Proceedings of the 25th International Conference on
Port and Ocean Engineering under Arctic Conditions
June 9-13, 2019, Delft, The Netherlands

Noise analysis of model ice contours in images

Petr Zvyagin[1,2], Anna Voitkunskaia[3] , Evgeniy Maksimov[4]
[1] Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia
[2] Krylov State Research Centre, St. Petersburg, Russia
[3] State Marine Technical University, St. Petersburg, Russia
[4] JSC «VNIIRA»

ABSTRACT

To obtain information about ice conditions, not only satellite navigation systems are used, but also ice reconnaissance by aircraft. This way, the problem of ice covered areas, ice floes and free water areas recognition on available images arises. Boundary recognition is an important part of ice image processing. In fact, different techniques suggest differing positions for the same ice floe in image.

In this paper we propose the classification for the noise of the ice floe segment in binary image. Proposed approach is intended to highlight the misrecognition of waterlogged ice floe edges. This classification also allows comparing results of different contouring methods. It also can be used as criteria for an ice floes image segmentation refinement.

Using the proposed classification and binary backing obtained by Otsu method, we have compared contours of three model ice floes obtained by the following methods: manually, by the novel automatic segmentation method, and by the active contour method. Expansion of the ice floe contour was accompanied by increasing of the noise ratio inside the corresponding segment.

KEY WORDS: Ice image; pattern recognition; noise; contour; Otsu.

INTRODUCTION

Ice floes contouring problem is connected with practical needs of ice floes size measuring as well as ice consolidation estimating in images. Ice floes are natural objects, they can have complicated shapes. Ice images usually have features, which obstruct an easy recognition of separate floes by the ordinary methods of image recognition. Close consolidation, presence of brush ice, shadows, water ponds and submerged parts are among such features.

Up to now there is no universal algorithm for complete solution of the ice floe contour detection problem. In early paper written by Rothrock and Thorndike (1984), the digitizing tablet with manual tracing of all contours in image was used for collecting ice floes size distribution data.

The problem of distinguishing of ice from water in images mainly was considered earlier in terms of estimation of ice concentration (Hall et al., 2002), (Ji et al., 2011). In these works, the thresholding was one of applied approaches: the threshold value separated pixels of one-channel images into two or more intensity ranges. Such intensity ranges were referred to ice or no-ice. Usual method of grayscale (or one-channel) image intensity threshold finding is Otsu (1979). After binarization, white color in such image is assigned to ice, while black – for open water and leads.

However, different types of ice formations have different reflecting capabilities, which influence the result of image recognition by thresholding. For example, the problem of "darker ice" recognition in infrared ice satellite images exists: some areas covered by ice are significantly less reflective than other ice-covered areas. So, it becomes difficult to distinguish them from the open water areas and leads. Baldwin et al. (2017) are discussing this problem for moderate-resolution (375 m) images taken by the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-Orbiting Partnership (Suomi NPP) spacecraft. Incorrect interpretation of "darker ice" areas leads to significant error in sea ice concentration detection. For higher resolution images of ice and leads, like made by the NASA's Digital Mapping System (10 cm resolution), the same detection problem arises for thin ice merged to main ice-covered areas.

Figure 1 presents an aerial photograph, made during Surface Heat Budget of the Arctic Ocean (SHEBA) program in July 1998 from the helicopter (Perovich et al., 2002). In this figure we can see that areas occupied by ice have a variety of colors, because of presence of melted ponds and leads with different depths.

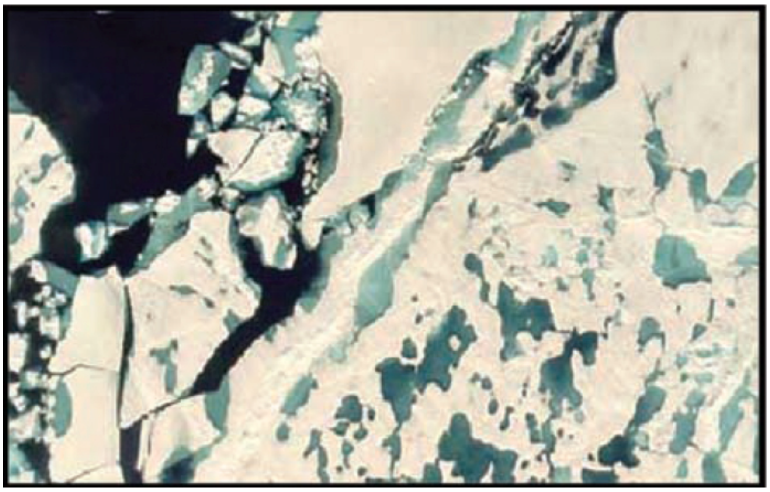


Figure 1. Aerial photograph of Arctic sea ice with ponds and leads (Perovich et al., 2002)

To distinguish "light ice", "dark ice" and water Zhang and Skjetne (Zhang and Skjetne, 2015) applied a method of k-means clustering. They determine "dark ice" in image by subtracting thresholded layers. However, due to uneven color of ice floes, sometimes "dark ice" piece was improperly detected inside the "light ice" floe.

Segmentation of broken ice pieces was performed by Zhang et al (Zhang et al., 2015) by means of GVF snake algorithm applied on preprocessed image. In images used in the mentioned paper ice pieces have mostly rectangular form and seem to be artificially cut from the ice floe. Thus, a problem of shaded edges of model ice pieces of irregular shapes obtained by natural breaking of untouched ice floe by a towing model was not considered in that paper.

Thresholding of ice images leads to the need of analysis of the noise around ice floes edges, which comes out after grayscale image thresholding. For example, we can see such black inclusions into white ice segments in the binary part of Figure 2. Natural ice image provided in this figure was obtained in February 2000 during the cruise to Greenland Sea, and taken by means of integrated visual monitoring system designed for deployment on a ship (Hall et al., 2002).

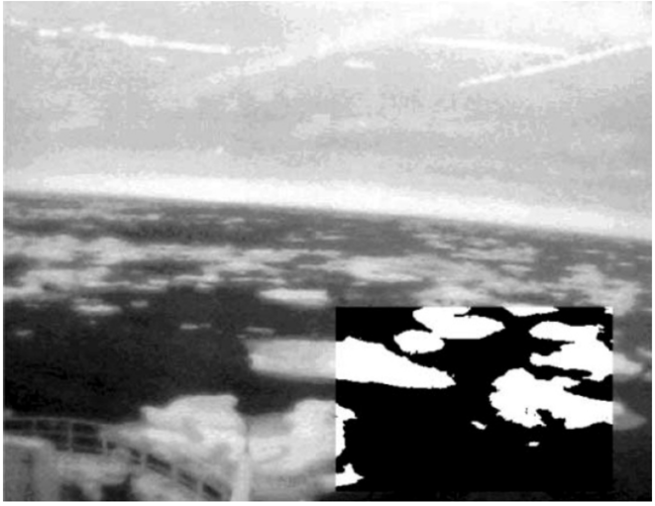


Figure 2. Ice-cam image with thresholded binary part in the bottom right-hand corner (Hall et al, 2002)

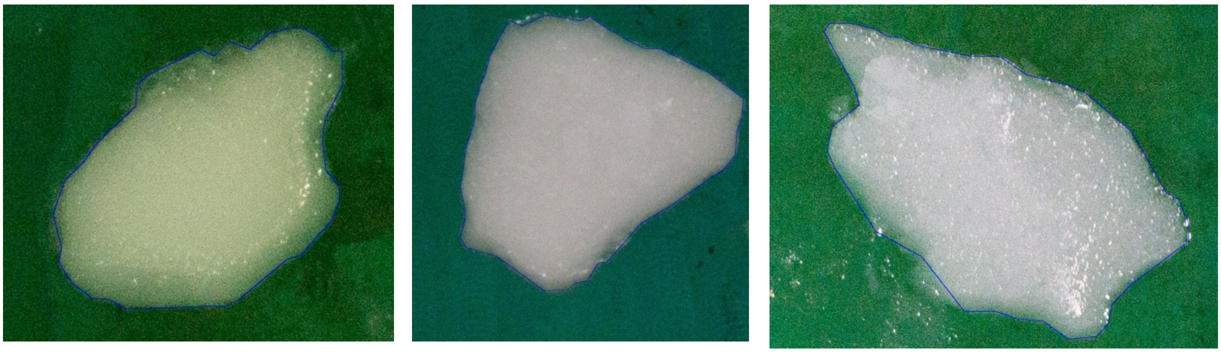
In this paper we analyze the noise in ice segments detection, which appears after Otsu thresholding of model ice images. This allows making contours comparison criteria for ice-water images. It is our continuation of work on routing in ice model (Voitkunskaia and Zvyagin, 2016) in the part of reliable map making. The following ways of ice floe contours acquisition will be considered in the paper: hand-made, automatic block segmentation, active contour (snake) smoothing. The study is based on analysis of images of model ice floes, obtained in the ice tank.

The structure of the paper is as follows. The first section is introductive. In the second section broken model ice images and their features are described. In the third section the classification of noise, which appears around ice edges after image binarization, is proposed; examples are provided. In the fourth section noise elimination and contours acquisition by automatic segmentation are discussed. In the fifth section the influence of active contour smoothing on captured noise amount is considered. The last section contains the conclusion.

BROKEN MODEL ICE EDGES FEATURES

The analysis performed in this paper is based on images obtained in the new ice tank of Krylov State Research Centre in St. Petersburg. This ice tank acquired a license from Kvaerner Masa Yards, Finland, for Fine grain (FG) model ice (Timofeev et al, 2015). The FG model ice technology is used by Aalto University (Finland) ice tank as well (von Bock und Polach and Ehlers, 2014). Fine grain model ice consists of several layers, from which top layer is of the most strength. Such structure leads to waterlogged edges of broken ice pieces, and floating ice crumble. Usually after a run of a model in the ice tank, the following ice features are in presence: broken ice of different sizes, submerged ice floes and pieces, ice crumble and large parts of untouched ice field. Being submerged or splashed, model ice soaks the water, which changes light reflecting capabilities of it.

Examples of three model ice pieces are presented in Figure 3. They were obtained by natural breaking of the model ice field during towing tests in the ice tank. We can see that floating unsubmerged model ice pieces have grainy surface with grains reflecting artificial light of the ice tank. In combination with photo camera flash, this provides small spotlights distributed on the surface of the ice floe (Figure 3 a, c), as well as inter-grain shadows. Being submerged, edges of model ice soak water and become mushy and semitransparent. Wet ice crumble, which comes out when ice crushes, floats on the surface and reflects light (Figure 3 c). This provides effect of small spotlights on free water.



a) b) c)

Figure 3. Three single floes of FG model ice with manually built polygonal contours

Let us analyze the segmentation of three images of single model ice floes. At first, we shall make a contour as a closed polygonal chain given by manually pointed vertices on the edge of model ice floe. The area inside this contour will be attributed to the ice floe, while outside of it will be attributed to water. This method reflects our understanding of what should be taken as ice floe edge, but is time-consuming, tedious and hardly applicable for images with masses of broken ice. However, manually defined contour can be not free of mistakes, as soon as stuck ice crumble can be mistakenly percept as the ice edge.

The procedure of Otsu threshold binarization with preliminary converting of the image to grayscale provides us binary image without any input parameters, except of grayscale converting formula. Such binary image is often used for estimating an approximate ice concentration as a ratio of white pixels in image. But, as it was mentioned in the introductive part, submerged and crumbled “gray” ice can be hardly detected by this thresholding technique. Thus, several questions remain open: what kind of error occurs when we use ice/water detection by means of Otsu threshold technique, how large this error can be in comparison to manual contouring, and how ice-water segmentation can be improved?

If we have an RGB image with three separate channels for red, green and blue colors, the formula of grayscale conversion will be the following:

$$I(x,y) = \alpha * R(x,y) + \beta * G(x,y) + \gamma * B(x,y) \qquad (1)$$

where $I(x,y)$ is the grayscale intensity value of the pixel with coordinates (x,y), while R, G, B – values of red, green and blue channels of pixel with the same coordinates in RGB-image; α, β, γ are numerical coefficients, which sum is unity.

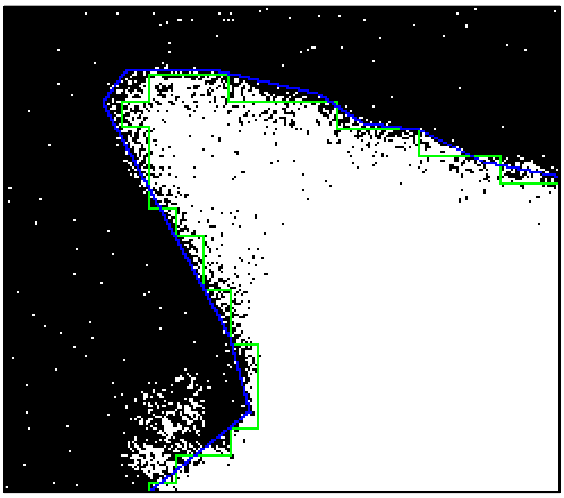


Figure 4. Result of Otsu threshold binarization of grayscale Figure 3 c

In Figure 4 the result of Otsu thresholding of the fragment from Figure 3 c, converted to grayscale by means of (1) with $\alpha = \beta = \gamma = 1/3$, is presented along with manually built ice piece contour (blue). From Figure 4 we can see, that not only "gray" ice grains near the edge were referred in this binary image to water, but some grains deep inside the contour were misrecognized as well.

Thus, the Otsu thresholding did not convert the model ice piece image to clearly segmented binary image; instead of this we have tangle of white and black pixels on the place of ice piece edge, as well as outlier pixels in homogenous areas.

NOISE CLASSIFICATION IN BINARY ICE-WATER PICTURE

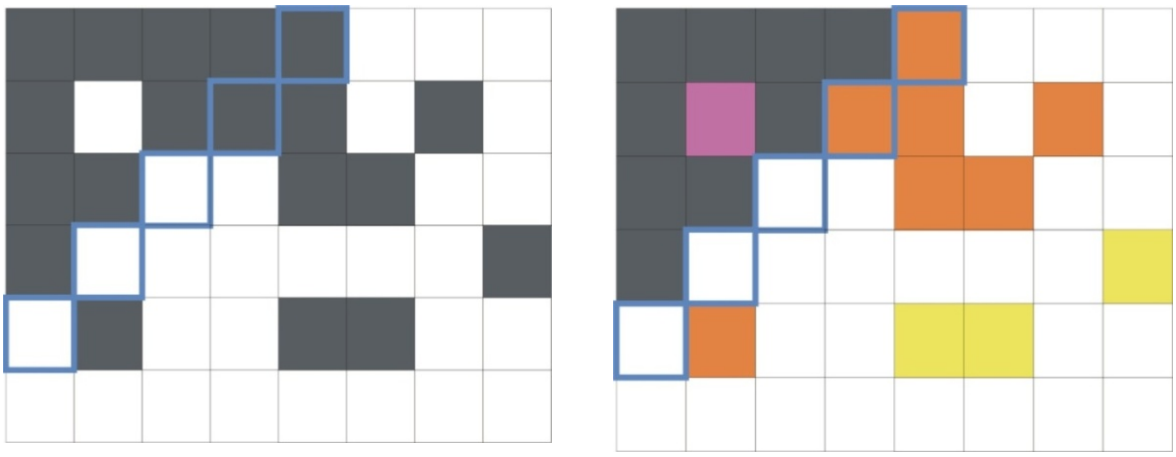
Let us suppose that a contour exists, which bounds a solid continuous segment of ice or water. This way, we have a contoured area to which we assign the specific color in binary image: white or black. In the following we shall consider segments as closed pixel sets, in other words − the contour of the segment belongs to that segment

Definition 1. We define as a noise those pixels, which have an opposite color than the segment, and located inside the contour of that segment.

We suppose that if the single ice floe under consideration does not have connection to an image borders, then "ideal" binarization provides us only two connected spaces. Practically, the thresholding does not lead to mentioned result. Let us give a classification to noise occurred inside the contour of the ice floe after an image binarization (Figure 5 a).

Definition 2. We shall define as a "noise of the type 1" those noise pixel sets, which are not connected to that complement of the segment, which of the opposite color than the segment.

In other words, noise of the type 1 pixels are totally immersed into the area inside the segment and do not have any "chain" connection to the area outside the contour. Pixels of this type are shown by yellow color in Figure 5 b. We can see that "inclusions" of the type 1 noise are essentially separate segments of the opposite color, included into larger segment. We can see an amount of such noise segments, usually consisting of single pixels, scattered in black water area as well as white ice area in Figure 4.



(a) (b)

Figure 5. An example of binary image fragment with the blue color marked edge of ice segment: before noise classification (a) and after noise classification (b). Here noise of the type 1 is marked with yellow, and noise of the type 2 is marked with orange

Presence of the noise of the type 1 can be a good indicator of the image binarization quality. If we shall list all of k_w separate segments of white color recognized in a binary image with a single ice floe in it, sorted by their cardinality s_i^w in descending order:

$$\mathrm{s}_1^{\mathrm{w}}, \mathrm{s}_2^{\mathrm{w}}, \dots, \mathrm{s}_{\mathrm{k_w}}^{\mathrm{w}} \quad (2)$$

then in the first place there is expected the cardinality s_1^w referred to the ice floe segment itself.

Accordingly, if considered ice floe lies in internal part of the image (has no connection to the image borders), then in the list of cardinalities for k_b black-pixel segments, sorted in descending order,

$$\mathrm{s}_1^{\mathrm{b}}, \mathrm{s}_2^{\mathrm{b}}, \dots, \mathrm{s}_{\mathrm{k_b}}^{\mathrm{b}} \quad (3)$$

the first place is expected to be occupied by the cardinality of the water segment. This way, the condition of binarization without any noise of the type 1 is the following:

$$\sum_{i=2}^{k_w} s_i^w + \sum_{i=2}^{k_b} s_i^b = 0 \quad (4)$$

Looking at manually built contour in Figure 4, which bounds the ice floe we can note, that black pixels inside that contour are usually simple “intrusions” of water segment due to the misrecognition of ice floe edge, because this edge is saturated with water. Such intrusions do not form separate segments, they are parts of water segment, which lies outside of the contour. Thus, in addition to noise of the type 1, another class of the noise needs to be introduced.

Definition 3. We shall define as “noise of the type 2” those pixel sets, which are noise, but not the noise of the type 1.

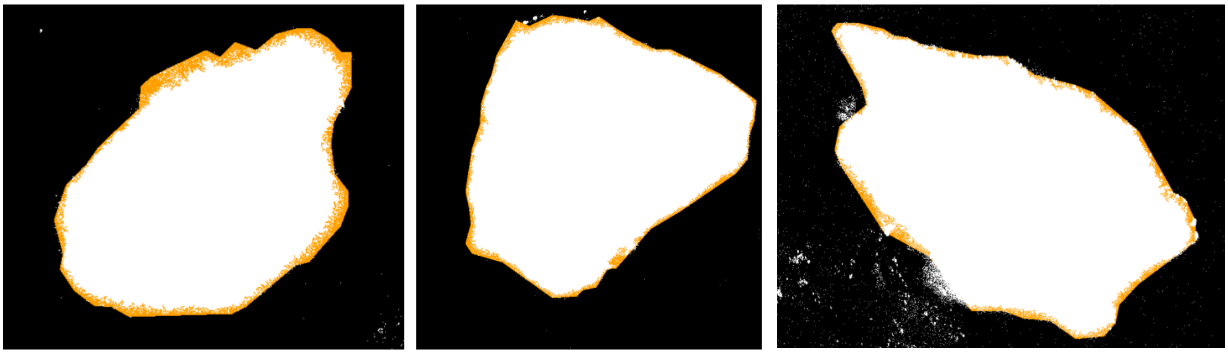
In other words, we shall define as noise of the type 2 those pixels of the color opposite to the segment color, which make “chains” protruding into the segment. In general, connection of pixels in those “chains” can be vertical, horizontal or diagonal. Pixels of this type of the noise are shown by orange color in scheme provided in Figure 5 b. Magenta pixel will be referred to noise of the type 2 for the water segment, which consists of black pixels.

The sense of provided noise classification is the following: noise of the second type is responsible for the fuzziness of the ice edge-water transition; while noise of the first type is mainly responsible for dark ice grains on the ice surface, particles of crumbled ice in the water and spotlights.

Let us study how simple Otsu binarization of ice floe image generates noise in relation to manually-built contours (Figure 6). To illustrate the noise of the type 2 distribution, pixels of that type are marked with orange. It is seen that Otsu thresholding referred water filled ice edges to water.

An example of the noise of the type 1 distribution for the top part of the floe from Figure 3 b is provided in Figure 7. It is seen that separate dark ice grains, which point out to exuding water, are clustered close to the ice floe edge. They make main contribution to the noise of the type 1.

In Table 1 ratios of black pixels inside manually built contours are provided for three ice floes from Figure 3. The Otsu thresholding error in estimating of ice area inside the manually suggested contour was about 5-10%. This error is divided to noise 1 and noise 2; latter takes larger share (5-6 times), than noise 1 does.



a) b) c)

Figure 6. Noise of the second type (orange pixels) inside ice floes segments, bounded by manually built contours; binary image was obtained by Otsu thresholding

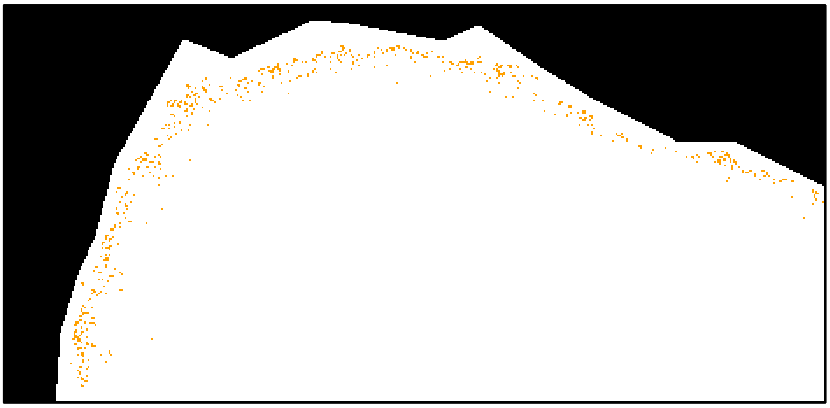


Figure 7. Noise of the first type inside of manually built contour of the ice floe provided in Figure 3 b, shown by orange pixels

Table 1. Ratio of the noise inside of manually built ice floe contours provided in Figure 3, after Otsu

	Figure 3 a	Figure 3 b	Figure 3 c
Ratio of black pixels inside the manual contour	0.108	0.056	0.06
Ratio of noise 1 inside the manual contour	0.013	0.008	0.01
Ratio of noise 2 inside the manual contour	0.095	0.048	0.05

NOISE LOCATED INSIDE CONTOURS BUILT AUTOMATICALLY

The problem of the single ice floe image segmentation improvement can be stated as the problem of minimization of the left part of (4):

$$f = \sum_{i=2}^{k_w} s_i^w + \sum_{i=2}^{k_b} s_i^b \qquad (5)$$

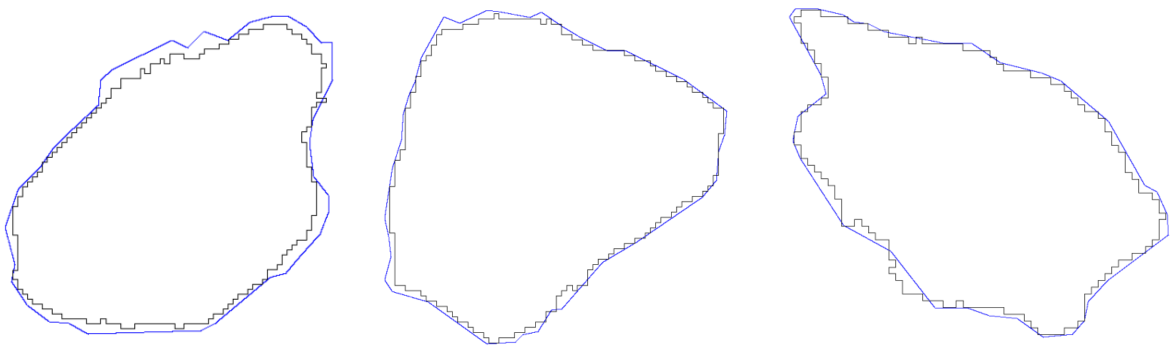
As it was said in the previous section, an "ideal" binarization of the image with the single ice floe, which does not have connections to image borders, should provide only two connected spaces: one for ice floe, and one – for surrounding water. This way, after filtering and segmentation the enumerations (2) and (3) should have only one element each.

Image features preventing an "ideal" binarization are usually small, like dark ice grains, light spots and ice crumble. We implemented image block filtering to equalize small inhomogenities, which are especially influential on the ice edge. Parameters of block filtering were customized automatically by minimization of (5) for filtered segmented image. However, the fulfillment of (4) for particular image can be difficult if semi-transparent ice crumble is in presence in the water surrounding the ice floe.

In Figure 8 results of such automatic segmentation (black polygons) in comparison with manually built contours are presented. Parameters of segmentation were customized automatically to eliminate noise 1 in filtered image, so the whole procedure was performed in "one click of the mouse". To analyze the segment contours obtained after noise elimination we shall compare them with manually built contours by amount of noise inclusions. For noise calculation we shall use the binary backing obtained after original grayscale image Otsu thresholding. It is seen that the area contoured by the segment boundary is slightly smaller than that contoured by the manually built boundary. But at the same time, the noise ratio inside of it is only 2-3% for considered images (Table 2), comparing to 5-10% inside of manual contours (Table 1). This decrease occurred mainly due to the noise 2 dropping.

Table 2. Ratio of the noise inside of automatically built ice floe segments (black polygons in Figure 8)

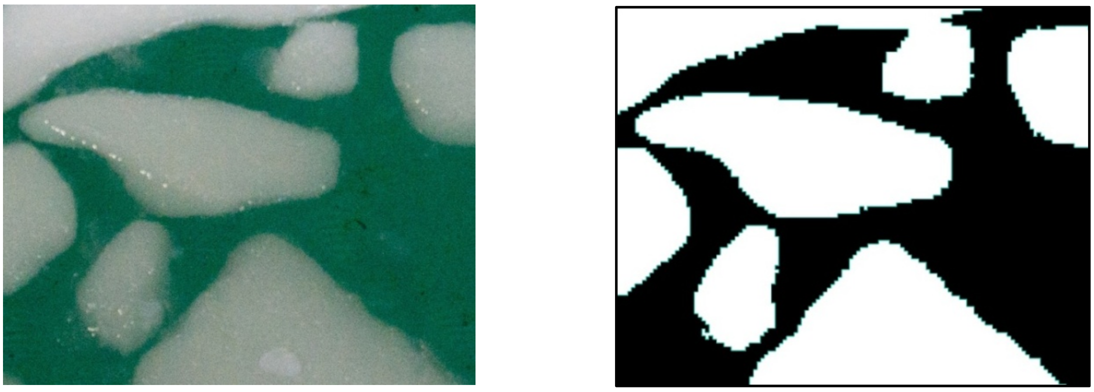
Original image of ice floe	Figure 3 a	Figure 3 b	Figure 3 c
Ratio of black pixels inside the ice floe segment	0.03	0.02	0.029
Ratio of noise 1 inside the ice floe segment	0.011	0.006	0.012
Ratio of noise 2 inside the ice floe segment	0.019	0.014	0.017
Area of the ice floe segment comparing to area contoured manually	89.7%	95.2%	95.1%



a) b) c)

Figure 8. Manually given contours (blue) and bounds of automatically built segments (black) of model ice floes

Block filtering with automatically adjusted parameters provides good results for images with several ice pieces in it. For example, in Figure 9 a several pieces of broken model ice are presented. Semitransparent waterlogged ice crumble is floating around some of them. For obtaining the segmentation presented in Figure 9 b the following criteria was used: cardinalities in (1) and (2) should be larger than 1. This way, all of the noise 1 is excluded.



a) b)

Figure 9. Several FG model ice pieces (a), and result of their boundaries detection after block filtering with automatically customized parameters (b)

NOISE CAPTURED AFTER CONTOUR UPDATE BY SNAKE ALGORITHM

Active contour or snake is the method applied by Zhang et al. (2015) for adjusting bounds of ice floes in image. This method demands good initial approximation to edges of the object. In the mentioned paper the initial approximation in the form of a circle inscribed in object was used. In this section we shall use the block contour given by the automatic segmentation (Figure 8) as an initial approximation. We shall use active contour function, which is embedded in MatLAB: it has single variable parameter – the number of iterations. Using the Otsu thresholded binary image as the backing we shall demonstrate, how noise ratio change within modified contour.

In Figure 10 plots of noise of the type 2 and 1 ratios inside the contour after 0-1000 iterations of algorithm are presented. Black contours from Figure 8 were taken as initial approximation. We can see that MatLAB snake algorithm expands contour by adding waterlogged areas to the ice segment, which increases noise ratio inside the resulting contour.

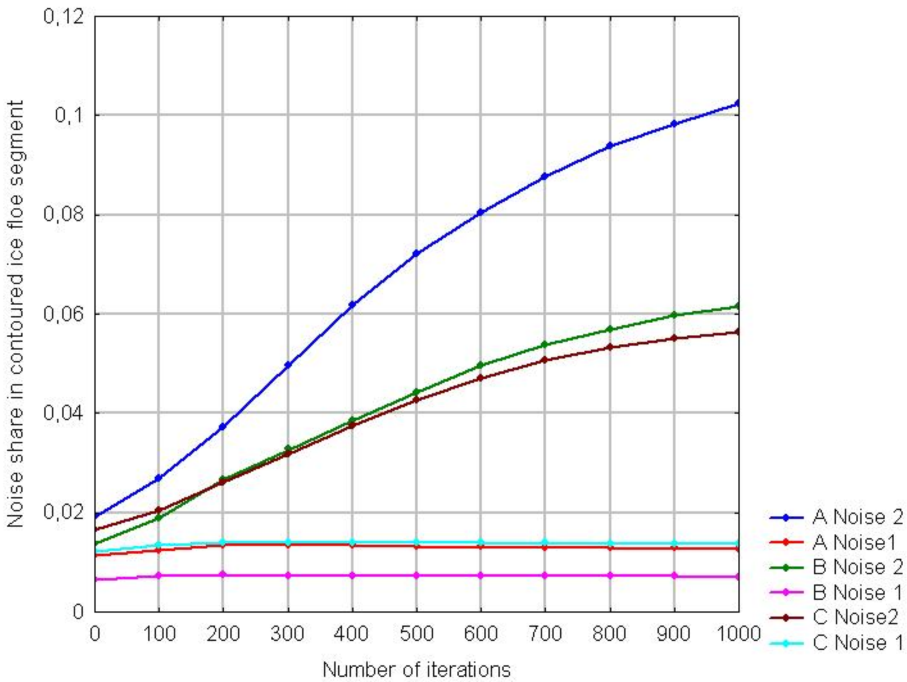


Figure 10. Noise ratio dynamics with active contour evolving on the image: A – Figure 3 a; B – Figure 3 b; C – Figure 3 c

An important thing is that noise increasing with contour expanding happens mainly due to noise 2 increasing (blue, green and brown lines). The overall ratio of noise 1 (red, cyan and magenta lines) even slightly fell.

VARIATION IN ICE CONCENTRATION DETECTION

As it was stated in the introductive part, ice image processing is often used for ice concentration (IC) estimation. Simplest way of it is the following: in obtained binary image all of white pixels referred to ice, while black – to water. We can see from noise ratios presented in Tables 1 and 2, that an error of such estimation can be significant.

In the Table 3 estimations of IC in images of Figure 3 by five different ways are provided. In first line there is a simple ratio of white pixels in image after the Otsu thresholding, including white pixels responsible for light spots and ice crumble. In second line there is ratio of pixels bounded by manually given contour of an ice floe. Third line presents the percentage of image area occupied by automatically built segment after block filtering. In the last three rows of the Table 3 the dynamics of automatically built contour correction by active contour method (snake) is shown for three different numbers of iterations.

The difference in IC estimations given by different methods, except of Otsu thresholding, can be refer to increasing/decreasing amount of the noise 2. For Figures 3 b and 3 c the IC estimation is not significantly different between the methods, but for Figure 3 a, it is significantly different because of the larger areas of "dark ice" close to the edges of the ice piece. Otsu algorithm referred these darker areas to water, which can be seen, for instance, in Figure 6 a.

Table 3. IC estimation in the image by means of different approaches

Image	Figure 3 a	Figure 3 b	Figure 3 c
Otsu thresholding	39.8%	44.3%	44.3%
Manual contouring	44.5%	46.9%	45.9%
Automatic segmentation	39.9%	44.6%	43.7%
Active contour expanding of automatic segmentation contour: 100 iterations	40.6%	45.1%	44.3%
500 iterations	43.2%	46.6%	45.9%
1000 iterations	44.8%	47.5%	46.7%

CONCLUSIONS

The study performed in this paper contributes to the issue of uncertainty in model ice floe edge detection in images. Model ice edges in image are places where transition of ice to water happens, so it becomes difficult to precisely locate their positions. Model ice is capable to soak the water, so ice surface close to the edge can look darker, which can lead to misrecognition of it parts.

In the paper we have introduced the noise classification inside the contoured ice/water segment based on binary image backing of it. As the reference binary image we used image obtained after Otsu thresholding of grayscale image converted from RGB image with using of equal coefficients for red, green and blue channels.

The study of three images of single model ice floes have shown that Otsu binarization left significant amount of noise in resulting binary images. Waterlogged areas close to ice floe edge and darker ice grains close to the edge were misrecognised.

Several ways of contour obtaining were considered in this paper and compared by the content of noise inside contoured segments. More conservative way of ice segment recognition leaves less noise of the type 2. Applying MatLAB's active contour function increased noise of the type 2 inside the floe contour up to 5-10%, while amount of noise of the type I almost did not changed.

Introduced noise classification improves our abilities of comparison of results of different contouring techniques with each other.

ACKNOWLEDGEMENTS

The research work was supported by The Ministry of Education and Science of the Russian Federation (task # 2.11665.2018/11.12).

REFERENCES

Baldwin, D., Tschudi, M., Pacifici, F., & Liu, Y., 2017. Validation of Suomi-NPP VIIRS sea ice concentration with very high-resolution satellite and airborne camera imagery. *ISPRS Journal of Photogrammetry and Remote Sensing,* 130, pp. 122–138.

Ji, S., Li, H., Wang, A., Yue, Q., 2011. Digital image techniques of sea ice field observation in the Bohai sea. *Proceedings of 21st Port and Ocean Engineering under Arctic Conditions Conference*, 9 p.

Hall, R. J., Hughes, N., & Wadhams, P., 2002. A systematic method of obtaining ice concetration measurements from ship-based observations. *Cold Regions Science and Technology*, *34*(2), pp. 97–102.

Otsu N., 1979. A threshold selection method from gray-level histograms / N. Otsu // *IIEEE Transactions on Systems, Man, and Cybernetics,* 9 (1), pp. 62–66.

Perovich, D. K., Tucker, W. B. & Ligett, K. A., 2002. Aerial observations of the evolution of ice surface conditions during summer. *Journal of Geophysical Research*, 107 (C10), p. 8048.

Rothrock, D. A., & Thorndike, A. S., 1984. Measuring the sea ice floe size distribution. *Journal of Geophysical Research*, 89(C4), pp. 6477–6486.

Timofeev O., Sazonov K., Dobrodeev A., 2015. New ice basin of the Krylov State Research Centre. *Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions*, 8 p.

von Bock und Polach, R., & Ehlers, S., 2014. On the Scalability of Model-Scale Ice Experiments. *Proceedings of the ASME 33rd International Conference on Ocean, Offshore and Arctic Engineering*, 9 p.

Zhang, Q., Skjetne, R., Metrikin, I., & Løset, S., 2015. Image processing for ice floe analyses in broken-ice model testing. *Cold Regions Science and Technology*, 111, pp. 27–38.

Zhang, Q., & Skjetne, R., 2015. Image processing for identification of sea-ice floes and the floe size distributions. *IEEE Transactions on Geoscience and Remote Sensing*, *53*(5), pp. 2913–2924.

Zvyagin, P. and Voitkunskaia, A., 2016. Model of Transit Transport in Arctic Based on Graph Algorithms. *Proceedings of the 35th OMAE Conf*erence, OMAE2016-54439, Busan, Korea, 6 p.