WERENSKIOLD GLACIER (SW SPITSBERGEN) — MORPHOMETRIC CHARACTERISTICS

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Abstract

A morphometric characteristic of relief forms is one of the initial steps in geomorphometrical, hydrological and also topoclimatical analyses. These initial analyses are often performed on the base of cartographic data before actual site investigation. Nowadays, when digital elevation data is widely available, there is a need and also possibility to develop a special kind of algorithm that will be able to perform a fast and synthesized multidimensional morphometric classification of a given terrain. The main aim of this paper is to introduce a sample algorithm being one of statistical classification methods. It is assumed that it should be an universal one classifying relief forms in morphometrical facet, giving a map of such forms as a result. In this context, a form means areas with similar morphometric features, in statistical meaning. The methodology of this process has been described by using the area of Werenskiold Glacier (SW Spitsbergen) as a sample. The sole input parameter of the algorithm was digital elevation model (DEM). The selection of morphometric features has been done by comparing currently used methods identifying morphometric features of a relief. There are many parameters describing terrain morphometry, including: slope, aspect, horizontal curvature, vertical curvature, mean curvature, landscape relief rate, stream lines lengths and many other regarding erosion base, flow system in drainage area etc. Apart from relative elevation, in order to perform the classification four additional morphometric parameters have been chosen: slope, aspect, plan curvature and profile curvature. These features can be evaluated by any contemporary GIS software that supports raster data. For each parameter a data layer has been generated by applying proper transformation in 5 × 5 raster frame. Evaluation of mean vector has been used as the transformation method for aspect and single-step median filtration for other parameters. During the classification, the shape of a form was emphasized ignoring both genesis and geologic structure of relief. In developing the classification method the main two assumptions were: 1) the method must not be dependent on any distribution of morphometric variables; 2) the method must be able to handle directional morphometric parameters. These requirements are met by modified k-mean – one of the unsupervised classification methods. The modification consists in

substituting the arithmetic mean by median function. It is necessary because of the assumption of non-Gaussian distribution. The other difference is applying the Manhattan metric instead of Euclidean to unify the way of evaluating the distance for all variables, both linear and directional. The area of Werenskiold Glacier and its surroundings has been classified respectively in 4, … 9 groups. Each grouping was a morphometric approach in a different generalization rate. Depending on the number of distinct groups the obtained classification results may be a base for further research on different levels of precision. In case of the mentioned area, initial characteristic concerned both mainland and glacier's surface. The conclusion of described classification is that the surface of the glacier is very coarse and, on the land, there are very sharp shaped forms related to the presence of the glacier, such as terminal moraine, medial moraine or receding glacier. The areas of hillsides, ridges or flows resulted in more compact sets. The generalization rate for divisions in the method applied depends not only on the number of groups, but also on the model's resolution, size or its internal diversity. The classification might give other results if the glacier and the land were processed separately. The presented morphometric classification is one of the automated and object-oriented analyses that are necessary at the beginning of terrain exploration. It may have a broad application especially in less accessible areas.

Introduction

A morphometric characteristic of relief forms is one of the initial steps in geomorphometric, hydrological and also topoclimatical analyses. These initial analyses are often performed on the base of cartographic data before actual site investigation.

Nowadays, when digital elevation data is widely available, there is a need and also possibility to develop a special kind of method that will be able to perform a fast and synthesized multidimensional morphometric classification of a given terrain.

Various approaches has been used before, for e.g. ISODATA (Azanon, Delgado & Gómez 2004), algorithm *k*-mean (Burrough et al. 2001; Arrell et al. 2007) *k*-median (M. Wieczorek 2008), or even neural networks (Ehsani & Quiel 2008).
This paper presents a sample use of statistical classification method — cluster analysis — for determining areas with similar morphometric characteristic. Analysis was performed on the area of Werenskiold Glacier (SW Spitsbergen, Svarbald). This area has a great variety of elevation. Also, variety of surface shape is different on glacier and mainland. The size of the sample area is 15 km × 18 km. The sole input data is DEM (fig. 1) with resolution of 10 m × 10 m. From this data, 5 other data sets are derived by using proper transformations available in ArcGIS 9.2. The data obtained is: relative elevation evaluated in 5 × 5 raster frame, slope, aspect, profile curvature and plan curvature.

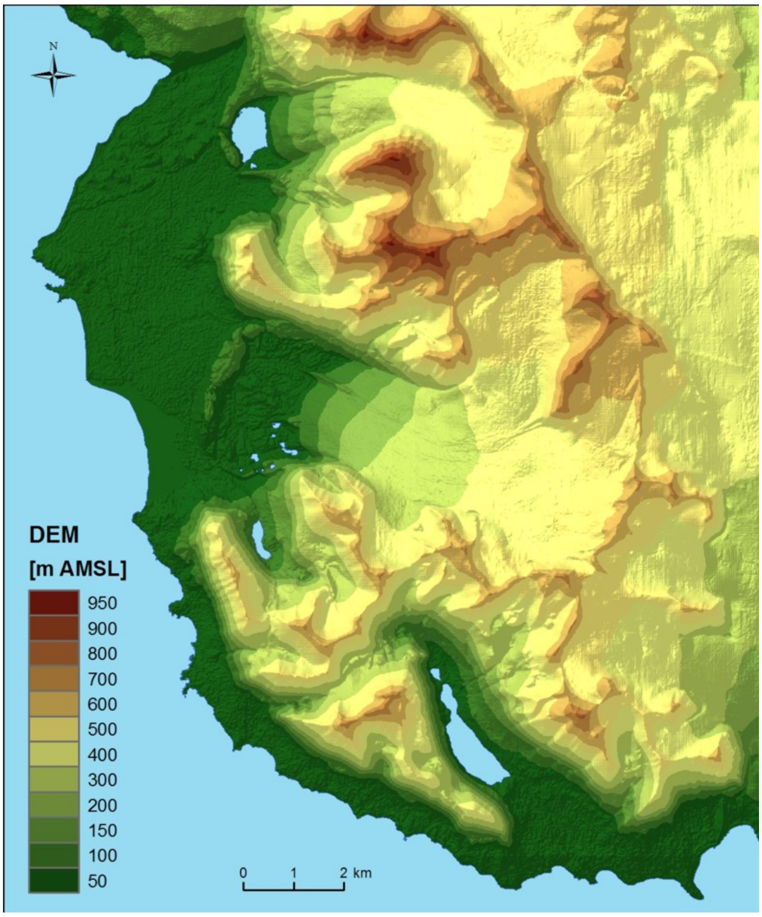

Fig. 1. Digital elevation model of SW Spitsbergen.

Median filtration

5-dimensional variable was obtained then for 2,7mln raster pixel. Each of them describe the area with size 10x10m. This is not enough in form classification. To eliminate extreme particular values, median filter in a 5x5 frame has been applied for all parameters (except aspect) (eq.1-4). This transformation meets the requirement that all morphometric variables must describe an area with the same size. Median filter is also more suitable for asymmetric distribution than arithmetic mean or modal value, what is very important for such variables like slope or relative elevation.

$$h_i = \mathrm{Me}(\{dH_{i(1)}, \ldots, dH_{i(25)}\}) \quad (1)$$

$$s_i = \mathrm{Me}(\{slope_{i(1)}, \ldots, slope_{i(25)}\}) \quad (2)$$

$$c_i^{prof} = \mathrm{Me}(\{prof_{i(1)}, \ldots, prof_{i(25)}\}) \quad (3)$$

$$c_i^{plan} = \mathrm{Me}(\{plan_{i(1)}, \ldots, plan_{i(25)}\}) \quad (4)$$

For aspect, which is a directional variable, as a transformation function the evaluation of a direction of average vector (eq. 5) has been applied in a frame with the same size as for other variables.

$$a_i = \text{arc}(\text{mean vector}(\{aspect_{i(1)}, \ldots, aspect_{i(25)}\})) \tag{5}$$

The result of these transformation was a set of layers. It was then the subject of final classification. The scope of values visibly decreased for variables transformed by single-step median filtration and didn't change for aspect. This was the expected result (Wieczorek 2008).

Cluster analysis

In the classification process, the main stress was put on the shape of a form. Origin of forms and their geological setting were both omitted. Two main assumption were considered while developing classification method:

1) the result of classification should not depend on the distribution of morphometric variables so the method cannot require Gaussian distribution (it was especially hard to achieve for slope);
2) the method must handle directional variables that is particularly important on areas, where intensity of topoclimatical components occurrence is related to aspect, for e.g. in topoclimatical analyzing for Spitsbergen.

To meet these conditions, as the final classification method, the iterated *k*-median method was chosen. It works with the same rules as for *k*-mean method, but the centre of a class is determined by using median instead of mean function.

The presence of a directional variable (aspect) also enforced use of Manhattan metric for it to evaluate the distance to the centre of a class. To keep the same metric for each variable, it was applied to the others also. All variables have the same importance in evaluating the distance to the class centre, so the values are normalized by using standard deviation. Cluster analysis was not performed in ArcGIS, but by a software specially prepared for this classification.

Results

The area of Werenskiold Glacier and its surroundings has been classified to 4 to 9 classes. Each classification is a proposal of a different morphometric view in a given generalization rate. However, apart from the number of classes, in all results the boundary between the glacier and the hills is sharply outlined. Depending on the number of classes the given classification result may be a base for further research on different generalization level. Regarding Werenskiold Glacier and its surroundings, the initial characteristic concerns both the glacier and the mainland as one area. Maps of forms (fig. 2 – fig. 4) illustrate spatial distribution of obtained classes. Apart from *k* values, boundaries of glacier are sharply outlined.
It is very hard to assign a specific name (peak, ridge, plain, etc.) to a class. Sometimes it is even useless, because the matter is to make a quantitative not qualitative classification. For adequate big number of classes the division is more detailed, for e.g. concave hillsides with different rate of slope or curvature. 9

classes division relates to the classification of slopes in facet of curvature, but in presented analysis 3 more variables were considered, so this interpretation is too general here.

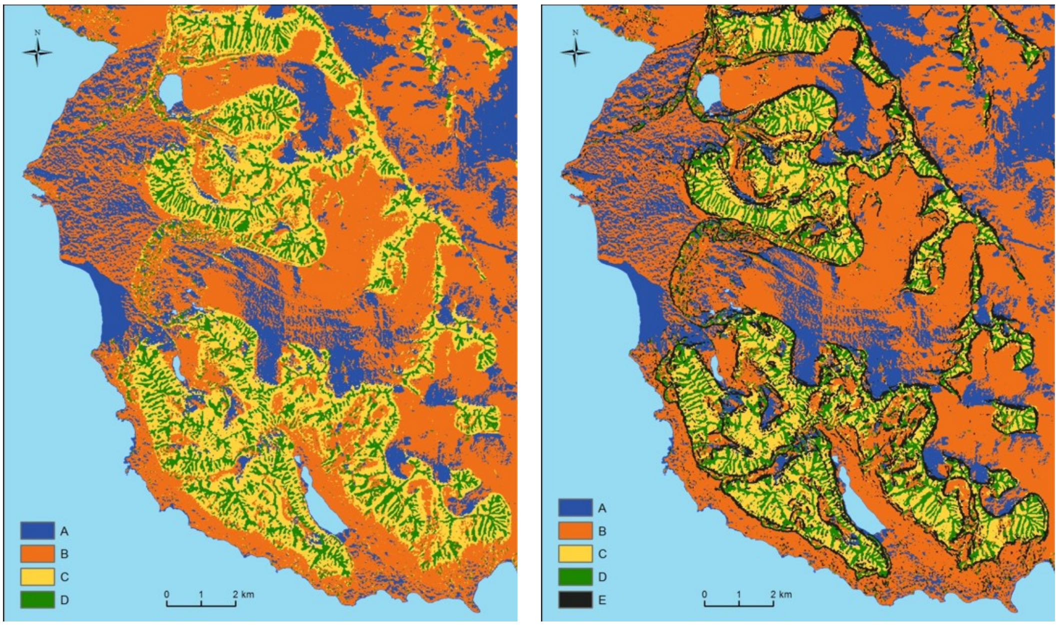

Fig. 2. Classification on 4 and 5 grups.

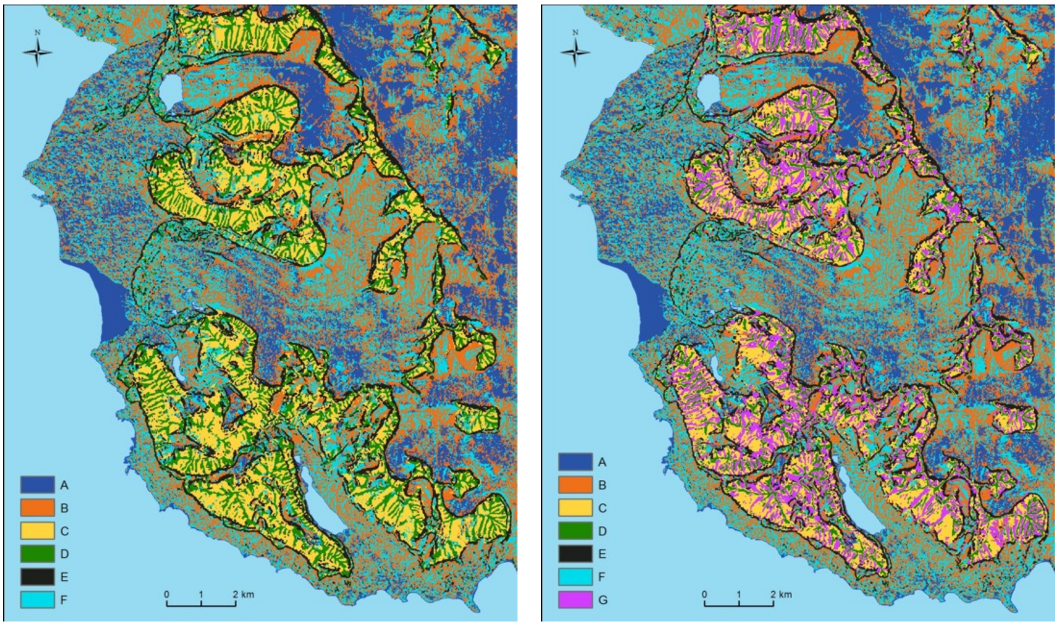

Fig. 3. Classification on 6 and 7 grups.

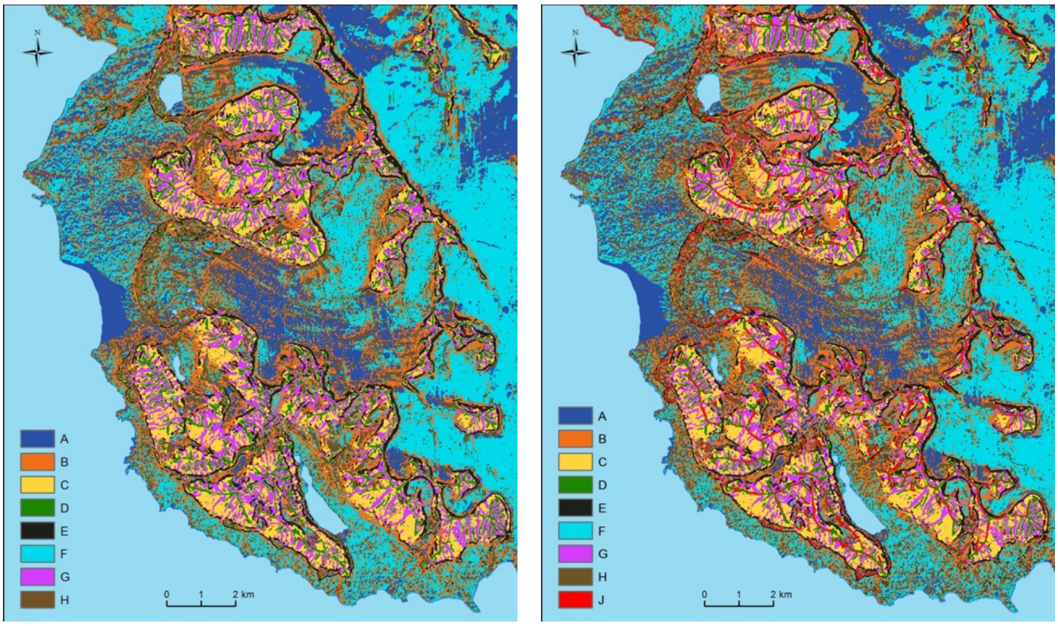

Fig. 4. Classification on 8 and 9 grups.

The presented classification (visual as well as tabular (tab. 1)) enables to extract the following features of a given area:

- the variable determining the extraction of class E is “profil curvature” (for $k \geq 5$);
- the surface of glacier is very coarse ($k = 6$ and $k = 7$);
- there are sharply outlined forms related to the glacier, such as terminal moraine, central moraine or glacier front ($k \geq 8$);
- the area with hillsides has been divided to more compact areas than the area with surface of the glacier.
- areas, that don’t change their color regardless of k, keep most uniform in morphometric aspect

	h	s	c^{profil}	c^{plan}	a
A	0,00	0,00	0,00	0,00	N
B	2,06	4,63	0,01	0,01	S
C	13,06	28,99	0,23	-0,15	SW
D	17,09	33,55	-0,12	0,42	SW

	h	s	c^{profil}	c^{plan}	a
A	0,00	0,00	0,00	0,00	N
B	1,99	4,42	0,00	0,01	S
C	17,08	34,48	0,09	-0,19	SW

D	17,03	33,46	-0,14	0,47	SW
E	7,35	18,97	0,38	-0,04	W

	h	s	c^{profil}	c^{plan}	a
A	0,00	0,00	0,00	0,00	N
B	2,08	4,80	0,05	-0,05	SW
C	17,45	34,74	0,08	-0,13	SW
D	17,71	34,44	-0,17	0,56	SW
E	8,70	22,15	0,46	-0,06	NW
F	2,44	5,21	-0,03	0,09	SW

	h	s	c^{profil}	c^{plan}	a
A	0,00	0,00	0,00	0,00	N
B	2,08	4,79	0,05	-0,05	SW
C	17,16	33,97	0,06	0,14	SW
D	17,71	34,54	-0,27	0,76	S
E	7,70	20,16	0,44	-0,06	NW
F	2,24	4,78	-0,04	0,08	SW
G	16,60	34,26	0,12	-0,34	SW

	h	s	c^{profil}	c^{plan}	a
A	0,00	0,00	0,00	0,00	N
B	2,97	7,54	0,16	-0,06	W
C	17,26	34,06	0,06	0,14	SW
D	17,98	34,93	-0,27	0,78	S
E	9,10	23,60	0,55	-0,06	NE
F	1,49	3,41	0,01	0,00	SE
G	16,72	34,28	0,10	-0,33	SW
H	3,41	6,88	-0,12	0,09	W

	h	s	c^{profil}	c^{plan}	a
A	0,00	0,00	0,00	0,00	N
B	3,16	7,59	0,10	-0,10	W
C	17,08	34,11	0,09	0,11	SW
D	18,56	36,09	-0,19	0,87	S
E	8,64	22,56	0,53	-0,06	NE
F	1,51	3,42	0,00	0,00	SE
G	16,96	34,96	0,13	-0,38	SW
H	2,46	5,35	-0,03	0,12	W
J	13,21	24,77	-0,58	0,20	W

Table 1. Lists of classes' centers for divisions into 4...9 groups.

Conclusion

The morphometric classification described here is an example of automated and object-oriented analysis needed at the beginning of terrain exploration, specially these less accessible.

Further planned morphometric analyses and method developing are related to operating on the glacier area and the land area separately.

Classification method results may be also clues for generalization, when the selection of the most important shapes of an area is needed. The particularity rate of the classes in such method depends on number of classes, model resolution, its size and internal variety.

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