A 10 m resolution land cover map of the Tibetan Plateau with detailed vegetation types

Anonymous Referee #1

General comments:

The authors introduced a new classification system and produced a detailed land cover map of the Tibet Plateau (TP) area in 2022, which is significant for climate change studies. The method and results are well-presented. However, there are some questions or issues.

Response: We are grateful for your kind acknowledgment of the value of our dataset and thank you for providing insightful comments and detailed suggestions. Following your constructive feedback, we have revised the text to strengthen the clarity and accuracy of this manuscript.

Specific comments:

1. **Lines 242–245 mentioned that the reason for not using time series is the dense cloud cover in southeastern TP. Could you provide a quantification of the cloud coverage in this region?**

Reply 1:

Thank you for pointing this out. Lowering the threshold of cloud filtering results in the reduction of image pixels available for analysis, particularly in the southeastern TP, where has heavy cloud contamination (Tang et al., 2022). Conversely, raising this threshold to a higher level compromises the quality control of Sentinel-2 images while maintaining image integrity. We have added a quantification of filtered Sentinel-2 imagery in the TP in the revised manuscript (Lines 273-278), which reads:

For example, during the summer of 2022 (June-August), when setting the "CLOUDY_PIXEL_PERCENTAGE" parameter to 10%, 20%, 30%, and 40%, and applying QA band masking, we lost 13.59%, 5.81%, 2.44%, and 1.32% of the Sentinel-2 image area in the TP. The removed pixels are concentrated mainly in the cloudy southeastern TP (only shown for 10% threshold in Fig. A3) (Tang et al., 2022). This constraint can preclude the attainment of desired outcomes in regions where cloud-free image availability is low (Chu et al., 2021; Coluzzi et al., 2018).

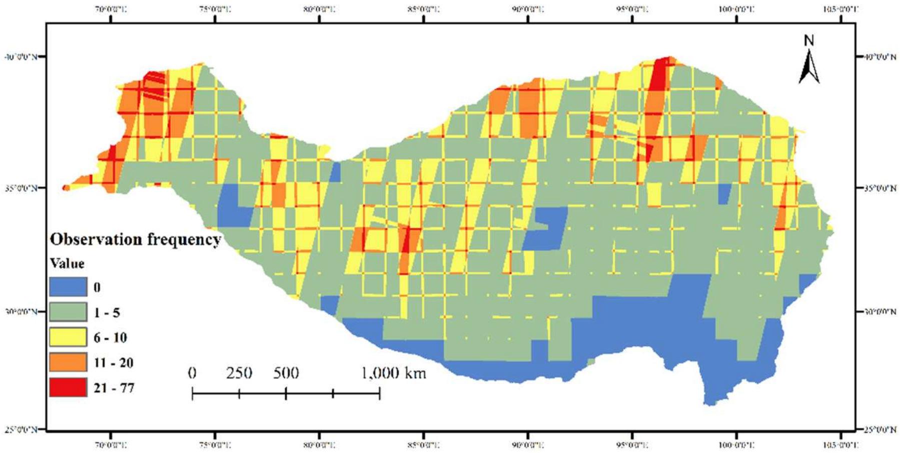

Figure A3. Number of available observations for the Sentinel-2 optical data in the Tibetan Plateau during summer in 2022 (June 1, 2022, to August 31, 2022) with cloud cover <10%.

Reference:

Chu, D., Shen, H., Guan, X., Chen, J. M., Li, X., Li, J., & Zhang, L. (2021). Long time-series NDVI reconstruction in cloud-prone regions via spatio-temporal tensor completion. Remote Sensing of Environment, 264, 112632. https://doi.org/10.1016/j.rse.2021.112632

Coluzzi, R., Imbrenda, V., Lanfredi, M., & Simoniello, T. (2018). A first assessment of the Sentinel-2 Level 1-C cloud mask product to support informed surface analyses. Remote Sensing of Environment, 217, 426–443.

Tang, J., Guo, X., Chang, Y., Lu, G., & Qi, P. (2022). Long-term variations of clouds and precipitation on the Tibetan Plateau and its subregions, and the associated mechanisms. International Journal of Climatology, 42(16), 9003–9022. https://doi.org/10.1002/joc.7792

2. **Lines 131–141. The Landsat NDVI time series from 2013 to 2022 was used to assist in selecting samples. I also noted that the study selected dense samples in the southeastern TP. Could the cloud cover in southeastern TP affect the Landsat time series from 2013 to 2022 and subsequently impact the accuracy of the sample selection?**

Reply 2:

The dense cloud cover does not affect the accuracy of sample selection over the entire study area. However, cloud cover does reduce the number of available NDVI observations from Landsat images in the southeastern TP. To mitigate this impact on the cloudy regions, we implemented the following two steps:

- Filtering out pixels with cloud coverage greater than 50% to eliminate severely contaminated pixels.

- Using harmonic analysis of time series (HANTS) model for data interpolation and smoothing to remove outliers and reconstruct missing data.

As a result of this process, only a small fraction of pixels remained severely contaminated, which were excluded from our sample selection.

3. In Fig. 3, the NDVI time series for evergreen needle-leaved forest, evergreen broadleaved forest, and evergreen shrubland look very similar. Can the NDVI time series effectively distinguish between these land cover types?

Reply 3:

Thank you for pointing this out. It is difficult to distinguish certain land cover types only using the Landsat NDVI time series, such as evergreen needle-leaved forest, evergreen broadleaved forest, and evergreen shrubland, due to their similar vegetation characteristics. However, the decision was made not only based on NDVI but also on their distinct crown shapes and texture characteristics that are visible in Google Earth images (see Fig. 3 and the figure below). We have revised the text to make it clearer to understand (Lines 164-166), which reads:

Evergreen needle-leaved forests, evergreen broadleaved forests, and evergreen shrublands exhibit similar trends and values in NDVI time series. However, they can be discerned in Google Earth images based on their distinctive crown shapes and textures (Fig. 3).

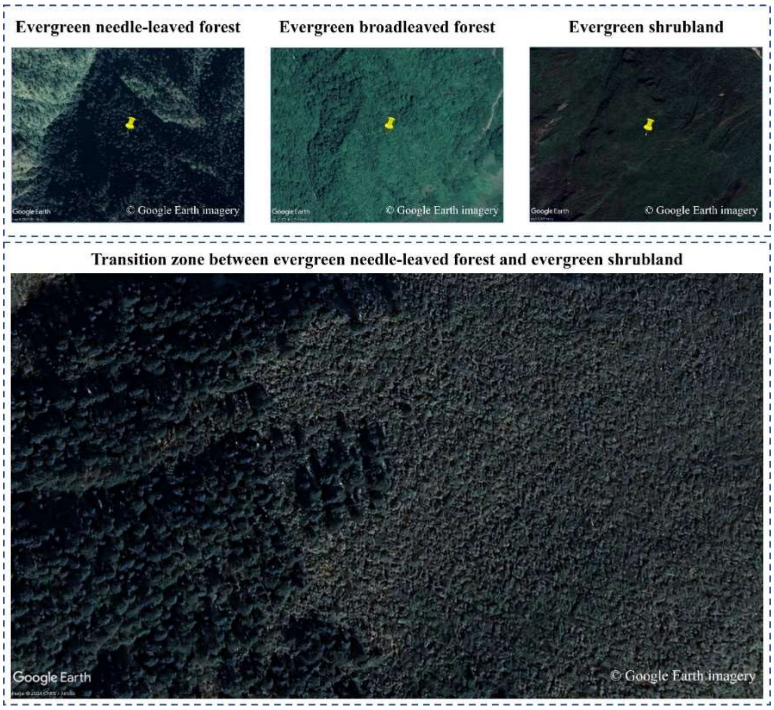

Figure R1 (only for response). Selected examples of auxiliary data derived from Google Earth imagery, including evergreen needle-leaved forest, evergreen broadleaved forest, evergreen shrubland, and transition zone between evergreen needle-leaved forest (left half) and evergreen shrubland (right half).

4. What is the proportion of samples that are directly visually interpreted from Google Earth images, samples using NDVI time series as auxiliary, and samples using only NDVI time series without Google Earth images?

Reply 4:

All samples were interpreted based on Google Earth images, with subsequent verification using NDVI time series as a supplementary measure to ensure stability and detect phenology. No samples are selected using only NDVI time series in our study. We apologize for the unclarity and have revised the text to make it clearer to understand (Lines 158-160), which reads:

All samples were interpreted based on Google Earth images, with subsequent verification using NDVI time series as a supplementary measure to ensure stability and detect phenology.

5. How can you eliminate the impact of land cover changes that may have occurred between 2013 and 2022 on the Landsat time series used in the sample selection?

Reply 5:

As described in Lines 148-150, we utilized Landsat time series to identify changes in land cover, including deforestation, during our stability verification process. The figures provided below illustrate examples of this verification process. Fig. A2(b) depicts a typical NDVI time series of deciduous needle-leaved forest derived from Landsat 7 and Landsat 8, while Fig. A2(a) shows a site where deforestation occurred. Through the stability verification process, sample sites that changed in selected years (2013-2022) are excluded. We have clarified this in our revised manuscript (Lines 155-156), which reads:

By following the steps outlined above, we detected land cover changes during 2013-2022 using Landsat NDVI time series (Fig. A2). This approach helps to avoid selecting sites where land cover change has occurred.

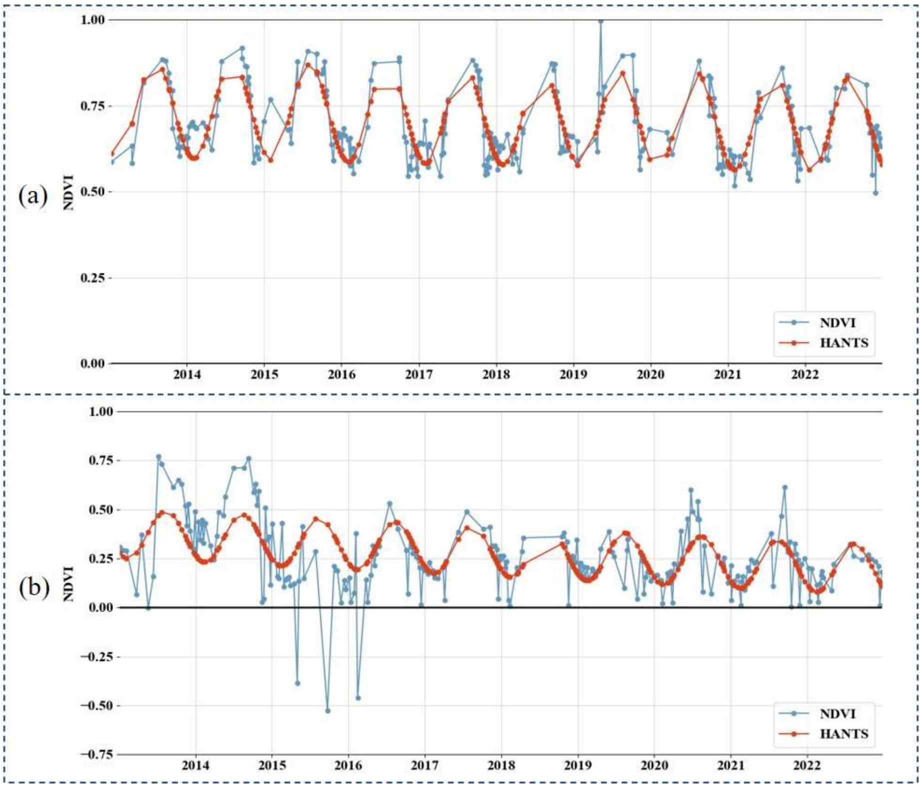

Figure A2. Landsat NDVI time series and HANTS filtered NDVI time series for stability verification. (a) depicts a deciduous needle-leaved forest, (b) shows a transition from forest to farmland at the edge of the deciduous broadleaved forest in 2015, where it was annually cultivated following deforestation.

6. According to Table A2, impervious surfaces or built-up areas are considered as bareland in the classification system. However, I noticed that built-up areas in cities such as Xining and Lhasa are incorrectly classified as cultivated vegetation and other land cover types in your product. I also noticed that the barelands in your training samples do not seem to include built-up area samples.

Reply 6:

Thank you for pointing out the misclassification of built-up areas in some cities as other land cover types in our product. We have added descriptions about why we merged built-up areas and bare land in our classification system (Lines 132-136), which reads:

In this study, we did not specifically select samples of built-up areas and instead categorized bare land together with built-up areas for two primary reasons. Firstly, built-up areas account for only 0.092% of the total area in ESA WorldCover2021, highlighting their relatively small extent compared to other land cover types (Zanaga et al., 2022). Secondly, bare land in our product exhibits spectral characteristics similar to those of built-up areas, resulting in the classification of most built-up areas as bare land (H. Li et al., 2017).

Furthermore, we discussed this issue in our revised manuscript (Lines 266-268), which reads:

In addition , the spectral variations within urban areas have also resulted in substantial uncertainties. Our approach of categorizing built-up areas and bare land may lead to misclassification of urban pixels. To minimize the uncertainties in urban areas on our final map, we applied the ESRI land cover map in 2022 to mask off urban pixels (Karra et al., 2021).

Reference:

Karra, K., Kontgis, C., Statman-Weil, Z., Mazzariello, J. C., Mathis, M., & Brumby, S. P. (2021). Global land use / land cover with Sentinel 2 and deep learning. 2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS, 4704–4707. https://doi.org/10.1109/IGARSS47720.2021.9553499

Li, H., Wang, C., Zhong, C., Su, A., Xiong, C., Wang, J., & Liu, J. (2017). Mapping Urban Bare Land Automatically from Landsat Imagery with a Simple Index. Remote Sensing, 9(3), 249. https://doi.org/10.3390/rs9030249

Zanaga, D., Van De Kerchove, R., Daems, D., De Keersmaecker, W., Brockmann, C., Kirches, G., Wevers, J., Cartus, O., Santoro, M., Fritz, S., Lesiv, M., Herold, M., Tsendbazar, N.-E., Xu, P., Ramoino, F., and Arino, O.: ESA WorldCover 10 m 2021 v200, Zenodo [data set], https://doi.org/10.5281/zenodo.5571936, 2022

7. Lines 159–161. "Interannual" refers to two or more years, but you have only selected images from one year. Did you mean "Annual"?

Reply 7:

Thank you for pointing out this mistake. We have rectified it in our revised manuscript (Line 78).

8. You used almost all bands from Sentinel-2 with four additional indices. The information provided by some of the bands may be duplicated. For example, the wavelengths of B8 and B8A are close. Is it sufficient to use only one of them?

Reply 8:

Thank you for this comment! Using either B8 or B8A alone is adequate to achieve high overall accuracy. However, incorporating B8A brings a minor improvement in the overall accuracy, despite its relatively lower importance in the Random Forest model used in this study. For instance, employing only the B8 band yields an overall accuracy of 86.1%, while incorporating B8A improves it to 86.5%. We have added the explanation of band selection in our revised manuscript (Lines 181-186), which reads:

The selected input bands for Sentinel-2 included B2-B8, B8A, B9, B11, and B12. Among these bands, B2-B8, B11, and B12 have been demonstrated to be effective in *classifying deciduous and coniferous tree species (Immitzer et al., 2016; C. Li et al., 2021). Additionally, B8A is suitable for boreal landscape classification (Abdi, 2020), while B9 values demonstrate differences between bare soil and vegetation-covered areas (Zhao et al., 2023), making them useful for classification purposes. For Sentinel-1 images, utilizing both VV and VH can enhance classification accuracy, leading to their selection as input features (Jacob et al., 2020; Steinhausen et al., 2018).*

Reference:

Abdi, A. M. (2020). Land cover and land use classification performance of machine learning algorithms in a boreal landscape using Sentinel-2 data. Giscience & Remote Sensing, 57(1), 1–20. https://doi.org/10.1080/15481603.2019.1650447

Immitzer, M., Vuolo, F., & Atzberger, C. (2016). First Experience with Sentinel-2 Data for Crop and Tree Species Classifications in Central Europe. Remote Sensing, 8(3), 166. https://doi.org/10.3390/rs8030166

Jacob, A. W., Vicente-Guijalba, F., Lopez-Martinez, C., Lopez-Sanchez, J. M., Litzinger, M., Kristen, H., Mestre-Quereda, A., Ziolkowski, D., Lavalle, M., Notarnicola, C., Suresh, G., Antropov, O., Ge, S., Praks, J., Ban, Y., Pottier, E., Mallorqui Franquet, J. J., Duro, J., & Engdahl, M. E. (2020). Sentinel-1 InSAR Coherence for Land Cover Mapping: A Comparison of Multiple Feature-Based Classifiers. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 13, 535–552. https://doi.org/10.1109/JSTARS.2019.2958847

Li, C., Ma, Z., Wang, L., Yu, W., Tan, D., Gao, B., Feng, Q., Guo, H., & Zhao, Y. (2021). Improving the Accuracy of Land Cover Mapping by Distributing Training Samples. Remote Sensing, 13(22), 4594. https://doi.org/10.3390/rs13224594

Steinhausen, M. J., Wagner, P. D., Narasimhan, B., & Waske, B. (2018). Combining Sentinel-1 and Sentinel-2 data for improved land use and land cover mapping of monsoon regions. International Journal of Applied Earth Observation and Geoinformation, 73, 595–604. https://doi.org/10.1016/j.jag.2018.08.011

Zhao, Y., Lei, S., Zhu, G., Shi, Y., Wang, C., Li, Y., Su, Z., & Wang, W. (2023). An Algorithm to Retrieve Precipitable Water Vapor from Sentinel-2 Data. Remote Sensing, 15(5), 1201. https://doi.org/10.3390/rs15051201

9. In the comparison with other products, these products are from different years. Due to land cover changes, comparison across years will introduce some error. Using validation samples in 2022 is also unfair to products of other years. These issues need to be discussed.

Reply 9:

Thank you. Our samples remain stable from 2013 to 2022, as explained in Reply 5. These consistent validation samples can be utilized to assess the accuracy of various land cover products spanning the years from 2013 to 2022. We have added additional description in revised text (Lines 294-297), which reads:

The land cover samples selected remained stable encompassing the years from 2013 to 2022 for all the other 4 land cover products, thus making them comparable to our TP_LC10-2022 map. Therefore, we validated the aggregation of samples into 8 categories and assessed the performance of TP_LC10-2022 and the 4 other land cover products in the TP region, as depicted in Table 5.

10. Are there plans to update the product annually or any other future research plans?

Reply 10:

Yes, we have been producing land cover maps of the TP using Sentinel-2 imagery over the past few years, and we are updating the available samples in 2023, which will be available online soon. Please keep an eye on our data portal, where we are currently hosting *TP_LC10-2022 product*: *https://doi.org/10.5281/zenodo.8214981*

11. Table 1, VV and VH are backscatter coefficients, not reflectivities. And it needs to be clarified with the direction of transmission and reception.

Reply 11:

Thank you for the correction. We have revised the mistake and clarified the direction and transmission in the revision. To be clearer, we also added the orbit parameter of the Sentinel-1 satellite in Table 2.

12. Typo in table 2, "DNSI" -> "NDSI".

Reply 12:

Thank you for the correction, we have updated the table in our revised manuscript.