Reply to the comments by Referee #1

In this document, the review comments are in black, our responses are in blue.

Referee #1

This paper downscales national GDP estimates across a global grid of 30 x 30 arcsec pixels. This is an interesting objective and recognizes that little work has indeed been done to move beyond people-based GDP-scaling to one that also considers the distribution of economic activities. The methodology as well as several involved assumptions and uncertainties are described transparently.

However, I have several concerns regarding this paper and the quality of the dataset. In addition to the detailed comments provided below, overall, it appears that the paper attempts to integrate two papers rather than producing a single focused paper; the paper namely both documents the creation of a global GDP map, and attributes much of the paper's attention (see e.g. the discussion section) on Thailand and Thai-specific issues.

> Thank you very much for your constructive comments which are very helpful for improving the manuscript. We made a plan for modifying the manuscript with additional background information. These are to be included in the revised version of the manuscript.

(1) The paper augments established European Commission data to differentiate global land use by residential, non-residential, and cropland uses. However, it is assumed (p.6) that residential use ("RES") represents the service sector of the economy. That is a very rough proxy given that this includes the housing of those who work in non-residential areas (the "industrial sector"), as most people do.

> We are sincerely grateful to Referee#1 for the comment. This paper focuses on "where GDP is generated" for the allocation of GDP, and does not consider "where the employees and users who generate GDP live." "Where the employees and users who generate GDP in each sector live" requires consideration of transportation networks and the estimation becomes complicated, so this is not considered in this paper.

Focusing on "where GDP is generated in each sector," it is possible to distribute simply by using existing global datasets by making the following assumptions:

•The service sector generates GDP in the Residential area where direct consumers exist.

•The industrial sector generates GDP in the Non-residential area where factories are located.

We understand that the fact that we do not consider the relationship between GDP production locations for each sector and workers' residential spaces is a limitation of this

study, as you pointed out. We plan to add this point to the Limitations section within the Discussion part.

Moreover, the non-residential areas being classified as the 'industrial' sector, if I understand the classification scheme correctly, pools together any services and manufacturing and other sectors as 'industrial,' separately from 'services'. This appears to be inappropriate and thus call into question whether the global map is able to distinguish between sectors. The data do appear to possibly reasonably allow for a global GDP map, without sectoral differentiation, that downscales national GDP estimates given local non-residential land use.

> Thank you for your valuable comments and suggestions. We appreciate your attention to detail and the opportunity to clarify our industry classification.

To address your concern regarding the clarity of industry classification in this paper, we have used the following definitions based on the International Standard Industrial Classification (ISIC) Rev 4 codes from the World Bank's World Development Index:

Agriculture: ISIC 01-03 (A)

Service: ISIC* 50-99

Industry: ISIC 05-43 (B-F)

* It should be noted that only the Service sector is based on ISIC Rev. 3

For further details, please refer to the following URL:

ISIC Rev 4, https://unstats.un.org/unsd/publication/seriesm/seriesm_4rev4e.pdf

ISIC Rev 3,

https://unstats.un.org/unsd/classifications/Econ/Download/In%20Text/ISIC_Rev_3_English.pdf

This means that our "industry" classification does not include "wholesale" or "professional services," which are categorized under "Service" in the World Bank's definitions. We believe that our dataset, with this classification method, aligns with widely used classification approaches. We acknowledge that this definition was not explicitly stated in the original manuscript. In response to your feedback, we have added the classification details mentioned above to the manuscript to ensure clarity for our readers.

Additionally, we present a comparative analysis between the National Land Use Database (NLUD) land classification data in the United States and the Global Human Settlement Layer (GHSL) data (RES/NRES categories) used in this paper.

The following table (Table R1) illustrates the proportion of areas classified as RES and NRES in GHSL within the service and industrial sectors of the NLUD land classification. The table reveals that a significant portion of service areas is identified as RES areas, while approximately half of the industrial areas are classified as NRES areas.

Table R1: Percentage (Area-Based) of GHSL Residential Area (RES) and Non-Residential Area (NRES) within NLUD Land Use Categories (Service and Industry)

	Service	Industry
NRES	9.2%	41.6%
RES	90.8%	58.4%

Based on this table, we argue that using RES areas as a proxy for service industries is reasonable. For NRES areas as a proxy for industrial industries, the results suggest that large-scale factories are classified as NRES areas, while small to medium-sized factories adjacent to residential areas are classified as RES areas. Therefore, assigning all industrial activities to NRES areas may not accurately represent industrial GDP in regions with small to medium-sized factories, which is a significant limitation of this study. This limitation will be added in the revised version of this paper.

However, we believe that this limitation does not significantly undermine the importance of our research. Given the absence of detailed global land classification data, finding a perfect proxy is challenging. Despite the inability to accurately represent the locations of small to medium-sized factories, which account for approximately 30% of manufacturing GDP (in the US, for example), our dataset still captures the industrial GDP distribution of large-scale factories, which contribute to the remaining 70% of GDP.

(2)Claims such as "in the United States, industrial GDP is widely dispersed regardless of urban areas" are interesting but also bold, given that the observation comes from the East coast of the USA which is relatively agglomerated (how are "cities" defined in the paper?) and paired with serious uncertainty, given that the validation of the global dataset is done for Thailand but not for the rest of the world. Ideally, analytical claims should be made only for regions for which the data are also validated to not over-assert the validity of the data that underpin the insights. In any case the validity of the findings could be asserted more carefully. It would also be helpful to compare the insights against to standing knowledge,

whether from estimates in other papers or also reports (e.g., such as the 2012 'Urban America' McKinsey report).

> Thank you for pointing out the limitation of our current validation, which focuses solely on Thailand. We acknowledge that this raises concerns about the generalizability of our findings to other regions.

To address this, we plan to expand our validation efforts in the revised manuscript. Specifically, we will conduct a similar sub-national scale validation for major regions beyond Thailand, with a primary focus on the United States, utilizing statistical data at that scale. This additional analysis will strengthen the credibility of our data and provide a more robust assessment of its applicability to diverse economic contexts.

(3) The paper could do more to underpin assumptions with field knowledge, in particular on how the assumptions could drive the outcomes observed in the global map. For instance, on p.6 it is stated that "the service GDP was distributed only in pixels within cities and the amount of distributed GDP was proportional to the population density of the city where the pixel is located". This appears to in effect assume away any service sector presence outside of urban areas, which is unrealistic, and that the amount of GDP attributed to a pixel is contingent on city density —other than the size of the city— which indeed drives productivity but not overall output levels as those instead respond predominantly to city scale.

> Thank you for your comment regarding the definition of service GDP production areas in our study. As you correctly pointed out, our current methodology confines service GDP generation to areas within urban polygons as defined by the GRUMP dataset.

We acknowledge this simplification and would like to explain our rationale. GDP generated outside of urban areas is generally significantly smaller in magnitude compared to GDP within urban centers. Furthermore, obtaining reliable proxies for distributing these minute amounts of GDP across vast rural areas presents a considerable challenge. Therefore, we believe that distributing service GDP exclusively within urban areas offers a reasonable approach when creating a spatially explicit GDP map. This assumption is supported by our comparative analysis in Thailand, where we examined the impact of including or excluding this "city effect."

Additionally, as highlighted in the manuscript (line 136), existing research indicates a strong correlation between urban population density and service sector GDP, rather than the total urban population. Furthermore, our preliminary analyses have confirmed that using population density yields service GDP classifications that more closely align with observed statistical data. When considering population density in this study, we calculated it using the population and total area of each urban polygon. Therefore, urban size is considered on a city-by-city basis (as larger cities contain larger populations and total areas). This reinforces our confidence in the chosen methodology.

Further comments

- The narrative flow and grammar should be checked closely throughout the manuscript (see, e.g., the first five sentences of the abstract).

> Thank you for your helpful feedback. We have revised the abstract as follows, incorporating your suggestions:

"Accurate global risk assessment of economic losses from natural disasters, accounting for diverse land uses, is crucial. However, globally consistent, high-resolution, sector-specific economic data at the pixel level remain unavailable for assessing exposure to localized hazards like floods. Here, we leverage novel land-use data to generate a global, spatially disaggregated map of sector-specific gross domestic product (GDP). We produced three 30 arcsec resolution global GDP maps for 2010, 2015, and 2020, representing the service, industry, and agriculture sectors. First, we observed that the spatial correlation between industrial GDP distribution and urban centers, where service GDP is concentrated, varies internationally. For instance, US industrial GDP is broadly dispersed independently of urban areas, while Indian industrial GDP clusters near urban areas. Second, validating against subnational statistics for Thailand, where ground-truth data exist, we found that traditional population-based GDP maps yielded a 63.0% relative error in sectoral GDP at the subnational level compared to official statistics. Our new sector-specific GDP map reduced this error to 26.2%. Subsequently, integrating this map with sector-level business interruption (BI) loss estimates from river flooding, we demonstrated that sectoral loss ratios to total loss varied considerably with flood hazard spatial distribution. Using the new GDP map, the estimated total loss approached reported values, although some discrepancies in sectoral loss ratios persist, highlighting the need for further refinement of loss-estimation models."

We are also planning to make further revisions throughout the manuscript based on your other comments.