User requirements for the Snow and Land ice services - CryoLand

E. Malnes[1], A. Buanes[1], T, Nagler[2], G. Bippus[2], D. Gustafsson[3], C.Schiller[4], S. Metsämäki[5], J. Pulliainen[6], H.E. Larsen[7], R. Solberg[8], A. Diamandi[9], and A. Wiesmann[10]

[1] {Norut, Tromsø, Norway}

[2] {ENVEO, Innsbruck, Austria}

[3] {Swedish Meteorological and Hydrological Institute, Norrkjöping, Sweden}

[4] {EOX, Vienna, Austria}

[5] {Finish Environmental Institute, Helsinki, Finland}

[6] {Finish Meteorological Institute, Helsinki, Finland}

[7] {Kongsberg Satellite Services, Tromsø, Norway}

[8] {Norwegian Computing Centre, Oslo, Norway}

[9] {Administratia Nationala de Meteorologie, Bucharest, Romania}

[10] {Gamma Remote Sensing, Bern, Switzerland}

Correspondence to: E.Malnes (eirik@norut.no)

Abstract

CryoLand (2011-2015) is a project carried out within the 7th Framework of the European Commission aimed at developing downstream services for monitoring seasonal snow, glaciers and lake/river ice primarily based on satellite remote sensing. The services target private and public users from a wide variety of application areas, and aim to develop sustainable services after the project is completed. The project has performed a thorough user requirement survey in order to derive targeted requirements for the service and provide recommendation for the design and priorities of the service. In this paper we describe the methods used, the major findings in this user survey, and how we used the results to design and specify the CryoLand snow and land ice service.

The user requirement analysis shows that a European operational snow and land ice service is required and that there exists developed cryosphere products that can meet the specific needs. The majority of the users were mainly interested in the snow services, but also the lake/river ice products and the glacier products were desired.

1 Introduction

Several international organization and projects devoted to remote sensing of the cryosphere have reviewed the requirements from their users for future products and services targeting different application fields (GCOS 2006; Malenovský et al., 2012). This paper reviews recent requirements for snow, lake/river ice and glacier products and services in addition to documenting our own user survey, and finally presents consolidated user requirements, which were used throughout the CryoLand project to design optimal products and services serving a field of applications.

CryoLand is an EU funded research project aimed at developing, implementing and validating a standardized and sustainable service on snow and land ice monitoring as a downstream service within Copernicus (The European Earth observation programme) in a value added chain with the Copernicus Land Monitoring Services. The CryoLand project team consists of private and public research institutes, small and medium sized companies and satellite image providers. According to the project plan (www.cryoland.eu) the service will provide geospatial products on the seasonal snow cover (snow extent, snow mass, melt state), glaciers (area, snow / ice extent, ice velocities, glacier dammed lakes), and lake/river ice (extent, temporal variations, snow burden) derived from Earth observation satellite data in response to user needs. Operational processing lines and service infrastructure for various product types will be developed on top of existing web service environments (decentralized business process architectures) supporting the publication, provision and chaining of geospatial data services. User information services offering interactive map search and order functions via Web browsers will be designed in a corporate “CryoLand Geoportal”. Full end-to-end system tests and verification in pre-operational environment has been performed in cooperation with users in near real time. Finally, the transition of the services developed within the project to an operational self-supportive snow and ice monitoring service is planned.

The objective of the user survey was to ask potential customers about their expectations and needs for a snow and land ice service. Their answers and additional requirements derived

from user surveys in previous projects and reports from major stakeholders within hydrology and cryosphere research is subsequently analysed in order to derive the consolidated user requirement in CryoLand which has been used throughout the project as a steering instrument in the service development.

2 Methods

CryoLand used multiple approaches to obtain as much information as possible from the users before the products and services were developed and specified. This secures that the service was in line with user needs and expectations. The methods applied were to review requirements from previous cryosphere monitoring projects, to perform web-based user surveys and discussing products and services with users directly in user workshops. The wide aspects of collected requirements finally enable us to define services and products for a wider European market. Figure 1 gives an overview of the methods applied to derive the user requirements.

2.1 Review of published requirements on snow and land ice products

Before the initiation of the user survey, the project performed a thorough review of previous user surveys and user recommendations for snow, glacier and lake/rivers ice products and web map services as specified by international working groups and organisations as well as from projects carried out since 2000. The analysed projects, their funding, and type of products they cover are listed in Table 1.

The Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (United Nations Framework Convention on Climate Change) (GCOS, 2010) serves as the basic document on observations of climate variables including parameters from the seasonal snow pack, glaciers and lake/river ice. It is compiled under the guidance of GCOS Steering Committee, with feedback from several hundreds of international experts.

Recommendations and requirements for cryospheric observations were published in the IGOS Cryosphere Theme report (IGOS, 2007). It emphasizes the need for sharing cryospheric observations and data products due to the high costs and importance of satellite instruments for the delivery of consistent observations of the global cryosphere. The primary snow product is a continuous data record of snow extent on global scale. Wet snow should also be monitored consistently with current sensors, while snow depth and SWE are highly desirable, and require investments in sensors and research to become observable at a suitable

scale/accuracy~~Snow water equivalent, snow depth and wet snow are mentioned as highly desirable variables.~~ Lake/river ice is not directly mentioned in the list of essential climate variables (ECV), it is relevant through lake temperature which linked to the lake freeze-up and break-up dates, serving as an indicator for regional climate modelling purposes.

2.1.1 Snow

The EU project EnviSnow (2002-2005) developed multi-sensor algorithms for retrieving snow information from earth observation data The EnviSnow user requirement assessment (EnviSnow, 2005) documented after a questionnaire that the main users requested regularly available accurate information on Snow Water Equivalent (SWE) and Snow Cover Fraction (SCF). Some users request snow mass and/or Snow cover Extent (SE), which we in this paper regard as parallel products with similar information content. The main application area is improved runoff forecast by assimilation of snow products into hydrological models. Specific recommendations were given on thematic accuracy and spatial and temporal resolution for in particular SWE and SCF products.

The ESA project GlobSnow (2008-2014; http://www.globsnow.info) derived its user requirements from a review meeting where representatives from several international agencies were present. GlobSnow partners concluded that snow monitoring products shall represent harmonized and globally consistent observations of the snow cover independent of sensor, landscape or algorithm. All provided products were requested to be validated against in-situ data and quality controlled. Based on the requirements from the users, the GlobSnow consortium developed a daily, weekly and monthly snow water equivalent (SWE) product starting from 1978 and for the snow extent from 1995.

2.1.2 Glaciers

The ESA ECV Glaciers and Icecaps addresses three products, namely: glacier outlines (area), glacier surface elevation change, glacier surface velocity. All products shall meet the quality recommendations defined in the IGOS Cryosphere Theme Report (IGOS, 2007).

A main international initiative for world-wide observation of glaciers is the Global Land Ice Measurement from Space (GLIMS) project (Bishop et al., 2004; Raup et al., 2007). GLIMS is a cooperative effort of over sixty institutions world-wide with the goal of inventorying a majority of the world's estimated more than ~~160000~~ 198000 glaciers. The GLIMS Glacier

Database is accessible at http://glims.org.~~http://nsidc.org/glims/.~~ GLIMS list basic glacier parameters such as glacier outlines, centrelines, snowlines, etc., to be derived from the satellite data, but does not define a quantitative list of requirements.

2.1.3 Lake and river ice

The ESA project STSE North Hydrology (2010-2013) has documented user requirements related to lake / river ice observations (Fernández-Prieto et al., 2012). The document contains the scientific and operational requirements associated with the major themes of the North Hydrology project. The users include CliC scientific community, the numerical weather prediction (NWP) and regional climate modelling (RCM) community, the hydrology community, and national and regional operational authorities. The main findings in the North Hydrology project are that the user groups highly desires to acquire satellite products from surface temperature and ice cover (fractional coverage) to be used in assimilation in climate models. Also within hydrological modelling the project identified a growing interest in river and lake ice products.

2.1.4 Infrastructure

Reviewing the spatial data infrastructure and service needs of various initiatives and projects it has been found that Open Geospatial Consortium (OGC) web services are being used for service provisioning and data access. Due to the complexity of environmental algorithm developments, data fusion and information provisioning it seems that distributed web services, installed at the location of best expertise in combination with organisations which get funded to provide sustainable services could provide the high quality and reliability of the information needed.

The EU INSPIRE directive encourages sharing spatial data free of charge. INSPIRE intends to trigger the creation of a European spatial information infrastructure that delivers to the users integrated spatial information services. These services should allow the users to identify and access spatial or geographical information from a wide range of sources, from the local level to the global level, in an interoperable way for a variety of uses. Most of the documents reviewed have adopted the idea of free data policy. Most of the products should be free of charge for all relevant users. However, tailored products for customers like industry would be chargeable in order to allow sustainable services to operate.

2.2 Identification of potential users

Parallel to the review of user requirements from previous projects, the CryoLand project partners identified potential users and user segments that should be approached for the user survey. An exhaustive list of institutions and contact persons was developed and maintained in a spreadsheet. The list contained users from the user segments hydrology, hydropower, climate research, environment conservation, avalanche monitoring, road maintenance etc. CryoLand contacted users in most European countries, but, as expected, the main response and interest was obtained from countries where snow and land ice plays a major role such as Nordic and Alpine countries.

2.3 User workshops

In May/June 2011 four user workshops were held in Vienna, Oslo, Helsinki and Bucharest to address users from mid/south Europe and northern Europe, respectively. At the user workshops the status of the product and service portfolio available at the CryoLand partners were presented, and the users discussed and commented on all parts of the products and services. After the first year of the project a new user conference was held in Stockholm in May 2012 to discuss and consolidate the proposed products and services. The user inputs from the workshops were properly documented in minutes and also played an important part in the final user requirements and specification of the products and services.

2.4 User survey

A questionnaire was designed based on the review from previous projects. The partners in CryoLand refined the questionnaire several times to assure that the questions covered all aspects of the project. The questionnaire was organized in six sections:

a) General information on the user, including contact person, address etc.

b) Present status of using snow and ice information in the organization

c) Specific requirements for snow products

d) Specific requirements for glacier products

e) Specific requirements for lake/river ice products

f) Technical information on service interfaces and services itself.

The questionnaire closes with the question if users are joining the CryoLand user group.

The questionnaire was implemented as a web-questionnaire in the software tool Enalyzer (www.enalyzer.com). The questionnaire was launched on 6 June 2011 for the Alpine users and on 9 June 2011 for Nordic users, synchronized with user workshops in the respective areas. A total of 47 users from 37 organisations completed the questionnaire.

3 Results

The results from the user survey were organized in different sections according to thematic products and technical questions related to the service.

3.1 General questions – user characteristics

A total of 47 users completed the questionnaire. The majority of responding users are from Austria, Norway and Sweden, but the Czech Rep., Denmark, Finland, Germany, Romania, Italy and Switzerland were also represented among the users. Figure 2 shows a histogram representation of the users that responded to the survey, and the geographical distribution of the users.

A diversity of organization types were represented (Table 2), but the largest organisation type was national authorities (25%). It should be noted that some of the users selected more than one type of organization (e.g. national and scientific). Although, a clear majority of the users represent the public sector (national, regional, scientific), there is also a significant amount of interest among several of the other organisation types.

The users were also asked to estimate the number of employees in their organization. The number ranged from1 to 5000 employees with a mean number of employees around 400 and a median number around 200. This indicates that the bulk of the user organizations are rather large and typical public organizations.

The respondents indicated also their main application area. Avalanche and road management, hydrology and flood forecast, glaciology, weather forecast, vegetation research and climate research. Figure 3 shows the how the application areas are distributed among the respondents. Depending on their application area, the users provided a wide variety of desired product types or services in an open section of the questionary. There was a geographical bias in some of the application areas (e.g. glaciology and lake/river ice), but few responders in each

country yields inconclusive findings with respect to the geographical distribution of the application areas

In the general section of the user survey, the users were also asked to indicate which of the 3 product categories (snow, lake/river ice and glacier) they were interested in. 84% responded that snow products was important, around 24% regarded lake ice and 24% glacier products as important.

3.2 User requirements for snow ~~cover~~ service

91% of the respondents were interested in snow products. Most users (84%) regarded the ~~snow cover and~~ snow fraction products as important, the low resolution snow water equivalent (SWE) product was ranked high by 55%, whereas the other had ratings between 34-46% ranked in descending order: Melting snow, statistical snow extent, surface wetness, albedo maps, snow surface temperature (Fig.4).

Most users need snow product as a full year service, but regard fall/winter/spring as more important than summer. The fall season is ranked almost as important as spring for several products. The majority of respondents indicate that all products should be provided on a daily basis. A majority need a latency time shorter than 12 hours, 31% shorter than 6 hours. Most users can use products with 250 m resolution. Some users, like avalanche and road authorities need high resolution data down to at least 50 m resolution, but such a requirement cannot be met with currently available sensors on a daily basis; at least not within a reasonable cost frame.

The majority of the users desire regional products over the Alps including Romania and in the Nordic countries. Many users (83%) also ask for Pan-European products. The majority of respondents (53%) preferred UTM projections. The remainder preferred geographic coordinates (38%) or other projections (10%), like the Lambert, European Equal Area.

3.3 Requirements for the glacier service

When asked about glacier products, 36% of the respondents said that they were interested in glacier products. Out of these, 88% stated that the glacier outline product is the most relevant, while the other products had lower ratings (See Figure 5). The summer is regarded as the most important period for acquisitions of glacier products (by 90%), and annual updates of the products was preferred by a majority of the users. The users need the product within 3 months.

All glacier products are desired at relatively high spatial resolution (10 m - 25 m) by a majority of the respondents. A majority of the users (63% -91%, depending on product type) preferred products in a UTM projection. A majority of the users were interested in glacier products from the Alps and Scandinavia including Svalbard and Greenland.

3.4 Requirements for the lake and river ice service

28% of the survey respondents are interested in lake ice products. Out of these 28%, a large majority (84%) regarded the lake and river ice extent product as important, first and last day of ice were rated high by 66% and snow burden was regarded important by 13% of these users (see Figure 6).

A majority of the users require a temporal resolution of less than 2-3 days. The required latency time is dependent on product types. A few products like river ice jam and flood products are required in near real-time, while other product are related to climate research, and requires annual updates. 33% of the users are interested in data with high resolution (25 m, typically river ice products), 33% needed data with medium resolution (100 m) and the remainder needed data with less than 1 km resolution.

The preferred map projection for lake ice products as specified by the users is geographical coordinates (Latitude, Longitude). Users in Scandinavia show very high interest in lake and river ice products, while it is less requested for users in central-Europe.

3.5 Technical requirements for the CryoLand user service

An important section in the user survey was related to the development of the CryoLand user service. The users were asked about specific issues related to the implementation of the service.

When asked about data formats (see Figure 7), the preferred raster format among the users is geotif (77%), whereas shape is the preferred vector format (66%). 94% of the users prefer to access CryoLand products in a Web-GUI. 76% preferred to view products in a WebGUI, 61% also wanted to view CryoLand products in an OpenGIS map service. The most favoured downloading method is FTP (73%). Using OpenGIS web feature service (WFS) is also of high interest (46%). 62% wanted to use the CryoLand Web-GUI to invoke processing services offered by CryoLand. 50% preferred upload of reference data using WFS-T as a necessary option for data upload. 46% liked the idea of uploading files utilizing the CryoLand Web-GUI. ESRI ARC GIS is the dominating software system in use, with OpenSource tools being the second largest group.

The preferences in this section was expected since many of the users are scientists and used to the ARC GIS market standard. Open GIS is still not widely used for analysis among these users.

4 DISCUSSION

Based on the reviews on previous projects, the discussions with the users at workshops and finally the thorough user survey we are confident to conclude that the prioritization of products and services reflects the needs of a wide user community interested in snow and land ice services within Europe. A large number of users within all the user segments that CryoLand addresses have responded. The responses gave, in most cases, clear directions towards which products and services that should be implemented.

As a critical point one might argue that the geographical spread of the users is somewhat biased as most of the users are located within the Nordic and the Alpine countries in Europe. Although, this is quite natural since these are the countries were snow plays a major role, it is somewhat unsatisfactory that major countries like France, UK, Poland and Russia were poorly represented. The countries represented in CryoLand are dominating the user community.

4.1 Balancing requirements against what is achievable with current technology

Since the questionnaire was open regarding which services that are possible to implement with current and near future satellite sensors, there is a need to harmonize the user

requirements (as they appear from the statistical results of the questionnaire) with what is achievable during the life-time of the CryoLand project. The analysis below takes into account the user requests on one hand, and on the other hand also the available EO data and status of retrieval algorithms and processing lines for the different products of the CryoLand product portfolio. Based on discussions in the user workshops, it was proposed to group the baseline CryoLand products into 3 categories depending on their level of maturity. The product categories are

Category 1: Operational products (a few very important products/data-sets).

Category 2: Pilot products (emerging operational products; undergoing full validation).

Category 3: Experimental products (delivered on demand, limited validation).

Most resources in the CryoLand project should go into research and development in Category 1. It is the intention that CryoLand should be able to increase the portfolio of Category 1 products by fulfilling work on validation for Category 2 products. Experimental products are important as well as these might be important products in the future. CryoLand, with its Copernicus downstream focus, is however not able to put significant resources into R&D for this category, but the project is an arena to discuss future products with the users and provide them with test samples.

Table 3 provides the consolidated product and service requirements. The spatial and temporal coverage were defined and consolidated by users operating in different applications. Due to the variety of products discussed it was necessary to specify the implementation priority of the products. Based on the ranking in the user survey, discussions within the CryoLand consortium and at the CryoLand user consultation meeting held in Stockholm in May 2012 we set an implementation priority for products and services within CryoLand. Different aspects were taken into account, including the size of the user community having interest in the product but also the availability of EO data and the matureness of the algorithms for generating the product.

Table 3 gives implementation priority for individual products. In order to simplify we order the ranking in categories 1, 2, and 3. Table 3 shows that the highest ranked snow products are the regional and the Pan-European snow extent products. Glacier extent and lake/river ice extent is also ranked high among their user communities.

5 Conclusions

The CryoLand project is aimed at developing, implementing and validating a standardized and sustainable service on snow and land ice monitoring as a downstream service within EU's Copernicus framework. The results from the CryoLand user requirement assessment clearly demonstrate that there is a need for a European operational service and well developed cryosphere products that can meet the specific needs. The majority of the users were mainly interested in the snow services, but also the lake/river ice products and the glacier products were desired. The user survey gave the project guidance and priorities for the further development of products and services.

The products were organized in 3 categories (operational products, pilot products and experimental products) based on the user ranking and the operational status of the products. This ordering gave the project directions to the implementation order and to the efforts needed to improve certain products.

The Copernicus sensors Sentinel-1, -2 and -3 will be well suited for addressing most of the prioritized products when they become operational from 2015. A particular point that was highlighted during the user requirement survey was the need for Pan-European services for snow water equivalent and snow cover fraction. These services, in addition to the need for highly accurate regional services, were prioritized highest and hence also rapidly implemented by the CryoLand consortium. A continuation of the CryoLand -snow and land ice services has been suggested as a Copernicus land monitoring core service. This service will need to focus on broadening the number of countries/users involved.

Acknowledgements

This work was financed by the European Union Copernicus project CryoLand (grant agreement #262925). We acknowledge B. Raupb, A.Devaris and an anonymous referee for valuable comments and suggestions for improvements.

Acronyms

CliC	Climate and Cryosphere, a WCRP core project
ECV	Essential climate variables

1	EO	Earth Observation
2	EU	European Union
3	FTP	File Transfer Protocol
4	GCOS	Global Climate Observing System
5	GIS	Geographic Information System
6	GLIMS	Global Land Ice Measurements from Space
7	GUI	Graphical User Interface
8	IGOS	Integrated Global Observing Strategy
9	NWP	Numerical Weather Prediction
10	OGC	Open Geospatial Consortium
11	RCM	Regional Climate Modelling
12	~~SCA~~	~~Snow Cover Area~~
13	SCF	Snow Cover Fraction
14	SE	Snow Extent
15	SWE	Snow Water Equivalent
16	UK	United Kingdom
17	UNFCCC	United Nations Framework Convention on Climate Change
18	UTM	Universal Transverse Mercator
19	WFS	Web Feature Service
20		

References

Bishop, M.P., Olsenholler, J.A., Shroder, J.F., Barry, R.G., Raup, B.H., Bush, A.B.G., Copland, L., Dwyer, J.L., Fountain, A.G., Haeberli, W., Kääb, A., Paul, F., Hall, D.K., Kargel, J.S., Molnia, B.F.,Trabant, D.C., Wessels, R. Global Land Ice Measurements from Space (GLIMS): remote sensing and GIS investigations of the Earth's cryosphere. *Geocarto International.*, 19, 57–84, 2004.

Copernicus, The European Earth Observation programme, www.copernicus.eu/

CryoLand Project Web Page, www.cryoland.eu/

Enalyser www.enalyzer.com

EnviSnow: User Requirement Draft Document, EnviSnow EVG1-CT-2001-00052,2005. http://igos-cryosphere.org/docs/EnviSnow_requirements.pdf

Fernández-Prieto D., Duguay C., Gauthier Y., Gustafsson D., Malnes E., Mattila O.-P. , Rontu L., Rott H., Samuelsson P. and Solberg R., "ESA STSE North Hydrology: Development of multi-mission satellite data products in support of atmospheric and hydrological modeling of cold regions", Geophysical Research Abstracts, 14, EGU General Assembly, 2012.

GCOS-107, 2006. Systematic Observation Requirements for Satellite-Based Products for Climate. WMO/TD-No. 1338. 90 pp.

GlobSnow project: http://www.globsnow.info/

IGOS, 2007: Cryosphere Theme Report 2007. WMO/TD-No 1405. 100 pp.

INSPIRE http://inspire.ec.europa.eu/

Malenovský Z., Rott H., Cihlar J., Schaepman M.E., García-Santos G., Fernandes R. and Berger M.: Sentinels for science: Potential of Sentinel-1, -2, and -3 missions for scientific observations of ocean, cryosphere, and land, Remote Sensing of Environment, 15,91-101, 2012.

OGC: http://www.opengeospatial.org/

Raup B., Racoviteanu A., Khalsa S.J.S., Helm C., Armstrong R. and Arnaud Y.: The GLIMS geospatial glacier database: A new tool for studying glacier change. Global and PlanetaryChange, 56, 101– 110, 2007.

Table 1. List of projects/organizations that have performed user surveys and/or made recommendations for snow, glacier, lake/river ice products and web-map services lately.

Name	Funding	Snow	Glacier	*Lake/river ice*	*Infrastructure*
GCOS	UN	x	x	x	
IGOS	UN	x	x	x	
EnviSnow	EU FP5	x			
GlobSnow	ESA	x			
GlobGlaciers	ESA		x		
CCI Glaciers	ESA		x		
CryoClim	ESA	x	x		
DUE Permafrost	ESA	x		x	
NAM	Romania	x		x	
GLOF	ESA		x		
GLIMS	NASA		x		
Polarview	ESA	x	x	x	
STSE North Hydrology	ESA			x	
OGC					x
INSPIRE	EU				x

Table 2. Type of organizations.

	Total	
Type of organization:	**Percentage**	**Number**
Private company	16%	19
National authority	25%	30
Regional authority	15%	18
Scientific	19%	23
Consulting	11%	13
Other	13%	16
Total	100%	119

[*] Several respondents identified their organization in more than one category, e.g. a meteorological office can have national and regional authority and perform scientific work.

Table 3. Requirements for spatial and temporal resolution of products and product ranking

Product type	Spatial resolution	EO sensors	Temporal resolution	*Implementation Priority*	*User ranking [%]*
Snow ~~extent~~cover fraction, regional in Nordic and Alps	250-500 m	MODIS, ASAR (archived), S1, S3	Daily, full year	1	83%
Snow extent (local)	25 – 50 m	Landsat, S2	monthly, full year	NA	NA
Snow ~~extent~~cover fraction, pan-European	500-1000 m	MODIS, S1,S3	Daily, full year	1	83%
Snow Water Equivalent (Low res)	10-25 km	SSMI/S, AMSR2	Daily, dry snow season	2	55%
Melting snow area	25-100 m	ASAR (archived), Sentinel S1, S3	Daily	2	52%
Snow Surface Wetness	1000 m	MODIS, Sentinel S3	Daily	3	38%
Statistical snow Information	HRU/basin	NA	Daily	2	45%
Spectral Surface Albedo	250-500 m	MODIS, Sentinel S3	Daily	3	40%
Snow Surface Temperature	1000 m	MODIS, Sentinel S3	Daily	3	37%
Glacier outlines	10-25 m	SPOT, Landsat, Ikonos, Sentinel S2	Annually	1	88%
Snow/ice area on glaciers	< 25 m	ASAR (archived), TSX, Landsat TM, SPOT, Sentinel S2	Annually	2	71%
Glacier Ice velocity	10-25 m	TSX, Sentinel	Annually	2	57%
Glacier lakes	10-25 m	TSX, Sentinel	Annually, weekly (fast analysis), hours (emergency)	2	57%
Ice extent and ice concentration	100 m	MODIS, ASAR (archived), TSX, Sentinel	Daily, Oct-May	1	85%
Snow covered area on lake ice	250 m	MODIS, Sentinel S1	Daily	3	13%
Snow Surface Temperature	1000 m	MODIS, Sentinel S3	Daily	3	37%
First and last day of ice cover	100 m	MODIS, ASAR (archived), TSX, Sentinel	Annually	2	67%
River ice jam, flood inundation area	30 m	ASAR (archived), TSX	Daily (emergency)	3	NA
Lake surface temperature	500 m	MODIS, Sentinel S3	Daily	3	NA
Snow depth on lake ice	25 km	SSMI/S, AMSR2	Daily	3	NA

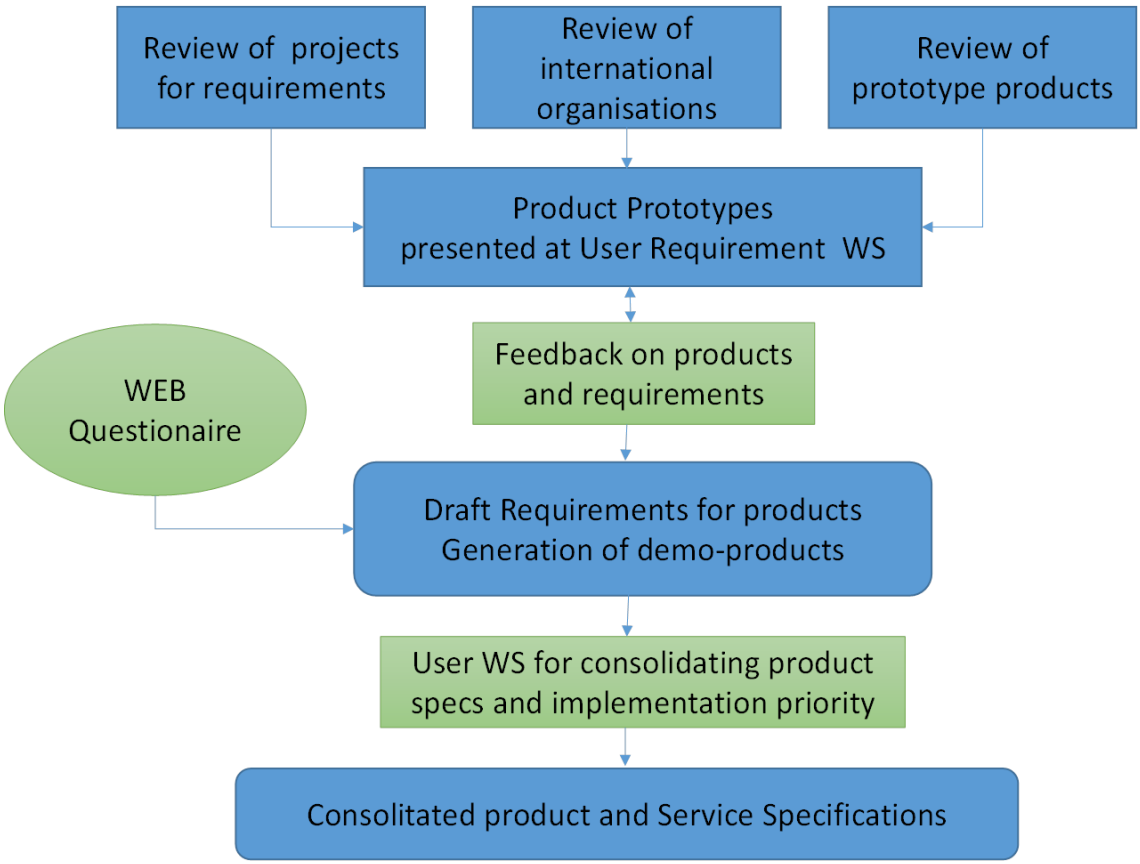


Figure 1. Methods applied to derive user requirements

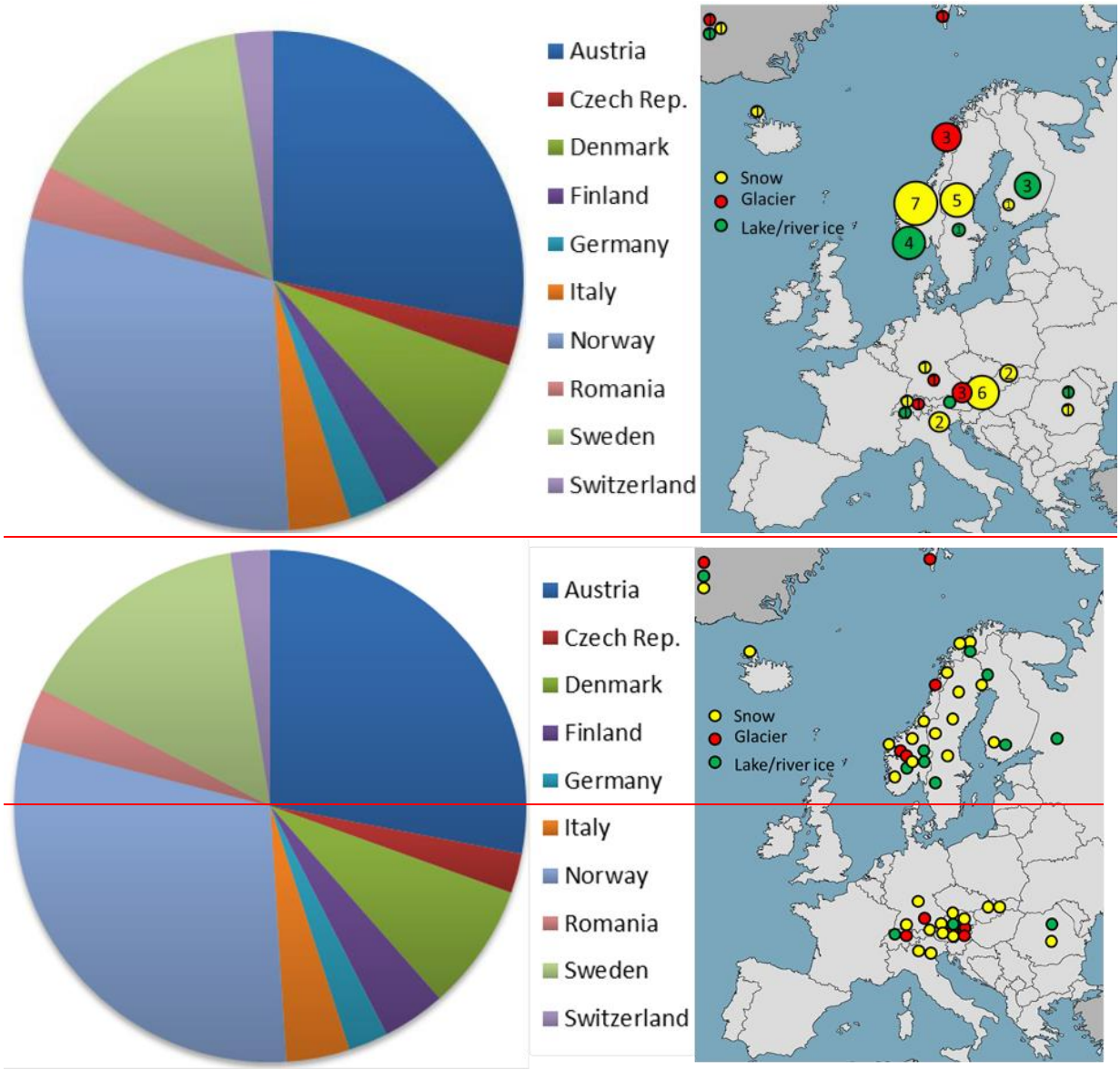


Figure 2. Nationalities of the users that responded to the user survey (left). Right: Location of the users and their field of interest. Dots are scaled according to the number of responders.

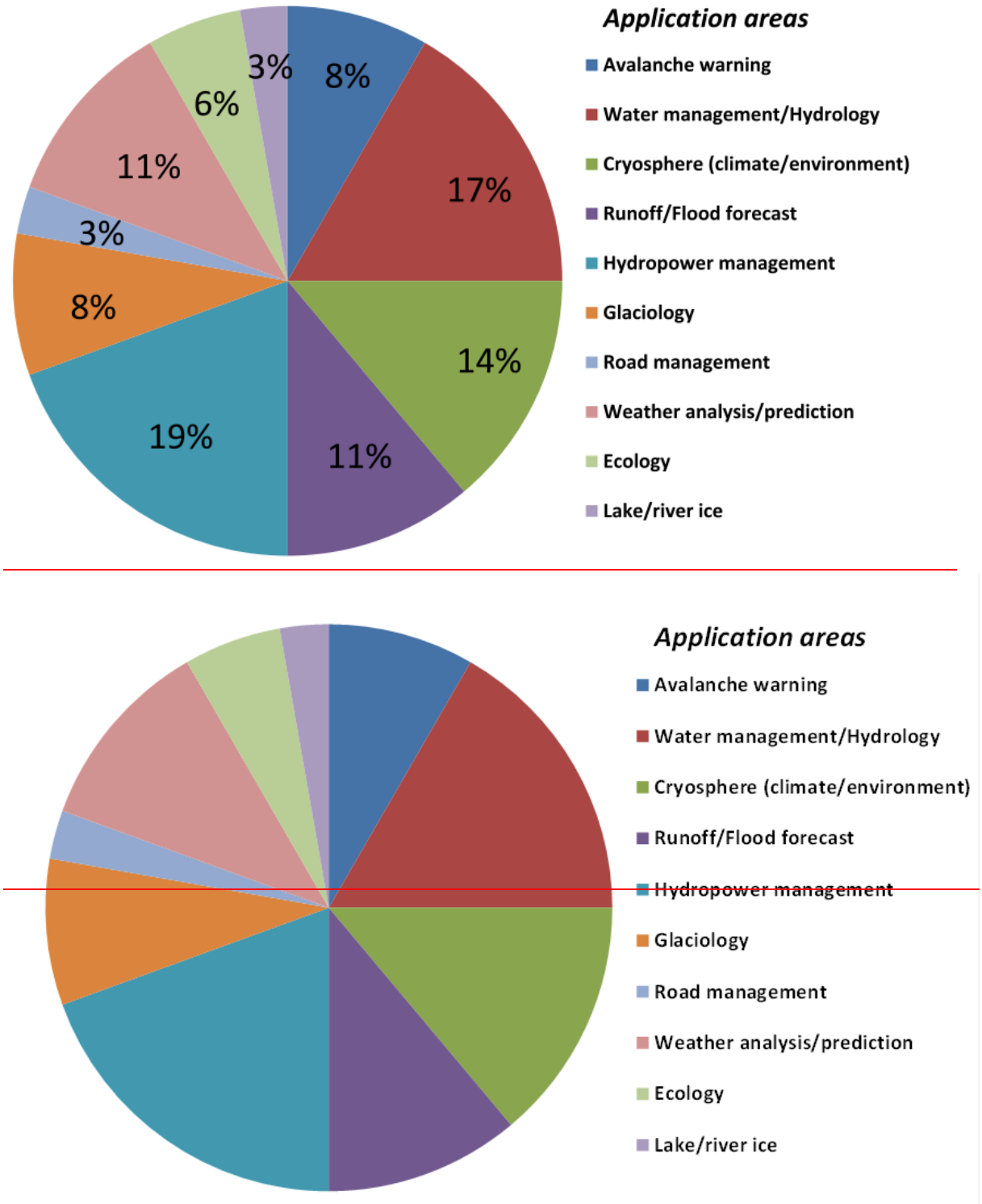
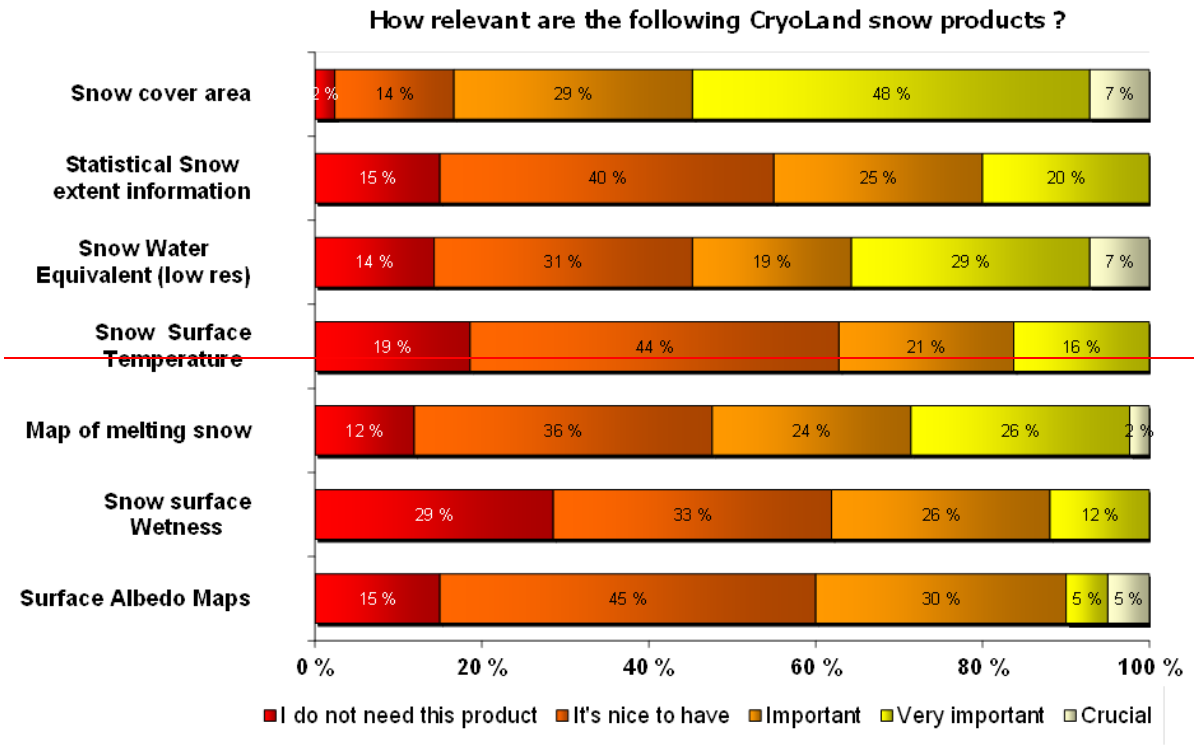
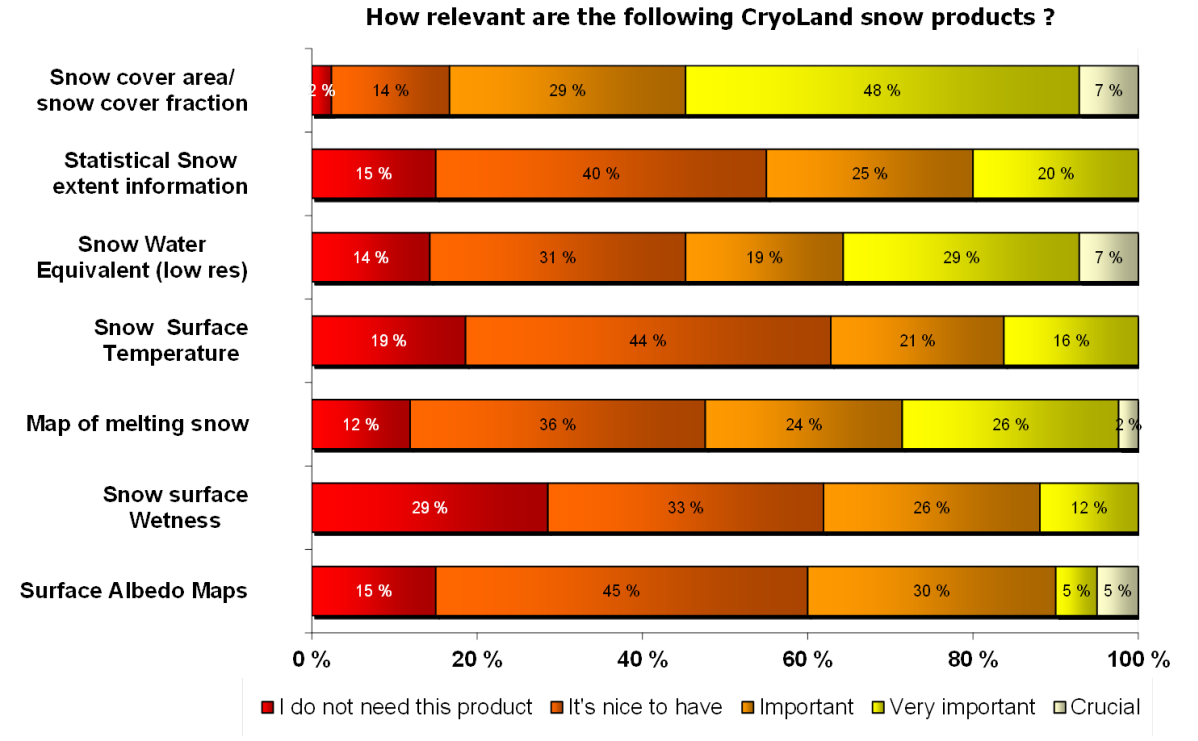


Figure 3. Application fields of users



1



2

3 Figure 4. Relevance of snow products.

4

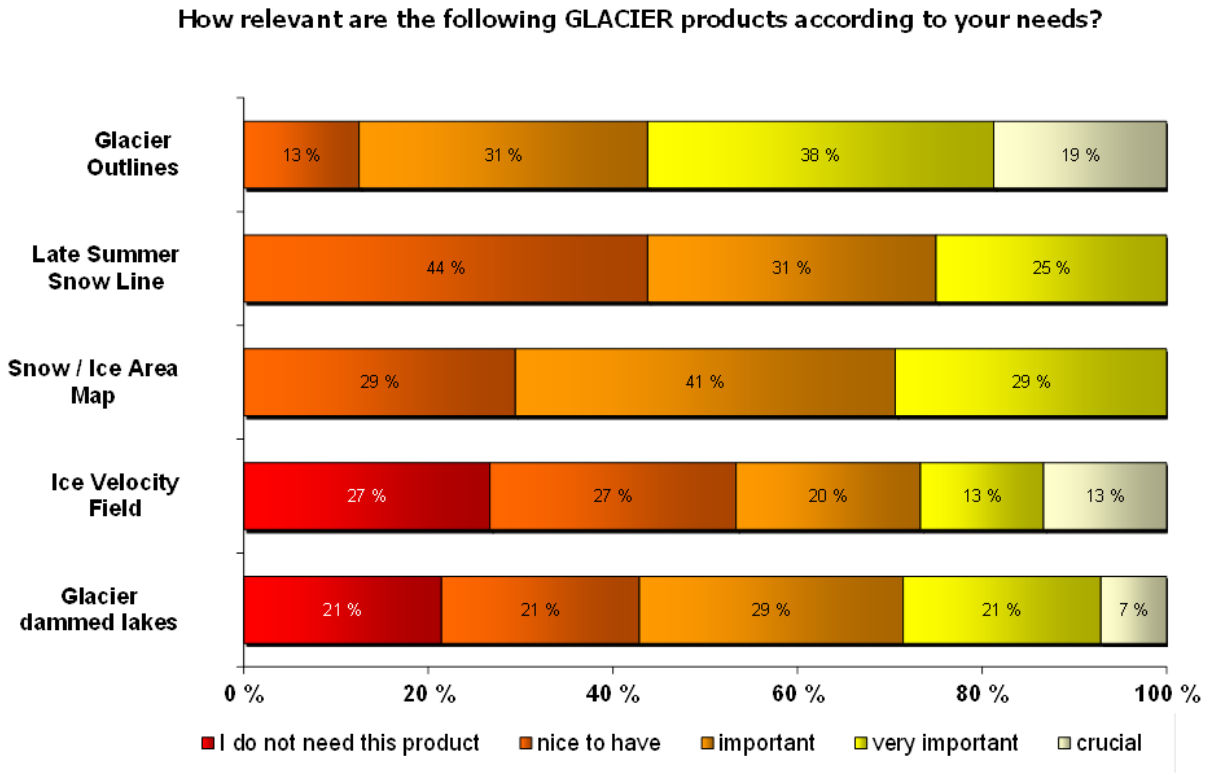


Figure 5. Relevance of glacier products.

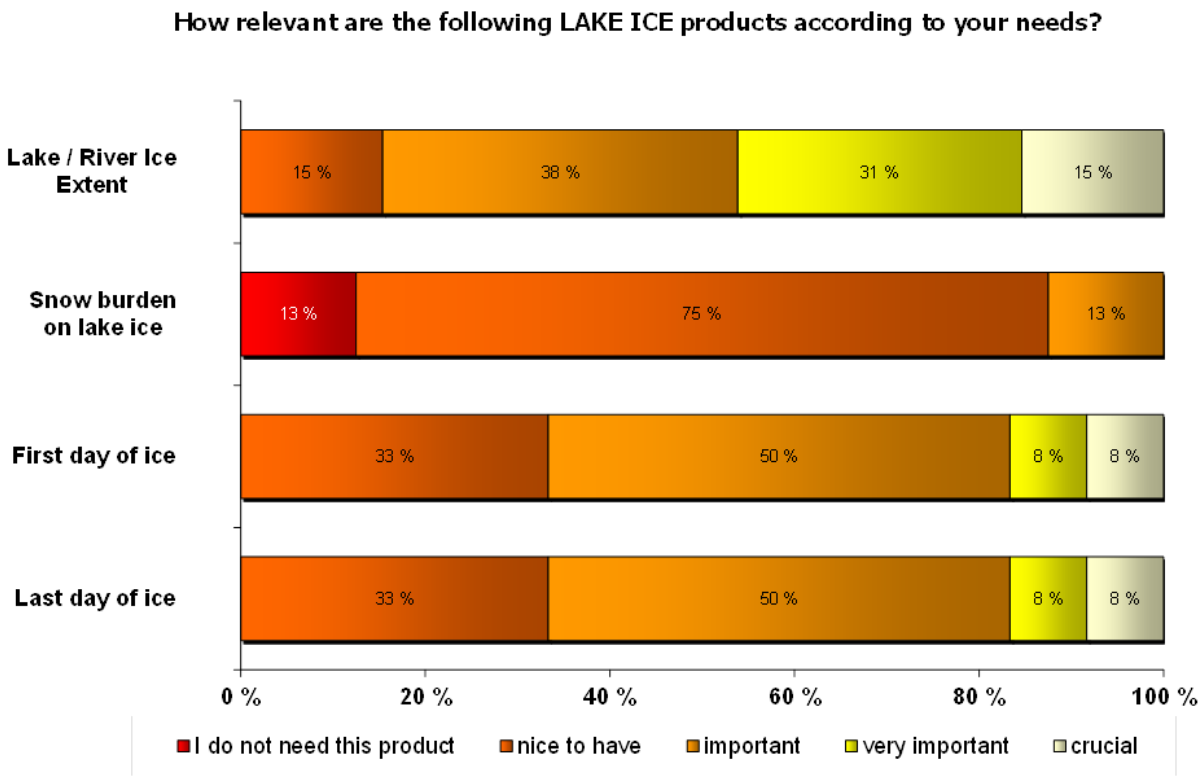


Figure 6. Relevance of lake ice products.

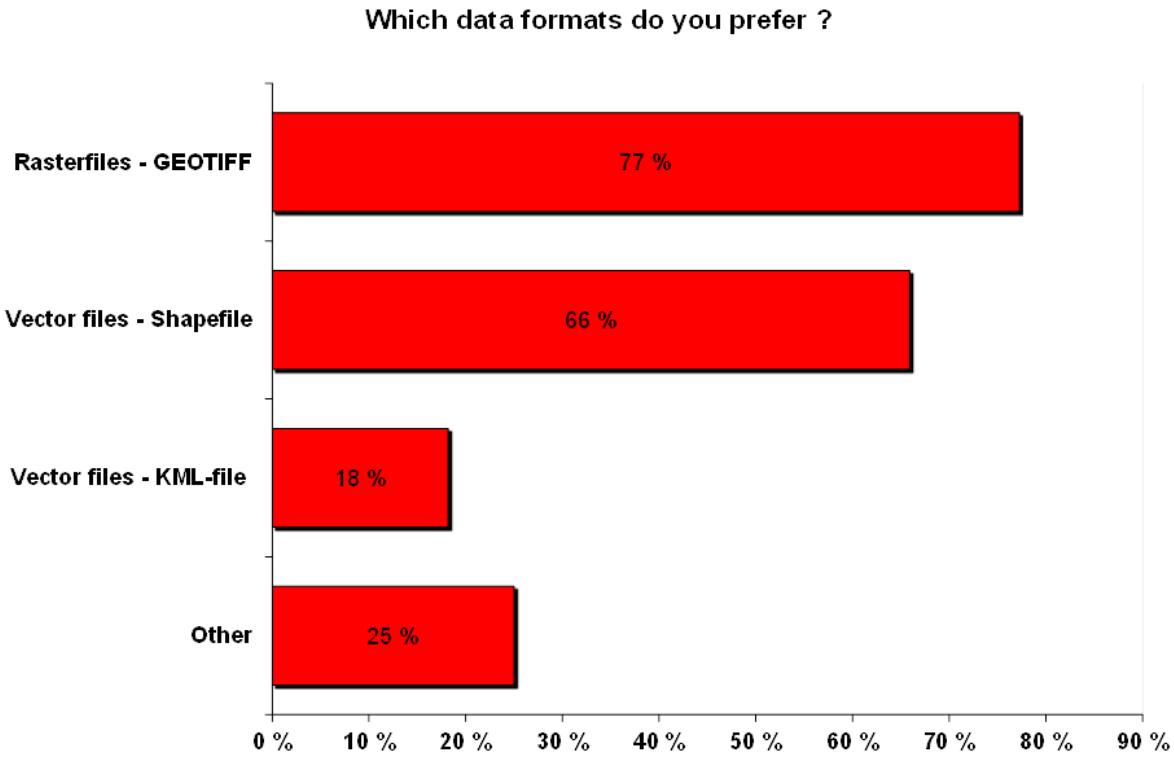


Figure 7. Preferred data formats.