Veðurstofa Íslands
Report

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Final report of work performed at the Icelandic Meteorological Office under European Union 3rd Framework Program Human Capital and Mobility

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Study of avalanche dynamics with the aim of mapping risk areas, training in the construction of models of natural phenomena.
(Acronym : TAMAM)

Avalanches in Iceland

Part 1
The use of a Geographic Information System (Arc/Info, version 7) for avalanche analysis in Iceland

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Part 2
The determination of avalanche risk in Iceland

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Report for the Human Capital and Mobility meeting of the 20 March 1997

Contents

Overview

In this report the results and conclusions of two studies performed in Iceland under the HCM contract are reproduced. The funding for this research and other needs of the project was provided by the Icelandic authorities.The first study is an investigation in to the most efficient manner by which avalanche data can be portrayed by a geographic information system (GIS). The initial layout of the GIS system was designed by Gilles Borrel (Cemagref) in collaboration with Magnús Már Magnússon (IMO). Mr. Borrel's visits to Iceland were funded by ACTIM (Agence pour la Cooperation Technique, Industrielle et Economique) at the request of the PEE (Poste d´Expansion Economique). Additional contributions to the system design were made by the staff of the IMO.

The selected methods by which avalanche data are portrayed were established in a manner that permitted information to be presented clearly and concisely, with the potential for links to an avalanche database, and risk and dynamics models in the future. The work was performed by Anne Choquet between November 1995 and October 1996 with the assistance of Sandrine Sanchez in January 1996. Ms Sanchez's stay in Iceland formed part of her training at the University of Savoie, France. She received a small bursary from the IMO.

In the second study, the avalanche records in Iceland are amalgamated in order to derive a Monte-Carlo model of avalanche encounter probability along the profile. This is used as the fundamental building block of an avalanche risk model. The model is developed in such a way that it has the potential to be readily incorporated into a GIS-Relational Database system such as that proposed for Iceland. This research was performed by Chris Keylock under the supervision of David McClung and Magnús Már Magnússon between July 1995 and October 1996.

Further funds available from the HCM contract were employed in several ways. An ARC/INFO University Laboratory Kit License was obtained and the digital maps used in the initial design and development of the GIS system were acquired. In addition, funds were used to pay for the transportation of the authors (MMM, AC & CK) to various meetings associated with the HCM contract.

Iceland's participation in this project has enabled the IMO to produce the foundations of an avalanche GIS system. From this state, further developments are possible, making use of, and building upon the knowledge of other nations participating in the project.

CK and MMM 13/03/97

Part 1

Avalanche conditions in Iceland

The year of 1995 saw a number of disastrous avalanches in Iceland. In particular, the two accidents at Súðavik and Flateyri killed 14 and 20 people respectively, which is very high considering the low Icelandic population (267 809 inhabitants).
As a result of this, the Avalanche Division of the Icelandic Meteorological Office (IMO) has grown very rapidly. The IMO has now been given the responsibility of establishing the hazard zoning and evacuation plans all over the country. In France, Cemagref deals with research issues while the "Restauration des Terrains en Montagne" is responsible for hazard mapping and public relations with local people. However, in Iceland, the IMO must deal with all such concerns. The IMO also has to decide the extent and timing of the evacuations. In the winter of 1996, the lack of snow provided a relief and allowed the setting up of the evacuation plans.
Of course, the help and advice from different countries is welcome. Icelanders are trying to work as much as possible with people abroad (Norwegians, Canadians, French, Swiss etc.).
This work at the IMO should be considered as such a cooperation.

Introduction

A Geographic Information System (GIS), Arc/Info (version 7.03) has been acquired for the Avalanche Division. The aim of this work is to set up the working procedures and to make the system useful in the future. Initially, this means setting up the avalanche mapping, but further concerns include working out the possibilities of avalanche modelisation in three dimensions and establishing the link with the Database (Ingres). Later on, the idea is to use Arc/Info as an aid for avalanche forecasting, meaning that it should be linked with the meteorological data. The Avalanche Division would like to be able to take the present meteorological conditions (including the previous few days) and find the most similar day in the past, to determine the likelihood of avalanching. This would have to be complemented with a snow stratigraphy analysis. This is expected to take much more than one year, but these needs must be considered from the start.
Until June 1996, most of the time was spent setting up the map prototype and choosing a way to store the geographical data. Hnifsdalur is our testing area for mapping. At this zone, we have tested the possibilities of the new *regions* feature class in version 7 of Arc/Info (as line, polygon, point). Other villages have also been examined to make sure that Hnifsdalur is a representative area. In the Avalanche Division, one person is responsible for each community. So by starting the work for other communities there is an opportunity to explain how to use Arc/Info to digitize the data, and to show how the maps will be made. One of the priorities in the avalanche division, concerning this project, is to allow people to get used to this new tool and thus, to ensure that it will be used effectively. It is quite obvious that people will avoid using such a new tool, if it requires a greater amount of effort than

existing methods. Consequently, it is very important to overcome the initial stage of getting acquainted to GIS.
Informing the Icelanders of French knowledge about avalanches (whether this is through articles or an expert) should also be considered a part of this work.

The file structure

The software Arc/Info has been set up on a Digital Alpha UNIX Workstation.
The first step in establishing the file structure was to consult each file, describe the contents, and try to find a better way to name it and rank it. Many files had been imported from another company (HNIT) and nobody at the IMO really knew their content. Consequently, this part of the job was very time consuming. However, it was a means of getting to know more about the available *coverages* (the Arc/Info term for a layer of information) used in avalanche map production.
Until 1995, the imported coverages from HNIT (which are to be used as *backcoverages*) were inconsistent. This could cause problems for the IMO who would like to produce similar maps for the whole country. Therefore, Gilles Borrel (from Cemagref, France) and Magnus Már Magnusson (leader of the Avalanche Division) began during the summer 1995 to set up the future *coverage* content, as it should be provided by HNIT in the future. These imported *coverages* have been renamed (using a similar name when the content is similar) and classified.
Figure 1.1, shows the new architecture. Under *GIS*, our superdirectory for Arc/Info, we have one *workspace* (the Arc/Info term for directory) for each community. If there are several villages in this community, we find other *workspaces* underneath. In these *workspaces* are the *coverages* concerning the respective area.
The coverages *hus* (houses), *strnlin* (limit of the shore), *elpoints* (elevation points), *hlin* (elevation lines), *vatnafar* (hydrology), *samg* (roads), *mannv* (human constructions)... are those imported from HNIT and contain different levels of information. They will be use as background for our maps.
The other coverages *snjfl-80*, *snjfl80-85*, *snjfl85-90*, *snjfl90-95*, *snjfl-95*, *hldsnjfl-95*... are those produced in the Avalanche Division.

Storage within the coverages linked with the Database

Another part of this project was to define how to store the geographical information concerning avalanches. The avalanches for each area will be digitized, but at present, neither the Database, nor the geographical data in Arc/Info are ready to be linked together. Nevertheless, for both the Database and Arc/Info, the system must be set up to account for the future link.
The avalanches were divided into 5-year coverages. For example, the coverage *snjfl85-90* contains all the avalanches occurring between 01/08/85 and 31/07/90. This choice was made to produce clear coverages, where it is easy to distinguish the different avalanches. Usually, there are fewer records in the past and therefore, it makes sense to stop splitting the data into 5-years

coverages. For instance, at Hnifsdalur, the *coverage snjfl-80* contains all the avalanches that occurred before the 31 July 1980.
In these coverages, we are using one *region* (Arc/Info meaning) for each avalanche event. The *region* possibilities have been studied with the help of a trainee, Sandrine Sanchez, from the "Maitrise Science et Technique de la Montagne" in Chambery, University of Savoie, France. She stayed at the IMO for one month, in January 1996. The *region* concept appears to be very useful for avalanche work. It permits avalanches to be recognized as an entity (made up of several polygons) which can easily be selected and highlighted in Arcedit using an *item* such as the avalanche number, the date, the type etc. Even more possibilities will exist once Arc/Info is linked to the Database. Those avalanches identified as *regions* can be moved to other *coverages* or *subclasses* very easily (using the commands *PUT* or *COPYFEATURES*).
Each *region* (each avalanche) can belong to 3 different *subclasses* that are called "certain", "certainin" (for certain-inaccurate) and "uncertain". The accuracy of the data will determine to which *subclass* the avalanche is allocated. *Subclasses* (like *regions*), have been introduced in version 7 of Arc/Info. A *coverage* containing *regions* may have several layers of information, and these are the *subclasses*.
Figure 1.2 explains the organisation within each cover. The coverage contains 3 subclasses, in which the avalanche events are drawn as regions.

Choice of the legend

At Hnifsdalur there were 2 different types of data. The avalanche was either well-known ("certain"), or not ("uncertain"). When the data for Neskaupstaður was digitized with Svanbjörg H. Haraldsdóttir (the person responsible of this area) it was apparent that the categories "certain" and "uncertain" had to be defined more precisely for two reasons:
Firstly, we had to be sure that everyone in the office would put a given avalanche into the same category (certain or uncertain); secondly, the legend of the map had to be made clearer to improve understanding. A review was necessary to ascertain all the types of data we were likely to obtain and use for mapping. In Iceland today, the data is recorded by local snow observers. They measure and map each avalanche event and send a report to the IMO. In addition, there are older data that we also wish to incorporate. After considering all the available data, it was decided that 3 categories would be necessary and they will be indicated in the legend as such :

"**- Outlines of avalanches are certain.**
Outlines of avalanches are measured or mapped with good accuracy by a contemporary.
- Outlines of avalanches are inaccurate.
Outlines of avalanches are mapped by a contemporary or according to reliable sources, but the outlines may be inaccurate.
- Outlines of avalanches are uncertain.
Outlines of avalanches are mapped according to uncertain sources."

It is more cumbersome to deal with 3 than with 2 classes, but this choice seems to better fit Icelandic data and permits us to distinguish data which should not be mixed, owing to their differing level of accuracy.
Once this legend had been chosen, it was necessary to add one subclass in each coverage and to allocate the corresponding avalanches to it. This was a further test of the utility of the *regions* feature. Yet again, this work was performed in the training area of Hnifsdalur.
The avalanche division will try to implement the French method of photointerpretation in the future, and if this is successful, a fourth subclass will be necessary.

The map

Before making a map-prototype, we had to define the exact information we wanted this map to display.
The Icelandic avalanche map, like the Carte de Localisation Probable des Avalanches (CLPA) in France, should display information clearly to make the map easy to understand. So, as for the CLPA, we decided to show the maximum extent of the avalanche events without distinguishing each avalanche path. This map should be considered as historical, and not a hazard map. It can only answer the question "Does the IMO know of avalanches occurring in this place ?". To avoid misunderstanding these sentences will be displayed on the map :

"The map shows the maximum extent of recorded avalanches. Neither frequency nor velocity is depicted on the map."
"The map only shows the extent of known avalanches. If an avalanche is not shown on the map it does not mean that the place has never been overridden by an avalanche."

Until now, the target audience for the map has not been determined. Certainly, this document should be available for the local snow observers. The rescue teams, which play a big part in Iceland, may also have access to it. It should be clear that this map should not be sold, shown publicly, or given away without an appropriate explanation. In France, the main problem was that people used such maps as hazard maps. To avoid the spread of this dangerous misunderstanding, it was decided that the CLPA will not be a public document in France... neither should this map be in Iceland, in my opinion.

Organisation of the data on the map

The *coverage snjfl-95* is made by adding all the 5-years *coverages* (+ *snjfl-80*) ; it contains all the avalanches we know. This *coverage* is very cluttered, but must be produced before one can erase all the limits and determine the maximum extent of avalanching.

As mentioned before, there are 3 kinds of data ; certain, certain-inaccurate and uncertain. The map should make this distinction too, with the more accurate information to be shown with greater priority than the inaccurate data. By way of an improved explanation, figure 1.3 shows how we would combine 2 layers of information : certain and uncertain. With one more layer (certain-inaccurate), the process is the same.
The *coverage hldsnjfl-95* is the cover used to make the map. As figure 1.3 explains, the maximum extent of the certain (c) data is placed on top of the maximum extent of the certain-inaccurate data (not shown), which is in turn placed on top of the uncertain avalanches (u). When there is only one kind of data [as shown in (a) and (b)], we drop all the limits within the different avalanche path. When there are several kinds of data [as shown in (c) and (d)] the limits of the most accurate data are kept.

The Arc/Info process

Once the composition of the map was decided upon, the Arc/Info process was defined as described below.
Firstly, to gather all the 5-years coverages, the UNION command was used. This Arc command adds two different coverages together. We had to make intermediate coverages (*snjfl-85, snjfl-90*) to be able to add *snjfl-80, snjfl80-85, snjfl85-90, snjfl90-95*. The final map gathering all those *coverages* is called *snjfl-95*. Figure 1.4 sums up the exact process. I will not give here further information about the UNION command, but I will just specify that we employed the "nojoin" specification to have fewer *items* copied in the *Polygon Attribute Table (PAT)* of the new cover. This would have taken memory and as we are using *regions*, we use the *PAT subclass* as a complete *Attribute Table* with all the *items* we need.
The next step is to make the *coverage hldsnjfl-95* using *snjfl-95*.
Hldsnjfl-95 should contain only the maximum extent of the known avalanche events and the data should be organized according to the definitions above.
For that, we had to build 3 coverages with the following respective maximum extents :
-Snjfl-u, contained the maximum extent of the uncertain avalanches;
-Snjfl-i, contained the maximum extent of the certain-inaccurate ones;
-Snjfl-c, contained the maximum extent of the certain avalanches.
This was done with the REGIONQUERY command. In each of the new coverages (snjfl-c, snjfl-i and snjfl-u), we have just one *subclass* (called max) and one *region* (with discontinuous components because the avalanches were not necessarily overlapping).
The next step was to place the coverage *snjfl-i* onto *snjfl-u* and keep the limits of *snjfl-i*, as explained in (c) and (d) of figure 3. For that, we used the UPDATE command and the resulting coverage was called *snjfl-ui*. The specification "keepborder" allowed us to keep the limits of the "strong" *coverage* (here, *snjfl-i*). The UPDATE command was reused to lay *snjfl-c* on *snjfl-ui* to give the final coverage: *hldsnjfl-95*.

The coordinate system

The existing avalanche data and imported coverages utilised a local coordinate system. These coordinates are not referenced and it seemed that a regular coordinate system fitted to Iceland would be advantageous in the future. Furthermore, the implementation of Global Positioning System recording techniques makes it necessary to adopt a universally accepted coordinate system. After considering the advice from other institutes, we choose to work with the Gauss-Krüger coordinate system. The cylindrical projection used is the Transverse Mercator. The Gauss-Krüger coordinate system is the same as the Universal Transverse Mercator except that there are twice as many zones, each spanning 3 degrees of longitude. Four belts cover Iceland, each one with a meridian in center line. The meridians are -24°, -21°, -18° and -15° (west from Greenwich).

In Iceland, the Hayford ellipsoid from 1924 is used with a = 6 378 388 m and b = 6 356 911.94613 m. In Arc/Info, those same parameters are settled for the ellipsoid International from 1909.

The transformation between local to Gauss-Krüger coordinates has been tested on Hnifsdalur. Five reference points had been measured with a Global Positioning System by another institute and were available to make the transformation. Other points have now to be measured all over the country to set up all the maps in Gauss-Krüger coordinates.

To perform these operations in Arc/Info we use the TRANSFORM command upon each cover. Then, PROJECTDEFINE has to be applied to one of the coverages. It is here that we define the parameters concerning the projection we use.

The dialogue defining the projection is :

Arc>projectdefine cover <name of the cover>	
Project>projection UTM	*For Universal Transverse Mercator*
Project>units meters	
Project>spheroid int1909	*For International from 1909*
Project>parameters	
Longitude > -24 0 0	*Parameters of the central meridian*
Latitude> 0 0 0	*within the UTM projection*

Then, for the other coverages, we can use the PROJECTCOPY command. To check whether the projection had been registered, we use the command DESCRIBE.

Transformations of the coverages have been made for Hnifsdalur, but some problems still need to be solved because the transformation deforms the covers, affecting some parameters.

The Arcplot command NEATLINE can be used to draw the new coordinate system on the map. We decided to have the latitude and longitude indicated as well. After this last step, the Hnifsdalur map will be ready and will act as a model for the mapping.

What else ?

From the 8 to the 12 of January, Harald Norem (from Norway) gave a course on snow engineering. Listening to this course, I had the opportunity to learn more about the Nordic weather conditions and the Norwegian methods in general.
The same month, I attended a two-day meeting with David McClung (Canada), Bruno Salm (Switzerland) and Karstein Lied (Norway) held at the IMO. This was primarily concerned with the acceptable risk level and was allowed me to better appreciate the Icelandic needs. A considerable number of houses in Iceland are in an unacceptably high risk situation as has been made all to clear by the catastrophic avalanches in 1995. I have visited Isafjordur and Flateyri, which was very impressive. The first defense structures will be built during the summers of 1996 and 1997. Most of the avalanche team is actually working on that project.
On the 28 and 29 of March, there was an ORACLE and ESRI conference where I gave a talk. I was presenting the way we use Arc/Info for the avalanche mapping.
As I already knew of the future plans of the IMO concerning avalanche forecasting, I wrote an article presenting the expert models Crocus, Safran and Mepra, used in Meteo-France.
Since then, I have read some articles about the models (topographical and dynamic) used by the Avalanche Division. It allowed me to learn more about the parameters we would like to calculate automatically with Tin and Grid in Arc/Info in the future.

Final status as of March 1997

Anne Choquet was able to complete the work at Hnifsdalur concerning the coordinate system and to generate the required avalanche registration maps. All the data from Neskaupstaður was successfully digitised with the help of Svanbjörg H. Haraldsdóttir. Furthermore, a method was defined that deals with avalanche events where only information about the maximum runout position is known. This situation can arise easily in Iceland, owing to the fact that it is very dark during the winter time, and bad weather commonly affects avalanche observation.
In January 1996, Vincent Bain visited the IMO for 6 weeks. His time in Iceland was funded by the French Embassy in Reykjavik. During his stay, he made substantial progress in establishing the methodology for evacuation map production. The eventual aim is to be able to interactively link the evacuation map with a database, so that when an area needs to be evacuated, it can simply be selected on the computer, and names and phone numbers of the residents of that zone will be produced, facilitating a rapid evacuation.

Figure 1.1 : Architecture of the files

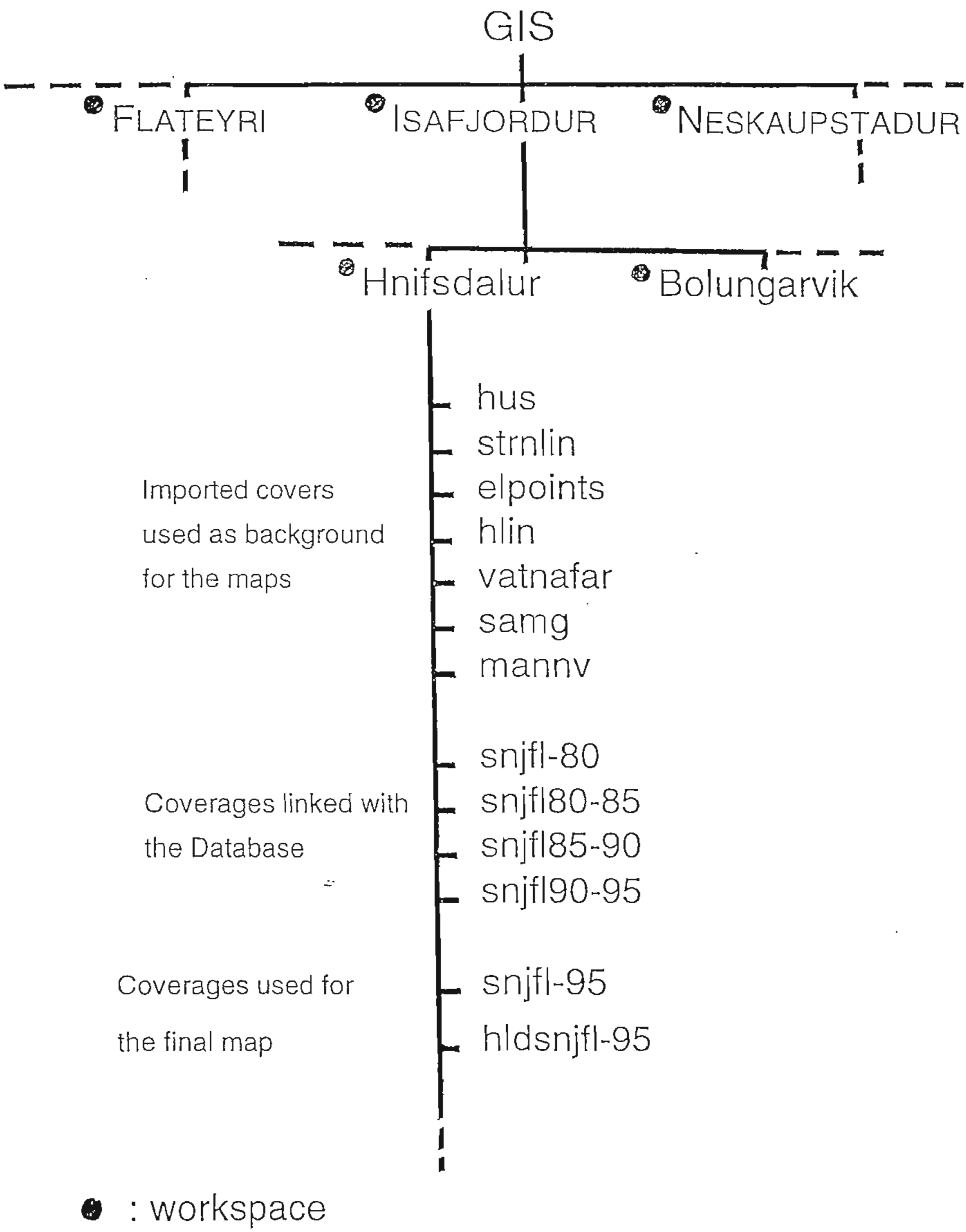
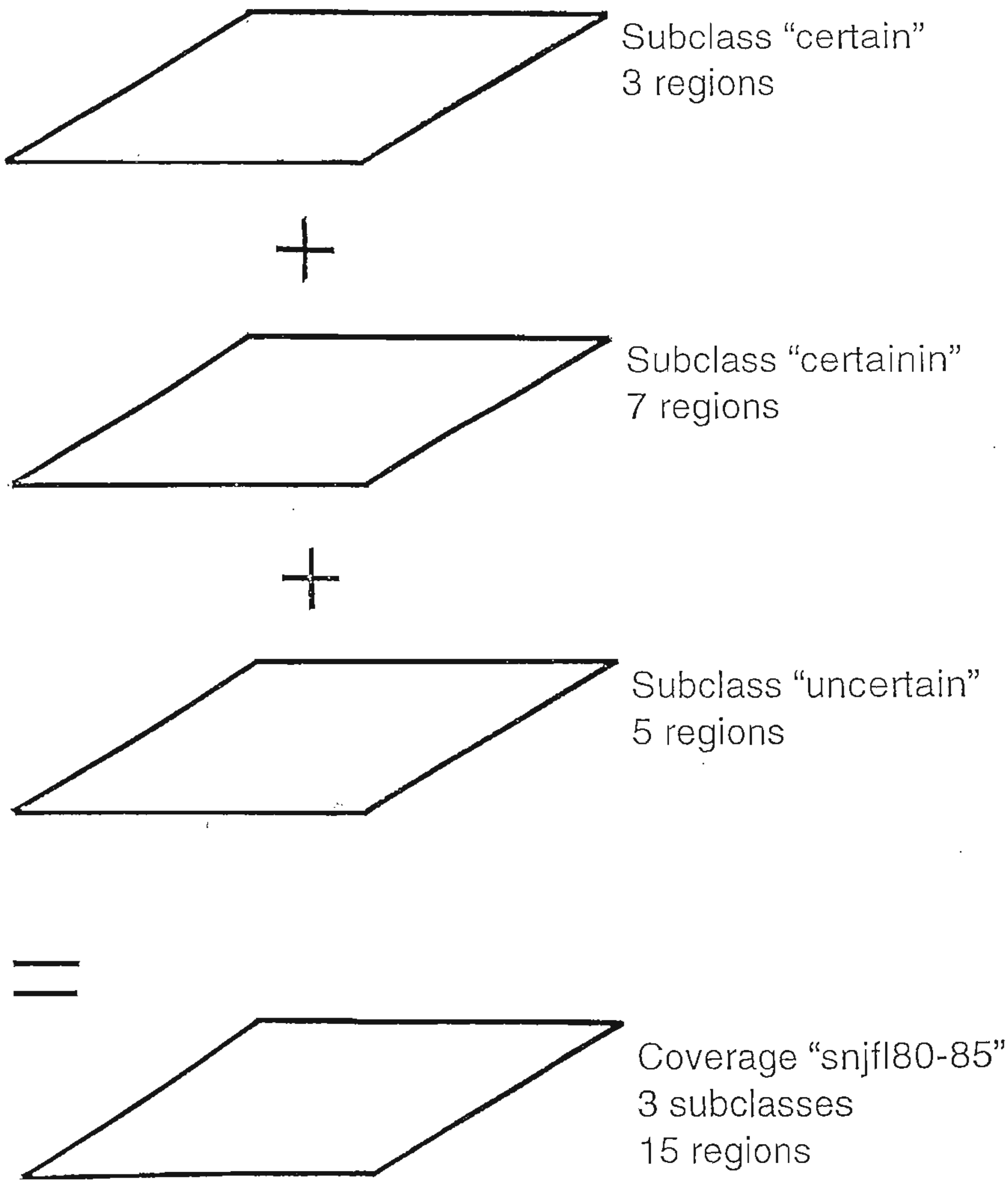
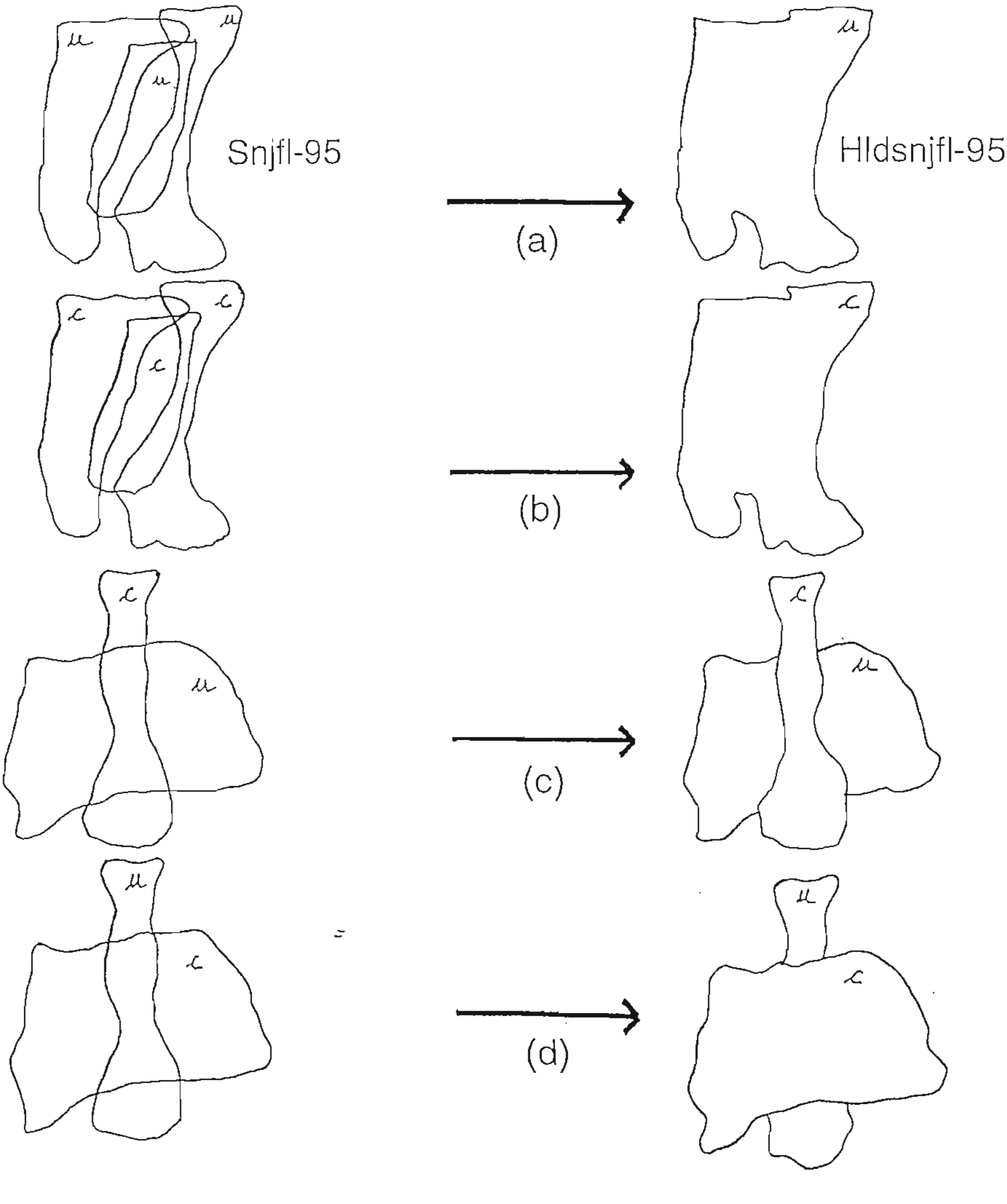


Figure 1.2 : Levels of organisation within a coverage

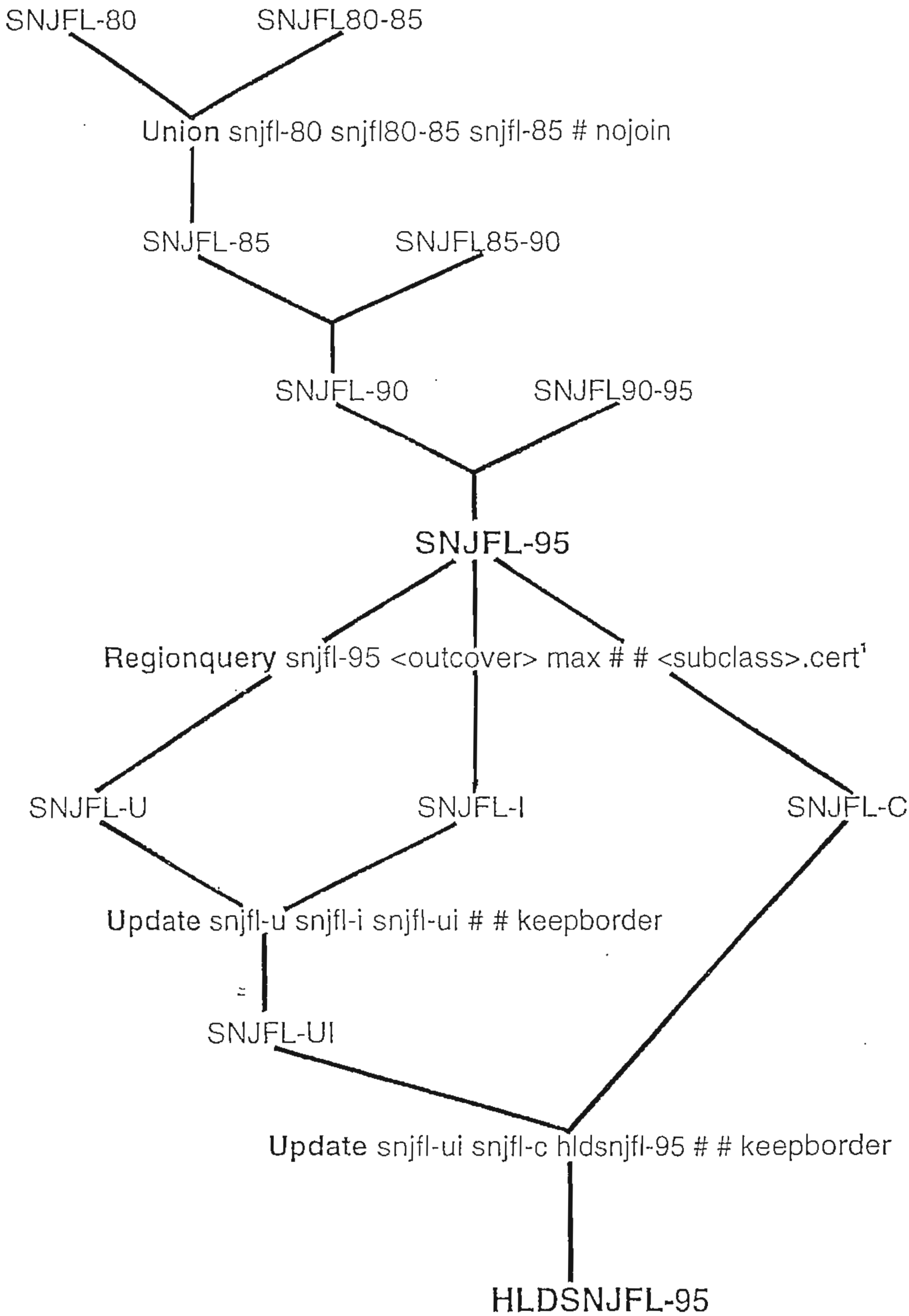


<u>Figure 1.3 : Organisation of the data on the map</u>



u : uncertain, c : certain

Figure 1.4 : The process to create hldsnjfl-95



[1] cert is the item that we want to keep from snjfl-95, in the outcover.

Part 2

Introduction

Risk is the probability of death or losses and is the product of three sub-components:

Encounter probability is the chance of an avalanche reaching a certain position in the path;

Exposure is defined as the proportion of time that the objects or people of concern are subject to the phenomenon under consideration;

Vulnerability is the degree of damage to the elements of concern.

The general form of this nomenclature is widely established (Carrara *et al*, 1991; Einstein, 1988; Fell, 1994). The risk to an individual from avalanching is primarily a function of the encounter probability which is dependent upon avalanche frequency and magnitude.

Secondly, there is the exposure term. If one is concerned solely with structures which are fixed in the avalanche path such as buildings, then exposure tends to unity as the natural lifetime of the building is long compared to that of an avalanche event. If one is dealing with the risk to the occupants of these buildings, then exposure is determined by the fraction of time that the building is occupied. In this study this is assumed to be half of the day.

Vulnerability can be formulated to varying degrees of complexity. Salient factors include construction materials, building height, building orientation, time of day and even the floor plan. The most important element of vulnerability is the magnitude of the avalanche in question. A sophisticated formulation of vulnerability is only possible for specific applications. In many cases, and for general studies such as this one, a simplified system suffices. The only factors incorporated into vulnerability here are the avalanche magnitude and whether or not the building is a reinforced construction.

It may be noted that by setting exposure to unity, one can derive values for potential risk in regions yet to be inhabited. This is obviously of concern when planning the location of new settlements or the enlargement of existing towns and villages.

By describing risk in this way, it is hoped that persons responsible for settlement planning in Iceland can be informed as to relative safety of various sites. For this to be truly effective, guidelines are required as to acceptable risk. Risk is a difficult concept as the willingness to be subjected to a risk varies from person to person, and is also dependent upon the personal perception of the risk and the degree of empowerment of the individual. For example, people are more willing to accept a particular risk with regards to driving a car (where they have an element of control over the situation) than they are for an avalanche. This issue is discussed in more detail by Bohneblust and Troxler (1987).

Method

Data on runout distances, volumes of avalanched material and avalanche path profiles were obtained from a number of 1 : 5 000 avalanche registration maps and their associated data sheets during the summer of 1995. Because vulnerability is a function of avalanche magnitude, the recorded avalanches were first grouped according to the Canadian size classification using half sizes (table 2.1 outlines this classification). It was then possible to conceptualize a model as a set of distributions:

(1) A general distribution for the relative frequency of different sized avalanches. This may be combined with a knowledge of the average frequency of events upon a path to give the frequency of different sized events at a given location.
(2) A set of distributions describing the probability of a particular runout distance being obtained for an avalanche of a certain size. In combination with the frequency of occurrence, these distributions permit the evaluation of encounter probability along the profile.
(3) A similar set of distributions that allow the calculation of the probability of an avalanche of a particular width for a specific avalanche size. The sets of distributions in (2) and (3) together define the area affected by an avalanche event and lead to an evaluation of the encounter probability in three dimensions.
(4) A relation between the size of the avalanche and the degree of damage it is liable to cause. This gives the vulnerability.

If it is assumed that avalanches are independent and discrete events that result from a set of continually occurring Bernouilli trials, then the frequency of avalanching can be expected to conform to a Poisson distribution. However, in the long term the average avalanche frequency is sufficient to characterize an avalanche path for risk calculations and is used in this model.

The avalanche record in Iceland emphasizes the large, destructive events. Consequently, small avalanches are under-represented. Thus, while data from Iceland was felt to be appropriate for calculating the relative frequency of the larger events, the systematic records from Rogers' Pass and Revelstoke in Canada were employed to derive the relative frequency of smaller sized occurrences.

In order to combine the avalanche runout data, the runout ratio of McClung and Lied (1987) was employed. The avalanche runout data was segregated by size and distributions were fitted to those sizes where 20 or more events had occurred. The other distributions were estimated by extrapolation of the trend of the distribution parameters from the reliably fitted distributions. A similar method was adopted for the width data, with no data standardisation adopted. When the relative frequency distribution was combined with the runout distributions, the combined results conformed to an extreme value type I distribution. This result is supported by the field study of Föhn and Meister (1981). A similar result holds for the width model, although the degree of fit to the extreme value distribution varies with position.

Vulnerability values were derived for fatalities and the specific loss to buildings (the cost of repair as a proportion of the cost of the structure) from the information available on the damage done by recent large avalanches in Iceland. Values for reinforced structures were obtained by using data in Sandi and Vasilescu (1982) who investigated earthquake damage in Romania. Their results show that on average, the damage per size class is 60% less for concrete structures than for non-reinforced buildings. This was the figure adopted in this study. Table 2.2 lists the parameter values for the relative frequency, runout and width distributions, while table 2.3 shows the 4 vulnerability functions available in this model.

Results

Figure 2.1 shows how the encounter probability diminishes downslope. These results may be converted from their standardised form to actual encounter probabilities by dividing by 100 and multiplying by the average avalanche frequency on a given path. An example risk calculation in table 2.4 gives the risk 50 m from the centre of a path (width = 100 m) at a runout ratio of 0.20. Risk here is expressed as the proportion of fatalities in low quality constructions. This is also the case for figure 2.2.

To produce a risk map, the calculations performed in table 2.4 must be repeated for a number of points. It is then possible to convert the runout ratio back to a runout distance and plot the points, risk contours can then be constructed. The automatic extraction of runout ratio parameters from digital terrain models permits rapid production of these maps.

Figure 2.2 is an example map for Traðargil at Hnifsdalur. Three contour lines are plotted. These contours conform to a recommendation of this study that the width model is *only* applied at the edges of the path due to uncertainties in the avalanche trajectory.

The problem of defining acceptable risk has already been noted. Fell (1994) notes that in Australia, communities appear willing to accept a voluntary risk (a risk to themselves or their homes) to the order of 10^{-3}. For avalanche applications, vulnerability in terms of specific loss yields a higher risk than fatalities at a given point. Therefore, this gives a more conservative estimate of risk. A government agency should use a risk criterion for planning that is *at least* as stringent as that accepted by the community. A critical value for avalanche ris of 2×10^{-4} has been officially established in Iceland. This would suggest that measures are required to protect residences in parts of Iceland.

Conclusion

In this section of the report I have outlined the development of an avalanche risk model for Iceland. This is based on path data and validation shows that the model works better in the West Fjords where many of the recorded events have occurred.

There are obvious benefits to linking this model to an avalanche database and GIS system, facilitating rapid risk map production and risk evaluation. The flexibility of the model means that it can be altered as more data become available. Ideally, a separate model would be derived for the east of the country where, based on the existing data, avalanche frequency and magnitude characteristics appear to be different.

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Table 2.1 : Canadian snow avalanche size classification and typical factors

Size	Description	Typical Mass ($\times 10^3$ kg)	Typical Path Length (m)	Typical Impact Pressures (kPa)
1	Relatively Harmless to people	<10	10	1
2	Could bury, injure or kill a person	100	100	10
3	Could bury a car, destroy a small building, or break a few trees	1000	1000	100
4	Could destroy a railway car, large truck, several buildings, or a forest with an area up to 4 hectares	10 000	2000	500
5	Largest snow avalanches known; could destroy a village or a forest of 40 hectares	100 000	3000	1000

From McClung and Schaerer (1993)

Table 2.2 : Parameter values for risk model distributions

Avalanche Size	Relative Frequency of Size Classes	Parameters for normal distributions of runout (expressed as runout ratios)	Parameters for Gamma distributions of avalanche width
1	0.32287	mean = -0.452 sd = 0.091	shape = 14.63 scale = 3.621
1.5	0.15453	mean = -0.276 sd = 0.108	shape = 10.08 scale = 0.590
2	0.21082	mean = -0.151 sd = 0.126	shape = 7.15 scale = 0.201
2.5	0.10663	mean = -0.054 sd = 0.143	shape = 5.82 scale = 0.094
3	0.16536	mean = 0.025 sd = 0.160	shape = 6.09 scale = 0.062
3.5	0.02896	mean = 0.092 sd = 0.177	shape = 7.98 scale = 0.053
4	0.00839	mean = 0.150 sd = 0.194	shape = 11.47 scale = 0.051
4.5	0.00217	mean = 0.201 sd = 0.211	shape = 16.57 scale = 0.050
5	0.00027	mean = 0.247 sd = 0.228	shape = 23.28 scale = 0.049

Table 2.3 : Vulnerability expressed as specific loss or proportion of fatalities for two different construction materials.

	Low Quality Constructions		Reinforced Concrete Structures	
Avalanche Size	Specific Loss (Percentage)	Fatalities (Percentage)	Specific Loss (Percentage)	Fatalities (Percentage)
1	0	0	0	0
1.5	3	0	2	0
2	7	0	4	0
2.5	12	3	7	2
3	20	7	12	4
3.5	30	13	18	8
4	39	21	24	13
4.5	66	33	40	20
5	82	50	50	30

Table 2.4 : An example risk calculation for Eyrarhryggur at Flateyri.
(Runout ratio 0.20; width 100 m; average frequency of 1.802 avalanches per year; vulnerability as specific loss to low quality constructions).

	Column 2	Column 3	Column 4	Column 5	Column 5	Column 6
Avalanche Size	Proportion of Each Size Exceeding a 0.20 Runout Ratio	Relative Frequency of the Individual Size Classes	Runout Encounter Probability (Product of Columns 2 and 3)	Proportion of Each Size Exceeding a 100 metre Width	General Encounter Probability (Product of Columns 4 and 5)	Path Specific Encounter Probability (Product of Column 5 and 1.802)
1	0.0	0.32287	0.0	0.0	0.0	0.0
1.5	0.0	0.15453	0.0	0.0	0.0	0.0
2	0.0026	0.21082	5.44×10^{-4}	0.0003	1.53×10^{-7}	2.76×10^{-7}
2.5	0.0374	0.10663	3.99×10^{-3}	0.0805	3.21×10^{-4}	5.78×10^{-4}
3	0.1367	0.16536	2.26×10^{-2}	0.4319	9.76×10^{-3}	1.76×10^{-2}
3.5	0.2707	0.02896	7.84×10^{-3}	0.8322	6.52×10^{-3}	1.12×10^{-2}
4	0.3983	0.00839	3.34×10^{-3}	0.9896	3.31×10^{-3}	5.96×10^{-3}
4.5	0.5022	0.00217	1.09×10^{-3}	1.0	1.09×10^{-3}	1.96×10^{-3}
5	0.5815	0.00027	1.57×10^{-4}	1.0	1.57×10^{-4}	2.83×10^{-4}
Sum		1				

	Column 7	Column 8	Column 9
Avalanche Size	Vulnerability (Specific Loss to Low Quality Structures)	Exposure for Buildings	Risk (Product of Columns 6,7 and 8)
1	0.0	1	0.0
1.5	0.03	1	0.0
2	0.07	1	1.93×10^{-8}
2.5	0.12	1	6.94×10^{-5}
3	0.20	1	3.52×10^{-3}
3.5	0.30	1	3.53×10^{-3}
4	0.39	1	2.32×10^{-3}
4.5	0.66	1	1.30×10^{-3}
5	0.82	1	2.32×10^{-4}
Sum			0.011

Figure 2.1 : Simulation model results for the percentage of avalanches attaining or exceeding a given runout ratio.

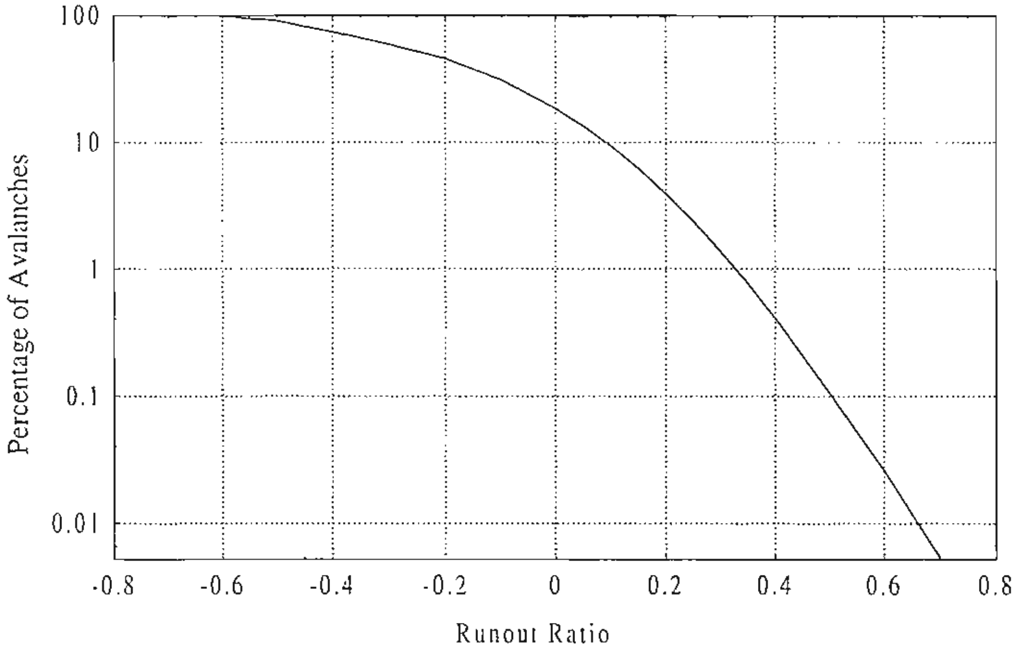

Figure 2.2 : Sample Risk Map for Traðargil at Hnifsdalur