Author's response to reviewers

The reviewers' comments and questions are marked in red while the author's response to the reviews including a list of all relevant changes made in the manuscript are marked in blue.

Response to reviewer 1

The work presented in this Brief communication includes a concise yet accurate description of the West European flood 2021 and several features on the inundation extent, particularly in agricultural areas. Information that is to date scarcely available. Although it brings limited research novelties, the contribution is timely. Another important point is that it comes with an extensive dataset of satellite derived inundation extent both in georeferences tiff and as images. I'm in favor of publication provided that the following comments are adequately addressed:

Respond: Thanks for your time to review the paper. Your comments are constructive and provide ways to improve the quality of the paper.

Figure 1: Please make country borders thicker. Now they are difficult to see

Respond: We have increased the line width of country borders, and changed the color map of precipitation. Now they are clear to see. See figure 2 (b) in the revised paper.

Figure 2: I suggest enlarging the 4 panels on the left and reducing the one on the right. The inundation extent is more informative than the overview map.

Respond: Thank you and we agree. Following your suggestion, we have enlarged the inundation extent maps for the four case areas on the left panel while reducing the figure size of the overview map on the right. Now they are in the same size. See figure 2 (b) in the revised paper.

L 83: I suggest avoiding nested parentheses "))"

Respond: We have revised accordingly.

For example, from line 115-117, page 4: *Over inundated agricultural areas as Figure 5 (b) shows, 35.9% (443.64 km^2) is pastures, 33.6% (416.07 km^2) is arable land (including non-irrigated arable land and rice fields, 339.09 km2 and 76.98 km^2, respectively) and 23.3% (288.59 km^2) is heterogeneous agricultural areas*

L 92: "the Netherlands" I think

Respond: We have corrected the typo.

In line 127, page 4: *In the Netherlands, 98.97 km^2 of agricultural land is inundated,*

L109-110: This is a sentence for an Abstract or Introduction, rather than for Closing remarks

I think that the information in Figure 3 is already included with more details in Figure 4. I suggest deleting Figure 3.

Respond: We have a new start sentence of the closing remarks

From line 145-147 in page 5: *The unprecedent precipitation heavily damaged the western Europe with catastrophic flooding, causing damage to agriculture which is yet minimally quantified.*

The Figure 3 (pie plot) has been removed, and the information of Figure 3 is detailed described in the text.

Response to reviewer 2

The brief communication "Western Europe flood in 2021: mapping agriculture flood exposure from SAR" is a very timely contribution for data on the exceptional flooding that took place this year. Particularly the associated data products are a valuable contribution to the knowledge base surrounding this event.

Whilst I support publication of new primary data, particularly in such a timely manner, I do, however, believe there are a couple of things that need to be improved in the communication before full publication is warranted. My main points are on: 1) more detail on the approach used, 2) comparison with other (more local) sources, 3) visualization of the results. Next to these three points, I have some additional minor remarks at the end. Particularly regarding point 2, I am concerned that there may be some artifact in the methodology that heavily impacts the results (see point 2 below).

Respond: Thanks for your time and effort to review the paper. Your comments helped us improve the quality of the paper

1. **The methodology is very succinct, but maybe a bit too much so. It is not clear to me as the reader for instance HOW the delineation is done from reading the manuscript. Is it a direct delineation? Or is a comparison made with an image pre-flooding to determine what is flooded and what is normally covered by water. If so, what period is used for reference? This matters as the rivers in question have floodplains that are regularly flooded during winter.**

Respond: We have added the details about the delineation method and the images acquired during the flood and used as dry reference in the methodology section. In summary, the RAPID system combines the "direct delineation" using a threshold determination approach, and the comparison using an improved change detection approach.

From line 58 -67 in the revised paper. we added the methodologic details:

" Specifically, the Radar Produced Inundation Diary (RAPID) system first segments water from non-water pixels by optimizing the threshold and probability density function (PDF) of the water class. Then, it runs an morphology-based procedure to reject false water bodies using rule sets defined at the body level instead of the pixel level. The morphological processing includes two sub modules, water source tracing (WST), and improved changed detection (ICD). WST traces water pixels from known water sources (e.g, rivers, lakes) indicated by a land use map. ICD rejects any water body that is disconnected from a known water source and does not have significantly increased area compared to the dry time. For dry reference, we use information from ground observation and satellite precipitation to determine non-flood period, and image cover that period is select as dry reference. The RAPID requires approximately five dry reference images for each SAR image sensed on the flood day to reduce the error caused by noise-like speckle. In the third and last processing steps, RAPID uses multi-threshold compensation and machine learning to further reduce the speckles and strong scatter-caused false negatives."

An example of inundation delineation by RAPID, as well as the corresponding SAR images sensed on flood and non-flood date in Louhans, France are presented in Figure 1. The dry reference images are introduced as Figure 1 (d) in the revised paper.

From line 68-70:

Figure 1 (a) presents an example of inundation delineation by RAPID system in Louhans, France. The CORINE land cover map, shown as Figure 1 (b). The corresponding SAR images sensed on July 16th 2021 (Figure 1 (c), flooding period) and images sensed on July 10th 2021 (Figure 1 (d), dry reference).

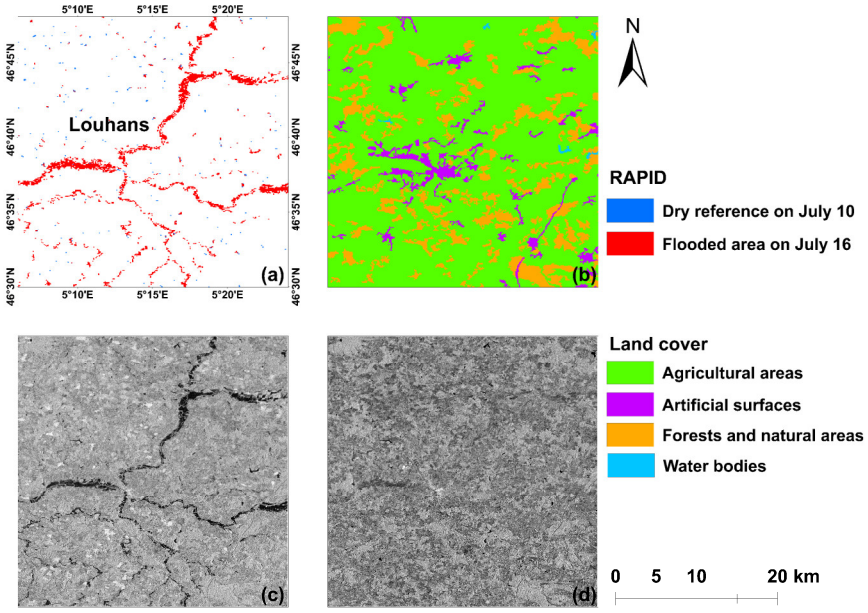


Figure 1. (a) RAPID flood map; (b) CORINE land cover map; (c) and (d) Sentinel-1 SAR image in VH polarization sensed on July 16th and 10th .

I'm also surprised that around line 50 where the inundation maps are described, there is no reference to the Shen and Yang papers which seem to form the basis for the delineation (judging from the references on the flood maps on AWS). This section really needs more detail for the reader to judge the results adequately.

We added the citations to the algorithm and system papers from line 52 to 55 in page 2:

We generate inundation extents in NRT using the RAPID system and archive these maps on Amazon Web Services (AWS) [available at https://rapid-nrt-flood-maps.s3.amazonaws.com/index.html#Global_Flood_Event/Europe_Flood_2021/]. RAPID is a fully automated system delineating NRT inundation extents from high resolution (10 m) synthetic aperture radar (SAR) imagery [Yang et al., 2021; Shen et al., 2019a; Shen et al., 2019b].

Shen, X., Anagnostou, E. N., Allen, G. H., Brakenridge, G. R., & Kettner, A. J. Near-real-time non-obstructed flood inundation mapping using synthetic aperture radar. Remote Sensing of Environment, 221, 302-315, 2019.

Shen, X., Dacheng W., Kebiao M., Anagnostou, E.N. and Hong Y., 2019b: Inundation Extent Mapping by Synthetic Aperture Radar: A Review, Remote Sensing, 11, 879.

Yang, Q., Shen, X., Anagnostou, E.N., Mo, C., Eggleston, J.R., & Kettner, A.J. (2021). A High-Resolution Flood Inundation Archive (2016–the Present) from Sentinel-1 SAR Imagery over CONUS. Bulletin of American Meteorological Society, 5, E1064-E1079

2. **The study is done at a relatively large scale to be consistent, which I understand. However, I would really like to see at least some comparison with other estimates. For instance, do the precipitation totals estimated by the authors correspond to some other estimates? These could be from national met offices, or rainfall radars, or other satellite sources, etc. I also noticed that spatially, there is a hotspot of precipitation over the south of Luxembourg. However, the estimates from the Dutch fact finding mission (see below for reference) show this more to the north (northern Luxembourg and eastern Belgium, see Figure 2.2 in the Dutch report). This is based on E-OBS data and in line with the impacts observed in this region.**

Respond: We updated the precipitation map using the IMERG half-hourly Final run product which is available now (https://disc.gsfc.nasa.gov/datasets/GPM_3IMERGHH_06/summary). The IMERG Final run product combines the multi-satellite data for the month with GPCC gauge analysis and thus provides the research-level products for precipitation estimation.

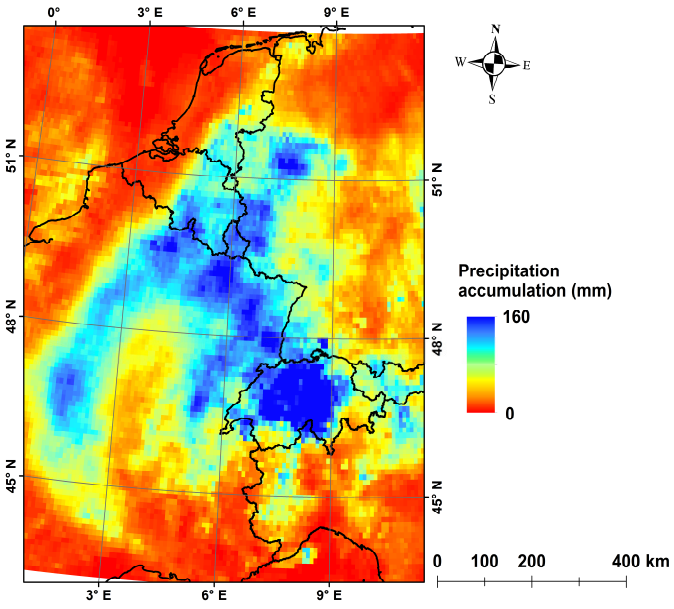
From line 48-51 on page 2:

"We extract half hourly precipitation data of the event from the Integrated Multi-satellitE Retrievals for Global Precipitation Mission (IMERG) Final Precipitation L3 V06 product with 0.1-degree spatial resolution [https://disc.gsfc.nasa.gov/datasets/GPM_3IMERGHH_06/summary, Huffman et al., 2019].

The IMERG half-hourly Final Run product combines the multi-satellite data for the month with GPCC gauge analysis and thus provides the research-level products for precipitation estimation."

From the precipitation map in Figure 2, we find precipitation concentrated in western Germany, eastern Belgium, southern Netherlands, Luxembourg, northeastern France and Switzerland. Specially, in the east of Belgium (Liège for example), the precipitation estimate from IMERG is around 100 mm while more than 200 mm rainfall is observed in these areas from L'Institut royal météorologique (IRM) (https://www.lavenir.net/cnt/dmf20210716_01598142/record-de-precipitations-dans-la-province-avec-plus-de-271-mm-releves-a-jalhay-en-48h). In northeastern France, IMERG estimates total precipitation around 120 mm while according to the observation around 158 mm precipitation fell in the area (https://meteofrance.com/actualites-et-dossiers/actualites/climat/inondations-catastrophiques-en-allemagne-et-belgique). In western Germany, the precipitation estimate from IMERG is around 100 mm and according to the report precipitation accumulations over western Germany are averaged 100 to 150 mm.

Overall IMERG precipitation shows high consistency with the observation on the distribution of precipitation accumulation, though it underestimates the amount in some regions.



Lastly but crucially, the communication mentions the main inundated area in the Netherlands to be in the north: in the regions of the Markermeer and Ijsselmeer. I know for sure that this is not the case (which is why I want to know more about the methodology) as the Markermeer/Ijsselmeer regions were not impacted at all during the floods. In the Netherlands the impact was way more upstream along the Meuse river (from Belgian border up to Roermond/Nijmegen). My knowledge is mainly on the Dutch situation, but I think it is im perative to check also the other areas for which claims are made.

Respond: In the regions of the Markermeer and Ijsselmeer, we made comparison between RAPID and Landsat-based flood inundation map on 2021-07-18.

From line 103-108 in page 4:

"In the northern Netherlands where more than 100 mm precipitation is observed, regions near Markermeer and Ijsselmeer, and regions around Hollands Diep and Meuse River are largely affected by the flood, which represents a total area of 140.7 km^2. We compared the RAPID inundation maps and Landsat-based flood inundation maps (FIMs) for North Netherlands, presented as Figure 4 (a) and (b) respectively. The RAPID and Landsat based FIMs shows high consistency on the flooded areas according to the result of quantitively comparison, with precision, recall, F-1 score and Cohen kappa metrics are 0.8816, 0.8439, 0.8624, 0.8571, respectively."

For Landsat based flood map, we first acquire surface reflectance image sensed on July 18 from Landsat-8 OLI collection 2 level-2 dataset (Sayler and Zanter 2020), which is available from USGS Earth Explorer. We then extract the flood inundation area by calibrating the pixel threshold based on the automated water extraction index (AWEI, Feyisa et al. 2014). The pixel samples are selected using the water occurrence (Pekel et al. 2016) and land cover (Gong et al. 2019) data. Specifically, pixel samples for water are taken from the persistent water body with more than 90% of water occurrence, and non-water pixel samples are equivalent extracted from the land cover type of cropland, forest, grassland, shrubland, Impervious surface, and bare land. To determine the optimal threshold, we delineate water and non-water pixels using all possible thresholds in the valid range of AWEI, and compute F-1 score by comparing to the sample pixels. Finally, we use the threshold with the highest F-1 score to extract flood inundation from Landsat image.

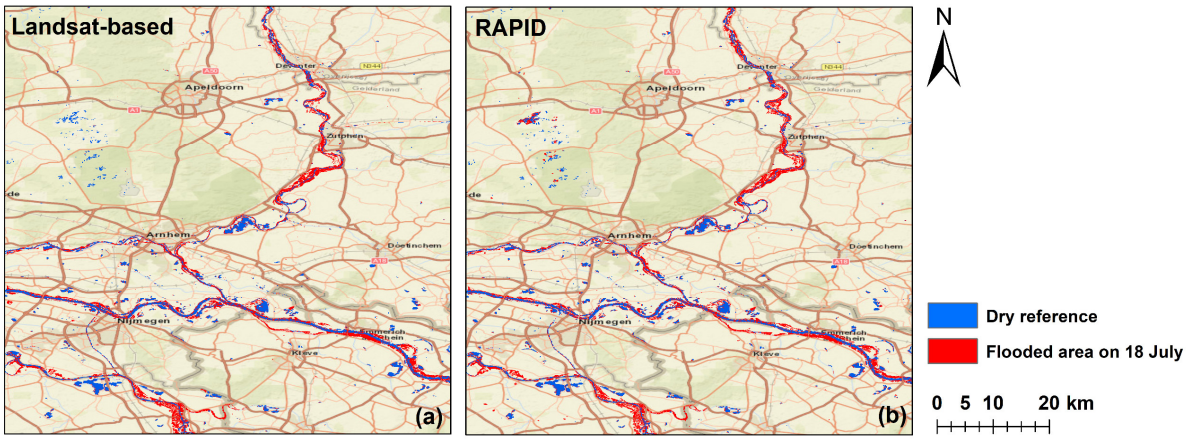
Reference:

Sayler, K., Zanter, K., 2020. Landsat 8 Collection 2 (C2) Level 2 Science Product (L2SP) Guide. Sioux Falls, South Dakota.

Pekel, J.F., Cottam, A., Gorelick, N. and Belward, A.S., 2016. High-resolution mapping of global surface water and its long-term changes. Nature, 540(7633), pp.418-422.

Gong, P., Liu, H., Zhang, M., Li, C., Wang, J., Huang, H., Clinton, N., Ji, L., Li, W., Bai, Y. and Chen, B., 2019. Stable classification with limited sample: transferring a 30-m resolution sample set collected in 2015 to mapping 10-m resolution global land cover in 2017. Science Bulletin, 64(6), pp.370-373.

From the comparison, we can find high agreement of inundation extent derived by RAPID and AWEI. The error metrics of precision, Recall, F-1 score, Cohen kappa are 0.8816, 0.8439, 0.8624, 0.8571, respectively.



I was for instance surprised to learn about the flooding near the coast of Marseille and Montpellier. I did not find any news items on this (though I only looked briefly and don't speak French) and the wiki page also doesn't mention this. So I would urge the authors to check this to make sure it is not the result of an artefact in the method (as I presume the Markermeer/Ijsselmeer probably is), particularly as these are areas that seem to constitute a large portion of the overall results.

A visual comparison of the SAR images acquired on the flood and dry dates is the most straightforward way to address the reviewer's comment.

In the coast of Marseille and Montpellier, we checked the pre-flood SAR image (June 22, 2021) and the in-flood SAR image (July 16, 2021). The flood areas in south-eastern France are mostly arable land. These areas exhibit clearly dampened backscattering from the dry date (June 22) to the flood date (July 16) while their backscattering on the flood date falls into the water category.

From line 96-100 in page 4:

"The south-eastern France, especially the coastal area, exhibits extensive flood inundation as well, though the accumulated precipitation in these areas is around 10 mm. The flooded areas in south-eastern France, shown as Figure 3 (a), are mostly arable land. These areas exhibit clearly dampened backscattering from the dry date (Figure 3 (c), June 22) to the flood date (Figure 3 (b), July 16) while their backscattering on the flood date falls into the water category. These rainfed arable lands might be flooded by overflow from the Rhône river or the raised water table."

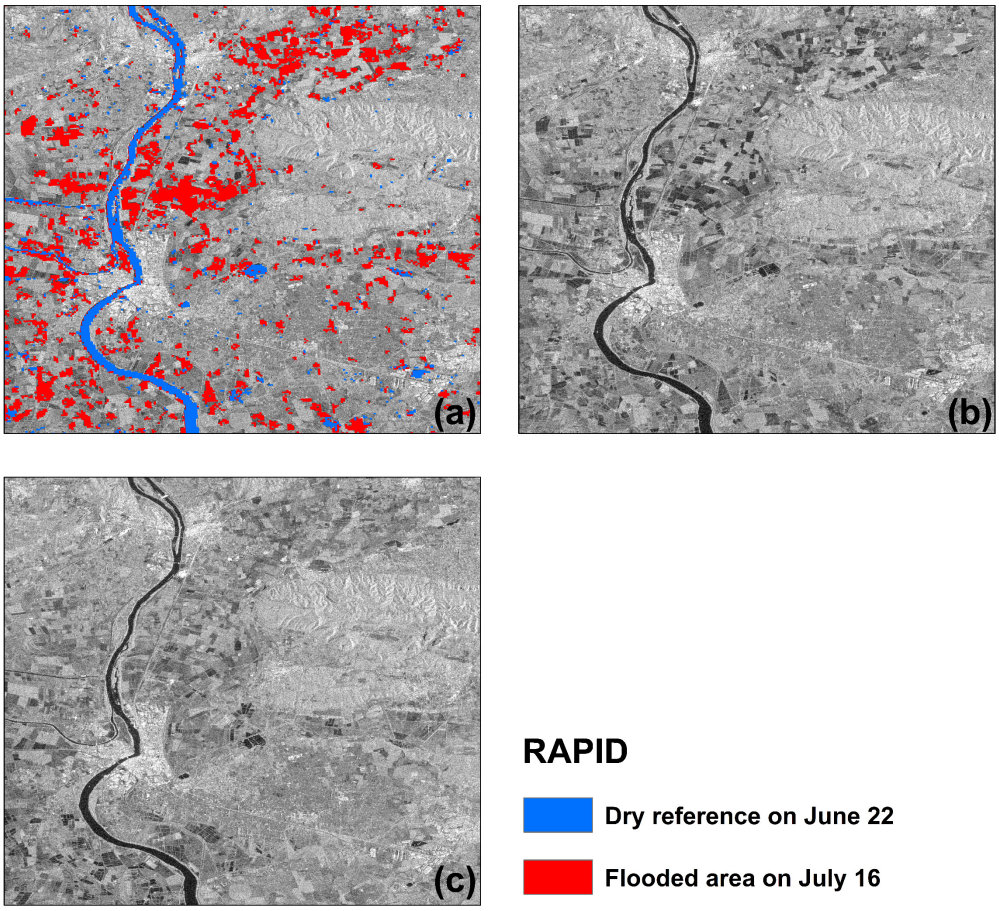


Figure .3 (a) RAPID flood map; (b) Sentinel-1 SAR image in VH polarization sensed on July 16th; (c) Sentinel-1 SAR image in VH polarization sensed on June 22.

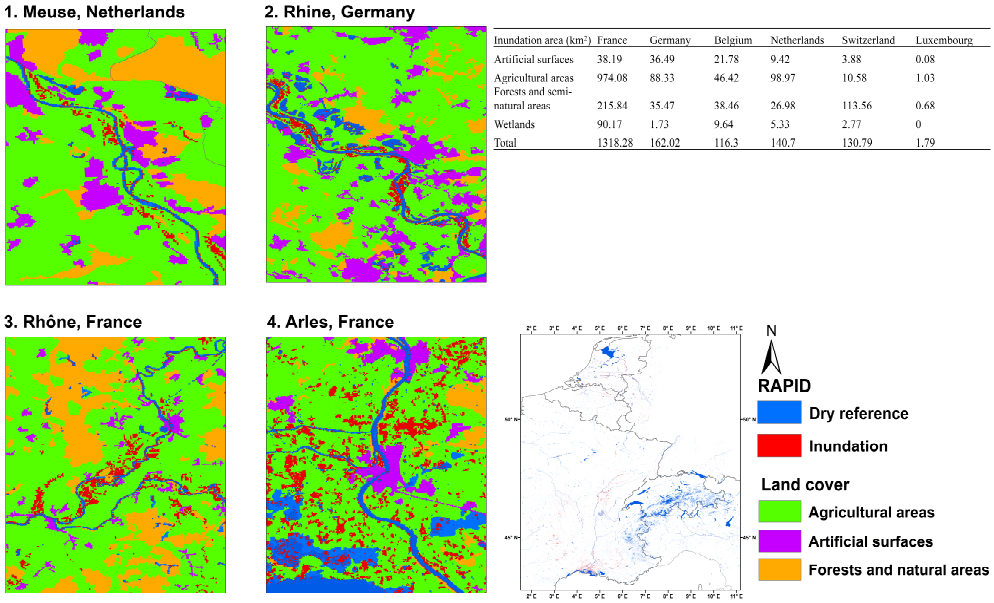
3. **The visualization of the results can be improved considerably in the brief communication. Particularly Figure 2 should be improved. Right now no inundation can be seen and even the legend only refers to land-use classes (inundation is not even a class) and it seems more of a land-use map than a flood map. The maps on AWS on the other hand are very informative, so I would put some of those images in the communication.**

Respond: We have reworked Figure 2 to improve the visualization in the revised paper. we have enlarged the inundation extent maps for the 4 case areas while reducing the figure size of the overview map.

I would also pick different areas as the four focus areas. For the Netherlands/Belgium more downstream along the Meuse, for Germany along

the Ahr (where most of the impacts where) and in France the communication mentions extensive flooding along the coast (Montpellier/Marseille) and along the Rhone. This would focus the panels on known heavily hit parts/key results. Next to Figure 2, I would propose to include a table with areas affected in the different countries. Now this is listed in text over a couple of paragraphs in the results, but by putting the numbers in a table it would be much easier to compare. Or when the authors feel Figure 4 is sufficient, I would only highlight the main findings from the figure, rather than listing all individual numbers.

4 case areas (Meuse river in the Netherland, Rhine river in Germany, Rhone river and Arles in France) where we find extensive inundation areas area selected and presented in the left panel of Figure 2 (b). In addition, a summary table concludes the areas affected in different countries is attached to the right of Figure 2 (b).



Inundation area (km²)	France	Germany	Belgium	Netherlands	Switzerland	Luxembourg
Artificial surfaces	38.19	36.49	21.78	9.42	3.88	0.08
Agricultural areas	974.08	88.33	46.42	98.97	10.58	1.03
Forests and semi-natural areas	215.84	35.47	38.46	26.98	113.56	0.68
Wetlands	90.17	1.73	9.64	5.33	2.77	0
Total	1318.28	162.02	116.3	140.7	130.79	1.79

Minor remarks:

- The introduction heavily relies on newspaper sources on the event. Whilst these are of course the first ones to report on it, there have been more specific reports from the research community as well. In the Netherlands for instance a fact finding report has been published with an English summary (https://www.enwinfo.nl/publish/pages/183541/fact-finding-hoogwater-2021-versie-1-2.pdf)

Respond: The detailed reports on the impact of the extreme flood in each country is cited in the text from Floodlist which is funded by Copernicus. Floodlist aims to report floods and flooding news since 2008 all over the world.

From line 20-23 in page 1:

"In addition, 46 people were confirmed dead in North Rhine-Westphalia state in Germany and in the neighboring state of Rhineland-Palatinate 110 fatalities were confirmed. At least 20 people died following catastrophic flooding in Belgium. The Netherlands, Luxembourg and Switzerland are also affected. Thousands of people had been evacuated from their homes [CNN, 2021; FloodList, 2021]."

CNN: Germany's deadly floods were up to 9 times more likely because of climate change, study estimates, https://www.cnn.com/2021/08/23/europe/germany-floods-belgium-climate-change-intl/index.html , last access: 24 August 2021.

FloodList: Europe, https://floodlist.com/europe, last access: 16 July 2021.

- Some more context can be given in the communication, particularly because it focusses on agricultural impacts. Most notably: the timing of theses summer floods was crucial as it occurred at the end of the growing season in NW Europe. As a result damage to agriculture can be expected to be relatively high. This is also very rare for NW Europe (Germany, Belgium, Netherlands) where flooding from the Meuse and Rhine rivers is usually during winter [I presume Rhone is similar, though I am less knowledgeable on that].

Respond: We have added the context of growing season period over Europe and discussed the potential impact of flooding on the crops.

From line 150-154 in page 5:

"The mid July when the extreme flood happened is the critical growing season for crops like corn in Belgium, France, Luxembourg and Netherlands, and also the harvest season for wheat in Belguim, France and Germany [Foreign Agricultural Service]. The oxygen supply is greatly reduced when a corn crop is submerged in water, which greatly reduces or even stops critical plant functions such as nutrient and water uptake [Lauer 2008]. The quality and production of these crops would be severely damaged."

Foreign Agricultural Service: Crop Calendars for Europe, https://ipad.fas.usda.gov/rssiws/al/crop_calendar/europe.aspx, last access: 1 March 2022

Lauer, Joe. "Flooding impacts on corn growth and yield." Agronomy Advice. University of Wisconsin. Agronomy Department, Field Crops 28 (2008): 49-56.

- In the communication both precipitation and inundation products are presented. However, the communication seems to focus on the latter one. Some words on how these products are related would be good so the precipitation results don't feel isolated.

Respond: The results of precipitation accumulation and distribution are discussed in the revised paper.

From line 83-89 in page 3:

"Heavy precipitation (peak rate > 20 mm/hr) is observed in western Germany, north-eastern France, norther Luxembourg, south-western Netherlands, western Switzerland, and western Italy. The most intensive precipitation (peak rate > 50 mm/hr) is found in western Germany, as well as western Switzerland and Italy over the Alps. Heavier than 150 mm accumulated precipitation is found in eastern France (Châtel-de-Joux, Le Fied), north-eastern France (Plainfaing, Villers-la-Chèvre), mid-eastern Luxembourg (Echternach and Mersch), western Belgium (Liège), southern Netherlands (Limburg), western Germany (North Rhine-Westphalia, Rhineland-Palatinate), Switzerland and Italy, which represent an equivalent of two-month precipitation accumulation in these areas. Furthermore, accumulated precipitation is shown to exceed 200 mm in some parts of the region (e.g., western Switzerland, north-eastern France, western Germany)."

Besides, linkages between precipitation and inundation results are discussed.

From line 93-96 in page 3:

"Figure 2 (b) shows the inundation extents over western Europe. The RAPID inundation map shows high consistency with the precipitation map. The total inundated area determined from RAPID inundation map is around 1920.26 km^2. We find extensive inundated areas in the upstream region of Rhône River where more than 120 mm precipitation fell in 72 hours."

From line 102-105 in page 4:

"In Germany, the main inundated area is found in the west which is caused by the intensive precipitation (120 mm), along the Rhine River (about 162.02 km^2). In the northern Netherlands where more than 100 mm precipitation is observed, regions near Markermeer and Ijsselmeer, and regions around Hollands Diep and Meuse River are largely affected by the flood, which represents a total area of 140.7 km^2."

- The communication is good to follow, though there are a couple of slightly awkward sentences English-wise (for instance the use of the threshold as a verb in line 51, and permafrost should probably be glaciated in line 52)

Respond: We have improved the language throughout the paper in a more academic way.

- Bibliography is not in alphabetical order

Respond: We have reordered the bibliography alphabetically.