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Brief communication: Western Europe flood in 2021: mapping agriculture flood exposure from SAR

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Abstract. In this communication, we present the exposure of agriculture lands to the flooding caused by extreme precipitation in western Europe from 12th to 15th of July 2021. Overlaying the flood inundation maps derived from the near-real-time RAdar-Produced Inundation Diary (RAPID) system on the CORINE land cover map we estimate a 2470 km^2 area affected by the flooding, with 57% representing agricultural land. Among the inundated agricultural land, 36% of the area is pastures while 33% is arable land. Most agricultural flood exposure is found in south-eastern France (~1680 km^2) along Rhône River and the coastal area of Marseille and Montpellier.

1. Introduction

The heavy precipitation between 12 and 15 July 2021 led to catastrophic floods in western European countries, including France, western Germany, Netherlands, Belgium, and Luxembourg. The flooding caused widespread power outages, infrastructure and crops damages in the affected areas. It is estimated that the loss from the flooding is up to €3 billion [Reinsurance News, 2021]. In addition, more than 200 people were killed, mostly in Germany and Belgium [CNN, 2021]. In the same period, intensive floods occurred in China and the United States. Researchers highlighted that this is an effect of climate change and concluded that the frequency and intensity of such events will increase in a rapidly warming climate [World weather attribution, 2021].

Besides life loss, the flooding in western Europe have also taken a heavy toll on the agricultural sector according to European farmers' association COPA-COGECA. The European Union's crop monitoring unit stated that the exceptionally high rainfall and severe floods would reduce the grain quality in the affected countries [Successful farming, 2021] and had "effectively eliminated" any hope of a successful harvest in these areas [Euractiv, 2021]. Examples of crop damages include crops of grain, rapeseed and flax which have been washed away in Wallonia, Belgium and flood-affected fruit trees along the Meuse River [Eurofruit, 2021]. In widespread crop loss scenarios like this one, damage assessment is an essential part of flood risk management and flood mitigation, which is also the basis of financial appraisals in the insurance sector [Tapia-Silva et al., 2011]. Even though the impact on the agriculture sector is expected to be severe, the magnitude of the damage is yet to be determined [Agence europe, 2021]. Therefore, it is important to have a quick assessment of the agriculture land exposure to

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flooding, which will inform crop loss estimates, especially for countries where agriculture plays an important role in the national economy, e.g., France and Germany. Near-real-time (NRT) flood mapping capability from satellite observations is vital to facilitate rapid assessment of flood loss and damage [Shen et al., 2019].

In this brief communication, we use NRT inundation extents from the near-real-time RAdar-Produced Inundation Diary (RAPID) system combined with CORINE land cover data to depict the flood-affected areas in western Europe, and particularly the agriculture land.

2. Methodology

We focus this communication on western Europe, which is mostly affected by the July 12-15 heavy precipitation event. The area extends from 1.5° E to 11.6° E, and 42.9° N to 53.1° N, and encompasses the Netherlands, Belgium, Luxembourg, Switzerland and portions of Germany, France, and Italy. This region is dominated by marine climate with abundant moisture supplemented by Atlantic Ocean. The weather is therefore moist and mild in winter, and moist and cool in summer.

We extract half hourly precipitation data of the event from the Integrated Multi-satellitE Retrievals for Global Precipitation Mission (IMERG) Late Precipitation L3 V06 product with 0.1-degree spatial resolution [Huffman et al., 2019]. IMERG Late Run is computed about 14 hours after observation time, which integrates more data from sensors aboard on satellites to improve the accuracy. We used IMERG data to calculate the maximum hourly precipitation rate and precipitation accumulation between 12 and 15 of July for each grid

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. To rule out false positives caused by glaciers and snow, we threshold the Height Above Nearest Drainage (HAND) data to mask out permafrost areas in Alps. The HAND used in this study is obtained from the Multi-Error-Removed Improved-Terrain (MERIT) Hydro Dataset [Yamazaki et al., 2019; Nobre et al., 2011]. Pixels over the Alps where HAND values are greater than 20 meters are removed from the inundated pixels. The threshold is determined by exploring the distribution of HAND for glaciers and perpetual snow recorded in CORINE land cover data and is large enough to avoid the removal of any true positives.

We obtain the latest land cover map over western Europe from Coordination of information on the environment (CORINE) Land Cover (CLC) inventory data [available at https://land.copernicus.eu/pan-european/corine-land-cover/clc2018]. CLC uses a Minimum Mapping Unit (MMU) of 25 hectares (ha) and a minimum width of 100 meter for linear elements The standard CLC nomenclature includes 44 land cover classes, grouped in a three-level hierarchy. Five main categories used in this study are "artificial surfaces", "agricultural areas", "forest and semi-natural areas", "wetlands" and "water bodies". The detailed description of CORINE program and its nomenclature can be found in https://www.eea.europa.eu/publications/COR0-part1 .

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3. Results

The spatial pattern of the maximum hourly precipitation and accumulated precipitation from the July 12-15 heavy precipitation event are shown in Figure 1 (a) and (b). Heavy precipitation (peak rate > 20 mm/hr) is observed in western Germany, south-eastern France, western Switzerland, and western Italy. The most intense precipitation (peak rate > 50 mm/hr) is found in south France, as well as western Switzerland and Italy over the Alps. Heavier than 200 mm accumulated precipitation is found in eastern France, Luxembourg, southern Belgium, western Germany, Switzerland and Italy, which represent an equivalent of two-month precipitation accumulation in these areas. Furthermore, accumulated precipitation is shown to exceed 250 mm in some parts of the region (e.g., western Switzerland and Italy, south France).

Figure 2 shows the inundation extents over western Europe. The total inundated area determined from RAPID is around 2470 km^2. We find extensive inundated areas in south-eastern France, especially the coastal area, including Marseille and Montpellier. The upstream region of Rhône River exhibits extensive flood inundation as well. The total inundated area over France is approximately 1680 km^2. In Germany, the main inundated area is found in the west, along the Rhine River (about 162 km^2). In the northern Netherland, regions near Markermeer and Ijsselmeer, and regions around Hollands Diep are largely affected by the flood, which represents a total area of 245 km^2. In Belgium and Luxembourg, the inundated areas are 116 km^2 and 2 km^2, mostly along Meuse River and Sauer River, respectively. In western Italy, an area of around 135 km^2 along the Po River is affected by flooding. The flash floods in Switzerland also cause a 131 km^2 inundation.

Figure 3 (a) shows the land use fraction in the inundated areas. Among them, 24% (597 km^2) of the land is forested/semi-natural areas. For wetlands and artificial surfaces, the fractions are 11% (269 km^2) and 8% (192 km^2), respectively. The majority, nearly 57% (1412 km^2) of the flood inundated area is from agricultural land. Over inundated agricultural areas as Figure 3 (b) shows, 36% (513 km^2) is pastures, 33% (463 km^2) is arable land (including non-irrigated arable land (382 km^2) and rice fields (81 km^2)) and 24% (342 km^2) is heterogeneous agricultural areas, which is the sum of complex cultivation patterns (272 km^2) and land principally occupied by agriculture, with significant areas of natural vegetation (70 km^2). The remaining 7% (93 km^2) is permanent crops consisting of vineyards (71 km^2), fruit trees and berry plantations (21 km^2) and olive groves (1 km^2).

Figure 4 (a) shows inundated area of land use grouped by countries over western Europe. Specifically, in France, 1085 km^2 of agricultural land cover is affected by the flood. Among those inundated agricultural areas in France (Figure 4 (b)), 363 km^2, 360 km^2, 271 km^2 and 91 km^2 are pastures, arable land, heterogeneous agricultural areas, and permanent crops, respectively. Especially, the non-irrigated arable land in France is severely affected, the area is up to 283 km^2 which is larger than the sum of inundated non-irrigated arable land in other countries. Besides, the rice fields and vineyards in France are also hit by flood. More than 70 km^2 of rice fields and vineyards, mainly in the coastal areas, are inundated. In Netherlands, 135 km^2 of agricultural land is inundated, mostly are pastures (74 km^2), followed by heterogeneous agricultural areas (36 km^2). The inundated area of arable land (mostly is non-irrigated arable land) in Netherlands is 25 km^2, while only 0.2 km^2 of permanent crops (mainly fruit trees and berry plantations) are affected by flood. In Germany, 88 km^2 of agricultural land is inundated with 59 km^2 and 25 km^2 of these areas being pastures and non-irrigated arable land. The inundation over heterogeneous agricultural areas and permanent crops (including vineyards, fruit trees and berry plantation) in Germany are estimated at 3 km^2 and 0.8 km^2, respectively. The total inundated areas in Belgium and Italy are both around 46 km^2. In Belgium, the inundated areas of heterogeneous agricultural land, pastures, and arable land were 19 km^2, 14 km^2 and 13 km^2, respectively, while nearly no permanent crop is affected by flood. In Italy, most inundation among agricultural areas is arable land (30 km^2 of non-irrigated arable land and 5 km^2 of rice field) and to a secondary effect heterogeneous agricultural area (9 km^2). Only 2 km^2 of pastures in Italy are inundated while 0.2 km^2 of permanent crops (vineyards) are affected by flood. In Switzerland, the inundated areas of non-irrigated arable land, pastures and heterogeneous agricultural areas are 5 km^2, 3 km^2 and 2 km^2, respectively. 0.5 km^2 of permanent crops, mainly fruit trees and berry plantations, is also found to be affected by flood in Switzerland. No permanent crop is inundated in Luxembourg, the total inundated area in Luxembourg is 1 km^2, with 0.4 km^2, 0.3 km^2 and 0.3 km^2 of them being heterogeneous agricultural areas, non-irrigated arable land and pastures, respectively.

4. Closing remarks

The July 12-15 unprecedented precipitation and the associated catastrophic flood heavily impacts the western Europe with more than 200 deaths and an estimated €3 billion of economic loss from infrastructure damages. However, the impact that the flooding across western Europe has on agriculture is yet minimally quantified. In this communication, we analyze the inundated area of agricultural land by overlaying the inundation extent derived from RAPID system with CORINE land cover data. The results indicate that the total inundated area over western Europe is about 2470 km^2, of which 1680 km^2 is in France. Around 57% of the flooded area is agricultural land. Because of the wide impact, we expect that the agricultural productivity in western Europe will be significantly reduced. Besides the direct damage to livestock and crops, the soil erosion and sedimentation due to the flood cause significant part of agricultural land be washed away or become less fertile [Mst et al., 2019; Morris and Brewin, 2014,18]. In addition, extra costs are needed for pastures and cultivable land to reconstruct and recover.

The limitation of this study is primarily inherited from the data sources. The RAPID system in Europe is triggered by IMERG precipitation data, which is a satellite-based precipitation product found to systematically underestimate precipitation in complex terrain areas, such as Alps [Navarro et al., 2019].

With the increasing flood observing capability brought by modern satellite constellations (for example, ICEYE [Ignatenko et al., 2020]), future directions of this study will include combining the NRT RAPID inundation estimates with developed flood models, crop data and other essential data (soil salinity, crop sensitivity, etc.) to predict flood-damaged cropland areas [Lazin et al., 2021] and associated socioeconomic impact [Gould et al., 2020].

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Author contribution: KH: formal analysis, writing – original draft and editing. QY: software, formal analysis, data curation. XS and EA: conceptualization, project administration, writing – review and editing.

Competing interests: The authors declare that they have no conflict of interest.

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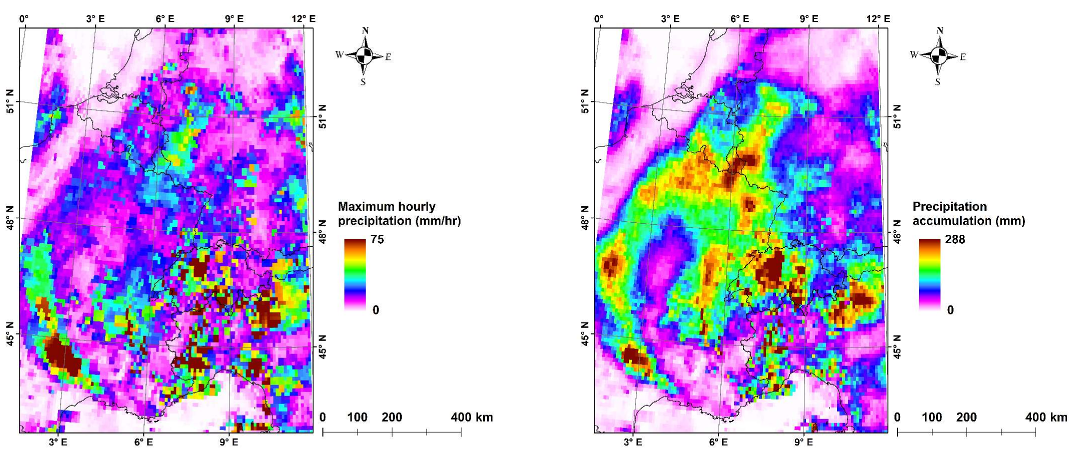

(a) (b)

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Figure 1. Spatial pattern of (a) maximum hourly precipitation and (b) precipitation accumulation during flooding period (12 to 15 July) over western Europe.

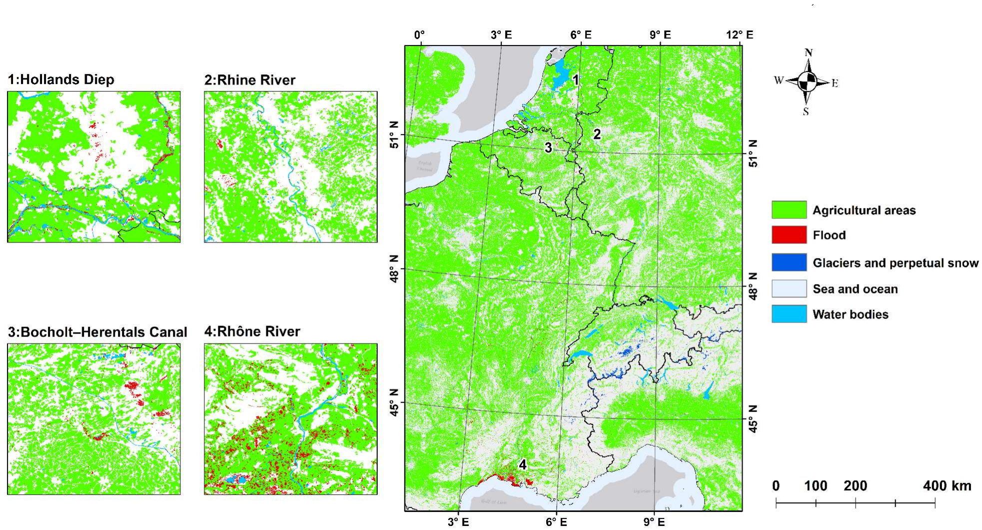

Figure 2. Inundation extents over western Europe from 15th to 18th July, derived from RAPID system.

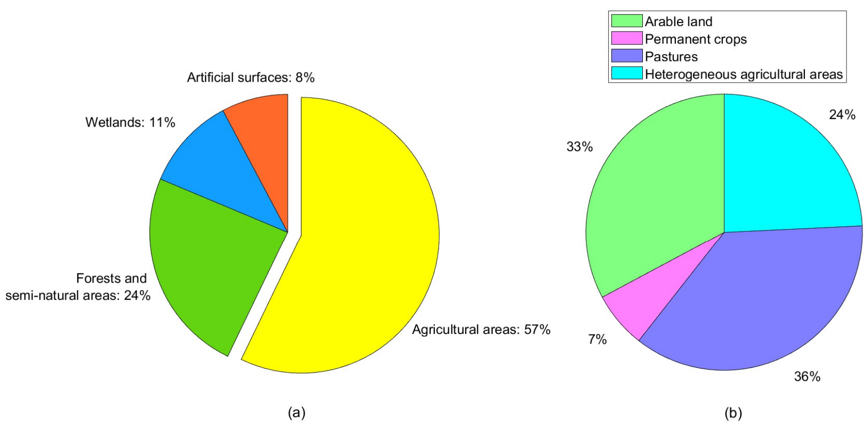

Figure 3. The land use fractions in inundated areas.

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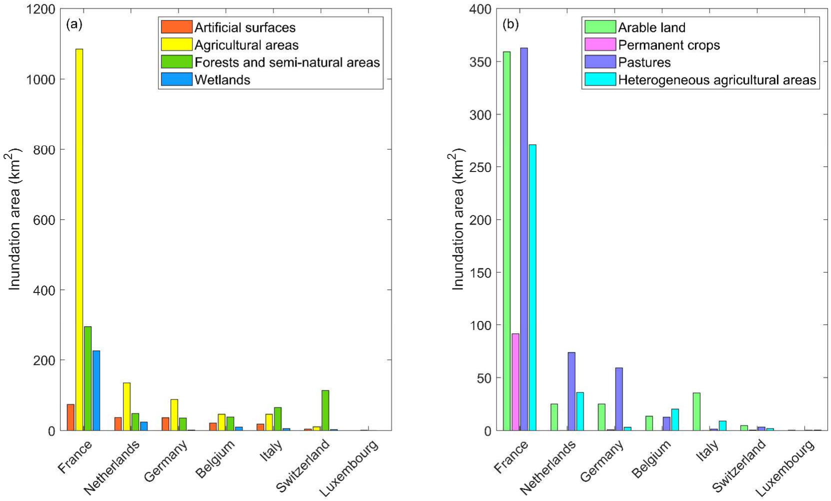

Figure 4. Inundated area of land use grouped by countries over western Europe