

Reply To Editor NHESS-2017-420

Dear Davide Notti and co-authors,

thank you very much for submitting the revised version of your manuscript.

I think all reviewer comments and your suggested changes to the manuscript have been implemented in a satisfactory manner.

However, reading through the manuscript it becomes apparent that English writing needs further improvement.

This concerns grammar, terminology and spelling. Please consider proof reading by a native speaker.

R: The English writing is now revised by the America Journal Expert service. We add the certificate in the attached PDF

Please harmonize writing and use of abbreviations (e.g. SfM, sfm; façades, facades)

R: done, we used: SfM, facades, RPAS

Please harmonize referencing to Figures (Fig. or Figure or Fig), and check the sequence of referencing to Figures.

R: Done, we used (Fig.)

specific comments:

L 397 Consider if 'Supervised Classification.' can be deleted.

R: Removed

L403 The last sentence is incomplete.

R: Changed in “*We obtained the worse results for the area flooded by the Chiosla and Oitana streams*”

L 465 ad -> as

R: Corrected

LL 500 - 502: how can infer an exponential decrease from two instances in time? please consider rephrasing.

R: We rewrite “*greatly decreases*” instead of “*exponential*”

L515 2 - 3 m. The upper limit of the legend is 2m.

R: The upper limit of WD model is 2-4 m, we better specify it in the legend of figure 11.

L526 units are missing

R: Added the units (m)

L534 purpose -> propose

R: Done

LL 577 - 579 This sentence is not clear, please rephrase.

R: We rewrite as follow: “*For example, the two Sentinel-1 satellites provided free images every six days all over Europe, while other satellites have quite high costs and the acquisition is often on-demand. Moreover, most of the time, the on-demand acquisitions are activated only when authorities activate an emergency procedure (e.g., the EMSR of the European Union or by civil protection).*”

L 600 and 604 measures - > measurements

R: Done

Please check if Fig. 2 is still needed after including Fig. 13.

R: We think that both figures are necessary because the flow charts, even similar, show different things: The first (Fig. 2) is the methodology used for this work, the second is a general methodological approach proposed for the readers.

caption Fig 6: photo took -> photos taken

R: Corrected

caption Fig 7: 'allowed' can this be deleted? ... 'cut a:an erosion' Please check.

R: Corrected

caption Fig 8: 'map of flooded Chisola flooded area' Please check. #

R: Changed in “*map of areas flooded by Chisola stream*”

Figure 11: In the legend: River embankment ropture -> rupture; the GPS and SfM symbols cannot be seen on the map

R: Corrected, we also improved the visibility of symbols



EDITORIAL CERTIFICATE

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Low cost, multiscale and multi-sensor application for flooded areas mapping.

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Abstract

Flood mapping and estimation of ~~the~~ maximum water depth are essential elements for ~~at~~the first ~~damages~~damage evaluation, civil protection ~~interventions~~intervention planning and detection of areas where ~~remedial are more~~remediation is needed.

In this work, we present and discuss a methodology for mapping and quantifying flood severity over ~~plain areas~~floodplains.

The proposed methodology considers a multiscale and ~~multi-sensor~~multisensor approach using free or low-cost data/sensors.

We applied this method to ~~the~~ November 2016 Piemonte (NW Italy) flood. We first mapped ~~the~~ flooded areas at ~~the~~ basin

scale using free satellite data from low- to medium-high resolution ~~using from~~ both ~~the~~ SAR (Sentinel-1, COSMO-SkyMed) and multispectral sensors (MODIS, Sentinel-2). Using very- and ultra-~~high-resolution~~ images from the low-cost aerial platform and Remotely Piloted Aerial System, we refined the flooded zone, and ~~we~~ detected the most damaged sector. The presented method considers both urbanized and ~~not non~~-urbanized areas. Nadir images have several limitations, in particular,

in urbanized areas, where the use of terrestrial images solved this limitation. Very- and ultra-high-~~resolution~~ images ~~have~~

~~been were~~ processed with Structure from Motion (SfM) for the realization of 3-D models. These data, combined with ~~an~~ available digital ~~elevation~~terrain model, allowed us to obtain maps of ~~the~~ flooded area, maximum ~~high~~ water ~~high area~~, and damaged infrastructures.

1 Introduction

Floods are ~~among the~~ natural disasters that cause significant ~~damages~~damage and casualties (Barredo, 2007).

Mapping and modelling ~~the~~ areas affected by floods is a crucial task to: i) identify the most critical areas for civil protection actions; ii) evaluate ~~damages, damage; and~~ iii) ~~and do correct~~perform appropriate urban planning. (Amadio et al., 2016). ~~In~~

~~order to make~~To perform a precise quantification of ~~damages, a damage~~, detailed mapping of flooded areas ~~is required, with~~ and a reasonable estimation of ~~the~~ water level and flow velocity ~~are required~~ (Arrighi et al., 2013; Luino et al., 2009; Merz et al., 2010; Kreibich, 2009). Advances in remote sensing and technology have introduced the possibility, in ~~the~~ last ~~few~~ years, of ~~having generating~~ rapid maps and models during or ~~little within a short~~ time after a flood event (e.g., Copernicus Emergency Management Service (© European Union, 2012-2017)). With satellite remote sensing data, it is possible to map flood effects over vast areas at different spatial and temporal ~~resolution, resolutions~~ using multispectral (Brakenridge, et al., 2006; Gianinetto et al., 2006; Nigro et al., 2014; Wang et al., 2012; Yan et al., 2015; Rahman and Di, 2017) or Synthetic Aperture Radar (SAR) images (Boni et al., 2016; Mason et al., 2014; Schumann et al., 2015; Refice et al., 2014; Pulvirenti et al., 2011; Clement et al., 2017; Brivio et al., 2002). A good description of ~~the~~ main methodologies ~~that are~~ used to map ~~flood, floods~~ with satellite data has been published by Fayne et al., (2017). Moreover, the increasing availability of free-of-charge satellite data with global coverage (e.g., Sentinel-1 and -2 from ESA, ~~and~~ Landsat and MODIS satellites from NASA) makes ~~possible~~ analyses of flooded areas with low-cost solutions ~~possible~~. Flood mapping and ~~damages, damage~~ assessment is also an important issue for European Communities authorities that support projects ~~like, such as~~ the Copernicus Emergency Management Service mapping (EMSR) and the European Flood Awareness System (EFAS), which manage the activation procedure to acquire satellite data over the areas affected by a natural hazard. De Moel et al., (2009) and Paprotny ~~at et~~ al., (2017) described further details about different experiences ~~in of~~ flood mapping in Europe.

In urban areas, remote sensing data are often less efficient ~~in for~~ the detection of flooded areas, especially if images acquired during the maximum of ~~the~~ inundation are not available. A partial solution could be the use of ~~a~~ Remotely Piloted Aerial Systems (RPAS) (Perks et al., 2016; Feng et al., 2015), ~~that which~~ are usually able to acquire ultra-high-resolution images over small areas. ~~The quantification~~Quantification of the maximum water level caused by the inundation is a crucial parameter, in particular, in urban areas, because it can supply ~~the damages, damage~~ estimations and support civil protection operations (Luino et al., 2009; Bignami et al., 2017). Very often, nadir remote sensed platforms cannot ~~be able to the definition of define~~ the level of water, and, for this reason, field surveys and ground-based photos are still necessary. A possible solution is the use of models for the estimation of ~~the~~ water depth based on ~~digital terrain model (DTM)~~ or hydraulic ~~model, models~~ (Bates and De Roo, 2000; Segura-Beltrán et al., 2016), but ground truth validation is needed. Recent ~~developments, development~~ of computer vision applications ~~like, such as~~ Structure from Motion (SfM) (Snavely, 2008) ~~made~~, ~~make~~ this system a possible valid alternative for the creation of a 3-D dataset based on terrestrial or aerial image acquisition systems. These datasets can be useful for ~~defining the definition of~~ water depth of flooded areas. ~~The~~ 3-D models derived from SfM are ~~nowadays, currently~~ used for geomorphological applications (Westoby et al., 2012) and flood mapping. This second application is often assisted using precise DTM derived from Lidar (Smith et al., 2014; Meesuk et al., 2015; Costabile et al., 2015). Particular applications

of SfM can be used to make 3-D models of ~~façades~~facades and acquire a useful dataset for the identification of marks left by water. The combined use of low-cost systems ~~able to~~capable of acquire nadiral images and oblique terrestrial pictures is essential for the definition of water ~~level~~levels and the estimation of ~~damages~~damage, especially for ~~the~~-flooded ~~area~~areas in an urban environment (Griesbaum et al., 2017).

Finally, geolocated photos or information ~~deriving~~derived from the internet and social media (Rosser et al., 2017; Fohringer et al., 2015) or by ~~a~~-volunteer geographic information (Hung et al., 2016; Schnebele and Cervone, 2013) can be handy for improving the mapping of flooded areas.

In this work, we present a smart ~~multi-scale~~multiscale and ~~multi-platform~~multiplatform methodology ~~that was~~ developed for the identification and mapping of flooded areas. The methodology has been tested in two areas struck by the flood ~~that~~ occurred in Piemonte (~~northwest~~ (NW) Italy) in November 2016. The paper presents different case studies that are representative of urban and ~~-~~or ~~not-non~~-urbanized areas.

2 Study areas

The Piemonte (~~Piedmont~~) region is located in NW Italy, and most of the territory is inside ~~the~~ Po ~~river~~River drainage basin- (Fig. 1 A). The Alps range surrounds the region from ~~North~~north to ~~South-west~~southwest (SW) with an elevation higher than 4000 m asl. In the southern sector, ~~the~~ Ligurian Alps and Apennines ~~range present lower elevation~~Range have lower elevations (1000-2000 m asl) and separate ~~the~~ Piemonte from the Liguria ~~sea~~Sea. On the eastern side, the basin is open to ~~the~~ Po ~~river~~River plain. This orographic setting tends to amplify ~~the~~ effects of some particular meteorological conditions ~~like, such as~~ severe and slow-moving cyclones located ~~at to the~~ west of Italy that cause a wet flow from ~~South / East~~the southeast that is blocked by ~~the~~ Alps ~~-range~~. This meteorological configuration causes heavy ~~rainfalls~~rainfall, especially in autumn when the warm Ligurian ~~sea~~Sea is a source of additional energy and humidity (Buzzi et al., 1998; Pinto et al., 2013). In the last 30 years, four main floods hit this region: September 1993 (Regione Piemonte, 1996; ~~Luino~~), November 1994 (Luino, 1999), October 2000 (Cassardo et al., 2013) and November 2016 (ARPA Piemonte, 2016)

In November 2016, a severe flood hit the Piemonte region (NW of Italy). In several areas of ~~the~~ Piemonte, in the period 21— ~~25~~ November 2016, different rain gauges registered an amount of rainfall up to 600 mm ~~that represents the, which represented~~ 50-% of the mean annual precipitation (Fig. 1 B). The basins of ~~the~~ Po and Tanaro rivers were the most affected by the flood that was very similar, for rainfall distribution and river discharge, to ~~the~~ 1994 event, which is considered one of the most destructive ~~that has~~ occurred in ~~last~~the past decades (Luino, 1999). This time, the event caused ~~huge damages~~large damage, activated ~~numbers of~~numerous landslides and debris flows and caused the inundation of large areas. The civil protection system

90 managed the emergency, and the number of victims was sharply reduced compared to ~~the~~ 1994 event that caused 70 victims. The 2016 flood caused a victim in Chisone ~~valley~~Valley, not far from Torino.

The presented case study area is located in the Po plain south of Turin ~~city~~ (Fig. 1 C). This area is mainly occupied by intensive agricultural activity and urban areas ~~mainly~~primarily located in the northern part. ~~At~~To the south of Turin, many industrial and commercial areas were built in ~~the~~ last decades ~~nearby~~near the rivers. From the geomorphological point of view, the actual

95 plain (Fig. 1 B and Fig. 1 C) corresponds to the fill of ~~the~~ Plio-Pleistocenic Savigliano basin (S.B.), delimited by ~~the~~ western Alps, Turin C) Hills (T.H.) and Poirino Plateau (P.P). In the western part, it is possible to find alluvial fans of ~~the~~ Chisone, Pellice and Chisola streams (Carraro et al., 1995). The fluvial terraces delimit ~~of the~~ actual Po ~~valley~~Valley with evident relict geomorphology ~~like, such as~~ paleo-~~meander~~meanders. The anthropic influence is remarkable with ~~like~~ quarry ~~lake~~lakes, revetments and ~~embankment~~embankments that constrain ~~the~~ riverbeds (Fig. ~~4C1~~C). The geomorphology is a crucial factor

100 that constrains ~~the~~ flooded area shape and the water height.

This area was affected by the ~~flooded~~flooding of ~~the~~ Po River and other tributaries, ~~in~~. In particular, ~~the~~ Chisola and Oitana streams ~~causing several damages~~caused severe damage. The Po ~~river~~River between ~~the~~ Carignano and Turin stations reached a maximum discharge of 2000—2200 m³/s in the late evening of 25 November 2016. The mean discharge of this monitoring station in November ~~is was~~ 70 m³/s. The Chisola ~~stream~~Stream registered a discharge of 200 m³/s (November average 17 m³/s)

105 near Moncalieri ~~in on~~ the afternoon of 25 November (ARPA Piemonte, 2016).

Inside this area (Fig. 1 C)), we focused our attention in particular on two sites ~~where~~where high-resolution data were acquired:

- The village of Pancalieri, located ~~in~~ on the left side of ~~the~~ Po ~~river~~River, just after the confluence with ~~the~~ Pellice ~~river~~River. In this area, it is evident ~~that the presence of~~ ancient Po ~~river~~River meanders ~~which are present, and they~~ were reactivated by the flood with ~~damages~~damage to some settlements and ~~the~~ destruction of communications roads.
- The town ~~of~~ Moncalieri (~~about 60'000~~approximately 60,000 inhabitants) is located south of Turin in a human-made environment. This area was flooded by Chisola ~~stream~~Stream on the late morning of 25 November partly due to the collapse of some sections of ~~the~~ river embankment. The water ~~interested~~entered many residential, service and industrial areas with a maximum water height of 1.5—2 m. Another sector of the Moncalieri municipality was also flooded by ~~the~~ Po River in the evening of 25 November, with other ~~damages~~damage to commercial and industrial infrastructures.

115 The activation of Copernicus Emergency Management Service (© 2016 European Union) EMSR-192 (<http://emergency.copernicus.eu/mapping/list-of-components/EMSR192>) allowed ~~to map the~~ mapping of the flooded areas (delineation maps) using Radarsat-2, COSMO-Skymed, and Pleiades images in the most critical areas of ~~the~~ Piemonte. In some areas ~~like, such as~~ Moncalieri ~~also~~, a map of ~~damages~~the damage (grading maps) was ~~also~~ produced. However, the available delineations maps represent the automatic extraction of the flooded area at the moment of image acquisition, and

generally not at the maximum extension. In the case of Piemonte, they cannot be used for exhaustive modelling and ~~damages~~ damage evaluations. The preliminary estimate of ~~damages~~ the damage to buildings made by the municipality of Moncalieri ~~is about~~ was approximately 50 million of € (M€) for industrial buildings and 13 M€ for residential buildings, and ~~others~~ another 6 M€ for ~~damages~~ damage to other goods (http://www.comune.moncalieri.to.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/3669).

3 Materials and Methods

The aim of this study is the definition of a possible methodology for the identification and mapping of flooded areas using low-cost solutions. For this reason, we have combined and compared data from different sensors. We used different approaches for flood mapping—some ~~have~~ already ~~been~~ tested ~~for a long time as reported in~~ the literature ~~from long time~~, and others ~~are~~ more innovative and experimental. We first introduce the concept of ‘co-flood’ and ‘pre/post-flood’ data. Co-flood data are collected around the time of ~~the~~ maximum inundation, while pre/post-flood data are acquired before or after the flood maximum. In the first case, the mapping of flooded areas is more straightforward, but the acquisition of co-flood images ~~could~~ was not always ~~be~~ possible.

Using a ~~multi-scale~~ multiscale approach, we developed a methodology (Fig. 2) that progressively considers the use ~~of~~ satellites and then high and ultra-high-resolution systems. The aim is the acquisition of a dataset that can be used to support the identification of ~~the~~ water depth and ~~extension~~ extent reached by the flood. The dataset also allowed making a first evaluation of ~~damages~~ damage in both ~~in~~ urbanized and ~~not non~~ urbanized areas.

The first identification of the flooded area can be made using ~~satellites~~ satellite results and *in situ* information ~~coming~~ from the civil protection system that collects reports from local authorities (co-flood phase). This first identification phase is mandatory to have a general and fast indication of the involved area and to plan more detailed acquisitions.

The second phase is aimed ~~to acquire~~ at acquiring a high definition dataset that can be used for a detailed mapping of the flooded area. For this step, ~~a system~~ is required ~~a system that is~~ able to fly on demand over large areas and acquire an RGB /multispectral dataset with a resolution of 10-20 cm/pixel. The high-resolution map obtained during this phase can be used for the identification and ~~map~~ mapping of flooded areas with acceptable detail. The resolution of the orthophoto can also support the identification of critical elements ~~like, such as~~ damaged infrastructures—bridges, levees, streets and urban areas involved in the flood. The map of ~~the~~ most damaged sectors can be obtained merging civil defence reports and the analysis of acquired

orthophotos. The identification of the most critical sectors is essential for a preliminary evaluation of the damage that occurred damages and the planning of the first remedial actions.

On For the most critical sectors, especially in urban areas, it is possible to acquire a ultra-high-resolution dataset (2-5 cm/pixel) that can be used for the quantification of damagesdamage or detailed mapping of flood markers. This third phase can be doneperformed using Remotely Piloted Aerial Systems (RPAS) or terrestrial systems. This last phase is aimed to quantifyat quantifying the flood severity. In our test, we started from the use of nadiral images acquired by airplane and RPAS, but we immediately realized that in urban areas this approach couldwould be not sufficient for the mapping of flooded limits and the identification of damages. One ofdamage. Among the most critical dataparameters is the water level reached by the flood that. it is often visible only on façades of buildings. building facades. The identification and mapping of water level markers on façadesfacades are mandatory for correct reconstruction of what happened. To obtain a 3D3-D representation of urbanized flooded areas, we decided to integrate terrestrial and aerial images using the SfM algorithm.

In the following chapters, we present the acquired datasets of the different phases (Table 1). All the proposed systems are low-cost solutions that could be adopted by national/regional Authoritiesauthorities with limited efforteffort.

3.1 Flood mapping at regional scale with satellite data

The developed methodology is based on a multi-scalemultiscale approach that starts from the use of low-resolution regional scale satellite images. The use of different available satellites images can support the identification of flood effects at a low resolution over large areas and at higher resolution at a local scale. The choice of the most appropriate satellite data depends on different factors: i) the characteristics of the study area; ii) the spatial resolution; iii) the revisit time; iv) the time of the acquisitions with respect to the moment of maximum inundation; and v) the availability and cost of images.

In this paper, only free of charge images were used to assure a low-cost approach. For every considered dataset, we produced a map of the flooded area that represents the synthesis of remote sensing data and geomorphological evidence from the 5-m DTM available from Regione Piemonte. We use a visual-operator approach to map the flooded areas asthat resulted in more preiseprecision than automatic classifications, especially in the case of post-flood images. IntableTable 2 arereportedpresents the satellite data related to the flood phase. We considered as co-flood data all of the images acquired between early 25 November 25 2016 (start of the first inundation) and the evening of 26 November 26, 2016 (withdrawnthe withdrawal of water).

3.1.1 SAR data

SAR instruments work in all-weather conditions and in the ~~night-time~~nighttime, thus ensuring a high observation frequency and increasing the opportunity ~~to provide~~of providing data ~~in correspondence at~~corresponding with the flood event.

I) Co-Flood mapping. If data are available during the maximum flooding phase, it is possible to accurately map the affected area using high-resolution SAR images, such as those acquired by the TerraSAR-X (Giustarini et al., 2013) and COSMO-SkyMed (CSKM) (Refice et al., 2014) satellites. In particular, the identification of the flooded area is performed by analysing the SAR backscattering, which shows low values in water-covered areas. In our analysis, we used a SAR image acquired by the X-band COSMO-SkyMed satellites constellation (wavelength ~ 3 cm) on 25 November 2016 (05:05 UTC acquisition time). Data ~~has been~~were provided free-~~of~~-charge by the E-Geos and the Italian Space Agency (ASI) in a quick-look preview format with a 60 m x 60 m resolution.

The CSKM data provided is a simple not-geocoded image in grey-scale format (0-255). After the geocoding, we re-~~classify through GIS software~~, classified the SAR amplitude images through GIS software, using empirical thresholds in three main classes: water covered areas (0-60); soil/vegetation (60-160); and urban area (160-255). The investigated area is almost flat, ~~so~~thus it is not affected by problems related to geometrical distortions of backscattering. We ~~validate~~validated the classification accuracy by comparing the reclassified ~~image~~images with an aerial photo, optical images, and land-use database. The analysis with such data ~~points out~~notes the relevance of co-flood images for the fast mapping of flooded areas. ~~We remark that it~~It is not possible to know *a priori* if a co-flood image will be available during the maximum of the flood event. However, the short revisit times achieved by the new generation of SAR satellites can significantly increase the possibility ~~to collect~~of collecting co-flood data.

II) Post-flood mapping. We also performed a post-flood mapping by exploiting data acquired by the Sentinel-1 ~~mission~~Mission, which is composed of a constellation of two satellites, Sentinel-1A and Sentinel-1B, launched on ~~2014~~3 April ~~3~~2014, and ~~2016~~25 April ~~25~~2016, respectively. Sentinel-1 satellites have been designed to acquire C-band SAR data in continuity with the first-generation ERS-1/ERS-2 and ENVISAT ~~mission~~Mission, developed within the European environmental monitoring program, Copernicus. The Sentinel-1A SAR operates at 5.405 GHz and supports four imaging modes providing images with different ~~resolution~~resolutions and ~~coverage~~coverages (Torres et al., 2012). We used the Interferometric Wide Swath Mode (IW) acquisition mode by employing the Terrain Observation by Progressive Scans (TOPS). The IW TOPS mode is the primary mode of operations for the systematic monitoring of surface deformation and land changes (De Zan and Monti-Guarnieri, 2006). This acquisition mode provides large swath widths of 250 km with a spatial resolution of 5 m $\times$ 20 m (IW). The repeat cycle of the twin Sentinel-1A/B constellation ~~is~~was reduced to 6 days.

For our analysis, we ~~have~~ acquired two IW Sentinel-1A/B images collected over the study area, in VH polarization along the descending satellite passes. In particular, we ~~have~~ exploited ~~the~~ data acquired after (on ~~28~~ November ~~28~~, 2016) and before (~~22~~ November ~~22~~, 2016) the flooding event (see Table 3).

~~The~~ SAR data, provided in the Single Look Complex (SLC) format, ~~has been were~~ first radiometrically calibrated to convert the digital number (DN) values into corresponding backscattering coefficients, i.e., sigma naught (σ^0) values, which contain information on the electromagnetic characteristics of the surface under investigation. Subsequently, ~~the~~ calibrated SAR data ~~have been multi-looked were multilooked~~ with one look in the azimuth direction and four looks in ~~the~~ range one, and finally geocoded, by converting the maps from radar geometry into Universal Transverse Mercator (UTM) coordinates (zone 32T). After these pre-processing steps, to detect land surface changes induced by flooding, we ~~have~~ computed the difference between the post- and the pre-flooding geocoded backscattering coefficient images, and produced the map of the temporal variation of the surface backscattering ($\Delta\sigma^0_{\text{post-pre-flooding}}$).

3.1.2 Multispectral satellite data.

In this category, we considered both low- and medium-resolution images. Unfortunately, we found co-flood images only for ~~the~~ low-resolution images.

I) Medium-Low resolution satellite data. MODIS (Moderate Resolution Imaging Spectroradiometer) is a system of two sun-synchronous, near-polar orbiting satellites, called Aqua and Terra, that daily acquire images all over the ~~World~~world (Justice et al., 1998). Terra acquires images in the late morning, while Aqua ~~acquires them~~ in the early afternoon. ~~The~~ satellites also have a ~~night time~~nighttime pass when they acquire ~~images~~ in the thermal bands. This repeat frequency does not occur along the same ground track, and the repeat cycle along the track is every 16 days. The high revisit time allows detecting ~~floods~~ with more probability ~~flood~~ over vast areas when they ~~are~~ still flooded and not covered by ~~cloud~~clouds. We searched for ~~the~~ first free-cloud MODIS images from ~~the~~ Earthdata portal of NASA (<https://worldview.earthdata.nasa.gov/>). The selected image was acquired by ~~the~~ Aqua satellite on 26 November 2016. We used the 6-bands products with a spatial resolution from 250 to 500 m that ~~range~~ranges from ~~the~~ visible to near-infrared (NIR) and shortwave infrared (SWIR) (Table 4). For the elaboration, we used the MYD09 - MODIS/Aqua Atmospherically Corrected Surface Reflectance 5-Min L2 Swath ~~500m~~500 m, (Vermote, 2015), downloaded from <http://ladsweb.nascom.nasa.gov/>. To have a benchmark of the non-flooded situation, we also used the Aqua satellite image of 12 November 2016, which was compared with the image taken during the flood. We did not apply an atmospheric correction to ~~the~~ images because the MYD09 product is adequate ~~for~~ our ~~aim~~purposes. Moreover, the study area is small (20 km), and the atmospheric parameters for correction available at 1 km of spatial resolution (water vapour,

ozone or aerosol) ~~don't~~did not show a significant change. For the identification of the flooded areas, we ~~make~~made the following elaborations:

- a) ~~False~~A false colour image was made with combinations of 7-2-1 bands for a visual interpretation of flooded areas;
- b) Modified Normalized Difference Water Index variation $MNDWI_{var}$ (Equation 1). The $MNDWI$ ~~allow detecting~~allows the detection of water masses or soil moisture. In the literature, different combinations for this index ~~are~~have been presented and discussed (Xu, 2006; Zhang et al., 2016; Gao, 1996). In our study, we used the ratio between B1 (red band) and B7 (Short Wavelength Infrared—; SWIR). The difference with a non-flooded situation can be used for identifying changes in the soil moisture. We used the results of the supervised classification to mask the cloud cover.
- See Equation 1:

$$MNDWI_{var} = MNDWI_{post} - MNDWI_{pre} \quad \text{where } MNDWI = \frac{(B1-B7)}{(B1+B7)} \quad (1)$$

- c) Supervised classification of co-flood image. The supervised classification has already been used in the literature to map flooded areas, using machine learning, as described in Ireland et al., (2015). In our work, we made a simple supervised classification with SAGA GIS. We first manually defined the training areas with the main land use typologies visible on the false colour image. We ~~try~~tried different methodologies for the classifications, and we chose as most accurate the maximum likelihood with the absolute probability reference and spectral angle methods. We ~~validate~~validated the reliability of these classifications with a comparison with the false colour image and land-use database. Then, using a GIS query, we extracted the category “area covered by water or wetland” that mostly ~~correspond~~corresponded to the flooded area for accuracy ~~staties~~statistics reported in ~~result chapter~~. Section 4 Results.

II) Medium-high resolution satellite data. Medium-high resolution multispectral satellites (e.g., Sentinel-2 A and B or Landsat 8) have a longer revisit time (from 5 days for the Sentinel-2 constellation to 16 days for Landsat-8), ~~and it~~. It is more difficult to have images at the same time of the maximum flood and that are cloud free. However, by comparing two images acquired before and after a flood event, it is possible to calculate the variation of different ~~indexes~~indices related to ~~change~~changes in the reflectance of the soil or/and of the vegetation. ~~In this way~~Thus, it is sometimes possible to map the flooded area indirectly (post-flood mapping).

In our study area, we used images taken by Sentinel-2 before the flood (~~2016, 11~~ November ~~11~~2016) and after (1st December ~~12~~2016). Sentinel-2 has some bands at 10-_m of spatial resolution and some bands and 20-_m of spatial resolution ~~resumed~~(reported in Table 5-). To detect the flooded area, we first made a visual interpretation using images with different ~~bands composition~~bands' compositions of post-flood data. The comparison of the considered images allowed ~~calculating~~us to calculate the difference between the following two ~~indexes~~indices:

1. The Normalized Difference Vegetation Index (NDVI) variation. The NDVI ~~was~~ calculated with 10 m of spatial resolution images ~~from~~ Sentinel-2 using the near-infrared band (NIR - B8), and the red band (B4). The NDVI is related to the activity of vegetation, ~~and it. It~~ is possible, by calculating its variation (~~equationEquation 2~~), to identify the decrease of ~~the~~ NDVI values as an effect of inundation on vegetation (Ahamed et al., 2017). The detection of this change allows ~~the~~ mapping flooded areas indirectly.

$$NDVI_{var} = NDVI_{post} - NDVI_{pre} \quad \text{where } NDVI = \frac{(B8-B4)}{(B8+B4)} \quad (2)$$

2. The Modification of Normalized Difference Water Index (MDWI) variation. We ~~useused~~ a similar index already tested for ~~the~~ MODIS data. We used Sentinel-2 to calculate the MNDWI considering the red edge band (B5) and the SWIR band (B11) at 20 m of spatial resolution. With this approach (~~equationEquation 3~~), it is possible to map the variation ~~of~~ soil moisture related to recently flooded areas or areas that are still covered by water.

$$MNDWI_{var} = MNDWI_{post} - MNDWI_{pre} \quad \text{where } MNDWI = \frac{(B5-B11)}{(B5+B11)} \quad (3)$$

3.2 Flood mapping at local scale with high and ultra-high-resolution data

The flood mapping at ~~the~~ local scale was made using high and ultra-high-resolution images.

Immediately after the event, a research project proposed by CNR-IRPI was conducted with the participation of ALTEC S.p.A., Digisky s.r.l. and the Civil Protection Agency of the Metropolitan City of Turin. The aim of the project is a methodological analysis of a possible low-cost solution that could be used for ~~the~~ high-resolution mapping of flood effects.

The study started from ~~the~~ SMAT F2 Project results (Farfaglia et al., 2015), where different solutions for the acquisition of RGB datasets with small and medium Remotely Piloted Aerial Systems (RPAS) were developed. ~~AlsoAdditionally, the~~ previous experiences of ~~the~~ CNR IRPI and Civil Protection Agency in the use of small RPAS for the study of geo-hydrological processes (Giordan et al., 2015; Boccardo et al., 2015; Fiorucci et al., 2017; Giordan et al., 2017) were useful for the definition of a correct use of these systems. These previous experiences ~~pointed-outnoted~~ how the use of low-cost systems for the acquisition of RGB images and the application of ~~structure-from-motionSfM~~ algorithm (~~SfM~~) can be considered ~~as~~ a good solution for the creation of high-resolution ~~3D3-D~~ models.

3.2.1 Aerial high-resolution images

Aerial ~~photo-took~~photos taken in a few hours or within a few days after the peak of inundation allow the mapping ~~theof~~ flooded ~~areaareas~~ with high precision over the most involved territories. In our case, aerial photos were acquired after the flood over the Po ~~river~~River near the village of Pancalieri and for ~~the town of~~ Moncalieri-~~town~~. We used a low-cost aerial platform (Tecnam P92-JS) provided by DigiSky s.r.l., equipped with a 16 Mp mirrorless camera (Panasonic Lumix GX7-~~camera~~ (~~mirrorless with 16 Mp~~) that allowed us to acquire aerial ~~photo~~photos with a spatial resolution of 10 cm/pixel. The system also has an onboard GPS that acquires ~~images~~image shooting points and allows the georeferencing of the photos sequence using SfM.

The use of a manned solution has several ~~addadded~~ values that can be very useful in this phase: i) it is possible to fly over urban areas without the strong limitations that ~~characterized~~characterize RPAS; ii) the system can acquire images over large areas ~~inwithin~~ a limited lapse of time; ~~and~~ iii) the system can ~~flight~~fly on demand during the flood or immediately after (with favourable weather conditions).

The adopted solution was used to acquire ~~images of the~~ 9.2 km² of the most damaged area of Moncalieri and 9.5 ~~Km²~~km² of the flooded area of Pancalieri. These two areas are representative of different conditions:

1) The area of Pancalieri is a rural area mainly dedicated to ~~the~~-agriculture. In this case, the Po ~~river~~River flood covered large uninhabited sectors of the Pancalieri plain and reached part of the town of Pancalieri. Here, using SfM, the ~~plane~~ images ~~of the plane~~-were also processed for the creation of a ~~digital surface model~~ (DSM) (resolution of 20 cm) with the aim of mapping geomorphological features related to the flood.

2) The selected area of Moncalieri is a strong urbanized sector of the municipality. In this area there are: i) a motorway; ii) several regional and local streets; iii) a residential area with recent unfamiliar houses and small condominiums; ~~and~~ iv) an industrial and commercial district. The inundation of this area is due to the Chisola ~~levees-breaks~~Stream levee's break. The map of Moncalieri was useful for the identification of ~~the most~~ ~~damages~~damaged elements, and in particular the levee. In the most critical areas, we also used RPAS to acquire ultra-high-~~resolution~~ images.

3.2.2 RPAS ultra-high-~~resolution~~ images

In the ultra-high resolution step, we used ~~the~~ RPAS and ~~the~~ terrestrial system. ~~The~~ RPAS ~~were~~was used to acquire nadiral photo sequences of the most damaged areas and infrastructures. In particular, we tested the possibility ~~to-use~~of using RPAS for the identification of ~~damages~~damage that occurred to the Chisola ~~river~~Stream levee and one of the most damaged sectors of ~~the town of~~ Moncalieri-~~town~~. The employed RPAS is a multirotor (CarbonCore 950 octocopter) equipped with a Canon

EOS M (Sensor CMOS APS-C, ~~48Mp~~18 Mp). The system is equipped with a flight terminator and a parachute and can also be used in inhabited areas. The Civil Protection Service of Turin metropolitan area provided the RPAS. The obtained aerial photos have a spatial resolution of 3 cm/~~Pixel~~pixel. Using SfM, the images of the drone were also used to create the 10-cm resolution DSM. All of the flood mapping methodology described ~~until now~~above are very often ~~not able~~unable to ~~give~~provide a consistent ~~measure~~measurement of water depth. This limitation is not due to the resolution or the time of acquisition, but it is intrinsic in nadir images. For this reason, in the Moncalieri area, we choose to deploy a ground-based solution.

3.2.3 Ground-based ultra-high-resolution images

As ~~previously~~ mentioned-before, we tested a low-cost terrestrial system for the acquisition of ultra-high-resolution images. In particular, we used an integrated system developed by ALTEC SpA, which ~~couple~~couples a Go-Pro HERO 3+ (Black Edition) camera with a GPS and an acquisition module. The system is able to record a STANAG 4609 geolocated HD video. We installed the experimental system over a CNR IRPI car, and a survey was ~~done~~performed a few days after the flood in the ~~considered~~study area of Moncalieri. The continuous record of geolocated ~~video~~videos can be a good solution for the acquisition of a significant amount of data immediately after the flood when marks of the water level are still clearly visible along building ~~façades~~facades. The identification of water ~~level~~levels of flooded areas based on the measurement of marks over ~~façades~~facades is not a novelty, but the manual acquisition of these data has often been a critical task. Citizens often want to quickly obliterate these signs as a reaction to the ~~critical~~life-threatening experience that they lived through. The use of field teams that look for these marks can be a time-consuming task that can produce few results with considerable ~~efforts~~alsoeffort because before the survey it is hard to have an idea of the number and the distribution of ~~façades~~facade marks that can be identified and measured. The number of marks strongly ~~decreased~~decreases after a few weeks, and for this reason, it is essential to have a system that can acquire very fast geolocated images and that can be easily used over large areas.

The presented system is straightforward and efficient. Other components of the team can analyse the geolocated video immediately after the acquisition or ~~after~~many days afterwards. The primary goal is the fast acquisition of numerical information of the flood effects that can be used for several purposes. For the identification and mapping of water levels, the video is analysed, and a frame sequence is extracted from it when the operator sees some marks ~~lefts~~left by water over ~~façades~~the facades. The developed system can extract not only frames but also their geocoding information, which are computed using SfM applications. The result is a georeferenced ~~3D~~3-D model of the façade that can be used to measure the water level with a good approximation (few cm). We ~~validate~~validated the accuracy ~~measures of~~measurements of the water level based on SfM with manual ~~measures~~measurements accurately geolocated with GPS RTK positioning.

3.2.4 Field data

Field survey, ~~and~~ ancillary data ~~like a measure, such as measurements~~ of river discharge stations, and civil protection reports, were used to validate the maps derived from remote sensing interpretation and the simulation models for ~~the~~ Pancalieri and Moncalieri areas. We made a GPS RTK campaign in ~~the~~ Tetti Piatti and Tagliaferro areas to have direct measurements of ~~the~~ flood marks. In particular, we acquired the ~~3D3-D~~ position of marks previously identified using the available video. We used third ~~part~~party materials ~~like, such as~~ newspaper reports, ~~photo~~photos and videos found on the web with a validation of their reliability regarding geolocation and time. Available data were used to check the extension of flooded area and water height mapped with other methodologies.

355 3.3 Water depth models based on DTM approach.

As ~~previously~~ mentioned ~~before~~, the primary goal of the presented methodology is the definition of the maximum depth reached by the water during the flood. The map of water maximum depth (WD) is an important document that can be used for the first definition of ~~damages~~damage and remedial actions. All the acquired material, and, in particular, data that define the water depth reached by the flood, were used to calculate the water maximum depth map. In our study, we adopted a simple raster-based model (Bates and De Roo, 2000), and we created an absolute water level (WL) raster. The first step is the acquisition of several ~~measure~~measurement points of water level (WL_p) that are calculated from the measured water depth point (WD_p). WD ~~measures~~measurements can be ~~done~~performed using: i) georeferenced photos (low accuracy); ii) ultra-high ~~-resolution~~ ~~measure~~measurements derived from SfM and integrated with a manual ~~measure~~measured geolocated GPS RTK positioning (high accuracy); iii) civil protections reports (the level of accuracy can be very different); ~~and~~ iv) data acquired by hydrometric river level monitoring stations. Starting from the collected spotted ~~measures~~measurements and the 5-m LIDAR ~~digital-terrain-model~~ (DTM) freely provided by Regione Piemonte, we calculated the WL value for each point using a simple formula: $WL_p = DTM + WD_p$. ~~Available~~The available WL points were used to create the water level contour lines and then interpolated using GIS software to obtain the raster of ~~the~~ WL gradient. The WL raster is used to create the raster map of water depth, which can be calculated with a simple raster calculator of GIS software using the reversed formula $WD = WL - DTM$. ~~The~~ WD map is necessary information to assesses and improve the limit of the flooded area, and, it is also fundamental for the phase of ~~the~~ preliminary ~~damages~~damage assessment. We produced maps of ~~the~~ water depth at a medium resolution for ~~the~~ Po ~~river~~River (Fig. 5) and high resolution for ~~the~~ Moncalieri (Fig. 11) and Pancalieri ~~area~~areas (Fig. 6).

4 Results

4.1 Flood mapping from low to medium-high resolutions with satellite data.

The satellite data allowed mapping ~~of~~ the flooded areas by ~~the Po river, River, and the~~ Chisola and Oitana ~~streamstreams~~, with a resolution that ranges from 500 m of MODIS to 10 m of Sentinel-2. We compared raster maps based on ~~the~~ remote sensing data with our perimeter of the flooded area (black polygon in Fig. 3, Fig. 4 and Fig. 5). We manually extrapolated the flooded area perimeters considering both satellite data and geomorphological features observed in the hillshade model derived from 5-m DTM of ~~the~~ Regione Piemonte. For the evaluation of automatic flooded area maps based on satellite data, we applied a GIS query for each map to create boolean rasters of ~~the~~ flooded ~~+/~~not flooded area. Then, we overlapped the obtained raster with manual polygons for a geo-statistical analysis, ~~foras~~ each polygon is reported ~~with~~ the percentage pixel classified as flooded/not-flooded. The main results are reported in ~~table~~Table 6.

For ~~the~~ Po ~~River~~ and part of Chisola, ~~Stream~~, we mapped the flooded areas also with the help of ~~the~~ WD model based on DTM. At the ~~moment of~~ writing ~~of~~ this paper (November 2017), ~~it is still not available~~ an official delimitation of flooded areas, ~~is still unavailable~~; a map made by ARPA Piemonte is under validation, and the data will be downloadable in the next months.

4.1.1 Flood mapping with SAR data

I) Co-flood mapping, the reclassified amplitude of CSKM data. The image classification allowed us ~~detecting to detect~~ three classes of SAR amplitude (Fig. 3 A) ~~-~~ that were defined by means of empirical thresholds: i) low, that correspond to water covered area (blue); ii) intermediate ~~like, such as~~ soil/vegetation (green); ~~and~~ iii) high, that are urban areas (pink). In the map (Fig. 3 A) ~~-~~, we also overlapped the quarry lake from ancillary data (cyan). The accuracy in the correct detection of land-use type is quite good, ranging from 80-% for soil and vegetation, ~~and~~ 67% for the urban area to 61% for ~~the~~ water body (tested in quarry lakes). Vegetation and buildings are factors that reduce the detection of water covered areas even using full-resolution images and more complex processing (Pierdicca et al., 2018). In a second step, we selected, with a GIS query, the low resolution (water covered) class that mostly ~~correspond~~~~corresponded~~ to the inundated areas and we compared ~~them~~ with the real flooded area. ~~Also~~ ~~Additionally~~, the ~~accuracy detection~~~~accuracy detection~~ of ~~the~~ flooded areas is quite good: it ranges from 57-% in the lower Oitana ~~stream~~~~Stream~~ to 2% in the Po area near Moncalieri. The low accuracy for some areas is related to the time of ~~the~~ satellite acquisitions (05:05 UTC of 26 November 2016) ~~at~~ some hour before the flood peak. The flood wave positions can be appreciated, especially along the Po ~~river~~~~River~~, where upstream (near Pancalieri) ~~about the~~~~approximately~~

42% of the flooded area was detected, while downstream (Carignano) ~~decreaseit decreased~~ to 4%. The urban area of Moncalieri limits the capability detection of inundated areas. The false positive errors are less than 5% of the area.

II) Post-flood mapping with Sentinel-1 data. The map of the post- ~~and~~ pre-flood SAR backscatter difference ($\Delta\sigma^0_{\text{post-pre-flooding}}$) through the application of an empiric threshold allowed us ~~detectingto detect~~ areas covered by water, i.e., flooded ($\Delta\sigma^0 < -4\text{dB}1\text{ dB}$) (Fig. 3 B). Such results show that most of the areas classified as flooded by the co-flood analysis were ~~not anymoreno~~ longer covered by water on 28 November 2016. Only small depressed areas, e.g., ancient meanders of ~~the Po riverRiver~~, were still flooded (Fig. ~~3D', 3D''3D', 3D"~~ and ~~3D'''~~), ~~the3D''~~). The case of Pancalieri will be discussed ~~in~~ more ~~deeplydepth~~ in ~~par~~Section 4.2.

4.1.2 Flood mapping with multispectral data

I) **Multispectral low resolution, MODIS-Aqua.** The MODIS-Aqua satellite took an image reasonably free of clouds over the entire Piemonte during the late morning of ~~26~~ November ~~26~~, 2016. The image allowed ~~detectingthe detection of~~ the flooded areas with a resolution of 500 m.

From the false colour images (Fig. 4 B), even if the area at the south of Turin ~~iswas~~ not yet directly flooded, it ~~iswas~~ only possible to detect that the soil was saturated ~~ofwith~~ water (dark green-blue in false colour composition). The comparison with ~~the~~ pre-flood image of ~~12~~ November ~~12~~, 2016 (Fig. 4 A) improved the detection of the flooded area.

We also ~~try~~tried to extract, in an automatic way, the flooded area with the equations previously described.

We identified ~~the~~ flooded area using a GIS query with the value $\text{MNDWI}_{\text{var}} \geq 0.3$ (Fig. 4 C). This value is an empirical threshold that allows ~~selectingthe selection of~~ most of the flooded area and minimizes false positive errors. The results show a good correspondence between the manually drawn and the automatically classified flooded area; however ~~around~~, approximately 35% of the flooded area was not identified. The mismatch can be explained with the satellite acquisition at the end of the co-flood stage when water started to withdraw. It is also possible to see some false positive pixels (<10 %) that correspond to the shadow of the clouds or haze that was not possible to entirely filter ~~out~~.

We also made a supervised classification of ~~the~~ 26 November MODIS image using ~~the~~ maximum likelihood (MLC) (Fig. 4 D) and spectral angle (SA) (Fig. 4 E) methods. In the study area, we classified, four primary land ~~covercovers~~: vegetation, bare soil, ~~cloudclouds~~, and water body ~~+/~~wet soil that almost identify the flooded sector (the water bodies ~~likesuch as~~ the quarry lakes are too small for MODIS pixel). After a visual checking of the classification reliability, we used a GIS query to select the “water covered and wet areas” classes. The query ~~createscreated~~ a boolean raster of flooded areas. The accuracy of flood map based on supervised classification ~~iswas~~ good: it ~~identifiesidentified~~ most of the flooded areas for ~~the Po riverRiver~~ (> 70

430 %) with low false positive ~~pixel (table)~~pixels (Table 6). We obtained ~~worst~~the worse results for the area flooded by ~~the~~ Chiosla and Oitana ~~streams~~.

For both ~~indexes~~indices, it ~~is~~ possible to see that the town of Moncalieri (red square 1 in Fig. 4) ~~that was~~ flooded by Chisola ~~stream~~Stream is not well identified.

435 **II) Multispectral medium-high resolution post-flood mapping Sentinel-2.** We ~~analyse~~analysed the data of Sentinel-2 by means of visual interpretation of RGB composite image ~~and~~, using two different ~~indexes~~indices (NDVI – MNDVI) to identify ~~the~~ flooded areas (Fig. 5). For both ~~indexes~~indices, we used GIS queries with empirical thresholds to extract the flooded area: 1) NDVI variation (NDVI_{VAR}) at 10 m of ~~Spatial~~spatial resolution (Fig. 5 A). The results show that for ~~the~~ Po, Chisola and Oitana, a clear pattern of negative NDVI variation corresponds to the flooded area. The study area is almost flat and mostly occupied by cultivated fields, and, in November, it was characterized by a ~~a~~ tillering of wheat. The flood caused ~~at~~the deposition of a thin layer of silt sediment that caused a decrease of vegetation activity (most of the flooded area shows an NDVI_{VAR} ~~<=~~ -0.06) that could be detected using the available dataset. ~~By the contrary~~In contrast, the wheat field outside ~~the~~ flooded area shows an increasing or stationary NDVI. In the maps are ~~the~~ visible negative NDVI_{VAR} also outside the flooded area that ~~is~~are related to: i) winter decreasing of activity of natural vegetation or some cultivations; ~~and~~ ii) ~~the~~ longest building shadow in ~~the~~ urban areas. The presence of false positives hampers the use of automatic classifications of flooded areas, and a visual interpretation is necessary. It is possible that flood effects and the layers of silts could have also affected the crop productivity with relative economic ~~damages~~damage, as reported in other cases (Tapia-Silva et al., 2011; Shrestha et al., 2017), but this evaluation is not the aim of this study.

440 2) MNDWI variation (MNDWI_{VAR}) at 20 m of spatial resolution. The index is directly related to the presence of water or high soil moisture. The results show that for ~~the~~ Po, Chisola and Oitana floodplain (Fig. 5 B), ~~there is~~ a clear pattern of positive MNDWI_{VAR} that indicates an increase of soil moisture and the presence of some areas that were still inundated. It is possible to see that a threshold of MNDWI_{VAR} + 0.1 is the best to delimit the flooded areas. However, ~~like for as with~~ NDVI, the presence of many areas with positive variations outside the flooded sector makes more accurate a manual interpretation compared to an automatic classification. The evidence also suggests that for this index, it is important to have images taken within few days after the flood when the affected areas are still covered by water or with ~~soil~~very wet. ~~In table soil. Table 6 are resumed~~shows the accuracy statistic for ~~the~~ automatic mapping of flooded areas based on satellite data: MNDWI ~~shows~~shows a little better accuracy than NDVI. ~~It is worth to note~~Note that for both MNDWI_{VAR} and NDVI_{VAR}, the flooded area is well detectable in ~~the~~and around the village of Pancalieri (> 50% of accuracy) where land use is mostly cultivated land. On the other hand, ~~it~~ is more difficult to detect the flooded area in the ~~high~~highly urbanized town of Moncalieri (< 20% of area detected).

460 **III) Water depth model.** We ~~create~~created a WD model for ~~the~~ Po ~~river~~River (Fig. 5 C) following the procedure described in paragraph 3.3. The simulated WD model has a good match with ~~the~~ benchmark polygon and the evidence from Sentinel-2 (Fig. 5 A and B); ~~and~~ MODIS data (Fig. 4). It is also possible to observe some discrepancy at ~~South-East~~the southeast of Moncalieri where ~~a~~ large area should be flooded, according to ~~the~~ model, but in reality, was not affected. This mismatch could be explained by the presence of artificial structures (e.g., ~~embankment~~embankments) that ~~protect~~protected the flood-prone areas and ~~that~~ our model cannot simulate. The uncertainty of our WD model is complicated to evaluate because it depends on many factors: the main ~~limits~~limit is the number of ground-based WD ~~measures~~measurements, their reliability and their geolocation. The interpolation to obtain ~~the~~ water table is also another source of error. The Lidar DTM of Regione Piemonte accuracy in elevation ~~is range~~ranges from ± 0.3 m to ± 0.6 m in urban areas. Over this vast area, we ~~do not~~ have ~~not a~~ ground measure for validation, but it is possible to estimate ~~it~~ from some photos found on the web that ~~shows the~~ model error is ~~about~~approximately 0.5 m. In the high-resolution WD model of Pancalieri and Moncalieri ~~show~~shown in ~~the next chapter~~Section 4.2, it was possible to validate data with ground-truth evidence.

The final limits of the flooded area are the results of both remote sensing and WD model interpretation. Its accuracy can be considered acceptable for large cultivated and flooded ~~area~~areas by ~~the~~ Po ~~river~~River, but ~~it is~~ less accurate for urban ~~zone~~zones, especially in Moncalieri where a local high-resolution analysis is needed to quantify the severity of the flood.

475 4.2 Flood mapping at local scale with high-resolution data.

Inside the area analysed using remote sensing systems, we ~~choose~~chose the most critical sectors of Moncalieri and Pancalieri to test ~~the~~ high and ultra-high-resolution images. As ~~previously~~ mentioned-before, the high resolution has been acquired using an aircraft, ~~and~~ the ultra-high resolution using RPASs and a ground-based photosystem. All ~~of~~ the images ~~have~~were processed using SfM that allowed ~~us~~ to obtain ~~orthophoto~~orthophotos and ~~3D~~3-D models.

480 4.2.1 High-resolution aerial photo, Pancalieri

~~The~~ Po ~~river~~River partially flooded the village of Pancalieri on the morning of November 25, 2016. We mapped this area also using high-resolution aerial ~~photo~~photos (10 cm/Pixel, RGB bands) provided by DigiSky. Aerial photos were taken November 28, 2016 (Fig. 6 A) and allowed ~~us~~ to refine the map of the flooded area ~~form~~from the medium resolution maps obtained with the interpretation of ~~the~~ Sentinel-2 data. With the help of ~~digital surface models~~ (DSM) at 0.2 m of spatial resolution derived from SfM, we also mapped geomorphological features ~~like, such as~~ erosion (meanders cut) ~~and~~, deposition areas and road ~~damages~~damage (Fig. 7 C). The integration of ~~the~~ aerial photo and DSM also allowed ~~making~~us to make a 3-D model ~~where~~,

in which it was possible to measure the water depth for some points where the water level marks are well detectable (Fig. 7 B).

Using the procedure described in paragraph 3.3, we produced a WD model for the Pancalieri area (Fig. 6 D) with higher accuracy with respect to the rest of the Po valley. The higher accuracy of the model was obtained using: i) high-resolution aerial photos; ii) spot measures derived from SfM; and iii) different videos and photos found on the web and geolocalized with the help of Google Street view (e.g., Fig. 6 B and 6 C). The model shows that there was a modest height of the water-flooded part of the Pancalieri village (< 0.5 m), while near the Po river, the WD reached 2-3 m with a fast flow that caused an erosion channel. From the map of the flooded area (Fig. 6 D), note that, during the flood, ancient meanders at the east of Pancalieri were reactivated, and, as consequence, some areas were flooded quite far from the Po River's main course.

Some months after the flood (April 2017), satellite photos available on Google Earth (0.5 m spatial resolution) still show some traces of flood-like erosion, the floods, such as erosion, and areas covered by sand deposits. The flooded area is much more difficult to identify and confirms the importance to acquire data as soon as possible after a flood event.

4.2.2 High-resolution aerial photo and ultra-high resolution RPAS 3D models, Moncalieri.

Some parts of Moncalieri municipality (Tetti Piatti, Carpice and Tagliaferro localities) were flooded in the late morning of 25 November by the Chisola stream that breached its embankment in different points (Fig. 8 B). On the left side of the Chisola, the area with a very dense residential and industrial settlement suffered severe damages. Civil protection evacuated hundreds of people. In the evening of November 25, The Po river flooded another sector of the Moncalieri municipality.

A few days after the flood, the area flooded by the Chisola was analysed with different methodologies:

1. High-resolution aerial photos. Like As in Pancalieri, on November 29 a very high resolution (0.1 m/pixel) aerial photo using the aerial platform of DigiSKY was taken over an area of approximately 9.2 km². The aerial photo allowed us to refine the map of the flooded areas (Fig. 8 A) and to detect the points where the river embankment collapsed (Fig. 8 B).
2. Ultra-high resolution RPAS photos. On December 3, 2016, the RPAS acquired photos (resolution of 0.02 / 0.03 m/pixel) over some of the most critical areas (e.g., Tetti Piatti – Fig. 8 C) for precise mapping of the flood effects. In this area, ultra-high resolution allowed us to detect some damages like of the damage, such as the toppling of a wall in a recently built urbanization, or the waste accumulation derived from damaged objects initially located in houses or industrial warehouses. The presence of these deposits is clear evidence of the damage that occurred damages, but also as well

as a confirmation that nadiral images are not able to supply a sufficient dataset for the identification and evaluation of damages in urban areas.

The DSM based on RPAS photos also allowed us to create a detailed 3-D model of the river embankment rupture (Fig. 9). The presented 3D model confirmed that the level of the Chisola during the flood was very critical, with a difference of fewer than 0.5 m from the top of the levee. The maximum water level considered under the security limits suggested by Po river authority is 1 m concerning the top of the embankment. The RPAS model also allowed us to map the geomorphological effects of the rupture of the embankment. In particular, the ultra-high-resolution photos (Fig. 8 A) and 3-D model (Fig. 9) allowed us to map a massive erosion of a field near the break and a pseudo alluvial fan created by the flow of water.

4.2.3 Measurement of water depth with SfM model from terrestrial camera, Moncalieri.

In the same days of the RPAS aerial photo campaign, a field survey using an integrated system provided by ALTEC S.p.A. installed on a car (Fig. 10 B) was made in the same urban areas of Moncalieri flooded by the Chisola (Fig. 10 A). The survey had the aim of measuring the maximum water level reached and making a rapid evaluation of the damage. The survey lasted approximately 1 h for 12 km of the path along the road of the most critical area hit by the flood.

Where the level reached by the water was still visible over several façades (Fig. 10 C and Fig. 10 D), it was possible to estimate the maximum water level of the flood. During the first survey, we found 11 points where watermarks over façades were still visible. During the post-processing, we realized that the quality of the images extracted from the video was insufficient for the SfM application: the bitrate was too low and the frames are too pixelated. For this reason, therefore, after a month, we performed a second survey with a higher bit rate along the same path, but, however, only six marks were still visible (Fig. 10 A). This reduction of available points confirmed that the delay between the flood and the survey is a fundamental element that should be carefully considered because the number of possible pieces of information intensely decrease greatly. For this second terrestrial camera acquisition, an improvement of the encoding quality was introduced. Such improvement allowed the extraction of high quality images compatible with the SfM application. We obtained 3D models of the surveyed sectors, and we measured the high of water marks on façades. Then, we validated the information obtained from SfM with a manual water height measurement geocoded with the GPS RtK systems for the 6 points and other additional 5 points. The accuracy of the measurement—considering that is a low-cost solution and one of the first experimental tries for this system—is excellent: the average error compared comparing the SfM

water level measurement with a manual measurement can be estimated into within a few centimetres (see tableTable 7).

4.2.4 High-resolution water depth models and ancillary data for damages-evaluationsdamage evaluation, Moncalieri.

The combined use of measuresmeasurements derived from: i) car camera elaborated with SfM; ii) manual GPS RTK; and iii) the hydrometric level of Chisola streamStream registered by ARPA Piemonte station (Fig. 11 B) represents a useful dataset for the estimation of the WD. Using the 5m5 m DTM Lidar of Regione Piemonte, we obtained the WL and the WD rasters (Fig. 11 A). The result shows that in a large part of the analysed area, the water height was between 0.5 and 1 m. Unfortunately, in some morphological depressions, the level was higher than 1.5 m. The model also shows that in the cultivated area close to the left of the Chisola embankment, the water probably reached 2-3 m in height.

The water level map can suffer from some errors from spot measuremeasurements. These are related to the quality of DTM or the effect of local structures that can modify the water flow and height at a local scale. The comparison of the water level measured with SfM +/GPS and the calculated level with DTM show variation within 0.2 m that is, a good result (Table 6).

Ancillary data like, such as photos or videovideos found on the web (local newspaper, social media), and geolocated with Google Streetview, allowed us to improve and validate the map of the flooded areas and the height of the water (Fig. 11 C). On the web, it is possible to find a lot of many photos or video of the flood event, but; however, only a small part of them can be geolocated with adequate precision and validated.

The water height map was crossed with buildingsa building database of Regione Piemonte to assign to each building the average of the water height reached by the flood (Fig. 12 A) to each building. The water height is one of the leading parameters that can be used for a preliminary estimation of the potential damagesdamage. We divideddivided the water height in 3into three main classes, corresponding to low (< 0.5 m), medium (0.5 – 1.5 m) and high (> 1.5 m) damages), of the damage expected. These thresholds have been empirically defined by Luino et al., (2009) and Amadio et al., (2016). The obtained map is a good representation of the level of damagesdamage caused by the flood that could be considered the final product of the presented methodology.

We comparecompared this result with ground data where possible for instance, For example, in the industrial warehouse showsshown in the focus map (Fig. 12 B) it was estimated that there was an average value of 0.8 m water level (medium degree of damage expected). The evidence from a geolocated photo from La Stampa newspaper confirms this value.

4.3 Flood mapping strategy flowchart

The flowchart (Fig. 13) shows the approach that we propose for the choice of instruments and methods to map the flooded areas, based on the results of this study. If free satellite data are available, it is possible to sort them, taking into account the parameters of time elapsed from the flood and the spatial resolution:

I) The priority is to search for co-flood images that allow an easy mapping. In case of night and cloudy conditions, it is necessary to use SAR ~~imageimages~~ (Sentinel-1)), while for multispectral data acquired during the day, the choice is related to the spatial resolution: ~~for instance,~~ For example, Sentinel-2 or Landsat-8 data are more resolute than MODIS data.

II) In the case ~~we have of a~~ post-flood satellite pass, only multispectral data can be used. ~~Also~~ Additionally, for post-flood data, the spatial resolution and time elapsed from the flood are the parameters that should drive the choice. The use of post-flood data implies more complicated post-processing (e.g., bands index variation)), and ~~with~~ the support of ancillary data and DTM to extract the flooded area map. In general, the rapid access to data portal of free satellite data allows us to download the data and to make an evaluation of the best solution for the case under study, ~~that; however, these data are not do~~ not necessarily ~~is the data with~~ have a high spatial resolution.

After this step, it is possible to make the first delimitation of flooded areas, ~~that in the~~ case that good data may ~~be include~~ an already corrected and ready ~~to use~~ map. Then, it is possible to focus the acquisition of on-demand of high-resolution sensors only in the most critical or unclear areas (case 2A). If we use only on-demand data, without rapid satellite mapping, we could map large ~~areaareas~~ at a high spatial resolution (case 2B). This solution, however, implies a higher cost. In case of direct mapping at very-high resolution, it is better to use low-cost aerial platforms that are more flexible with respect to on-demand commercial satellites. The integration with DEM data allows ~~creating the creation of~~ the water depth model at the basin scale and a further refinement of flooded area maps (2C).

Urban area flood mapping (3) can be considered a hotspot priority inside the general flood map. It needs a more accurate and high-resolution mapping with the use of ground-based ~~measures (like~~ measurements (such as the SfM model based on car photo), RPAS survey, and the creation of a water depth model that is essential for a precise flood magnitude assessment.

~~It is important to remind~~ Note that it is not possible to select *a priori* which type of data/processing is ~~the~~ better for flood mapping. The best method to use depends on different factors: 1. Satellite acquisition and time elapsed from flood peak; 2. Type of satellite data (SAR ~~+/~~ multispectral, spatial resolution); 3. Study area features and risk (dimension, cloud cover, land-use and element at risk); ~~and~~ 4. Affordable cost (e.g., we ~~useused~~ commercial satellite data or traditional aerial ~~photophotos~~ only if they give significant advantages to flood mapping)).

5 Discussion and conclusions

In this work, we tested different methodologies for a low-cost and rapid flood mapping and water depth assessment using the November 2016 Piemonte ~~flood~~Flood as a case history. We used a multiscale and ~~multi-sensor~~multisensor approach to know ~~the~~ pros and cons of each methodology about the site conditions and available data. We also proposed a flowchart model to map flooded areas from ~~satellites~~satellites to ground-based data.

At the regional scale, satellite remote sensing showed a good performance in the flood mapping: the combined used of ~~the~~ SAR data of Sentinel-1 and CSKM, and multispectral data of MODIS-Aqua and Sentinel-2 allowed ~~creating~~the creation of maps of the flooded area. The maps of flooded areas automatically extracted from remote sensing data were used with the help of DTM and ~~a~~ water depth model as a base map for an accurate manual drawing. In our study area (320 km²)~~-about~~, ~~approximately~~ 66 km² ~~was~~were flooded by ~~the Po river~~,River and the Chisola and Oitana streams. ~~The~~ WD models show that some areas were flooded up to 2 m of water height.

Concerning SAR data, we reclassified a simple preview low-resolution CSKM amplitude image acquired some hours before the co-flood time. The results show that the time of satellite pass is fundamental: if the area is covered by water (~~like~~such as ~~the~~ upstream part of Po ~~river~~)River), up to 60% of ~~the~~ pixels was correctly classified as flooded, and it was possible to observe a definite pattern. We compared pre- and post-flood SAR images of ~~the~~ Sentinel-1, making SAR ~~the~~ backscattering difference of radiometrically calibrated images. The result shows that SAR is weaker for post-event mapping; in our case 3 days after the flood (Sentinel-1), less than 4% of the flooded area ~~is~~was still detectable. By considering the obtained results, it is also ~~clear~~the importanceclearly important to have free and constant SAR satellite data provided by ~~a~~ national agency. ~~a~~ A short revisit time and a constant acquisition are factors that increase the probability ~~to have~~of having a SAR image for real-time flood mapping. For ~~instance~~example, the two Sentinel-1 ~~provides~~satellites provided free images every six days all over Europe, while other satellites have quite high costs and the acquisition is often on-demand. Moreover, ~~most of the time~~, the on-demand acquisitions ~~most of the times~~ are activated only when authorities activate an emergency procedure (e.g., the EMSR of the European Union or by civil protection).

The low-resolution MODIS image acquired near the co-flood stage allowed a good identification of ~~the~~ flooded areas using different methods: MNDWI variation and supervised classifications. The detection accuracy is good, especially for the area ~~flood~~flooded by ~~the Po river~~River where ~~about~~the~~approximately~~ 70% of the flooded area was correctly identified.

Medium-High resolution ~~multi-spectral~~multispectral data have more capability with post-event images. In this work, we tested NDVI and MNDWI variations for the detection of flooded areas based on the comparison of pre- and post-event images. Both methodologies show quite good performance in cultivated land, (40 % - 45% of accuracy). Here, ~~it is~~was possible to detect a clear pattern: inside the inundated area, the percentage of pixel classified as flooded ~~is~~was four times greater than in ~~the~~ not

630 flooded area. The inundated areas are more difficult to detect in the dense urban area of Moncalieri (only 4% ~~of the~~ area was correctly mapped). ~~Water~~The water depth model of ~~the~~ Po River and DTM ~~gave an important help~~helped greatly in the improvement of the flood map based on remote sensing data. In ~~the~~ last ~~few~~ years, the revisit time for free multispectral data was sharply reduced (Landsat-8 has a revisit time of 16-days and Sentinel-2 ~~has a revisit time~~ of 5 days from March 2017 with the launch ~~of the~~ second satellite). This ~~increase~~increases the probability ~~to have of having~~ an image free of ~~cloud~~clouds within few days or weeks after the flood or, in some cases, during the inundation phase. At the local scale, flood mapping showed a good agreement with regional scale mapping.

635 The high-resolution aerial photo and ultra-high resolution aerial photo from RPAS allowed ~~the~~ mapping ~~of the~~ flooded areas with more precision. The application of ~~Structure from Motion (SfM)~~ allowed creating high-resolution DSM ~~that was~~ useful to map the geomorphological effects (e.g., ~~meanders cut~~meander cuts) and the widespread ~~damages~~damage (embankment ~~rupture~~ruptures) in ~~the~~ Pancalieri and Moncalieri ~~area~~areas.

640 In the urban area of Moncalieri, where satellite data have ~~a~~ low accuracy, and precise evaluation of water depth is necessary for flood ~~damages~~damage evaluation, the solution is the integration with ground-based data. In our work, we tested a low-cost solution with a GO-PRO HERO 3+ (Black Edition) camera installed on a car that allowed ~~us~~ to make ~~3D3-D~~ models and to measure the water height reached during the flood. These measurements, validated with GPS, showed good accuracy, but it is necessary to do the survey within ~~a~~ few days after the flood when many water signs are visible. A proposal for the future is to use this system during the emergencies, for ~~instance~~example, on ~~a~~ civil protection car, to have a map of ~~the~~ water depth with a much higher density of points.

645 Using these measurements and a high-resolution DTM, it was possible to generate a raster model of water depth that has a good match with the ground truth ~~about +/-~~, with approximately ± 0.2 m of accuracy. We used the ~~results of~~WD model ~~results~~ for a preliminary evaluation of building ~~damages~~damage. The model could also be used in the future for flood prevention ~~policy~~policies or civil protection plans.

650 Finally, from our work it is also clear ~~of~~ the importance to collect ancillary data also from the new sources on the web: the ~~photo~~photos and ~~video~~videos collected during the flood by simple citizens can be a precious help for the validation of flooded area maps.

Data availability.

655 MODIS data were downloaded from NASA LAADS - DAAC portal (<http://ladsweb.nascom.nasa.gov/>) link retrieved 30-03-2018

12/11/2016: MYD09.A2016317.1215.006.2016319043220

26/11/2016: MYD09.A2016331.1225.006.2016333031908

660 Sentinel data were download from Copernicus Scihub: <https://scihub.copernicus.eu/> link retrieved 30-03-2018

Sentinel-2:

1/12/2016: S2A_OPER_MSI_L1C_TL_SGS__20161201T104644_20161201T141912_A007541_T32TLQ_N02_04_01

8/11/2016: S2A_OPER_MSI_L1C_TL_SGS__20161108T103641_20161108T154744_A007212_T32TMQ_N02_04_01

Sentinel-1:

665 28/11/2016: S1A_IW_GRDH_1SDV_20161128T053526_20161128T053551_014138_016D3F_7094

22/11/2016: S1B_IW_GRDH_1SDV_20161122T053445_20161122T053514_003067_005376_AD1

COSMO-Skymed data portal (E-Geos <http://www.e-geos.it/>)

Image ID 627100 acquired on 25/11/2016 05:11 UTC COSMO-SkyMed© ASI [2016] [http://catalog.e-](http://catalog.e-geos.it/#product:productIds=627100)

670 [geos.it/#product:productIds=627100](http://catalog.e-geos.it/#product:productIds=627100) link retrieved 30-03-2018

-5-m LIDAR DTM Regione Piemonte is available at:

<http://www.geoportale.piemonte.it/geonetworkrp/srv/ita/metadata.show?id=2552&currTab=rndt> link retrieved 16-02-2018

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Reference

685 Ahamed, A., Bolten, J., Doyle, C. and Fayne, J.: Near Real-Time Flood Monitoring and Impact Assessment Systems, In Remote Sensing of Hydrological Extremes (pp. 105-118) Springer International Publishing, doi: 10.1007/978-3-319-43744-6_6, 2017.

Amadio, M., Mysiak, J., Carrera, L. and Koks, E.: Improving flood damage assessment models in Italy, Nat. Hazards, 82(3), 2075-2088, doi: 10.1007/s11069-016-2286-0, 2016.

690 ARPA Piemonte: Evento alluvionale 21-26 novembre 2016 – rapporto preliminare (Italian), 21-25 November flood event preliminary report, Available at http://www.arpa.piemonte.gov.it/pubblicazioni-2/relazioni-tecniche/analisi-eventi/eventi-2016/rapporto-preliminare-novembre-2016-def.pdf/at_download/file (accessed 1-12-2017), 2016.

Arrighi, C., Brugioni, M., Castelli, F., Franceschini, S. and Mazzanti, B.: Urban micro-scale flood risk estimation with parsimonious hydraulic modelling and census data, Nat. Hazard Earth Sys., 13(5), 13, 1375-1391, <https://doi.org/10.5194/nhess-13-1375-2013>, 2013.

695 Barredo, J.I.: Major flood disasters in Europe: 1950–2005, Nat. Hazards, 42(1), 125-148, doi: <https://doi.org/10.1007/s11069-006-9065-2>, 2007.

Bates, P.D. and De Roo, A.P.J.: A simple raster-based model for flood inundation simulation, Journal of Hydrology, (236), 54–77 doi: [https://doi.org/10.1016/S0022-1694\(00\)00278-X](https://doi.org/10.1016/S0022-1694(00)00278-X), 2000.

700 Bignami, D.F., Rulli, M.C. and Rosso, R.: Testing the use of reimbursement data to obtain damage curves in urbanised areas: the case of the Piedmont flood on October 2000, Journal of Flood Risk Management., doi: <https://doi.org/10.1111/jfr3.12292>, 2017.

Boccardo, P., Chiabrando, F., Dutto, F., Tonolo, F.G. and Lingua, A.: UAV deployment exercise for mapping purposes: Evaluation of emergency response applications. Sensors, 15(7), pp.15717-15737., doi:[10.3390/s150715717](https://doi.org/10.3390/s150715717), 2015

705 Boni, G., Ferraris, L., Pulvirenti, L., Squicciarino, G., Pierdicca, N., Candela, L., Pisani, A.R., Zoffoli, S., Onori, R., Proietti, C. and Pagliara, P.: A prototype system for flood monitoring based on flood forecast combined with COSMO-SkyMed and Sentinel-1 data, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 9(6), pp.2794-2805, doi: <https://doi.org/10.1109/JSTARS.2016.2514402>, 2016.

Brakenridge, R. and Anderson, E.: MODIS-based flood detection, mapping and measurement: the potential for operational hydrological applications, Transboundary floods: reducing risks through flood management, 1-12, doi: https://doi.org/10.1007/1-4020-4902-1_1, 2006.

- 710 Brivio, P.A., Colombo, R., Maggi, M. and Tomasoni, R.: Integration of remote sensing data and GIS for accurate mapping of
flooded areas, *International Journal of Remote Sensing*, 23(3), 429-441, doi: <https://doi.org/10.1080/01431160010014729>,
2002.
- Buzzi, A., Tartaglione, N. and Malguzzi, P.: Numerical simulations of the 1994 Piedmont flood: Role of orography and moist
processes, *Monthly Weather Review*, 126(9), pp.2369-2383. doi: [https://doi.org/10.1175/1520-0493\(1998\)126<2369:NSOTPF>2.0.CO;2](https://doi.org/10.1175/1520-0493(1998)126<2369:NSOTPF>2.0.CO;2), 1998.
- 715 Carraro, F., Collo, G., Forno, M.G., Giardino, M., Maraga, F., Perotto, A., Tropeano, D.: L'evoluzione del reticolato idrografico
del Piemonte centrale in relazione alla mobilità quaternaria (Italian)- The evolution of the hidrographic network in the central
Piedmont related to the Quaternary mobility- , In: Polino, R., Sacchi, R. (Eds.), *Rapporti Alpi-Appennino Accad. Naz. Scienze*,
(14), 445–461, 1995
- 720 Cassardo, C., Cremonini, R., Gandini, D., Paesano, G., Pelosini, R. and Qian, M.W.: Analysis of the severe flood of 13t-16th
October 2000 in Piedmont (Italy), *Cuadernos de Investigación Geográfica*, 27, pp.147-162., DOI:
<http://dx.doi.org/10.18172/cig.1120>, 2013.
- Clement, M.A., Kilsby, C.G. and Moore, P.: Multi-Temporal SAR Flood Mapping using Change Detection, *Journal of Flood
Risk Management*, doi: <https://doi.org/10.1111/jfr3.12303>, 2017.
- 725 Copernicus Emergency Management Service (© 2016 European Union), EMSR192 - Floods in Northern Italy, available at
<http://emergency.copernicus.eu/mapping/list-of-components/EMSR192>, (accessed 01/12/17) 2016.
- Copernicus Emergency Management Service (© 2016 European Union), [EMSR192] Moncalieri: Grading Map available at
http://emergency.copernicus.eu/mapping/list-of-components/EMSR192/ALL/EMSR192_18MONCALIERI (accessed
01/12/17), 2016
- 730 Costabile, P., Macchione, F., Natale, L. and Petaccia, G.: Flood mapping using LIDAR DEM. Limitations of the 1-D modeling
highlighted by the 2-D approach, *Nat. Hazards*, 77(1), 181-204, doi: <https://doi.org/10.1007/s11069-015-1606-0>, 2015.
- De Moel, H., Van Alphen, J., and Aerts, J. C. J. H.: Flood maps in Europe – methods, availability and use, *Nat. Hazards Earth
Syst. Sci.*, 9, 289-301, <https://doi.org/10.5194/nhess-9-289-2009>, 2009.
- De Zan, F. and Monti-Guarnieri, A., 2006. TOPSAR: Terrain observation by progressive scans, *IEEE Transactions on
735 Geoscience and Remote Sensing*, 44(9), pp.2352-2360.

- Farfaglia, S., Lollino, G., Iaquina, M., Sale, I., Catella, P., Martino, M. and Chiesa, S.: The use of UAV to monitor and manage the territory: perspectives from the SMAT project, In *Engineering Geology for Society and Territory-Volume 5* (pp. 691-695). Springer, Cham, https://doi.org/10.1007/978-3-319-09048-1_134, 2015
- 740 Fayne, J., Bolten, J., Lakshmi, V. and Ahamed, A.: Optical and Physical Methods for Mapping Flooding with Satellite Imagery, In *Remote Sensing of Hydrological Extremes* (pp. 83-103). Springer International Publishing. doi: https://doi.org/10.1007/978-3-319-43744-6_6, 2017.
- Feng, Q., Liu, J. and Gong, J.: Urban flood mapping based on unmanned aerial vehicle remote sensing and random forest classifier—A case of Yuyao, China, *Water*, 7(4), 1437-1455, doi: <https://doi.org/10.3390/w7041437>, 2015.
- 745 Fiorucci, F., Giordan, D., Santangelo, M., Dutto, F., Rossi, M., and Guzzetti, F.: Criteria for the optimal selection of remote sensing images to map event landslides, *Nat. Hazards Earth Syst. Sci. Discuss.*, <https://doi.org/10.5194/nhess-2017-111>, in review, 2017.
- Fohringer, J., Dransch, D., Kreibich, H. and Schröter, K.: Social media as an information source for rapid flood inundation mapping, *Nat. Hazard Earth Sys*, 15(12), 2725-2738, doi: <https://doi.org/10.5194/nhess-15-2725-2015>, 2015.
- 750 Gao, B.C.: NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space, *Remote sensing of environment*, 58(3), 257-266, doi: [https://doi.org/10.1016/S0034-4257\(96\)00067-3](https://doi.org/10.1016/S0034-4257(96)00067-3), 1996.
- Gianinetto, M., Villa, P. and Lechi, G.: Postflood damage evaluation using Landsat TM and ETM+ data integrated with DEM, *IEEE Transactions on Geoscience and Remote Sensing*, 44(1), 236-243, doi: <https://doi.org/10.1109/TGRS.2005.859952>, 2006.
- 755 Giordan, D., Manconi, A., Facello, A., Baldo, M., Allasia, P. and Dutto, F.: Brief Communication: The use of an unmanned aerial vehicle in a rockfall emergency scenario, *Nat. Hazards Earth Syst. Sci.*, 15(1), pp.163-169, doi: <https://doi.org/10.5194/nhess-15-163-2015>, 2015.
- Giordan D., Manconi A., Remondino F. and Nex F.: Use of unmanned aerial vehicles in monitoring application and management of natural hazards, *Geomatics, Natural Hazards and Risk*, 8:1, 1-4, DOI: <https://doi.org/10.1080/19475705.2017.1315619>, 2017.
- 760 Giustarini, L., Hostache, R., Matgen, P., Schumann, G. J. P., Bates, P. D. and Mason, D. C.: A change detection approach to flood mapping in urban areas using TerraSAR-X, *IEEE transactions on Geoscience and Remote Sensing*, 51(4), 2417-2430. doi: [0.1109/TGRS.2012.2210901](https://doi.org/10.1109/TGRS.2012.2210901), 2013.

- Griesbaum, L., Marx, S. and Höfle, B.: Direct local building inundation depth determination in 3-D point clouds generated from user-generated flood images. *Natural Hazards and Earth System Sciences*, 17(7), p.1191, 2017.
- 765 Hung, K.C., Kalantari, M. and Rajabifard, A.: Methods for assessing the credibility of volunteered geographic information in flood response: A case study in Brisbane, Australia, *Applied Geography*, 68, 37-47, doi: <https://doi.org/10.1016/j.apgeog.2016.01.005>, 2016.
- Ireland, G., Volpi, M. and Petropoulos, G.P.: Examining the capability of supervised machine learning classifiers in extracting flooded areas from Landsat TM imagery: A case study from a Mediterranean flood, *Remote Sensing*, 7(3), 3372-3399, doi: <https://doi.org/10.3390/rs70303372>, 2015.
- 770 Justice, C.O., Vermote, E., Townshend, J.R., Defries, R., Roy, D.P., Hall, D.K., Salomonson, V.V., Privette, J.L., Riggs, G., Strahler, A. and Lucht, W.: The Moderate Resolution Imaging Spectroradiometer (MODIS): Land remote sensing for global change research, *IEEE Transactions on Geoscience and Remote Sensing*, 36(4), 1228-1249, 1998.
- Kreibich, H., Piroth, K., Seifert, I., Maiwald, H., Kunert, U., Schwarz, J., Merz, B. and Thieken, A.H.: Is flow velocity a significant parameter in flood damage modelling?, *Nat. Hazards Earth Syst. Sci.*, 9, 1679-1692, <https://doi.org/10.5194/nhess-9-1679-2009>, 2009.
- 775 Luino, F., Cirio, C.G., Biddoccu, M., Agangi, A., Giulietto, W., Godone, F. and Nigrelli, G.: Application of a model to the evaluation of flood damage, *Geoinformatica*, 13(3), 339-353, doi: 10.1007/s10707-008-0070-3, 2009.
- Luino, F.: The flood and landslide event of November 4–6 1994 in Piedmont Region (Northwestern Italy): Causes and related effects in Tanaro Valley, *Physics and Chemistry of the Earth, Part A: Solid Earth and Geodesy*, 24(2), 123-129, doi: [https://doi.org/10.1016/S1464-1895\(99\)00007-1](https://doi.org/10.1016/S1464-1895(99)00007-1), 1999.
- 780 Mason D.C., Giustarini L., Garcia-Pintado J., Cloke H.L.: Detection of flooded urban areas in high resolution Synthetic Aperture Radar images using double scattering, *International Journal of Applied Earth Observation and Geoinformation*, Volume 28, Pages 150-159, ISSN 0303-2434, <http://dx.doi.org/10.1016/j.jag.2013.12.002>, 2014.
- 785 Meesuk, V., Vojinovic, Z., Mynett, A.E. and Abdullah, A.F.: Urban flood modelling combining top-view LiDAR data with ground-view SfM observations, *Advances in Water Resources*, 75, 105-117, doi: <https://doi.org/10.1016/j.advwatres.2014.11.008>, 2015.
- Merz, B., Kreibich, H., Schwarze, R., and Thieken, A.: Review article "Assessment of economic flood damage", *Nat. Hazards Earth Syst. Sci.*, 10, 1697-1724, <https://doi.org/10.5194/nhess-10-1697-2010>, 2010. Nigro, J., Slayback, D., Policelli, F. and

- 790 Brakenridge, G.R.: NASA/DFO MODIS near real-time (NRT) global flood mapping product evaluation of flood and permanent water detection. Evaluation, Greenbelt, MD, 2014.
- Paprotny, D., Morales-Nápoles, O., and Jonkman, S. N.: Efficient pan-European river flood hazard modelling through a combination of statistical and physical models, *Nat. Hazards Earth Syst. Sci.*, 17, 1267-1283, <https://doi.org/10.5194/nhess-17-1267-2017>, 2017.
- 795 Perks, M. T., Russell, A. J., and Large, A. R. G.: Technical Note: Advances in flash flood monitoring using unmanned aerial vehicles (UAVs), *Hydrol. Earth Syst. Sci.*, 20, 4005-4015, <https://doi.org/10.5194/hess-20-4005-2016>, 2016.
- Pierdicca, N., Pulvirenti, L. and Chini, M.: Flood Mapping in Vegetated and Urban Areas and Other Challenges: Models and Methods. In *Flood Monitoring through Remote Sensing* (pp. 135-179). Springer, Cham., https://doi.org/10.1007/978-3-319-63959-8_7, 2018
- 800 Pinto, J.G., Ulbrich, S., Parodi, A., Rudari, R., Boni, G. and Ulbrich, U.: Identification and ranking of extraordinary rainfall events over Northwest Italy: The role of Atlantic moisture, *Journal of Geophysical Research: Atmospheres*, 118(5), 2085-2097, doi: <https://doi.org/10.1002/jgrd.50179>, 2013.
- Pulvirenti, L., Chini, M., Pierdicca, N., Guerriero, L. and Ferrazzoli, P.: Flood monitoring using multi-temporal COSMO-SkyMed data: Image segmentation and signature interpretation, *Remote Sensing of Environment*, 115(4),990-1002, doi: <https://doi.org/10.1016/j.rse.2010.12.002>, 2011.
- 805 Rahman, M.S. and Di, L.: The state of the art of spaceborne remote sensing in flood management, *Natural Hazards*, 85(2), 1223-1248., doi: <https://doi.org/10.1007/s11069-016-2601-9>, 2017.
- Refice, A., Capolongo, D., Pasquariello, G., D'Addabbo, A., Bovenga, F., Nutricato, R., Lovergine, F.P. and Pietranera, L.: SAR and InSAR for flood monitoring: Examples with COSMO-SkyMed data, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 7(7), 2711-2722, doi: <https://doi.org/10.1109/JSTARS.2014.2305165>, 2014.
- 810 Regione Piemonte: Gli eventi alluvionali del settembre-ottobre 1993 in Piemonte (Italian), <http://www.arpa.piemonte.gov.it/approfondimenti/temi-ambientali/geologia-e-dissesto/pubblicazioni/immagini-e-files/ev93>, (accessed 01/12/17), 1996.
- Rosser, J.F., Leibovici, D.G. and Jackson, M.J.: Rapid flood inundation mapping using social media, remote sensing and topographic data, *Natural Hazards*, 87(1), 103-120, doi: <https://doi.org/10.1007/s11069-017-2755-0>, 2017.
- 815

- Segura-Beltrán, F., Sanchis-Ibor, C., Morales-Hernández, M., González-Sanchis, M., Bussi, G. and Ortiz, E.: Using post-flood surveys and geomorphologic mapping to evaluate hydrological and hydraulic models: The flash flood of the Girona River (Spain) in 2007, *Journal of Hydrology*, 541, pp.310-329. <https://doi.org/10.1016/j.jhydrol.2016.04.039>, 2016.
- 820 Schnebele, E. and Cervone, G.: Improving remote sensing flood assessment using volunteered geographical data, *Nat. Hazards Earth Syst. Sci.*, 13, 669-677, <https://doi.org/10.5194/nhess-13-669-2013>, 2013.
- Shrestha, R., Di, L., Eugene, G.Y., Kang, L., SHAO, Y.Z. and BAI, Y.Q.: Regression model to estimate flood impact on corn yield using MODIS NDVI and USDA cropland data layer, *Journal of Integrative Agriculture*, 16(2), 398-407, doi: [https://doi.org/10.1016/S2095-3119\(16\)61502-2](https://doi.org/10.1016/S2095-3119(16)61502-2), 2017.
- 825 Smith, M. W., J. L. Carrivick, J. Hooke, and Kirkby M. J.: Reconstructing flash flood magnitudes using ‘Structure-from-Motion’: A rapid assessment tool, *Journal of Hydrology* 519, pp 1914-1927, doi: <https://doi.org/10.1016/j.jhydrol.2014.09.078>, 2014.
- Schumann, G.J.P. and Moller, D.K.: Microwave remote sensing of flood inundation. *Physics and Chemistry of the Earth, Parts A/B/C*, 83, pp.84-95., doi: <https://doi.org/10.1016/j.pce.2015.05.002>, 2015
- 830 Snavely, N., Seitz, S.M. and Szeliski, R.: Modelling the world from internet photo collections, *International Journal of Computer Vision*, 80(2), 189-210, doi: <https://doi.org/10.1007/s11263-007-0107-3>, 2008.
- Tapia-Silva, F.O., Itzerott, S., Foerster, S., Kuhlmann, B. and Kreibich, H.: Estimation of flood losses to agricultural crops using remote sensing, *Physics and Chemistry of the Earth, Parts A/B/C*, 36(7), 253-265, doi: <https://doi.org/10.1016/j.pce.2011.03.005>, 2011.
- 835 Torres, R., Snoeij, P., Geudtner, D., Bibby, D., Davidson, M., Attema, E., Potin, P., Rommen, B., Floury, N., Brown, M. and Traver, I.N.: GMES Sentinel-1 mission, *Remote Sensing of Environment*, 120, pp.9-24, doi: <https://doi.org/10.1016/j.rse.2011.05.028>, 2012.
- Vermote E. - NASA GSFC and MODAPS SIPS – NASA: MYD09 MODIS/Aqua L2 Surface Reflectance, 5-Min Swath 250m, 500m, and 1km. NASA LP DAAC, doi: <http://doi.org/10.5067/MODIS/MYD09.006>, 2015
- 840 Yan, K., Di Baldassarre, G., Solomatine, D.P. and Schumann, G.J.P.: A review of low-cost space-borne data for flood modelling: topography, flood extent and water level, *Hydrological Processes*, 29(15), 3368-3387, doi: <https://doi.org/10.1002/hyp.10449>, 2015.

Wang, Y., Colby, J.D. and Mulcahy, K.A.: An efficient method for mapping flood extent in a coastal floodplain using Landsat TM and DEM data, International Journal of Remote Sensing, 23(18), 3681-3696, doi: <https://doi.org/10.1080/01431160110114484>, 2012.

845 Westoby, M. J., J. Brasington, N. F. Glasser, M. J. Hambrey, and Reynolds J.M.: ‘Structure-from-Motion’ photogrammetry: A low-cost, effective tool for geoscience applications, Geomorphology 179, 300-314, doi: <https://doi.org/j.geomorph.2012.08.02>, 2012.

Xu, H.: Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery, International journal of remote sensing, 27(14), 3025-3033, doi: <https://doi.org/10.1080/01431160600589179>, 2006.

850 Zhang, D. and Zhou, G.: Estimation of Soil Moisture from Optical and Thermal Remote Sensing: A Review, Sensors, 16(8), p.1308, doi: <https://doi.org/1016/j.pce.2011.03.005>, 2016.

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Table 1. Resume of the datasets used to map and characterize flooded ~~area~~areas in this study.

Type	Sensor used	Spatial resolution (m)	Covered area by a single scene (km ²)	Min. Revisit time (Day)
1 – Satellite Data				
SAR –X band	COSMO-SkyMed	60	> 1'000 1,000	4
SAR- C band	Sentinel-1A/B	5 (ground range) x 20 (azimuth)	> 10'000 10,000	6
Multi-spectral Multispectral	MODIS-Aqua	500	100'000 100,000	Daily
Multi-spectral Multispectral	Sentinel-2	10 / 20	> 10'000 10,000	10 (5)
2- Aerial data				
Very High res. visible band	Tecnam P92-JS	0.01	100 km ²	On-demand
Ultra-High resolution visible band	RPASs CarbonCore 950 octocopter	0.02 / 0.03	< 10 km ²	On-demand
DTM LIDAR	Airborne	5	Piemonte region	Archive data
3- Ground-Based				
Photo / video from car platform	GO-PRO HERO 3+	0.02 / 0.03	Local /urban	On demand

Table 2. Resume of satellite data in relation with ~~the~~ flood stage.

Satellite	Spatial Resolution	Acquisition time		
		Pre-flood	Co-flood	Post-flood
COSMO-SkyMed	Medium	05:05 UTC – 25/11/2016		
Sentinel-1 A/B	Medium	05:35 UTC – 22/11/2016		05:35 UTC – 28/11/2016
MODIS Aqua	Medium- Low	12:30 UTC - 12/11/2016	12:30 UTC - 26/11/2016	
Sentinel-2	Medium- High	15:19 UTC - 11/11/2016		14:19 UTC – 01/12/2016

Table 3. Characteristics of the Sentinel-1 dataset used in this study.

Satellite	Sentinel-1 A/B
Sensor Parameter	C-band 5.405 GHz
Orbit	Descending
Pre-flood acquisitions	22/11/2016
Post-flood acquisitions	28/11/2016
Data format	Single Look Complex (SLC)
Azimuth pixel spacing [m]	~13
Range pixel spacing [m]	~2

Table 4. Characteristics of the Aqua MODIS data used in this work.

Band	Bandwidth (nm)	Band type	Spatial resolution (m)
B1	620 – 670	Red	500
B2	841 – 876	NIR	500
B3	459 – 479	Blue	500
B4	545 – 565	Green	500
B5	1230 – 1250	SWIR	500
B7	2105 – 2155	SWIR	500

Table 5. Characteristics of Sentinel-2 data used in this work.

Band	Wavelength (nm)	Band type	Spatial resolution (m)
B2	490	Blue	10
B3	560	Green	10
B4	665	Red	10
B8	842	NIR	10
B5	705	NIR	20
B6	740	NIR	20

B7	783	NIR	20
B8a	865	NIR	20
B11	1610	SWIR	20
B12	2190	SWIR	20

895 **Table 6. Accuracy in automatic flooded and not flooded area detection.**

Sector	Area km ²	Sentinel-2		MODIS-Aqua			COSMO-SkyMed	Sentinel-1
		MNDWI _{var}	NDVI _{var}	MNDWI _{var}	MLC	SA	Recl Ampl	$\Delta\sigma^0$
Not Flooded	259.5	87%	87%	91%	94%	95%	96%	99%
Flooded area								
- Po	47.8	48%	37%	49%	70%	64%	23%	4%
- Oitana	11.6	49%	42%	60%	11%	36%	37%	1%
- Chisola	7.3	21%	51%	30%	24%	23%	12%	1%
- Chisola urban	1.1	4%	24%					

Table 7. Water height ~~measures~~measurements obtained from structure-from-motion, GPS survey and simulation with DTM.

Measure point coordinates		Water Depth (m)		
UTM X	UTM Y	SfM	GPS	DTM
		(+/-) ($\pm$ 0.05)		(+/-) ($\pm$ 0.2)
395132	4983240	1.56	1.60	1.61
395242	4983152	1.45	1.40	1.42
395140	4982644	0.84	0.78	1.01
395142	4981624	0.82	0.81	0.78
395022	4981188	1.28	1.35	1.56
394877	4980993	1.40	1.37	1.34

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Figure 1. A) Location of Piemonte region in Italy; B) Rainfall in Piemonte region during the 21-25 November flood event (~~Based~~based on ARPA Piemonte data) and location of study area, S. B. = Savigliano Basin, P. P. = Poirino Plateau, T.H = Turin Hills; C) Detailed view of the study area with discharge in the stream gauge stations and the location of Pancalieri (1) and Moncalieri (2) local areas case history.

Figure 2. The flowchart illustrating the multiscale flood mapping approaches proposed in this work.

Figure 3. A) Reclassified Quicklook Amplitude SAR Image acquired at 05:05 UTC of 25 November 2016 - COSMO-SkyMed© ASI [2016] - B) Sentinel-1 geocoded backscattering coefficient difference ($\Delta\sigma^\circ$); C) Example of change backscattering between the pre- and the post-flood image is detectable. ~~D'; D'' D''' D'; D'' D'''~~) detail of some areas where $\Delta\sigma^\circ$ still detect water.

Figure 4. MODIS Aqua satellite image A) False colour band composition 7-2-1 acquired during the 12 November 2016~~;~~ event; B) False colour band composition 7-2-1 acquired during the 26 November 2016~~;~~ event; C) ~~automatic~~Automatic detection of the flooded area using $MNDWI_{var} \geq 0.3$; automatic detection of the flooded area using supervised classification with maximum likelihood method (D) and with spectral angle method (E). The red box identifies the local case history of Moncalieri (1) and Pancalieri (2).

Figure 5. Sentinel-2 analysis and validation: A) NDVI variation 10 m of spatial resolution, B) MNDWI variation 20 m of spatial resolution, C) Simulation of flooded area water depth for the Po ~~river~~River based on 5-m DTM and river height level registered in the Arpa Piemonte stream gauge.

Figure 6. A) Aerial photo at 10 cm of resolution taken the 28 November 2016; B and C) ~~photos~~Photos taken from a local newspaper and geolocalized with Google Streetview; D) Geomorphological elements and model of estimated water depth (m).

Figure 7. The SfM 3-D model obtained from the very high-resolution aerial photo, near the Po River at the south of Pancalieri. A) Location of 3-D models; -B) The approximate ~~measurmanet~~measurement of water depth on sand deposits of a quarry (A);- C) The effect of meander cut: an erosion channel and the destruction along a stretch of road.

Figure 8. A) ~~map~~Map of areas flooded by Chisola stream in Moncalieri municipality with location of detailed photo; B) Aerial photo at 0.1 m of resolution showing the breach of river embankment and the 'alluvial fan' created by water flow showed with a 3-~~d~~d view in ~~figure~~Figure 9; C) RPASs photo at 0.02 m of spatial resolution showing a collapsed wall in the Tetti Piatti area and a deposit of damaged goodgoods from the nearby house.

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Figure 9. 3-D Model derived from the RPASs aerial photo and SfM elaborations photo overlap. The model shows the river embankment rupture (point B in ~~figure~~Figure 8A), the geomorphological effects in the neighbour areas. It is also possible to estimate ~~the~~ water depth from the signs on the embankment.

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Figure 10. A) Map of the flooded area by Chisola ~~stream~~Stream in the Moncalieri municipality with measured water height and location of 3-~~dD~~ photo; B) Installation of the GO-PRO HERO 3+ (Black Edition) camera and GPS antenna over the car (the processing system for STANAG 4609 encoding was installed inside the car); C and D-) Examples ~~of~~ 3-~~dD~~ models made with ~~Structure from Motion~~SfM in which ~~it~~ was possible to measure the water height. -

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Figure 11. A) Water depth levee map based on SfM data and 5-m DTM model; B) Water level reached by Chisola ~~stream~~Stream in ARPA Piemonte station; C) Geolocated third part photo: 25/11/2016 aerial view of flooded area ~~find~~found on the web (<https://vivere-moncalieri.it/2016/11/30/3760/> ~~)~~).

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Figure 12. A) Water level height map based on SfM data and 5-m DTM model; C) Zoom on the building of figure D; B and D) Photo where it is possible to observe the water depth from the newspaper “La Stampa” geolocated using Google Street view.

Figure 13. -Flowchart of the proposed flood mapping strategy.