Author response to anonymous referee #2 (RC2)

Dear Reviewer,

We sincerely thank you for your careful and constructive review of our manuscript. We greatly appreciate the time and effort you have devoted to evaluating our work and providing valuable comments and suggestions. We have carefully considered and addressed all the issues raised in your review, both in our responses below and in the revised manuscript. In addition, we have taken this opportunity to correct further typographical errors and improve the wording and clarity of the manuscript.

Our detailed responses to each of your comments are provided below.

Best regards,
Corresponding author: Guangyin Hu
(on behalf of all co-authors)

Initial view

The topic is interesting and the spatial patterns shown in the paper are worth investigating. My main concern is that the current analysis shows a strong spatial relationship between sediment distribution and LST, but this is sometimes presented as proof that sediments are causing the temperature differences. I think the paper will be much stronger if the authors explain the Landsat-MODIS matching clearly, provide more information about the satellite processing and regression models, address the uncertainty in the data, and make the conclusions more careful.

Conceptual overview

The researchers stated that MGWR provides best model performance among two other methods: OLS and GWR. The study contributes to the knowledge on the freeze-thaw cycle, supporting earlier findings on the positive linkage between sediments and surface temperature. The spatial pattern that aeolian sediment forms and drives the albedo in different ways, when comparing two observational datasets is itself very interesting and is the main focus of the discussion.

This paper addresses a relevant scientific question that fully aligns with the extent of TC interests. It offers a wide range of comparable methods, searches for the best fitting method to observe sediment spatial patterns and their impact on radiative properties of the surface. A previously unexplored regional relationships between the spatial patterns of aeolian sediments and surface temperature of the Zonag Lake are presented. The authors reach a clear conclusion, suggest possible future directions and consider their limitations. The scientific method of this study is valid, but could be clarified with greater care. The result is fully sufficient and supports the main conclusion. The interpretation is coherent but it is missing possible influence of physical drivers of sedimentation and sediment transport. The description of data retrieval and processing is unfortunately insufficient, but with greater detail it

should be reproducible. The researchers follow on recent literature, contributing new measures to the field, which is directly stated in the title. The abstract fully grasps the articles' structure, which is sufficient and clear as well. The language can partially be improved in structure and coherency. On the other hand, the mathematical equations, used symbols and abbreviations are well explained and properly used in the text. The general amount of description, provided visualizations and references in the text is appropriate.

Major Comments

Comment (1): Starting in 3.1 on Data Sources, the data choice and matching should be explained in further detail.

Comment (1) part (1): I am concerned about the quality of the LST product on sediment covered lake ice. Sediments will have a very different thermal emissivity than clean lake ice (which can also be seen in the differences in albedo) which might confuse the LST algorithm. Can you rule out, that sediments create a positive bias in the LST product which would also create a spurious correlation with NDSLI? Please discuss this in the manuscript and give references for the quality of MOD11A1 on lake ice and, ideally, sediment covered lake ice.

Reply: Thank you for raising this important concern. We agree that uncertainty in surface emissivity needs to be considered when interpreting MOD11A1 temperatures over sediment-covered lake ice.

MOD11A1 uses a generalized split-window algorithm involving MODIS thermal-infrared bands 31 and 32. The emissivities used in the retrieval are estimated primarily from land-cover and daily snow-cover information. Such classification-based estimates may not adequately represent mixed sediment–ice surfaces. Consequently, an emissivity error associated with sediment coverage could affect both the retrieved temperature contrast and its relationship with NDSLI. The contrast in shortwave albedo does not, by itself, quantify the corresponding thermal-infrared emissivity contrast, because these properties refer to different spectral regions. Measurements also demonstrate that snow and ice emissivities vary with wavelength, surface type, and viewing angle (Hori et al., 2006).

Published MODIS LST validation studies provide useful information on general product performance (Wan, 2014), but do not establish its accuracy over sediment-covered lake ice. More specifically, Cheng et al. (2014) compared MODIS-derived lake-ice surface temperatures with in situ observations and thermodynamic simulations at Lake Orajärvi. However, their study used University of Waterloo processing and different surface conditions, rather than directly validating MOD11A1 V6 over sediment-covered ice. We are not aware of a dedicated validation for the latter surface type.

Given the absence of independent surface-temperature and emissivity measurements for our study, we cannot rule out a sediment-dependent retrieval bias, including a positive bias that could contribute to the observed NDSLI–LST relationship. Our analysis therefore cannot independently separate physical temperature differences from sediment-related retrieval errors. We will explicitly discuss this limitation in the revised manuscript and qualify the interpretation: the results establish an association between sediment coverage and MODIS-retrieved surface temperature, while the magnitude of any physical warming remains uncertain.

Cheng, B., Vihma, T., Rontu, L., Kontu, A., Pour, H. K., Duguay, C., and Pulliainen, J.: Evolution of snow and ice temperature, thickness and energy balance in lake orajärvi, northern finland, Tellus A: Dynamic Meteorology and Oceanography, 66, 21564, https://doi.org/10.3402/tellusa.v66.21564, 2014.

Hori, M., Aoki, T., Tanikawa, T., Motoyoshi, H., Hachikubo, A., Sugiura, K., Yasunari, T. J., Eide, H., Storvold, R., Nakajima, Y., and Takahashi, F.: In-situ measured spectral directional emissivity of snow and ice in the 8–14 μm atmospheric window, Remote Sensing of Environment, 100, 486–502, https://doi.org/10.1016/j.rse.2005.11.001, 2006.

Wan, Z.: New refinements and validation of the collection-6 MODIS land-surface temperature/emissivity product, Remote Sensing of Environment, 140, 36–45, https://doi.org/10.1016/j.rse.2013.08.027, 2014.

Comment (1) part (2): LST was obtained from two datasets, MOD11A1 V6 with temporal resolution of 1 day and spatial resolution of 1km. OLI has spatial resolution of 30 meters, there is no clear information on the temporal resolution which should be 16 days. The first paragraph mentioned that the MODIS LST was resampled to higher resolution (1km x 1km), but the data already comes with 1km spatial resolution. Researchers compare this dataset directly to a higher resolution OLI (30m resolution) to provide detailed identification of surface features. A clarification on down-scaling and smoothing out the finer features could be provided.

Reply: Thank you for identifying the unclear description of the spatial resolution and matching procedures. We have revised Sections 3.1 and 3.2.2 to clarify the respective roles of the two datasets and their spatial correspondence.

LST was obtained exclusively from the MODIS/Terra MOD11A1 product, which provides daily observations at a nominal spatial resolution of approximately 1 km. Landsat 8 OLI imagery, with 30 m multispectral resolution and a nominal revisit period of 16 days, was used to calculate NDSLI and characterize aeolian sediment distribution.

The previous statement that MODIS LST was resampled to a "higher resolution (1 km × 1 km)" was inaccurate and has been removed. Specifically, the MOD11A1 raster was reprojected in ArcGIS with an output cell size of 1000 m to establish the analysis grid. This operation did not enhance the spatial resolution of the temperature observations, and MODIS LST was not downscaled to 30 m.

For spatial matching, a fishnet grid corresponding to the processed MOD11A1 raster was generated. The NDSLI value at each grid-cell centroid was extracted from the 30 m Landsat-derived raster and paired with the LST value of the corresponding grid cell. Thus, the regression dataset contained one matched sample per processed MODIS grid cell.

We acknowledge that the centroid NDSLI value may not represent the sediment distribution throughout the corresponding temperature grid cell, particularly where sediment deposits are narrow or patchy. Furthermore, fine sediment features identifiable in Landsat imagery may not be resolved in MODIS LST. The remaining spatial-scale mismatch therefore introduces uncertainty into the interpretation of the NDSLI–LST relationship.

Comment (1) part (3): The temporal matching between MODIS and OLI is not persuasive, even if no other is accessible. Five out of seven are one day apart, which should be acceptable with careful physical reasoning. However, the remaining two are several days apart e.g. 2017-12-26 (OLI) and 2017-12-20 (MODIS) with a six-day difference. Given the nature of dust and sand particles, they can be easily moved by the wind masses within hours. This concerns already sedimented dust, which can be uplifted again by stronger wind gusts and transported far from the inspected location. The short-life of the particles does not support the long-term effect on the surface temperature. How can one be sure that the LST/NDSLI on both days come from the same spatial pattern of the sediment? I would advise a

short description concerning possible matches and the temporal scales of physical drivers of sedimentation.

Reply: Thank you for raising this important concern. We agree that selecting the closest available MOD11A1 observation does not, by itself, establish that the paired observations represent comparable sediment-cover patterns. We have therefore added a cross-date optical-image comparison to evaluate this assumption directly.

Specifically, MODIS/Terra MOD09GA daily surface reflectance imagery acquired on the dates of the MOD11A1 observations was compared with the corresponding Landsat 8 OLI imagery. The comparisons cover 20–23 December 2016 and 20–26 December 2017, addressing the three- and six-day mismatches, respectively.

The comparisons show that the main sediment-covered areas were broadly consistent in extent and location at the paired acquisition dates. No major displacement or reorganization of the dominant sediment-covered zones was apparent at the spatial scale resolved by MOD09GA. These observations provide qualitative support for the spatial comparability of these image pairs despite their longer temporal separations. The comparison is presented in Fig. R1 below.

We also distinguish the movement of individual particles from the persistence of the sediment-cover pattern. Wind-driven deposition can occur rapidly; for example, lake-ice observations elsewhere have documented substantial deposition within a 12-hour wind event (Dougherty et al., 2026). Our matching does not require individual grains to remain stationary throughout the interval. Rather, it requires sufficiently comparable sediment-cover patterns at the paired observation times, which the additional optical comparisons help assess.

Nevertheless, this visual assessment cannot exclude local redistribution below the 500 m resolution of MOD09GA or changes in meteorological conditions between acquisitions. It also does not demonstrate uninterrupted sediment coverage or warming throughout the intervening periods. We have added the comparison method and findings to Section 3.1 and retained an explicit statement of the remaining temporal uncertainty.

Dougherty et al. (2026), Remote Sensing Sediment–Albedo Feedbacks Affecting Ice Thickness on Taylor Valley Lakes, Antarctica. Geophysical Research Letters, 53(3).

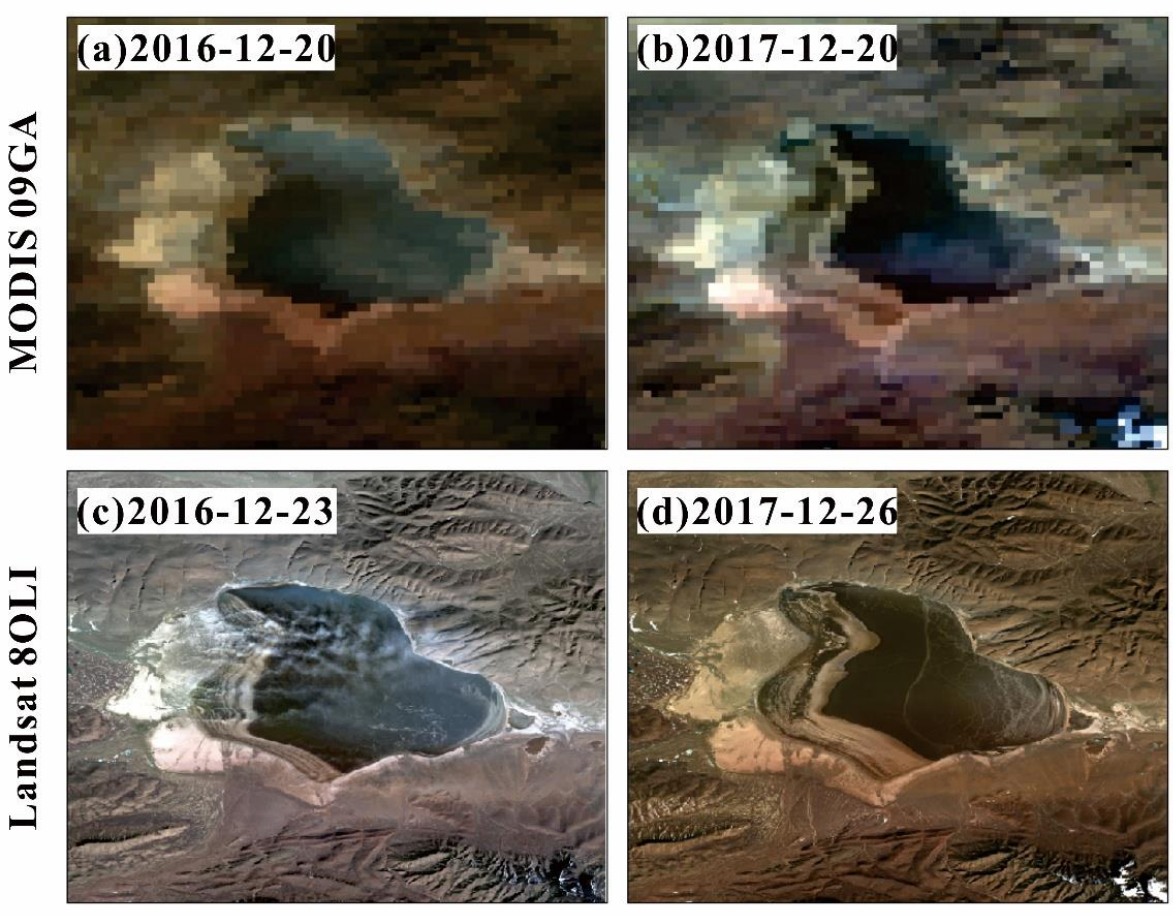

Figure R1. Comparison of sediment distribution between MOD09GA and Landsat 8 OLI imagery for image pairs with temporal offsets of 3 and 6 days.

Comment (1) part (4): Crucial information on data processing is missing as well. What are the errors that come already with the datasets? Especially, given the big difference in spatial resolution, if OLI is down-scaled, isn't the result smoothed out? MODIS v6 provides LST from the nighttime and daytime, which one was used?

Reply: Thank you for pointing out the missing processing details. We have revised Sections 3.1 and 3.2.2 to clarify these procedures. Daytime LST from the MOD11A1 V6 LST_Day_1km band was used in this study.

The MODIS observations were screened using QC_Day, retaining pixels with mandatory QA bits 0–1 equal to 00, indicating good-quality retrievals. A 1 km inward buffer was applied to reduce shoreline contamination. The Landsat OLI imagery underwent radiometric calibration and atmospheric correction before NDSLI calculation. We have also clarified the remaining uncertainties, including emissivity and atmospheric effects in MODIS LST, and residual radiometric, atmospheric and geolocation errors affecting the Landsat-based analysis.

Regarding spatial resolution, the Landsat-derived NDSLI was retained at 30 m. Values were extracted at the centroids of the processed 1000 m MODIS grid cells and paired with the corresponding LST values. This sampling procedure is now explicitly described. We acknowledge that MODIS cannot resolve fine temperature variations within each grid cell and that sediment heterogeneity may affect the

representativeness of the extracted NDSLI values.

Comment (2): In the first part of the results, is there an uncertainty of the NDSLI retrieval from the images? The retrieval of NDSLI is explained in 3.2.1 and the formula is presented. The mask of NDSLI 0 would be then reasonable, but why does one put another threshold at NDSLI -0.15? Is the final threshold at 0 or -0.15?

Reply: Thank you for highlighting the ambiguity in our description. The NDSLI classes were used to characterize relative degrees of sediment accumulation. NDSLI < 0 identifies areas with pronounced sediment accumulation, while NDSLI < −0.15 distinguishes greater relative accumulation within this range. Positive NDSLI values were further divided into intervals of 0.2, with increasing values interpreted as progressively lower sediment accumulation.

Thus, 0 was the boundary for identifying pronounced sediment accumulation, whereas −0.15 was an additional boundary for finer grading within that category. They were not alternative thresholds for the same purpose, and positive NDSLI values were not necessarily interpreted as sediment-free conditions.

These empirical divisions were supported by visual interpretation and the transect comparison in Fig. 2. We nevertheless acknowledge that reflectance uncertainty and variations in snow and ice conditions may affect the index and its interpretation. We will clarify the classification scheme in Section 3.2.1 and replace overly definitive wording such as “accurately extracted” with more cautious descriptions.

Comment (3): Is there any seasonality to the wind directions? Does it explain the patterns? It is said that the analysis does not provide continuous time-series analysis. The spatial patterns can change on day-to-day basis, which depends on the daily wind direction. The only information is in the section 2 on the dominant wind direction which is southwest-west.

Reply: Thank you for this comment. We have added winter and spring sand drift potential calculated from 2018 wind observations at the Wudaoliang Meteorological Station (Fig. 2j). These results provide supplementary information on the direction and relative strength of potential sediment transport. The prevailing southwest to west winds and the exposed lakebed provide context for interpreting sediment transport onto the lake ice.

The five sediment-bearing cases were observed in December or January, so the winter–spring comparison offers limited insight into differences among them. Sediment patterns may change from day to day in response to wind direction, wind speed, and preceding transport events. Our analysis captures the spatial patterns on selected dates.

Comment (4): On Figure 3 we observe spatial distribution of resampled LST based on MODIS data. The text mentions that the uniform temperature pattern is visible on days without sediment accumulation, possibly referring to figure 2, which is based on OLI data (of different temporal resolution). The dates are different, even if it's just one day of difference, the connection may be weak. It would be generally nice to have those two figures next to each other, so one can directly compare the corresponding days having the satellite images as in fig. 2 next to the spatial distribution of LST from fig. 3.

Reply: Thank you for this suggestion. Figure 6 in Section 4.4 presents side-by-side comparisons of the Landsat OLI imagery and the corresponding MODIS LST distributions. We acknowledge that this comparison was not sufficiently highlighted in the original text and that the incorrect section numbering

caused confusion. We have corrected the numbering and added an explicit reference to Fig. 6 where the temperature patterns in Fig. 3 are discussed. The acquisition dates of both datasets are clearly identified.

Comment (5): The section numbering is mixed up, there are two sections 4.4 (one leading to and one following section 4.5)

Reply: Thank you for pointing out this error. We have corrected the duplicated section numbering and carefully checked the section numbering throughout the revised manuscript to ensure consistency.

Comment (6): In section 4.5, the authors mention the effect of sediment accumulation on LST. The visualization is really clear, the result is reasonable and explainable.

Reply: Thank you for your positive comment. We appreciate your recognition of the visualization and interpretation of the relationship between aeolian sediment accumulation and LST in Section 4.4.

Comment (7): Part 4.4.5 ('Spatial distribution characteristics of Local R^2 in the MGWR'), including Figure 9 should be explained in more detail. For each location and date there is only one NDSLI and one LST value, correct? Where do the R^2 values actually come from?

Reply: Thank you for requesting this clarification. Yes, each sampling location has one NDSLI value and one LST value for each image date. However, Local R^2 is not calculated from that individual pair alone. It summarizes local goodness of fit using spatially weighted observations from multiple locations around the target location within the same date's spatial dataset.

The values shown in Fig. 9 were obtained directly from MGWR 2.2. According to the software documentation, this diagnostic is calculated using the optimal GWR bandwidth. The output values were assigned to the corresponding fishnet cells and mapped in ArcGIS; ArcGIS was used for visualization rather than recalculating R^2.

Comment (8): Part 4.4 ("Regression analysis of NDSLI and LST") is good, but there is explanation missing on the actual regression values. OLS is poorly explained (you give the model but e.g. do not mention what is minimized), the F-statistic is not mentioned in the text. Only fitting is described, based on the and the adjusted. What does the * mean next to p-values? Same issue is with table about GWR and MGWR, the results are nicely presented in a clear table but the description could be extended.

Reply: Thank you for this comment. We have clarified that OLS estimates the regression coefficients by minimizing the sum of squared residuals. We have also explained that the overall F-test evaluates the null hypothesis that the NDSLI coefficient is zero. The footnote to Table 2 now explicitly states that the asterisk indicates $p < 0.05$ and that the reported p-values correspond to the overall F-test.

We have expanded the interpretation of the regression coefficients, standard errors, and model diagnostics, including R^2, adjusted R^2, and AICc, in the relevant OLS, GWR, and MGWR sections. These additions clarify how the reported statistics are used to assess the NDSLI–LST relationship and compare model performance.

Minor issues

Comment (1): L1, L7: Terminology confusion. The authors abbreviate Lake Surface Temperature as LST, but LST retrieved from MOD11A1 usually denotes Land Surface Temperature. This needs to be clarified in detail — whether it is merely a naming coincidence — and whether MOD11A1 (designed for land observation) can fully observe the lake surface.

Reply: Thank you for pointing out this terminology ambiguity. In the revised manuscript, "LST" consistently denotes lake surface temperature, whereas the MODIS dataset is explicitly identified as the "MOD11A1 Land Surface Temperature/Emissivity product."

MOD11A1 provides clear-sky surface temperature retrievals over lakes, as described in the MODIS product documentation, and has been used to derive lake surface temperatures on the Tibetan Plateau (Guo et al., 2022). In this study, quality-screened MOD11A1 observations were used to estimate the radiometric temperature of the exposed lake surface, including ice and snow during the frozen period. Cloud cover, mixed pixels, and emissivity uncertainties nevertheless constrain data availability and retrieval accuracy. We have clarified this application in Section 3.1, while the uncertainties associated with sediment-covered lake ice are addressed in the Discussion.

Comment (2): Grammar and Wording

L50: "On Mars", not "In Mars".

L52: The sentence "Aeolian sediments in its high-altitude..." is grammatically incorrect — it lacks a main verb (predicate).

L57: No "scientific questions" were directly posed earlier; suggest "knowledge gaps" instead.

L77: Missing period (.) after "regional aeolian conditions".

L167-8: "The observation data shows" — data is traditionally plural; "The observational data show" sounds more natural. "under the driven of the wind" should be "driven by the wind" or "under the drive of the wind".

L189: Remove "was".

Reply: Thank you for carefully identifying these grammatical and wording issues. We have corrected all the indicated expressions accordingly: "In Mars" was changed to "On Mars"; the sentence at L52 was revised to include a complete predicate; "scientific questions" was replaced with "knowledge gaps"; the missing period after "regional aeolian conditions" was added; "The observation data shows" was revised to "The observational data show"; "under the driven of the wind" was corrected to "driven by the wind"; and the unnecessary "was" at L189 was removed. We have also carefully checked the manuscript for similar grammatical and wording issues.

Comment (3): Style and Consistency

Part (1) L93: The sentence starting with "Secondly, ..." and those following are stylistically inconsistent. Choose either passive voice or active/imperative voice when describing step-by-step processes.

Reply: Thank you for this helpful comment. We have revised the description of the data screening process to ensure stylistic consistency. Specifically, passive voice is now used consistently for all three screening criteria.

Part (2) L267: L262 vs L265: "study used..." and "we constructed..." mix passive and active voice; pick one.

Reply: Thank you for this comment. We have revised the relevant sentences to ensure consistency in narrative voice. Specifically, the first-person active voice is now used consistently when describing the analytical procedures.

Part (3) L173: Although the data are arranged chronologically, the seven dates are spaced far apart, so calling this a "time-series" is not ideal and may confuse readers.

Reply: Thank you for this helpful comment. We agree that the term “time-series” may imply temporally continuous or closely spaced observations, whereas the seven image dates in this study are relatively widely separated. We have therefore replaced “time-series images” with “multi-temporal images” to more accurately describe the dataset. We have also revised the corresponding interpretation to avoid implying that the available images continuously captured the sediment transport and deposition processes.

Comment (4): Citations and References

Part (1) L103: "Gao et al. 2025" in the text should be "Gao et al. 2026", matching the references.

Reply: Thank you for pointing out this inconsistency. We have corrected “Gao et al. (2025)” to “Gao et al. (2026)” in the revised manuscript to ensure consistency with the reference list.

Part (2) L103: L124: The citation is debatable. Equation (2) (L125) is essentially the same as equation (9) in Guo et al. 2020, p. 4, with very similar explanation. Adding the original paper (doi.org/10.2307/2332142) would be a good addition. Information is also missing on the interpretation of Moran's I and Local Moran's indices and their range of possible values (-1 to 1). More generally, the methodology could be explained in more detail.

Reply: Thank you for this suggestion. We have added Moran (1950) as the original reference for Global Moran’s I and Anselin (1995) for Local Moran’s I. Section 3.2.3 now explains the interpretation of global spatial autocorrelation, local clusters, and spatial outliers. We have also specified the KNN spatial weights ($k = 4$), row standardization, and GeoDa implementation, including 999 random permutations and a 0.05 significance threshold for the local analysis.

Regarding the ranges, we have clarified that the attainable bounds of Global Moran’s I depend on the spatial weights matrix, while Local Moran’s I is not restricted to $[-1, 1]$.

Comment (5): Methodological Accuracy & Wording

Part (1) L175: "calculated the remote sensing images" is incorrect — images cannot be calculated. They can be processed, or spectral indices (e.g., NDSLI) can be calculated from the images.

Reply: Thank you for pointing out this inaccurate wording. We agree that remote sensing images themselves cannot be “calculated.” We have revised the sentence to clarify that NDSLI was calculated from the remote sensing imagery and subsequently used to characterize the spatial distribution of aeolian sediments.

Part (2) L256: "demonstrate a clear association" is debatable; a change of words is advised. The relationship between

NDSLI and LST is somewhat visible, but the interpretation (p. 13) seems very loose.

Reply: Thank you for pointing this out. We agree that the original wording overstated the pattern shown in Fig. 7b. We will revise the text to describe the differences in median LST across NDSLI classes on four of the five dates with pronounced sediment accumulation and identify 10 January 2018 as the exception. We will also remove the inference about spatially concentrated zones of elevated temperature from the interpretation of the boxplots.

Part (3) L208: November 20, 2017 does not appear to be analyzed in Figures 2 and 3. Since this date shows no ice cover (right?), it might be best to include it as a test but exclude it from the following analysis.

Reply: Thank you for pointing this out. This was a labeling error in the figure. The correct date for panel (f) is December 20, 2017, rather than November 20, 2017. We have corrected the date in the revised figure. December 20, 2017 represents an ice-covered observation and is included in the subsequent analysis.

Part (4) L210: April 1, 2018 is not the date in Figure 4, but in Figure 2.

Reply: Thank you for pointing this out. The reference to Figure 4 is correct, but the date in the text was incorrectly written as April 1, 2018. The correct date is March 31, 2018, which corresponds to the Moran's I result shown in Figure 4. We have corrected this date in the revised manuscript.

Comment (6): Figure Caption

Figure 2: The dataset is labeled OLI, but Fig. 2a does not match the dates in Table 1 (2013-12-31 and 2013-12-30).
Figure 4: Very small.
Figures 5 & 6: Labels are rather unclear.
Figure 7: Some dates seem to come from one dataset, some from the other. If both datasets are used, the dates could be removed or a common label added for comparison. The legend in the lower-right corner is redundant, since each subfigure already has its own.
Figure 8: The color choice is questionable — especially the small difference between GWR and MGWR is not well visible.

Reply: Thank you for these helpful suggestions regarding the figures. We have revised the figures accordingly. For Figure 2, the date labels have been corrected to correspond to the actual Landsat OLI acquisition dates listed in Table 1. Figure 4 has been enlarged to improve readability, and the labels in Figures 5 and 6 have been revised for greater clarity. For Figure 7, the date labels have been standardized to avoid confusion arising from the different acquisition dates of the Landsat and MODIS datasets, and the redundant legend in the lower-right corner has been removed. For Figure 8, the color scheme has been adjusted to improve the visual distinction between GWR and MGWR. These changes have been incorporated into the revised manuscript.