Responses to comments from anonymous referee #1

Original comments are in **black.** Our point by point responses are in **blue**. All changes in the context have been highlighted with yellow background.

This paper summarises a wintertime observation-modelling study in a small lake on the Qinghai-Tibet plateau. The thermodynamics of the lake is analysed in an air/ice/water column by using in-situ measurements and thermodynamic model HIGHTSI, earlier applied for several studies on lake and sea ice all over the Northern Hemisphere. Energy balance at the top and bottom of the lake ice shows features typical for the conditions of the "third pole" but unusual elsewhere on the globe.
The manuscript presents unique observations and modelling results in the unique environmental conditions of the Qinghai-Tibet plateau. I have enjoyed reading it, meeting a lake whose thermodynamics seem to differ crucially from all other lakes I have met in earlier studies. In my opinion, the manuscript has potential to become an outstanding paper that can point a way to future studies for understanding the impact of changing climate on the cryosphere and its feedbacks to atmosphere over this area of global importance. In the manuscript there is sufficient material, good methods and well posed research questions and the structure of the manuscript is good. However, this rich material deserves better presentation in order to be understood by researcher colleagues and general reader.
Several questions arise when reading the paper, concerning not only details but also more general aspects of the impact of lakes on the "third pole". There is both general background information and details about the studied lake but it might be possible to better tie these together at the regional (QTP) level. Unfortunately, it is not always possible to understand what the authors want to say, due to poorly formulated, too general or unfinished statements and problems of English language. The paper should be rewritten in a more focused way by removing material that is not essential to the study.
Next, I will present some general comments on how I understood, based on your manuscript, the unique properties that determine the lake thermodynamics and mass balance over the plateau and in the studied lake. More specific comments are written into the manuscript pdf using Adobe reader. I also hope the authors will have a possibility to request linquistic support in order to improve the English in the paper.

Thank you for the comments. We have responded your general and point by point comments below.

During the revision, we removed the dispensable materials and statements, reformulated the manuscript structure, and improved the English readability by a native speaker. All parts are now bound up with the key issues of the manuscript.

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General comments or how I understood the unique properties that influence the lake thermodynamics and mass balance
A small lake with the surface area of 1.5 hectars, shallow with mean depth of 2.5m at high altitude of ca. 4000m. At the bottom: talik and permafrost.

Strong, gusty wind prevails during winter. Clear sky conditions, strong solar radiation with the daily maxima up to 1140 Wm-2. Strong LW cooling to space at the surface. In the air, small humidity on average 34%. Yearly precipitation is 353 mm but potential evaporation is 1613 mm. No rivers flow to/from the lake. Subsurface inflow/outflow?

Sublimation of lake ice - up to 40 % of lake ice disappears to air during winter. Small ice surface melting in spring. Melting at the ice bottom due to penetrating solar radiation.

Possibly falling snow is blown away from ice surface. Dust gathers on ice in the end of winter. These lead to 1) smaller albedo 2) no thermal insulation by snow.

Penetration of SW radiation into the (transparent?) ice and water below, absorption in ice and water. Melting of ice from bottom in interior ice layers. Convection under ice.

Diurnal cycles of freezing and melting, ice temperatures.

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Did I understand correctly the main features? Would you consider developing this kind of summary a bit further, perhaps presenting a comparison (Table, Figure?) with an Arctic lake you have been studying earlier? This would illustrate the unique nature of lakes in your study area and perhaps highlight open questions that call for further research. Such a comparison might suit the concluding section. Also it would be interesting see comments on what is required from a model to correctly simulate lake thermodynamics in these conditions. HIGHTSI works but would for example the bulk lake model FLake be able to simulate the QTP lakes?

Yes, the main features you summarized above are correct. We have incorporated such kind of a summary in the manuscript.

We have added in the conclusion section comparisons between the shallow QTP lake and a lake in the high Arctic (Orajärvi) to emphasize the uniqueness of QTP shallow lakes and their climate characteristics (Table R1).

From a modeling perspective, the radiation reflection, absorption, and transmission should be constrained accurately since (1) extremely low surface albedo was reported by Li et al. (2018, J Glaciol) in large deep QTP lakes, and it needs confirmation in small shallow lakes; (2) the impact of deposited fine sand/dust on ice surface albedo should be evaluated properly; (3) the penetration of solar radiation is believed to strongly affect the water-to-ice heat flux (F_w) that controls the basal growth and melt of ice. Schemes and parameterizations of solar radiation in ice (albedo, extinction, and transmission) need further validation using in situ investigations. Furthermore, F_w needs more careful treatment, and is a time dependent variable in these lakes. Using a constant F_w (e.g. in FLake) does not give reasonable results compared with observations.

We did not conduct experiments using FLake model, but we think the above-mentioned concerns should also be taken in mind since HIGHTSI and FLake use similar key formulations for simulation of ice thickness. Particularly, new schemes for F_w should be proposed regarding the under-ice radiation and hydro-thermodynamic processes. These call for many more field observations and modeling efforts.

Table R1 Comparisons of lake and meteorological features between Lake BLH-A and an Arctic lake (Lake Orajärvi)

Items	Lake BLH-A	Lake Orajärvi**
Surface area	0.015 km2	11 km2
Mean depth	2.5 m	4.4 m
Altitude	4600 m	182 m
Annual precipitation	353 mm	500 mm
Annual evaporation	1613 mm	450 mm (Venäläinen et al., 2005)
Air temperature*	-10.6 ℃	-9~-10 ℃
Wind speed*	6.5 m/s	2.3 m/s
Relative humidity*	34%	85%~87%
Short-wave radiation*	390 W/m^2	41-46 W/m^2
Long-wave radiation*	180 W/m^2	240-260 W/m^2
Net long-wave radiation*	-89 W/m^2	-19~-27 W/m^2
Snow cover	Negligible (light dust)	Up to over 30 cm
Ice surface sublimation	30 cm	Negligible
Ice structure	Congelation ice	Snow-ice + superimposed ice + congelation ice

*averaged over the entire ice season

**data during winters of 2010-2012 were used for statistics

According to the Global Surface Water Explorer, global-surface-water.appspot.com, during the last decades there is a tendency to new permanent and seasonal small lakes and ponds to appear, not disappear, over the plateau. In their maps, Lake BLH-A has got permanent, new permanent and new seasonal pixels. How do you explain the dynamics of your lake (over the whole year, not only in winter conditions that you discuss here), that evidently loses yearly a significant amount of water by evaporation/sublimation but still stays well alive? Large-scale permafrost melting, something else? Would be interesting to discuss the related aspects from the point of view of the possible impact of the (new) small lakes in the weather and climate of QTB and connections to even larger areas. Anyway, the area and mass of water in the lakes and ponds is currently relatively small?

Actually, we do not know very well the hydrology or water balance of Lake BLH-A but we believe it is permanent and its age is around 900 years according to environmental isotopic dating of its sediment core (Niu et al., 2011, Geomorphology). It holds water all year around and its surface area shows an increasing trend and many new lakes have appeared in the Beiluhe Basin during recent decades on the basis of Google Earth images and SPOT data (e.g. Luo et al., 2015, Sci Bull.).

Additionally, a very minor gully flows into Lake BLH-A during summertime without outflow, and there is no surface inflow/outflow during the freezing period. Although P-E-WSD (annual precipitation–evaporation–wintertime subsurface discharge) is negative, this can be compensated by the supra-permafrost inflows and slope runoff (confluence) during thaw seasons (especially summer) resulting from precipitation, glacier melting, and underground ice melting (Pan et al., 2017, J Hydrol; also Lei et al., 2017, GRL; Zhang et al., 2014, Sci Bull.). According to field investigations by Pan et al (2017) in similar thermokarst lakes, a large portion of lake water storage change is because of the supra-permafrost discharge resulting from precipitation, and the recent lake expansion is linked with increasing supra-permafrost discharge especially with an increasing trend in precipitation in QTP.

More results are coming since our group is currently planning and conducting field campaigns on lake water balance dynamics in Beiluhe Basin.

In section 4.3, we have added a general statement on the physics governing the lake water balance through a hydrological year. But the thorough discussion above is not necessary since we focus on lake ice thermodynamics.

Actually, the area and mass of water in these very small shallow lakes and ponds are currently relatively small, but the number of small lakes and their total shoreline length, which are of importance for lake environment, ecology and benthic community, account for >90% of those of total lakes over QTP. Due to climate warming, permafrost and glacier melting and rising precipitation result in generation of many more new small shallow (thermokarst) lakes, especially in continuous permafrost regions. Individual lakes and lake networks in turn accelerate the surrounding permafrost degradation through lateral heat erosion, and also alter the hydrological processes and patterns in permafrost regions.

Lake ice phenology/thickness is demonstrated to be the principal driver of ecological change in Arctic lakes and ponds (Griffiths et al., 2017, PLOS One), and is also expected to have an impact on the duration of the lake bank lateral collapse. Remote sensing products have shown significant spatial variability of lake ice phenology evolution (of climatological importance) over QTP (Kropáček et al., 2013, TC). Using the HIGHTSI model, lake ice evolution and lake water loss by sublimation can be estimated over QTP. Moreover, our study discusses the wintertime lake-atmosphere heat and moisture exchanges that are not well known up to now due to scarce field observations. In the future, schemes for freeze-up and break-up dates can be incorporated to HIGHTSI. After a solid validation, a deep insight into atmosphere-ice-water heat and mass balance over QTP can be achieved.

Specific comments — written into the manuscript pdf.

L20: Rephrased to "The growth and decay at the ice bottom dominated the seasonal evolution of the lake ice."

L21: deleted.

L22-23: Rephrased to "Simulation results matched the observations well with respect to ice mass balance components, ice thickness, and ice temperature."

L24: "freezing air temperature" → "negative air temperature".

L31-33: deleted. But L21-22 have been rephrased to "Basal growth and melt

dominated the seasonal evolution of lake ice, but also surface sublimation was crucial for ice loss, accounting for up to 40% of the maximum ice thickness. Sublimation was also responsible for 41% of the lake water loss during the ice-covered period."
L36: "freezing climate"→ "cold climate".
L37: rephrased to "It owns thousands of lakes covering a total area of approximately 40,700 km^2 (1.4% of the QTP area) and accounting for about 50% of lakes located in China (Zhang et al., 2014)."
L47: We meant that the number and total area of QTP lakes show annual variation. To be clearer, we have rephrased it to "The number and surface area of the lakes varies inter-annually"
L51-52: deleted (including the cited reference Yang et al. 2015).
L59-60: deleted.
L62-65:
Q: Rephrase (something about the need of modelling to understand observations?) or skip. Remote sensing observations are clearly out of context
A: Rephrased to "Because of sparse field observations, there is an increasing need of models and parameterizations to better understand the lake-air interaction and lake thermal regime (Kirillin et al., 2017; Wang et al., 2015; Wen et al., 2016)."
L72: delete "Nevertheless".
L75: delete "of years".
L76-77:
Q: please specify "High-resolution remote sensing techniques and products were deployed tentatively to …"
A: Further, moderate- to high-resolution remote sensing techniques and products, such as MODIS and ENVISAT-ASAR, have been found to be promising and convenient tools for large-scale QTP lake ice research (Kropáček et al., 2013; Tian et al., 2015).
L81: We have added the reference "Yang et al. 2013".
L82-85:
Q: Good! Please check that your conclusions tell about reaching these objectives.
A: Done, we have revised the conclusions to state reaching these goals.
L102: Q: At which altitude is this lake located?
A: The lake is 4,600 m above the sea level. We indicated it in the updated version.
L106: Yes, it is a unit of concentration. The TDS (total dissolved solids) is 1.30 g L^{-1}, corresponding to 1.30 kg m^{-3}.
L109: Q: please specify on "its disturbance to surrounding frozen ground"
A: heat intrusion from the lake water to surrounding permafrost.
L115-123:
Q: Are all your measurements listed here: T_ice, T_water, T_sediment, T_air, D_f D_b H_b, H_s. Are there temperature profiles or 4 values?
A: Yes, there are temperature profiles for T_ice, T_water, T_sediment, and T_air, etc. We have added these nomenclatures to the corresponding observed variables.
L121-123:
Q: Perhaps this is explained in Huang et al. 2016 but might be good to tell here a bit more

details about the temperature and position measurements. How do you obtain the vertical positions - measure everything starting from the bottom perhaps?

A: We added new text reading: "a floater was designed and deployed onto the water surface. A thermistor cable was fixed to the floater to measure the ice-water temperature at 5 cm intervals. An upward looking ultrasonic sensor was also fixed to the floater and positioned at 100 cm depth to monitor the depth of the ice-water interface. A downward looking ultrasonic sensor was fixed to a steel pipe, which had been inserted into the lake sediment by ~60 m, to monitor the position/depth of ice surface."

For a better clarity and illustration, we added also a sub-figure describing the instrumentation in Figure 1.

L136: Q: What means dry here? Without snow/melt water/...?

A: Yes, it is, without snow and melt-water, we modified the text accordingly.

L139: Added.

L183-184: Q: Is this an average between sunrise and sunset, or 24h?

A: It is an average over the whole day (24 h).

L185: Q: Local time? What about 7-8, 19-20?

A: Corrected by "during daytime (8:00-19:00), and nighttime (19:00-8:00)".

L202: Changed to "Huang et al., 2019". And this reference was added to the reference list.

L205: were→ are.

L213: Q: Your components are 4: surface ice melting and sublimation, bottom freezing and melting?

A: Yes, we updated the sentence. The bottom freezing and melting contribute to the bottom evolution.

L221: Yes, it is the modeled ice bottom depth.

L228: Yes, it is local time.

Table 2:

Q: Table 2 shows model-observation validation for ice surface and bottom heights and their difference in cm? Does the total mass balance mean ice thickness here? Otherwise it is not easy to understand a balance in cm. Please use consistent names.

A: Yes, it is quantified in unit [cm]. The total mass balance means the ice thickness. In order to be easy to understand, we used surface height, bottom height, and the ice thickness in the revised version.

L240: rephrased to "when it revealed some cycles of daytime-melting and nighttime-freezing at the surface."

L263: rephrased to ". Therefore, it was divided into three parts: …"

L267: added.

L274: corrected.

L275: Q: Ice surface to atmosphere? Atmospheric surface layer?

A: No, it is a thin ice layer below ice skin surface.

L278: added.

L281: For the surface heat balancing → According to the surface heat balance

L282: corrected.

L287: internal melting in way of gas pore expansion → interior melt in a manner of gas pore expansion
L297: added.
L299: have been carrying out → have been performed
L300: deleted.
L303: added.
L313: differ from → different from
L314: was → is
L323: of → to be
L329-331: deleted.
L348: rephrased to "Diurnal changes in turbulent heat fluxes, however, are large and commonly seen in high latitude and high altitude lakes".
L351: are → were
L352-354: rephrased to "At seasonal scale, the Q_h and Q_{le} over lake ice are approximately 40%-60% lower than values during ice-free seasons, demonstrating the role of ice as an insulator.".
L377-383:
Q: You might compare this to what happens during the ice-free period that might indicate why the lake is still there. You probably have such measurements available, published earlier?
A: Actually, the lake level decreases continuously (totally by ~ 0.5 m) from Aug/Sept to May/Jun of the next year (including the ice-covered seasons) due to subsurface seepage, evaporation, and ice sublimation, and increases rapidly (totally by ~ 0.5 m) due to heavy precipitation and melting glaciers (induced surface and supra-permafrost recharge) during warm seasons (Jul. to Aug.) (Lin et al., 2017; Pan et al., 2017). Consequently, over the entire hydrological year, the lake water loss through surface/sub-surface flows and evaporation/sublimation (during ice-covered period) can be roughly compensated/offset by the precipitation and subsurface/surface inflow during warm seasons. Therefore, these shallow lakes can be still there.

Since the water balance during ice-free seasons is somehow out of context, we have added only brief info to the updated manuscript as well as some new citations.
L380: Q: please remind the reader what is talik
A: It is a layer of year-round unfrozen ground. We added in the revised manuscript.
L384: 5. Summary and conclusion
Q: This is a good summary of your findings. However, discussion of more general aspects of the impact of lakes on QTP in the conditions of changing climate could be added, also an outlook to further studies might be given. Please consider the idea given in my general comments to summarise and compare the unique features of your lake v.s. another, e.g. Arctic lake using a figure or table.

A: We have added comparison with other lake, and general characteristic of this QTP lake based on your summary and suggestions. The new text reads: "Comparisons with an Arctic lake revealed the uniqueness of QTP lakes especially with respect to the atmospheric forcing, lake geometry, ice cover (free of snow), and under-ice hydro-thermodynamics (Table 4). These features challenge the existing lake ice models that are mainly developed for Arctic and temperate regions. However, present modeling experiments indicated that HIGHTSI could yield reasonable results in terms of the surface and bottom freezing/ablation and ice thermodynamics."

And we also indicated our future work regarding estimation of wintertime lake sublimation over-QTP, investigating physics governing under-ice heat flux, and light transfer within air-ice-water column, etc. These future investigations are vital to understand QTP lake thermodynamics and accurately constrain lake (ice) models, like FLake, HIGHTSI, etc.

L424: Q: Wouldn't it be possible to measure reflected SW radiation on ice? Perhaps also the other radiative fluxes? If Li et al, 2018 already reports such measurements, perhaps an abledo value could be mentioned here?

A: In fact, we carried out TriOS spectro-radiometers measurement during 2012-2013 season in the lake but unfortunately without a major success due to instrumental malfunction. Only 10-hours daytime incident and reflected SW radiative fluxes were obtained and a surface albedo of about 0.6-0.65 was derived (ice thickness= 45 cm, air temperature= -3.4 ℃). This observed value agreed well with parameterized albedo in HIGHTSI when modelled ice was around 45 cm. The albedo measurements by Li et al (2018) are from other large and deep lakes in QTP. The unprecedentedly small surface albedo was around 0.2 when ice was 60 cm. For our lake due to the impact of ice texture (gas bubbles), color, deposited sand, the surface albedo is higher than 0.2, but when ice was thinner than 10 cm, the parameterized surface albedo was around 0.2. We have modified the text and added the albedo values, accordingly.

L437: meteorology → meteorological forcing

Table 2: Corrected.

Figure 1:

Q: Please consider to show, as in the presentation at Lake17 workshop, a satellite map where the lake is seen. More interestingly, please explain what is seen in the photo on the lake ice - looks like deposition ice but perhaps it is something else?

A: The map is updated accordingly.

Figure 2: Q: Here and in the following figures: would it be possible to replace the julian days with year/month/day format?

A: Done.

Figure 5: Corrected.

Figure 7: Corrected.

Figure 8: Corrected.

Figure 11: Corrected.

Figure 12: Corrected.

You may have forgotten one reference to your own studies, possibly relevant for this manuscript:

Yang, Y., Cheng, B., Kourzeneva, E., Semmler, T., Rontu, L., Leppäranta, M., Shirasawa, K. & Li, Z. J. 2013: Modelling experiments on air–snow–ice interactions

over Kilpisjärvi, a lake in northern Finland. Boreal Env. Res. 18: 341–358.
Added.

Other changes

(1) We improved the English readability by a native speaker, many definite/indefinite articles, singular/plural nouns, simple phrases, and sentence patterns have been modified, but are not shown in this response letter.

(2) Julian dates have been removed and replaced by calendar in the text and in all figures.

(3) All “2010/2011” have been reformed to “2010–2011”.

(4) Lines 98-101 (and references therein) were removed since it is not essential to the topics.

(5) Line 105: delete “with a stable water level through the year”, and “fresh” → brackish”.

(6) Line 106-107: delete “Submerged plants grow abundantly in the lake sediment throughout the year.”, since it is not essential to the topics.

References listed in the above response:

Griffiths, K., Michelutti, N., Sugar, M., Douglas, M. S. V., Smol, J. P., 2017. Ice-cover is the principal driver of ecological change in High Arctic lakes and ponds. PLoS ONE, 12(3): e0172989, doi:10.1371/journal.pone.0172989.

Kirillin, G., Wen, L., and Shatwell, T.: Seasonal thermal regime and climatic trends in lakes of the Tibetan Highlands, Hydrol. Earth Syst. Sci., 21, 1895-1909, 2017.

Kropáček, J., Maussion, F., Chen, F., Hoerz, S., and Hochschild, V.: Analysis of ice phenology of lakes on the Tibetan Plateau from MODIS data, The Cryosphere, 7, 287-301, 2013.

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Li, Z., Ao, Y., Lyu, S., Lang, J., Wen, L., Stepanenko, V., Meng, X., and Zhao, L.: Investigations of the ice surface albedo in the Tibetan Plateau lakes based on the field observation and MODIS products, J. Glaciol., doi: 10.1017/jog.2018.35, 2018.

Luo, J., Niu, F., Lin, Z., Liu, M., and Yin, M.: Thermokarst lake changes between 1969 and 2010 in the Beilu River Basin, Qinghai-Tibet Plateau, Chinese Sci. Bull., 60(5), 556-564, 2015.

Pan, X., Yu, Q., You, Y., Chun, K. P., Shi, X., and Li, Y.: Contribution of supra-permafrost discharge to thermokarst lake water balances on the northeastern Qinghai-Tibet Plateau, J. Hydrol., 555, 621-630, 2017.

Tian, B., Li, Z., Engram, M. J., Niu, F., Tang, P., Zou, P., and Xu, J.: Characterizing C-band backscattering from thermokarst lake ice on the Qinghai-Tibet Plateau, ISPRS J. Photogramm. Remote Sens., 104, 63-76, 2015.

Venäläinen A, Tuomenvirta H, Pirinen P, Drebs A. 2005. A Basic Finnish Climate Data Set 1961-2000 – Description and Illustrations. Finnish Meteorological Institute Reports 5.

Wang, B., Ma, Y., Chen, X., Ma, W., Su, Z., and Menenti, M.: Observation and simulation of lake-air heat and water transfer processes in a high-altitude shallow lake on the Tibetan Plateau, J. Geophys. Res., 120, 12327-12344, 2015.

Wen, L., Lyu, S., Kirillin, G., Li, Z., and Zhao, L.: Air-lake boundary layer and performance of a simple lake parameterization scheme over the Tibetan highlands, Tellus A, 68, 31091, doi:10.3402/tellusa.v68.31091, 2016.

Zhang. G., Yao, T., Xie, H., Zhang, K., and Zhu, F.: Lakes' state and abundance across the Tibetan Plateau, Chinese Sci. Bull., 59(24), 3010-3021, 2014.