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S. Fuchs, M. Keiler, A. Zischg: The hostel or the warehouse? Spatiotemporal exposure assessment for natural hazards

Dear Referee,
We kindly would like to acknowledge your detailed comments on our manuscript. In the following we will answer these comments as well as your concerns and suggestions step-by step. In red, you will find comments while in blue we included suggestions to improve the current version on the manuscript. Once the NHESSD interactive discussion is closed by the Editor, and we will have the permission to revise the manuscript, these parts will be used to improve the manuscript.

In the paper an amazing and outstanding data set containing the total building stock in Austria is analysed with regard to exposure to mountain hazards (torrential floods and avalanches) and river floods. The main aim is to investigate whether rising disaster losses can be attributed to land use development and growing exposure of assets.
The paper is well-structured and well-written. Due to the uniqueness of the data set (apart from a flood exposure analysis for the Netherlands, to my knowledge, such detailed data have not been analysed for an entire country) and the multi-hazard perspective of the investigation the paper should be considered for publication. The analysis is well done. However, a few amendments should be made before the paper can be published. In particular, the discussion section should be revised and extended. In the current version too many results are repeated and too few explanations for the findings are provided. Furthermore, the results are rarely compared with the results of the mostly local studies that were mentioned in the introduction; some topics are completely missing. To be more precise, I would suggest following a similar structure for each aspect. An aspect could be e.g. the exposure of the total stock building to natural hazards. The discussion could then be structured as follows:
- What was the average outcome of the analysis?
- Which regional differences were found? Which regions were above average, which ones below (Min/Max)? Why?
- Which differences occurred with regard to the different hazards? – floods, torrential processes, avalanches and multiple hazards – in general and in the regions – How can these patterns be explained?
- Are there comparable local studies? Are the results consistent? If not – any explanation?
- How certain/uncertain is the analysis?
- What are the implications of the results?

Thanks for your suggestions. We will re-write the discussion section in order to be clearer and to better link the introduction section with the identified gaps to the results. Moreover, we will make changes to the introduction section (pages 2421 and 2422) in order to be more concise. This includes also a re-formulation of the research gap.

> Focusing on exposure, the effectiveness of natural hazard risk management depends on the availability of data and in particular an accurate assessment of elements at risk (Jongman et al., 2014), which also requires a temporal and spatial assessment of their dynamics. It has been repeatedly claimed with respect to flood hazards in Europe that the main driver of increases in observed losses over the past decades is increased physical and economic exposure (Bouwer, 2013; Hallegatte et al., 2013; Jongman et al., 2014). Until now, however, in mountain regions of Europe such conclusions remain fragmentary since property data has only been available on the local scale as a result of individual case studies. These – often conceptual – studies related to the temporal dynamics of exposure to mountain hazards include both the long-term and the short-term evolution. Long-term changes were found to be a result from the significant increase in numbers and values of properties endangered by natural hazard processes, and can be observed in both rural and urban mountain areas of Europe (Keiler, 2004; Fuchs et al., 2005; Keiler et al., 2006a; Shnyparkov et al.,

2012). Short-term fluctuations in elements at risk supplemented the underlying long-term trend, in particular with respect to temporary variations of people in endangered areas and of vehicles on the road network (Fuchs and Bründl, 2005; Keiler et al., 2005; Zischg et al., 2005). These results suggest that the spatial occurrence of losses is not so much dependent on the occurrence of specifically large events with high hazard magnitudes but more a result of an increased amount of elements at risk in endangered areas (Fuchs et al., 2012). Most of the recent works, however, rely on local object-based studies (Zischg et al., 2004; Fuchs et al., 2012) or aggregated land use data (Bouwer et al., 2010; de Moel et al., 2011; Cammerer et al., 2013), leading to substantial uncertainties if up-scaled to a larger spatial entity (de Moel and Aerts, 2011; Jongman et al., 2012a). Because of the limited data availability, comprehensive object-based and therefore spatially explicit analyses have thus not been extended beyond the local level (Kienberger et al., 2009; Huttenlau et al., 2010; Zischg et al., 2013), and studies focusing on the national level in mountain regions using such data remain fragmentary (Fuchs et al., 2013).
To contribute to this gap, we show how detailed property level data can be used to improve the understanding of trends in hazard exposure on a national level. We will explicitly focus on dynamics in elements at risk, neglecting (a) any changes in the natural process dynamics due to underlying changes in the natural system including the effects of climate change, (b) any shifts in exposure due to the implementation of technical mitigation measures, and (c) any changes in vulnerability. This allows for the assessment of dynamics in property exposure, and will provide insights in the impact elements at risk may have on changing risk in mountain environments leaving other risk-contributing factors constant.

In addition, the following aspects should be discussed:
- For the flood exposure analysis the 100-year flood was taken, while the analysis of the mountain hazards is based on events with return periods of 150 years. You should discuss how this difference may influence the results and what role the chosen return period could play. Would the outcome be very different if you investigated the 300-year events?

We do not want to explicitly focus on the discussion of whether or not probabilities/design events are useful I the context of hazard and risk analysis. We will modify the methods section in order to better explain our choice. When taking the 1/300 flood event, the number of exposed buildings will change surprisingly low to 246,000 compared to 219,000 using the 1/100 flood event. We will include this number somewhere in the discussion section (limitations, uncertainties).

> Hazard information was compiled from two different sources. For mountain hazards, available local-scale hazard maps were used, and for river flooding, the results of a nation-wide flood modelling were available. This method of data combination was chosen because (a) for mountain hazards, no nation-wide modelling is available in Austria and (b) for river flooding, no nation-wide compilation of hazard maps is available so far since in contrast to mountain hazards, river flooding lies within the competency of the individual Federal States.
In Austria, the method for hazard mapping is regulated by a national legal act (Republik Österreich, 1975) and an associated decree (Republik Österreich, 1976). The implementation of these regulations is assigned to the Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW) and administrated by the governmental departments of the Austrian Service for Torrent and Avalanche Control (WLV). Since the mid-1970s, these governmental departments had been progressively compiling hazard maps for the communities affected by mountain hazards based on available data and information on hazards as well as modelling exercises (Holub and Fuchs, 2009). These hazard maps are mostly compiled on a detailed local scale of 1:2,000 to 1:10,000 in order to decide whether or not individual plots are affected by the different hazard types. Hazard maps usually refer to individual catchments within individual communities, and depict the area affected by a design event with a return period of 1 in 150 years. So far, 92 % of all communities with an obligation for hazard mapping in Austria do have a legally valid hazard map. According to the Decree on Hazard Zoning (Republik Österreich, 1976), red hazard zones indicate

those areas where the permanent utilisation for settlement and traffic purposes due to the exposure to the design event is not possible or only possible with extraordinary efforts for mitigation measures. Yellow hazard zones indicate those areas where a permanent utilisation for settlement and traffic purposes is impaired by the design event. Red and yellow hazard zones of different catchments and multiple hazard types may overlap, and as a result elements at risk may be exposed to more than one hazard type (multi-exposure, Kappes et al. 2012a,b). While in some catchments there may be a temporal separation of processes (snow avalanches during winter and torrential processes in summer) affecting the same elements at risk, in other catchments there may be a temporal overlap of different processes occurring in the same period of time (debris flows from the tributary and flooding in the receiving channel, both affecting the same elements at risk). The available red and yellow hazard zones were provided digitally by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management in March 2013 in order to select exposed property.

- Furthermore, the differences between the hazards should be reflected with the land use regulations that are in place. This is briefly mentioned on p. 2436, line 6/7, but it is hardly understandable. Provide some more information (in section 4, not only in section 5).

We will include this topic in a revised version.

- The exposure of people is not discussed well. Please add.

Thank you for this comment. Together with the comments of other referees on exposed citizens we decided to exchange the set of maps (right column) and to include information on exposed citizens. The additional data will then also be included in the results section.

- I like the very rough estimate on the exposure of the building stock until 2100. However, no removal of buildings is considered. In a timeframe of 100 years, it is likely that a given percentage of buildings will be destroyed. At least, this aspect should be mentioned.

Indeed, we did not consider removal since such information is not available for the future (the existing data we used contains information on removed buildings in the attribute table. But we did not explicitly focus on this topic here). Usually, a removed building is replaced by another (new) one, which then is again included in our set of calculations.
Generally, these ideas are already included and will remain in a revised version (modified conclusion and discussion section).

> While some regions have shown a clearly above-average increase in assets, other regions were characterised by a below-average development. [this is in line with other studies on exposure such as Fuchs and Bründl (2005) who had shown on a community level that there are highly variable trends in the development of population and building numbers in the canton of Grisons, Switzerland. Some communities even had shown an absolute decreasing trend in both numbers since the 1950s] This mirrors the topography of the country, but also the different economic activities: as such, hotels and hostels were found to be extraordinary prone to mountain hazards, and commercial buildings as well as buildings used for recreation purpose to river flooding. Residential buildings have shown an average exposure, compared to the number of buildings of this type in the overall building stock.

Furthermore, the numbers demonstrate well that – besides prevention by spatial planning – other risk reduction measures are needed to decrease exposure. Protective measures are mentioned. I feel a reduction of vulnerability and the role of object-based mitigation measures, retrofitting etc. should also be discussed.

Taking the definitions of risk, exposure and vulnerability, exposure will not be reduced if the vulnerability is reduced by e.g., local structural protection. A discussion on these issues can be found in our works related to vulnerability (e.g., Totschnig et al., 2011 and Totschnig and Fuchs, 2013).
Totschnig R, Fuchs S (2013) Mountain torrents: quantifying vulnerability and assessing uncertainties. Engineering Geology 155:31-44
Totschnig R, Sedlacek W, Fuchs S (2011) A quantitative vulnerability function for fluvial sediment transport. Natural Hazards 58 (2):681-703

Some minor aspects are:
The title should make clear that the data are from Austria and the meaning of the first part of the title is hard to understand. I suggest: "Spatiotemporal exposure analysis of Austrian buildings to multiple hazards".

Our suggestions is to change the title to "A spatiotemporal multi-hazard exposure assessment based on property data"

Abstract: In its current version, the abstract is lacking important information and there is (too much) focus on the results. You should start with a sentence explaining the problem and your aim. In addition, the data base that was used should be mentioned and the methods should be briefly described.

We will improve the abstract according to your suggestions.

p. 2421, line 11-13: I do not agree with the description of Fig. 1. I can't detect a decrease of 60 % between 1960 and 2000.

This suggestion is absolutely understandable since so far the description is a bit narrow. In a revised version we will shift this statement to a more detailed comment, see below.

> In Fig. 1, the annual number of damage-causing mountain hazards occurring in the Eastern European Alps (Republic of Austria) is shown. The underlying event documentation focused on the hazard processes but no further detailed information on individual losses is provided. The data for the period 1900-2014 is describing snow avalanches, torrential flooding, landslides and river flooding, as well as the 10 years moving average of the total amount per year. While between 1900 and 1959 an increase in the annual number of hazard events of around a factor of four can be concluded – presumably also due to an increased event observation – between 1960 and 1964 a decrease of around 50 % is traceable, followed by an increase due to the excessive events in 1965 and 1966. Since then, the 10 years moving average is steadily decreasing again, which is in line with the increasing efforts into technical mitigation measures since the mid-1960s (Holub and Fuchs, 2009). Due to the high number of events in 1999, 2002, 2005 and 2009, however, the curve is again increasing to around 440 events per year. This shape is in clear contrast to the trends repeatedly shown for world-wide data and indicating an exponential increase in the number of events since the 1950s (e.g., Keiler, 2013). Apart from hazard dynamics (the natural frequency and magnitude of events), decreasing dynamics in mountain hazard losses may result from (a) increased efforts into technical mitigation (Keiler et al., 2012), (b) an increased awareness of threats being consequently considered in land-use planning (Wöhrer-Alge, 2013; Thaler, 2014), both leading to less exposure, and (c) a decline in vulnerability (Jongman et al., 2015) which will not be further considered in the following sections. During the period of investigation, specific years with an above-average occurrence of individual hazard types (…)

p. 2422, line 3 and 4: rephrase (the relative clause doesn't make sense)

The wording will be changed.

> Focusing on exposure, the effectiveness of natural hazard risk management depends on the availability of data and in particular an accurate assessment of elements at risk (Jongman et al., 2014), which also requires a temporal and spatial assessment of their dynamics. It has been repeatedly claimed with respect to flood hazards in Europe that the main driver of increases in observed losses over the past decades is increased physical and economic exposure (Bouwer, 2013; Hallegatte et al., 2013; Jongman et al., 2014). Until now, however, in mountain regions of Europe such conclusions remain fragmentary since property data has only been available on the local scale as a result of individual case studies.

p. 2422, 13 and 21 (and several other lines): I'm not a native speaker, but I don't like the phrase "endangered area". In the context of natural hazards, I would suggest "hazard-prone area" or more specific "flood-prone area".

Thanks, the phrases will be changed.

p. 2424, line 4/5: eHORA is not unique. In fact, after the 2002-flood, the German ZÜRS-system served – in many aspects – as a prototype for HORA. Meanwhile, the information content of HORA is, however, much larger than the information provided by ZÜRS.

We will change the paragraph to be more precise.

> This study is based on two different datasets, (a) hazard information providing input to the exposure of elements at risk, and (b) information on the building stock combined from different spatial data available on the national level. We considered hazard information for river flooding, torrential flooding including debris flows, and snow avalanches since these hazard types are responsible for the majority of damages in the European Alps (Sinabell and Url, 2007; Hilker et al., 2009). In the following, the composition and preparation of datasets is described.
(…)
For river flooding data from the digital eHORA platform (http://www.hochwasserrisiko.at/) was used. This platform provides information on the exposure to river flooding using web-GIS techniques, and has been jointly implemented by the Federal Ministry of Agriculture, Forestry, Environment and Water Management and the Austrian Insurance Association in terms of a public-private partnership on more than 25,000 of a total of 39,300 river kilometres (Stiefelmeyer and Hlatky, 2008). By using a hydrological model probabilistic runoff data for a 1 in 30, 100, and 300 year event was computed and converted into water levels and flood zones based on a nation-wide DEM and a digital slope model. Following an ongoing discussion on the harmonisation of hazard mapping in Austria (Rudolf-Miklau and Sereinig, 2009), the 1 in 100 year event was provided by the Austrian Insurance Association in terms of a vector representation of flood plain boundaries and taken for our analysis.

Section 2.2: Some information on the building classification shown in Tab. 3 and Fig. 2 should be provided. What is a pseudo-building? Give some examples for "other buildings".

We will include this information in the caption of Table 3.

Tab. 3. Buildings exposed to natural hazards according to different building categories. Building category 13 (pseudo buildings) includes mobile and temporary accommodation facilities such as mobile homes and barracks if persons are living there, and building category 14 includes all other buildings not included in categories 1-13 (Statistik Austria, 2012).

Section 2.3: The methods that are referred to in the second paragraph (line 16 to 24, p. 2425) should be briefly described. The same holds for the population register (line 11 and 12, p. 2426).

We are wondering about this comment since in section 2.3, the method to model exposure is concisely presented. For the economic evaluation the respective sources are indicated in the manuscript.

Section 3.1; Fig. 3 and presentation of the results in the text: The legend is not well readable and I was wondering whether the mean number of buildings is really a good indicator.

Thank you for sharing your concerns here. Together with the comments of the other referees on Figure 3 we decided to exchange the set of maps (right column) and to include information on exposed citizens. The additional data will then also be included in the results section. We will provide the publisher with a high-resolution version of this Figure so that the elements should be accessible. With respect to your second concern the question of course is whether or not the mean over Austria is a good indicator. Our starting point was that we have to deal with dynamics in exposure and we would like to show these regions of the country where we have strong deviation from the averaged country trend. Therefore we chose the classical bipolar representation of data.

Section 3.2; Fig. 4 and presentation of the results in the text: In the figure caption, the explanations for the sub-figures a) to e) are missing. Please add.

Apart from the layout of Figure 4, which will be revised, we will also change the order of charts. Fig. (a) and (b) show the temporal development in terms of cumulative data, therefore the graphs are increasing (the number of buildings is increasing). Fig. 4 c will be converted in a new Figure 5 and separately discussed (also in the results section), we will also include the data on exposed citizens. Fig. (c) and (e) are based on averaged construction activities (the construction periods available in the dataset), and therefore the graphs are stepwise. We will also extend the Figure caption:

> Figure 4. Temporal development of building stock in Austria. In Fig. 4 (a), the cumulative absolute increase in the number of buildings is shown for non-exposed buildings and buildings exposed to snow avalanches, torrential as well as river flooding. In Fig. 4 (b), the relative increase of the building stock is shown for the total number of buildings and buildings exposed to snow avalanches, torrential as well as river flooding, 1919 = 1. In Fig. 4 (c) the average annual number of newly constructed buildings is shown for buildings exposed to snow avalanches, torrential as well as river flooding. In Fig. 4 (d) [in the current version = 4 (e)] the annual number of newly-constructed exposed buildings versus the total number of newly-constructed buildings is shown for buildings exposed to snow avalanches, torrential as well as river flooding.

p. 2430, line 18: “both curves” is not well referenced. Which two curves are meant?

We will revise this statement in order to be precise.

> What is evident, however, that the curves for river flooding and torrential flooding follow the same pattern over the study period.

Section 5: Of course, the provision of object data enables detailed analyses. However, I feel that some of the conclusions presented on p. 2436/2437 are not well supported by the performed analyses, but by a general preference of the authors to conduct object-based analyses. For example, in many cases the hazard information is uncertain and does actually not legitimate an object-based, precise analysis (or an object-based presentation of the analysis, also due to data privacy). The building values are still estimated and contain huge uncertainties as well. The allocation of investments to areas with higher assets at risk might lead to social injustice (richer regions are better protected than poorer regions). In addition, this could also be regarded as a kind of reward for mismanagement in former land use planning procedures. And I don’t find the proof in the paper that such an allocation of money could not be done by an assessment based on aggregated land data.

We will revise the results, discussion and conclusion sections in order to be more concise. Moreover, we will add some information on implications and limitations.

Table 1 and 2: Why is Fuchs and Zischg (2013) given as source? I thought the data were provided by the Austrian building register.

We will improve the captions accordingly. Even if the underlying preliminary but original study was done by Fuchs and Zischg (2013), the Tables in their present form contain new data and therefore we deleted this information.

> Tab. 1: Information on non-exposed buildings and buildings exposed to river flooding, torrential flooding and snow avalanches, aggregated on the level of Federal States in Austria. Additionally, information on multi-exposed buildings is given.
> Tab. 2. Information on non-exposed principal residents and principal residents exposed to river flooding, torrential flooding, and snow avalanches, aggregated on the level of Federal States in Austria. Additionally, information on multi-exposure is given.

Figure 2: The colours of the dashed lines for river and torrential flooding have to be swapped.

Thanks for this hint, we will correct the legend.

Figure 4: see above; the font is too small; why were “non-exposed buildings” considered in Fig. 4a, while the red line in Fig. 4b refers to “Total amount of buildings”. This should be consistent in both figures. Ideally, the information for both categories should be provided.

Please see our comments above.

Despite my critical comments I am really looking forward to a revised version of the paper.