# Interactive comment on “Multi-scenario urban flood risk assessment by integrating future land use change models and hydrodynamic models” by Qinke Sun et al.

The authors would like to thank Anonymous Referee #2 for reviewing the paper and providing these thought-provoking perspectives. We really appreciate the comments and suggestions and have given them careful consideration. Below are our point-by-point responses to the comments. In addition, we really thank the referee's efforts in the in-depth analysis in the attached document, as well as his/her helpful indications, which certainly improved the quality of our manuscript. The Referee can find our corrections in the attached file entitled Replies to specific comments.

R1: The paper tackles an important subject in future management perspectives of coastal urban regions. Nevertheless, there are some major constraints/critisism to the current version of the paper. The land cover data set seems to be outdated (2014) and has only a coarse spatial resolution (100 m). Based on this, to model the year 2015 with land cover data from 2014 is not so difficult and shows a high coincidence as expected. Why not using a higher spatial resolution from Sentinel-2 (10 m) from the year 2020? Six years after the acquired land use data set from 2014 this would show whether the performance of the land use model is good enough or not...,

A1: Thanks for your comments. First, the FLUS model predicts future land use/land cover determined by the amount of future land use type demand and the driving factors affecting land change. Here we use a Markov chain model to predict the amount of future land use demand. The model requires at least two periods of historical land use data to predict the amount of land use for the same time interval in the next period. In predicting the future land use changes we used two steps to do so, one is the model testing and the other is the model prediction. We used two steps to predict future land use changes, one is model validation and the other is model prediction.

1. Model validation. **We predict the land use change in 2015 based on the land use data in 2010.** In this process, the quantity of land demand in 2015 was first predicted by Markov chain model based on the land use data in 2005 and 2010, and then it was input into the FLUS model to simulate the type of land use in 2015. Finally, we compared the simulated results and the actual land use in 2015 pixel by pixel to test the reliable performance of the model.

2. Model prediction. After the model and impact factor selection were evaluated by reliability accuracy, we predicted the future land demand quantity in 2020, 2030, through Markov chain model based on the land use data in 2010 and 2015. Then we combine the impact factor data and the land demand quantity to predict the future land use results.

In addition, we have attempted to use high-resolution land use data (e.g., GlobeLand30) for prediction. The images for land cover classification of development and update of GlobeLand30 are mainly 30-meter multispectral images, including TM5 ETM+, and OLI multispectral images of Landsat (USA) and HJ-1 (China Environment and Disaster Reduction Satellite), the 16-meter resolution GF-1(China High Resolution Satellite) multispectral image are also used for GlobeLand30 2020. (http://www.globeland30.org/home.html?type=data). **We selected the land use data of GlobeLand30 for the periods of 2000, 2010, and 2020, and simulated the prediction of the study area by Markov chain model and FLUS model,** but the results were very unsatisfactory. We compared the simulation results for 2020 and found that kappa coefficient (kappa) was 0.64 and overall accuracy (OA) was 76.85%, and the producer accuracy was lower for each land use type. And we used 100 m land use data to produce an OA was 93.20% and a kappa was 0.89.

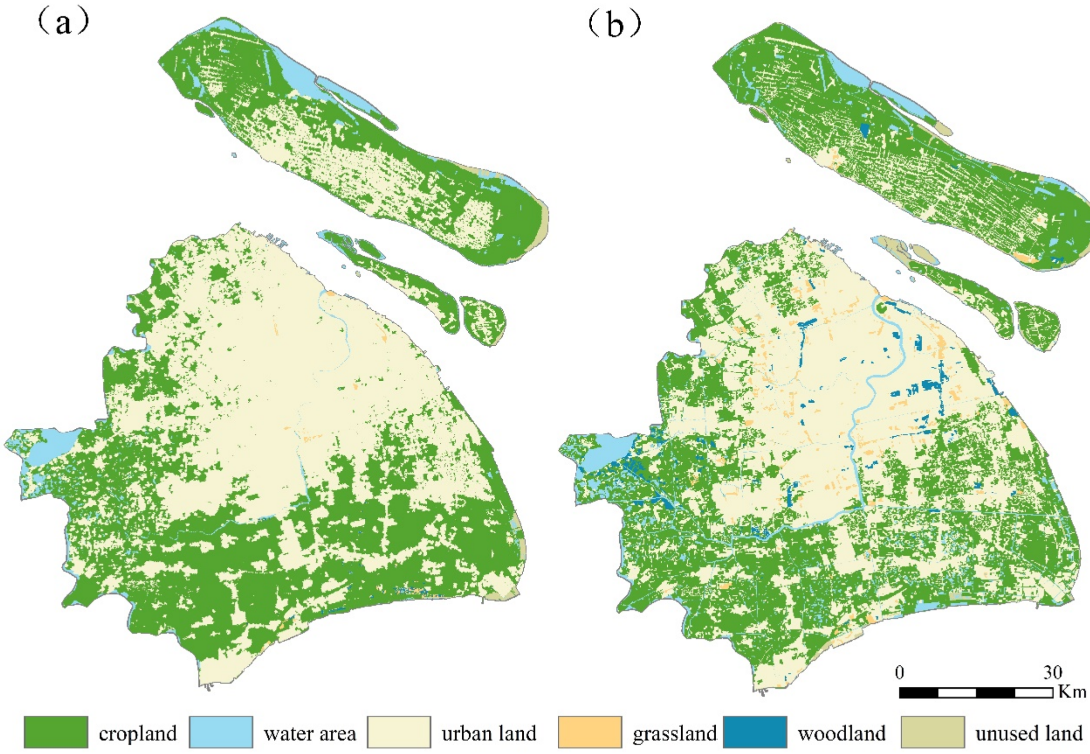


Figure 1: Comparing the simulation results using GLC30 data with the actual situation, (a) simulation result in 2020; (b) actual land use in 2020

Furthermore, our team also considered selecting 2020GLC data to be used with our data set, but there are more problems between different data due to the large differences in the production and classification standards. Meanwhile, the high precision Sentinel-2 has more detailed descriptions for spatial details (Claverie et al., 2019), but there is no long time series (10 years) and annual integrated land use classification product (Nurfadila et al., 2019). Related studies have demonstrated that medium-resolution (100 m) is more adequate to detect most human–nature interactions, while medium-high resolution sensors (Landsat 8/OLI and Sentinel-2/MSI) are more suitable for detailed studies of plant phenology (Chaves et al.,2020). Therefore, we chose this set of 100-m resolution land use data produced by the Chinese Academy of Sciences from the perspective of data consistency and accuracy of model simulation. In addition, we have analyzed the data for research limitations in the discussion section of this manuscript.

Thanks again to the Referee for the comments.

[1] Claverie, M., Ju, J., Masek, J., Dungan, J., Vermote, E., Roger, J., Skakun, S., Justice, C.: The Harmonized Landsat and Sentinel-2 surface reflectance data set. Remote Sens. Environ, 219, 145–161, 2018.

[2] Nurfadila, J., Baja, S., Neswati, R., Rukmana, D., Zylshal, Z.: Initial Results on Landuse/Landcover Classification Using Pixel-Based Random Forest Algorithm on Sentinel-2 Imagery over Enrekang Region, IOP Conference Series: Earth and Environmental Science, 280(1), 012036, 2019.

[3] Chaves, M., Picoli, M., Sanches, I.: Recent Applications of Landsat 8/OLI and Sentinel-2/MSI for Land Use and Land Cover Mapping: A Systematic Review, Remote Sens, 12, 3062, 2020.

R2: the ASTER-DEM used has a 30 m spatial grid, but everybody knows, that the vertical accuracy may vary up to 5 m and more. This is a major drawback in coastal lowlands, where just small height differences may cause large discrepancies in flooded areas. Better use LIDAR data if available,

A2: Thank you very much for your suggestion. In flood inundation simulations, the use of different DEM products can produce differences in inundation results. The reason is that different open-access DEMs use different observation satellites and algorithms, producing various vertical differences. This is another research direction of interest for our team, which has successfully simulated inundation differences due to differences in DEM products (Xu et al., 2021). This study compared the inundation results produced by six different open-source DEM products (SRTM, ASTER-DEM, AW3D, MERIT, NASADEM and CoastalDEM) under different flood return periods. Based on the results of this study, we finally selected the ASTER-DEM product that performs more stably under different flood scenarios. **Here, we choose the open-access DEM product due to funding and modeling power constraints.** We have added additional descriptions in the corresponding section of the manuscript. The Referee can read the new part in the following:

*ASTER-DEM has been shown to be the most stable data performer among six types of open access DEM products (SRTM, ASTER-DEM, AW3D, MERIT, NASADEM and*

*CoastalDEM) for flood inundation simulations with different return periods (Xu et al., 2021).*

[1] Xu, K., Fang, J., Fang, Y., Sun, Q., Wu, C. and Liu, M.: The importance of digital elevation models selection in flood simulation and a proposed method to reduce DEM errors: a case study in Shanghai, Int. J. Disaster Risk Sci., 2021 (accepted).

R3: the single forward modelling of the urban development may not concider the polycentric development of the agglomeration,

A3: Thanks for your comments. For most developing cities, especially fast-growing cities, the development of cities or urban agglomerations will show expansion patterns such as infill, edge-expansion, and outlying (Fig. 1). Numerous empirical studies by scholars have found that diverse patterns across cities are due to geographic and economic conditions. For example, Nanjing's urban expansion is mainly based on infill and outlying development (Xu et al., 2007). Beijing's urban expansion is based on concentric circles of urban outward expansion (Xie et al., 2007). While Hangzhou and Wuhan show a typical polycentric expansion pattern (Yue et al., 2010; Liu et al., 2011). In contrast, Shanghai's urban growth pattern is mainly based on infill and edge-expansion (Li et al., 2014; Zhou et al., 2020). Moreover, Shanghai's urban development is in transition to high-quality development, and it is difficult to appear a polycentric development pattern of outlying or satellite cities in the future.

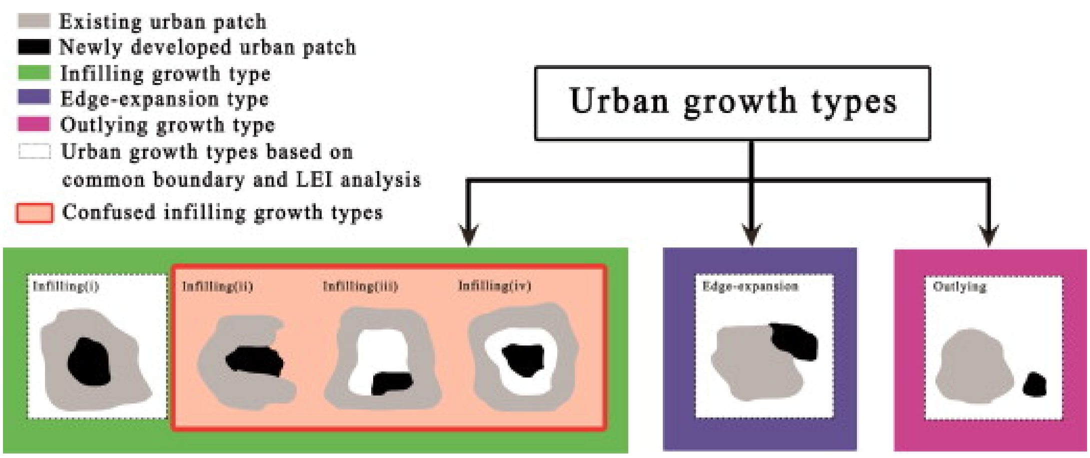


Fig. 1. Spatial modes for three urban growth types (From Shi et al, 2012).

In addition, the important influencing factors such as GDP, population and traffic roads are considered in our selected drivers of urban expansion, especially the application of FLUS model based on adaptive inertial competition mechanism has good self-organizing ability for urban expansion. Therefore, the combination of multiple expansion modes of future cities is also considered in our study.

[1] Shi, Y., Sun, X., Zhu, X., Li, Y., Mei, L.: Characterizing growth types and analyzing growth density distribution in response to urban growth patterns in peri-urban areas of Lianyungang City, Landscape & Urban Planning, 98(4), 425-433, 2010.

[2] Xu, C., Liu, M., Zhang, C., An, S., Yu, W., Chen, J.: The spatiotemporal dynamics of rapid urban growth in the Nanjing metropolitan region of China, Landsc. Ecol., 22, 925–937, 2007.

[3] Xie, Y., Fang, C., Lin, G., Gong, H., Qiao, B.: Tempo-spatial patterns of land use changes and urban development in globalizing China: A study of Beijing, Sensors, 7, 2881–2906, 2007.

[4] Yue, W., Liu, Y., Fan, P.: Polycentric urban development: The case of Hangzhou, Environ. Plan. A, 42, 563–577, 2010.

[5] Liu, Y., Yue, W., Fan, P.: Spatial determinants of urban land conversion in large Chinese cities: A case of Hangzhou, Environ. Plan. B, 38, 706–725, 2011.

[6] Li, H., Wei, Y., Huang, Z.: Urban Land Expansion and Spatial Dynamics in Globalizing Shanghai, Sustainability, 6, 8856-8875, 2014.

[7] Zhou, L., Dang, X., Sun, Q. and Wang, S.: Multi-scenario simulation of urban land change in Shanghai by random forest and CA-Markov model, Sustain. Cities Soc., 55, 102045, 2020.

R4: land subsidence is not equally everywhere. It depends very much on the ground substrate. Fluvial sediments may subside more than rocky underground. And it also depends on the anthropogenic use. Roads on sedimentary ground, where heavy trucks are driving each day may subside much more than anywhere else... It's not enough to analyze that statistically, one would hove to look attentive where this would happen. Interferometric evaluation of multitemporal microwave data would provide a propoer estimation on that...,

A4: Thanks for your comments. As you have analyzed, land subsidence in Shanghai is mainly caused by tectonic subsidence and compaction of sediments due to natural conditions and human activities. "(1) Compaction subsidence has a long history in Shanghai. It is one of the first few cities in China to suffer from serious land subsidence, with an average rate of 22.94 mm/year from 1921 to 2007 (Gong and Yang 2008). According to the monitoring data, compaction subsidence of Shanghai can be divided into three stages as: (i) rapid subsidence stage from 1921 to 1965 caused by excessive groundwater extraction; (ii) recovery stage from 1965 to 1985 with artificial recharge; (iii) slow subsidence stage from 1985 to 2007 due to large-scale construction of high-rise buildings and underground projects. Shanghai Geological Environmental Bulletin and land subsidence control plan estimate that **the average rate of compaction subsidence will be stabilized at 5 mm/year after 2010** (Shanghai Municipal Bureau of Planning and Land Resources 2007). (2) The crust of Shanghai has experienced gradual subsidence since the Pliocene. Based on the analysis of long-term monitoring data of very long baseline interferometer (VLBI) in the Sheshan bedrock, **the average rate of tectonic subsidence is estimated to have been nearly 1 mm/year** in Shanghai (Qian 1996). Since tectonic movement is relatively stable, it is assumed the rate of tectonic subsidence in Shanghai remain constant." --Reference to the analytical study by Yin et al. (Yin et al., 2013).

Therefore, prediction for land subsidence in Shanghai was generated by combining compaction subsidence and tectonic subsidence, resulting in a total land subsidence by 2030 and 2050 120 mm and 240 mm, respectively. However, due to the uncertainty of future anthropogenic activities and spatial distribution, there could be large variations in the projection.

We have rewritten the expressions related to the land subsidence projections for 2030 and 2050 in the corresponding places in the manuscript, in order to better understand the basis of our projections. The Referee can read the new part in the following:

*Land subsidence in Shanghai is mainly caused by tectonic subsidence and compaction of sediments due to geological structure conditions and human activities. With reference to the long-term tectonic subsidence monitoring data of the very long baseline interferometer (VLBI) in the Sheshan bedrock and the land subsidence analysis rules of Yin et al* (Yin et al., 2013)*. therefore, the total land subsidence is predicted to be 0.12 m and 0.24 m by 2030 and 2050, respectively. However, due to the uncertainty of future anthropogenic activities and spatial distribution, there could be large variations in the projection.*

[1] Qian Z.: Dftermination of the crustal vertical motion at Sheshan area, shanghai by VLBI, Annals of Shanghai Observatory Academia Sinica, 1996.

[2] Gong S., Yang S.: Effect of Land Subsidence on Urban Flood Prevention Engineering in Shanghai, Sci. Geogr. Sin, 28, 543–547, 2008.

[3] Shanghai Municipal Bureau of Planning and Land Resources (2007), Shanghai geological environmental bulletin, 2007.

[4] Yin, J., Yu, D., Yin, Z., Wang, J. and Xu, S.: Modelling the combined impacts of sea-level rise and land subsidence on storm tides induced flooding of the Huangpu River in Shanghai, China, Clim. Change, 119(3–4), 919–932, doi:10.1007/s10584-013-0749-9, 2013.

R5: the result showed a stronger inundation by the GE scenario than with the GP scenario. Flooding per se is not bad, so one would not rank the GE scenarion worse than the GP scenario, since it might consider clean air allies or urban green spaces. The authors mention that in their chapter 5.2 "Recommendations", but should emphasize that much more...

A5: Thank you very much for your suggestion. We strongly agree with the point that flooding is not inherently good or bad, but only makes a difference when it has an impact on human life. We have added a discussion in section 5.2 of the manuscript. The Referee can read the new part in the following:

*Furthermore, our results show that the area of future urban flood risk varies by scenario. Although the GE scenario performs higher than the GP scenario in terms of flood inundation area, this does not mean that the GE scenario is worse. From the cases of advanced flood risk management countries such as the Netherlands (Kabat et al., 2009; Song et al., 2018), an important success lesson for future flood protection design is to leave enough space along coasts for wetland migration and leave space for nature. In other words, "soft strategies" such as "working with rivers and nature" are considered in the flood protection measures. Therefore, from this perspective the GE scenario may be a more likely future development scenario among these three scenarios. Future, it is necessary to learn from the practical experience of advanced countries to strengthen the development and construction of coastal wetlands and tidal flat ecosystems, and further reduce the residual risk through the adaptive regulation of coastal ecosystems and other soft strategies.*

## Replies to specific comments.

RC: Line27, 29: Change the location of the references in chronological order.

AC: We have changed the position of the references.

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RC: Line29: Delete “the”.

AC: Done.

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RC: Line31: Add “the…”

AC: Done.

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RC: Line31: Add “the…”

AC: Done.

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RC: Line38,44, 45, 48, 57: Change the location of the references in chronological order.

AC: Done.

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RC: Line49: Add “need”

AC: Done.

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RC: Line59-60: Change “how can combining different urban growth scenarios with climate change scenario analysis help inform preparedness for flood risks from climate change in urban flood risk assessments” with “how different urban growth scenarios combined with climate change scenario analysis may help to inform preparedness for flood risks from climate change in urban flood risk assessments”.

AC: Done.

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RC: Line61: Add “areas may”

AC: Done.

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RC: Line66: Add “to”

AC: Done.

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RC: Line70: Change “west” with “West”. Add “(Fig. 1)”

AC: Done.

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RC: Line71: Add “a”

AC: Done.

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RC: Line73: Add “area”

AC: Done.

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RC: Line78: Change “due to land subsidence and the increasing frequency and intensity of storm surge make Shanghai will become one of the most sensitive regions to the global climate change.” with “due to land subsidence and the increasing frequency and intensity of storm surges, Shanghai will become one of the most sensitive regions due to the global climate change.”.

AC: Done.

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RC: Line89: Change “was” with “were”. Change “manually” with “visually”.

AC: Done.

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RC: Line96: Add “area”

AC: Done.

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RC: Line106: Change “validation” with “validated”.

AC: Done.

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RC: Line110: Change the format

AC: Done.

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RC: Line114: Change “complexity” with “complex”.

AC: Done.

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RC: Line116: Change “combine” with “combining”.

AC: Done.

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RC: Line133: Change “change” with “changes”.

AC: Done.

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RC: Line135: Change “The FLUS model is an upgraded version of cellular automata model (Liu et al., 2017), which can solve…” with “The FLUS model is an upgraded version of a cellular automata model (CA-model, Liu et al., 2017) which can solve…”

AC: We have changed “The FLUS model is an upgraded version of a cellular automata model (Liu et al., 2017) which can solve…”, because the abbreviation of CA model has appeared in Line54

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RC: Line139: Add “area, an”

AC: Done.

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RC: Line142: Change “The difference is as follows:” with “The differences are as follows:”.

AC: Done.

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RC: Line149: Add “the”

AC: Done.

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RC: Line150: Change “which” with “where the”.

AC: Done.

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RC: Line154: Add “the”

AC: Done.

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RC: Line156-157: Change “combines” with “combining”. Change “is” with “are”. Add “an”

AC: Done.

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RC: Line160-161: Add “considering”.

AC: Done.

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RC: Line160-161: Change “To better validate the model before predicting future change, we compared output to the actual land use 2015.” with “To better validate the model before predicting for future change, we compared the output with the actual land use 2015.”

AC: Done.

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RC: Line177: Change “scenario” with “scenarios”.

AC: Done.

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RC: Line178-181: Change “which” with “with”. Add “a”. Change “followed to” with “following”.

AC: Done.

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RC: Line186: Change “that is considered” with “to be”.

AC: Done.

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RC: Line192-193: Change “Overall, the model accuracy outputs are measured shows an acceptable or good level of prediction, therefore the model is suitable for predicting changes in land use the Shanghai.” with “Overall, the measured model accuracy outputs showed an acceptable or good level of prediction, therefore the model is suitable for predicting changes in land use of the Shanghai area."

AC: Done.

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RC: Line205-208: Change "project, compare" with "projected, compared".

AC: Done.

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RC: Line211: Change "due to" with "since".

AC: Done.

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RC: Line216: in the text GP always comes before GE…, would avoid confusion…

AC: Thanks to the reviewer's suggestion, we have switched the positions of GE and GP in the figure.

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RC: Line218: Change "Simulation results of different scenarios in 2030 and 2050." with "Simulation results of different scenarios in 2030 (top) and 2050 (bottom).".

AC: Done.

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RC: Line227: Change "the submerged area increasing trends with time" with "the submerged area is increasing with time".

AC: Done.

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RC: Line234: Change the format

AC: Done.

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RC: Line237: Add "area"

AC: Done.

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RC: Line246: Change "new growth urban area" with "new grown urban areas".

AC: Done.

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RC: Line247: Add “scenarios”

AC: Done.

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RC: Line249: Change “with the rapid expansion of the urban” with “with a rapid expansion of the urban area”.

AC: Done.

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RC: Line253: Change “be reached” with “reach”.

AC: Done.

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RC: Line255: Change “due to the average altitude of Shanghai is around 4 m” with “since the average altitude of Shanghai is only around 4 m”.

AC: Done.

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RC: Line256-258: Change “Inundate of each land use type under different scenarios. The inundated areas of different land use types, including cropland, woodland, grassland and urban land, were calculated for each scenario, where a indicates new growth area of urban affected by flooding.” with “Inundation of each land use type under different scenarios. The inundated areas of different land use types, including cropland, woodland, grassland and urban land, were calculated for each scenario, where a indicates new grown areas of the urban class affected by flooding.”.

AC: Done.

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RC: Line266: Add “it”

AC: Done.

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RC: Line279: Change “future flood risks in coastal areas also are not fully reflected through using of hydrodynamic models,” with “future flood risks in coastal areas are also not fully reflected through the use of hydrodynamic models,”.

AC: Done.

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RC: Line283: Change “not be” with “is not yet”.

AC: Done.

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RC: Line285: Add “of”

AC: Done.

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RC: Line291: Add “act”

AC: Done.

---

RC: Line300: Add “which”

AC: Done.

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RC: Line303: Change “SLR” with “sea level rise”.

AC: Done.

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RC: Line320: Add “the”

AC: Done.

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RC: Line326: Change “potentially” with “potential”.

AC: Done.

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RC: Line329: Add “areas”

AC: Done.

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RC: Line330: Add “global warming”

AC: Done.

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RC: Line331: Delete “have”

AC: Done.