMS Glacier Inventory

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1 Overview of glacier classification systems and instructions to homogenize glacier data compilation for GLIMS Glacier Inventory

1.1 Introduction

The detailed classification of a glacier is an important task during a GLIMS analysis session. To describe their morphological shape, a common terminology was established in order to evaluate different glacial types and features. Because of the enormous variety of glaciers around the world, it is often not easy to assign these glaciated forms one unambiguous expression.

The overall aim of each classification is to give an impression about the inner dynamics, the present state of development, and the surrounding climatic conditions of the glacier. Depending on the purpose of the observer, different kinds of methods were developed for classifying glaciers. Most common are various morphological and thermal classifications.

This document provides an overview on the World Glacier Monitoring Service (WGMS) glacier classification scheme (chapter 1.2)and proposes an expanded classification system to be used within the GLIMS research initiative (chapter 1.3). Furthermore, the illustrated GLIMS Glacier Classification Manual (chapter 2) provides practical guidance for the analysts in order to achieve an overall consistent and homogenous morphological classification of worldwide glaciers.

1.2 The World Glacier Monitoring Service (WGMS) glacier classification system

In 1970 the UNESCO first introduced, as a contribution to the International Hydrological Decade, a classification scheme for perennial snow and ice masses. The aim was to provide a useful database of glacial observations in a standardised, digital form. The system was designed to characterise the morphology of glaciers rapidly and precisely. The major advantage of this system was that it allowed the assignment of not only one characteristic, but several to the glacier. A series of six key parameters which describes various glacial characteristics, facilitates the subsequent compilation. By applying a matrix-type classification based on specific glaciological characteristics, this provides a defined number of values for each parameter. This system offers a multitude of possibilities for description of individual glaciers (Table 1). It has been adopted by the World Glacier Monitoring Service (WGMS; http://www.geo.unizh.ch/wgms/) in a revised form, and has proven its general applicability to over 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) which is located at the National Snow and Ice Data Center (NSIDC; http://nsidc.org).

Table 1: Parameters used to characterize the morphological shape of glaciers in the WGMS glacier classification system.

	Digit 1 Primary classification	**Digit 2 Form**	**Digit 3 Frontal characteristic**	**Digit 4 Longitudinal profile**	**Digit 5 Major source of nourishment**	**Digit 6 Activity of tongue**	**Digit 7 Moraine code 1**	**Digit 8 Moraine code 2**
0	Uncertain or miscellaneous	Uncertain or miscellaneous	Normal or miscellaneous	Uncertain or miscellaneous	Unknown	Uncertain	No moraines	No moraines
1	Continental ice sheet	Compound basins	Piedmont	Even, regular	Snow / Drift snow	Marked retreat	Terminal moraines	Terminal moraines
2	Ice-field	Compound basin	Expanded	Hanging	Avalanches	Slight retreat	Lateral and/or medial moraine	Lateral and/or medial moraine
3	Ice cap	Simple basin	Lobed	Cascading	Super-imposed ice	Stationary	Push moraine	Push moraine
4	Outlet glacier	Cirque	Calving	Ice-fall		Slight advance	Combination of 1 and 2	Combination of 1 and 2
5	Valley glacier	Niche	Coalescing, non contributing	Interrupted		Marked advance	Combination of 1 and 3	Combination of 1 and 3
6	Mountain glacier	Crater				Possible surge	Combination of 2 and 3	Combination of 2 and 3
7	Glacieret and snowfield	Ice apron				Known surge	Combination of 1,2 and 3	Combination of 1,2 and 3
8	Ice shelf	Group				Oscillating	Debris, uncertain if morainic	Debris, uncertain if morainic
9	Rock glacier	Remnant					Moraines, type uncertain or not listed	Moraines, type uncertain or not listed

1.3 The GLIMS (Global Land Ice Measurements from Space) glacier classification system

With the development of new methods over the last three decades, particularly in the field of remote sensing technologies using data from satellites, the capabilities of observing glaciers in detail has greatly improved. These new techniques now give the opportunity to observe glaciers in even the most remote regions, and to collect data from vast ice covered areas in a short time with little or no logistical effort.

The creation of a worldwide glacier inventory by means of satellite imagery is the major aim of the GLIMS program. This will be done primarily by the use of data from the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) instrument aboard the EOS Terra spacecraft. The spatial resolution of 15 meters gives excellent impression for optical analysis.

To realise the creation of the GLIMS glacier database, a network of Regional Centres (RC) was introduced, each working on a specific ice-covered area of the world. These RCs collect glacial data which will fill the new GLIMS glacier database. Due to the fact that there already exists a World Glacier Inventory (WGI), evaluated in many regions but still incomplete, there is great interest to adopt to this existing scheme so that data can be incorporated and transferred from and to the new GLIMS database. This forces the GLIMS database design to be flexible in order to compile as much data as possible or necessary. The expansion of the availability of glacier data from all regions of the world will make future investigation in glacial and climatic changes more easy and more precise. Furthermore, a major difference between GLIMS and the inventory of WGMS is the addition of GIS-like structures, where vector and raster datasets play a key role in the visualisation and analysis of glacial parameters and data storage.

1.3.1 Morphological glacier parameters of GLIMS

In taking the experience on glacier classification of WGMS one step further GLIMS is trying to improve the system and clarify especially instructions for data compilation. In general, there are many similarities between GLIMS and WGMS databases due to the adoption of WGMS description and coding used by GLIMS. Especially in the way the morphological features of a glacier is described and coded. The actual GLIMS database design (July 2003) comprises the following glacier morphology parameter classes to be used for characterisation of the morphology of glaciers (Table 2). They are displayed in the table GLACIER_DYNAMIC in the GLIMS database.

Table 2: Current and proposed GLIMS glacier morphology parameter classes.

Database parameters	Number of valid values (GLIMS, July 2003)	Number of valid values (suggestions from RC 18, May 2004)
Primary classification	10	11
Form	10	10
Frontal characteristics	6	13
Longitudinal characteristics	6	6
Dominant mass source	4	4
Tongue activity	9	9
Moraine code 1	-	10
Moraine code 2	-	10
Debris coverage of tongue	-	5

1.3.2 Glacier classification classes proposed for GLIMS

In alpine regions the WGMS glacial morphology description has proven practical for many years. However the vast variety of possibilities which occur worldwide, can sometimes be problematic. Initial observations at the RC "Antarctic Peninsula" would suggest that, despite the effectiveness of the WGMS classification scheme, further detail is necessary to accurately describe particular glacial features especially in polar regions. This has become evident in local case studies on the Antarctic Peninsula, and by looking at the Greenland Glacier Inventory published by WEIDICK et al. (1992), where changes in the compilation of glacier morphology have been made. Hereby, the preliminary results indicated that the enormous number of glaciers and the multiplicity of types and sizes could not be sufficiently represented using the current WGMS / GLIMS classification system. This has led the Regional Center "Antarctic Peninsula" to realise the necessity for system modification in some cases in order to guarantee accurate classifications (Table 2). Hereby, the integrity of the glacial classification depends mainly on two points:

- Accurate and specific class definitions to ensure the clarity for all users
- A variety of suitable classes that enable the description of glacier morphology in **all** regions of the world with the utmost of accuracy

Based on the current WGMS scheme, the GLIMS Regional Center "Antarctic Peninsula" proposes the following classification scheme (Table 3).

Table 3: Proposed parameters to characterize the morphological shape of glaciers in the expanded GLIMS glacier classification system.

	Digit 1 Primary classification	**Digit 2 Form**	**Digit 3 Frontal characteristic**	**Digit 4 Longitudinal profile**	**Digit 5 Major source of nourishment**	**Digit 6 Activity of tongue**	**Digit 7 Moraine code 1**	**Digit 8 Moraine code 2**	**Digit 9 Debris coverage of tongue**
0	Uncertain or miscellaneous	Uncertain or miscellaneous	Normal or miscellaneous	Uncertain or miscellaneous	Unknown	Uncertain	No moraines	No moraines	Uncertain
1	Continental ice sheet	Compound basins	Piedmont	Even, regular	Snow / Drift snow	Marked retreat	Terminal moraines	Terminal moraines	Debris free
2	Ice - field	Compound basin	Expanded	Hanging	Avalanche	Slight retreat	Lateral and/or medial moraine	Lateral and/or medial moraine	Partly debris covered
3	Ice cap	Simple basin	Lobed	Cascading	Superimposed ice	Stationary	Push moraine	Push moraine	Mostly debris covered
4	Outlet glacier	Cirque	Calving	Ice-fall		Slight advance	Combination of 1 and 2	Combination of 1 and 2	Completely debris covered
5	Valley glacier	Niche	Coalescing, non contributing	Interrupted		Marked advance	Combination of 1 and 3	Combination of 1 and 3	
6	Mountain Glacier	Crater				Possible surge	Combination of 2 and 3	Combination of 2 and 3	
7	Glacieret and snowfield	Ice apron				Known surge	Combination of1, 2 and 3	Combination of1, 2 and 3	
8	Ice shelf	Group				Oscillating	Debris, uncertain if morainic	Debris, uncertain if morainic	
9	Rock glacier	Remnant					Moraines, type uncertain or not listed	Moraines, type uncertain or not listed	
10	Ice stream		Calving & Piedmont						
11			Calving & Expanded						
12			Calving & Lobed						
13			Ice shelf nourishing						
14			Floating						
15			Terrestrial calving						
16			Confluent (contributing)						

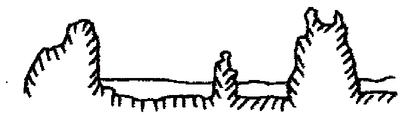
The expanded class definitions were achieved by improving the existing WGMS class definitions in a way suitable for many cases. To narrow the margin of error in choosing a specific value for classification, key words, from a so-called "Check-List", have been developed to assist in glacial parameter identification. The proposed "Check-List" will improve the accuracy of classification by means of greater detail in class definition. In addition to greater definition detail, ASTER images, and Photos have been added to the "Glacier Classification Manual" whenever possible.

The further addition of specific class definitions will not only assist in the accurate classification of the Antarctic Peninsula and other polar regions, but will be useful in all regions world wide. All proposed new classifications occurring in the "GLIMS Glacier Classification Manual" are represented by a double digit ID code, starting with 10. By this the WGMS classes can be maintained and keep their full information as they were compiled by now.

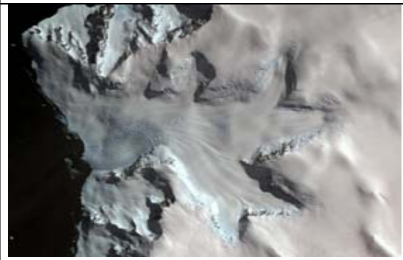
2 GLIMS Glacier Classification Manual

2.1 Primary classification

The 10 categories of the parameter group "Primary classification" attempt to classify glaciers into morphologically distinct units, which facilitate an identification of almost every type of glacier in the world. Combining these primary classification values with those of other parameter groups it becomes possible to typify also commonly known glacier types which seem to be "primary types" as like cirque glaciers, tidewater glaciers or hanging glaciers.

Name	**GLIMS glacier parameter identification checklist for remote sensing observations**	**Definition WGMS**	**Comments**	**Satellite Image / Photo / Graphics** (numbers in () refer to figure references in 2.10; 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)	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")	 Fig. 1 – **Ice field** (1)  Fig. 2 – **Ice field** (1)	**2**

	• Smaller than 50.000km^2 (approx. 220 x 220 km)		Excluded classification combinations: - Niche - Apron - Hanging - Cascading - Ice fall - Interrupted		Fig. 3 – **Ice field –** Uncertain or miscellaneous – Uncertain or miscellaneous – Even, regular– Snow (5)	
					Fig. 4 – **Ice field** – compound basins– Confluent – Even, regular– Snow (5)	
					Fig. 5 – **Ice field** (1)	
					Fig. 6 – **Ice field** (2)	

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) <u>Excluded classification combinations:</u> - not classifiable in "Form" at all - Therefore it is set " 0" - Hanging - Interrupted	 Fig. 7 – **Ice cap** (1)  Fig. 8 – **Ice cap** – Uncertain or miscellaneous – Lobed – Even, regular – Snow (5)	**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 <u>Excluded classification combinations:</u> - Cirque - Niche - Crater - Apron - Group	 Fig. 9 – **Outlet glacier** – Compound basin – Calving and expanded – Cascading – Snow (5)  Fig. 10 – **Outlet glacier** (4)	**4**

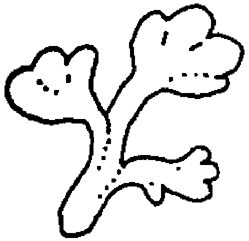
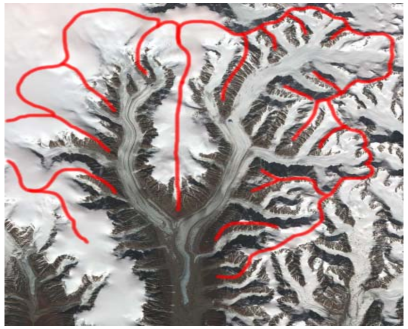
Valley glacier	• Accumulation area is clearly defined and limited by the topography • Ice free slopes normally overlook glacier surface • Follows a pre-existing valley	Flows down a valley; the catchment area is well defined	Excluded classification combinations: - Cirque - Niche - Apron - Group	 	Fig. 11 – **Valley glacier** – Comp. basin – Normal – Cascading – Snow (5) Fig. 12 – **Valley glacier** (1)	**5**
Mountain glacier	• Glaciers adhering to mountain sides, and fitting in no other primary classification pattern • E.g. Cirque-, Niche-, 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	 	Fig. 13 – **Mountain glacier** – Single basin – Calving – Cascading – Snow (5) Fig. 14 – **Mountain glacier** (1)	**6**

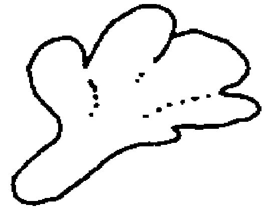
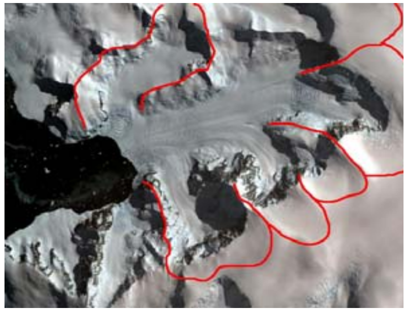
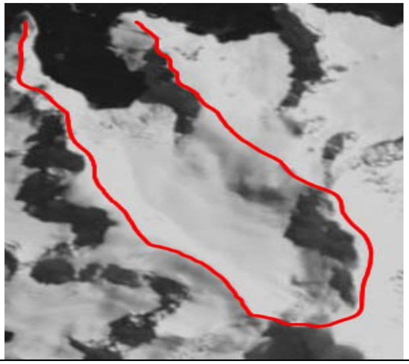
Glacieret and snowfield	• Very small ice or snow masses • Virtually no ice movement • Accumulation and ablation area not always clearly detectable	Small ice masses of indefinite shape in hollows, river beds and on protected slopes, which has developed from snow drifting, avalanching and/or especially 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 <u>Excluded classification combinations:</u> - Compound basins - Compound basin - Piedmont - Expanded - Lobed	 Fig. 15 – **Glacieret** (2)	**7**
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 effected 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. <u>Excluded classification combinations:</u> - Is not classifiable in "Form" - Longitudinal profile is always even/regular	 Fig. 16 – **Ice shelf** – Uncertain or miscellaneous – Floating – Even – Snow (MODIS)  Fig. 17 – **Ice shelf** (4)	**8**

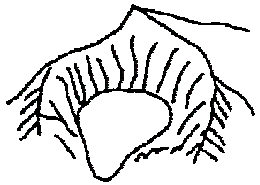
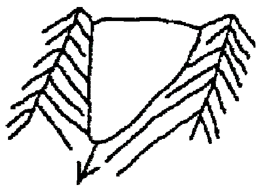
Rock glacier	• Lava stream like debris mass containing interstitial ice • Movement is primarily due to debris mass under the influence of gravity, and not due to ice flow patterns • Not a debris covered glacier, but permafrost phenomenon	A glacier-shaped mass of angular rock in a cirque or valley either 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 down slope (**WGMS 1998**)	• A debris covered glacier is not necessarily a rock glacier. To distinguish between rock glaciers and debris covered glaciers the parameter group "Debris coverage of tongue" is offered. <u>Excluded classification combinations:</u> - Compound basins - Aprons		Fig. 18 – **Rock glacier** – remnant – normal – even – uncertain (2)	**9**
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**

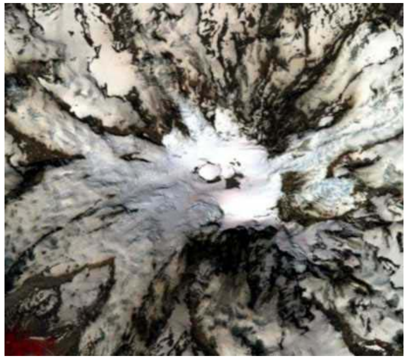
2.2 Form

The parameter group "Form" essentially describes the outline of a glacier. Most categories do also correspond to the catchment area and therefore give important information on the extent and the shape of a glacier. To get an impression about the whole accumulation basin, a DEM is very helpful in facilitating automatic delineation of glacier catchment areas. Due to the fact that 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 do not have to be classified in "Form" any more and are set "0" (this includes i.e. "Ice shelf" and "Ice cap" or in some cases "Ice fields" and "Mountain glaciers").

Name	**GLIMS glacier parameter identification checklist for remote sensing observations**	**Definition WGMS**	**Comment**	**Satellite Image / Photo / Graphics** (numbers in () refer to figure references in 2.10; 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		 Fig. 19 – **Compound basins** (3)  Fig. 20 – Outlet glacier - **Compound basins** – normal – Cascading – Snow (5)	**1**

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	 Fig. 21 – **Compound basin** (3)  Fig. 22 – Outlet glacier – **Compound basin** – Calving- Interrupted – Avalanche (5)	**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)	 Fig. 23 – **Simple basin** (3)  Fig. 24 – Outlet glacier – **Simple basin** – Calving – Even – Snow (5)	**3**

Cirque	• Located in an arm chair shaped bedrock hollow • No tongue developed, in contrast to simple basin • As wide or even wider as their length • Catchmant area is created through the process of glacial erosion	Occupies a separate, rounded, steep-walled recess which it has formed on a mountain side	<u>Excluded classification combinations:</u> - Piedmont	 Fig. 25 – **Cirque** (3)  Fig. 26 – Mountain glacier – **Cirque** – Normal – Even – Snow (5)  Fig. 27 – **Cirque** (1)	**4**
Niche	• Small glaciers in v-shaped couloirs or depressions • Adhering 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**)	<u>Excluded classification combinations:</u> - Piedmont - Expanded	 Fig. 28 – **Niche** (3)	**5**

Crater	• Glaciers in and / or on volcano craters • Network of glacier 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**)		 	Fig. 29 – **Crater** (Photo: Peter Knight) Fig. 30 – Mountain glacier – **Crater** – normal – even – Snow (5)	**6**
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 covered mountain flank (ice flanks or steep "ice fields") <u>Excluded classification combinations:</u> - Piedmont - Expanded - Cascading	 	Fig. 31 – **Ice apron** (1) Fig. 32 – **Ice apron** (1)	**7**

Group	• Neighbouring 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**

2.3 Frontal Characteristic

To make the Frontal Characteristic classification more precise we propose modifications to the WGMS system. 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 were kept to a minimum in order to maintain the compatibility to 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 on their entire extent on bedrock and do not have any contact to 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 or where there is no more topographic limitation it might expand.

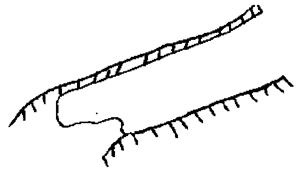
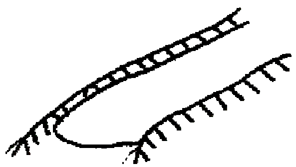
Name	**GLIMS glacier parameter identification checklist for remote sensing observations**	**Definition WGMS**	**Comment**	**Satellite Image / Photo / Graphics** (numbers in () refer to figure references in 2.10; if present: Primary classification - Form - Frontal Characteristics - Longitudinal Profile - Major source of nourishment)	**Code**
Normal or miscellaneous	• The entire width of the tongue terminates on dry ground • Irregular or single lobe frontal line	Normal or miscellaneous		 Fig. 33 – Outlet glacier – Simple basin – **Normal** – Cascading – Snow (5)  Fig. 34 – **Normal**; example of normal frontal characteristic with irregular tongue (1)  Fig. 35 – **Normal;** example of normal frontal characteristic with single lobed tongue (1)	**0**

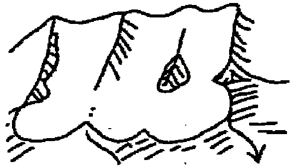
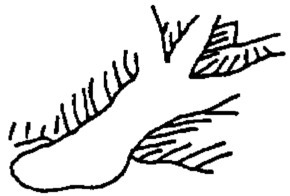
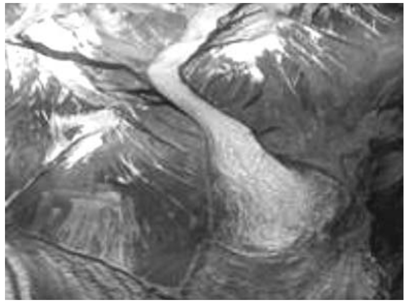
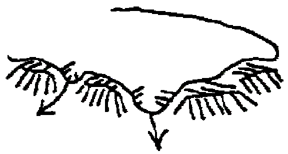
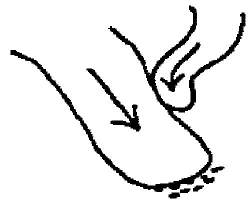
				 Fig. 36 – **Normal**, “single lobe” (4)	
Piedmont	• Occurs in unconstrained topographic areas (lowland) • Expanding glacial fronts • Radial frontal shape • “Terrestrial glaciers” • If it terminates into sea, use class “calving and piedmont”!	Icefield formed on a lowland by lateral expansion of one or coalescence of several glaciers		 Fig. 37 – **Piedmont** (3)  Fig. 38 – **Piedmont** (3)  Fig. 39 – Outlet glacier – Compound basin – **Piedmont** – Cascading – Snow (5)	**1**

				 Fig. 40 – **Piedmont** (4)	
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 on 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 on to a less restricted and more level surface. Lateral extension markedly less than for piedmont. (**WGMS 1977**)		 Fig. 41 – **Expanded** (3)  Fig. 42 – **Expanded**(2)	**2**
Lobed	• Initial stage of tongue formation (occurs on both micro and macro scales) • In many cases part of an ice sheet, cap, field • Large or small scale radial ice margin • Is not an outlet or a valley glacier • "Terrestrial glaciers" • If it terminates into	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**)		 Fig. 43 – **Lobed** (3)	**3**

	sea, use class "calving and lobed"!				Fig. 44 – Ice cap – Uncertain – **Lobed** – Even – Snow (5)	
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"	 	Fig. 45 – Outlet glacier – Compound basin – **Calving** – Even – Snow (5) Fig. 46 – **Calving** (2)	**4**

Coalescing, non contributing	• Glaciers whose tongues come together and flow in parallel without coalescing • No merging of ice masses	See Fig. 47 (WG**MS 1970, 1998**) Glaciers whose tongues come together and flow in parallel without coalescing (**WGMS 1977**)		 Fig. 47 – **Coalescing, non contributing** (3)	**5**
Calving and Piedmont	• Combination of Calving and Piedmont	-		 Fig. 48 – Outlet glacier – Compound basins – **Calving and Piedmont** – Even – Snow (5)	**10**
Calving and Expanded	• Combination of Calving and Expanded	-		 Fig. 49 – Outlet glacier – Compound basins – **Calving and Expanded** – cascading – Snow (5)	**11**

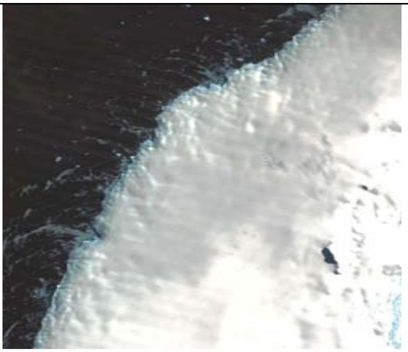
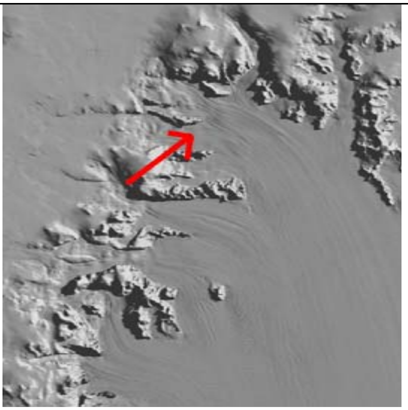
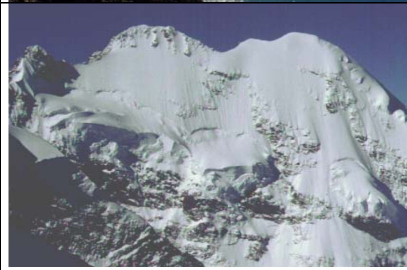
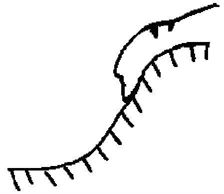
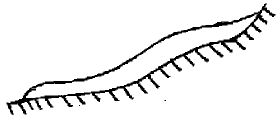
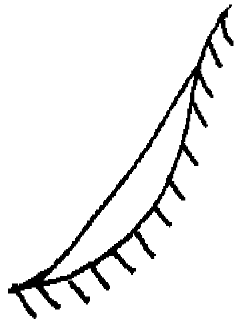
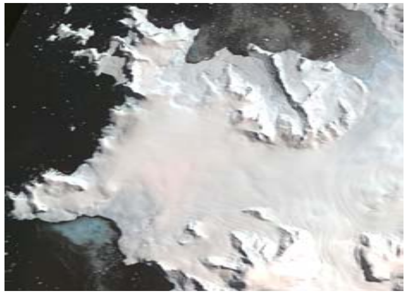
Calving and Lobed	• Combination of Calving and Lobed • "Grounded glaciers"	-			Fig. 50 – Ice cap – Uncertain – **Calving and lobed** – Even – Snow (5)	**12**
Ice shelf nourishing	• Glaciers which are tributaries of an ice shelf • Approximate grounding line may be detectable	-	• This class has been introduced due to the necessity for classifying glaciers which are tributaries of an ice shelf.		Fig. 51 – Outlet glacier – Simple basin **– Ice Shelf nourishing** – Cascading – Snow (5)	**13**
Floating	• Glacier terminus is floating in the sea • Approximate grounding line may be detectable • Tidewater glacier • Implies that the glacier is calving	-			Fig. 52 – Outlet glacier – Compound basin – **Floating** – Cascading – Snow (5)	**14**

					Fig. 53 – **Floating** (1)	
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.	 	Fig. 54 – **Terrestrial calving** (1) Fig. 55 – **Terrestrial calving** (1)	**15**
Confluent	• Tributary glacier tongues that merge into other glaciers • Merging ice masses	-			Fig. 56 – <1> Outlet glacier – Compound basins – normal– cascading – Snow <2> Valley glacier – Compound basin – **Confluent** – Cascading – Snow (5)	**16**

2.4 Longitudinal characteristics

The Longitudinal characteristic encodes the description of the surface profile of a glacier.

Name	**GLIMS glacier parameter identification checklist for remote sensing observations**	**Definition WGMS**	**Comment**	**Satellite Image / Photo / Graphics** (numbers in () refer to figure references in 2.10; if present: Primary classification - Form - Frontal Characteristics - Longitudinal Profile - Major source of nourishment)	**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**)		 Fig. 57 – **Even** (1)  Fig. 58 – **Even** (1)  Fig. 59 – Ice field – Uncertain or miscellaneous – Uncertain or miscellaneous – **Even**, regular– Snow (5)	**1**

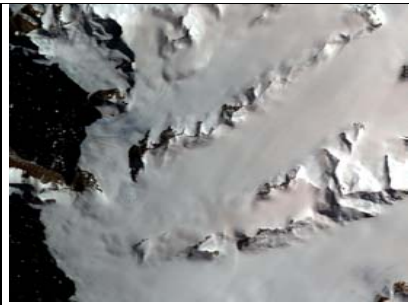
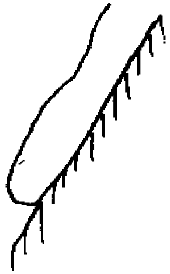
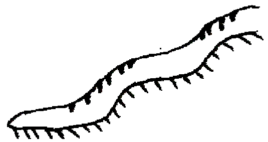
				 Fig. 60 – **Even** (5)	
Hanging	• Hanging only • No connection with mountain foot • up to 60° slope	Perched on a steep mountain-side or issuing from a hanging valley (**WGMS, 1970**) Perched on a steep mountain-side or issuing from a steep hanging valley (**WGMS, 1977**) Not included in (**WGMS, 1995**)		 Fig. 61 – **Hanging** (1)  Fig. 62 – **Hanging** (1)	**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**)		 Fig. 63 – **Cascading** (1)	**3**

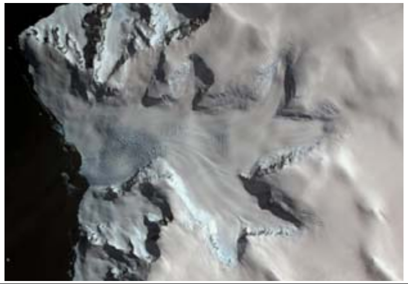
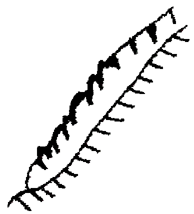
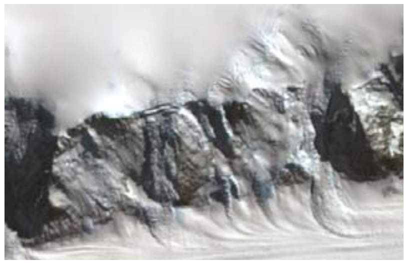
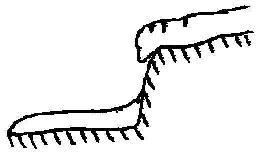
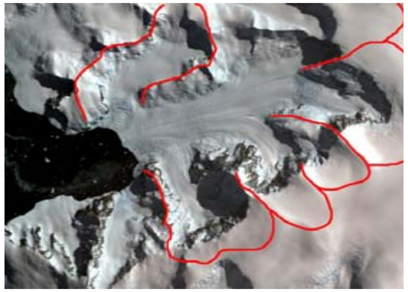
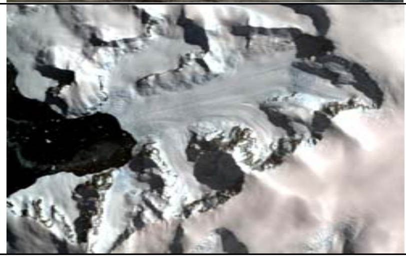
				 Fig. 64 – **Cascading** (1)  Fig. 65 – Outlet glacier – Compound basin – Calving – **Cascading** – Snow (5)	
Ice-fall	• Closed ice cover over a steep mountain side • Entirely crevassed with many seracs	Break above a cliff, with reconstitution to a cohering ice mass below (**WGMS, 1970**) A glacier with 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.	 Fig. 66 – **Ice-fall** (1)  Fig. 67 – **Ice-fall** (5)	**4**

				 Fig. 68 – **Ice-fall** (1)	
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!	 Fig. 69 – **Interrupted** (1)  Fig. 70 – Outlet glacier – Compound basin – Calving- **Interrupted** – Avalanche (5)  Fig. 71 – **Interrupted** (4)	**5**

2.5 Major source of nourishment

The Dominant mass source values are in some cases 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.

Name	GLIMS glacier parameter identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image / Photo / Graphics (numbers in () refer to figure references in 2.10; if present: Primary classification - Form - Frontal Characteristics - Longitudinal Profile - Major source of nourishment)	Code
Unknown	• Unknown	Unknown			**0**
Snow / Drift snow	• Snow • Wind transported snow and accumulation in lee sides • Hoar	Snow and / or drift snow		 Fig. 72 – **Drift snow** (1)	**1**
Avalanches	• Snow avalanches • Ice avalanches	Avalanche ice and / or avalanche snow		 Fig. 73 – Outlet glacier – Compound basin – Calving-Interrupted – **Avalanches** (5)	**2**
Super-imposed ice	• Superimposed ice	Superimposed ice			**3**

2.6 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. The proposed rates should be regarded as a rough estimation, as for example a 20 m recession of a glacieret of 150 m length will be definitely be marked retreat, whereas in contrast a 30 m retreat of an outlet glacier would be only a slight retreat.

Name	GLIMS glacier parameter identification checklist for remote sensing observations	Definition WGMS	Comment	Code
Uncertain	• Uncertain, unknown or not measured	Uncertain		**0**
Marked retreat	• Marked retreat	More than 20 m 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 advancing		**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**

2.7 Moraine code 1 (in contact with present day glacier)

To characterise the morphology of glaciers, the World Glacier Inventory (WGI) has introduced a moraine code. It consists of two fields, one describing moraines in contact with present day glaciers, and the other describes moraines farther downstream. These two classes are neither described by the WGMS nor currently used by GLIMS. In fact it would make sense to add these two classes to the GLIMS database despite the fact that there will be glacier boundaries implemented (vector type) which outline moraines. Recently published glacier inventories have shown interest in storing data on the extent of debris coverage of glaciers. By the fact that automatic acquisition processes can be developed to assess this information, it would make sense to give at least the opportunity to compile the moraine code. Therefore it is suggested to introduce this class into the GLIMS database which gives the opportunity to indicate the debris coverage of the glacier surface.

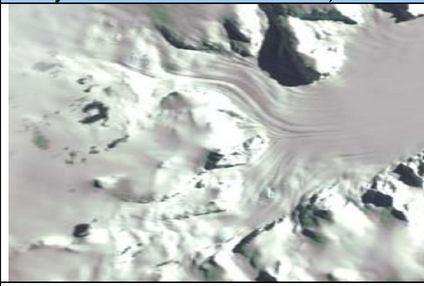
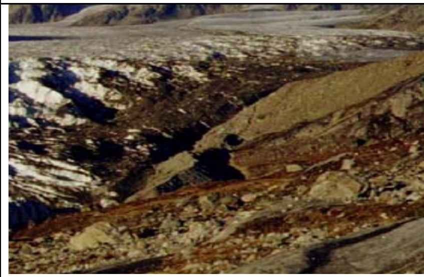
Name	**GLIMS glacier parameter identification checklist for remote sensing observations**	**Definition WGMS**	**Comment**	**Satellite Image / Photo / Graphics** (numbers in () refer to figure references in 2.10; if present: Primary classification - Form - Frontal Characteristics - Longitudinal Profile - Major source of nourishment)	**Code**
No moraines	• No moraines	No moraines		 Fig. 74 – Outlet glacier – Compound basin – Shelf nourishing – Cascading – Snow – Uncertain – **No moraine** (5)	**0**
Terminal moraines	• Terminal moraines	Terminal moraines	• Sometimes problematic to identify in satellite imagery due to the lack of distinction between terminal moraine and debris surface coverage of a glacier.		**1**
Lateral and/or medial moraine	• Lateral and/or medial moraine	Lateral and/or medial moraine	• Sometimes problematic for detection by means of remote sensing techniques due to the lack of distinction between lateral moraine and debris surface coverage of a glacier.	 Fig. 75 – **Lateral moraine** (1)	**2**

				 Fig. 76 – **Medial moraine** (1)	
Push moraine	• Push moraine	Push moraine	• Push moraines are difficult to identify unambiguously by remote sensing techniques, because in satellite images they are often not distinguishable from "normal" terminal moraines.		**3**
Combination of 1 and 2	• Combination of 1 and 2	Combination of 1 and 2			**4**
Combination of 1 and 3	• Combination of 1 and 3	Combination of 1 and 3	• Difficult to identify because of push moraine		**5**
Combination of 2 and 3	• Combination of 2 and 3	Combination of 2 and 3	• Difficult to identify because of push moraine		**6**
Combination of 1,2 and 3	• Combination of 1,2 and 3	Combination of 1,2 and 3	• Difficult to identify because of push moraine		**7**
Debris, uncertain if morainic	• Debris, uncertain if morainic	Debris, uncertain if morainic			**8**
Moraines, type uncertain or not listed	• Moraines, type uncertain or not listed	Moraines, type uncertain or not listed			**9**

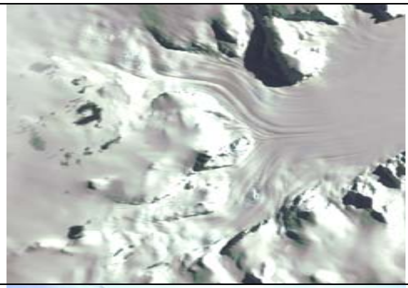
2.8 Moraine code 2 (moraines farther downstream)

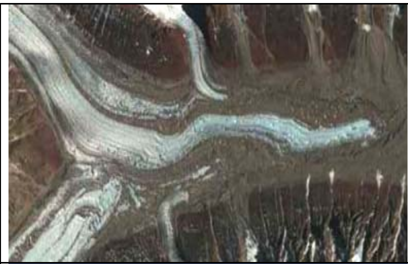
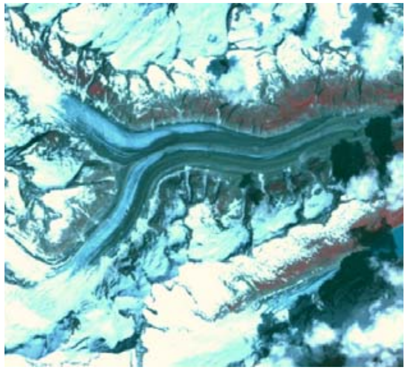
Name	GLIMS glacier parameter identification checklist for remote sensing observations	Definition WGMS	Comment	Satellite Image / Photo / Graphics (numbers in () refer to figure references in 2.10; if present: Primary classification - Form - Frontal Characteristics - Longitudinal Profile - Major source of nourishment)	Code
No moraines	• No moraines	No moraines			**0**
Terminal moraines	• Terminal moraines	Terminal moraines		 Fig. 77 – Valley glacier – Compound basin – Calving-cascading – Snow – Uncertain – **Terminal moraine** (5)  Fig. 78 – **Terminal moraine** (1)	**1**
Lateral and/or medial moraine	• Lateral and/or medial moraine	Lateral and/or medial moraine		 Fig. 79 – **Lateral moraine** (1)	**2**

Push moraine	• Push moraine	Push moraine	• Push moraines are difficult to identify unambiguously by remote sensing techniques, because in satellite images they are often not distin-guishable from "normal" terminal moraines. The only way to identify push moraines is by ground observations		**3**
Combination of 1 and 2	• Combination of 1 and 2	Combination of 1 and 2			**4**
Combination of 1 and 3	• Combination of 1 and 3	Combination of 1 and 3	• Not detectable because of push moraine		**5**
Combination of 2 and 3	• Combination of 2 and 3	Combination of 2 and 3	• Not detectable because of push moraine		**6**
Combination of 1,2 and 3	• Combination of 1,2 and 3	Combination of 1,2 and 3	• Not detectable because of push moraine		**7**
Debris, uncertain if morainic	• Debris, uncertain if morainic	Debris, uncertain if morainic			**8**
Moraines, type uncertain or not listed	• Moraines, type uncertain or not listed	Moraines, type uncertain or not listed			**9**

2.9 Debris coverage of tongue

Debris cover of a glacier has a great influence on its mass balance. This is especially due to the change of the albedo of the glacier surface for thin debris, or the insulating effect of a thicker debris cover. It has to be pointed out, that this class only refers to optical thick supraglacial debris covers composed of pebbles, stones and boulders, whereas a temporary coverage of a glacier tongue with dust, ash and soot (e.g. at the end of an ablation season) should no be classified as a debris cover.

Name	**GLIMS glacier parameter identification checklist for remote sensing observations**	**Definition WGMS**	**Comment**	**Satellite Image / Photo / Graphics** (numbers in () refer to figure references in 2.10)	**Code**
Uncertain	• Uncertain, unknown or not identifiable				**0**
Debris free	• Almost no debris coverage on the glacier surface	• Clean ice		 Fig. 80 – **Debris free** (5)	**1**
Partly debris covered	• More than 10% and less than 50% of the glacier surface in the ablation area is debris covered • Patchy distribution			 Fig. 81 – **Partly debris covered** (1)	**2**

Mostly debris covered	• More than 50% and less than 90% of the glacier surface in the ablation area is debris covered • Continuously dis-tributed debris cover				Fig. 82 – **Mostly debris covered** (5)	**3**
Completely debris covered	• Almost the entire ablation area is covered by debris	• Debris covered ice		 	Fig. 83 – **Debris covered ice** (1) Fig. 84 – **Debris covered ice** (5)	**4**

2.10 Figure References

(1) Mauz, Fabian (Institute for Physical Geography, University of Freiburg)

(2) NSIDC Glacier Glossary: http://nsidc.org/glaciers/glossary/index.html

(3) UNESCO (1970): *Perennial ice and snow masses. A guide for compilation and assemblage of data for a World Glacier Inventory*. UNESCO/IAHS Technical Papers in Hydrology Nr.1.

(4) De Angelis, Hernán (Instituto Antártico Argentino, Buenos Aires)

(5) ASTER Satellite Image

3 Acknowledgements

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4 Bibliography and recommended literature

ARMSTRONG, T., ROBERTS, B. & SWITHINBANK, C. (1966): Illustrated Glossary of Snow and Ice. Cambridge University Press, Cambridge.

BENN, D. & EVANS, D. (1998): Glaciers and Glaciation. Arnold, London.

EVANS, S. E. & COX, N. J. (2001): Editing glacier inventories to provide reliable baselines for studies of change: consistency between Alpine countries. Unpublished draft from Alpine Glaciology Meeting in Munich (Feb. 2001)

KNIGHT, P. (1999): Glaciers. Stanley Thornes, Cheltenham.

PATERSON, W.S.B. (1994): Physics of Glaciers. Pergamon, London.

SUGDEN, D. & JOHN, B. (1976): Glaciers and Landscape. Arnold, London.

UNESCO (1970): Perennial ice and snow masses. A guide for compilation and assemblage of data for a World Glacier Inventory. UNESCO/IAHS Technical Papers in Hydrology Nr.1, Paris.

UNESCO/IAHS(ICSI)/UNEP (1977): Instructions for a compilation and assemblage of data for a World Glacier Inventory (Müller, F.; Calflisch, T. & Müller, G.). Temporal Technical Secretariat for the World Glacier Inventory (TTS/WGI), Zürich.

UNESCO/IAHS (1998): Fluctuations of Glaciers 1990-1995, Paris.

WEIDICK, A., BOEGGILD, C. E. & KNUDSEN, N. T. (1992): Glacier inventory and atlas of West Greenland. Rapport Groenlands Geologiske Undersoegelse, 158.

WILHELM, F. (1975): Schnee- und Gletscherkunde. Walter de Gruyter, Berlin.

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