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1 Crowdsourced data for flood hydrology: feedback from recent citizen 2 science projects in Argentina, France and New Zealand

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5

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10

11

12 **Abstract**

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

23

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

25

26 1 Introduction

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

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

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

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

- 50 • Flood Patrol (Philippines), an Android mobile phone application developed for allowing people send
51 flood reports to NOAA^d (Nationwide Operational Assessment of Hazards) for mapping;
- 52 • SIGNALERT^e (France), a smartphone application to report various situations of natural hazards
53 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>

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

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

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

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

79 We introduce three recent citizen science initiatives which have been launched independently by research
80 organisations to document floods in some catchments and urban areas of Argentina, France and New
81 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/>

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

85

86

87 **2 The three projects**

88 **2.1 Flood Chasers (Argentina)**

89 *2.1.1 Objectives*

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

101

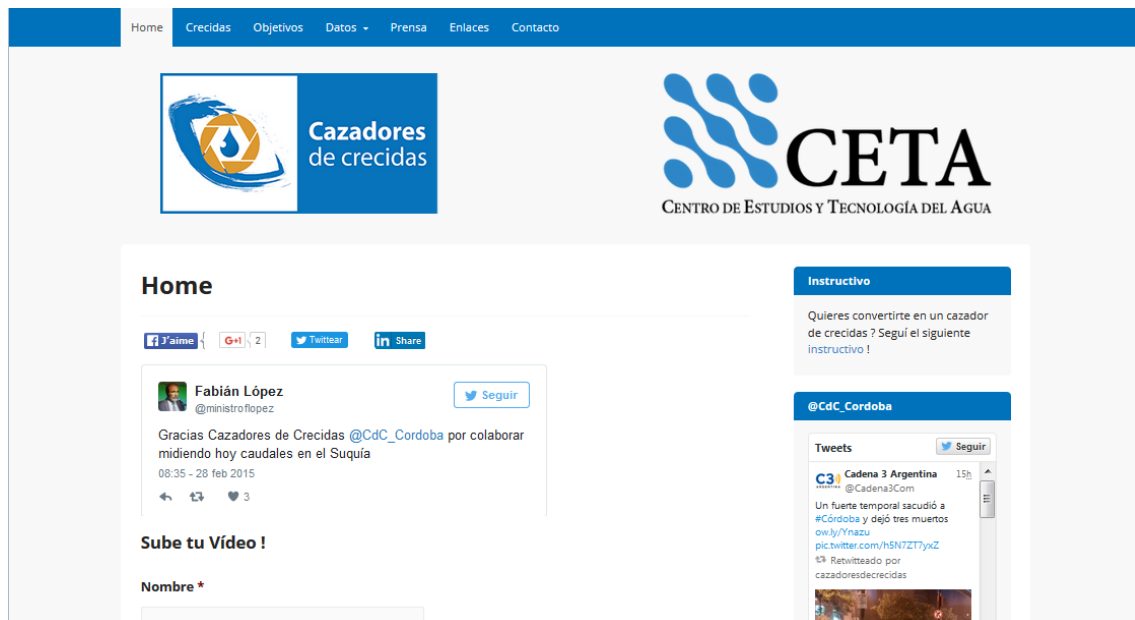
102 Flood videos recorded by citizens are then processed to estimate river flow velocity and discharge using
103 image velocimetry techniques such as Large Scale Particle Image Velocimetry (LSPIV, Patalano et al., 2014).
104 The implementation of LSPIV using non-professional videos appears as a valuable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

^h <http://crowdhydrology.geology.buffalo.edu/>

110 2.1.2 Implementation

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

124



125

126

Figure 1. Home page of the website of the Flood Chasers Project¹

127

128

129

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)

130 software. RIVeR has been developed in the Center for Water Research and Technology (CETA) at the
131 National University of Córdoba, Argentina, since 2013. It has been developed in order to provide an efficient
132 experimental Large Scale water surface characterisation (e.g. flow velocities, streamlines) and flow discharge
133 estimation in rivers and artificial channels (e.g. irrigation, treatment plant, etc.).
134 Image sequences of recorded videos are processed as follows: after converting the color images extracted
135 from the videos to grayscale images, they are processed using Matlab tool PIVlab (Thielicke and Stamhuis
136 2014) for calculating the displacement vector field from each pair of images. Each of these instantaneous
137 velocity fields is processed and the average displacement field in pixels per image pair is calculated. The
138 results are exported to the RIVeR (Rectification of Image Velocity Results) toolbox, which transform the
139 displacement data into velocity data in [m/s] by rectifying the results for perspective due to the oblique capture
140 of the videos with respect to the flow surface. The rectification is made using distances between fixed points
141 (ground reference points) observed in the images that were surveyed in situ after the flood event. Combining
142 the surface velocity profile in the area of interest with the bathymetry profile subsequently surveyed and a
143 relationship between depth-average and surface velocity, the flood discharge at the time of the video in a
144 defined river cross-section can be estimated.

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

151

152

ⁱ <http://www.cazadoresdecrecidas.unc.edu.ar/>

153 *2.1.3 Examples of results*

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

164

165 (a)

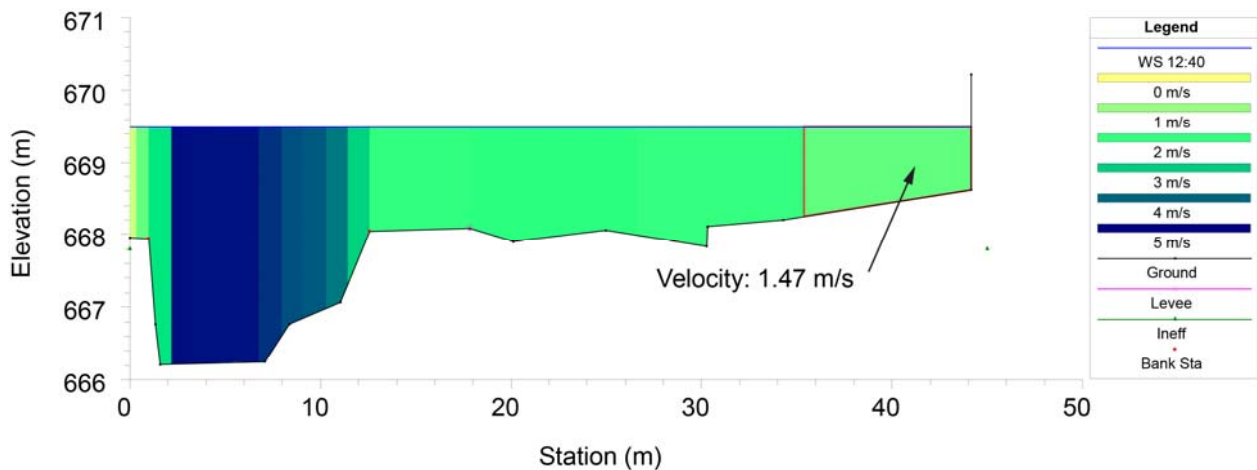


166 (b)



167 **Figure 2.** Successive frames (a) of a video recorded during the flood in the Ceballos River in Río Ceballos, Province of
 168 Córdoba, Argentina, on 15 February 2015, and time-averaged surface displacement vector field (green vectors) in the
 169 area of interest (b). Red crosses show discarded grid nodes where the flow free surface is not visible.
 170

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



181
 182 **Figure 3.** Bathymetry of the cross-section of interest and depth-averaged velocity field estimated using a 1D
 183 hydrodynamic model (HEC-RAS). The velocity (1.47 m/s) on the right side is the velocity obtained by LSPIV and used for
 184 the model roughness calibration.



185

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

188 The main problem faced in the Flood Chasers Project in Argentina is that many of the videos are not
189 suitable for processing because they do not meet the required conditions: most people record videos with
190 continuous movements of the camera and zooming, and in many cases it is not possible to detect the ground
191 reference points necessary for image ortho-rectification. For the next rainy season, the scientists are looking
192 for training groups of people who can be great partners. For example the civil defence workers (i.e.
193 firefighters) will be contacted for training since they are usually the first to arrive to the rivers when flash floods
194 occur. Advanced students (16 to 17 years old) from high schools that are located near rivers will also be
195 trained. The youth of that age usually use cell phones which now have the minimum resolution required to
196 implement the image velocimetry technique. A strong message of safety is also transmitted to all trained
197 people because it is very important to avoid any life in danger and be sure there is no risk in recording a video.
198

199 2.2 FloodScale (France)

200 2.2.1 Objectives and background

201 As part of the ANR^j FloodScale project (France) on Mediterranean flash floods (Braud et al., 2014), a
202 similar action was independently launched throughout the Ardèche river catchment, South-East France. The
203 FloodScale project, a contribution to the HyMeX^k project (Hydrological cycle in the Mediterranean Experiment,
204 Drobinski et al., 2014) was designed to make progress in the understanding and modelling of flash floods. The
205 observation strategy combined a four year multi-scale data collection in two meso-scale catchments in South-
206 East France with opportunistic measurements during the autumn season, when flash floods are more likely to
207 occur. To decrease the uncertainty of stage-discharge ratings and streamflow records, innovative methods for
208 gauging rivers during flash floods were implemented, including portable surface velocity radars (Welber et al.,
209 2016) and Large Scale Particle Image Velocimetry (LSPIV) at permanent video camera stations (Le Coz et al.,
210 2010) or using home movies from the public in post-flood surveys (Le Boursicaud et al., 2016).

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

218 _____
^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>

219 2.2.2 Implementation

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

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

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

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

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

244 The project followed a fully reproducible approach, based on free software only. LSPIV analysis was
245 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>

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

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

258

CALL FOR CONTRIBUTIONS FOR THE STUDY OF FLASH FLOODS

Estimations of water level and discharge of swollen rivers is fundamental for understanding the formation process of flash floods.

Unfortunately the speed and violence of the stream make flow measurements virtually impossible with conventional methods. We have developed image analysis techniques to estimate water levels and discharges from amateur films.

You can contribute to our research filming streams during flash flood events.

Measurements made from your movies will then be used in the Floodscale ANR project, whose goal is to better understand the formation of particularly devastating flash floods, and improve forecasting.

This document tells you how to participate in the measurement of these extreme events.



Example of a picture sampled from a flash flood movie made in June 2013 in Cauterets, South-West France.



SAFETY FIRST

During floods, access to surrounding streams and bridges presents significant risks. Flow conditions may change rapidly in all circumstances. Never go in the bed of the river or on its banks. Observe the safety rules and access prohibitions issued by the competent authorities.

Observing or recording a flood does not justify taking risks



259

(a)

ⁿ <https://www.ffmpeg.org/>

^o <http://hugin.sourceforge.net/>

^p <https://floodscale.irstea.fr>

How to record ?

- **Film the river over the entire width of the flow.** Make sure that the edges of both sides of the river are clearly visible in the image.
- **Any kind of camera can be used**, there is no resolution threshold, but avoid deforming lenses effect such as wide angle.
- **Filming should be as stable as possible** (steady braced position or use of tripod even better).
- **In optimal conditions 5 seconds of film are enough.**
- **Note the exact date and time of the recording, as well as the precise location** (name of the river, city, street,...)
- **Choose the highest possible point of view** (without taking risks!). A view from a bridge is more favorable than a view from the shore.
- **Include fixed and permanent reference points that can later be surveyed** (e.g. corners of buildings, road signs, windows, bridges, etc...).
- **Film a zone where flow is more regular.** Avoid wave or riffle patterns, and favor flow above some control like a dam).
- **If known, preferably film over a river section that has a stable bottom not subject to erosion.**
- **Avoid reflections, shadows or sparkling patterns on filmed surface.** Heavy rain and snow are not a problem, as long as the lens stays clean. If the movement of the water is visible to the eye on the film, it may be exploitable.

To contribute, please send your videos at:

crues.films@lists.irstea.fr

Along with your movies, please join contact information (name, phone number, and email address). That information will not be shared without your explicit agreement.

Feel free to join any observation as well.

Learn more :

Learn more about the image analysis process:

<http://floodscale.irstea.fr/donnees/videos-amateurs-de-rivieres-en-crue>

ANR FloodScale project (2012-2015): Multi-scale hydro-meteorological observation and modelling for flash floods understanding and simulation
http://floodscale.irstea.fr/front-page-en?set_language=en

Hydro-meteorological observatory of Mediterranean Cévennes-Vivarais
www.ohmcy.fr/

HyMeX Project
www.hvmex.org

260

(b)

Etude des rivières en crue...

Vous pouvez nous* aider !



En filmant quelques secondes de l'événement par tout moyen à votre disposition
 (Smartphones, tablettes, appareils photo, etc...)

sur la rivière ARDECHE et ses affluents

Objectif

La connaissance des débits et des niveaux d'eau atteints par les rivières en crue est fondamentale pour l'étude des crues éclair.

Afin de récolter un maximum d'informations et d'enrichir nos connaissances sur ces événements, nous avons mis au point des techniques d'analyse d'images permettant de calculer des vitesses et des débits à partir de films amateurs.

Vous pouvez ainsi contribuer à nos travaux de recherche en filmant les cours d'eau en crue.

Ces mesures seront ensuite utilisées dans le cadre du projet de recherche ANR FloodScale dont l'objectif est de mieux comprendre la formation des crues éclair, et d'en améliorer la modélisation.

Méthode

- Filmez la rivière sur **toute sa largeur** : les deux berges de part et d'autre de la rivière doivent être visibles.
- Englobez dans l'image des **repères fixes** (coins de bâtiment, panneaux de signalisation, fenêtres, ponts, etc.).
- La prise de vue doit être aussi **stable** que possible : plans fixes, sans zoom ni mouvement de caméra.
- Filmez de préférence une zone **sans remous ni vagues**.
- **Ne vous mettez pas en danger**, restez à l'écart du cours d'eau et des infrastructures fragiles.
- **Tout type** d'enregistreur vidéo est utilisable.
- Filmez au minimum **5 secondes** par séquence.
- Indiquez le **lieu, la date et l'heure** de l'enregistrement.

Envoyez-nous vos films par lien de téléchargement* ou de visualisation (YouTube) à :
crues@irstea.fr
avec vos coordonnées et toute remarque concernant la crue observée

* Sites d'envoi de fichiers volumineux :
www.wetransfer.com www.dl.free.fr www.mega.co.nz

En savoir plus...
 Consulter la vidéo exemple et en savoir plus sur l'analyse d'images
<http://floodscale.irstea.fr/donnees/vidéos-amateurs-de-rivieres-en-crue>



Observatoire Hydro-météorologique Méditerranéen Cévennes-Vivarais
<http://www.ohmcv.fr>

Projet HyMeX
<http://www.hymex.org>

Projet de recherche ANR FloodScale (2012-2015)
<http://www.floodscale.irstea.fr>



⚠ Avertissement sécurité ⚠

Lors des crues, l'accès aux abords des cours d'eau et aux ponts présente des risques importants. Les conditions d'écoulement peuvent varier rapidement en toutes circonstances. Ne vous aventurez jamais dans le lit du cours d'eau ni sur ses berges. Respectez les consignes de sécurité et les interdictions d'accès émises par les autorités compétentes.

Observer ou filmer une crue ne justifie pas de prendre des risques !







* Chercheurs d'établissements publics de recherche

261

(c)

262

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

263

FloodScale Project^q

264

265

^q <https://floodscale.irstea.fr/donnees-en/>

266 2.2.3 Examples of results

267 Partly due to communication restrictions, few videos were received by the scientists, even after the series
268 of significant floods which occurred during the 2014 autumn. And none of those were actually usable because
269 they generally did not follow the recommendations. Some of them were not located in the study area. In turn,
270 some useful videos were harvested by scientists after each flood of interest, especially drone videos
271 (Figure 6) shared on YouTube^r by a local company^s specialising in UAV-borne image recording. The footage
272 was also shown by local and national TV channels. Valuable sequences with remarkable stability and clear
273 views of the Ardèche river channel upstream and downstream of the submersible Sampzon bridge
274 (44°25'46.4"N; 4°21'25.6"E) were selected (Figure 6).

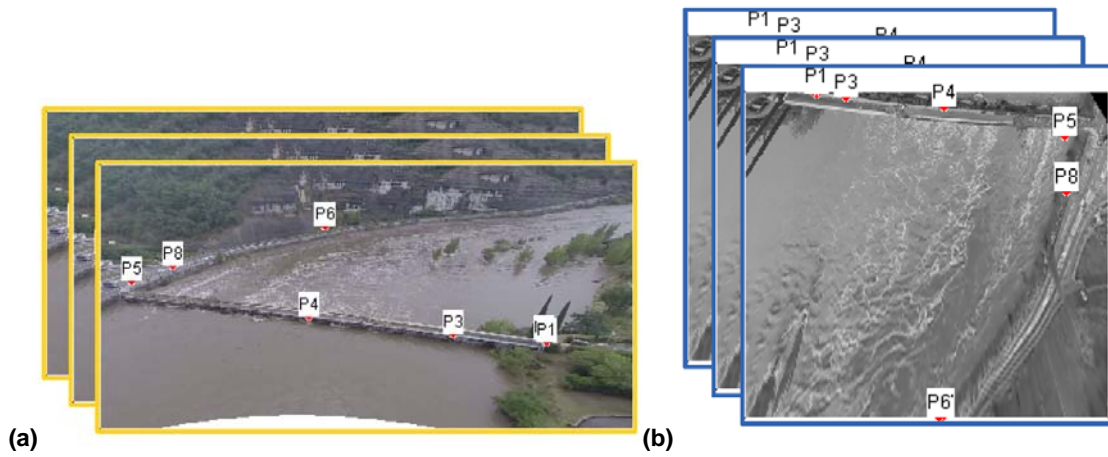
275 Some fixed ground reference points could be identified, especially road signs and marks and elements of
276 the bridge structure. Their positions were topographically surveyed using a differential GPS and cross-
277 sectional bathymetry profiles were also measured using a hydro-acoustic profiler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

285

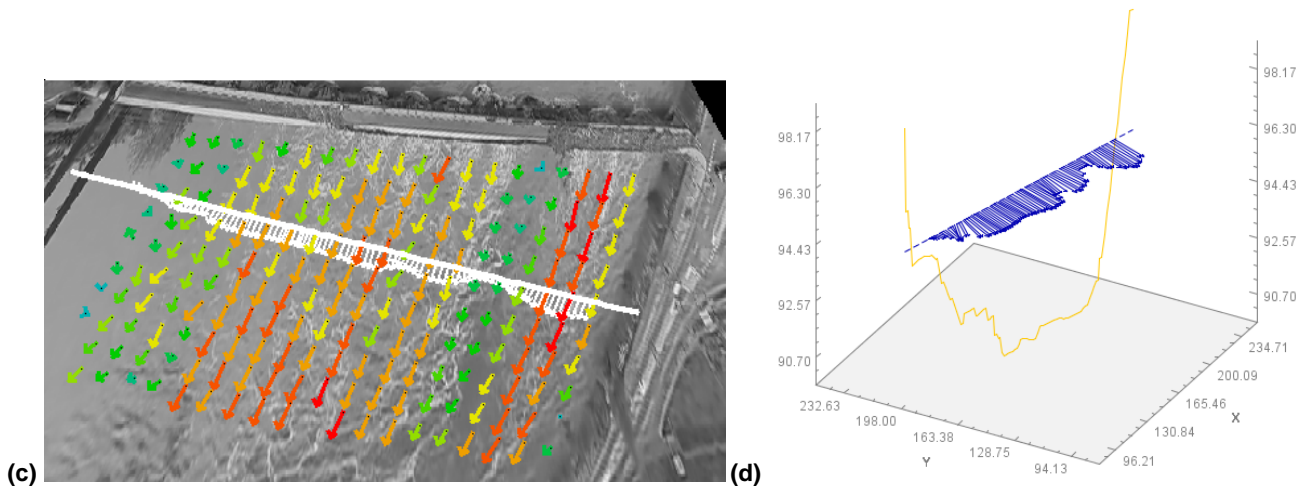
^r <https://www.youtube.com/watch?v=4lgws8pvFyg>

^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

292

293

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

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

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

309 **2.3 RiskScape (New Zealand)**

310 *2.2.1 Objectives*

311 The New Zealand national institute NIWA has called citizens to contribute to flood mapping during recent
312 inundation events in the cities of Christchurch (43°31'S; 172°38'E) in 2014 and Dunedin (45°52'S; 170°30'E) in
313 2015. Residents were invited to send in their pictures of flooded areas, which were further used to build flood
314 hazard maps, as part of the RiskScape^t project.

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

^t www.riskscape.org.nz

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

322 *2.2.2 Implementation*

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

^u <http://sciblogs.co.nz/waiology/2014/03/07/calling-for-christchurch-flood-photos/>



333

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

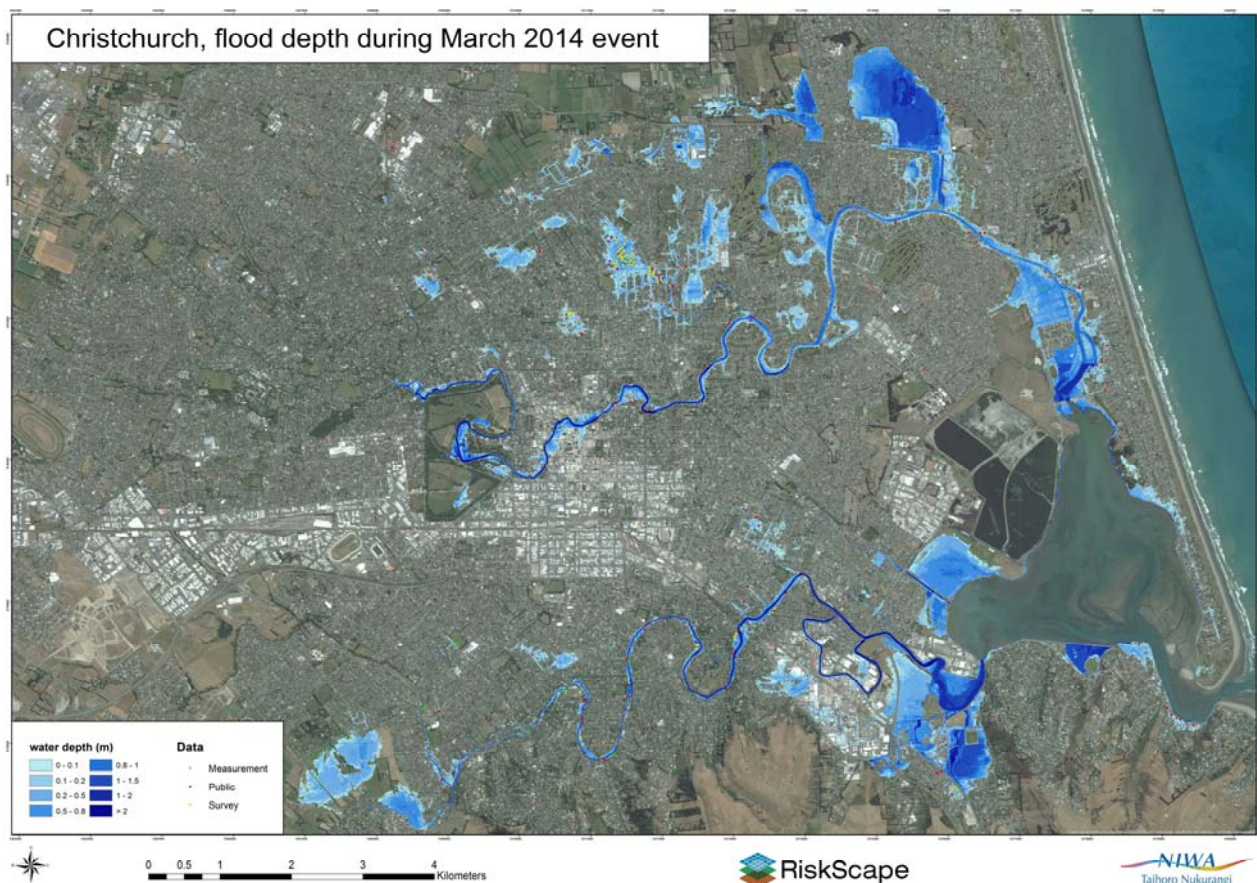


337

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

340 *2.2.3 Examples of results*

341 Over 600 photos were received for the Christchurch study (e.g., Figures 7 and 8). Not all photos were
 342 used or could be used, and for various reasons – the flood level may not have been discernible; the time or
 343 location was unknown; or flood data may have been available from other photos or another source. Ultimately,
 344 300 photos were used to get a fix on 289 water levels around the city. Combined with field surveys, the
 345 resulting inundation map (Figure 9) indicates flooding along the Avon and Heathcote Rivers as well as various
 346 residential suburbs throughout Christchurch, including the severely impacted Flockton Basin. High media and
 347 public interest suggested that, in addition to providing useful data, the public engagement fostered a greater
 348 appreciation of flood hydrology and its scientific study.



349 **Figure 9.** Interpolated flood depths based on citizen scientist photos and field surveys, for the 5th March 2014 flood in
 350 Christchurch, New Zealand.
 351

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

358 **3 Lessons learnt**

359 **3.1 Write a clear and simple procedure**

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

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

^v <http://wikhydro.developpement-durable.gouv.fr/>

380 **3.2 Develop suitable tools for data collection and processing**

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

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

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

399 The use of crowdsourced hydrologic data in models and scientific studies also requires suitable
400 techniques that are able to assimilate data coming with contrasted and possibly large uncertainties. This is
401 typically the case of the Bayesian techniques implemented in the FloodScale project for stage-discharge
402 rating curve development (Le Coz et al. 2014b), hydrologic modelling and flood frequency analysis (Renard et
403 al. 2010). The FloodChasers and RiskScape projects illustrate how such data can be successfully included in
404 1D/2D hydrodynamic models, post-flood surveys and flood risk and damage assessment.

405 **3.3 Implement an efficient communication plan**

406 Communication is key to efficiently mobilise flood observers, make them aware of flood-related dangers
407 (and discourage them from risking their lives), avoid conflicts with local authorities, and provide feedback on
408 the use of collected data. Simple and direct explanations are essential, even when it comes to science or legal

409 terms. Such initiatives are usually well received by the locals and the media. Communication efforts should be
410 directed at both the general public and specific community groups such as kayakers or storm/flood chasers. It
411 is important to communicate with and train groups of more advanced operators (firemen, civil defence,
412 hydrologic services, volunteers, etc.) so they can make better quality videos that fit the requirements of the
413 data processing, in optimal safety conditions.

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

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

427 **3.4 Get the support of local stakeholders**

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

439 **3.5 Public awareness and engagement matter**

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

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

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

458 **4 Conclusions**

459 The reported three projects are typical of emerging citizen science initiatives for crowdsourcing flood
460 hydrology data. These photo-based flood mapping (RiskScape, New Zealand) and video-based flow
461 estimation (Flood Chasers, Argentina, and FloodScale, France) projects were specifically designed to produce
462 georeferenced and time-stamped hydraulic quantities readily usable for flood hydrology studies and hydraulic
463 modelling. Compared to other similar projects, they involved similarly simple procedures for the public, but
464 more advanced data processing and reviewing by the scientists. An exciting perspective would be to combine
465 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>

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

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

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484 **References**

- 485 Al-Saggaf Y., and Simmons P. (2015) Social media in Saudi Arabia: Exploring its use during two natural
486 disasters, *Technological Forecasting & Social Change*, **95**, 3–15
- 487 Braud I., Ayrat P.-A., Bouvier C., Branger F., Delrieu G., Le Coz J., Nord G., Vandervaere J.-P., Anquetin S.,
488 Adamovic M., Andrieu J., Batiot C., Boudevillain B., Brunet P., Carreau J., Confoland A., Didon-Lescot J.-F.,
489 Domergue J.-M., Douvinet J., Dramais G., Freydier R., Gérard S., Huza J., Leblois E., Le Bourgeois O., Le
490 Boursicaud R., Marchand P., Martin P., Nottale L., Patris N., Renard B., Seidel J.-L., Taupin J.-D., Vannier O.,
491 Vincendon B., Wijbrans A. (2014) Multi-scale hydrometeorological observation and modelling for flash flood
492 understanding, *Hydrology and Earth System Sciences*, **18(9)**, 3733-3761

- 493 Drobinski, P., Ducrocq, V., Alpert, P., Anagnostou, E., Béranger, K., Borga, M., Braud, I., Chanzy, A.,
494 Davolio, S., Delrieu, G., Estournel, C., Filali Boubrahmi, N., Font, J., Grubisic, V., Gualdi, S., Homar, V.,
495 Ivancan-Picek, B., Kottmeier, C., Kotroni, V., Lagouvardos, K., Lionello, P., Llasat, M.C., Ludwig, W., Lutoff,
496 C., Mariotti, A., Richard, E., Romero, R., Rotunno, R., Roussot, O., Ruin, I., Somot, S., Taupier-Letage, I.,
497 Tintore, J., Uijlenhoet, R., Wernli, H., 2014. HyMeX, a 10-year multidisciplinary program on the Mediterranean
498 water cycle, *Bulletin of the American Meteorological Society*, **95(7)**, 1063-1082
- 499 Fohringer J., Dransch D., Kreibich H., and Schröter K. (2015) Social media as an information source for rapid
500 flood inundation mapping, *Natural Hazards and Earth System Sciences*, **15**, 2725–2738
- 501 Fujita I., Muste M., Kruger A. (1998) Large-scale particle image velocimetry for flow analysis in hydraulic
502 engineering applications. *Journal of Hydraulic Research*, **36(3)**, 397–414
- 503 Fujita I., Kunita, Y., and Tsubaki R. (2013) Image analysis and reconstruction of the 2008 Toga River Flash
504 Flood in an urbanised area, *Australian Journal of Water Resources*, **16(2)**, 12
- 505 Gaitan S., ten Veldhuis M.-C., van de Giesen N. (2015) Spatial distribution of flood incidents along urban
506 overland flow-paths, *Water Resources Management*, **29**, 3387–3399
- 507 Hirata E., Giannotti M.A., Larocca A.P.C., and Quintanilha J.A. (2016, in press) Flooding and inundation
508 collaborative mapping – use of the Crowdmap/Ushahidi platform in the city of Sao Paulo, Brazil, *Journal of*
509 *Flood Risk Management* (in press)
- 510 Koswatte S., McDougall K., and Liu X. (2015) SDI and crowdsourced spatial information management
511 automation for disaster management, *Survey Review*, **47 (344)**, 307-315
- 512 Le Boursicaud R., Le Coz J., and Dramais G. (2015) Guide méthodologique - Collecte et préparation de film
513 amateur en vue d'une exploitation par analyse d'image [Methodological Guide - Collection and pre-processing
514 of home movies for operations by image analysis, in French], Technical report, Irstea, 23 p.
- 515 Le Boursicaud R., Pénard L., Hauet A., Thollet T., and Le Coz J. (2016) Gauging extreme floods on YouTube:
516 Application of LSPIV to home movies for the post-event determination of stream discharges, *Hydrological*
517 *Processes*, **30**, 90-105

- 518 Le Coz J., Hauet A., Pierrefeu G., Dramais G. and Camenen B. (2010) Performance of image-based
519 velocimetry (LSPIV) applied to flash-flood discharge measurements in Mediterranean rivers, Journal of
520 Hydrology, **394 (1-2)**, 42-52
- 521 Le Coz J., Jodeau, M., Hauet, A., Marchand, B. and Le Boursicaud, R. (2014a) Image-based velocity and
522 discharge measurements in field and laboratory river engineering studies using the free Fudaa-LSPIV
523 software. In RIVER FLOW 2014 conference, 1961–1967, Lausanne, Switzerland
- 524 Le Coz J., Renard B., Bonnifait L., Branger F. and Le Boursicaud, R. (2014b) Combining hydraulic knowledge
525 and uncertain gaugings in the estimation of hydrometric rating curves: a Bayesian approach, Journal of
526 Hydrology, **509**, 573–587
- 527 Lowry C. S. and Fienen, M. N. (2013). CrowdHydrology: Crowdsourcing Hydrologic Data and Engaging
528 Citizen Scientists. Ground Water, **51**, 151–156
- 529 Patalano A., García C.M, Guillén N., García C., Díaz E., Rodriguez A. and Ravelo A. (2014) Evaluación
530 experimental de la técnica de velocimetría por seguimiento de partículas a gran escala para la determinación
531 de caudales en ríos serranos [Experimental evaluation of large scale particle tracking velocimetry technique
532 for flow discharge measurements in mountains rivers, in Spanish], Aqua-LAC, **6(1)**, 17-24
- 533 Patalano A., Moreno L., García C.M. and Guillén N. F. (2015) Desarrollo e implementación del proyecto
534 “Cazadores de crecidas” en ríos de la provincia de Córdoba [Development and implementation of the
535 Cazadores de crecidas project in rivers of the Córdoba province, in Spanish], IV Simposio sobre métodos
536 experimentales en hidráulica, La Plata, Argentina, 2 p.
- 537 Patalano A., and García C.M. (2016) RIVeR - Towards affordable, practical and user-friendly toolbox for Large
538 Scale PIV and PTV techniques. IAHR RiverFlow Conference, St. Louis, USA.
- 539 Renard B., Kavetski D., Thyer M., Kuczera G. and Franks S.W. (2010) Understanding predictive uncertainty in
540 hydrologic modeling: The challenge of identifying input and structural errors, Water Resources Research, **46**.
- 541 Ruin I., Creutin J.D., Anquetin S. and Lutoff, C. (2008) Human exposure to flash-floods-relation between flood
542 parameters and human vulnerability during a storm of September 2002 in Southern France, Journal of
543 Hydrology, **361**, 199-213.

544 Schnebele E., Cervone G., and Waters N. (2014) Road assessment after flood events using non-authoritative
545 data, *Natural Hazards and Earth System Sciences*, **14**, 1007–1015.

546 Thielicke W., and Stamhuis E.J. (2014) PIVlab – Towards Userfriendly, Affordable and Accurate Digital
547 Particle Image Velocimetry in MATLAB, *Journal of Open Research Software*, **2**.

548 Welber M., Le Coz J., Laronne, J.B., Zolezzi G., Zamler D., Dramais G., Hauet A. and Salvaro M. (2016) Field
549 assessment of non-contact stream gauging using portable surface velocity radars (SVR), *Water Resources*
550 *Research*, **52 (2)**, 1108-1126.