Crowdsourced data for flood hydrology: feedback from recent citizen science projects in Argentina, France and New Zealand

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Abstract

New communication and digital image technologies have enabled the public to produce large quantities of flood observations and share them through social media. In addition to flood incident reports, valuable hydraulic data such as the extent and depths of inundated areas and flow rate estimates can be computed using messages, photos and videos produced by citizens. Such crowdsourced data help improve the understanding and modelling of flood hazard. Since little feedback on similar initiatives is available, we introduce three recent citizen science projects which have been launched independently by research organisations to quantitatively document flood flows in catchments and urban areas of Argentina, France, and New Zealand. Key drivers for success appear to be: a clear and simple procedure, suitable tools for data collecting and processing, an efficient communication plan, the support of local stakeholders, and the public awareness of natural hazards.

Keywords: Crowdsourced data; citizen science; flood hydrology; flood mapping; LSPIV

1 Introduction

New communication and digital image technologies have enabled the public to produce and share large quantities of flood observations. Such observations are often authored, time-stamped, georeferenced and eventually shared through social media (Fohringer et al. 2015). Social media actually convey flood information of diverse nature including flood hazard and damage reports, but also rational discussion (understanding), public debate, appeal and remark to the government and local authorities, and emotional messages and expression of feelings (Al-Saggaf and Simmons 2015).

As for other fields, initiatives for crowdsourcing flood data have emerged in the recent years, with a main focus on rapid, near real-time mapping of the reports of flood damages and emergencies, generally to support disaster management (Fohringer et al. 2015, Koswatte et al. 2015). Efficient tools for collecting, filtering, reviewing and analysing massive amounts of data in social media have to be developed. Typically, Fohringer et al. (2015) implemented the PostDistiller tool for the data mining of Twitter posts and applied it to map the inundation extent and depths of the June 2013 flood in Dresden, Germany. As done for other types of volunteered geographical information, interactive maps have also been developed for crowdsourcing flood data and reports, for instance:

- PetaJakarta[a], an open source flood map of Jakarta, Indonesia, to share real-time flood information using social media (Twitter);
- The QLD Flood Crisis Map, an interactive map based on the open-source Ushahidi[b] platform and operated by Australian Broadcasting Corporation (ABC) to allow citizens report information during the 2011 Queensland floods (Koswatte et al. 2015);
- Flooding Points[c], a collaborative flood map for São Paulo, Brazil, also based on the open-source Ushahidi platform and the concept and prototype elaborated by Hirata et al. (2016, in press).

Another way to enhance flood data crowdsourcing is through dedicated mobile phone applications such as, for instance:

- Flood Patrol (Philippines), an Android mobile phone application developed for allowing people send flood reports to NOAH[d] (Nationwide Operational Assessment of Hazards) for mapping;
- SIGNALERT[e] (France), a smartphone application to report various situations of natural hazards including floods;

[a] https://www.petajakarta.org/banjir/en/
[b] https://www.ushahidi.com/
[c] http://g1.globo.com/sao-paulo/mapa-do-alagamento/platb

- mPING[f] (Meteorological Phenomena Identification Near the Ground, NOAA, USA), a free mobile phone application used to collect public weather reports, including flooding across the USA as contributions to the Flood Observations - Citizens As Scientists using Technology Project (FLOCAST[g]) launched in 2013.

Most of these projects and the related research focussed on volunteered geographic information, usually flood damages rather than quantitative hydraulic data. Despite of quality and credibility issues related to crowdsourced data, their filtering and mapping allows for unprecedented spatio-temporal analyses of the flood hazard and flood damages. Combining crowdsourced data and authoritative data, Schnebele et al. (2014) were able to assess the spatio-temporal dynamics of the damages to the transportation infrastructure in New York City flooded by Hurricane Sandy (29-30 October 2012). Using telephonic reports of flood incidents in Rotterdam from 2004 to 2011, Gaitan et al. (2015) analysed the spatial distribution of flood damages and their (lack of) relation with the subcatchments and flow paths derived from a DEM of the urban area.

Quantitative hydraulic data such as the extent and depths of inundated areas (Fohringer et al. 2015) or flow rate estimates (Fujita et al. 2013, Le Boursicaud et al. 2016) can be computed using messages, photos and videos from eyewitnesses and help improve the understanding and modelling of flood hazard. This way, ordinary citizens or some enthusiastic flood chasers can contribute to hydrological science in the same way the so-called storm chasers have historically contributed to meteorological science since the Tornado Intercept Project (1975) of the National Severe Storm Laboratory (USA).

Projects encouraging the public to act as citizen scientists in flood hydrology still appear to be scarce. The main well-established initiative of that kind is the CrowdHydrology[h] project (Lowry and Fienen, 2013), which encourage citizens to read and text the station number and the water level to the phone number listed on the gauge of gauging stations in the USA. The water level is then added to a publicly available database. To our best knowledge, besides the CrowdHydrology project there is no available feedback on such specific projects, and more generally there is a lack of feedback and guidance on the failure and success factors of data crowdsourcing and citizen science projects for flood hydrology.

We introduce three recent citizen science initiatives which have been launched independently by research organisations to document floods in some catchments and urban areas of Argentina, France and New Zealand. These projects were specifically designed to derive quantitative hydraulic data from digital photos

[d] http://noah.dost.gov.ph/
[e] http://www.signalert.eu/
[f] http://www.nssl.noaa.gov/projects/ping/
[g] http://flash.ou.edu/flocast/

and videos from the public for further retrospective analysis and modelling of the flood processes. While the three projects differ in their objectives, methods and hydrological situations, they provide convergent feedback on the potential and limitations of such initiatives for flood hydrology.

2 The three projects

2.1 Flood Chasers (Argentina)

2.1.1 Objectives

The mountainous rivers of the Córdoba province, Argentina, are characterised by the occurrence of flash floods with very high volumes of fast flows during the rainy season (October to April). Due to the sudden nature of flash floods, it is very unlikely to be able to survey several river sections of interest using instruments and techniques suitable for recording the peak flow and its temporal evolution during the flood. Even when it is possible to visit the study sites in time, flow velocities and floating river debris endanger both the instruments and operators. Considering this issue, the researchers of the National University of Córdoba have developed and implemented the Flood Chasers Project ("Cazadores de crecidas" in Spanish, Patalano et al., 2015) to populate a database of videos and photos of flash floods in rivers of the province of Córdoba recorded and shared by citizens using advanced digital technology (cell phones, digital cameras, tablets, etc.) on the basis of the willingness of people filming these extreme hydrological events to share their footage in social networks, websites, forums, etc.

Flood videos recorded by citizens are then processed to estimate river flow velocity and discharge using image velocimetry techniques such as Large Scale Particle Image Velocimetry (LSPIV, Patalano et al., 2014). The implementation of LSPIV using non-professional videos appears as a valuable alternative or supplemental technique to traditional post-flood discharge estimation methods such as the slope-area method, and proves great potential in the Córdoba province, Argentina (Patalano et al., 2015). During the last rainy season (2014-2015), extreme hydrological events occurred in the Córdoba province and in some cases the data obtained with such technique are the only available information to characterise the observed hydrological events.

[h] http://crowdhydrology.geology.buffalo.edu/

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2.1.2 Implementation

The first step of the Flood Chasers Project was to create a website with domain of the University, then perform an intensive dissemination of the existence of this webpage in major newspapers and some television channels. On the Project website (Figure 1) people can upload their flood videos along with metadata (recording date and time, location of the river section, etc.). In case the recording conditions are favourable, the videos are manually screened, analysed and processed using the Large Scale Particle Image Velocimetry technique (LSPIV, Fujita et al., 1998). This technique allows quantifying the surface velocity field of the rivers remotely. The website provides guidelines for users without prior knowledge of hydraulics about the best way to make contributions that are useful for quantifying flood discharges. Users who are interested in participating in the Flood Chasers Project can send or upload their videos using different platforms (i.e. Dropbox, Mega and WeTransfer) following basic tutorials generated by the scientists. There is also a webpage listing all the recorded floods and including the flow results if the video has been suitable for analysis. In turn, there is a YouTube channel called "Cazadores de Crecidas" in which the Project leaders upload their own collection of videos, which are also published on the website.

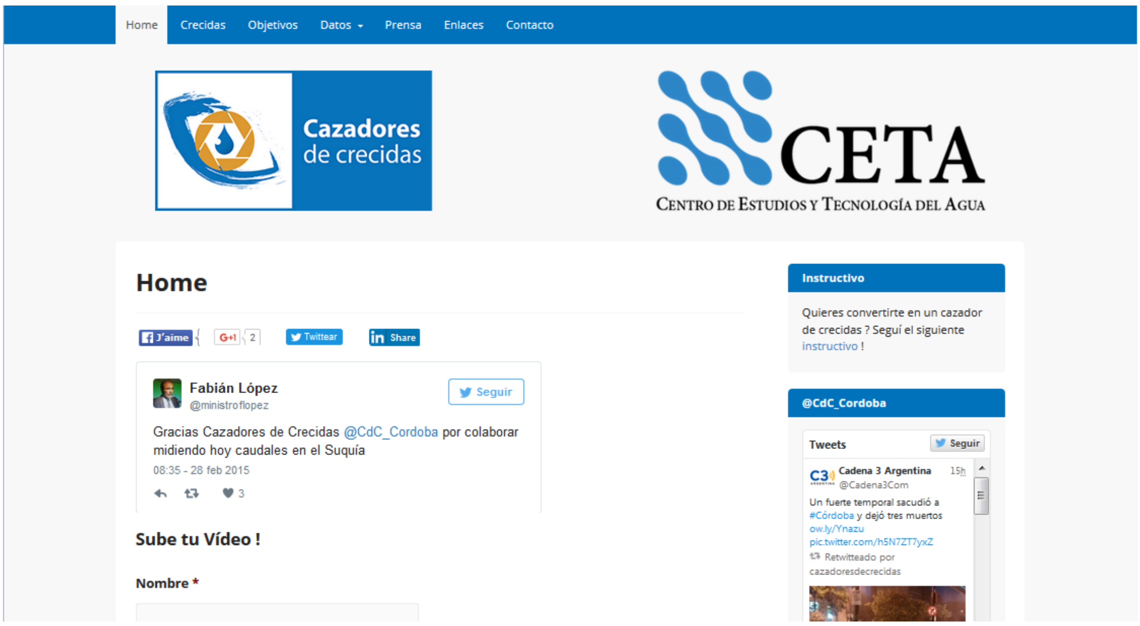

Figure 1. Home page of the website of the Flood Chasers Project[i]

The images are analysed following the methodology described by Patalano and García (2016) that uses state-of-the-art tools (i.e. that apply classical PIV/PTV analysis) and brings them to Large Scale surface flow characterisation, using the the first operational version of the RIVeR (Rectification of Image Velocity Results) software. RIVeR has been developed in the Center for Water Research and Technology (CETA) at the National University of Córdoba, Argentina, since 2013. It has been developed in order to provide an efficient experimental Large Scale water surface characterisation (e.g. flow velocities, streamlines) and flow discharge estimation in rivers and artificial channels (e.g. irrigation, treatment plant, etc.).

Image sequences of recorded videos are processed as follows: after converting the color images extracted from the videos to grayscale images, they are processed using Matlab tool PIVlab (Thielicke and Stamhuis 2014) for calculating the displacement vector field from each pair of images. Each of these instantaneous velocity fields is processed and the average displacement field in pixels per image pair is calculated. The results are exported to the RIVeR (Rectification of Image Velocity Results) toolbox, which transform the displacement data into velocity data in [m/s] by rectifying the results for perspective due to the oblique capture of the videos with respect to the flow surface. The rectification is made using distances between fixed points (ground reference points) observed in the images that were surveyed in situ after the flood event. Combining the surface velocity profile in the area of interest with the bathymetry profile subsequently surveyed and a relationship between depth-average and surface velocity, the flood discharge at the time of the video in a defined river cross-section can be estimated.

The relationship of the Flood Chasers Project leaders with government authorities is more than optimal. The minister of water, environment and energy of the Córdoba province is a professor at Universidad Nacional de Córdoba (at leave) who is interested in the implementation of the technique. The results obtained in the project have been used by the government to hydrologically evaluate some of the recorded events. Due to this interest the project has received support from the government including logistics for conducting the required surveys (topography survey, fieldwork, etc.).

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[i] http://www.cazadoresdecrecidas.unc.edu.ar/

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2.1.3 Examples of results

The methodology was applied to a video recorded by the witness of a flash flood that occurred in the Ceballos River in the city of Río Ceballos (31°10′S; 64°19′W), Province of Córdoba, Argentina, after an extreme rainfall event occurred on the morning of 15th February 2015. The return period of the rainfall event was estimated to be more than 100 years with observed rainfall depth of about 250 mm during 12 hours. The witness uploaded the video to the project website (Figure 1) with the sufficient metadata so the scientists could reach the place where the video was recorded. Subsequently, the scientists went to the place and surveyed the river cross-section bathymetry using a topographic total station. The camera movement during the record due to the videographer holding the camera by hand without a tripod was preliminarily corrected. Such movement created significant errors in the processing of the images (Figure 2a). Then, the surface velocity profile was computed (Figure 2b) and ortho-rectified.

(a) 

(b) 

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Figure 2. Successive frames (a) of a video recorded during the flood in the Ceballos River in Río Ceballos, Province of Córdoba, Argentina, on 15 February 2015, and time-averaged surface displacement vector field (green vectors) in the area of interest (b). Red crosses show discarded grid nodes where the flow free surface is not visible.

The computed surface velocity data in the area of interest were used for the calibration of the hydraulic numerical model (HEC-RAS) implemented to simulate the flow conditions of the analysed event. The Digital Terrain Model of the whole reach of interest required to implement the hydraulic model was provided by the government of the Córdoba Province. Based on the surface velocity field and the water level data at the measured section, the bed and banks roughness could be estimated iteratively and the flow discharge computed. By the time that the video was recorded, the total discharge estimated using the calibrated model was 225 m^3/s (Figure 3), which was not the peak discharge. The maximum water level (not observed in the video) was measured in situ using a post-event survey of the high water marks. Using the calibrated model, the peak discharge of the event was estimated to be 290 m^3/s. The flooded area predicted using the calibrated flood model of the Ceballos River can be seen in Figure 4.

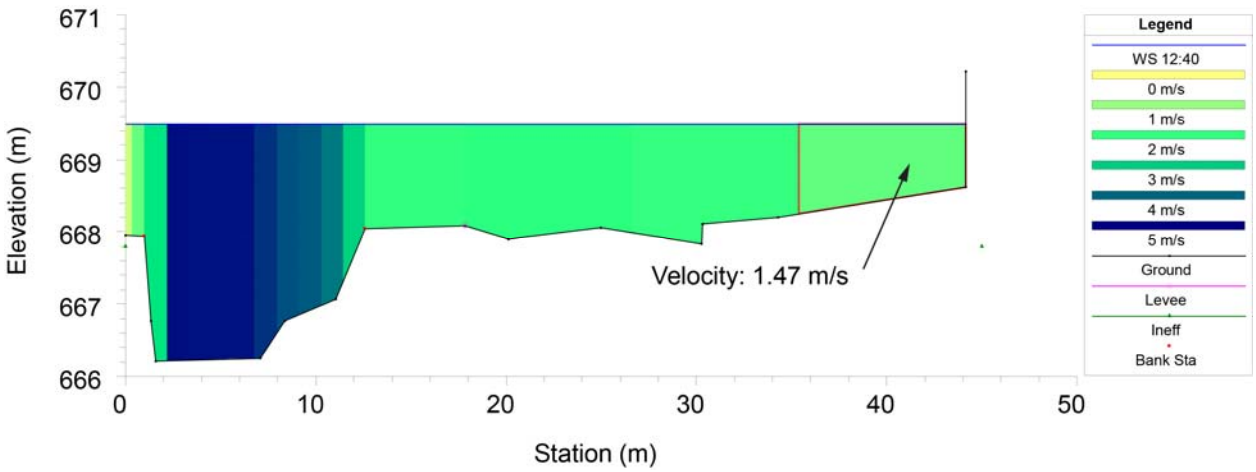

Figure 3. Bathymetry of the cross-section of interest and depth-averaged velocity field estimated using a 1D hydrodynamic model (HEC-RAS). The velocity (1.47 m/s) on the right side is the velocity obtained by LSPIV and used for the model roughness calibration.

Figure 4. Flooded area estimated using the HEC-RAS flood model calibrated with the LSPIV velocity measurement and the water level data in the section of interest (marked Cs). The peak discharge was estimated to be 290 m^3/s.

The main problem faced in the Flood Chasers Project in Argentina is that many of the videos are not suitable for processing because they do not meet the required conditions: most people record videos with continuous movements of the camera and zooming, and in many cases it is not possible to detect the ground reference points necessary for image ortho-rectification. For the next rainy season, the scientists are looking for training groups of people who can be great partners. For example the civil defence workers (i.e. firefighters) will be contacted for training since they are usually the first to arrive to the rivers when flash floods occur. Advanced students (16 to 17 years old) from high schools that are located near rivers will also be trained. The youth of that age usually use cell phones which now have the minimum resolution required to implement the image velocimetry technique. A strong message of safety is also transmitted to all trained people because it is very important to avoid any life in danger and be sure there is no risk in recording a video.

2.2 FloodScale (France)

2.2.1 Objectives and background

As part of the ANR[j] FloodScale project (France) on Mediterranean flash floods (Braud et al., 2014), a similar action was independently launched throughout the Ardèche river catchment, South-East France. The FloodScale project, a contribution to the HyMeX[k] project (Hydrological cycle in the Mediterranean Experiment, Drobinski et al., 2014) was designed to make progress in the understanding and modelling of flash floods. The observation strategy combined a four year multi-scale data collection in two meso-scale catchments in South-East France with opportunistic measurements during the autumn season, when flash floods are more likely to occur. To decrease the uncertainty of stage-discharge ratings and streamflow records, innovative methods for gauging rivers during flash floods were implemented, including portable surface velocity radars (Welber et al., 2016) and Large Scale Particle Image Velocimetry (LSPIV) at permanent video camera stations (Le Coz et al., 2010) or using home movies from the public in post-flood surveys (Le Boursicaud et al., 2016).

Specific communication actions focussed on the determination of flood discharges within the Ardèche river catchment (France) using home movies shared by observers and volunteers. Safety instructions and a simplified field procedure (see flyer and poster in Figure 5) were shared through local media and were made available in French and English on the project website[l]. Legal aspects including a copyright transfer form have been settled with the help of Irstea's (National Research Institute of Science and Technology for Environment and Agriculture) legal services. This way, simple flood observers or even some enthusiastic flood chasers were encouraged to contribute to hydrologic sciences.

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[j] Agence Nationale pour la Recherche (National Agency for Research, France)
[k] www.hymex.org
[l] https://floodscale.irstea.fr/donnees-en/videos-amateurs-de-rivieres-en-crue/videos-amateurs-de-rivieres-en-crue

2.2.2 Implementation

The processing of flood videos to extract surface flow velocities and discharges is based on the LSPIV technique originally proposed by Fujita et al. (1998). The cross-correlation analysis of visible movements in image pairs is similar to the conventional PIV technique used in hydraulic laboratory studies, but large-scale outdoor applications require suitable image ortho-rectification and discharge computation steps. The applicability of the LSPIV technique to flood home movies was investigated by Le Boursicaud et al. (2016), as already done by Fujita et al. (2013) using the STIV (Space-Time Image Velocimetry) technique, and is also the core of the Flood Chasers Project (Argentina). LSPIV steps are similar to the technique used in the Flood Chasers project, except that ortho-rectification was applied to every image pair before velocity computation.

Flood videos recorded by witnesses usually do not match the requirements of the traditional LSPIV technique. Using such videos raises several issues (Le Boursicaud et al., 2015, 2016) that must be solved for the video to be successfully processed:

- Fixed points that can be located in the images and in the real world are needed to calibrate the orthorectification;
- Both river banks should be visible in the image so that a complete cross-section is monitored;
- The video should be recorded from a fixed point of view: a shake with limited amplitude was found to be acceptable;
- The precise location and timing of the video are necessary;
- Authors of the videos must be contacted in order to get their personal agreement for the use of their video materials and additional information.

Using flood home movies therefore requires some image pre-processing to be applied before the LSPIV analysis, such as:

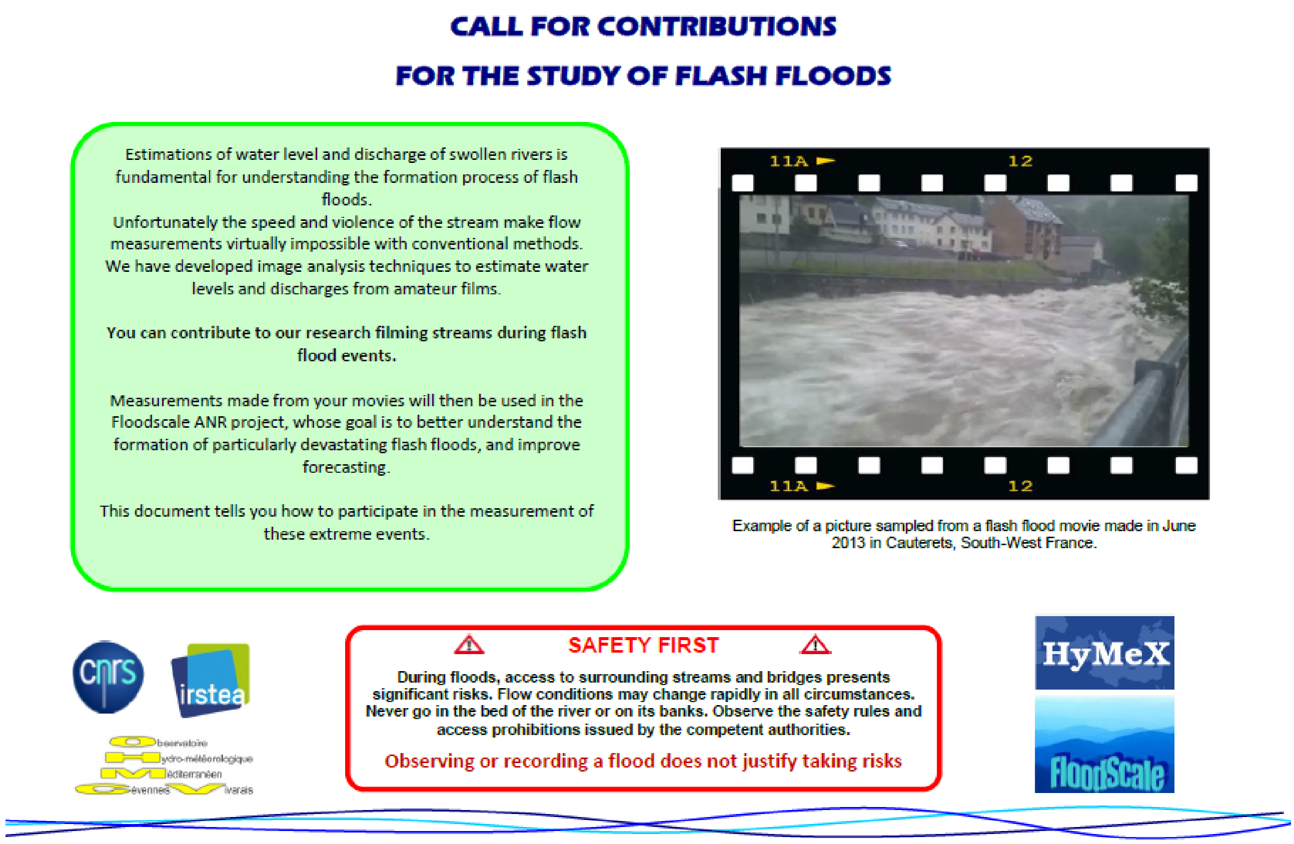
- Correction of hand-held camera movement: image alignment;
- Correction of distortion due to non rectilinear camera lenses;
- Relative positioning of the free-surface.

The project followed a fully reproducible approach, based on free software only. LSPIV analysis was conducted using Fudaa-LSPIV (Le Coz et al. 2014a), a free, user-friendly software available online[m]. Frames

[m] https://forge.irstea.fr/projects/fudaa-lspiv/files

were sampled from the video at an adequate time rate using ffmpeg[n], and image pre-processing was conducted using Hugin[o]. The complete procedure to collect and pre-process home movies for further LSPIV analysis comes as a short methodological guide (Le Boursicaud et al., 2015).

Simple procedures for taking useful flood videos, highlighting safety warning (Figure 5) have been disseminated to the public through various media including the project website[p] and local media (newspapers, radio). Communication campaign was well received by locals and municipalities, but jeopardised by local issues (update of official flood risk mapping) and lack of coordination with and support from local authorities (civil defence and prefecture). The main expressed concerns were that the call would encourage the public to record videos from unsafe locations by the flooded rivers and that it would suggest that further research on flood discharges was required before a flood risk map could be firmly established. After long discussions, the communication campaign had to be postponed. Permissions for distributing flyers and putting posters in places attended by the public were never obtained.



(a)

[n] https://www.ffmpeg.org/
[o] http://hugin.sourceforge.net/
[p] https://floodscale.irstea.fr

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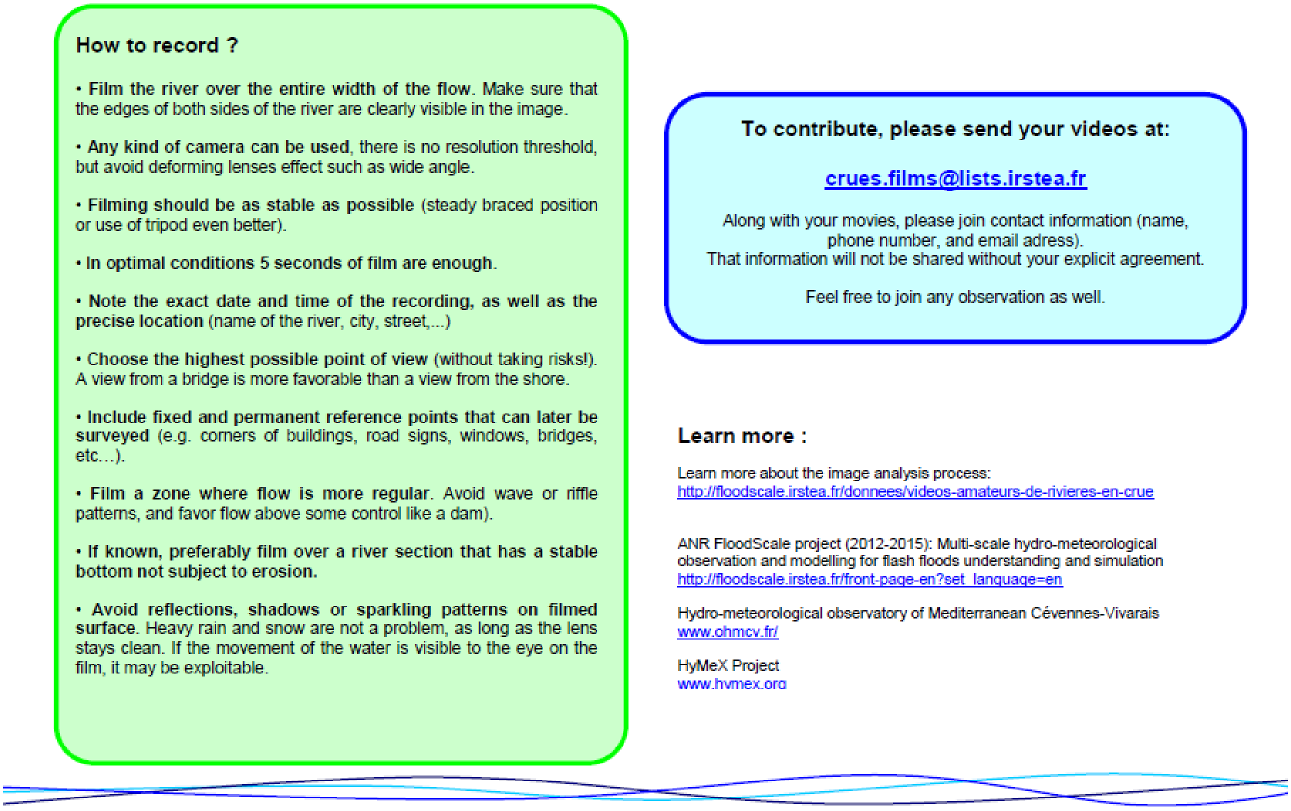
(b) 

(c)

Figure 5. Instructions provided to the public as a flyer (a, b) and a poster (c) for the information campaign of the FloodScale Project[q]

[q] https://floodscale.irstea.fr/donnees-en/

2.2.3 Examples of results

Partly due to communication restrictions, few videos were received by the scientists, even after the series of significant floods which occurred during the 2014 autumn. And none of those were actually usable because they generally did not follow the recommendations. Some of them were not located in the study area. In turn, some useful videos were harvested by scientists after each flood of interest, especially drone videos (Figure 6) shared on YouTube[r] by a local company[s] specialising in UAV-borne image recording. The footage was also shown by local and national TV channels. Valuable sequences with remarkable stability and clear views of the Ardèche river channel upstream and downstream of the submersible Sampzon bridge (44°25'46.4"N; 4°21'25.6"E) were selected (Figure 6).

Some fixed ground reference points could be identified, especially road signs and marks and elements of the bridge structure. Their positions were topographically surveyed using a differential GPS and cross-sectional bathymetry profiles were also measured using a hydro-acoustic profiler (ADCP). Then image sequences were extracted, converted in grey scale levels, ortho-rectified, and instantaneous velocity fields were computed. Time-averaged velocities were interpolated at each node of a transect used for discharge computation. As often, the water level estimation appeared to be the main source of uncertainty (Table 1). However, discharge estimates were found to be consistent with the flow rated at the upstream gauging station when realistic time lags due to flood propagation are considered (between 30 and 60 minutes). Even with uncertainties possibly as large as 15% or 20% such discharge estimates remain highly valuable to reduce the uncertainties of rating curve extension and post-flood peak discharge assessment.

[r] https://www.youtube.com/watch?v=4lgws8pvFyg
[s] http://www.ardechevideo.com/

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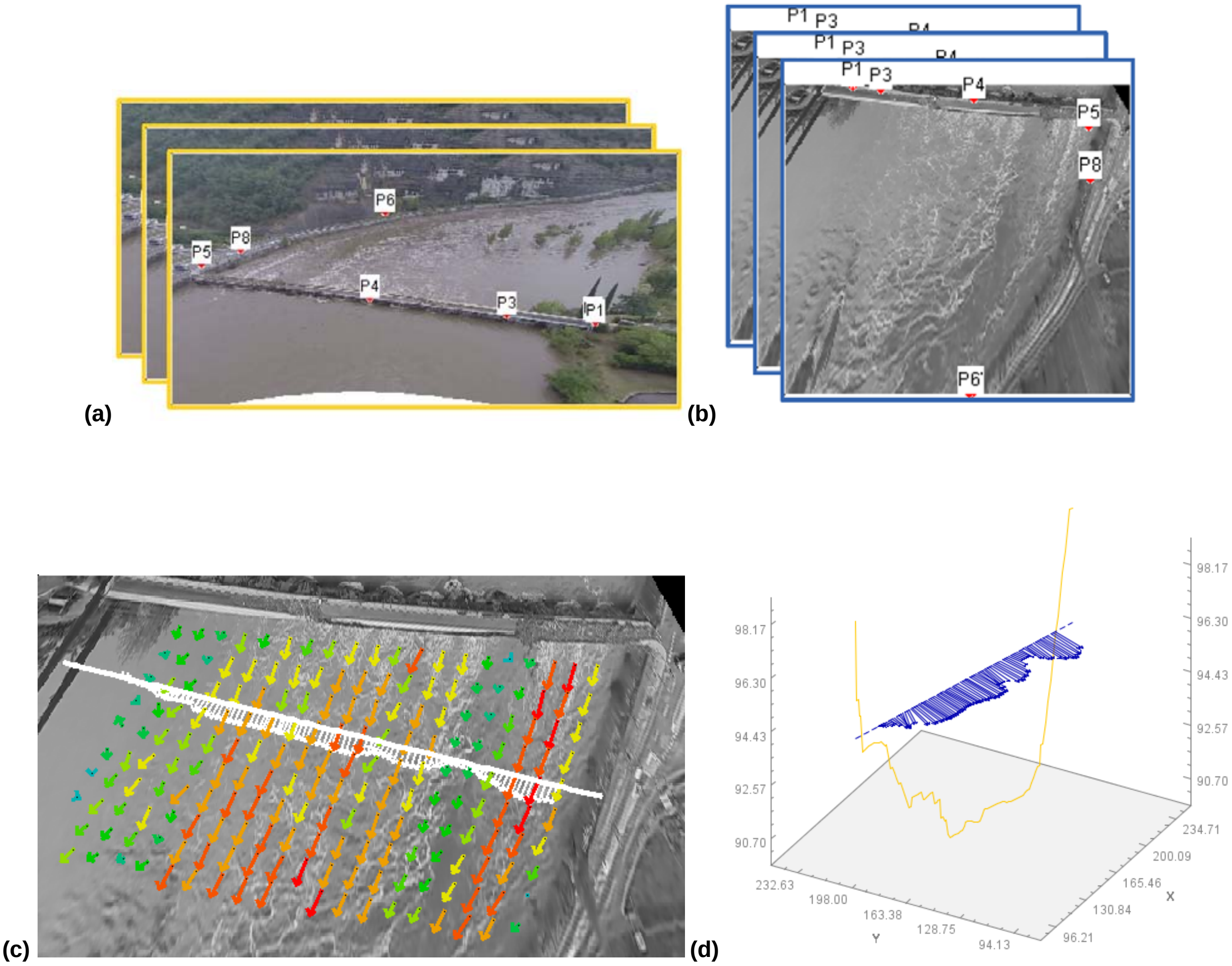

Figure 6. Applying Fudaa-LSPIV software to a drone video of the Ardèche River at Sampzon Bridge, France, shared on YouTube after 2014 floods: raw image sequence with ground reference points (a), same images converted to grey scales and ortho-rectified (b), time-averaged surface velocity field (up to 4 m/s) and depth-averaged velocities interpolated at the transect used for discharge computation (c), 3-D view of the transect (d)

Water Level (metres above sea level)	LSPIV Discharge Q (m^3/s)	Q difference (%) Time lag: 30 min	Q difference (%) Time lag: 60 min
94.5	1053	+16	+25
94.0	913	+3.6	+13
93.5	795	-11	+0.6

Table 1. Discharge results and comparison with records from upstream gauging station

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The main perspectives are to reiterate communication campaigns with the twofold objective of mitigating issues with the local governmental authorities, and increasing the quantities of usable videos spontaneously provided by the public. This would certainly be reached with opportunistic calls to be launched through any media just after a flood in the affected area. Thus the hydrologic watch could focus on a broader region such as the French Mediterranean belt, or even at a larger scale as part of the HyMex project which develops post-flash flood surveys throughout the catchments contributing to the Western Mediterranean Sea.

Engaging with the locals in preparation of future floods at research sites like the Ardèche catchment would remain feasible through poster campaign at key observation points with safe conditions, especially near gauging stations which provide the water level data that are critical for velocity and discharge computations. Such sites could be pre-surveyed and permanent ground reference points could be marked. A best viewpoint for videos could be marked and suggested on an adjacent poster or sign, for instance. The public could be asked to read the staff gauge like in the CrowdHydrology project and provide the water level along with their videos. Specialised partners such as technical staff from local municipalities, firemen, civil defence, volunteering observers, storm/flood chasers, kayakers, UAV-borne image companies, etc. could be informed and trained.

2.3 RiskScape (New Zealand)

2.2.1 Objectives

The New Zealand national institute NIWA has called citizens to contribute to flood mapping during recent inundation events in the cities of Christchurch (43°31′S; 172°38′E) in 2014 and Dunedin (45°52′S; 170°30′E) in 2015. Residents were invited to send in their pictures of flooded areas, which were further used to build flood hazard maps, as part of the RiskScape[t] project.

The 2010-2011 Canterbury earthquakes changed surface elevations across the region and the city of Christchurch, in the South Island of New Zealand. This led to changes in flood risk, which was highlighted by the 5th March 2014 flood as some suburbs of Christchurch experienced uncharacteristically severe inundation. The flood not only highlighted the altered risk profile, but it also presented a rare opportunity to update flood hazard knowledge of the city. With the widespread availability of camera phones and photos of inundation,

[t] www.riskscape.org.nz

this research project sought to employ citizen science to supplement professional measurements of inundation.

2.2.2 Implementation

Two days after the flood peak, members of the public were invited, via press releases to mainstream media, a scientific blog[u] and outreach via social media (Facebook, Twitter), to send photos of maximum flood levels to NIWA, indicating when and where each photo was taken. The photos were assessed by professionals in terms of the ability to identify a clear water level around the time of the peak inundation. Water surface levels were derived from the photos in conjunction with LiDAR scans of the city. In locations where photos did not permit clear identification of water levels, field visits were carried out to make supplemental measurements. The resulting point data were interpolated, along with additional survey data, to derive a RiskScape flood hazard model to calculate flood risk and potential losses across the city. During flooding in the city of Dunedin in 2015, the same request for photographs was made, but the project was discontinued due to a lack of responses.

[u] http://sciblogs.co.nz/waiology/2014/03/07/calling-for-christchurch-flood-photos/

Figure 7. Photos of the 5th March 2014 inundation in Christchurch, New Zealand, received from the public. (a) Slater Street, Richmond. (b) Francis Avenue, Mairehau. (c) Buxton Terrace flow gauging site, Saint Martins. (d) Intersection of Oxford Terrace and Barbadoes Street.

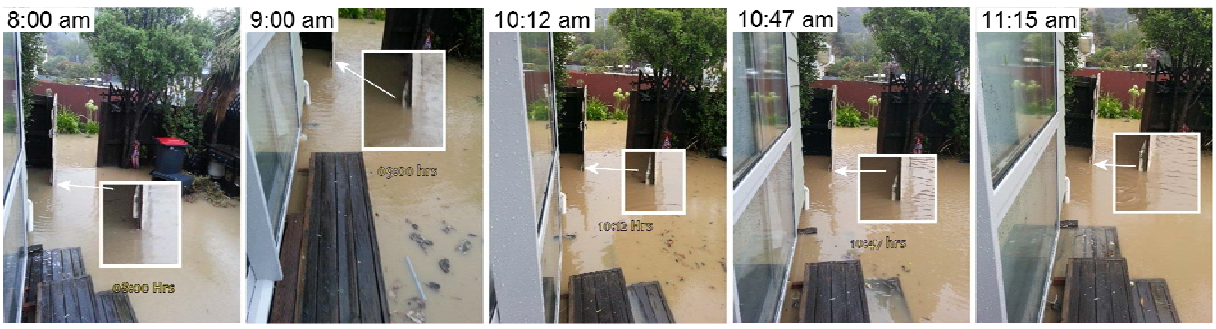

Figure 8. Sequential photos of the same gate traces the flood hydrograph and can help pinpoint the time of maximum inundation during the 5th March 2014 flood in Christchurch, New Zealand.

2.2.3 Examples of results

Over 600 photos were received for the Christchurch study (e.g., Figures 7 and 8). Not all photos were used or could be used, and for various reasons – the flood level may not have been discernible; the time or location was unknown; or flood data may have been available from other photos or another source. Ultimately, 300 photos were used to get a fix on 289 water levels around the city. Combined with field surveys, the resulting inundation map (Figure 9) indicates flooding along the Avon and Heathcote Rivers as well as various residential suburbs throughout Christchurch, including the severely impacted Flockton Basin. High media and public interest suggested that, in addition to providing useful data, the public engagement fostered a greater appreciation of flood hydrology and its scientific study.

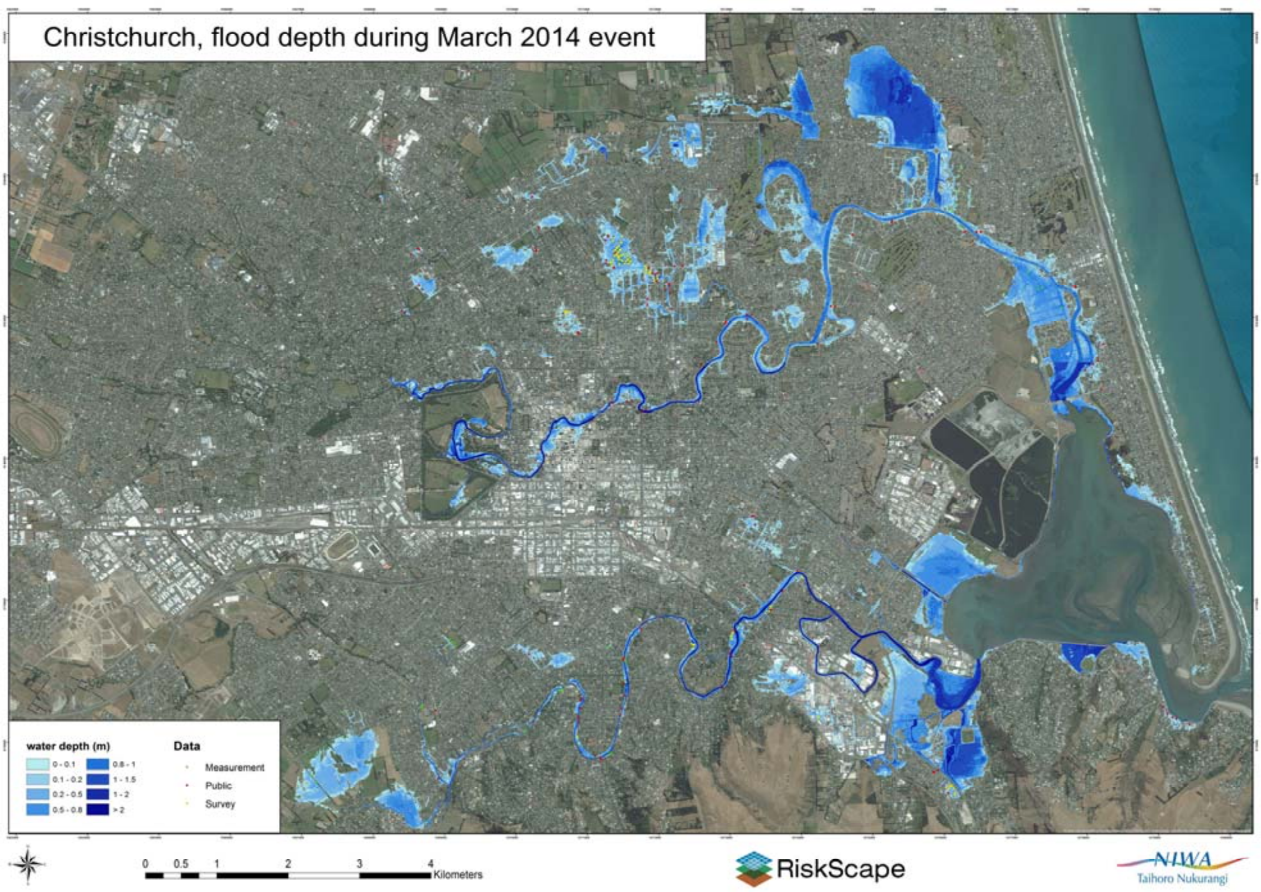

Figure 9. Interpolated flood depths based on citizen scientist photos and field surveys, for the 5th March 2014 flood in Christchurch, New Zealand.

The resultant information has been invaluable in understanding the changed flood risk for post-earthquake Christchurch. These data were used to validate hydrodynamic models and are being used to plan mitigation, response and evacuation plans and to calculate human and economic costs of flooding. The widespread use of camera phones provided data on flood levels and extent that could not have been obtained by field surveys by hydrology technicians due to insufficient resources to cover the wide extent of relatively short duration flooding.

3 Lessons learnt

3.1 Write a clear and simple procedure

Once the objectives and tools of the project have been defined, a clear and simple procedure has to be written for the attention of the public. This is a key driver of the success of all citizen science projects. The three projects have produced procedures in the form of simple instructions for recording the images and sending the data in good agreement with their distinct objectives, either flood mapping or flood discharge estimation. The type of images and metadata, the protocols to send them to the scientists and the safety and copyright aspects were dealt with in a concise and precise manner. However, the simple but more demanding requirements on flood videos for LSPIV applications in the Flood Chasers and FloodScale projects proved to be much less followed than those on flood mark photos for the RiskScape project. The rate of photos usable for flood mapping was much higher than the rate of videos usable for discharge estimation. For the capture of valuable videos, a written procedure may not be sufficient and additional training should be provided as tutorials and short videos, e.g. on collaborative websites like WikHydro in France[v]. Instructions displayed in situ may also be more efficient.

Crowdsourcing flood hydrology data makes the most of modern digital image technologies and social media. It is advisable to target the kinds of equipment most commonly used by people in the area of interest, smartphones typically but also drones (UAV) increasingly. Drone images show great potential for the LSPIV technique, through excellent viewpoint stability and negligible perspective effects to correct since images are often taken vertically from the sky. Then image ortho-rectification is not absolutely necessary, only estimation of the size of the pixels, which requires much less ground reference points to be surveyed. Aerial photos taken from drones could certainly be used in flood mapping projects as well, in conjunction with high-resolution DEM.

[v] http://wikhydro.developpement-durable.gouv.fr/

3.2 Develop suitable tools for data collection and processing

From a technical point of view, suitable tools are requested to collect, process the image materials, and assess the quality of results, in order to reach the scientific objectives of the project. It is necessary to develop platforms able to collect large quantities of data coming with contrasted formats and quality levels. Website forms and uploads, as well as smart (apps) or basic (texts) phones, are efficient tools to collect crowdsourced data, as long as the effort required from the user is kept minimal. Developing dedicated smartphone apps could be very efficient for the data collection.

However, it sometimes remains more efficient for scientists to harvest adequate image materials from sharing platforms and social media, and further locate and contact the authors for more information. As exemplified by the three projects described in this paper, both bottom-up and top-down ways of collecting data should be explored.

The processing of the collected data generally requires specific techniques and tools that are not previously available off the shelf. Research groups need to be committed into the development of suitable imagery techniques, hydrologic and hydrodynamic models, GIS applications and flood risk assessment methods. It is important to carefully review the quality of the crowdsourced data, in particular through post-event field investigation and cross-checking of the results with other sources of information, including professional data. Locating precisely the photo/video viewpoints is often easy whereas their precise timing may be not, especially when the authors cannot be contacted. The determination of the water level is a major source of uncertainty in the discharge estimation.

The use of crowdsourced hydrologic data in models and scientific studies also requires suitable techniques that are able to assimilate data coming with contrasted and possibly large uncertainties. This is typically the case of the Bayesian techniques implemented in the FloodScale project for stage-discharge rating curve development (Le Coz et al. 2014b), hydrologic modelling and flood frequency analysis (Renard et al. 2010). The FloodChasers and RiskScape projects illustrate how such data can be successfully included in 1D/2D hydrodynamic models, post-flood surveys and flood risk and damage assessment.

3.3 Implement an efficient communication plan

Communication is key to efficiently mobilise flood observers, make them aware of flood-related dangers (and discourage them from risking their lives), avoid conflicts with local authorities, and provide feedback on the use of collected data. Simple and direct explanations are essential, even when it comes to science or legal terms. Such initiatives are usually well received by the locals and the media. Communication efforts should be directed at both the general public and specific community groups such as kayakers or storm/flood chasers. It is important to communicate with and train groups of more advanced operators (firemen, civil defence, hydrologic services, volunteers, etc.) so they can make better quality videos that fit the requirements of the data processing, in optimal safety conditions.

The reported experience highlights the necessity of adapting the communication vectors to each project. Communicating through radio and TV allows to reach a wide audience. Local newspapers and scientific blogs can probably reach a more specific audience but are efficient to release punctual and periodic reminders of the projects which are useful, especially at the beginning of the project or flood season, during or after flood events, and when results and outputs are available. Distributing flyers and displaying posters and signs at key observation points and at places attended by the public when there is a flood cannot be done extensively throughout a large catchment, but it may dramatically increase the quantity of image materials at particularly strategic sites.

Social media like Twitter and Facebook are essential as they allow to reach a wide audience and to do it at any time, but you first have to communicate to make people `follow' you. Typically, the Flood Chasers Project received more videos when the minister of Water, Environment and Public Services of the Córdoba Province, Argentina, `re-twitted' the project on Twitter. Then, people forgot about it until an article was published in a local newspaper. Being constantly active in the whole range of available media is important.

3.4 Get the support of local stakeholders

As consistently illustrated in the polarised French and Argentinian experiences, getting the support of local authorities or not can significantly enhance or jeopardise your citizen science project. The local context and profiles of people in charge are of course important as given factors of the issue, but the communication strategy should account for this issue from the beginning. In the specific context of the FloodScale project, calling for images before rather than during or just after the flood appeared to be the main source of concerns for the administration. Though arguably hypocritical, you will not be blamed for encouraging people to unsafe behaviour if you call for existing images, as usually done by mass media. It also appears advantageous to focus on a recently flood-affected area rather than spending communication efforts over a large region in preparation of future floods. Still, the support of local stakeholders and authorities should be sought actively. There is always a chance that they realise the potential of citizen science initiatives for the success and acceptance of flood risk policies.

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3.5 Public awareness and engagement matter

The call is much more successful when the public and the media are prepared and aware of natural hazards, as was the case in Christchurch, New Zealand, after the earthquakes of 2010 and 2011. During this time, both the public and media became more attuned to natural hazard science, and also became more receptive to citizen science-based initiatives such as the earthquake felt reports on GeoNet website[w]. This was not the case for Dunedin, hence one potential reason for the failure to receive photographs, although there are others (e.g., flooding was not as extensive and occurred during the end of the day).

Provided there is sufficient expert oversight during project design and data analysis, such citizen science seems a viable means of improving our understanding of flood risk. In turn, the reported projects highlight the value of citizen science initiatives as a means of both gathering data and engaging with the community. In some cases, the value of the obtained data is much less than the impact and engagement of the citizen community (Lowry and Fienen, 2013). Feedback to the public is absolutely essential, through any available means: project website, online database, publication of results, follow-ups on scientific blogs[x,y] and communication through the media.

Social studies could also profit from such crowdsourced feedback from people on how they have been affected by the flood and how they have reacted, as done through calls and interviews in social science projects like in HyMex[z] project (Ruin et al. 2008). Not only eyewitnesses of the flood but broader communities, which are not always visible in more formal reporting procedures, may use social media to express their feelings and contribute to the public debate (Al-Saggaf and Simmons 2015).

4 Conclusions

The reported three projects are typical of emerging citizen science initiatives for crowdsourcing flood hydrology data. These photo-based flood mapping (RiskScape, New Zealand) and video-based flow estimation (Flood Chasers, Argentina, and FloodScale, France) projects were specifically designed to produce georeferenced and time-stamped hydraulic quantities readily usable for flood hydrology studies and hydraulic modelling. Compared to other similar projects, they involved similarly simple procedures for the public, but more advanced data processing and reviewing by the scientists. An exciting perspective would be to combine such 'measurement-oriented' and 'citizen hydrologists' approaches with the powerful tools developed in other

[w] http://www.geonet.org.nz/quakes
[x] http://sciblogs.co.nz/waiology/2014/06/16/citizen-scientists-help-map-christchurch-flooding/
[y] http://sciblogs.co.nz/waiology/2014/09/04/full-citizen-science-flood-map-for-christchurch-march-2014/
[z] www.hymex.org and web form: http://goo.gl/forms/q80gfQbPNN

projects for data mining the social media contents and conducting the spatial analysis of volunteered geographic information.

The three projects illustrate the great potential of citizen science initiatives for improving flood risk assessment in interaction with the local communities. Key drivers for success appear to be: a clear and simple procedure, suitable tools for data collecting and processing, an efficient communication plan, the support of local stakeholders and authorities, and the public awareness of natural hazards. Beyond the technical and communication challenges, this is an efficient way to enhance the culture of flood risk and make people more engaged collectively. We hope that this feedback may help such initiatives emerge and develop successful strategies.

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