The authors present a study on the morphological properties of ice cover on ~200 km2 large shallow Lake Chagan in China. The ice cover morphology was investigated in terms of formation of ice ridges, their evolution during the ice-covered period, and relationship to the wind force/direction. The central point of the ms is the exploration of the ability of satellite-based remote sensing with regard to quantification of the ice ridge properties. A second "parallel" story develops throughout the ms, discussing a distinct and rarely reported type of lake ice---the "ice balls"---which were encountered by the authors during their field campaigns in support of the remote sensing data analysis.

The subject of the study is suitable for "The Cryosphere" and can potentially be of interest for the journal's wide audience: seasonal lake ice is a relatively poorly investigated part of the cryosphere, which attracts growing attention of researchers during the last several decades. Indeed, ice cover on lakes with large (compared to the length scales based on the ice thermal expansion coefficient or on the length scales of the mechanical deformation) spatial dimensions tends to have a complex morphological structure with long-lasting ridges, cracks, stamukhi, and other quasi-regular features requiring a deeper investigation for correct understanding of the role played by seasonal ice cover in large lake dynamics and land-atmosphere interaction. In this sense, the authors present a valuable dataset and a well-supported methodology with a potential for expansion on other large lakes worldwide.

Reply to comment: Thank you for your comments concerning our manuscript entitled "The Capability of high spatial-temporal remote sensing imagery for monitoring surface morphology of lake ice in Chagan Lake of Northeast China" (tc-2022-175). Those comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our work. We have carefully gone through the comments and made corrections accordingly, marked as red in the manuscript. Regarding English usage and grammar, we used a professional English editing service by Essentialink Language Service to improve our manuscript, and the certificate is provided as an attachment.

Essentialslink Language Services

ENGLISH EDITING CERTIFICATE

This document certifies that the manuscript listed below was edited for proper English language, grammar, punctuation, spelling, and overall style by one or more of the highly qualified native English-speaking editors at Essentialslink Language Services

Manuscript title

Fusion of Landsat 8 OLI and COCI for hourly monitoring surface morphology of lake ice with high resolution in Chagan Lake of Northeast China

Authors

Qian Yang, Xiaoguang Shi, Weibang Li, Kaishan Song, Zhijun Li, Xiaohua Hao, Fei Xie, Nan Lin, Zhidan Wen, Chong Fang and Ge Liu.

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Date Issued

December 30, 2022

This document certifies that the manuscript listed above was edited for proper English language, grammar, punctuation, spelling, and overall style. Neither the research content nor the author's intentions were altered in any way during the editing process. Documents receiving this certification should be Englishready for publication; however, the author has the ability to accept or reject our suggestions and changes. If you have any questions or concerns about this document or certification, please contact business@essentialslink.cn.

I had several major concerns raised when reading the manuscript:

- The story about the ball-shaped ice structures discovered by the authors on the lake surface is not connected to the declared subject of the study on the capability of satellite imagery for monitoring ice morphology. The phenomenon of “ice balls” per se is interesting for understanding the physics behind the processes of ice formation at different weather conditions, and the authors presented a reliable hypothesis on their formation supported by meteorological observations. However, it should be considered in a more consequent way and presented as a separate study in glaciological literature. Otherwise, the results will remain hidden under a wrong title and will only disturb the presentation of the actual topic of the study. As a separate study, the presentation of the “ball ice” should be accompanied by an extended discussion on frequency of its formation in waters of different types and geographical location and on its potential effects on the ice properties and under-ice conditions with analysis of information from other reports on the phenomenon. In addition to the works cited by the authors, the phenomenon was described in the literature on Lake Baikal under the russian term “kolobovnik”, see, e.g.,

Granin, N.G., Aslamov, I.A., Kozlov, V.V. et al. (2019) Methane hydrate emergence from Lake Baikal: direct observations, modelling, and hydrate footprints in seasonal ice cover. Sci Rep 9, 19361. https://doi.org/10.1038/s41598-019-55758-8

Vologina, E. G., Granin, N. G., Vorobeva, S. S. et al. (2005). Ice-rafting of sand-silt material in South Baikal. Russian Geology and Geophysics, 46(4), 420-427.

and citations therein.

Reply to comment: We appreciate your recognition of our work, and we deleted the related contents with the ice ball. We presented the preliminary analysis of ice balls of Lake Sihai and Lake Chagan (Xie et al., 2020) [1], and we hope to map the spatial distribution of the ice balls, and explain the formation by local weather, the flow field, and the topography underwater. We are planning to write a paper focusing on ice balls in an extended English version.

Reference:

[1] Xie, F., Lu, P., Cheng, B., Yang, Q., and Li, Z.: Magical spherical ice (ice balls, ice eggs), Journal of lake sciences, 695-698, 2022(in Chinese).

- The discussion on the main topic of the study, the detection of ice ridges from satellite imaging, is rather short and superficial. To put the results in the right context, it should be extended with information on the potential application of the results in lake ice studies and comparative analysis against other publications on the same subject.

Reply to comment: Thank you for the professional suggestion, and we re-wrote this part (Line 255-294).

The lake ice experiences different types during the freezing and thawing cycle, including the phases of ice crystals, frazil ice, nails, pancake ice, and ice layers (Leppäranta, 2015). Lake ice expands and contracts as the air temperature rises and drops during cold seasons. The temperature difference between night and day results in the thermal expansion and contract of lake ice, which differ significantly within a given lake. Furthermore, long and narrow cracks are generated and likely to evolve into ice ridges under pressure when lake ice bulk, collides, and piles up. The definitions of lake ice are limited by the view ranges of field measurements, and the satellite remote sensing provides a new perspective for surface morphology in a larger-scale observation. The large-scale linear structure has been found on remote sensing images during the cold season from 2018 to 2019. Similar phenomena have also been found in lakes and reservoirs in Northeast China (Liu et al., 2018b). In our previous work, we used 4 Landsat 8 OLI images to monitor the monthly changes due to the limitation of temporal resolution (Hao et al., 2021). In this study, we took advantage of the hourly revisit of the GOCI and generated 53 and 43 ESTARFM fusion images in the freeze-up and break-up processes, respectively. This makes it possible to explore the linear structure in details. The recurrent large-scale linear structure was further verified as ice ridges in the fieldwork. The spatial scales of ice fractures and ice ridges is a changeling work when considering the data source. The UAV is suitable to monitor the lake ice fractures at small scales (0-100m), and the satellite sensors are suitable to monitor the ice ridges *at large scales (10-100 km).*

Besides the thermal forces, the lake ice fractures and ridges are also a dynamic process under the control of mechanical forces. The wind above ice covers and water currents beneath ice covers force the shift of ice bulk (Tan et al., 2012). Wang et al. (2006) compared the machinal changes of leads and ice covers based on modelling results and satellite monitoring (Wang et al., 2006; Leppäranta, 2010) and revealed the influence of winds on the drift of ice. In the freeze-up process, the winds and water currents can push the ice toward the shore, preventing ice covers from freezing; in the break-up process, the wind can break ice covers and accelerate melting. The ice ridges underwent three stages during the cold season of 2018-2019, in which the wind directions and speeds exhibited remarkable differences. The ice ridges grew from southeast to northwest with an average direction of 334.38° and decayed from northwest to southeast with an average direction of 332.90°. The direction of the ice ridges was nearly perpendicular to the WSW direction (247.5°). The WSW direction frequently happened in all three stages, revealing the crucial role of winds in the development of ice ridges. The air temperature created a cold environment for ice cover to freeze, the wind provided a mechanical force for ice bulk to shift, and ice ridges and ice fractures formed. In addition, the direction of the ice ridges had a similar shape to the southwest shoreline, and the stable shoreline geometry could explain the recurrent ice ridges with a specific direction, which was reported in previous studies (Leppäranta, 2015).

Linear structures are common natural phenomena on the surfaces of sea ice and lake ice and profoundly influence light transfer and ice ecology. Lake ice ridges alter surface roughness and light transfer and contribute to the thickness and volume of ice. People in cold regions have skillfully taken advantage of frozen ice covers for fishing, food storage, and commercial transportation. The capacity and stability of floating ice can be evaluated by the ice thickness and the spatial distribution of ice fractures and ridges (Tan et al., 2012). Generally, 30 cm is the thickness suggested for safe human activities *on the ice (Leppäranta, 2015). Ice fractures and ice ridges potentially threaten human activities. In the field investigations, we measured the ice thicknesses along the linear structure when the ice covers were steady. The ice thicknesses along the ice ridges were supposed to be thinner than other areas (Leppäranta, 2015), but no significant difference of ice thickness had been found in our field measurements. Thus, the surface morphology of lake ice would be a reliable sign of danger travelling. Besides, we monitored the horizon changes in lake ice ridges using optical satellite images but ignored the vertical heights of ice ridges, which need to consider in future work.*

- It is annoying to put language issues on the list of concerns. However, in this case, the authors have to perform hard and responsible work to make this text understandable to the reader. The text is full with repeated words, unfinished phrases, and sentences. Figures lack comprehensive legends and are overloaded with irrelevant information. Apart from a careful proofread, the help of a native speaker is recommended. Some of my remarks are provided in the (non-exhaustive) list of detailed comments below.

Reply to comment: Regarding English usage and grammar, we used a professional English editing service by Essentialink Language Service to improve our manuscript, and the certificate is provided as an attachment.

Line 14: “prosed” -> proposed

Reply to comment: Thank you for the careful check. We updated the Abstract, and delete the sentence. (Line 14).

Line 20: “closed related” -> closely related

Reply to comment: Thank you for the careful check, and we modified it as you suggest (Line 21).

Line 30: “scarce work studies” -> studies on… are scarce

Reply to comment: Thank you for the careful check, and we modified it as you suggest (Line 32).

Line 34: "has the advantages of" -> is

Reply to comment: Thank you for the careful check, and we modified it as you suggest (Line 36).

Line 44: "the cost is too expensive" -> costs are high

Reply to comment: Thank you for the careful check, and we updated the sentence as follows (Line 45-47).

Although the temporal resolution of active microwave remote sensing data has been improved from 30 days (ERS) to daily return visits (Radasat-2), the optimized technique is too costly and more suitable for case studies of small or medium lakes.

Line 45: "time series" -> "temporal coverage"

Reply to comment: Thank you for the careful check, and we modified it as you suggest (Line 47).

Line 61: "coarse and fine resolution and coarse resolution…" -> ?

Reply to comment: Thank you for the careful check, and we have made changes in the text (Line 63).

Lines 74-76: The abbreviations SAR and UAV are in the meantime widespread. Nevertheless, they should be better expanded.

Reply to comment: Thank you for the careful check, and we modified it as you suggest (Line 75-76).

Line 90: how the lake length of 107 km was determined? With the surface area of 253 km2, it would mean the lake "width" of less than 3 km. The map in Fig. 1 looks however different from that.

Reply to comment: Thank you for your careful question. The length of the lake mentioned in the text refers to the perimeter of the lake. The perimeter of the lake is obtained by calculating the perimeter of the vector data of Lake Chagan without the recalculated area in Figure 1. We recalculated the length and area of Lake Chagan and updated them in the paper, and the perimeter of Lake Chagan are 329.72 km^2 and 201.03 km, respectively (Line 91-92). We used the geometric calculation of ArcGIS based on the vector of Lake Chagan.

Figure 1 The spatial distribution of Chagan Lake

Line 129: What is meant under “A 16-degree angle with an interval of 25°”? Reformulate in a clear way.

Reply to comment: Thank you for the careful check and we are sorry for the mistake. Sixteen directions describe the wind field in the winter, and the angle of wind direction in each direction is 22.5°. We update the sentence as follows (Line 135-138):

Sixteen directions with an interval of 22.5 ° describe the wind direction, covering north (N), north northeast (NNE), northeast (NE), east northeast (ENE), east (E), east southeast (ESE), southeast (SE), south southeast (SSE), south (S), south southwest (SSW), southwest (SW), west southwest (WSW), west (W), west northwest (WNW), northwest (NW), north northwest (NNW).

Line 151: “The morphological extraction”: replace the section title with a meaningful one

Reply to comment: Thank you for the helpful suggestion, and we replace it with “The quantitative analysis of linear structures” (Line 164).

Line 153: “Canny operator”: replace with “the Canny edge detection algorithm” and provide a reference.

Reply to comment: Thank you for the professional suggestion. We updated it and add a new reference.

Reference:

Canny, J.: A computational approach to edge detection, IEEE Transaction on Pattern Analysis and Machine Intelligence, PAMI-8, 679-698, 1986.

Line 153-156: revise the whole sentence to make it understandable.

Reply to comment: Thank you for the careful check, and we have modified the whole paragraph.

At the beginning, the Landsat-GOCI fusion images were transformed into binary images. We extracted the original linear network by the Canny edge detection algorithm (Canny, 1986) and then conducted edge detection to remove the outer boundaries. The morphological processing, including opening, filling, and eroding sequentially, was implemented for the internal part of the linear network. Then, the linear structure was derived from the largest connected domain of linear network without boundaries, and the length is calculated by the shortest path of largest connected domain. We connected the northmost and southmost ends into a straight line. The angle followed the definition of wind direction above. We compared auto-extraction and visual interpretation in our previous work (Hao et al., 2021). The R^2 values of the length and angle of 0.96 and 0.98, respectively, which proved the well performance of auto-extraction.

Line 155: "inter" -> inner (?)

Reply to comment: Thank you for the careful check, and we modified it as you suggest (Line 168)**.**

Lines 160-180: the whole paragraph is barely understandable and controversial. At Lines 160-170 the validation of a predicted image on Nov 22 is discussed and the correlation value of 0.93 is declared. On Lines 171-180 the correlation of 0.935 is referred to the date of Nov 28 (???) What is the difference between the two validations? Why was Nov 28 additionally used to Nov 22? What kind of new information is provided at Lines 171-174 compared to the Lines 160-170? The paragraph has to be deeply revised, repeated information removed, and the results delivered in an unambiguous way.

Reply to comment: thank you for the professional questions. We re-wrote this part. We only carried out one validation on November 22, 2018, and November 28, 2018 is the wrong date. We update this paragraph as follows (Line 175-188):

We predicted the fine images from two pairs of fine Landsat and coarse GOCI data to fill the data gap caused by the low revisit frequency of the Landsat. The two known pairs of data in the freeze-up process were captured on November 6, 2018, and December 8, 2018, and 53 fine ESTARFM fusion images were predicted from coarse GOCI images. The two known pairs of data of the break-up process were captured on February 26, 2019, and April 15, 2019, and 43 fine ESTARFM fusion images were predicted. Figure 3 compares the spatial distribution of the original images and predicted images on November 22, 2018. In the predicted images, the texture of the ground objects was maintained, and enlargement figures in Figure 3 (c) and Figure 3 (d) clearly display the distribution of linear structure. The predicted images were well consistent with the original images, and indicates a good fusion effect of ESTARFM. Figure 4 illustrates the scatter plots of the actual and predicted reflectance values along the 1:1 line. The R^2 value is 0.935, indicating that the predicted image was highly correlated with the actual image. The ranges of predicated and actual images were consistent; their mean reflectance values were both 0.10 ± 0.03. The performance of the ESTARFM results was limited by (1) the limited image pairs available during the cold season from 2018 to 2019; (2) the time lag between the predicted and actual images; (3) the inconsistency of capture time between the predicted images and two pairs of input images (Lu et al., 2019; Liu et al., 2018a). Therefore, the ESTARFM fusion images had a good performance and can provide reliable materials for further exploration.

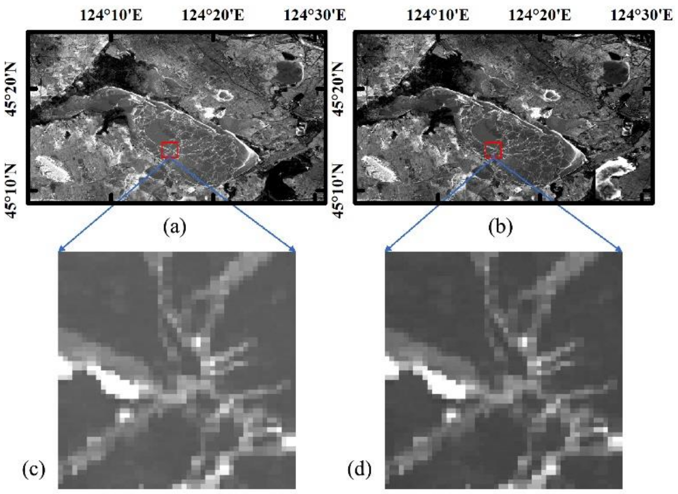

Figure 3 The actual image observed on November 22, 2018 (a) and its prediction images by the ESTARFM (b). The lower row images (c) and (d) display the enlargement figure of red rectangle in upper row images (a) and (b).

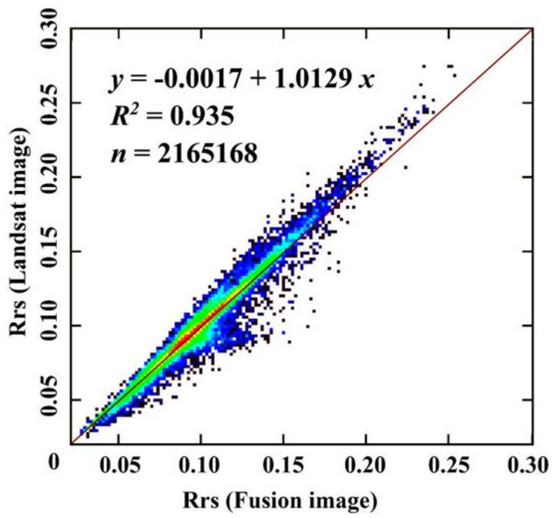

Figure 4 Scatter plot of the real and the predicted reflectance by the ESTARFM for the blue band. The capture date was November 22, 2018.

Line 183: “display” -> “displays”

Reply to comment: Thank you for the careful check, and we modified it as you suggest (Line 193).

Line 187:”liner” -> “linear”

Reply to comment: Thank you for the careful check, and we modified it as you suggest (Line 197).

Line 191: "Figure 9" -> Figure 6

Reply to comment: Thank you for the careful check. We deleted the related contents of ice ball, and Figure 9 is deleted (Line 198).

Line 200: remove "rapid"

Reply to comment: Thank you for the careful check, and we modified it as you suggest (Line 209).

Line 212: "ball" -> balls

Reply to comment: Thank you for the careful check, We deleted the related contents of ice ball.

Lines 213-214 -> insert "In 2022" (?) Otherwise, the sentence is senseless

Reply to comment: Thank you for the careful check. We deleted the related contents of ice ball.

Lines 218-224: The whole passage is completely distracting. "The ice thickness had the smallest value" - WHERE? The difference between summer 2021 and winter 2021 - the difference of WHAT? "Differences were not significant enough to explain what we observed.." WHAT did you observe? "The ice thickness… showed spatial coherence... especially with the ice thickness" - the phrase is senseless. The passage looks like a piece of a draft text understandable to the author only and inserted into the ms without any editing. As I mentioned above, the information on the "ice balls", as presented here, is irrelevant to the main subject of the study and should be completely removed for consistency. However, this presentation style is inacceptable for a scientific work and should be reconsidered by the authors before submitting it somewhere else.

Reply to comment: Thank you for the careful check, and we have modified the whole paragraph as follows.

Considering the safety of traveling on ice, we conducted two field investigations during *the two recent cold seasons, from December 30 to 31, 2020, and January 2 to 4, 2022, respectively. We located ten sampling points along the linear structure on the satellite images and collected field photos of ice ridges and fractures (Figure 1). We further verified the large-scale fractures on the images as ice ridges. We divided the whole lake into three regions according to the surface morphology. Region 1 was distributed along the ice ridges. The surface of lake ice is uneven, ice fractures and ice ridges were widely distributed. Region 2 was distributed along the northeastern coast, where Chagan Lake Ice and Snow Fishing and Hunting Cultural Tourism Festival has been held at the end of December each year. Region 3 covered the southern part of Chagan Lake. The lake ice in Regions 2 and Region 3 were flat and smooth.*

We also measured the ice thicknesses and water depths of 16 sampling points (Figure 7). The ice thicknesses in the winter of 2021 ranged from 437.55 mm to 668.25 mm, with an average value of 582.24 ± 58.14 mm. The average ice thicknesses of Regions 1, 2, and 3 were 551.58, 547.75, and 645.74 mm, respectively. The average water depths of Regions 1, 2, and 3 were 3.48, 2.99 and 3.00 m, respectively. Among the three regions, Region 2 had the smallest average values of ice thickness and water depth. The differences in water depth between the fall of 2021 and the winter of 2021 had an average value of 0.12 ± 0.05 m and a maximum value of 0.2 m. The water depth in winter was lower than that in fall, and the decreasing water level also was a cause of lake ice fracturing in winter (Leppäranta, 2015). The ice features first formed in the nearshore area of the southeast coast, where the water depth was relatively smaller than that in other regions in Figure 7. The ice thicknesses and water depths showed spatial coherence with the surface morphology.

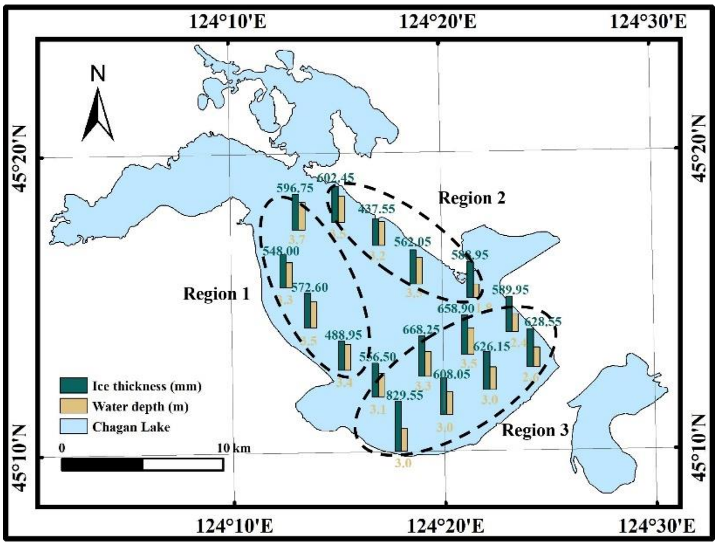

Figure 7 The ice thickness (mm) and water depth(meter) of Chagan Lake was measured during the periods from January 2 to 4, 2022. Ice balls were discovered along the southern coast, and the location is marked with red square.

Line 226: what is “wind rise” in this context? Revise phrasing

Reply to comment: Sorry for the spelling mistake. It should be wind rose, and we modified it (Line 236).

Line 227: how the freeze-up and break-up dates were defined?

Reply to comment: Thank you for your careful question. The lake ice phenology of cold season from 2018 to 2019 was extracted from the combined time series of the surface temperature of lake water provided by MOD11A1 and MYD11A1 product (Song et al., 2016; Hao et al., 2021). The freeze-up date is defined as the first day when the surface temperature of lake water is below 0℃ in winter; the break-up date is defined as the first day when the surface temperature of lake water is above 0℃ in spring (Line 130-134). We haven't published the related work yet.

Line 246: “uncanny” -> replace with a stylistically neutral word.

Reply to comment: Thank you for the careful check, and we modified it as you suggest (Line 248-252).

Line 247: “ball” -> balls

Reply to comment: Thank you for the careful check. We deleted the related contents of ice ball.

Lines 274-275: there are no reports from Finland in the cited works. What is "...and so on"? The majority of the reports on "ice balls" comes from the coastal ocean and Laurentian Great Lakes.

Reply to comment: Thank you for pointing this out, and we delete the description of ice ball in the new version.

Line 277: How was the exact threshold of -10°C determined? Why is it not -8°C or -12°C?

Reply to comment: Thank you for the helpful suggestion. and we delete the description of ice ball in the new version.

Line 480, Fig. 6: The legend lacks explanation of the panels a-d. Information on Panels a-b is barely understandable and has no reference to other Panels. The in-figure legend on Panel c seems to be wrong: red line refers to "stable process" not to "growth process". It is unclear what kind of statistics (spatial or temporal) is used in the box-whiskers chart in Panel d.

Reply to comment: Thank you for the useful suggestion, and we modified figure 6 and its title.

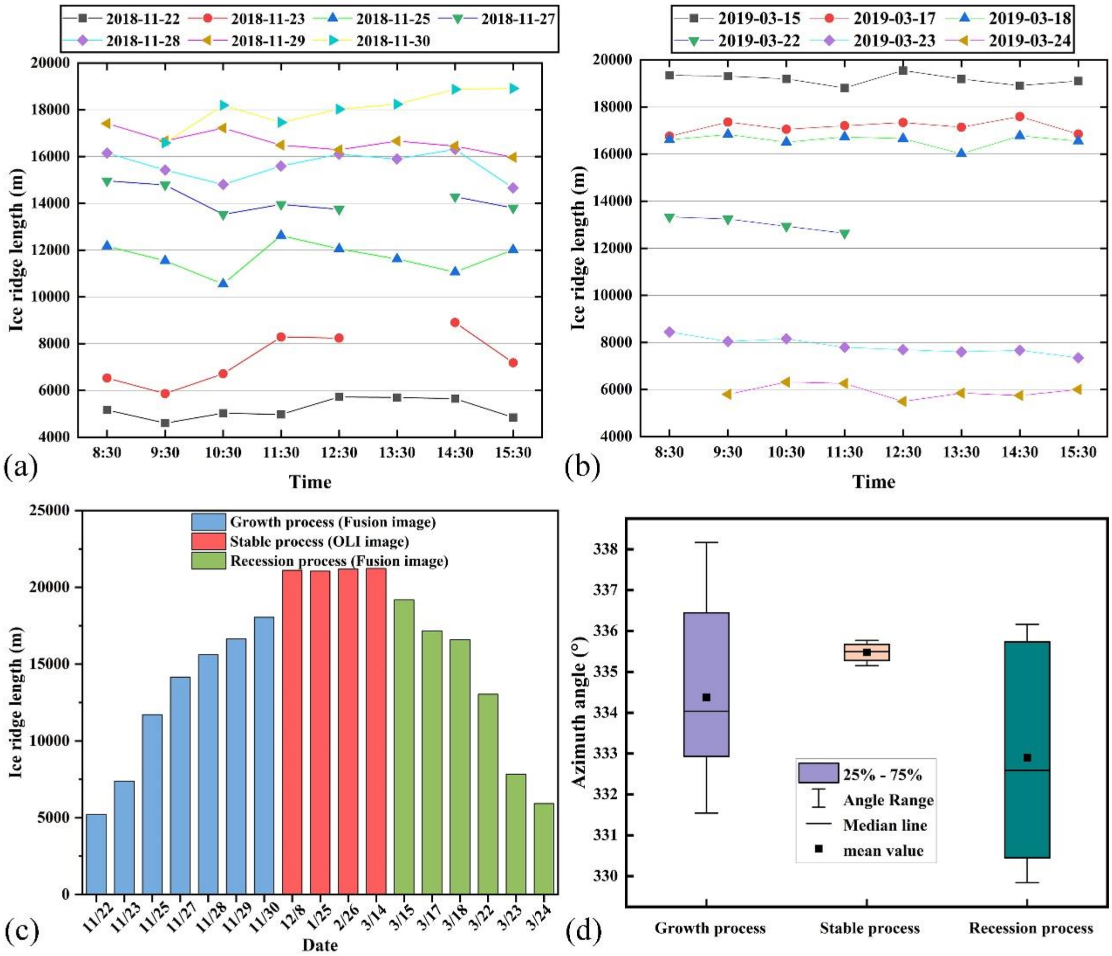

Figure 6 The changes of ice ridges during the cold season of 2018-2019: (a) length changes during the growth process from November 20 to November 30, 2018 measured from 53 ESTARFM-fused images; (b) length changes during the recession process from March 15 to 24, 2019, measured from 43 ESTARFM-fused images; (c) the daily average length; (d)the angles of ice ridges in different stages.

All figures are overloaded with unnecessary and unexplained information. They should be deeply revised to provide essential information in an unambiguous way.

Reply to comment: Thank you for the useful suggestion, and we modified all the figures and delete the unnecessary information. You can check it in Lines 480-505.

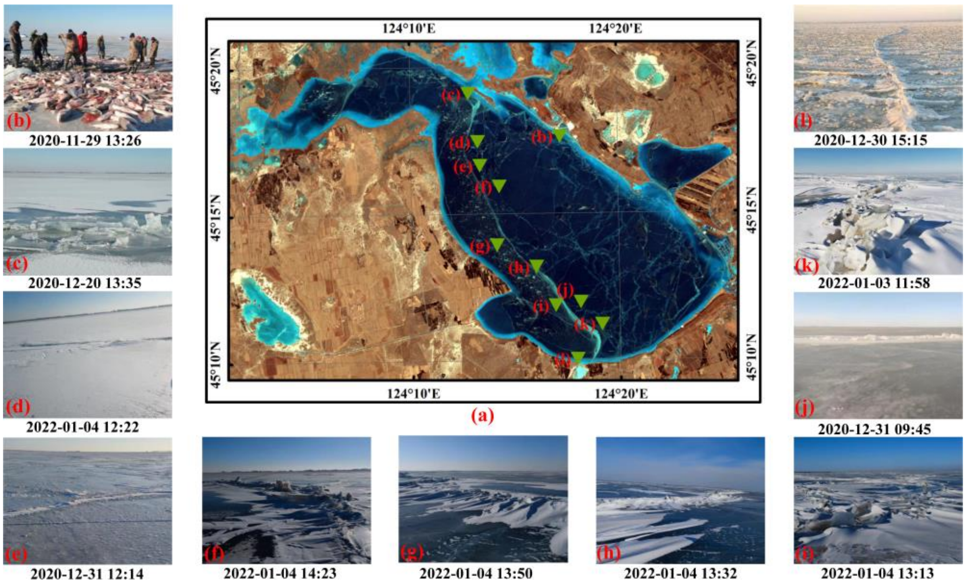

Figure 1 The spatial distribution of Chagan Lake and field photographs. Figure 1 (a) is provided Landsat 8 OLI on February 10, 2019 with the band composite: R(5) + G(4) + B(3). Figure 1 (b)- (h) displays the field photographs captured in field investigations.

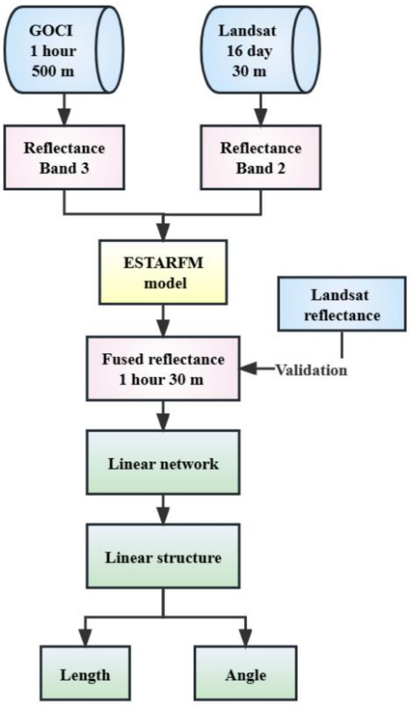

Figure 2 The workflow of this study.

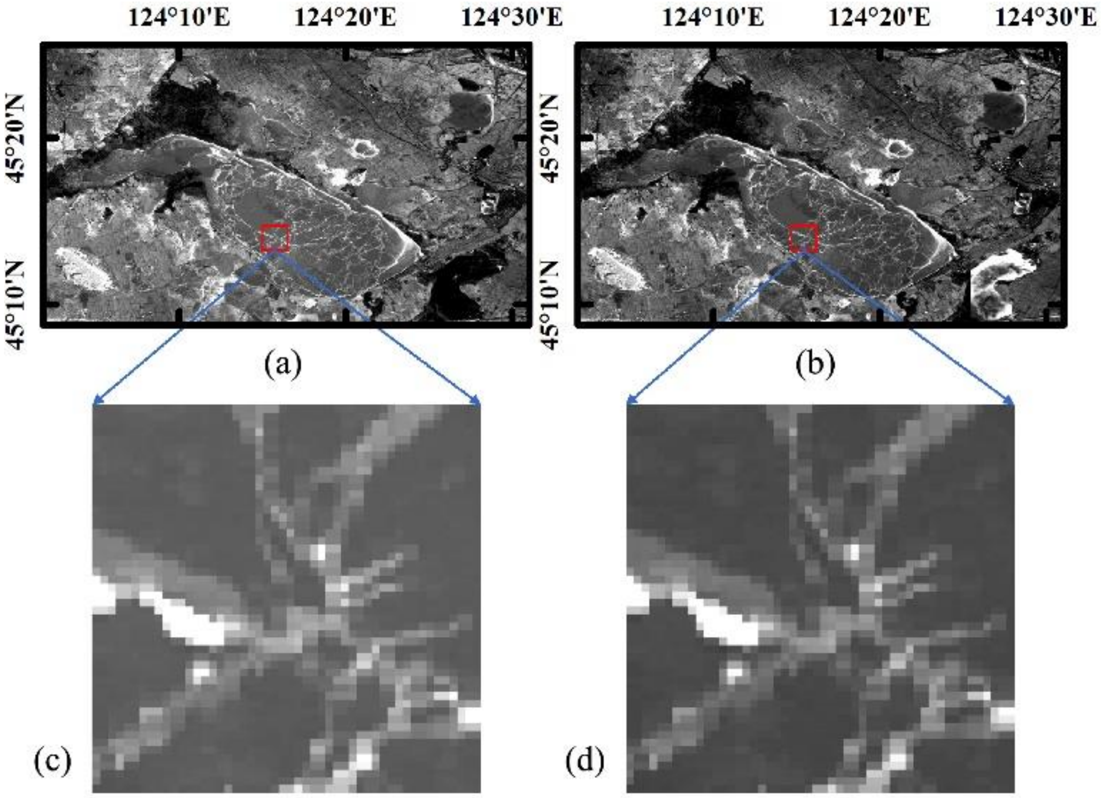

Figure 3 The actual image observed on November 22, 2018 (a) and its prediction images by the ESTARFM (b). The lower row images (c) and (d) display the enlargement figure of red rectangle in upper row images (a) and (b).

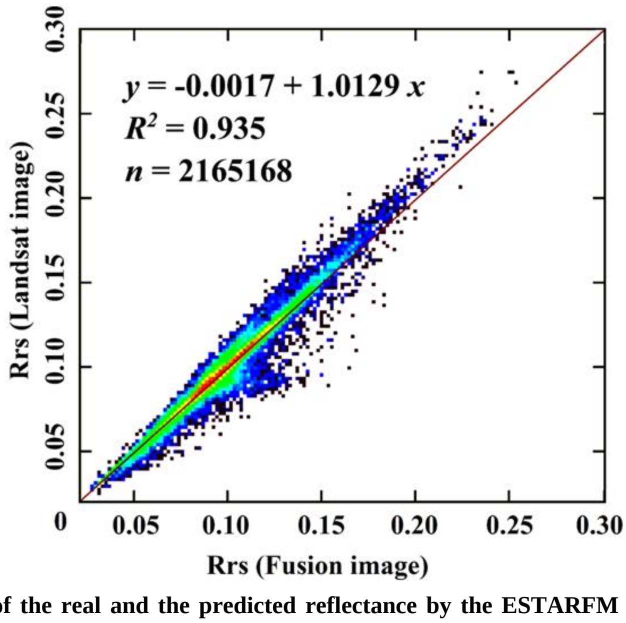

Figure 4 Scatter plot of the real and the predicted reflectance by the ESTARFM for the blue band. The capture date was November 22, 2018.

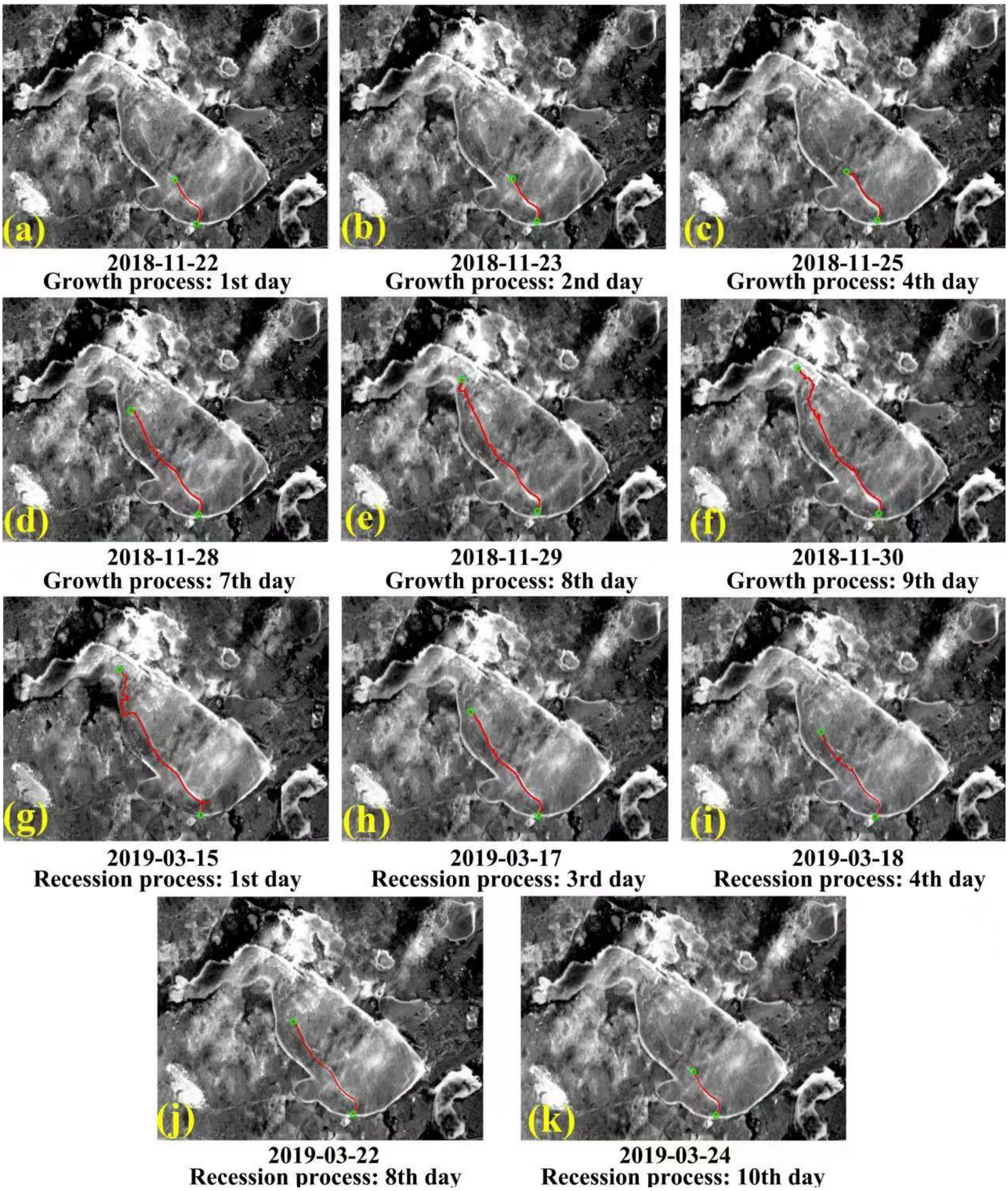

Figure 5 The temporal changes of linear structure on fusion images of Lake Chagan during the cold season of 2018-2019.

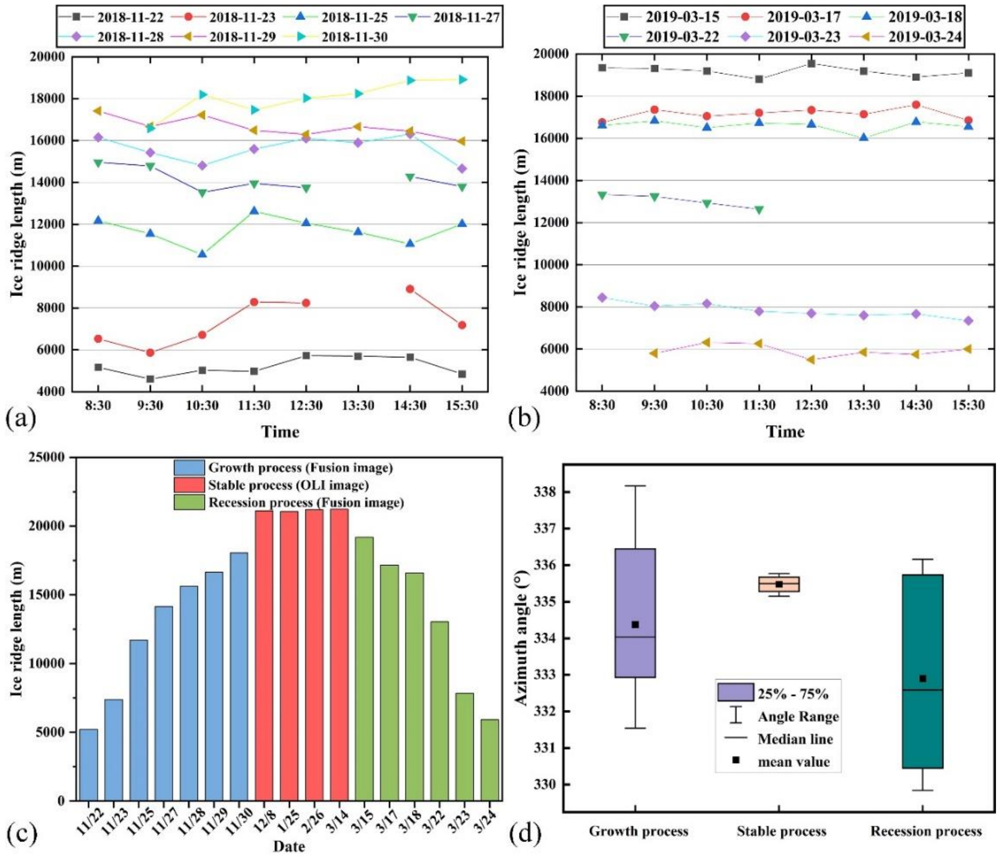

Figure 6 The changes of ice ridges during the cold season of 2018-2019: (a) length changes during the growth process from November 20 to November 30, 2018 measured from 53 ESTARFM fusion images; (b) length changes during the recession process from March 15 to 24, 2019, measured from 43 ESTARFM fusion images; (c) the daily average length; (d)the angles of ice ridges in different stages.

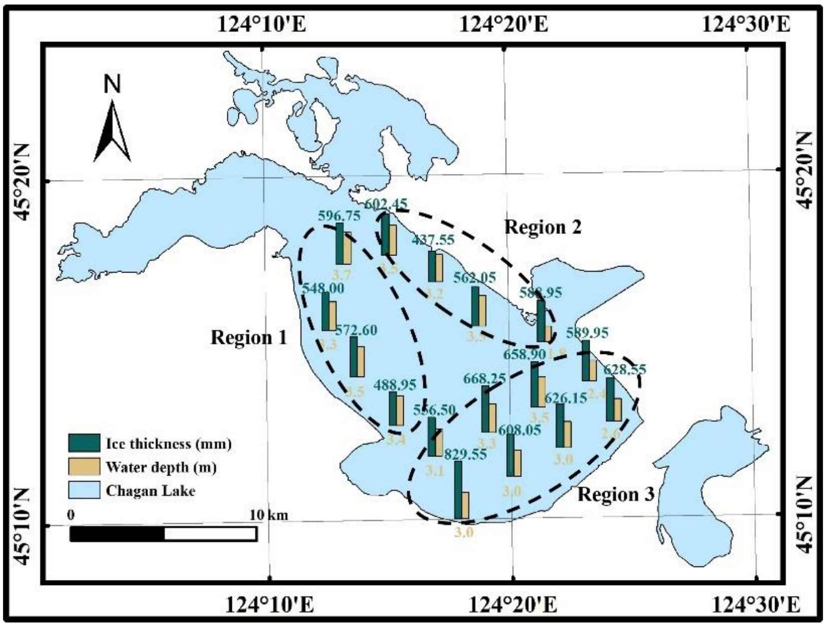

Figure 7 The ice thickness (mm) and water depth (m) of Chagan Lake was measured during the periods from January 2 to 4, 2022.

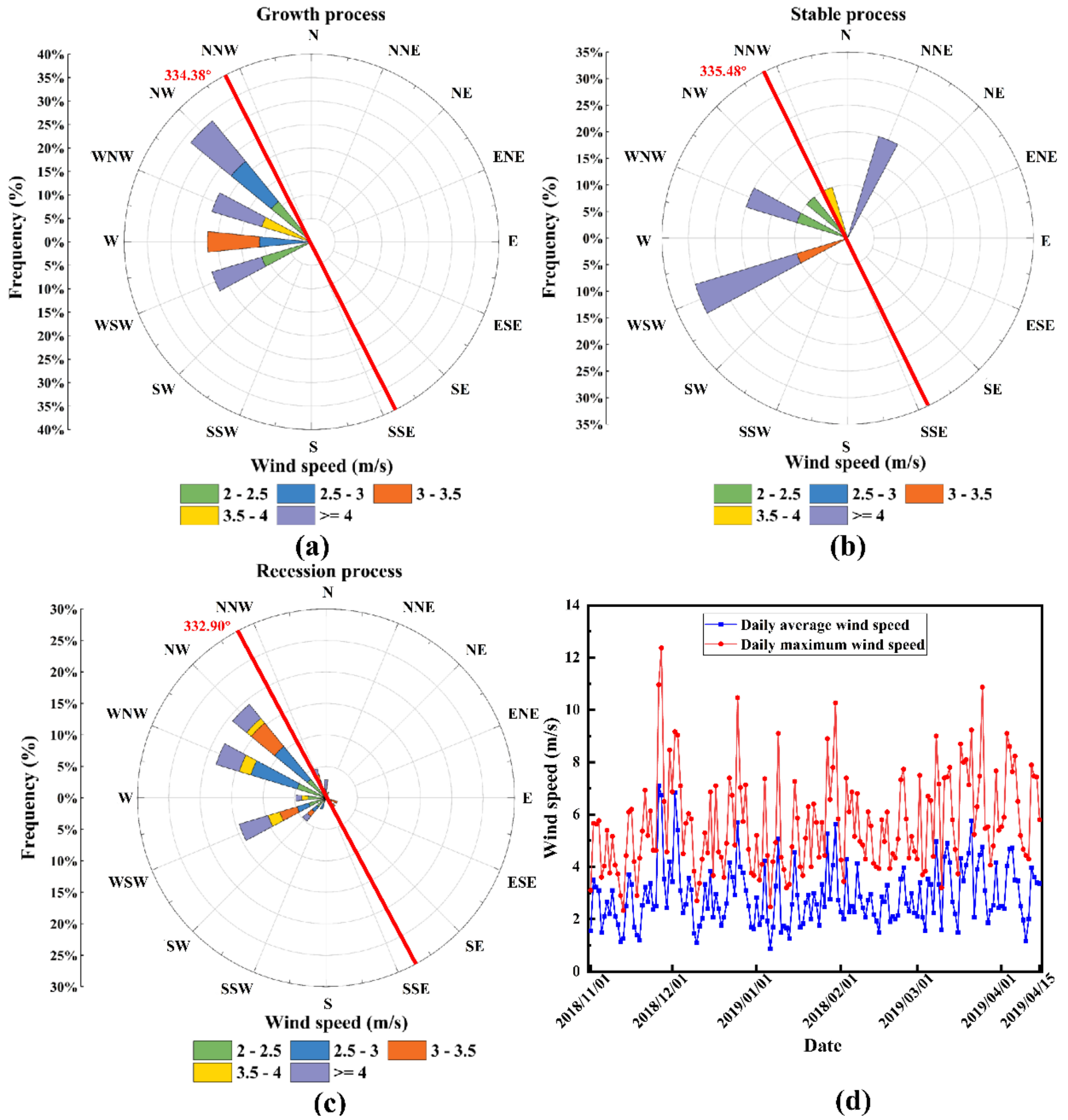

Figure 8 The wind rose of Chagan Lake during the cold season of 2018: (a) growth process from November 22, 2018, to November 30, 2018; (b) stable process; (c) recession process from March 15 to March 24, 2019; (4) daily average and maximum weed speed from November 1, 2018, to April 15, 2019.