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## Comment on **essd-2022-206**

Samuel Gagnon (Referee)

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Referee comment on "A new 2010 permafrost distribution map over the Qinghai–Tibet Plateau based on subregion survey maps: a benchmark for regional permafrost modeling" by Zetao Cao et al., Earth Syst. Sci. Data Discuss., <https://doi.org/10.5194/essd-2022-206-RC2>, 2022

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Dear authors,

This paper presented a new 2010 map of permafrost distribution for the Qinghai-Tibet Plateau (QTP) produced through a modified version of Hu et al. (2020)'s model. The model used a combination of field data from around 2010 and satellite-derived ground surface thawing/freezing indices as input, and survey-based subregion permafrost maps as constraints. They present the resulting map as the best available one as of now, which could be used in the future as a benchmark for calibration and validation of simulations. Although their goal of the paper and the methodology used to reach it are not entirely new or innovative, their approach is robust and results of high quality.

Please note that since I am not a modeller, I was not able to comment on the pertinence of the model. I could only comment on the overall quality of the paper and the scientific approach to the problem.

In general, the paper would benefit from being more concise. The description of the model is quite exhaustive and some sections could go in supplementary materials (see specific comments). I also found that the manuscript would benefit from having a results section and then a discussion rather than a Results and Discussion section together. This would facilitate reading and encourage the authors to describe their ideas/conclusions more clearly. I also suggest adding a section for "Simulation limitations", which would acknowledge the limitations of the model/study and what could not be done with the present paper.

Below you will find specific and technical comments that I hope you will find useful.

Best regards,

Samuel Gagnon

**Specific comments:**

Line 62: Be careful with the tone when comparing with other works as sometime the adjectives you are using sound condescending. I've seen this multiple times throughout the text. Although I don't think it is intentional, sometime your choices of word is harsher than it needs to be. Previous work may seem flawed now with new technology/knowledge, but it was the best that could be done at the time, and we have to keep that in mind when evaluating past work.

Line 79: Could you be more specific and refer to the works you are talking about? I don't think it's true for all works done in all areas with permafrost, so it would be good to have specific references pertinent to the QTP.

Line 88: Do you mean that ideally a map should be based on field observations, or that that they should be specifically independent of land surface model simulations but that other types of simulations are ok? Be specific, you could remove "land sur face model" and just put simulations. Also, there's not mention of the number of observations, which is important because a map based on only a handful number of observations is unreliable. The first criterion of a good benchmark map could be changed to "a map based on a large number of robust observations independent of simulations".

Line 98: Before we go into the data used for mapping, I'm missing a "Study site" section where you describe the QTP. It could be brief and even integrated with another section, but I think it would be useful to have a description of the area with some baseline information about the climate (e.g., snow, summer & winter temperatures, insolation) and permafrost. In other words, mention what is typical of the QTP so that we can have a better idea of what you are simulating.

Line 99: I think section 2.1 could be longer and have more information about the study by Zhao et al., 2017 since it's in Chinese. It would be good to have more information about the maps, i.e., their resolution and how exactly they were created (e.g., just field observations? Mapping software/algorithm?). It doesn't have to be too long, but in its current form I feel that we are missing so key information about those reference maps.

Line 101: what is the "surroundings" of permafrost? Consider removing it

Line 101: Representative of what? Of the QTP? Please specify

Line 102: The tone of the sentence is too engaged in my opinion. I've seen it a couple of times in the paper, be careful to remain formal/informative, which is more typical of scientific writing.

I suggest changing the sentence to "Comprehensive information was acquired through field observations, mechanical excavation, geophysical exploration techniques (ground penetrating radar, time-domain electromagnetic), and borehole drilling, which allowed to map the permafrost distributions with high precision in all five subregions."

Line 110: I suggest that you revise the color schemes of the permafrost maps. Shades of purple have been used in other maps (e.g., Obu et al., 2019, <https://doi.org/10.1016/j.earscirev.2019.04.023>), which is very useful if you want to include bodies of water and avoid blue shades. Also, with the scale of the maps (other ones in the paper), it is difficult to differentiate glacier and water bodies, consider changing the colors. It would be nice if the colors of the topographic map and the permafrost maps did not repeat.

Line 121: I find the acronyms DDT and DDF confusing. DDT should be TDD for Thawing Degree-Days, and DDF should be FDD for Freezing Degree-Days. In addition, TDD and FDD don't denote the freezing and thawing indices. While degree-days are the departure of the mean daily temperature from a reference temperature (0°C), the thawing index (Ti) and freezing index (Fi) are the sum of degree-days for the thawing and freezing seasons, respectively. This should be explained in the text, i.e., what are TDD and FDD, and how they are used to calculate the freezing and thawing indices (use different acronyms, e.g., Ti and Fi). Change the acronyms in the rest of the text accordingly. You kind of mention what are FDD and TDD at lines 245 and 247, so remove it once you make the change here.

Line 121: "which in theory are aggregated from the 0 cm ground temperature", actually, Fi and Ti can be calculated for any depth, so you have to specify that for your study, you used the 0 cm, so remove "in theory". This sentence needs to be adjusted with the redefinition of the thawing and freezing indices.

Line 127 to 130: You use the NDVI for estimating the vegetation conditions over the study area and I agree with that approach. However, you assume that the NDVI is a perfect match for vegetation cover over your study area, which it inherently isn't. For instance, when was the product obtained? Does that impact the result? Was cloud cover an issue? Are there specific areas that are not represented well? I suggest that you add the limitations or at least that you acknowledge that there could be some in the use of the NDVI. Conversely, you could also explain why you think this is a good proxy on the QTP (is tundra represented well?).

Line 137: Could you explain how the soil texture type data was used in the mapping approach?

Line 142: Having 131 meteorological stations with long-term record is fantastic. However, there is an obvious bias in the coverage in the station, as you mention in the text. Could this have affected the results? If so, how? It would be good to acknowledge it and mention it somewhere in the text.

Line 143: Please indicate what are the "standard meteorological variables".

Line 150 to 155: I'm not familiar with permafrost conditions at the QTP (hence my comment above on site description). Hence, I don't know what permafrost thickness to expect. How did you determine the presence of permafrost with two measurements, i.e., 10 and 20 m depths? Also, at what depths were the MAGT for your three categories determined? Please specify in the text.

Line 168 to 174: This sentence is too long, and each map needs to be explained separately. For the Zou map, was it developed using the TTOP model? The phrasing makes it unclear. You could remove "Glaciers, Frozen Ground and Deserts in China" and just put the reference to shorten it.

Line 189: "using techniques [...]", is this for the model parameter  $E$  or for the model in general? Clarify

Line 190: "such as", this suggest an example, does it mean that there are more techniques than those listed in the text? If so, it would be better to avoid "such as" and list all of the techniques.

Line 242: A reference to snow cover on the QTP in a "site description" section would be great, see comment for line 98.

Lines 226 to 239: Consider putting this section in supplementary material.

Line 269: You used the 131 weather stations for evaluating the performance for the interval-based estimation only or also the one-year estimation? The first and second sentence makes this confusing

Lines 278 to 286: Is this just an explanation of what Hu et al. (2020) have done? If so, this could be removed or put in supplementary material.

Lines 283 to 286: Verb tense to revise.

Line 308: How was  $\delta^{13}C_k$  determined? You mention it for  $\delta^{13}C_B$ , but not the other, unless I missed it.

Lines 325 to 345: This section should be in supplementary material, and the paragraph at line 346 should be added to the paragraph ending at line 324.

Line 343: Can you add a reference to the C5.0 decision tree method?

Line 369: Can you say why you specifically chose the Zou map for specific comparisons?

Line 371: Can you give an example of how satellite images can provide indicative landscape evidence of permafrost existence?

Line 379 to 381: Is it possible to cut this sentence or divide it in two? It's hard to read. In addition, the "good consistency" followed by the "despite considerable discrepancies" could be separated into two sentences, which would make it less confusing when reading, something like "however, there were considerable differences in absolute values".

Lines 384 and 385: This explanation and references should reflect what is presented in the "Study site" section (see line 98 comment)

Line 386: You don't need to describe the figure/table in the text. I've seen a couple of times in the text (e.g., line 403). I personally think it's redundant with the figure/table caption and adds unnecessary length to the text. You can directly start talking about your observations from the figure/table (like in line 394). To correct in other places where you talk about figures/tables.

Lines 386 to 393: In this paragraph, you describe almost the entirety of table 1, except for the ranges. It makes me wonder if table 1 is indeed needed, you could just add the ranges in the text. Something to consider.

Lines 386 to 393: This section along with table 1 could be in supplementary material or condensed in the methods. A sentence in the text like "the interval-based estimation method was used to correct the discrepancy between modelled and in situ DDT because it yielded lower errors (see supplementary material)".

Lines 411 and 412: I don't know where the Qaidam Basin or the Qiangtang Plateau are, please specify or indicate in one of the maps prior to Figure 9.

Line 417: Figure 4: Please split the first sentence, e.g., "Observed discrepancies between annual thawing degree-days aggregated from in situ and interpolated data. The data was obtained from MODIS LST [...]".

Line 423: Table 1: Potentially put in supplementary material (see earlier comment). If you leave the table in the manuscript, remove "The training sets consist of 70% of the available stations, and the metric values provided were calculated over the remaining 30% as testing stations.", it's redundant with the information in the text. For the ranges, please change ~ to -.

Line 441: How did you determine a "dominant" cluster? Is it above 50%? Above 20%? I think it would be good to add percentages in the text in brackets.

Lines 463 to 471: This section is really interesting to me. You could develop more on the potential links between the soil clusters (and characteristics) and permafrost occurrence. Then, you could contrast later in the text with the final map, which includes climatic factors, and highlight the importance of both when estimating permafrost occurrence. It's a suggestion.

Line 497: You mention thermal erosion as an unfavorable condition leading to SFG. What do you mean exactly by thermal erosion? Thermal erosion is defined as the erosion of ice-rich permafrost by the combined thermal and mechanical action of moving water. Thus, it does occur in permafrost areas and is not symptomatic of non-permafrost environments. Do you actually mean heat advection by water, which is the transport of heat by water? This would make more sense as the heat from the large bodies of water would be enough to promote talik formation and thus prevent permafrost formation. Please explain if heat advection, and if so, change elsewhere in the text where there's mention of thermal erosion.

Line 505: Consider changing the color scheme to avoid using blue as it is hard to distinguish the water bodies and the glaciers (see comment line 110). Also, please add the resolution of the map (1km).

Line 555: "among which our map achieves the best performance with 54.5% accuracy in predicting SFG locations", does this affect the overall quality of the QTP map, especially considering that the western part is underrepresented in terms of boreholes?

Line 570: I really like Figure 10 and I think it's one of the most important in the paper to highlight the performance of your map with regards to other works. A couple of things:

- You should change the color scheme according to your other maps based on my earlier suggestion
- You should enlarge the figure so that it is as big as possible, i.e., as large as the page
- I find it hard to compare one map with another. A possible solution to this would be to add a new class with "differences between modeled maps and the survey-based map". Seeing the highlighted differences would give a point of reference and help the reader identify the performance of each map with regards to the others. You did that for figures 11 and 12 and I think this figure would also benefit from it, but using the survey-based data as reference

Line 576: Table 4 caption: just to be consistent, in the figure 10 caption you use the full reference for the Zou map and the Wang map, but here you don't (same for Table 5). Please adjust one or this other according.

Line 579: Table 5: This table could be condensed by having the rates in parentheses beside the confusion values. Change caption accordingly.

Lines 587: This sentence needs to be rephrased because it sounds like your map is not that different from the Zou map, which defeats the purpose of this paper.

Line 590: "Those headwater regions have been reported to be the critical regions where permafrost is more vulnerable and very sensitive to climate change (Jin et al., 2011; Zhang et al., 2021)." Could you expand on this and give more explanation as to why and why it is difficult to model?

Line 593: Figure 11: Same as other figures, reconsider color scheme. The figure could be larger to fit the width of the page. Also, the sections with more inconsistencies could be inserts on the side or below the map, otherwise we can't really see well. If you only want to use the figures after, please show the map as it is with the same classes and legend (i.e., Both P, Both SFG, Zou-P, etc.) before showing other maps (like in figure 12).  
Caption: change "tremendous" to "significant"

Line 616: Do you mean permafrost degradation or permafrost absence caused by the presence of the rivers? Because rivers don't necessarily cause degradation, but they do affect distribution. In addition, I'm having a hard time linking the distribution of the rivers with the DDT/DDF. Could you add arrows or more detailed explanations in the text as to where they affect permafrost? Unless you're just saying that their presence could potentially lead to more degradation? If so, rephrase to say this more explicitly.

Line 621: Figure 12: Color schemes to revise based on previous comments. Caption: Remove "Elaborate", for (c), please add indicators (e.g., arrows, boxes) and a description to help us understand what you want to illustrate between the two maps, otherwise we don't understand why it's there. The last sentence could be condensed to "See Figure 11 for notation"

Line 638: Could you give us an indication of the warming in the area, e.g., the mean annual temperature in 2010 vs 2020? Even better would be borehole temperatures to know how close to thawing the ground was in 2010.

Line 639: Why does permafrost thawing occur more downstream than upstream? Is it because of elevation? If so, please explicitly say.

Line 646: "likely statistically unreasonable", so is it or is it not? Not clear with the wording.

Line 651: Can you develop more as to why it is a bad thing that permafrost and SFG are overlapping for the Zou map and a good thing that your values are not overlapping? The entire paragraph (lines 643 to 652) looks more like just results than discussion, it needs to be developed.

Line 654: Figure 13:

- I suggest you put the same map (but zoomed in) as Figure 11, otherwise it's very difficult to see the differences between the two maps a) and b).
- Change the first sentence to have " (c) permafrost zonation index (PZI) in this region showing the spatial distribution of PZI"
- There's no mention of figure 13c in the text, and I don't really see why you have the figure here. You need to explain what it shows and mention it in the text.
- Explain what the red box is in the caption, not just in the text.
- Please a different notation (maybe dashed line) to circle the borehole from 2010 because it is confusing with the boreholes inconsistent with map
- Explanation for (d) needs to be repeated.

Line 660: Can you mention the year of the recorded data by the boreholes?

Line 675: Figure 14:

- Same comment as figure 13, I suggest you put the same map (but zoomed in) as Figure 11, otherwise it's very difficult to see the differences between the two maps a) and b).
- There needs to be mention in the caption as to why the 4300m is present, both in figure a-b but also in c.
- Explanation for (d) can refer to figure 13 or be repeated.

Line 679: Data availability: I don't know if it's a journal requirement, but this section should go after the conclusion in my opinion.

#### **Technical corrections:**

Line 43: Add "the" in front of carbon cycle and change "thermodynamic" to "heat exchange"

Line 44: Begin sentence with "In addition"

Line 45: Remove sentence "Meanwhile, the consequences will lead to vital feedbacks to climate systems (Zhang et al., 2020; Wang et al., 2021)."

Line 52: You could add the references (Zhang et al., 2020; Wang et al., 2021)

Line 53: Join the two sentences together with "[...] for these studies because compared with the large [...]"

Line 54: Change sentence to "Hence, there is a need for an accurate permafrost distribution map that would serve as a reference to validate results. The map could be used as a target to calibrate modeling parameters and to provide a constraint for future projection studies to minimize biases arising from the modeling process. Moreover, an accurate permafrost distribution map could serve as a fundamental dataset for hydrological, carbon, ecological and engineering studies in cold regions (Hu et al., 2019; Li

et al., 2020; Song et al., 2020; Mu et al., 2020).”

Line 62: Remove “the quality of these maps is often unsatisfactory, and”

Line 70: I don’t like the use of “unsatisfactory” (see the related specific comment), and it too broad. Why is it unsatisfactory? Here you could remove “and unsatisfactory performances on the QTP” or change it to something like “their coarse spatial resolution inadequate for the QTP”

Line 71: Verb tense? It looks like it should be “[...] would consequently restrict [...]”

Line 73: Change “popular” to “common”

Line 74: Change “it will” to “Consequently, this leads to misrepresentation [...]”

Line 79: Add “[...] to a large region with more spatial variability and thus more complex conditions.”

Line 88: Change “firstly, secondly, last but not least” to “should be: 1) a map based on [...]; 2) a map based on multi [...]; and 3) a map of adequate [...]”

Line 91: Remove “adequate accuracy”, it’s too vague, change the sentence to “a map that considers the impacts of local factors and that is well constrained during the mapping process”

Line 92: Change “under such circumstances” to “Based on these criteria”

Line 92: Change “provide” to “produce”

Line 92: Remove “high-quality”

Line 93: Change “over” to “of”

Line 94: Remove "fully"

Line 95: Change the sentence to "Our goal is also to provide a new reference map of 2010 for permafrost simulation studies of the QTP and provide a benchmark for transient land surface models under climate change"

Line 102: Remove "west to east in"

Line 111: Remove "(West Kunlun, Gaize, Aerjin, G308, and Wenquan, from west to east)"

Line 113: Remove "(WQ)"

Line 115: Cut sentence in two, e.g., "The land surface temperature (LST) product from the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Terra and Aqua satellites is one of the most widely used LST products due to its high spatial and temporal resolutions (Wan, 2008). It has a global coverage and has been applied in many permafrost mapping studies to provide temperature conditions (Gisnås et al., 2017; Zou et al., 2017; Obu et al., 2019; Wang et al., 2019)."

Line 120: Change "data" to "observations" and "are" to "were"

Line 123: Make into one paragraph with the previous one

Line 123: Remove "Moreover"

Line 123: Change "it is necessary" to "it was necessary"

Line 124: Change the sentence to: "For this reason, we used MODIS LST products from 2005, when automatic weather stations were put into operation in the study area, to 2010"

Line 123: Change "related to" to "influencing"

Line 130: Please reference the section to where vegetation was used to estimate DDT (section 3.2?)

Line 132: "to a spatial resolution of 1 km", could you add why? i.e., "to match the resolution of the LST data."

Line 149: The three paragraphs could be together in one paragraph since they are so short.

Line 149: Change "collected" to "used" and "revealed by" to "from"

Line 150: Remove "A newly published synthesis dataset of permafrost thermal state on the QTP" and change the sentence accordingly, it's too long and you can only cite the reference, no need to add more.

Line 152: Write 65 in letters because of beginning of sentence

Line 156: Numbers below 10 are usually written in letters, change accordingly in the rest of the text.

Line 157: Change "are" to "were". There are multiple inconsistent verb tenses in the text, please verify throughout.

Line 161: Remove "during the Second Tibetan Plateau Scientific Expedition and Research"

Line 163: Change "at" by "in"

Line 166: Change title to "Comparison with existing QTP permafrost maps"

Line 168: Replace "cited in this study" with "used"

Line 168: Break the two maps into two sentences, too long

Line 175: Remove "Recently" and change "was" to "has been"

Line 177: Change "Cao et al. (2019a) regarded the Zou map as the best" to "Cao et al. (2019a) have determined that the Zou map is the best"

Line 179: Change "For the sake of simplicity" to "For simplicity"

Line 179 to 182: Long and difficult to read, to re-write, consider removing the name of the datasets and only cite the authors.

Line 185: Change "we applied a newly developed mapping method, namely FROSTNUM/COP (Hu et al., 2020)" to "we applied a mapping method developed by Hu et al. (2020)."

Line 185 to 190: Repetition of "this method", redundant

Line 191: Change DDT and DDF in the equation for Thawing and Freezing indices acronyms as mentioned in the specific comment about line 121.

Line 207 to 215: Remove the verbs at the beginning of each description, e.g., "lists the, shows the, shows the, etc."

Line 223: Unless you still don't know, remove "theoretically"

Line 225: Rephrase "making it advanced in uncertainty control"

Line 226: Change the beginning of sentence to "First, in this SCSG-based stepwise interpolation approach, clear-sky [...]"

Line 247: Change to "the growing season"

Line 248: Change sentence to "We estimated the annual DDT from raw LST-derived thawing degree-days based on a multilinear regression model where GST is a function of independent variables including LST, NDVI, and latitude at weather stations Huang et al., 2020)."

Line 280: Remove "in this study", repetitive with the one said at the beginning of sentence

Line 290: Remove NDVI and FSC, then say "to which we added NDVI and FSC to further account [...]"

Line 313: Remove "the" in "the types of frozen"

Line 313: What do you mean by neighborhood? Do you mean neighboring cells or surrounding cells? If so, change it and other mention of it.

Line 367: Change 5 to five

Line 374: The sentence beginning with "in some regions" seems to be missing a word between QTP and thermally.

Line 394: Remove "which generally underestimates the in situ annual DDT at most of the QTP weather stations from 2005 to 2010".

Line 395 to 397: Long sentence, to split into two.

Line 409: "up to 9000°C day" and "up to 8000°C day", Before you say "wide spectrum" so I was expecting a range, otherwise it's difficult to tell if you are saying the maximum range or the maximum value of the range. Change the sentence accordingly.

Line 430: Figure 5: Change first sentence to "Bias correction of MODIS-LST-derived annual DDT with the interval-based approach". Change "from the diagonal line (black solid line)." to "from the 1:1 diagonal line (solid black line)."

Line 435: Figure 6: Enlarge the figures so that they fit the width of the page

Line 440: "where lakes were excluded", do you mean in the subregions or in the approach? If you mean in the approach, rephrase.

Line 444: Put at the beginning of section 4.2, maybe as the second sentence.

Line 445: Change "Figure 8 presents the primary characteristics of the soil clusters in the five subregions." to "In the five subregions, clusters 1, 2, and 3 [...]".

Line 457: Remove "As summarized in Table 2" and add (table 2) at the end of the sentence.

Line 461: Please specify what is the percentage covered by snow (ideally glaciers) from the study by Dail et al. (2018)

Line 473: Figure 7: Please change the color scheme with colors that are less associated with temperature. Change figure 8 accordingly.

Line 478: Figure 8: add to the figure that the values are obtained from the soil clusters in the five subregions, otherwise it looks like it's from the entire QTP.

Line 484: Table 3. Change to "Ranges and mean values as the most optimal values of the soil parameter E associated with the 8 soil clusters. The results were obtained from 1000 optimization trials."

Line 488: Remove "Figure 9 shows" and change the sentence accordingly. Verb tense should be in the past. Mention the date.

Line 488: Remove the "about" in that sentence, you give precise numbers so there's no point.

Line 502: Do you mean a small amount of frozen ground? Because I mainly see SFG on the southeastern part of the QTP. Also, what do you mean by southeastern periphery?

Periphery = the outer limits, and I'm not sure how to identify this on the QTP.

Line 510: Remove "high"

Line 547: Remove "well"

Line 552: Change "and the resulting measures are listed in Table 5" to "(table 5)"

Line 553: Change sentence to "Our map shows good agreement ( $\delta_{\square\square} = 0.43$ ) with the borehole observations in terms of  $\delta_{\square\square}$  compared to the Zou map ( $\delta_{\square\square} = 0.30$ ) and Wang map ( $\delta_{\square\square} = 0.14$ )"

Line 584: Remove "widely recognized performance" and change sentence accordingly

Line 587: Change "consistent" to "comparable"

Line 589: Change "remarkable" to "noticeable"

Line 606: Remove "it seems that much"

Line 607: Remove "obviously"

Line 610: "Despite [...]", rephrase the sentence, hard to read

Line 617: Remove "based on limited evidence"

Line 633: "for the frozen soil type" please specify exactly what that is.

Line 648: Remove "it is found that"

Line 652: Change "turn out to be more distinguishable" to "did not overlap"

Line 667: Remove "obviously"

Line 670: This paragraph needs to be phrased differently, it's awkward to read, especially the first sentence up to "The improved performance of our map may benefit from the increased accuracy of model inputs, consideration of local factors, and full exploitation of the survey-based subregion permafrost map. Therefore, as a better estimation of permafrost"

Line 685: Remove "(Hu et al., 2020)" and you should mention that you use a modified version of it

Line 688: Change "(relative error < 10%)" to "with a relative error <10%"

Line 695: "to multifaceted effects of low latitude and local factors" be more explicit and list more, also I'm not sure thermal erosion is appropriate (see earlier comment).

Line 697: Remove the Kappa coefficient and simply mention that your map performed better than other recently published maps. Same for the lines after, reduce the numbers and talk about main conclusions for the comparison part of the paper.

Lines 701 to 706: Sentence too long, cut into two sentences

Line 707: This does not need to be a paragraph on its own, change the initial The to "Our"

Line 708: Remove "of sufficient quality"

Line 707: Change the sentence to "The new 2010 permafrost distribution map provides accurate and fundamental information for QTP permafrost and can serve as a historical reference when projecting future changes of QTP permafrost and as benchmark map to calibrate/validate spatial simulations of land surface models"