GEOMORPHOMETRY 2020 PERUGIA, ITALY JUNE 22 - 26 2020

Detection of crevasses using high-resolution digital elevation models: Comparison of geomorphometric modeling and texture analysis

Olga T. Ishalina [a], Dmitrii P. Bliakharskii [a], Igor V. Florinsky [b, §]

[a] Department of Cartography and Geoinformatics
Institute of Earth Sciences, St. Petersburg University
St. Petersburg, 199034, Russia

[b] Institute of Mathematical Problems of Biology
Keldysh Institute of Applied Mathematics, Russian Academy of Sciences
Pushchino, Moscow Region, 142290, Russia

[§] iflor@mail.ru

Abstract—**The Vostok Station is the only Russian inland polar station in Antarctica. It is supplied by sledge and caterpillar-track caravans via a long sledge route. There are a lot of crevasses on the way. In this article, we compare capabilities of two techniques – geomorphometric modeling and texture analysis – to detect open and hidden crevasses using high-resolution digital elevation models (DEMs) derived from images collected by unmanned aerial survey. The first technique is based on the derivation of local morphometric variables. The second one includes estimation of Haralick texture features. The study area was the first 30 km of the sledge route between the Progress and Vostok Stations, East Antarctica. We found that, in terms of crevasse detection, the most informative morphometric variables and texture features are horizontal and minimal curvatures as well as homogeneity and contrast, correspondingly. In most cases, derivation and mapping of morphometric variables allow one to detect crevasses wider than 3 m; narrower crevasses can be detected for lengths from 500 m. Derivation and mapping of Haralick texture features allow one to detect a crevasse regardless of its length if its width is 2-3 pixels. Geomorphometric modeling and Haralick texture analysis can complement each other.**

I. INTRODUCTION

There are five year-round operating Russian polar stations in Antarctica. Four of them – Bellingshausen, Novolazerevskaya, Progress, and Mirny Stations – are located on the coast of the Southern Ocean. The inland Vostok Station is situated at 3,488 m above sea level, at the southern Pole of Cold, near the Southern Pole of Inaccessibility and the South Geomagnetic Pole. Since 2007, the Vostok Station is supplied by sledge and caterpillar-track caravans via a 1430-km sledge route from the Progress Station.

The sledge route is intersected by a large number of crevasses formed due to glacier movements. The width of crevasses can vary from a few millimeters to tens of meters [1]. Crevasses hidden by snow bridges are extremely dangerous for researchers. Monitoring and timely detection of crevasses is important for the safety of participants of sledge and caterpillar-track caravans.

There are two main approaches for rapid detection of hidden crevasses: ground-based and remote sensing ones. The ground-based approach involves studying a glacier with geophysical methods. Ground penetration radars are particularly applied, with antennas usually mounted in front of a vehicle. However, the safety and effectiveness of this approach is questionable [2]. The use of aerial and satellite imagery to detect open crevasses has high potential [1, 3, 4]. In this context, texture analysis of satellite data showed great efficiency. Low resolution of data is the main disadvantage of this approach [5].

In recent years, unmanned aerial systems (UASs) and UAS-derived products – orthomosaics and digital elevation models (DEMs) – have been increasingly used in glaciology [6]. In this article, we compare capabilities of two techniques – geomorphometric modeling and texture analysis – to detect open and hidden crevasses using UAS-derived high-resolution DEMs.

II. STUDY AREA

The study area is located south of the Progress Station, Princess Elizabeth Land, East Antarctica. We consider the first 30 km of the sledge route between the Progress and Vostok Stations (Fig. 1). From north to south, ice sheet elevations increase uniformly from 230 m to 850 m above sea level.

Olga Ishalina, Dmitrii Bliakharskii and Igor Florinsky (2020) Detection of crevasses using high-resolution digital elevation models: Comparison of geomorphometric modeling and texture analysis: in Massimiliano Alvioli, Ivan Marchesini, Laura Melelli & Peter Guth, eds., Proceedings of the Geomorphometry 2020 Conference, doi:10.30437/GEOMORPHOMETRY2020_3.

This area is characterized by a particularly large number of open and hidden crevasses, which makes the sledge route very dangerous. The width of crevasses varies from 0.5 m to 23 m. It was decided to detect crevasses in a buffer zone 1.5 km wide relative to the axis of the sledge route.

III. MATERIALS AND METHODS

An unmanned aerial survey (Fig. 1) was performed within the frameworks of the 62nd Russian Antarctic Expedition (austral summer 2016–2017); for details see [7]. For the study area, we obtained orthomosaics with a resolution of 0.08 m and DEMs with resolutions of 0.25 m, 0.5 m, and 1 m.

A hidden crevasse has a snow bridge, which makes it difficult to detect. However, a snow bridge can sink under gravity and, so, forms some sort of ditch. In fact, hidden crevasses are micro-landforms of the ice sheet topography. They should be manifested in a high-resolution DEM. Thus, to detect hidden crevasses, we previously used local and nonlocal morphometric variables derived from UAS-based DEMs [8].

On the other hand, crevasses can be reflected by changes in surface texture characteristics. Thus, to detect hidden crevasses, DEMs can also be processed by texture analysis techniques, in particular, using Haralick texture features [9]. Such approach was earlier utilized to reveal crevasses from satellite imagery [5].

To compare and validate these two approaches, we decided, first, to detect crevasses in areas where they can be visually recognized on orthomosaics or single images. For this purpose, 15 test crevasses were visually detected (Fig. 1). Length and approximate width of each crevasse were measured (Table 1).

It is not known *a priori* which particular morphometric variable will allow detecting crevasses. Therefore, for a site with two neighboring test crevasses (## 6 and 7), digital models for a set of fourteen local morphometric variables were derived from the DEMs, namely: slope, aspect, horizontal curvature, vertical curvature, mean curvature, Gaussian curvature, minimal curvature, maximal curvature, unsphericity curvature, difference curvature, vertical excess curvature, horizontal excess curvature, ring curvature, and accumulation curvature. For their definitions, formulas, and interpretations, see [10]. Both test crevasses were detected by only two morphometric variables, namely, horizontal and minimal curvatures. These two variables were used to reveal other crevasses at the further stages of the study.

These calculations were initially performed using the 1-m gridded DEM. Then, the DEMs with a resolution of 0.25 m and 0.5 m were tested. However, the experiment showed that these DEMs are marked by a high level of high-frequency noise resulted from photogrammetric processing of aerial images. These DEMs are not suitable for geomorphometric modeling [8].

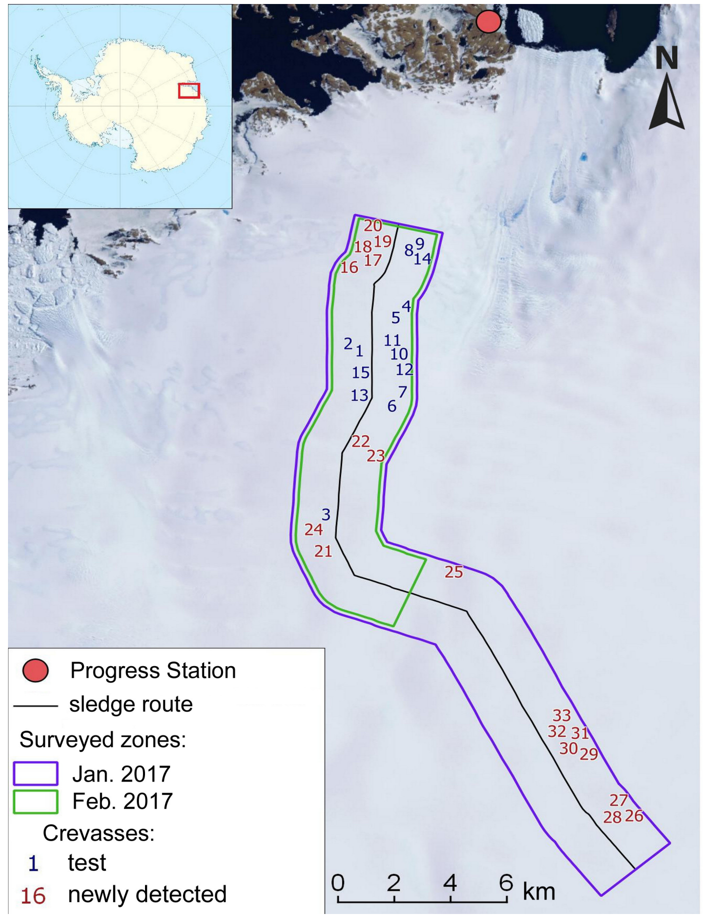

Figure 1. Study area, zones of the UAS surveys, and location of crevasses.

Table 1. Characteristics of test crevasses (Fig. 1)

Crevasse, #	Length, m	Width, m
1	123	1.5
2	77	1.5
3	883	2.0
4	191	3.0
5	170	5.0
6	913	7.0
7	476	8.0
8	117	0.5
9	99	0.6
10	644	5.0
11	247	7.0
12	501	2.0
13	300	3.0
14	155	0.6
15	139	2.0

Next, for the site with test crevasses ## 6 and 7, we derived a set of eleven Haralick texture features from the DEMs, namely: angular second moment (homogeneity), contrast, correlation, variance, inverse difference moment, sum average, sum variance, sum entropy, entropy, difference variance, and difference entropy. For their definitions, formulas, and interpretations, see [9]. In terms of crevasse detection, two Haralick texture features were the most informative, such as, homogeneity and contrast. These features are reciprocal, so only homogeneity was used in the next stages of the study.

To calculate the Haralick texture features, a gray level coincidence matrix (GLCM) is used [9]. GLCM is a table describing how often different combinations of brightness values or gray levels between adjacent pixels occur in an image in a certain direction.

To calculate the Haralick texture features, one should choose the following parameters:

- Size of a moving window.
- Number of gray levels.
- Distance between compared pixels.
- Direction.

The smaller is the size of features under study, the smaller should be a moving window. Elevation is a continuous variable, so elevation values should be re-coded into integer 'gray levels' before calculating the Haralick texture features from DEMs. If the number of gray levels is too small, the elevation range for each level will be too large. As a result, some topographic features will not be described because the corresponding pixels will have the same gray value. So, the number of gray levels should be as large as possible. A DEM has to be splitted into blocks, within which an elevation range does not exceed a certain value. In the calculation, each direction emphasizes topographic features of a certain orientation.

In this study, the size of a moving window was 3×3 pixels because crevasses are described by a small number of pixels. The distance between compared pixels was 1 pixel, that is, the values of neighboring pixels were compared. The number of gray levels was 256. We assumed that there could be different crevasse orientations, so all possible directions were considered. The 1-m gridded DEM was split into blocks so that an elevation range did not exceed 30 m.

Calculation and visualization of both local morphometric variables and Haralick texture features was carried out using QGIS software.

Table 2. Test crevasses detected (+) by different techniques

Crevasse, #	Horizontal curvature	Minimal curvature	Homogeneity
1	+		
2	+	+	+
3	+	+	+
4	+	+	+
5	+	+	+
6			+
7	+	+	+
8			
9			
10	+	+	+
11	+	+	+
12		+	+
13			
14			
15			+

IV. RESULTS AND DISCUSSION

In contrast to local morphometric variables, Haralick texture features are not so sensitive to the high-frequency noise and can be applied to DEMs with resolutions of 0.5 m and 0.25 m. As a result, the homogeneity map derived from the 0.25-m gridded DEM allowed us to reveal crevasses less than 1 m wide.

Figure 2 shows examples of crevasse manifestation on the orthomosaic and maps of elevation, horizontal curvature, and homogeneity. One can see no sign of two crevasses on the orthomosaic and elevation map, some traces of two crevasses on the horizontal curvature map, as well as clear image of two crevasses on the homogeneity map.

To compare capabilities of two techniques, we used the 1-m gridded DEM only. As a measure of technique effectiveness, we estimated the probability of test crevasse detection, that is, the probability is 1 if all 15 test crevasses are recognized by a technique.

Using the geomorphometric modeling, 9 of 15 crevasses were detected. The Haralick texture analysis allowed us to find 10 of 15 crevasses. As expected, all crevasses cannot be revealed by either technique (Table 2).

The probability of crevasse detection by the geomorphometric modeling and the Haralick texture analysis is 0.60 and 0.66, correspondingly. Combination of two techniques leads to the probability of 0.73. Notice that among 15 test crevasses, 3 ones were less than 1 m wide (c.f. Tables 2 and 1). According to the first consequence of the sampling theorem [10], these crevasses cannot be detected using the 1-m gridded DEM: to keep the information on topographic features with typical planar sizes λ in a DEM, one should use the DEM grid size $w \leq \lambda/(2n)$, where $n \geq 2$. Excluding these 3 test crevasses, the probability of the geomorphometric and Haralick detection increases up to 0.75 and 0.83, correspondingly. Combination of both techniques leads to the probability of 0.91. Thus, the two techniques complement each other.

There is a relationship between the possibility of detecting a hidden crevasse and its geometrical characteristics. No crevasses with a width of less than 1 m were detected by both approaches, even if they are clearly visible on the orthomosaic due to the lack of clear subsidence of a snow bridge.

In most cases, mapping of morphometric variables allow one to detect crevasses wider than 3 m; narrower crevasses can be detected only for lengths from 500 m. Derivation and mapping of Haralick texture features allow one to detect a crevasse regardless of its length if its width is 2–3 pixels.

Notice that new hidden crevasses were detected within the study area by the described analysis (Fig. 1; Table 3). Totally, 18 new crevasses with lengths ranging from 80 m to 1 km were found; the average width of crevasses was 10 m.

V. CONCLUSIONS

The results show that the processing of UAS-derived high-resolution DEMs is an effective way to detect open and hidden crevasses. Geomorphometric modeling and Haralick texture analysis can complement each other.

VI. ACKNOWLEDGMENTS

The work is supported by the Russian Foundation for Basic Research and the National Natural Science Foundation of China, grant # 20-51-53016.

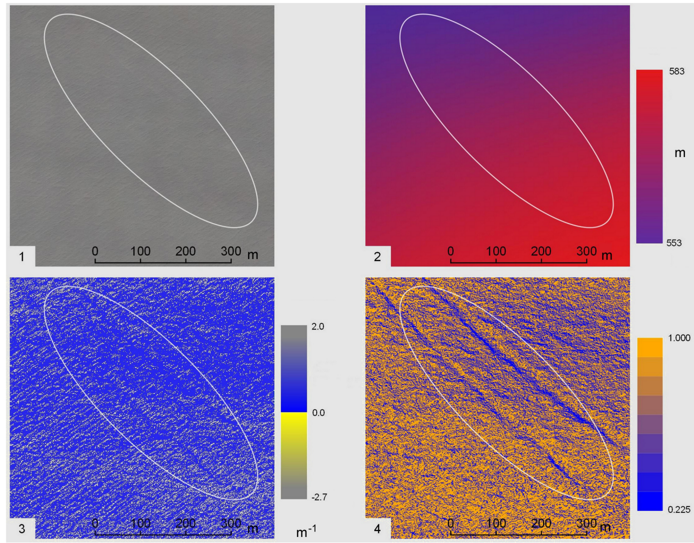

Figure 2. Examples of the crevasse manifestation: 1 – orthomosaic, 2 – elevation, 3 – horizontal curvature, 4 – homogeneity. The white oval shows location of two test crevasses, ## 6 and 7.

Table 3. Characteristics of newly detected hidden crevasses.

Crevasse, #	Length, m	Width, m	Latitude*, °S	Longitude*, °E
16	319	8	69.46525	76.26893
17	185	6	69.46396	76.28075
18	285	7	69.4626	76.27525
19	85	5	69.46041	76.28082
20	120	2	69.46023	76.28308
21	322	12	69.57285	76.25495
22	1115	10	69.53393	76.28528
23	930	15	69.54094	76.31048
24	175	7	69.56875	76.25538
25	640	20	69.57085	76.37607
26	619	11	69.65806	76.55022
27	232	12	69.65868	76.54793
28	190	12	69.66001	76.54977
29	437	13	69.63652	76.46882
30	423	10	69.63779	76.4677
31	812	15	69.63578	76.46726
32	169	10	69.63518	76.47282
33	471	10	69.63314	76.47313

* Coordinates are for crevasse centroids.

REFERENCES

[1] Colgan, W., H. Rajaram, W. Abdalati, C. McCutchan, R. Mottram, M.S. Moussavi, S. Grigsby, 2016. “Glacier crevasses: observations. models and mass balance implications”. Rev. Geophys., 54(1), 119–161.

[2] Popov, S.V. and S.P. Polyakov, 2016. “Georadar location of cracks in the region of the Russian Antarctic stations Progress and Mirny (East Antarctica) in the 2014/15 season”. Earth’s Cryosphere, 20(1), 90–98 [in Russian].

[3] Glasser, N. and T. Scambos, 2008. “A structural glaciological analysis of the 2002 Larsen B ice-shelf collapse”. J. Glaciol., 54(184), 3–16.

[4] Holt, T., N. Glasser, D. Quincey, 2013. “The structural glaciology of southwest Antarctic Peninsula ice shelves (ca. 2010)”. J. Maps, 9(4), 37–41.

[5] Xu, T., W. Yang, Y. Liu, C. Zhou, Z. Wang, 2011. “Crevasse detection in Antarctica using ASTER images”. Lec. Notes Comp. Sci., 6754, 370–379.

[6] Bhardwaj, A., L. Sam, Akanksha, F.J. Martín-Torres, R. Kumar, 2016. “UAVs as remote sensing platform in glaciology: present applications and future prospects”. Remote Sens. Envir., 175, 196–204.

[7] Bliakharskii, D.P., I.V. Florinsky, T.N. Skrypitsyna, 2019. “Modelling glacier topography in Antarctica using unmanned aerial survey: assessment of opportunities”. Int. J. Remote Sens., 40(7), 2517–2541.

[8] Florinsky, I.V. and D.P. Bliakharskii, 2019. “Detection of crevasses by geomorphometric treatment of data from unmanned aerial surveys”. Remote Sens. Lett., 10(4), 323–332.

[9] Haralick, R.M., K. Shanmugam, I. Dinstein, 1973. “Textural features for image classification”. IEEE Trans. Syst. Man Cyber., SMC-3(6), 610–621.

[10] Florinsky, I.V., 2016. Digital Terrain Analysis in Soil Science and Geology. 2nd ed. Amsterdam: Academic Press.