Dear Editor and Reviewers,

We revised the manuscript in accordance with the editor and reviewers' comments and carefully proofread the manuscript to minimize typographical, grammatical, and bibliography errors. Here below is our point-by-point reply to the comments. The point-to-point responses to your comments are listed below in blue, and the specific revised contents are indicated in bold blue italics.

Reply to the editor:

Thank you for submitting the revision! We have received comments and suggestions from the referees, who were all positive with the value of the dataset but still think that the manuscript can be further improved. I would like to draw your attention on the following:

Point 1： Please carefully check the formats, such as dates, measure unites, etc. Also, make sure the acronyms are correctly used and defined at the first time of their occurrences.

Response: Thank you for your comments. As you suggested, we have rechecked all the date formats, as well as the units of measurement. In the revised version, we have given the acronyms their full names when they first appear. For specific changes, please refer to the revised version with change tracks.

Point 2： There are still grammar issues and ill-expressions in the manuscript. The referee made specific suggestions on many of them. I would also encourage the authors to carefully check them and possibly seek help from language professions.

Response: Thank you for your comments. Based on your suggestions, we have corrected the grammatical issues point by point, as requested by the reviewer. In addition, we have carefully checked and revised the entire manuscript for grammar issues and ill-expressions. For specific changes, please refer to the revised version with change tracks.

Point 3： Considering reclassifying the grassland types as the referee commented if you think it would be needed.

Response: Thank you for your comments. Based on your suggestions, we have reclassified the grassland types. Moreover, the grassland types in the text and diagrams were modified

accordingly in the revised version. For specific changes, please refer to the revised version with change tracks.

Point 4： Considering further explain how the BELT mode images were used.

Response: Thank you for your comment. We only used BELT flight mode to help data collection during the field experiment so that the ground staff could quickly and evenly place sampling quadrats to ensure the GRID photos could easily capture them. In this study, the photos from BELT were not used. We mentioned BELT mode to describe the process of ground biomass sampling.

The necessary explanations were given in both the data processing (2.4.1) and model construction (2.5.2) sections to avoid confusion. We also discussed why we did not use BELT photographs in Section 4.3.

Point 5： I would encourage the authors to revise the manuscript accordingly and submit it for consideration of publication.

Response: We would like to express our sincere gratitude for your valuable advice.

Reply to reviewer#1:

Thanks for the authors efforts of this revision. Most of my concerns has been answered and revised. I still have one question. In Section 2.3.2 synchronization experiment of UAV and field sampling, Line 146-148, page 8, The authors mentioned three waypoints were randomly selected from the GRID mode to set the BELT flight mode. I still didn't see how these BELT mode images were used in the modeling process and final validation results. The authors can give a further explanation because the UAV images have two spatial scales and what's their roles or relationship is not very clear.

Response: Thank you for your comments. **As you said, the photos obtained from the BELT flight mode were not used to construct/validate the grassland AGB model in this paper.**

We only used BELT flight mode to help data collection during the field experiment so that the ground staff could quickly and evenly place sampling quadrats to ensure the GRID photos could easily capture them. In this study, the photos from BELT were not used. We mentioned BELT mode to describe the process of ground biomass sampling.

The necessary explanations were given in both the data processing (2.4.1) and model construction (2.5.2) sections to avoid confusion.

Lines 155-157:

"2.4.1 UAV photo pre-processing and indices calculation

Pre-processing of UAV photos included image quality inspection, cropping, and calculation of different indices. *It should be noted that only UAV photos at 20 m height were used in this paper.* "

Lines 218-221:

"2.5.2 AGB RF estimation model at the quadrat scale (0.25 m²)

Since the spatial coverage of a 20-meter-high UAV photo (26 m × 35 m) is much larger than a

single 2-meter-high UAV photo (0.8 m × 1 m), making it easier to match the MODIS pixel scale (250 m × 250 m). Hence, the 20-meter-high UAV photos containing the sample quadrats were chosen for constructing the quadrat-scale AGB estimation model."

In addition, we also discussed why we did not use BELT photographs in Section 4.3 (Lines 385-392):

"4.3 Comparison of the estimated AGB with previous studies

We compared our results with previous studies at the quadrat, pixel, and regional scales. *At the quadrat scale, consistent with our previous study, we further confirmed that the UAV RGB photos could be used to estimate grassland AGB (Zhang et al., 2022a; Zhang et al., 2018). Similar to the 2-meter-high UAV photo, the indices from the 20-meter-high UAV photo could be used to estimate the grassland AGB at the quadrat scale (R^2 = 0.73, RMSE = 44.23 g·m^{-2}, Figure 6a). Compared with the 2-meter-high UAV photo (0.8 m × 1 m), the 20-meter-high UAV photo is more suitable for matching the MODIS pixel due to its larger spatial coverage area (26 m × 35 m). In addition, the direct use of a 20-meter-high photo eliminates the need to consider spatial scale conversions when upscaling the AGB estimation from the quadrat scale to the photo scale."*

Reply to reviewer#2:

Comments for ESSD-2022-210

This manuscript attempts to propose a novel model to fill the gap among filed harvested AGB, UVA photos and MOIDS images. With the application of the novel model, the AGB in whole QTP was projected from 2000 to 2019. Moreover, the spatial-temporal pattern was also analyzed. The results of this manuscript can provide a baseline for further studies which focus on the estimation of AGB in QTP. But, there still are some issues in the revised manuscript. The suggestions and comments are as follows.

Response: We appreciate your insightful comments on our paper. The comments provided have been extremely helpful to us. We have revised the manuscript in response to your comments and carefully proofread the manuscript to minimize typographical, grammatical, and bibliography errors. The point-to-point responses to your comments are listed below in blue, and the specific revised contents are indicated in bold blue italics.

Point 1. P2, lines 36-37 and P34, line 639, the initial letter of the author's family name should be Ó.

Response: Thank you for your comments. As you suggested, we have modified "O'" into "Ó" in the revised version (Lines 35-37):

"Grasslands, accounting for approximately 37% of the earth's surface, play an essential role in global carbon cycling and food supply (***Ómara***, 2012). However, most natural grasslands have been degraded to a certain extent due to overgrazing, farmland encroachment, soil erosion, and global climate change (Suttie et al., 2005; Ramankutty et al., 2008; ***Ómara***, 2012)."

Point 2. P2, line 38, insert "of livestock" after "sustainable development"

Response: Thank you for your comments. As you suggested, we have inserted "of livestock" after "sustainable development" and changed it to (Lines 38-39):

"Therefore, timely monitoring of grassland health is crucial for the sustainable development *of livestock* and understanding of the global carbon cycle."

Point 3. P2, line 44, insert "sensors" after "satellites", because sentinel, landsat and modis are sensors. Satellite is a general term.

Response: Thank you for your comments. As you suggested, we have inserted "sensors" after "satellites" and changed it to (Lines 43-45):

"Spectral information from different satellite *sensors* has been employed for biomass estimation, such as Sentinel-2, Landsat, and MODIS (Wang et al., 2019; Zhang et al., 2016)."

Point 4. P2, line 57, insert "images" after satellites

Response: Thank you for your comments. As you suggested, we have inserted "images" after "satellites" in the revised version (Lines 57-58):

"In addition, fine-resolution satellite *images* were used as a bridge to reduce the impact of scale mismatch on AGB estimation (Yu et al., 2021; He et al., 2019)."

Point 5. P2, lines 58-59, change "the satellite resolution" to "the resolution of satellite image"

Response: Thank you for your comments. As you suggested, we have changed "the satellite resolution" to "the resolution of satellite image" in the revised version (Lines 58-60):

"The rationale is that the finer *the resolution of satellite image*, the smaller the spatial gap with the ground samples (Wang and Sun, 2014; Morais et al., 2021)."

Point 6. P2, line 60, change "satellite" to "satellited"

Response: Thank you for your comments. As you suggested, we have changed "satellite" to "satellited" (Lines 60-61):

"Therefore, filling the spatial gap between satellite pixels and ground samples is the key to improving the accuracy of *satellited* AGB estimation."

Point 7. P2, lines 59-60, maybe "therefore, retrieving fine-resolution satellite images that match the filed samples is key to improving the accuracy of satellited AGB estimation" is better, because whole this paragraph is mainly talking about the satellite's images.

Response: Thank you for your comments. In this sentence, we wanted to express that the smaller the spatial gap between ground samples and satellite pixels, the more beneficial it is to improve the accuracy of satellited AGB estimation. To avoid confusion, we modified the sentence to (Lines 60-61):

"Therefore, ***filling the spatial gap between ground samples and satellite pixels is the key*** to improving the accuracy of satellited AGB estimation."

Point 8. P2, line 63, listing the author (Yang et al.) is not suggested in this sentence. In order to respond the above sentence, maybe "five years and ?? labors were spent in completing the collection…." is better.

Response: Thank you for your comments. As you suggested, we have modified this sentence in the revised version as follows (Lines 64-65):

"For example, ***five years were spent in completing the collection*** of ground samples to retrieve the grassland AGB in China (Yang et al., 2010)."

Point 9. P2, line 65, change "expand the sample size" to "increase the sample amount", because the size of field sampling is fixed (as shown in line 52, 0.5 × 0.5 m or 1 × 1m).

Response: Thank you for your comments. As you suggested, we changed "expand the sample size" to "increase the sample amount" in the revised version (Lines 65-67):

"Moreover, with limited original ground data, some scholars had to use the data published by others to ***increase the sample amount*** (Xia et al., 2018; Jiao et al., 2017)."

Point 10. P3, line 67, does the author means quadrat size, plot size and harvested methods?

Response: Thank you for your comments. As you suggested, we changed the sentence as follows (Lines 67-68):

"However, datasets from different sources may affect the overall accuracy due to the differences *in quadrat size, plot size, and harvesting methods*."

Point 11. P3, lines 69-70, change this sentence to "as a linkage/bridge between filed observation and satellites detecting for grassland biomass, the development and popularity of unmanned aerial vehicle (UAV) technology has provided a new solution to the abovementioned two issues".

Response: Thank you for your comments. As you suggested, we revised the sentence as follows (Lines 70-71):

"*As a linkage/bridge between field observation and satellites detecting for grassland biomass, the development and popularity of unmanned aerial vehicle (UAV) technology has provided a new solution to the abovementioned two issues*."

Point 12. P3, line 70, give the full name of FVC, because it was addressed in the body for the first time.

Response: Thank you for your comments. As you suggested, we have inserted the full name of FVC in the revised version (Lines 71-73):

"UAV photograph has been successfully used to estimate ecological metrics such as *fractional vegetation cover* (FVC), biomass, and canopy height (Chen et al., 2016; Zhang et al., 2018; Bendig et al., 2015)."

Point 13: P3, line 70, 75, change "UAV images" to "UAV photograph"

Response: Thank you for your comments. As you suggested, we have changed "UAV images" to

"UAV photograph" in the revised version (Lines 71-73):

"***UAV photograph*** has been successfully used to estimate ecological metrics such as fractional vegetation cover (FVC), biomass, and canopy height (Chen et al., 2016; Zhang et al., 2018; Bendig et al., 2015)."

Point 14: P3, line 71, insert "two" after "following"

Response: Thank you for your comments. As you suggested, we have inserted "two" after "following" in the revised version (Lines 73-74):

"The use of UAVs has the following ***two*** unparalleled advantages over traditional sampling methods."

Point 15: P3, line 76, change "small-scale, with few regional-scale studies" to "conducted on a small scale, but few studies on a regional scale".

Response: Thank you for your comments. As you suggested, we have changed "small-scale, with few regional-scale studies" to "conducted on a small scale, but few studies on a regional scale" in the revised version (Lines 78-79):

"However, most current UAV-based grassland biomass estimations are ***conducted on a small scale, but few studies on a regional scale***."

Point 16: P P3, line 77, 84, gap cannot be reduced, only can be filled. So, change "reduce" to "fill".

Response: Thank you for your comments. As you suggested, we have changed "reduce" to "fill" in the revised version (Lines 79-80):

"Whether UAVs can be used to ***fill*** the spatial gap between traditional ground sampling and satellite pixels remains an open question."

Lines 85-87:

Point 17: P3, line 78, change this sentence to "there is short of multi-years validation…due to the limited sample amount in previous studies"

Response: Thank you for your comments. As you suggested, we have modified the sentence as follows (Lines 80-81):

Point 18: P3, line 81-82, change this sentence to "….combining traditional ground sampling, UAV photograph, and satellite image to produce…..".

Response: Thank you for your comments. As you suggested, we have modified the sentence as follows (Lines 83-84):

Point 19: P3, line 85, insert "estimation" after "AGB", and delete "Qinghai-Tibetan Plateau" and "()".

Response: Thank you for your comments. As you suggested, we have modified the sentence as follows (Lines 85-88):

Point 20: P3, line 92, delete "of China".

Response: Thank you for your comments. As you suggested, we have modified the sentence as follows (Lines 95-96):

"In this study, *the boundary of the QTP* (Zhang et al., 2014) was downloaded from the National Earth System Science Data Center, National Science & Technology Infrastructure of China (http://www.geodata.cn)."

Point 21: P3, line 94, change "Grassland type data was" to "Grassland types were", and insert a blank after Colon.

Response: Thank you for your comments. As you suggested, we have changed "Grassland type data was" to "Grassland types were" in the revised version (Lines 96-98):

"*Grassland types were* derived from the *1: 1000000* Chinese digital grassland classification map provided by the China Resource and Environmental Science and Data Center (https://www.resdc.cn/)."

Point 22: P3, line 95, delete the blank between "data" and "set".

Response: Thank you for your comments. We have deleted the blank between "data" and "set" as you suggested (Lines 98-99):.

"This *dataset*, generated through field surveys in the 1980s and supplemented by satellite and aerial imagery, is the most detailed grassland-type map available."

Point 23: P4, line 97, other grassland types map? Change "combined" to "regrouped"

P4, line 98, change "resampled to 250 m" to "resampled this regrouped vector to grid with 250 m spatial resolution".

Response: Thank you for your comments. As you suggested, we have modified the sentence as follows (Lines 99-101):

"To facilitate comparison with others' AGB estimates, we *regrouped* the grassland types into three categories: meadow, steppe, and desert, and *resampled this regrouped vector to a grid with 250 m spatial resolution* (Table A1)."

Point 24: P4, figure 1, in the map, if you use the Graticule, please do not insert a north arrow, which both indicate the direction.

Response: Thank you for your comments. As you suggested, we have removed the north arrow in Figure 1 (P4, Lines 101-105). In addition, we have removed the north arrows in Figure 8 (P18, Lines 340-345) and Figure 10 (P19, Lines 350-353) in the revised version.
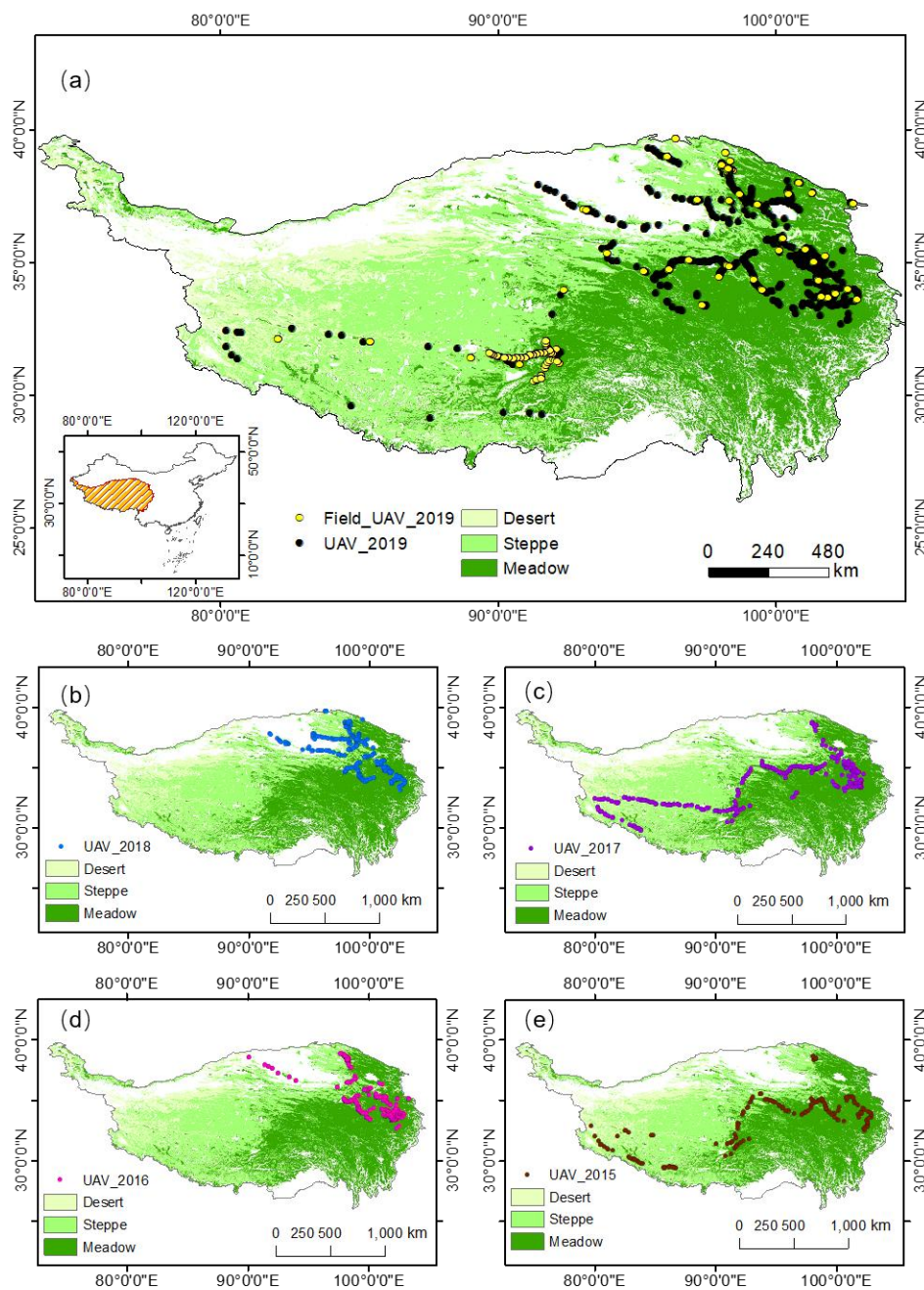

Figure 1. Distribution of field and UAV sampling sites in 2019 (a); UAV sampling sites in alpine grasslands on the QTP from 2015-2018 (b-e). Field_UAV_2019 represents the quadrat-scale

sampling sites for the 2019 UAV-Field synchronous grassland biomass experiment. UAV_year represents the UAV sampling point based on the GRID or RECTANGE mode of the corresponding year.
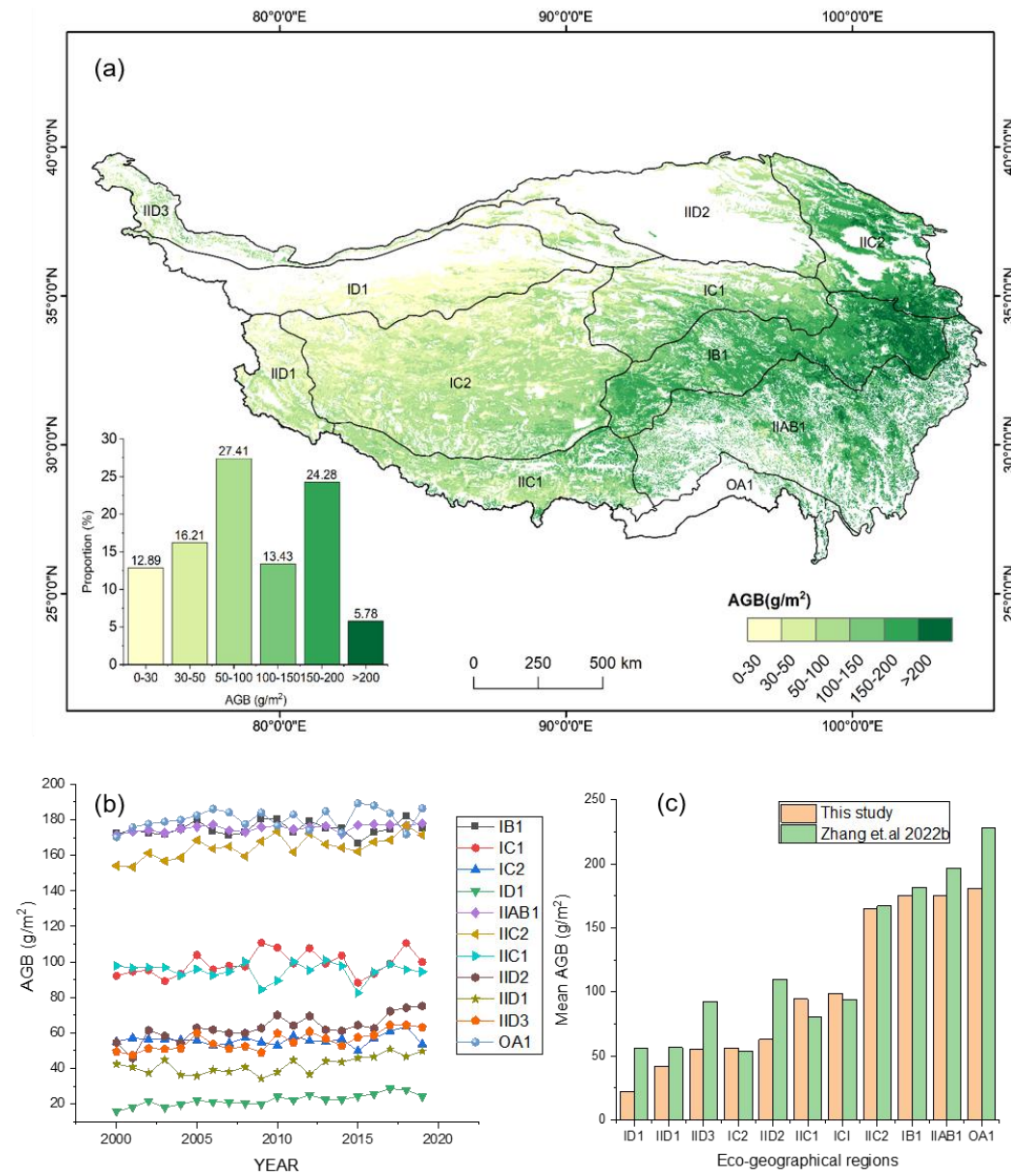

Figure 8. (a) The spatial distribution of average grassland AGB on the QTP from 2000 to 2019. IID1, IID2, IID3, ID, IIC1, IIC2, IC1, IB1 IIAB1, and OA1 are the eco-geographical regions of the QTP(Zheng, 1996). The full names of each eco-geographical region were listed in Table A5. (b) AGB values of each eco-geographical region from 2000 to 2019. (c) Comparison of multi-year AGB averages in the different eco-geographical regions.
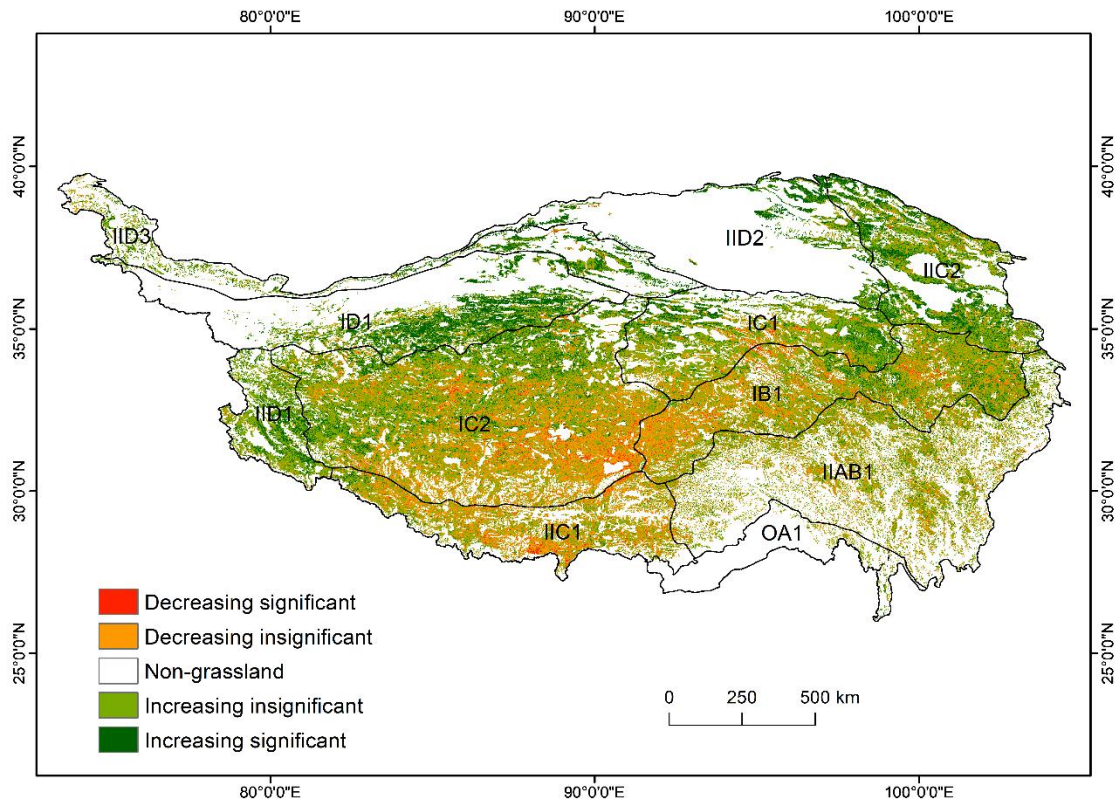
Figure 10. Spatial trends of grassland AGB on the QTP from 2000 to 2019. IID1, IID2, IID3, ID, IIC1, IIC2, IC1, IB1 IIAB1, and OA1 are the eco-geographical regions of the QTP (Zheng, 1996). The full names of each eco-geographical region were listed in Table A5.

Point 25: P4, line 105; P5, line 106, insert "(250 m)" after "MODIS pixel scale", because there is other spatial resolution for MODIS images, such as 500 m, 1 km et al.

Response: Thank you for your comments. As you suggested, we have inserted "(250 m)" after "MODIS pixel scale" in the revised version (Lines 108-109):

"3) upscaling the grassland AGB to the MODIS pixel scale *(250 m)*; 4) building the AGB estimation model at the MODIS pixel scale *(250 m)* and applying it to the QTP region."

Point 26: P5, figure 2, the color sub-figures (AGB values at MODIS pixel-scale and AGB values at photo-scale) were placed at the inverse location. Because it is an upscaling from photo-scale to MODIS pixel-scale. Moreover, please pay more attention to the terms used in this figure, such as "clip" and "average", maybe the "split" and "merge" are more suitable , please see the difference between "clip" and "split", which was addressed in the help document in ArcMap
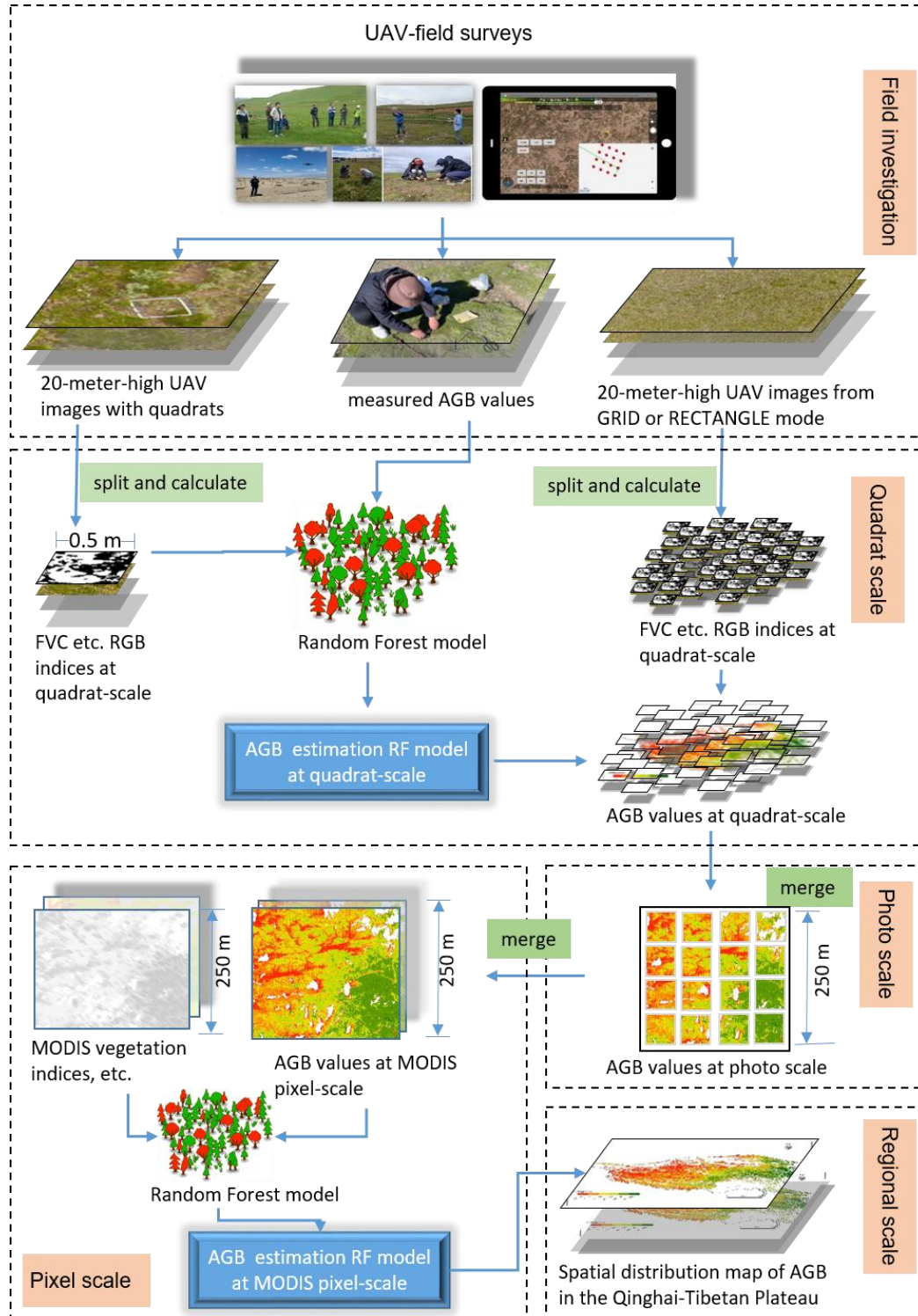
Figure 2. The overall flowchart of UAV field survey and the construction of grassland AGB estimation models at different spatial scales.

Point 27: P6, line 124, change "reliable" to "sufficient".

Response: Thank you for your comments. As you suggested, we have changed "reliable" to "sufficient" in the revised version (Lines 125-127):

"Over 2,000 fixed flight routes were set up during this period, and more than 40,000 UAV photos were collected, providing a *sufficient* dataset for this study (Table 1)."

Point 28: Table 1, suggest change the format of date listed in the column "Acquistition time", change dot format to forward slash. And, change "Acquistition time" to "Acquistition date", change "routes" to "route".

Response: Thank you for your comments. As you suggested, we have modified Table 1 as follows (Line 129):

Table 1. UAV sampling information from 2015 to 2019

Year	Flight Mode	*Number of route*	Photo number	*Acquisition date*
2015	RECTANGLE	214	2568	*7/05 ~ 8/24*
2016	RECTANGLE	334	4008	*6/20 ~ 9/29*
	GRID	150	2400	*6/20 ~ 9/23*
2017	RECTANGLE	315	3780	*5/10 ~ 10/24*
	GRID	322	5152	*7/15 ~ 8/22*
2018	RECTANGLE	79	948	*7/22 ~ 8/03*
	GRID	303	4848	*7/04 ~ 8/29*
2019	GRID	885	14160	*7/12 ~ 9/21*
	BELT	151	2416	*7/12 ~ 9/21*
Total		2753	40280	

Point 29: Table 1, in the next paragraph and figure 3, the GRID and BELT modes were applied in your research, but in this table, the RECTANGLE and GRID modes were listed in the column "Flight Mode". Please check and correct this issue.

Response: Thank you for your comments. As you suggested, we have added the information of BELT mode in the revised version (Line 129).

Table 1. UAV sampling information from 2015 to 2019

Year	Flight Mode	Number of route	Photo number	Acquisition date
2015	RECTANGLE	214	2568	7/05 ~ 8/24
2016	RECTANGLE	334	4008	6/20 ~ 9/29
	GRID	150	2400	6/20 ~ 9/23
2017	RECTANGLE	315	3780	5/10 ~ 10/24
	GRID	322	5152	7/15 ~ 8/22
2018	RECTANGLE	79	948	7/22 ~ 8/03
	GRID	303	4848	7/04 ~ 8/29
2019	GRID	885	14160	7/12 ~ 9/21
	BELT	*151*	*2416*	*7/12 ~ 9/21*
Total		*2753*	*40280*	

Point 30: P6, line 128, change "commonly" to "widely".

Response: Thank you for your comments. As you suggested, we have changed "commonly" to "widely" in the revised version (Line 131):

"GRID, RECTANGLE, and BELT are the most *widely* used flight modes in the FragMap software."

Point 31: P7, line 133, change "Typically" to "Normally".

Response: Thank you for your comments. As you suggested, we have changed "Typically" to

"Normally" in the revised version (Lines 135-136):

"***Normally***, the BELT size is set to 40 m × 40 m, and the flying height and speed are set to 2 m and 1 m/s to ensure that field crews have enough time to place sampling quadrats under the UAV waypoints."

Point 32: P7, line 134; P8, lines 147-148, 155, change "frame" and "frames" to "quadrat" and "quadrats", respectively.

Response: Thank you for your comments. As you suggested, we have changed "frame" and "frames" to "quadrat" and "quadrats", respectively (Lines 135-136):

"Normally, the BELT size is set to 40 m × 40 m, and the flying height and speed are set to 2 m and 1 m/s to ensure that field crews have enough time to place sampling ***quadrats*** under the UAV waypoints."

Lines 149-150:

"For each BELT, a sampling ***quadrat*** (0.5 m × 0.5 m) was placed at its 6, 7, 10, and 11 waypoints to ensure that the GRID image could contain the four abovementioned ***quadrats*** (Figure 3b-c)."

Point 33: P7, line 135, delete "flight".

Response: Thank you for your comments. As you suggested, we have deleted "flight" in the revised version (Lines 138-140):

"Compared with the ***MOSAIC mode*** (which requires a guaranteed overlap rate between photos to obtain a full view of an area), our design is more in line with the traditional ecological sampling concept and more conducive to rapid sample collection."

Point 34: Figure 3, suggest label the length and width for all the sub-figures (a-f). in figure 3, sub-figures (a, b) only label the length, and sub-figures (e, f) only label the width. However, sub-figure (c) both label the length and width, sub-figure (d) both miss the labels of length and

width. Meanwhile, the authors can label the height at the bottom of each sub-figure like c-f.

Response: Thank you for your comments. As you suggested, we have modified Figure 3 in the revised version (Lines 141-144):
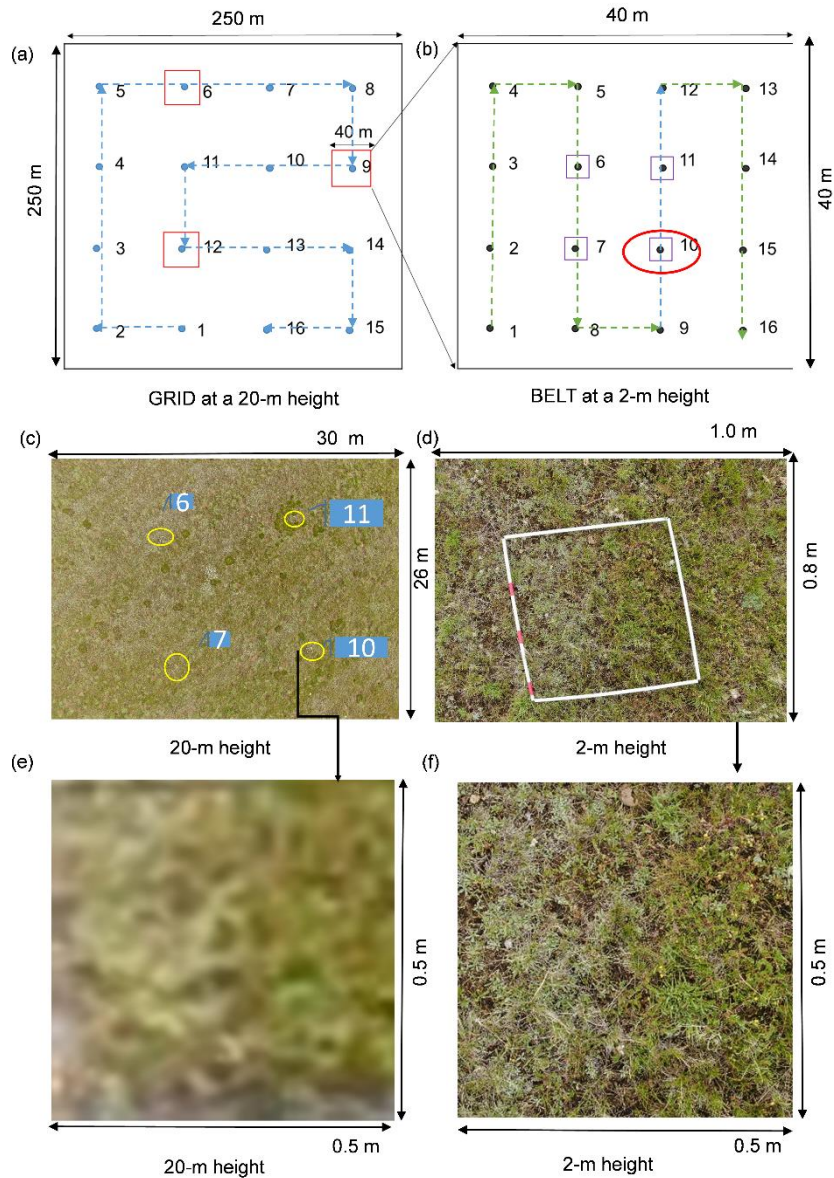

Figure 3. Schematic diagram of the UAV-field synchronization experiment in 2019: a combination design of GRID (a) and BELT (b) flight modes; a UAV photo with a quadrat from the BELT mode at the height of 2 m (d); a 20-meter-high UAV photo including four sample quadrats (c); and the cropped UAV photos at quadrat scale from 20 m (e) and 2 m (f) height, respectively.

Point 35: P8, line 144, change "designed" to "conducted".

Response: Thank you for your comments. As you suggested, we have changed "designed" to

"conducted" in the revised version (Lines 146-147):

"A UAV-field biomass synchronization experiment was ***conducted*** in 2019 to ensure spatial matching among satellites, UAVs, and ground sampling (Figure 3)."

Point 36: P8, line 145, change "implementation" to "four".

Response: Thank you for your comments. As you suggested, we have changed "implementation" to "four" in the revised version (Line 147):

"The specific ***four*** steps were as follows."

Point 37: P8, line 146, "three waypoints were randomly selected.", but seen from the figure 3a, the waypoints were regularly selected (points6, 9, 12). Insert "flight" before "mode".

Response: Thank you for your comments. As you suggested, we have deleted "randomly" from the sentence, and inserted "flight" before "mode" in the revised version (Lines 148-149):

"Secondly***, three waypoints were selected*** from the GRID ***flight*** mode to set the BELT flight modes (40 m × 40 m)."

Point 38: P8, line 148, change "four frames mentioned above" to "four abovementioned quadrats".

Response: Thank you for your comments. As you suggested, we have changed "four frames mentioned above" to "four abovementioned quadrats" in the revised version (Lines 149-150):

"For each BELT, a sampling quadrat (0.5 m × 0.5 m) was placed at its 6, 7, 10, and 11 waypoints to ensure that the GRID photo could contain the ***four abovementioned quadrats*** (Figure 3b-c)."

Point 39: P8, lines 148-149, change "at the end of all flights" to "after the implementation of all fights".

Response: Thank you for your comments. As you suggested, we have changed "at the end of all flights" to "after the implementation of all fights" in the revised version (Lines 150-151):

"Thirdly, *after the implementation of all fights*, the grassland samples were cut, bagged, and numbered."

Point 40: P8, line 149, delete "AGB".

Response: Thank you for your comment. As you suggested, we have deleted "AGB" from the sentence (Lines 150-151):

"Thirdly, after the implementation of all fights, *the grassland samples* were cut, bagged, and numbered."

Point 41: P8, line 158, delete "vegetation".

Response: Thank you for your comment. As you suggested, we have deleted "vegetation" from the sentence in the revised version (Lines 160-161):

"In addition, 30 other *RGB indices* were added as candidate independent variables."

Point 42: P8, line 162, what does inversion mean? Maybe "detecting" is more suitable.

Response: Thank you for your comment. As you suggested, we have changed "inversion" to "detecting" in the revised version (Lines 163-164):

"The MOD13Q1(v006) product was downloaded from the National Aeronautics and Space Administration (NASA) earth explorer website (https://earthexplorer.usgs.gov/) for *detecting* the alpine grassland AGB on the QTP."

Point 43: P8, line 165, change "stitched" to "mosaiced".

Response: Thank you for your comment. As you suggested, we have changed "stitched" to "mosaiced" in the revised version (Line 167):

"Then, the MODIS images were reprojected and *mosaiced* using the MODIS Projection Tool

(MRT).”

Point 44: P8, line 165, does "corresponding vegetation indices" mean both the NDVI and EVI were used in your research? If so, how do the authors overcome the difference between NDVI and EVI?

Response: Thank you for your comments. As you said, both the NDVI and EVI were used in the paper. Since MOD13Q1 provides both NDVI and EVI, there is no time difference between the two indices. Compared with NDVI, EVI can reduce the influence of the vegetation background signal and atmosphere to overcome the saturation and soil noise problems of NDVI. It is useful in estimating the grassland AGB of the QTP. Therefore, both indices were employed in our study.

Point 45: P8, line 166, change "time" to "date". Because time includes the hour, minute and second.

Response: Thank you for your comments. As you suggested, we have changed "time" to "date" in the revised version (Lines 167-169):

"After that, the corresponding vegetation indices closest to the ***date*** of the UAV sampling were extracted to construct/validate the MODIS pixel-scale AGB estimation model."

Point 46: P8, line 167, delete "index".

Response: Thank you for your comments. As you suggested, we have deleted "index" from the sentence in the revised version (Lines 169-170):

"In addition, the ***kNDVI*** was calculated to overcome the NDVI saturation issue based on the equation kNDVI = TANH (NDVI^2) (Camps-Valls et al., 2021)."

Point 47: P8-P9, lines 173-174, why not abbreviate the three meteorological factors as MAT (mean annual temperature), MAP (mean annual precipitation) and TASR (total annual solar radiation)? Actually, these three abbreviations are widely used in a lot of literatures.

Response: Thank you for your comments. We have modified the three meteorological factors as you suggested in the revised version (Lines 175-177):

"Meteorological factors, including mean annual temperature *(MAT)*, mean annual precipitation *(MAP)*, and total annual solar radiation *(TASR)*, were calculated based on the daily meteorological dataset from the National Meteorological Information Center of China (http://data.cma.cn/)."

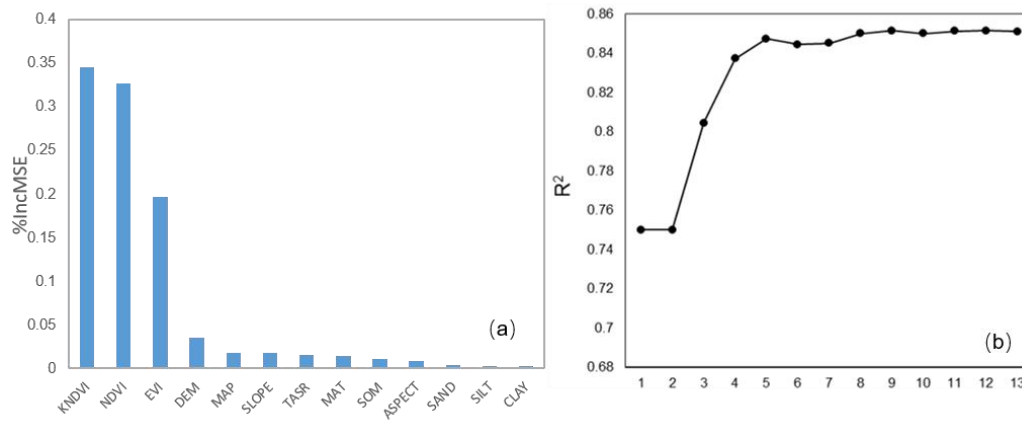Moreover, we also have modified the three abovementioned abbreviations in Figure A3:

Figure A3. The importance values for each independent variable (a) and the R^2 results of the different number of input variables at the MODIS pixel scale.

Point 48: P9, line 175, insert the hyperlink address of website (http://data.cma.cn) after "China".

Response: Thank you for your comments. We have inserted the hyperlink address of the website (http://data.cma.cn) after "China" in the revised version (Lines 175-177):

"Meteorological factors, including mean annual temperature (MAT), mean annual precipitation (MAP), and total annual solar radiation (TASR), were calculated based on the daily meteorological dataset from the National Meteorological Information Center of China *(http://data.cma.cn/)*."

Point 49: P9, line 176, because the original meteorological datasets are stored with points attached

with attributes. So, checking and eliminating the anomalous values of attributes is the first step. Summing the daily values of precipitation and temperature to calculate the annual precipitation and annual temperature is the second step. Averaging the annual temperature to calculate mean annual temperature is the third step. Using the interpolation method to project the raster datasets is the last step. So, interpolation is the last step. It should be placed after averaging.

Response: Thank you for your comments. As you suggested, we have updated and reordered the processing steps as follows (Lines 177-179):

"The data processing steps mainly included ***checking and eliminating the anomalous values of attributes, cumulative summation, annual averaging, and interpolation*** to obtain a meteorological raster dataset with a spatial resolution of 1 km (Li et al., 2021)."

Point 50: P9, Line 177, change "1000 meters" to "1 km".

Response: Thank you for your comments. As you suggested, we have changed "1000 meters" to "1 km" in the revised version (Lines 177-179):

"The data processing steps mainly included checking and eliminating the anomalous values of attributes, cumulative summation, annual averaging, and interpolation to obtain a meteorological raster dataset with a spatial resolution of ***1 km*** (Li et al., 2021)."

Point 51: P9, line 179, insert "raster" before "datasets" and change "resampled" to "regridded". Please give out the version and company of software.

Response: Thank you for your comments. As you suggested, we have inserted "raster" before "datasets" and changed "resampled" to "regridded". In addition, we have added the version and company of the ArcGIS software in the revised version (Lines 181-183):

"All the meteorological and soil ***raster*** datasets were ***regridded*** into 250 m by ArcGIS software ***(Version 10.2, Environmental Systems Research Institute, Inc.)*** to match the MODIS image."

Point 52: P9, line 180, change "data" to "image".

Response: Thank you for your comments. As you suggested, we have changed "data" to "image" in the revised version (Lines 181-183):

"All the meteorological and soil raster datasets were regridded into 250 m by ArcGIS software (Version 10.2, Environmental Systems Research Institute, Inc.) to match the MODIS *image*."

Point 53: P9, line 182, change "digital elevation model (DEM)" to "altitude". So, this sentence can be modified with "Terrain factors including altitude, slope and aspect, were derived from digital elevation model (DEM) using the terrain analysis tool of Arc GIS software".

Response: Thank you for your comments. As you suggested, we have modified the sentence as follows (Lines 185-186):

"*Terrain factors including altitude, slope, and aspect, were derived from the digital elevation model (DEM) using the terrain analysis tool of ArcGIS software.*"

Point 54: P9, lines 182-183, change "derived" to "retrieved", and change "resampled" to "".

Response: Thank you for your comments. As you suggested, we have changed "derived" to "retrieved", and changed "resampled" to "regridded" in the revised version (Lines 186-187):

"The DEM was *retrieved* from Shuttle Radar Topography Mission (SRTM) imagery (version 004, 90 m) and *regridded* to 250 m."

Point 55: P9, lines 183-184, delete this sentence.

Response: Thank you for your comments. We have removed "The slope and aspect data were derived from DEM data using the terrain analysis tool of ArcGIS software." in the revised version.

Point 56: P9, line 186, change "satellite" to "MODIS".

Response: Thank you for your comments. We have changed "satellite" to "MODIS" in the revised version (Lines 189-190):

"We estimated the grassland AGB at three scales: the quadrat scale, the photo scale, and the *MODIS* pixel scale (Figure 4)."

Point 57: Figure 4, give out the length of quadrat; change "Satellite Pixel" to "MODIS pixel"; the grid covering on the photo is not same, which may be caused by the different distance among vertical lines; the photos were not aligned in one line at vertical line and horizontal line; please rename the three steps, the authors can use the gerund as the starting for a phrase, for example, Step1: harvesting grassland AGB at quadrat scale; Step 2: merging the quadrats at photo scale; Step 3: merging the photos at MODIS pixel scale; place a note of "a MODIS pixel includes 16 UAV photos" at the bottom of sub-figure of MODIS pixel scale; "about" and "~" are the same meaning. Delete the aircraft photo and its dash lines and notes, et al. in the sub-figure of MODIS pixel scale.

Response: Thank you for your comments. As you suggested, we have modified Figure 4 as follows (Lines 191-192):
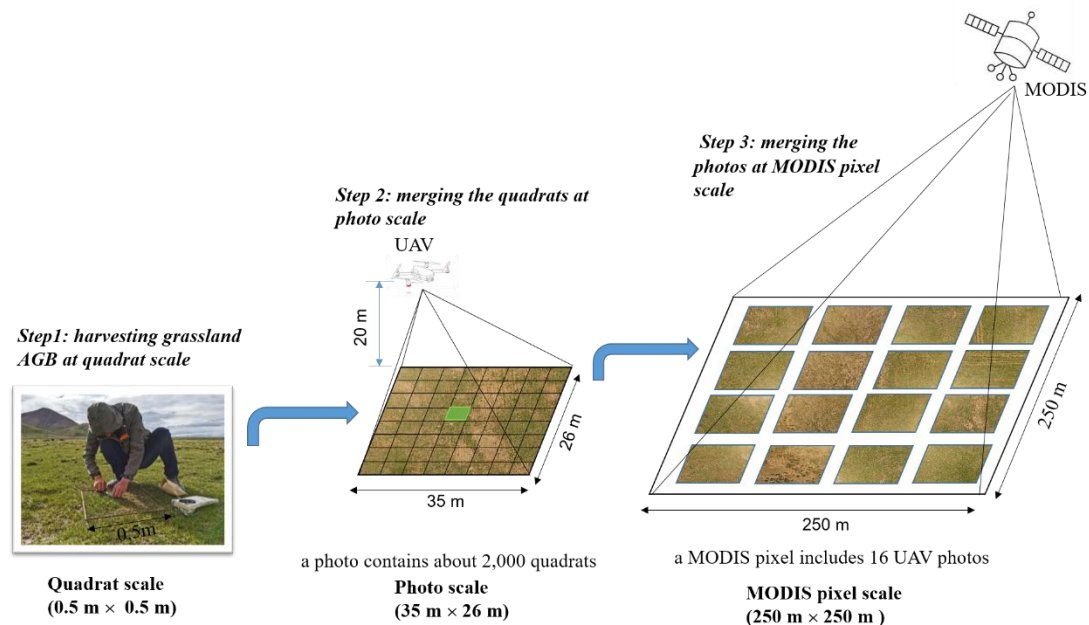
"

Figure 4. Upscaling steps to estimate grassland AGB matching the MODIS pixel scale. "

Point 58: P10, line 190, change "Modeling method" to "Random forest model".

Response: Thank you for your comments. As you suggested, we have modified "Modeling method" to "Random forest model" in the revised version (Line 193):

"2.5.1 ***Random forest model***"

Point 59: P10, line 193, change "namely" to "named".

Response: Thank you for your comments. As you suggested, we have changed "namely" to "named" in the revised version (Lines 195-197):

"The two primary parameters, ***named*** the number of regression trees in the forest (ntree) and the number of feature variables required to create branches (mtry), were firstly optimized based on the root mean square error (RMSE) of training data."

Point 60: P10, line 194, change "first" to "firstly".

Response: Thank you for your comments. As you suggested, we have changed "first" to "firstly" in the revised version (Lines 195-197):

"The two primary parameters, named the number of regression trees in the forest (ntree) and the number of feature variables required to create branches (mtry), were ***firstly*** optimized based on the root mean square error (RMSE) of training data."

Point 60: P10, line 196, change "increase" to "increased".

Response: Thank you for your comments. As you suggested, we have changed "increase" to "increased" in the revised version (Lines 198-200):

"In addition, the importance of each predictor was ranked by calculating the percentage ***increased*** in mean square error (%IncMSE)."

Point 61: P10, lines 200-201, change "predictor variables" to "predictors"; delete "index"

Response: Thank you for your comments. As you suggested, we have changed "predictor variables" to "predictors" and removed "index" in the revised version (Lines 203-204):

"1) constructing an AGB RF model by including all ***predictors*** in the initial stages and calculating the ***%IncMSE*** for each variable;"

Point 62: P10, line 207, insert "MODIS" before "pixel".

Response: Thank you for your comments. As you suggested, we have inserted "MODIS" before "pixel" in the revised version (Lines 210-211):

"At the ***MODIS*** pixel scale, 30% of the UAV-estimated AGB samples in 2019 were randomly selected as an independent validation dataset due to its large size."

Point 63: P10, line 208, change "the large sample size" to "its large size".

Response: Thank you for your comments. As you suggested, we have changed "the large sample size" to "its large size" in the revised version (Lines 210-211):

"At the MODIS pixel scale, 30% of the UAV-estimated AGB samples in 2019 were randomly selected as an independent validation dataset due to ***its large size***."

Point 64: P10, line 209, change "cross-year" to "multi-year".

Response: Thank you for your comments. We have changed "cross-year" to "multi-year" in the revised version (Lines 212-213):

"Meanwhile, the UAV_AGB values from 2015 to 2018 were used for ***multi-year*** validation to test the robustness of the model over time."

Point 65: P10, formula (1), the symbol "⁻" is far away "yi". please use the formula editor.

Response: Thank you for your comments. We have modified the formula in the revised version

(Line 214):

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (\hat{y}_i - y_i)^2}{\sum_{i=1}^{n} (\hat{y}_i - \bar{y}_i)^2}$$

Point 66: P10, line 217, delete the second "to", and change "frames" to "quadrats".

Response: Thank you for your comments. As you suggested, we have deleted the second "to", and changed "frames" to "quadrats" in the revised version (Lines 219-221):

"Since the spatial coverage of a 20-meter-high UAV photo (26 m×35 m) is much larger than a single 2-meter-high UAV photo, making it easier to **match the** MODIS pixel scale. Hence, the 20-meter-high UAV photos containing the sample **quadrats** were chosen for constructing the quadrat-scale AGB estimation model."

Point 67: P10, line 218, change "of quadrat-scale UAV-field AGB observation" to "between field harvested AGB and UAV sub-photos".

Response: Thank you for your comments. As you suggested, we have changed "of quadrat-scale UAV-field AGB observation" to "between field harvested AGB and UAV sub-photos" in the revised version (Lines 221-223):

"A total of 906 pairs **between field harvested AGB and UAV sub-photos** were collected, with good spatial representativeness (Figure 1a, yellow dots)."

Point 68: P10, line 219, delete "data"; delete blank between "1" and "a". in the figure 1a, there is no red dot. Please check and revise.

Response: Thank you for your comments. As you suggested, we have deleted "data" and the blank between "1" and "a". In addition, we have modified Figure 1a by expanding the size of the dot symbol and changing the color (Lines 221-223):

"A total of 906 pairs between **field** harvested AGB and UAV sub-photos were collected, with good spatial representativeness (***Figure 1a***, ***yellow dots***)."
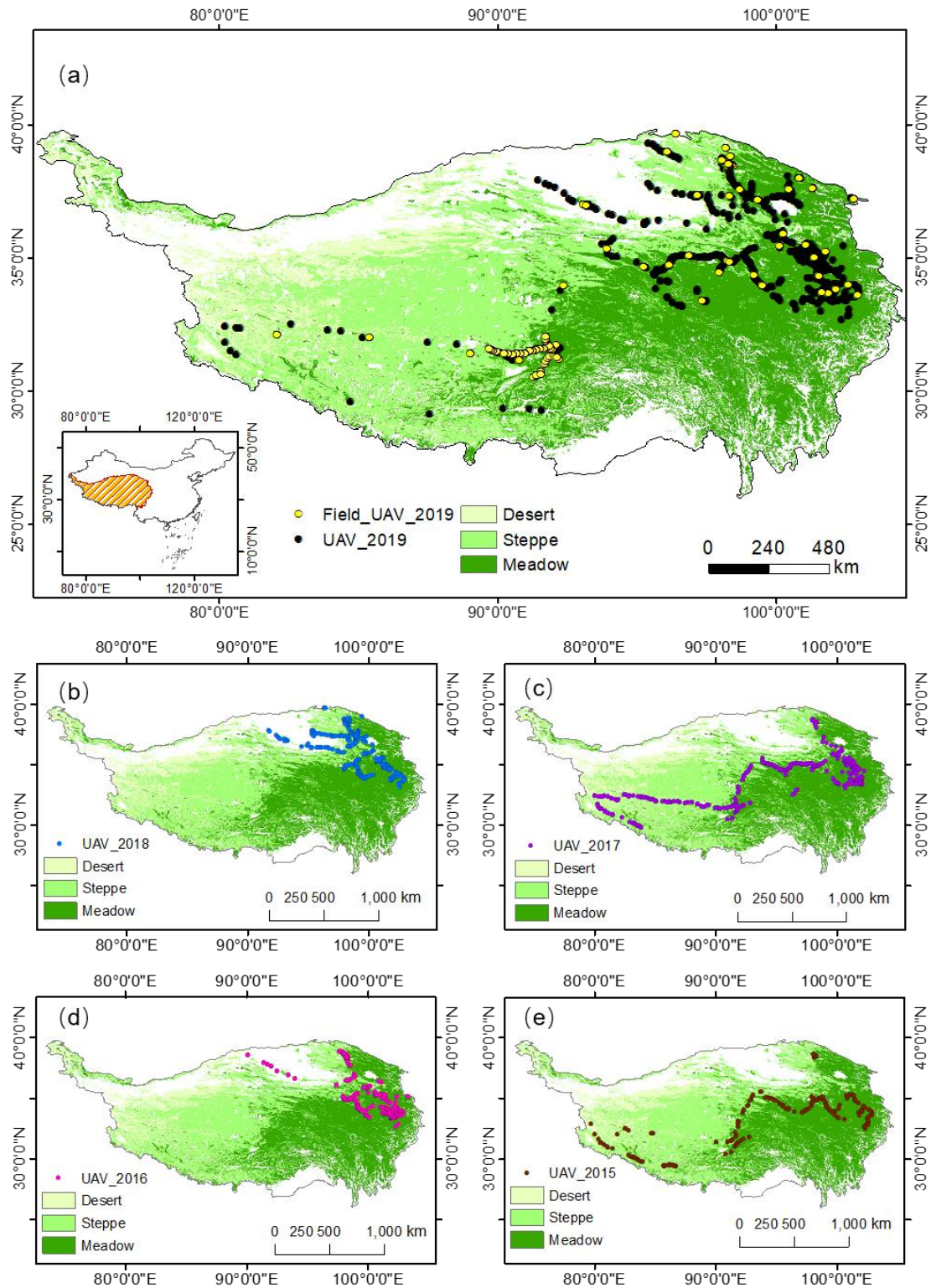
Figure 1. Distribution of field and UAV sampling sites in 2019 (a); UAV sampling sites in alpine grasslands on the QTP from 2015-2018 (b-e). Field_UAV_2019 represents the quadrat-scale sampling sites for the 2019 UAV-Field synchronous grassland biomass experiment. UAV_year represents the UAV sampling point based on the GRID or RECTANGE mode of the corresponding year.

Point 69: P10, Line 220, change the format of measuring unit from "g/m2" to "g·m-2".

Response: Thank you for your comments. As you suggested, we have changed the format of the measuring unit from "g/m^2" to "g·m^{-2}" in the revised version (Lines 223-224):

"The observed AGB values ranged from 0 to 450 ***g·m^{-2}***, with mean and median values of 59.75 ***g·m^{-2}*** and 33.04 ***g·m^{-2}***, respectively (Figure 5a)."

Point 70: P11, line 221, change "image" to "photo".

Response: Thank you for your comments. As you suggested, we have changed "image" to "photo" in the revised version (Lines 224-225):

"The cropped 20-meter-high UAV ***photo*** indices and the measured AGB values were used as the independent and dependent variables to build the RF model at the quadrat scale (Figure 2)."

Point 71: P11, lines 224-225, change "first" and "second" to "firstly" and "secondly".

Response: Thank you for your comments. As you suggested, we have changed "first" and "second" to "firstly" and "secondly" in the revised version (Lines 227-229):

"1) ***Firstly***, each UAV photo was split into ~2,000 quadrat-sized small patches. 2) ***Secondly***, the AGB of each small patch was calculated based on the quadrat-scale AGB estimation model."

Point 72: P11, line 227, change "images" to "photos"; the number is 37487, but in table 1, it is 37864. what is the reason caused the missing of 377 photos?

Response: Thank you for your comments. As you suggested, we have changed "images" to "photos" in the revised version. In addition, we rechecked our data and found we had made a mistake in the number of photos. We apologize for this (Lines 230-231):

"Based on the above steps, the AGB values of more than 75 million quadrats in 37,864 ***photos*** in GRID or Rectangle mode were calculated (Table 1)."

Point 73: P11, line 228, are more than 74 million AGB values based on the filed harvested biomass?

Response: Thank you for your comments. To calculate the AGB of a single UAV photo at the height of 20 m, we should first split the whole photo into ~2000 quadrat patches, then use the AGB RF estimation model at the quadrat scale to calculate the AGB value of each piece. Thus, we used more than 75 million (37,864 × 2000) AGB values at the UAV quadrat scale. We modified the sentences as follows to eliminate the confusion (Lines 230-231):

"***Based on the above steps, the AGB values of more than 75 million quadrats in 37,864 photos in GRID or Rectangle mode were calculated (Table 1).***"

Point 74: P11, figure 5, from the figure 5a, we can see that filed harvested AGB at 0 g·m^{-2} accounting the largest frequency in 2019, but in the figure 5b, the UVA-estimated AGB at 200 g·m^{-2} accounting the largest frequency in 2019, what results in this difference?

Response: Thank you for your comments. In the field sampling, we did not do a sample without vegetation. We obtained a total of 604 grassland samples at the quadrat scale. However, when constructing the AGB estimation model at the quadrat scale using the collected 604 samples, it was found that many non-vegetation areas, such as riverbeds, soils, gravel, roads, and water bodies, would also get AGB values from the model. Therefore, to avoid this problem, 302 zero-value AGB samples of various types at quadrate scale were artificially constructed from UAV photos to solve the overestimation in non-vegetation areas (Figure R1).
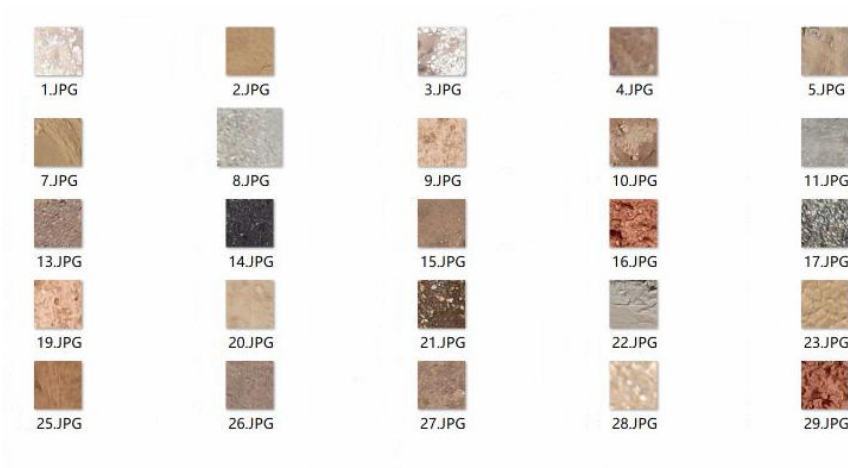

Figure R1. Zero-value AGB samples from UAV photos at the quadrat scale

Figure 5b was the histogram of the AGB estimates at the photo scale. As can be seen in Figure 1, most of our UAV sampling sites (GRID/RECTANGLE) were concentrated in meadows and steppe, with relatively few of the desert grassland type. Therefore, the UVA-estimated AGB at 200 g·m^{-2} accounting the largest frequency in 2019.
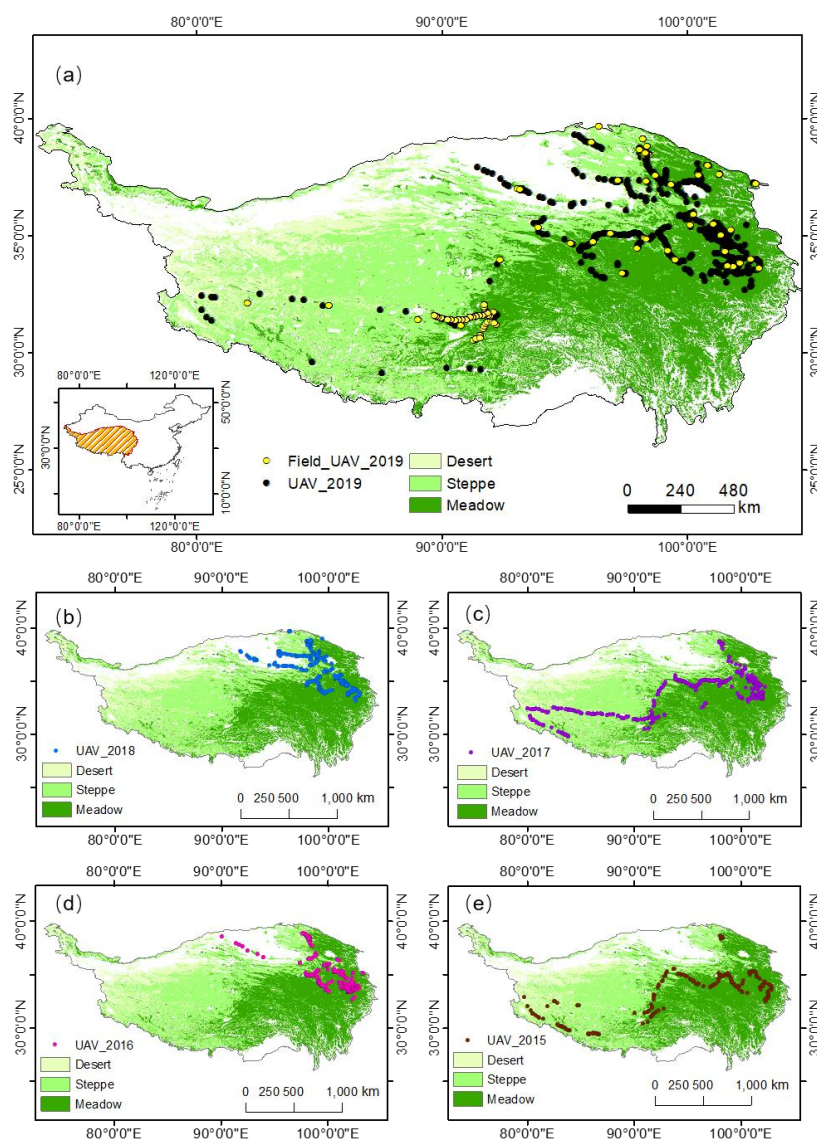

Figure 1. Distribution of field and UAV sampling sites in 2019 (a); UAV sampling sites in alpine grasslands on the QTP from 2015-2018 (b-e). Field_UAV_2019 represents the quadrat-scale sampling sites for the 2019 UAV-Field synchronous grassland biomass experiment. UAV_year represents the UAV sampling point based on the GRID or RECTANGE mode of the corresponding year.

Point 75: P11, line 235, insert "MODIS" before "pixel", and "area" before "of".

Response: Thank you for your comments. As you suggested, we have inserted "MODIS" before "pixel", and "area" before "of" in the revised version (Lines 238-240):

"The following steps were involved in constructing the AGB estimation model at the **MODIS** pixel scale. 1) Since the coverage **area** of a GRID or RECTANGLE mode was similar to that of a **MODIS** pixel, the average value of 16 or 12 UVA photos' AGB was taken as the AGB value of the corresponding MODIS pixel."

Point 76: P11, line 236, change this semi-sentence to "the average value of 16 or 12 UVA photos' AGB was taken as the AGB value of the corresponding MODIS pixel".

Response: Thank you for your comments. As you suggested, we modified the sentence as follows (Lines 238-240):

"1) Since the coverage area of a GRID or RECTANGLE mode was similar to that of a MODIS pixel, *the average value of 16 or 12 UVA photos' AGB was taken as the AGB value of the corresponding MODIS pixel.*"

Point 77: P11, line 237, change "From" to "During".

Response: Thank you for your comments. As you suggested, we changed "From" to "During" in the revised version (Lines 240-241):

"*During* 2015-2019, a total of 2,602 UAV-estimated AGB samples were obtained at the MODIS pixel scale (Table 1)"

Point 78: P11, line 238, insert "MODIS" before "pixel".

Response: Thank you for your comments. As you suggested, we have inserted "MODIS" before "pixel" in the revised version (Lines 240-241):

"During 2015-2019, a total of 2,602 UAV-estimated AGB samples were obtained at the **MODIS**

pixel scale (Table 1)."

Point 79: P11, line 240, change "time" to "date" and insert a blank before "3)".

Response: Thank you for your comments. As you suggested, we have inserted "MODIS" before "pixel" and inserted a blank before "3)" in the revised version (Lines 243-246):

"Here, the MODIS NDVI, EVI, and kNDVI indices closest to the sampling ***date*** were chosen to minimize the time difference between sampling and satellite overpass. ***3)*** Subsequently, the UAV-estimated AGB values, MODIS vegetation indices, and other spatial metrics were used as dependent and independent variables to build MODIS AGB estimated model at MODIS pixel scale using the RF model."

Point 80: P12, line 241, change "the extracted spatial indices" to "MODIS vegetation indices".

Response: Thank you for your comments. As you suggested, we have changed "the extracted spatial indices" to "MODIS vegetation indices" in the revised version (Lines 244-246):

"3) Subsequently, the UAV-estimated AGB values, ***MODIS vegetation indices***, and other spatial metrics were used as dependent and independent variables to build MODIS AGB estimated model at MODIS pixel scale using the RF model."

Point 81: P12, line 242, change "the" to "MODIS" and "algorithm" to "model".

Response: Thank you for your comments. As you suggested, we have changed "the" to "MODIS" and "algorithm" to "model" in the revised version (Lines 244-246):

"3) Subsequently, the UAV-estimated AGB values, MODIS vegetation indices, and other spatial metrics were used as dependent and independent variables to build MODIS AGB estimated model at ***MODIS*** pixel scale using the RF ***model***."

Point 82: P12, line 244, do the authors mean "regression coefficient between vegetation indices and estimated AGB". If so, please change "vegetation indices" to "regression coefficient between vegetation indices and estimated AGB".

Response: Thank you for your comments. As you suggested, we have changed "vegetation

indices" to "regression coefficient between vegetation indices and estimated AGB" in the revised version (Lines 248-249):

"Since the actual AGB values of MODIS pixels cannot be directly obtained, the ***regression coefficient between vegetation indices and estimated AGB*** was used to quantify the uncertainty of different AGB estimation methods."

Point 83: P12, line 249, change "randomly" to "regularly".

Response: Thank you for your comments. As you suggested, we have changed "randomly" to "regularly" in the revised version (Lines 244-246):

"We also explored the uncertainties of UAV sampling coverage by ***regularly*** combining the number of photos in a MODIS pixel, and tested whether the estimated AGB was closer to the "true" value as the number increased."

Point 84: P12, line 250, insert a double quotation mark for "true". Change "results from" to "between", and "or" to "and".

Response: Thank you for your comments. As you suggested, we have inserted a double quotation mark for "true", and changed "results from" to "between" and "or" to "and" in the revised version (Lines 253-256):

"We also explored the uncertainties of UAV sampling coverage by regularly combining the number of photos in a MODIS pixel, and tested whether the estimated AGB was closer to the ***"true"*** value as the number increased. Furthermore, the AGB validation results ***between*** GRID ***and*** RECTANGLE at the pixel scale were compared to understand the uncertainties caused by different flight modes."

Point 85: P12, line 254, change the second "of" to "in".

Response: Thank you for your comments. As you suggested, we have changed the second "of" to "in" in the revised version (Lines 258-259):

"This study combined the Theil-Sen median trend analysis and Mann-Kendall test to analyze the temporal variation characteristics of grassland AGB *in* QTP (Jiang et al., 2015)."

Point 86: P12, line 259, change "in" to "provided by".

Response: Thank you for your comments. As you suggested, we have changed "in" to "provided by" in the revised version (Lines 264-265):

"The detailed formulas for the Theil-Sen median trend analysis and the Mann-Kendall method are *provided by* Jiang et al. (2015)."

Point 87: P12, lines 262, 264, insert "MODIS" before "pixel".

Response: Thank you for your comments. As you suggested, we have inserted "MODIS" before "pixel" in the revised version (Line 268):

"The independent variables for AGB estimation at the quadrat and *MODIS* pixel scales were presented in Table 2."

Lines 270-271:

"At the *MODIS* pixel scale, five variables were selected, including NDVI, kNDVI, EVI, MAP, and DEM (Figure A3)."

Point 88: P12, line 263, change "6" and "4" to "six" and "four", respectively.

Response: Thank you for your comments. As you suggested, we have changed "6" and "4" to "six" and "four", respectively (Lines 268-270):

"A total of 36 independent variables were selected at the quadrat scale, including 26 vegetation RGB indices, *six* histogram indices, and *four* color space indices (Figure A2)."

Point 89: P13, line 268, change colon to dot. Please check the style, because there is a dot in the title of table 1.

Response: Thank you for your comments. As you suggested, we have changed colon to dot in Table 2. In addition, we have checked the style of the other tables (Lines 274-276):

Table 2. Selected independent variables for the AGB modeling at quadrat and pixel scales. The full names of each variable at the quadrat scale were listed in Table A3.

Scale	Model	Number	Independent variables
Quadrat	RFQ	36	FVC, WI, GI, EXG, TGI, EXGR,VEG, GRATIO, COM, CIVE, RGBVI, EXR, GLA, GRRI, MVARI, MGRVI, GRVI, RGRI, GBRI, VARI, NDI, RRATIO, EXB, V, IPCA, INT, HOC_R_CORR, HOC_B_CHIS, HOC_R_CHIS, HOC_G_CHIS, HOC_G_CORR, HOC_B_CORR, B, H, G, R
Pixel	RFP	5	NDVI, kNDVI, EVI, DEM, MAP

Point 90: Table 2, please rearrange the variables in the last column and delete the last comma after "R".

Response: Thank you for your comments. As you suggested, we have rearranged the variables in the last column and deleted the last comma after "R" (Lines 274-276):

Table 2. Selected independent variables for the AGB modeling at quadrat and pixel scales. The full names of each variable at the quadrat scale were listed in Table A3.

Scale	Model	Number	Independent variables
Quadrat	RFQ	36	FVC, WI, GI, EXG, TGI, EXGR,VEG, GRATIO, COM, CIVE, RGBVI, EXR, GLA, GRRI, MVARI, MGRVI, GRVI, RGRI, GBRI, VARI, NDI, RRATIO, EXB, V, IPCA, INT, HOC_R_CORR, HOC_B_CHIS, HOC_R_CHIS, HOC_G_CHIS, HOC_G_CORR, HOC_B_CORR, B, H, G, **_R_**
Pixel	RFP	5	NDVI, kNDVI, EVI, DEM, **_MAP_**

Point 91: P13, line 273, insert a blank before and after "=" and "<".

Response: Thank you for your comments. As you suggested, we have inserted a blank before and after "=" and "<" in the revised version (Lines 278-279):

"For the AGB estimation model at the quadrat scale, the results of 10-cross validations showed that there was a significant linear relationship between the estimated and the measured values (**_R^2 = 0.73, p < 0.001_**, Table 3, Table A4)."

Point 92: P13, line 275, change "p=0.51>0.05" to "p > 0.05".

Response: Thank you for your comments. As you suggested, we have changed "p=0.51>0.05" to "p > 0.05" in the revised version (Lines 279-281):

"There was no significant difference (**_p > 0.05_**) between the predicted and the measured values of the mean AGB at a confidence level of 95% (Table 4) with an RMSE of 32.94 g·m^{-2} (Table 3)."

Point 93: P13, lines 277-278, change this sentence to "it may be caused by the relatively small

samples of more than 200 g · m-2, only accounting for 8.5% of whole samples".

Response: Thank you for your comments. As you suggested, we changed this sentence in the revised version as follows (Lines 282-283):

"***It may be caused by the relatively small samples of more than 200 g·m⁻², only accounting for 8.5% of whole samples*** (Figure 5a)*.*"

Point 94: P13, line 278, change "size" to "amount".

Response: Thank you for your comments. As you suggested, we have changed "size" to "amount" in the revised version (Lines 284-285):

"Although the sample ***amount*** of UAVs varied year by year, most of the AGB values estimated from UAV-photos ranged from 0 to 300 g·m⁻² (Figure 5b)."

Point 95: P13, line 279, delete the first "from" and change the first "to" to "by". Insert "UVA-" before "photos".

Response: Thank you for your comments. As you suggested, we have modified the sentence in the revised version as follows (Lines 284-285):

"Although the sample amount of UAV ***varied year by year***, the AGB values estimated from UAV photos typically ranged from 0 to 300 g·m⁻² (Figure 5b)."

Point 96: P13, line 281, 284, insert "p < ????" and "p > 0.05" after "a strong linear relationship" and "no significant differences", respectively.

Response: Thank you for your comments. As you suggested, we have inserted "p < 0.01" and "p > 0.05" after "a strong linear relationship" and "no significant differences", respectively, in the revised version (Lines 287-288):

"For the AGB estimation model at MODIS pixel-scale, there was a strong linear relationship ***(p < 0.05)*** between the estimated AGB and that measured by UAV photos for 2015-2019 (Table A4)."

Lines 290-291:

"In addition, we found no significant differences *(p > 0.05)* between the predicted and measured values of the average AGB, except for 2017 and 2018 (Table 4)."

Point 97: P13, 287, change "~" to "-".

Response: Thank you for your comments. As you suggested, we have changed "~" to "-" in the revised version (Lines 294-295):

"Therefore, the constructed pixel-scale AGB estimation model had good performance and robustness in different years (*Figure 6b-f*)."

Point 98: P13, lines 285-286, it is confused me a lot, please revise this sentence.

Response: Thank you for your comments. As you suggested, we have revised the sentence as follows (Lines 291-294):

"*The average AGB estimated by the MODIS pixel-scale model for 2017 and 2018 were 131.48 g·m^{-2} and 120.60 g·m^{-2}, which were 14.72% and 13.78% lower than those of estimated by UAV photos. Although the estimated average AGB between the MODIS pixel-scale model and UAV were different in 2017 and 2018, the error percentages were acceptable.*"

Point 99: P14, lines 298-299, change "the traditional sampling method" to "that between MODIS-estimated AGB and filed harvested AGB".

Response: Thank you for your comments. As you suggested, we have changed "the traditional sampling method" to "that between field harvested AGB and MODIS vegetation indices" in the revised version (Lines 306-307):

"The correlations between the UAV-estimated AGB values and MODIS vegetation indices were much better than *that between field harvested AGB and MODIS vegetation indices (Figure 7a).*"

Point 100: P14, line 300, whose correlation between a single UVA image was higher than that

between NDVI and filed harvested AGB?

Response: Thank you for your comments. As you suggested, we modified the sentence in the revised version as follows (Lines 307-309):

"For example, the correlation between NDVI and *field harvested AGB* was only 0.53, *considerably lower than the correlation between NDVI and AGB obtained from a UAV photo (r = 0.74)*."

Point 101: P14, line 301, increased with the increasing or decreasing number of UAV photos? Whose number increased from 1 to 4?

Response: Thank you for your comments. As you suggested, we have modified the sentence in the revised version as follows (Lines 309-311):

"Moreover, the correlation between NDVI and UAV-estimated AGB *increased with the increasing number of UAV photos*. It increased rapidly *as the number of UAV photos* increased from 1 to 4 (from 0.74 to 0.86), then slowed down and stabilized (from 0.87 to 0.88)."

Point 102: P14, line 305, change "photographs" to "photos".

Response: Thank you for your comments. As you suggested, we have changed "photographs" to "photos" in the revised version (Lines 313-314):

"While using the UAV sampling method, the linear relationship was greatly improved and increased with the increasing number of *photos.*"

Point 103: P17, line 322, change "biomass" to "AGB".

Response: Thank you for your comments. As you suggested, we have changed "biomass" to "AGB" in the revised version (Lines 330-331):

"The average *AGB* of eastern OA1, IIAB1, IB1, and IIC2 eco-geographical regions ranged from 150 to 190 $g·m^{-2}$, and the average AGB of IC1 and IIC1 ranged from 80 to 110 $g·m^{-2}$ (Figure

8b)."

Point 104: P17, line 324, please check the format of comma.

Response: Thank you for your comments. As you suggested, we have changed the format of comma in the revised version (Lines 331-332):

"The average AGB of IID2, IID3, IC2, and IID1 in the west was relatively low**,** ranging from 35 to 75 $g \cdot m^{-2}$."

Point 105: P17, line 326, change "between…and…" to "from…to….".

Response: Thank you for your comments. As you suggested, we have changed "between…and…" to "from…to…." in the revised version (Lines 334-335):

"Except for the low AGB due to low precipitation in 2015 (Figure A4), the mean AGB showed an overall increasing trend ***from*** 2000 ***to*** 2019, with an average growth rate of 0.22 $g \cdot m^{-2} \cdot a^{-1}$ (Figure 9a)."

Point 106: P17, line 327, please correctly address the format of unit. For example, gm-2a-1.

Response: Thank you for your comments. As you suggested, we have modified the format of unit in the revised version (Lines 334-335):

"Except for the low AGB due to low precipitation in 2015 (Figure A4), the mean AGB showed an overall increasing trend from 2000 to 2019, with an average growth rate of 0.22 $\boldsymbol{g \cdot m^{-2} \cdot a^{-1}}$ (Figure 9a)."

Point 107: P17, lines 330-331, change "some degradation" to "a decreasing trend". Because only based on the decreasing trend, we cannot get a conclusion that the grassland, in these regions, are experiencing degradation.

Response: Thank you for your comments. As you suggested, we have changed "some degradation" to "a decreasing trend" in the revised version (Lines 337-339):.

"As shown in Figure 10, the IID3, ID1, IID2, and IIC2 eco-geographical regions of the northern QTP showed an increasing trend from 2000 to 2019, while the IC2, IB1, and IIC1 regions showed *a decreasing trend.*"

Point 108: Figure 9a, why the mean AGB in 2015 is much lower than that in other years.

Response: Thank you for your comments. Since the mean annual precipitation (MAP) in 2015 was relatively lower than the other years, the mean AGB in 2015 was much lower than in other years. As you suggested, we have added Figure A4 to show the MAP of QTP from 2000-2019. In addition, we have explained the possible reasons for the low AGB in 2015 as follows (Lines 334-335):

"***Except for the low AGB due to low precipitation in 2015 (Figure A4)***, the mean AGB showed an overall increasing trend from 2000 to 2019, with an average growth rate of 0.22 g·m^{-2}·a^{-1} (Figure 9a)."
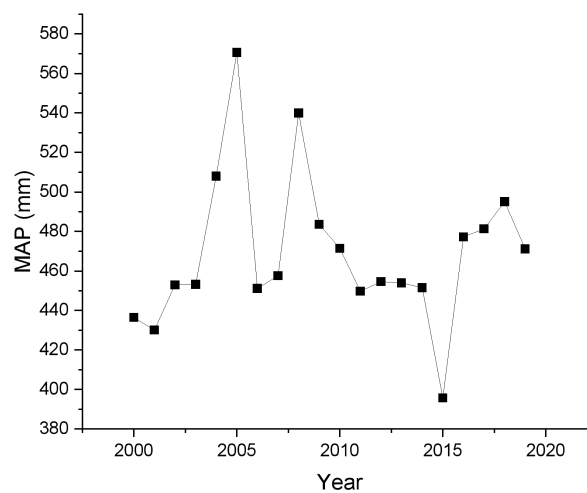

Figure A4. Mean annual precipitation (MAP) on the QTP from 2000-2019.

Point 109: P20, line 351, change "influence" to "impact".

Response: Thank you for your comments. As you suggested, we have changed "influence" to

"impact" in the revised version (Line 355):

"4.1 Scale matching and its **_impact_** factor"

Point 110: P20, lines 356, 373, change "reduce" to "fill".

Response: Thank you for your comments. As you suggested, we have changed "reduce" to "fill" in the revised version (Lines 359-360):

"Therefore, we used the UAVs as a bridge to **_fill_** the spatial gap."

Point 111: P20, lines 357, 358, change "first" and "then" to "firstly" and "secondly", respectively.

Response: Thank you for your comments. As you suggested, we have changed "first" and "then" to "firstly" and "secondly", respectively (Lines 361-364):

"**_Firstly_**, at the quadrat scale, the independent variables were all derived from cropped 20-meter-high UAV photos corresponding to the ground samples (Figure 3e). **_Secondly_**, the 20-meter-high UAV photo was split into ~2000 quadrat-sized patches to ensure consistency with the quadrat-scale model, and the average of these patches was used as the final AGB at the photo scale."

Point 112: P20, line 362, delete "the traditional" and the third "the".

Response: Thank you for your comments. As you suggested, we have delete "the traditional" and the third "the" in the revised version (Lines 365-366):

"With these three steps, we successfully upscaled the measured AGB from **_quadrat_** scale (0.5 m×0.5 m) to **_photo_** scale (26 m×35 m) and MODIS pixel scale (250 m×250 m)."

Point 113: P22, line 379, change "image" to "photo". Delete "vegetation and".

Response: Thank you for your comments. As you suggested, we have changed "image" to "photo"

and deleted "vegetation and" in the revised version (Lines 381-382):

"Thus, the UAV *photo* could *capture non-vegetation background information*, such as roads, water, soil, gravel, and riverbed (Figure A5)."

Point 114: P22, line 381, delete ", to avoid overestimation". Change "true" to "suitable".

Response: Thank you for your comments. As you suggested, we have deleted ", to avoid overestimation" and changed "true" to "suitable" in the revised version (Lines 382-384):

"Adding non-vegetation samples could improve the accuracy of AGB estimation at the photo scale, *especially for areas with low vegetation cover*. It was also *suitable* for the MODIS pixel-scale AGB estimation model."

Point 115: P22, lines 382-383, suggest delete these two sentences. The non-vegetation background can be taken as a baseline for detecting AGB. But, in the filed sampling, it is unnecessary to do a sample without grassland vegetation. In fact, we always do the samples at different grassland types, such as alpine meadow (high coverage), alpine grassland (median coverage), and sparse grassland (low coverage).

Response: Thank you for your comments. As you suggested, we have deleted the two sentences in the revised version.

Point 116: P22, lines 390-393, change "image" to "photo" and "images" to "photos".

Response: Thank you for your comments. As you suggested, we have changed "image" to "photo" and "images" to "photos" in the revised version (Lines 386-391):

"At the quadrat scale, consistent with our previous study, we further confirmed that UAV RGB *photos* could be used to estimate grassland AGB (Zhang et al., 2022a; Zhang et al., 2018). Similar to the 2-meter-high UAV *photo*, the 20-meter-high UAV *photo* could be used to estimate the grassland AGB at the quadrat scale ($R^2 = 0.73$, RMSE = 44.23 g·m^{-2}, Figure 6a). Compared with the 2-meter-high UAV *photo* (0.8 m × 1 m), the 20-meter-high UAV *photo* (26 m × 35 m) is more

suitable for matching the MODIS pixel due to its larger spatial coverage area."

Point 117: P22, line 401, change "reducing" to "filling".

Response: Thank you for your comments. As you suggested, we have change "reducing" to "filling" in the revised version (Lines 398-399):

"Our results confirmed that the R^2 of the linear model could be increased from 0.29 to 0.78 after ***filling*** the spatial gap between measured AGB and NDVI (Figure 7)."

Point 118: P22, line 402, change "AGB" to "technology". Insert "photos" and "MODIS" before "matching" and "pixel", respectively.

Response: Thank you for your comments. As you suggested, we have changed "AGB" to "technology" and inserted "photos" and "MODIS" before "matching" and "pixel", respectively, in the revised version (Lines 399-400):

"In addition, thanks to the rapid sampling of UAV ***technology***, a total of 2,602 sample photos matching the ***MODIS*** pixel scale were collected during 2015-2019."

Point 119: P22, line 403, change "cross-year" to "multi-year".

Response: Thank you for your comments. As you suggested, we have changed "cross-year" to "multi-year" in the revised version (Lines 400-402):

"It allowed us to perform ***multi-year*** validation to assess the robustness of the model over time, which has rarely been performed in previous studies."

Point 120: P22, line 404, p23, line 428, change "size" to "amount".

Response: Thank you for your comments. As you suggested, we have changed "size" to "amount" in the revised version (Lines 402-403):

"Our results showed similar validation results for 2017-2019, despite different sample **_amounts_** and spatial distributions (Figure 1, Table 1)."

Line 428:

"Firstly, the sample **_amount_** and spatial distribution of ground samples were different."

Point 121: P22, line 406, does "abnormal white balance" mean "abnormal white gap"? in figure A5, the abnormal white gap is not clear.

Response: Thank you for your comments. We have changed "abnormal white balance" to "unnatural white balance" to avoid confusion. "Unnatural white balance" is a phenomenon in which the color of objects in a photograph does not match the natural color as seen by the human eye. It is due to the color temperature difference of the light sources, which induces the shift of the reflection spectrum of the object from the "true" color. For example, when a white object is illuminated with low color temperature light source, the reflection becomes reddish. On the other hand, the high temperature light source causes bluish in color to the same white object. In Figure A6, the white balance of four photos (DJI_0064.JPG, DJI_0065.JPG, DJI_0073.JPG, and DJI_0074.JPG), is natural, while the white balance of all other photos is unnatural. This phenomenon is because we selected auto-white balance mode when shooting. To avoid this, we set the white balance mode according to the weather conditions after 2016. We have explained the shortcomings of this in Section 4.4.
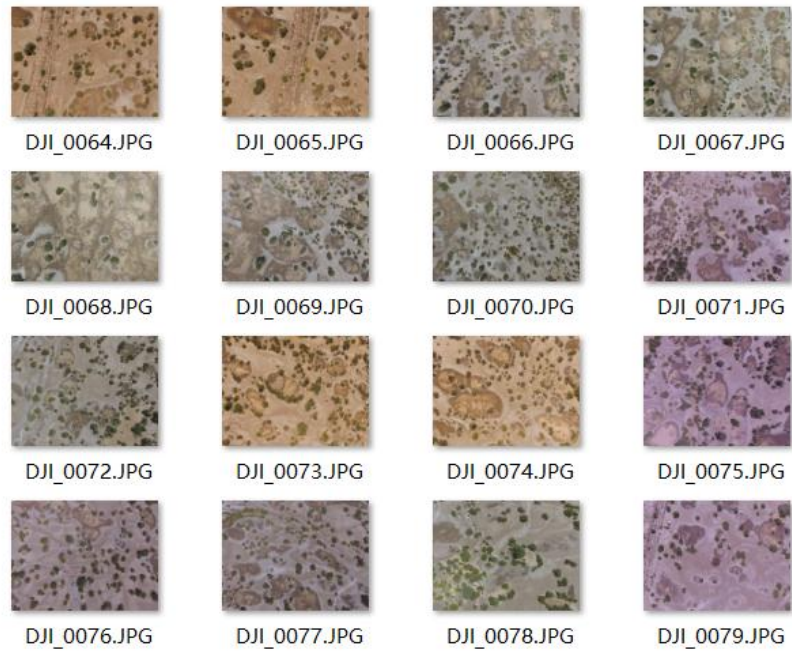
Figure A6. An example of a set of GIRD photos with unnatural white balance in 2015.

Lines 404-405:

"The reason was that during 2015-2016, some photos with **_unnatural white balance_** were obtained due to improper settings, which reduced the estimation accuracy (Figure A6)."

Lines 463-465:

"3) **_During 2015-2016, we set the automatic white balance mode for UAV shooting due to inexperience._** As a result, some photos with **_unnatural white balance_** were obtained, reducing the accuracy of AGB estimation at the photo scale (Figure A6)."

Point 122: P24, line 443, give the full name of "ANN".

Response: Thank you for your comments. We have added the full name of "ANN" in the revised version (Lines 442-444):

"Yang et al. (2017) found that the model performance of the **_artificial neural network (ANN)_** was much better than the linear regression model when using the same dataset to estimate grassland AGB in the Three-River Headwaters Region of China."

Point 123: P24, lines 445-446, insert "(2017)" before "compared" and delete "(Wang et al., 2017)".

Response: Thank you for your comments. As you suggested, we have inserted "(2017)" before "compared" and deleted "(Wang et al., 2017)" in the revised version (Lines 445-447):

"Wang et al. *(2017)* compared the RF with the bagging, mboost, and support vector regression (SVR) algorithms, and found that the RF yielded the best performance in grassland AGB estimation."

Point 124: P24, line 453, as we know, it is very difficult for spectrum images to detect the height of grassland species. Recently, some lidar images were used to detect the height of forest species. However, in QTP, the grassland species are much lower than forest species in tropical regions.

Response: Thank you for your comments. As you said, it is still challenging to detect the height of grassland in a large area. In 2021, we purchased a DJI Zenmuse L1 Lidar UAV and conducted preliminary experiments to detect grassland heights. The vertical positioning accuracy of DJI Zenmuse L1 can reach ±1.5 cm. Figure R2 is an example of Lidar point cloud data with a height of 20 m in a small area, and its detected vegetation height results. It can be seen from the result that vegetation at low heights (0-100cm) can also be discriminated. Therefore, we think that DJI Zenmuse L1 has the potential to monitor grassland height on the QTP.
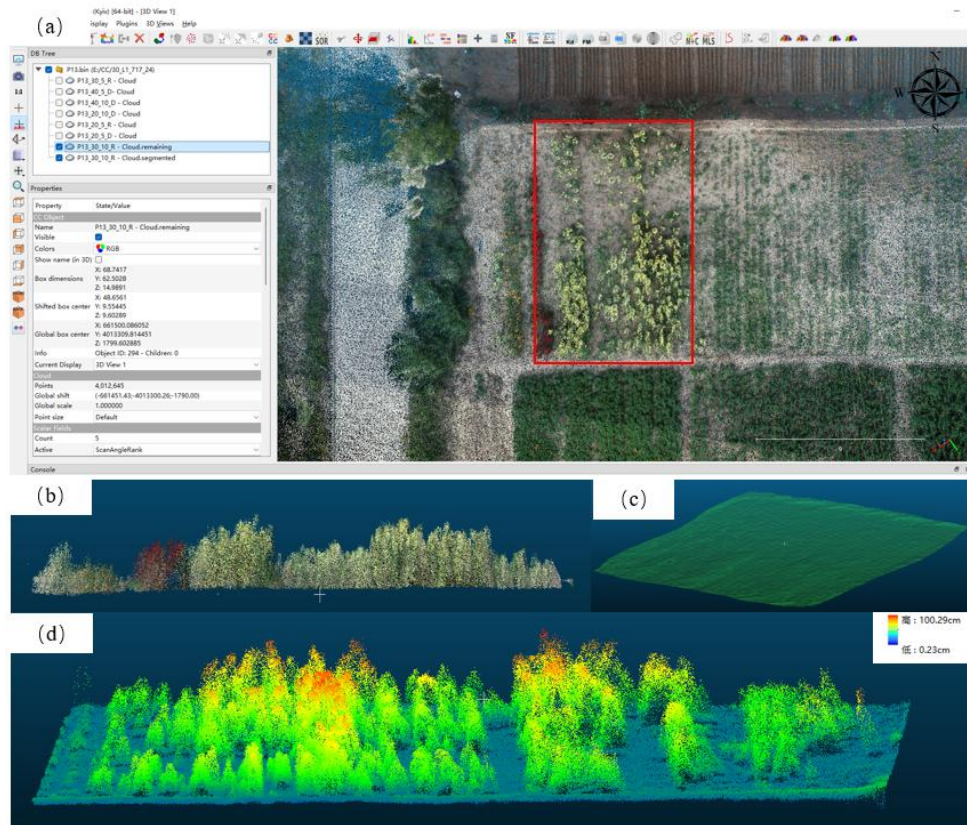
Figure R2. The LIDAR point cloud data acquired at a flight altitude of 20 m (a), the point cloud data of the Lily crop (b), the generated DEM (c), and the vegetation heights result (d).

Point 125: P24, lines 451-454, suggest revise these two sentences.

Response: Thank you for your comments. As you suggested, we have modified the two sentences in the revised version as follows (Lines 451-454):

"*One of the reasons may be that the number of samples larger than 250 g·m^{-2} at the quadrat scale is relatively small, accounting for only 5.18% of the total samples. Another possible reason is that the height of the grassland could not be detected by a single UAV photo. Therefore, it could lead to an underestimation of AGB for grassland species with the same FVC but greater heights.*"

Point 126: P24, line 459, change "difference" to "gap". Change "errors" to "uncertainties".

Response: Thank you for your comments. As you suggested, we have changed "difference" to "gap" and "errors" to "uncertainties", respectively, in the revised version (Lines 458-460):

"Although the MODIS indices closest to the sampling date were chosen for the construction/validation of the AGB estimation model, there was still a time *gap* between the measured samples and the MODIS indices, which might lead to estimation *uncertainties*."

Point 127: P24, line 460, change "of" to "in".

Response: Thank you for your comments. As you suggested, we have changed "of" to "in" in the revised version (Lines 460-462):

"In addition, the NDVI saturation problem was not considered in this study, which might affect the AGB estimation accuracy *in* QTP (Tucker, 1979a; Gao et al., 2000; Mutanga and Skidmore, 2004; Tucker, 1979b)."

Point 128: P25, line 463, delete the blank between "data" and "set".

Response: Thank you for your comments. As you suggested, we have delete the blank between "data" and "set" in the revised version (Lines 462-463):

"In the next step, we will continue to collect samples with high biomass and try to correct the NDVI saturation problem to optimize the simulation accuracy of the *dataset*."

Point 129: P25, line 466, change "limited" to "poor".

Response: Thank you for your comments. As you suggested, we have changed "limited" to "poor" in the revised version (Lines 467-468):

"During the modeling process, due to the *poor* positioning accuracy, only the center points of the flight path were used to find the corresponding MODIS pixels."

Point 130: P29, table A1, there may be issues for reclassifying the grassland types. Suggest reclassify the eight grassland types into "meadow", "steppe" and "desert". Because the lowland meadow and temperature steppe do not be characterized with alpine climate. These two grassland

types normally located in the southern Himalaya and south-eastern QTP. So, the climate in these regions is not cool, but warm. Moreover, there still are grassland species in the desert, for example the short-life species. When the temperature and precipitation are suitable, the grassland species grow sharply. But, as the temperature and precipitation decrease at a certain extent, the grassland species die. Normally, we call these short-life grassland species as annual plant.

Response: Thank you for your comments. As you suggested, we have reclassified the eight grassland types into "meadow", "steppe" and "desert" in the revised version (P30, Line 527). In addition, we modified the grassland types in Figure 1 (P4, Lines 102-106) and Figure 9 (P19, Lines 350-353).

Table A1. Combined grassland types

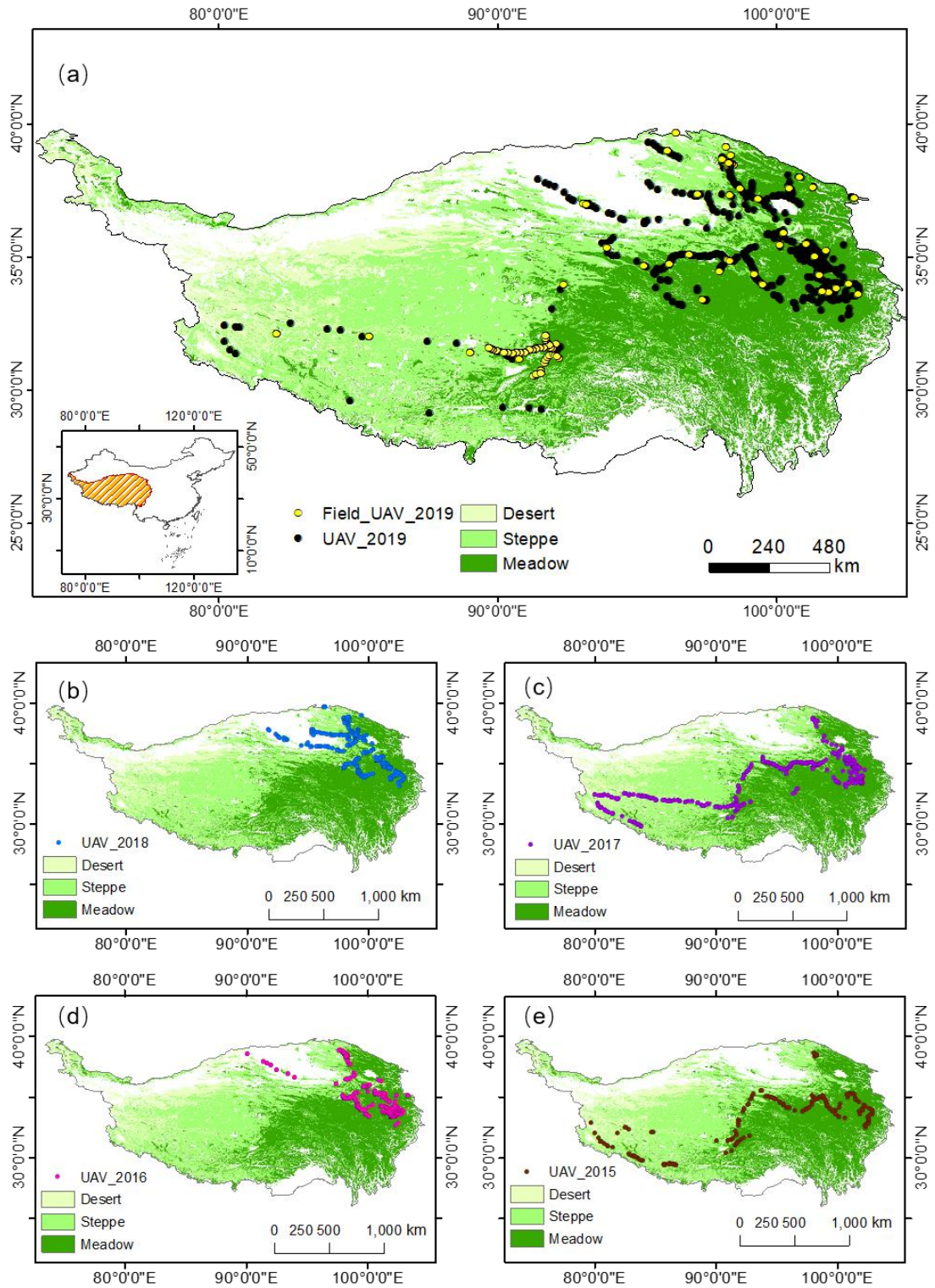| New grassland type	Original grassland type
Meadow	Alpine meadow, Lowland meadow, Montane meadow,
Steppe	Temperate steppe, Alpine steppe, Alpine meadow steppe
Desert	Temperate steppe desert, Alpine desert

Figure 1. Distribution of field and UAV sampling sites in 2019 (a); UAV sampling sites in alpine grasslands on the QTP from 2015-2018 (b-e). Field_UAV_2019 represents the quadrat-scale sampling sites for the 2019 UAV-Field synchronous grassland biomass experiment. UAV_year represents the UAV sampling point based on the GRID or RECTANGE mode of the corresponding year.
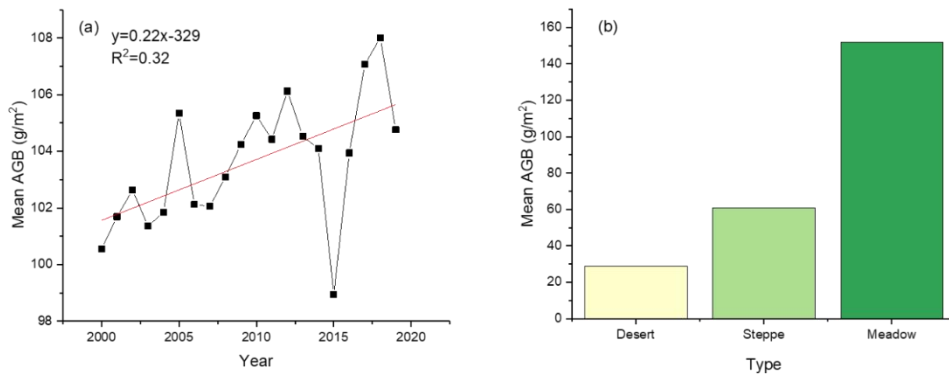
Figure 9. Variation trend of average grassland AGB on the QTP from 2000 to 2019 (a) and average AGB of different grassland types (b).