Reviewer 1

 # Comment 0

My concerns were well addressed by the authors. Thank you to the authors for your revisions, and for providing the additional information and data requested. The new dataset included with the revised submission ("global spatially explicit map of urban development probability") will be another useful resource. I recommend to accept the paper.

Response: thank you for your positive comments and suggestions to improve our manuscript.

Reviewer 2

 # Comment 0

The manuscript describes the development details of a future fractional urban impervious surface area (ISA) dataset for 2015-2100 at a 5-year interval. I think the newly developed future urban ISA dataset will be very useful for understanding the impact of future urbanization on the ecosystem. I have reviewed the revised manuscript and the point-by-point responses to the comments. The authors have revised the manuscript following the suggestions and comments closely. They did a lot of work in quantifying the uncertainties of data harmonization, which increased the reliability of the model and dataset. Overall, the authors have done a good job in addressing these comments, and the manuscript has been improved a lot. But I still have several small suggestions and provide them in the specific comments.

Response: thank you. As suggested, we have carefully revised our manuscript and provided a detailed point-by-point response below.

 # Comment 1

P4, Line 16-19. "Given that there are currently no urban fractional ISA dataset in high spatial resolution (e.g., 1km) directly obtained from satellite observations, here we adopted the commonly used strategy through spatial aggregation from high-resolution (e.g., 30m) urban extent data to derive the ISA time series data for modeling."

As I know, there are at least two fractional impervious surface area datasets have been developed. For example, the Global Man-made Impervious Surface (GMIS) developed by NASA Socioeconomic Data and Applications Center could be available since 2017, which can be accessed at https://sedac.ciesin.columbia.edu/data/set/ulandsat-gmis-v1.

Response: thank you for this great suggestion. We agree that the GMIS data are fractional products with detailed information on impervious surfaces within each 30m grid. However, as we stated in our manuscript, the temporal dynamics of urban fractional information derived from satellite observations are crucial to our model development with improvements, which needs to be improved in the GMIS data due to its one epoch (i.e., 2010). As such, we clarified this issue and rephrased our descriptions in our manuscript as below.

"Probably due to the absence of long-term and fine resolution annual global urban extent time series data (Li et al., 2015; Shi et al., 2017; Song et al., 2016; Brown De Colstoun et al., 2017), characterizing the temporal pattern of urban sprawl dynamics has not been comprehensively explored, in particularly coupling with urban CA models. Although urban fractional data with detailed impervious surfaces have been developed recently, such as the Global Man-made Impervious Surface (GMIS) data (Brown De Colstoun et al., 2017),

information of long-term urban fractional dynamics is still highly required for urban CA model improvement (Page 3, Line 17-22).

"Given that there are currently no long-term urban fractional (i.e., ISA) dynamic products in high spatial resolution (e.g., 1km) directly obtained from satellite observations (Brown De Colstoun et al., 2017), here we adopted the commonly used strategy through spatial aggregation from high-resolution (e.g., 30m) urban extent data to derive the ISA time series data for modeling." (Page 4, Line 20-23)

Comment 2

P7, Line 15, the stochastic disturbance item is missed in equation (4), and no description of the 'SP' item.

Response: we are sorry about it. As suggested, we have included the stochastic disturbance item (SP) in Eq. (4) in our revised manuscript, with details provided in our Supplementary Texts.

$$"P_{dev} = P_{suit} \times \Omega \times Land \times SP \quad (4)$$

where P_{dev} indicates the development probability; P_{suit}, Ω, $Land$, and SP represent the suitability surface, neighborhood, land constraint, and stochastic disturbance, respectively. Details of these parameters can be referred to in the Supplementary texts." (Page 7, Line 19-22)

Comment 3

P9, Line 4-6. "Here we assumed the trend of urban sprawl at the state level is consistent with that at the country level, as population and GDP change are commonly estimated at the country and regional scale".

This is a simple downscaling method to get the future urban land area demand of each state, and may result in some uncertainties as the urbanization stage varies. It is also contradictory to the description in the first paragraph of section 3.1, indicating the urbanization stages information was not used in the future urban land area prediction. The better way to downscale the future urban land area from country to state is to set the urbanization stage as a weight.

Response: thank you for these valuable suggestions. The modeling of future urban dynamics includes two components: 1) urban area estimation within a given administrative unit and 2) spatial fractional growth of urban extent. As stated in the first paragraph of Section 3.1, we characterized different urban growth patterns at the state level, considering their varying urbanization stages. This is helpful to deepen our modeling mechanism at the grid scale with gradual ISA change. Whereas for the future urban land area, we directly harmonized the trend gained from the integrated assessment model (IAM) under diverse SSP-RCP scenarios, where the urban area was commonly estimated by the population and GDP without explicitly considerations of urbanization stages (*Hurtt et al., 2011*). As suggested, this factor could be considered in future urban land area estimation by weighting the urbanization stages. We discussed this issue in our revised manuscript.

"It is worthy to note that here we directly inherited the future trend of urban areas from the integrated assessment model (IAM) under diverse SSP-RCP scenarios (Hurtt et al., 2011) across different states in each country, harmonized with historical urban extent dynamics

from satellite observations. However, the urbanization stage was not considered in those IAM models, which were mainly driven by demographical and socioeconomic factors. In the future, the urbanization stages could be a weight factor when downscaling urban areas from country to state." (Page 14, Line 18-22)

Comment 4

One of the corresponding authors published related work in 2019 and 2021 (Li et al., 2019; Li et al., 2021). The two papers also simulated the future urban land expansion based on the nightlight data derived urban land. So, what are the improvements of the newly developed dataset compared with previous work? It can be included in the discussion.

Response: thank you. Compared to our previous work (*Li et al., 2019; Li et al., 2021*), this study developed an ISA-based urban CA model that considers long-term temporal contexts of urban evolution from satellite observations, enabling urban fractional modeling at the grid scale. Such a modeling mechanism is quite different to those studies with binary conversions. As suggested, we highlighted it in our revised manuscript.

"Compared to other global urban products under future scenarios, our results can promote future urban land use efficiency by simulating gradual urban fractional change with notably improved spatial details (i.e., 1km) (Li et al., 2021; Li et al., 2019a; Gao and O'neill, 2020; Chen et al., 2020a)." (Page 17, Line 9-11)

Comment 5

Same as Reviewer 2, Fig. S6. I note that there will be no low-density ISA area in the city you show after 2060, and it seems that most of the urban area have the same ISA fraction. It also existed in other metropolitan areas (e.g., Fig. 10 and 11, New York city).

This may be resulted from the spatial allocation algorithm. Specifically, the grid cell with high suitability always has more ISA increment. On the other hand, no enough newly developed urban land grid cells to allocate the increased ISA. Thus, there should be a balance between urban land expansion and ISA increase in the existing urban land pixels. It will be good to improve the spatial allocation model by constraining the filling of urban inner space and expansion of urban bound. Thus, there should be some discussions about the uncertainties of the spatial allocation model.

Response: thank you for raising this comment. Yes, we acknowledged this effect, whereas it can be explained from the following two aspects. On the one hand, urban growth in these cities (e.g., Atlanta) almost plateaued after 2060, primarily determined by the trend in LUH2. On the other hand, although most pixels in the urban fringe areas show similar ISA values (i.e., almost the same color), their values are different regarding the ISA gain within each period (Fig. R1). In general, the ISA-based growth in these cities (e.g., Atlanta) was also related to the calibrated state-specific Sigmoid growth curve, which was determined primarily by the long-term urban extent time series from satellite observations.

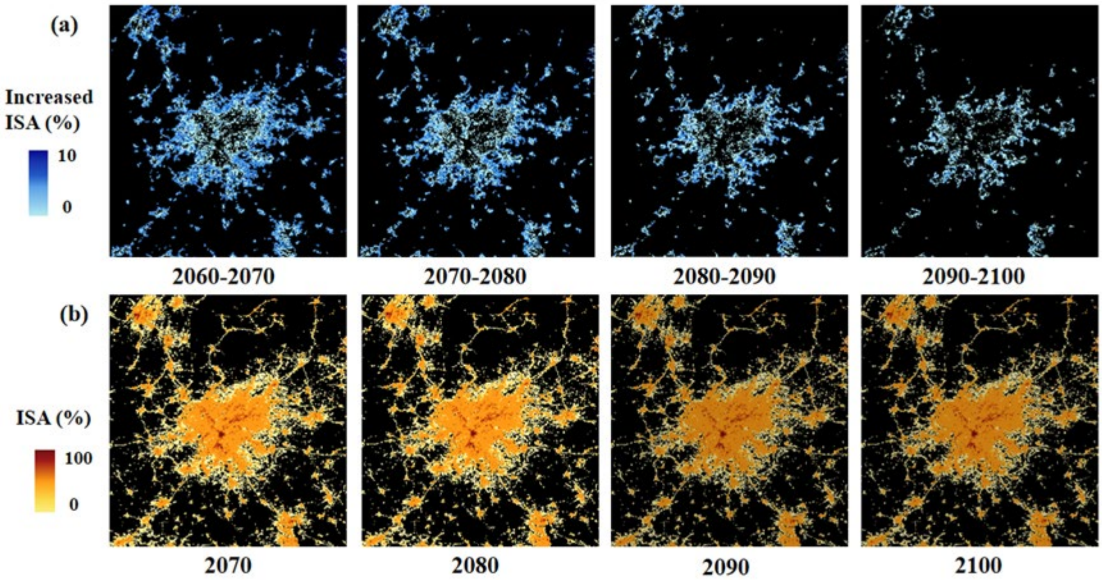

Fig. R1. The distribution of ISA increase within a given period (a) and the corresponding ISA value at the end year (b) in Atlanta (US), under the middle of the road (SSP2-RCP4.5).

As suggested, we also discussed the uncertainties of the spatial allocation model in our revised manuscript. It is worth noting that grids with higher ISA increments were mainly determined by the suitability values and the urbanization level (i.e., indicated by ISA) during the iteration. For instance, grids with relatively high ISA values are associated with lower growth rates than those at the Sigmoid curve's middle stage. Also, although we introduced the stochastic term to promote new seeds of urban development in our model, the probabilities for those non-urbanized pixels are relatively low for development in the future, given that the urban growth is relatively slow when the ISA value is very low (i.e., close to zero). We clarified this issue in our revised manuscript as below.

"In addition to the suitability, the state-based trend of ISA growth from satellite time series data may also impact the ISA growth at the pixels, particularly for those with extremely low and high ISA values. It's worth noting that the ISA-based growth in our modeling mechanism may underestimate the growth of pixels with very low ISA values or non-developed, although the stochastic disturbance term has been involved in our modeling mechanism. Meanwhile, the rate of urban fractional growth is slow for pixels around the city centers with relatively high ISA values. Appropriate strategies by constraining the filling of urban inner spaces and the expansion of urban bound should be developed to improve the spatial allocation of urban CA model." (Page 11, Line 15-21).

#Reviewer 3

Comment 0

The authors have developed a global urban fraction change dataset with a resolution of 1 km from 2020 to 2100 (with 5-year intervals), covering eight socio-economic development pathways and climate change scenarios. The researchers used an S-shaped growth model and annual Global Artificial Impervious Area (GAIA) data to describe the ISA growth pattern over the past few decades (i.e., 1985-2015). By combining the ISA-based growth mechanism with the CA model, the researchers quantitatively evaluated state-specific urban CA models on a global scale. This method can capture the spatially explicit changes in ISA and the gradual ISA changes within pixels, which is very useful for supporting quantitative analysis of ecological and environmental changes caused by urbanization at a fine scale.

Overall, this paper provides a novel and practical approach and a valuable dataset for studying global urbanization. The authors have provided detailed descriptions of their data and methods, and have provided ample evidence to support their conclusions. Therefore, I believe this paper can be accepted.

Response: thank you for the positive comments. As suggested, we have carefully checked the missing statement in our updated manuscript.

Comment 1

However, there is a minor spelling issue that needs to be corrected. I could not find the definition of SP in Eq. 4. Please check this issue.

Response: thank you for your suggestions. We have included the definition of the stochastic disturbance item (SP) in equation (4) in our revised manuscript and more details of these spatial parameters can be found in the Supplementary texts.

$$"P_{dev} = P_{suit} \times \Omega \times Land \times SP \quad (4)$$

where P_{dev} *indicates the development probability;* P_{suit}, Ω, $Land$, *and* SP *represent the suitability surface, neighborhood, land constraint, and stochastic disturbance, respectively. Details of these parameters can be referred to in the Supplementary texts." (Page 7, Line 19-22)*