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Check for updates

A social bot in support of crisis communication: 10-years of @LastQuake experience on Twitter

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Social media such as Facebook or Twitter are at present considered part of the communication systems of many seismological institutes, including the European–Mediterranean Seismological Center (EMSC). Since 2012, the EMSC has been operating a hybrid Twitter system named @LastQuake comprising a bot for rapid information on global felt earthquakes and their effects, which is complemented by manual moderation that provides quasi-systematic and rapid answers to users' questions, especially after damaging earthquakes and earthquake sequences. The 2022 release of @LastQuake transcends a mere alert service and possessess additional capabilities, including fighting against misinformation and enhancing earthquake risk awareness and preparedness by exploiting the teachable moments opened by widely felt but non-damaging earthquakes. @LastQuake significantly increases the visibility and audience of the European–Mediterranean Seismological Center services, even in regions where its smartphone application (app) and websites are well known. It also contributes to increasing the volume of crowdsourced eyewitness observations that are collected, notably through the publication of rapid non-seismic-wave-based detections, as well as by reaching out to Twitter users who post about felt experiences through individual invitation messages. Although its impact, especially in raising awareness and preparedness is difficult to evaluate, @LastQuake efficiently supports crisis communication after large earthquakes and receives positive feedback from users for satisfying identified information needs of eyewitnesses automatically and in a timely manner. This study shares the experience gained over the last 10 years of operating the bot, presents the impact of users' feedback on empirically driving its evolution, and discusses the ways by which we can move toward a more data-driven assessment of its impact.

KEYWORDS

Twitter bot, social media in emergency situations, risk reduction, crisis communication, people-centered communication, citizen science, earthquake, risk awareness

Introduction

The use of social media in crisis management has been studied extensively over the past decade, with three main topics, namely, the effects of emergencies on social media (how populations use them following a disaster), the ways to exploit information shared on social media for improved situational awareness (e.g., event detection and crisis mapping), and, finally, social media usage in crisis and disaster communication (for a recent review, see Saroj and Pal, 2020). The role of social media in disaster communication is at present well established, as illustrated by the number of organizations publishing their own usage recommendations, from the Organization for Economic Co-operation and Development (OECD) and the International Air Transport Association (IATA) to the Red Cross (Eriksson, 2018). Despite the existence of such recommendations and although they could help to handle some of the many tasks in crisis communication, social media bots, i.e., the software programs that automatically publish messages and/or interact with users, have received little attention to date in the literature. In this study, we focused solely on bots that support crisis communication and excluded from this discussion social media bots that aim to influence online discussions by promoting the visibility of some content (e.g., by sharing or liking them) (see Khaund et al., 2018). Hofeditz et al. (2019), the main research on this topic, concluded in their study that no overview was available for the tasks that social media bots could perform to support crisis communication and that there were very few such bots despite their significant potential and that the ones identified were basic and often limited to simple alert systems.

In the field of seismology as well, social media has revolutionized the dissemination of rapid public earthquake information over the last decade in various ways. Many institutes have advantageously complemented their traditional websites with Facebook and/or Twitter accounts to better serve and extend their audiences. This strategy is beneficial due to the large base of active users on such platforms, often including journalists and other potential information intermediaries, while being free to use. Importantly for seismology, they can easily cope with the large traffic surges observed after widely felt earthquakes which often render the institute websites inaccessible at the very moment when they are the most needed by the public (Schwarz, 2004; Bossu et al., 2008, 2012, 2019; Quigley and Forte, 2017). In addition, being present on popular social media can expedite the circulation of information and in turn raise the efficiency of risk communication after a strong earthquake. This occurs in part due to the familiarity principle, whereby people tend to turn first to tools that they are already familiar with during emergencies (Steelman et al., 2015), and also because of user-defined notifications that push information to users.

The microblogging site Twitter has become the *de facto* source of recent news as a result of its concise, real-time, and unrestricted (i.e., accessible to anyone) lines of communication. This makes it well suited for public information during emergencies, particularly for rapid onset, unpredictable events such as earthquakes. Several usages of Twitter may be distinguished regarding seismology specifically. One use concerns the public discussion and dissemination of research results, especially after a significant earthquake, a process that publicly illustrates how scientific collaborations work and how new knowledge is built and, therefore contributes to the dialogue between science and society (Britton et al., 2019; Lacassin et al., 2020). Other initiatives focus on education, for example, @IRIS_EPO regularly publishes existing education materials on Earth sciences and seismology concepts (e.g., magnitude vs. intensity) while some individual scientists, such as @JudithGeology, devote time to preparing detailed and easy-to-understand threads on questions such as “Why earthquakes cannot be predicted?” or “The reason why rocks often naturally break at 90-degree angles” (Hubbard, 2022). National monitoring agencies, on the other hand, often operate bots for the rapid publication of information on recent earthquakes in their region (e.g., source parameters); some of these bots have a large number of followers, such as, @INGVterremoti (from the National Institute of Geophysics and Volcanology in Italy), with 280,000 followers, or @BMKG (from the National Institute for Meteorology and Geophysics of Indonesia), with 6.4 million followers. These bots generally only broadcast information by publishing automatic tweets, have no (or very limited) interactions with their followers, do not follow any (or only a few) other accounts, and are, as identified by Hofeditz et al. (2019), mere alert systems. When an institute engages in direct dialogue (questions/answers) on Twitter (exchanges which are the raison d’être of social media), it generally takes place on a separate and dedicated account. This is the scheme used by the United States Geological Survey (USGS) where @USGSted publishes recent earthquake locations, while @USGS_Quake is a manually operated account focused on science communication and public interactions.

The European–Mediterranean Seismological Center (EMSC) also operates two accounts, a classic bot—or alert system—@EMSC that reports all EMSC seismically located earthquakes worldwide (50,000–70,000/year) and @LastQuake, a hybrid system combining a bot and manual publications but focused on earthquakes known to have been felt and their effects. There are 3,800–4,200 felt earthquakes per year; defined in this article are events that have been detected *via* crowdsourcing (see later) or for which at least three consistent felt reports have been collected through the app or websites. In addition, @LastQuake covers institutional matters, answers Twitter users’ questions, and has manual moderation of exchanges. There is a quasi-systematic rapid response to users’ questions, and the incoming queries are generally numerous after damaging earthquakes or during a sequence of earthquakes when significant efforts are often devoted to answering rapidly.

The purpose of this study is not to describe all of the features and technical details of @LastQuake but to present its main characteristics as well as to share the experience gained and lessons learned over the last 10 years of this global experiment in event-driven and people-centered dynamic risk communication by a Twitter bot. More precisely, we intend to illustrate how, at little cost, a Twitter bot can complement existing communication tools, enlarge the audience, engage with global earthquakes’ eyewitnesses, and contribute to improved crowdsourcing. We will also describe how the second release of the bot intends to contribute to the fight against earthquake misinformation (such as prediction claims), as well as improve seismic risk awareness and preparedness. Finally, we will discuss the tools put in place to move toward more data-driven performance evaluation systems.

In order to do so, we first outline the empirical methods and principles that led to the development and evolution of the bot. We then present the objectives and features of the first version of the bot, and how lessons learned from damaging earthquakes and user feedback drove its evolution, guided the establishment of a moderation policy, and led to the design of its 2022 version. Finally, we discuss the perceived benefits, limitations, and challenges of such a tool and argue that a Twitter bot can advantageously complement existing information systems and enhance people-centered dynamic risk communication.

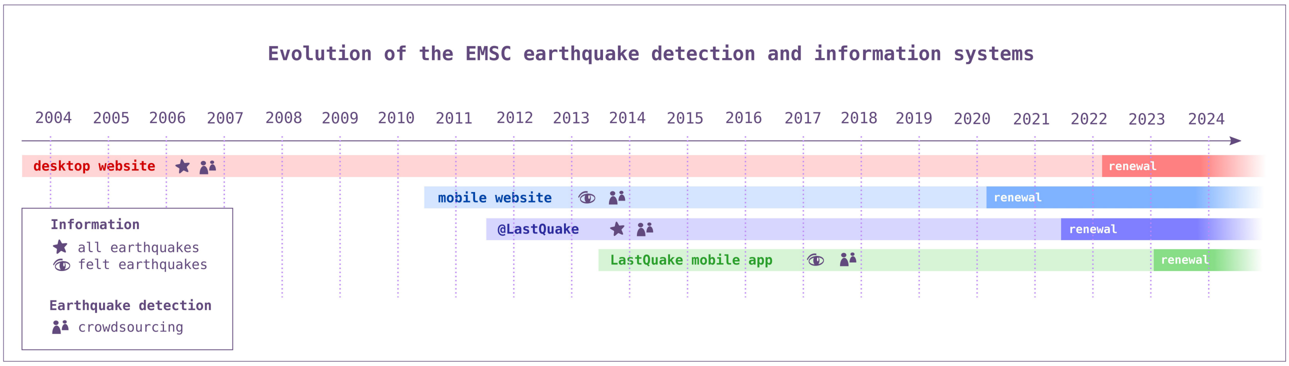

FIGURE 1
Evolution of the different components of the LastQuake information and crowdsourcing system, along with their principal individual features. The website for desktops provides data for all earthquakes (felt and not felt) while the other components target eyewitnesses and are focused on felt and damaging earthquakes. For the sake of completeness, there is also a Telegram account that publishes the same messages as the @LastQuake Twitter bot but more details are not deemed necessary because of its limited audience and the absence of interactions with users.

Method and principles guiding @LastQuake bot evolutions

The goal of the @LastQuake bot is to make information on felt earthquakes readily available and circulate their effects to the public in a timely and easy-to-understand manner while remaining as consistent as possible with the LastQuake smartphone app. Feedback from users has been the main driver of the bot's evolution. Feedback has been collected through direct exchanges on Twitter but also *via* feedback from app users [collected through online questionnaires (Bossu et al., 2015) and on publicly available reviews on app stores] or emails. For example, the systematic questions about earthquake prediction after damaging earthquakes led us to integrate advice to combat misinformation into the 2022 bot's features. Furthermore, the confusion generated by many felt events swiftly occurring in the same area in a short period of time during aftershock sequences led to the numbering in the tweets of events constituting the sequence. The publication of felt report maps on both the app and the bot even when no earthquake has been seismically located resulted from exchanges about the app during the Mayotte earthquake sequence in 2018 (Fallou et al., 2020). A moderation policy was also gradually developed following the same experimental and empirical approach. Ultimately, we consider that we have fulfilled the public's information needs when the number of questions decreases even while increasing followership and level of interactions (likes, views, retweets, etc.). In other words, this method aimed to develop a bot to support crisis communication by automatically answering as many of the recurrent information needs as possible that appear after felt and damaging earthquakes and thus limit direct (human) answers to only the trickiest and/or unusual questions.

A Twitter bot for engaging with global earthquake eyewitnesses

The @LastQuake bot, launched in 2012, was part of the development of the people-centered LastQuake communication system initiated a year earlier by a new website for mobile devices and completed in 2014 by its eponymous smartphone app (Figure 1). LastQuake is an information and crowdsourcing system focusing on felt earthquakes and their effects, an approach that implicitly assumes that this is the most important information for the general public (Bossu et al., 2011, 2018). The Twitter quake bot, the website for mobile devices, and the app publish the same information (detections, earthquake parameters, felt report maps, and comments) but in different formats (e.g., a rolling banner on the website and a white text box on the app). Felt experiences are crowdsourced through the websites and the app (Figure 1). Beyond increasing the EMSC's reach to new users, the bot's purpose is to pull earthquake eyewitnesses from Twitter to our websites to crowdsource their felt experiences. Twitter users are known to be present within tens of seconds of tremor in regions where Twitter is popular (Earle et al., 2011).

To do so, fast preliminary information is published so as to engage with eyewitnesses (Figure 2) (Bossu et al., 2011, 2019) which comes from "crowdsourced detections" whereby a felt earthquake is detected through the digital footprints generated by eyewitnesses seeking information (e.g., traffic increase on the EMSC websites or concomitant launches of LastQuake, the EMSC's smartphone app) (Bossu et al., 2008, 2012, 2019). Since these detections are fast (12 to 120 s after an earthquake occurrence), they initiate early and efficient crowdsourcing (Bossu et al., 2018). The tweet (the name of a message published on Twitter) reporting a crowdsourced detection is geo-located at the detection location and includes a hashtag (a tag that eases the cross-referencing of content by topic) of the keyword "earthquake" in both English and the local language to improve its findability by eyewitnesses of this specific event.

A widely felt earthquake in Jakarta in Indonesia, a country known for its extensive Twitter use (Carley et al., 2015), illustrates the significance of this early and preliminary information (Figure 2). The resulting impact is illustrated by the user interaction metrics measured for each tweet, especially the number of retweets (7,000), which is the reposting of the initial message to the user's followers and so is an indication of the viral propagation of the information, and also the number of "likes" (20,000) given to

FIGURE 2
An example of an automatic tweet reporting a crowdsourced detection, in this case based on the online reactions of eyewitnesses following a M6.6 earthquake in Sunda Strait in January 2022 that was widely felt in Jakarta. It includes a hashtag with the keyword earthquake in the local language ("gempa" in Indonesian), as well as the name of the region, the country, and a link to the EMSC website to encourage sharing of felt experiences. It was published 97 s after the earthquake while the first seismic location was available 440 s later. Two-thirds of the 438 felt reports collected were crowdsourced through the websites.

the tweet which indicates users' appreciation (Figure 2). As the author of the tweet, the EMSC has access to additional impact measurements such as the number of views and the number of times users visited its profile, which were 2 million and 12,000 for this tweet, respectively (significant numbers compared to an estimated 15,000 Indonesian followers of @LastQuake Twitter handle).

The link to EMSC's website (Figure 2) pushes eyewitnesses toward the website and nudges them to share their felt experiences. In this case, the link did increase eyewitnesses' visits immediately after the earthquake with 77% of the 4,873 Indonesian website visitors within 30 min of the earthquake arriving *via* this link. There is no known method to evaluate the actual numbers of felt reports collected from these referred visitors; however, the vast majority (66%) were collected through websites (rather than the app) and half of them were collected before the first seismic location was available (537 s after the earthquake occurrence). Beyond this specific case, the publication of this early detection has likely contributed, among other factors, to the large increase in the number of felt reports collected yearly by the EMSC from 2012 to 2021 (14,000–576,000) as well as the rapidity of their collection. Indeed, the proportion of reports collected before seismic information was available or an app notification was issued increased from 8 to 37% during the same period.

The Twitter bot publication did not stop with this first tweet (Figure 2). For each crowd sourced detection, a thread of tweets was published within a 90 min window. Typically, they included the seismic location, macroseismic maps (representing collected felt reports), and when necessary, some updates (e.g., due to revision of earthquake parameters, or large collections of felt reports). More tweets were published in the same time window in cases of tsunamigenic or destructive earthquakes. For example, 42 automatic tweets were published within 90 min of the 2015 destructive Nepal earthquake, which are available as an electronic supplement in Bossu et al. (2015).

Lessons learned from past earthquakes

Widely felt and destructive earthquakes can expose flaws or limitations in the @LastQuake automatic information system and provide hints for possible improvements. We list in this section, the main lessons learned since 2012. After the Nepal 2015 destructive earthquake, LastQuake app users requested the integration of behavioral recommendations to guide them after shaking. These were introduced both in the app and in the Twitter bot through a set of cartoons (*dos and don'ts*) that are systematically published after destructive earthquakes (Bossu et al., 2015; Fallou et al., 2019) and were complemented by similar tsunami safety tips after the 2018 Palu (Indonesia) earthquake and tsunami (Carvajal et al., 2019).

In 2018, in Mayotte, an island located between Mozambique and Madagascar, a widely felt M5.9 earthquake was followed in the next 6 months by more than 100 widely felt aftershocks with 12,000 accumulated felt reports, the vast majority being non-seismically located due to the then poor local and regional seismic coverage (Fallou et al., 2020). The possibility that some widely felt earthquakes would not be seismically located had not been anticipated. A crowdsourced detection not confirmed by seismic data within 15 min was assumed to be a false detection. As a consequence, even when numerous felt reports had been associated with it, in the absence of seismic location, the crowdsourced detection (Figure 1) was simply deleted from the app and website after 15 min, which fed rumors and conspiracy theories (Fallou et al., 2020). Following this experience, preliminary macroseismic maps are published on Twitter (and made available on the app) as soon as the crowdsourced detection was confirmed by consistent felt reports regardless of the availability of seismic data. This not only avoids possible misunderstandings by the users but also speeds up publicly available impact-related information. To avoid possible misunderstandings, a video presenting the functioning methods of crowdsourced detections and of the LastQuake system is online as an @LastQuake pinned tweet (a Twitter post that remains at the top of the profile).

In 2018, Lombok, a tourist region of Indonesia, was shaken by a sequence of three earthquakes (one M6.4 event and two M6.9 events) between 28 July and 19 August (Supendi et al., 2020). This

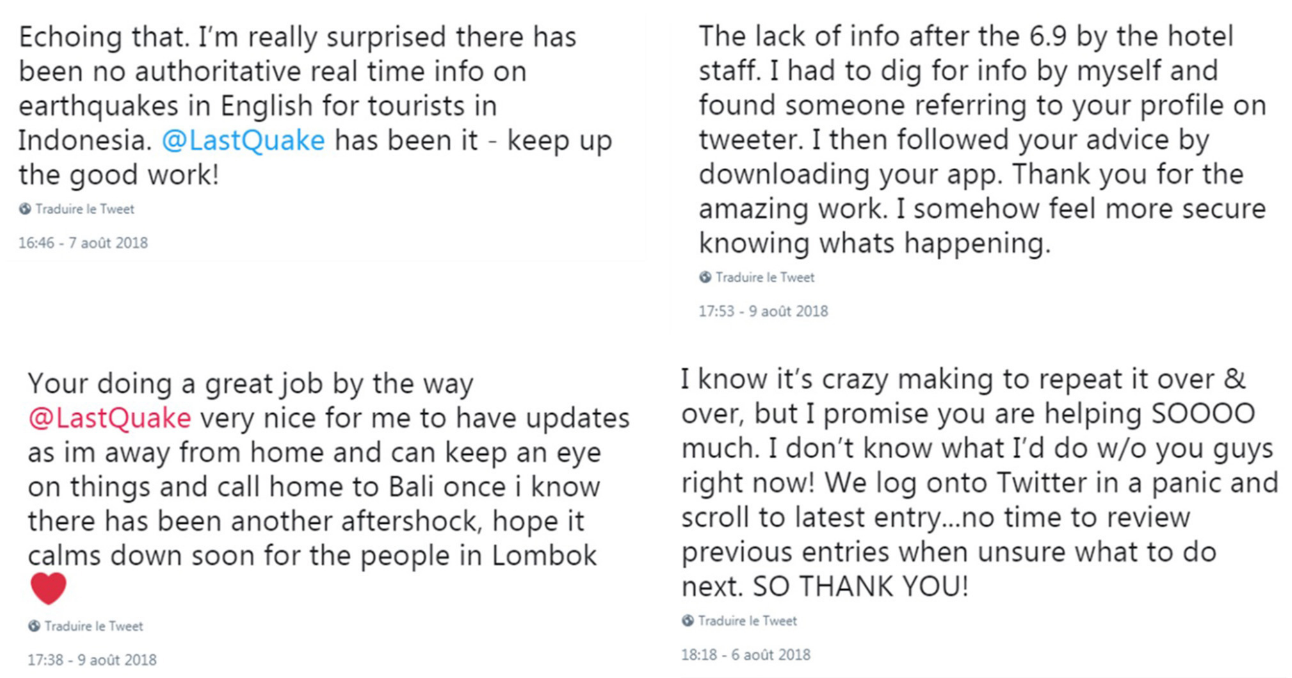

FIGURE 3
A set of example tweets received during the Lombok (Indonesia) earthquake sequence illustrating the difficulty for tourists to find information in English, the usefulness of the @LastQuake information also for people from Indonesia's diaspora and how timely people-centered information can reduce anxiety.

inevitably generated many questions on the possible evolution of the seismicity and whether it was safe to stay for holidays. Users were grateful that we took the time to answer with empathy, even if our answers on the possibility of future larger shocks fell short of their initial expectations (Figure 3). The questions came from foreigners, not from Indonesians who were probably receiving satisfactory information from national authorities in their native language. Hence, this case illustrated the need for seismological institutes to offer information services not only to their nationals but also to foreigners (e.g., tourists) present in the area and also to their diaspora (Figure 3).

There were extensive exchanges with Twitter users over significant periods of time in relation to two of the recent destructive earthquakes in Europe: the M6.4 2019 Albanian (Bossu et al., 2020) and M6.4 2020 Petrinja (Croatia) earthquakes (Markuši et al., 2021). When they occurred, the EMSC's local audiences and visibility were already significant as they were both preceded by significant earthquake activity in the previous months: an M5.6 foreshock 2 months before the Albanian event and the M5.5 Zagreb earthquake 9 months before the Petrinja event and 50 km away (Markušić et al., 2020; Contreras et al., 2021). At its peak, the penetration rate of the LastQuake app reached 7% of the Croatian population. There were lessons similar to the ones learned from the Lombok earthquake. Users sought the reduction of anxiety conferred by answers and rapid information (see Figure 10 in Bossu et al., 2020 for tweets), a well-identified phenomenon in psychology (Saathoff and Everly, 2002), and confirmed by independent studies of the Zagreb earthquake (Mustać et al., 2021). In addition, both cases had individuals claiming to predict future events that required rebuttals with dedicated tweets (Fallou et al., 2022a) (Figure 3). The most important lessons were linked to the high visibility and large adoption of EMSC's information tools by the local population. Since crowdsourced detections reflect eyewitnesses' online reactions, a large local user base means an enhanced detection sensitivity as the number of "human sensors" increases, i.e., as more earthquakes are detected, many of low magnitude, and for larger magnitude earthquakes, the online reactions become much larger. For example, out of the 38 earthquakes detected to date, for which at least 4,800 felt reports have been collected, 35 were in Croatia and one was an M1.4 Petrinja aftershock. Outside Croatia, the smallest magnitude earthquake in this list was an M4.8 in Bosnia and Herzegovina.

Improved detectability impaired the clarity of the information of the Twitter quake bot by causing multiple threads about small magnitude aftershocks, with very similar tweets from one thread to the next (as aftershocks are close in time and space). These threads could even be intertwined when the aftershocks were close enough in time. This lack of hierarchy, with a timeline dominated by tweets about small-magnitude events, made the information about larger events (the more important ones) difficult to find.

Large online reactions overloaded EMSC servers, slowing services and interrupting them on a number of occasions, especially during the first weeks of the aftershock sequences. In both Croatian and Albanian cases, the ability to maintain the information flow on Twitter and explain to some of our users with full transparency and openness the reasons for these difficulties proved essential. Explanations were, with a few exceptions, well accepted despite the inconvenience for users. When it was explained that the EMSC is a not-for-profit NGO, Twitter users exhibited a strong willingness to help with actual financial donations, an invitation to a hackathon organized in Albania in February 2020, or propositions from experts to improve our services (the ergonomics of the next version of LastQuake app is being defined with the pro bono help of a Croatian professional). Casual and open exchanges about these service interruptions, including local media interviews (web, radio, and TV), gradually personalized the EMSC team on Twitter and especially our main IT staff member ("Fred"), who began to receive tweets of encouragement at each service interruption, which themselves were reported by local media on several occasions (e.g., https://www.rtl.hr/vijesti/hrvatska/saznali-smo-tko-je-misteriozni-fred-i-tko-stoji-iza-popularne-aplikacije-koju-su-hrvati-srusli-5639294c-b9f3-11ec-8db4-0242ac120035, last accessed 8 July 2022. In Croatian language).

@LastQuake allows users to ask questions and some general questions appear repeatedly, such as the cause of magnitude discrepancies between agencies. Others, based on their personal experiences, challenged the very possibility for a given aftershock to have been felt, or questioned the magnitude estimate, a misunderstanding due to the frequent confusion between intensity and magnitude. This highlighted the need for educational messages on seismology and the way the LastQuake system operates.

In addition, the LastQuake system has also detected some non-seismic events. This was the case in 2017 when the online reaction of the public proved to be related to an earthquake prediction that did not materialize in Punjab India (Martin et al., 2021). In other cases, the cause can be identified by Twitter users themselves, such as in the cases of sonic booms and of a meteor's atmospheric entrance on 20 February 2020 over the region of Zagreb (Croatia).

Finally, in practice, @LastQuake is the place to communicate with the public about the different components of the LastQuake system (Figure 1). A seismic activity grid pattern was observed on an interactive seismicity map of La Palma (Canary Island) during the 2021 eruption of the Cumbre Vieja volcano, occurring due to the rounding up of earthquake location coordinates; in a related article, Fallou et al. (2022b) present how the grid pattern was exploited in support of conspiracy theories and how EMSC attempted to debunk them on Twitter. There are also far more positive usages; Twitter has been used to identify volunteers for translating the LastQuake app, which is now available in 42 languages due to their contributions.

Moderation policy for @LastQuake

The @LastQuake moderation policy was developed from experiences faced over time. It is applied to any tweet containing our Twitter handle. This can be an interaction with one of our own tweets, a direct question, or an attempt to benefit from our large followership (e.g., for advertising purposes). The policy aims to maximize the reliability and credibility of our timeline and avoid the exposure of inappropriate messages or content *via* @LastQuake. Inflammatory, insulting, and offensive language is banned, as well as spam, advertisements, proselytism, and any type of discrimination or political statements. More specifically to @LastQuake, we refuse the association of our timeline with any non-scientifically based claims, notably earthquake predictions. This moderation has been implemented by asking for the deletion of the tweet by its author and/or by blocking the account.

This strict moderation policy has been made necessary by experience and is explained to @LastQuake users when it is enforced. Earthquakes occurring close to a disputed territory often generate nasty inflammatory comments which need to be rapidly deleted to avoid attracting more inappropriate exchanges and trolls. On one occasion, several dozens of tweets reporting the same prediction claim were received in a few tens of minutes, and when these accounts were blocked (following their refusal to delete them), a second wave of tweets still associated with the @LastQuake timeline and still about the same prediction claim complained about our supposed lack of willingness for scientific debate and suppression of free speech. Since then, this possibly concerted effort has not been observed again. There are currently several hundreds of blocked accounts.

Main features of the 2022 @LastQuake bot

The new version of the @LastQuake bot was released in February 2022. Besides technical changes (e.g., maximum tweet length changing from 140 to 280 characters) and visual improvements, the February 2022 release's aims were: (1) adapting the rate, duration, and content of publications to the estimated societal importance of each earthquake, (2) ensuring the diversity of threads through the utilization of alternative tweets expressing the same information, (3) exploiting teachable moments produced by felt earthquakes for enhanced public preparedness and awareness, (4) fighting misinformation, (5) extending the audience of the bot beyond eyewitnesses, and (6) nudging users tweeting about earthquakes to share their felt experience with us. In addition, we developed a performance analysis tool to quantitatively monitor public interactions with the different tweets, which will be useful for steering future improvements and evolutions of the bot.

The implementation of these objectives required the definition of six categories of earthquakes and their association with five classes of information and time windows for their publication (Figure 4). The category of "Destructive earthquakes", i.e., causing significant damage and/or fatalities as identified by our internal impact assessment tool (Julien-Laferrière, 2019; Guérin-Marthe et al., 2021), is the category with the longest publication time window. The last tweet is published 12 h after the earthquake occurrence and is intended to fight misinformation, especially earthquake predictions. It may contribute to "pre-bunking" if misinformation has not yet been propagated or in debunking it otherwise (Fallou et al., 2022a,b, which is a sister paper in this same issue that contains more details on EMSC's practices to fight misinformation). The threads contain information about the event, its effects, safety tips, and a wrap-up summarizing the available information (which is aimed at people not directly affected and journalists) (Figure 4). Earthquakes of M7.5 or greater, because they are rare, are a category on their own even if not felt.

The final four categories are for non-destructive earthquakes (i.e., not identified as such) defined using two criteria, the magnitude (above and below M4.5) and whether or not they have

FIGURE 4
Schematic view of the possible types of information automatically published by the @LastQuake bot as a function of the classes of earthquakes and time. Large earthquakes are arbitrarily defined as having magnitudes above 4.5. The existence of an audience is defined by the number of collected felt reports (the threshold being set at 50). A specific category of earthquake has been made for unfelt $M > 7.5$ events which due to their magnitude may still attract public interest. While key information on earthquakes (e.g., parameters) and their effects are systematically published, additional publication parameters are used to avoid repetition of the same tweet within a short period of time. Educational tweets or misinformation debunking ones contain some external resources; some concepts have multiple variations of tweets. Consecutive educational or misinformation fighting tweets are always different. Altogether, the bot can generate 56 different tweets.

attracted public attention (as measured by the number of collected felt reports) (Figure 4).

The M2.9 earthquake of 25 October 2021 below the city of Athens for which 1,500 felt reports were collected is an example of a "small magnitude earthquake with audience" (Figure 4). Such events create a teachable moment where eyewitnesses and people concerned by this earthquake are actively looking for information and are more receptive to learning about earthquake risk. Such events are therefore an opportunity to share some educational or awareness materials and potentially reach people efficiently (Stallings, 1986; Bravo and Hubenthal, 2016). Once formal education in science has ended, this may be one of the few opportunities available to widely teach seismologically related information (Baram-Tsabari and Segev, 2015). We also invite Twitter users to join our LastQuakers forum to have more targeted and in-depth interactions. In contrast, a small magnitude earthquake or aftershock only felt by a few people does not set up such a teachable moment, and in such cases, tweets are limited to earthquake parameters and a macroseismic map within a time window limited to 20 min (Figure 4).

The magnitude threshold has been set to M4.5 because, above it, the existence of undetected damage immediately after the event is possible in the absence of *in situ* observations (Bossu et al., 2016). The M5.9 Afghanistan earthquake of 21 June 2022, which killed more than 1,200 people, falls in such a category. In such a case, the Twitter thread avoids the casual tone that can be used for smaller magnitude events but would be highly inappropriate here (Figure 5). For comparison, the thread automatically generated for a small-magnitude earthquake in South Carolina is presented in Figure 6. All earthquake threads end with a final message referencing the EMSC websites and app, where further updates can be found.

We have also replicated a system first set-up for the PetaJarkata project (@petabencana) in Indonesia (Ogie and Forehead, 2017) to optimize the crowdsourcing of eyewitness observations immediately after a disaster. Using the Twitter API (application programming interface), tweets containing the keyword "earthquake" in the local language and published after the occurrence of a felt event are automatically detected. An automatic reply is then published, inviting its author to share her/his observations using the LastQuake app or website to help document the earthquake's effects. To avoid spamming, especially during aftershock sequences, the same user cannot receive more than one invitation every 6 months.

Finally, after destructive earthquakes or a sequence of earthquakes, contact with the national seismological institutes is established to avoid possible unwanted hindrances to their own communication. Such contacts were established in Albania, Croatia, and very recently in Cyprus; in these three cases, the national and EMSC's activities on social media proved to be synergetic.

A performance evaluation tool

Along with the new LastQuake bot, a tool has been developed to monitor the key parameters associated with each published tweet that are available through the Twitter API (e.g., number of views, retweets, and likes) as well as utilize external services to determine, when possible, the geographical origin of followers. This tool's goal is to move EMSC toward a more data-driven evaluation of the LastQuake bot's performance and weaknesses, a need for social media monitoring also identified in other cases like the 2016 Kaikoura earthquakes in New Zealand (Woods et al., 2017). Statistics are derived for each category of tweets and threads (Figure 4). We ultimately aimed to identify effective and ineffective tweets in terms of user interactions. This is of particular importance for assessing the interest raised by educational or misinformation messages but also for understanding how reactions may change during an aftershock sequence. The same applies to the number of followers and learning how it evolves with time in relation to local seismic activity and determining the typical follower retention duration. This tool is essential for moving toward a more data-driven service enhancement and to better understand the roles of the different LastQuake components in a given region and during earthquake sequences.

Discussion and conclusion

@LastQuake is a Twitter bot developed to automatize rapid public information about global felt earthquakes and their effects. While the potential of such bots to support crisis communication is well recognized, we have not identified in the literature other bots going beyond basic alert systems (Hofeditz et al., 2019), making @LastQuake a potentially unique experiment to date. This bot complements the LastQuake websites and smartphone app even in regions where the latter is well known, increasing the visibility and reach of the information service. For example, on the day of the 2020 Petrinja (Croatia) earthquake, an area with a high LastQuake app penetration rate, there was a similar number of views on Twitter and the app (9 and 10 million, respectively) (Table 1) compared to the 5 million on our websites. Nevertheless, one should not overestimate the actual reach among the public affected by such an earthquake, which remains low compared to traditional media (e.g., TV and radio).

The use of bots is also rendered necessary in seismology by the speed needed to engage efficiently with eyewitnesses. The speed of automatic systems, from crowdsourced detections, earthquake locations, or the collection of felt reports is such that it does not leave time for human intervention. Despite the limited information they convey, the large visibility of crowdsourced detections tweets (Figure 2) and the efficiency of the felt report crowdsourcing they trigger, both illustrate the public need for immediate information during emergencies, even if that information is incomplete.

The new version of the @LastQuake bot outlined in this article has extended its objectives beyond rapid public information and efficient crowdsourcing to include actively fighting misinformation and testing the possibility of utilizing the teachable moments created by widely felt but non-damaging earthquakes to raise awareness, enhance preparedness, and foster new behaviors. It uses an enhanced hierarchy of information (essential during aftershock sequences), the integration of educational content, and dedicated tweets to refute the existence of earthquake prediction. It also improves the links between the different components of the LastQuake system.

In addition, the bot encourages the collection of felt reports from people reporting an earthquake on Twitter through a system of individual invitation tweets. The invitations have so far been well perceived, with nearly 90% of invitees clicking on the link to the EMSC crowdsourcing tool. We cannot demonstrate at this stage whether @LastQuake has had any impact to fight misinformation or raise awareness and preparedness. However, a precondition for success is to reach an audience as large as possible, i.e., both the direct audience on Twitter itself and the indirect one

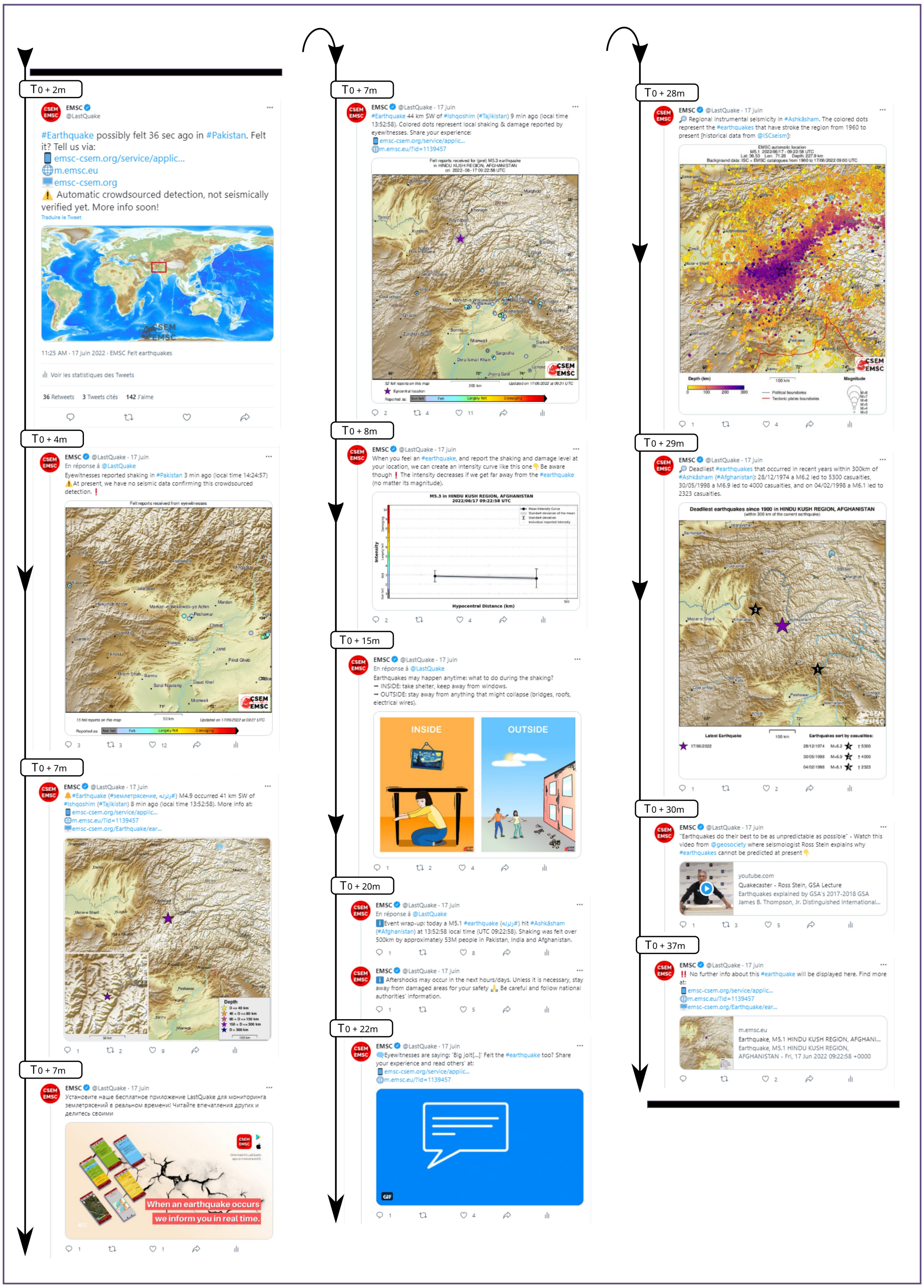

FIGURE 5
A thread of tweets automatically published in relation to the destructive M5.9 earthquake on 21 June 2022. Since the damage was not automatically detected, this event was placed in the category "large, with audience" (Figure 4). The publication time for each tweet is indicated with respect to the origin time.

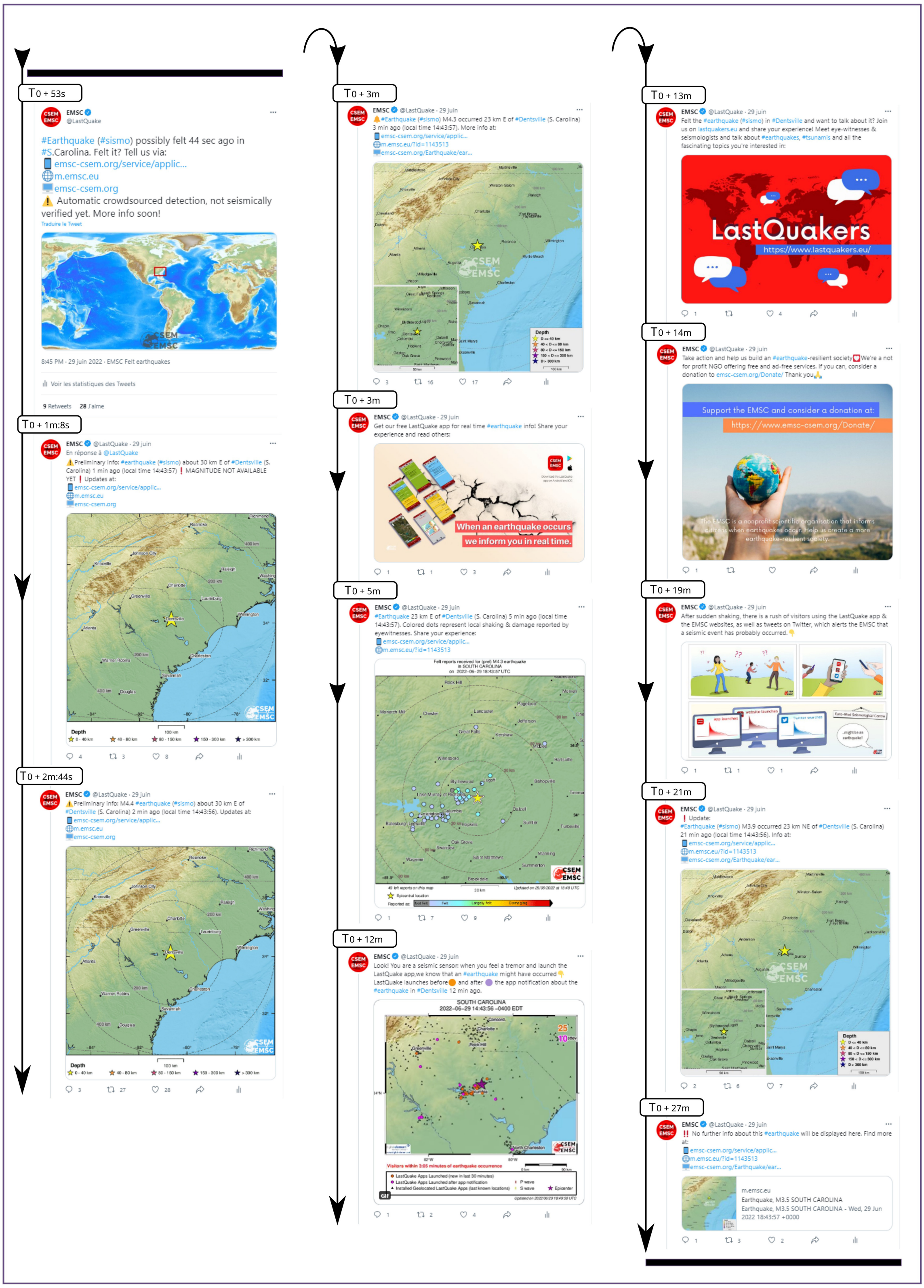

FIGURE 6
Threads of tweets automatically published in relation to South Carolina's M3.5 earthquake of 29 June 2022 and their publication times after earthquake occurrence. This earthquake was in the category "small with audience" (Figure 4). This category is considered to open a teachable moment and include in this case information on the system (tweet numbers 7 and 10). The second tweet presenting an epicentral location without magnitude estimate originated from the CsLoc method based on the combined analysis of crowdsourced and seismic data for the rapid location of felt earthquakes (Steed et al., 2019; Bondár et al., 2020).

TABLE 1 Number of views and unique visitors to the different components of the LastQuake system on 29 December 2020, the day of the damaging Petrinja (Croatia) earthquake.

December 29, 2020, M6.4 Petrinja Croatia earthquake		
	Views	Unique visitors
App	10M	320k
Twitter	9M	>200k
Website (mobile)	4M	260k
Website (desktop)	1.2M	110k

The number of unique visitors is not available on Twitter; it was assumed to be greater than the number of followers.

through the relay Twitter offers to the more traditional media. @LastQuake can contribute both to the dilution of the visibility of possible misinformation and to filling the information gap present immediately following a significant earthquake that is often exploited to spread misinformation (Fallou et al., 2020; Peng, 2020; Zhou et al., 2021). The positive users' feedback and the continuous increase of followership (210,000 in February 2022, 226,000 in November 2022, 272,000 in February 2023) are currently proxies providing qualitative support that @LastQuake is having an impact. A tool is presently in place to quantify whenever possible the bot's performance and whether its impact changes from one country to the next, while remembering that the @LastQuake bot remains a global service that does not take into account local cultural factors and social interactions affecting human behaviors and reactions (e.g., Oreskes, 2015).

Finally, although the @LastQuake bot strives to optimize the automatic delivery of timely, people-centered earthquake information and to limit human communication, such interactions remain essential and are highly appreciated on social media, contributing to limiting anxiety during crises as well as developing trust and credibility essential for an institute to provide effective communication during emergencies (Appleby-Arnold et al., 2019).

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

RB: initiation, supervision, funding, review of the project, and writing of the manuscript. MC: definition and preparation of the tweets, project management, figure preparation, and review of the manuscript. J-MC: technical implementation of the bot, development of the monitoring tool, and review of the manuscript. LF: review of the project and the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Appleby-Arnold, S., Brockdorff, N., Fallou, L., and Bossu, R. (2019). Truth, trust, and civic duty: cultural factors in citizens' perceptions of mobile phone apps and social media in disasters. *J. Conting. Crisis Manag.* 27, 293–305. doi: 10.1111/1468-5973.12282

Baram-Tsabari, A., and Segev, E. (2015). The half-life of a "teachable moment": the case of Nobel laureates. *Pub Understanding Sci.* 24, 326–337. doi: 10.1177/0963662513491369

Bondár, I., Steed, R., Roch, J., Bossu, R., Heinloo, A., Saul, J., et al. (2020). Accurate locations of felt earthquakes using crowdsource detections. *Front. Earth Sci.* 8, 272. doi: 10.3389/feart.2020.00272

Bossu, R., Fallou, L., Landès, M., Roussel, F., Julien-Laferrière, S., Roch, J., et al. (2020). Rapid public information and situational awareness after the November 26,

2019. Albania earthquake: Lessons learned from the LastQuake system. *Fronti. Earth Sci.* 2020, 235. doi: 10.3389/feart.2020.00235

Bossu, R., Gilles, S., Mazet-Roux, G., and Roussel, F. (2011). Citizen seismology: How to involve the public in earthquake response. *Comp Emerg Manage Exam Global Reg. Resp. Disasters* 16, 237–260. doi: 10.1201/b10974-15

Bossu, R., Gilles, S., Mazet-Roux, G., Roussel, F., Frobert, L., and Kamb, L. (2012). Flash sourcing, or rapid detection and characterization of earthquake effects through website traffic analysis. *Ann. Geophys.* 54, 5263. doi: 10.4401/ag-5265

Bossu, R., Laurin, M., Mazet-Roux, G., Roussel, F., and Steed, R. (2015). The importance of smartphones as public earthquake-information tools and tools for the rapid engagement with eyewitnesses: a case study of the 2015 Nepal earthquake sequence. *Seismol. Res. Lett.* 86, 1587–1592. doi: 10.1785/0220150147

Bossu, R., Mazet-Roux, G., Douet, V., Rives, S., Marin, S., and Aupetit, M. (2008). Internet users as seismic sensors for improved earthquake response, Eos Trans. *AGU* 25, 225–226. doi: 10.1029/2008EO250001

Bossu, R., Roussel, F., Fallou, L., Landès, M., Steed, R., Mazet-Roux, G., et al. (2018). LastQuake: From rapid information to global seismic risk reduction. *Int. J. Disaster Risk Reduct.* 28, 32–42. doi: 10.1016/j.ijdrr.2018.02.024

Bossu, R., Steed, R., Mazet-Roux, G., Roussel, F., Etivant, C., Frobert, L., et al. (2016). *The Key Role of Eyewitnesses in Rapid Impact Assessment of Global Earthquakes. Earthquakes and their Impact on Society*. Cham: Springer, 601–618.

Bossu, R., Steed, R., Roussel, F., Landès, M., Fuenzalida, A., Matrullo, E., et al. (2019). App earthquake detection and automatic mapping of felt area. *Seismol. Res. Lett.* 90, 305–312. doi: 10.1785/0220180185

Bravo, T., and Hubenthal, M. (2016). Using earthquakes as "teachable moments". *Science Teacher* 83, 14.

Britton, B., Jackson, C., and Wade, J. (2019). The reward and risk of social media for academics. *Nat. Rev. Chem.* 3, 459–461. doi: 10.1038/s41570-019-0121-3

Carley, K. M., Malik, M. M., Kowalchuck, M., Pfeffer, J., and Landwehr, P. (2015). Twitter usage in Indonesia. Available online at: https://www.academia.edu/download/47790848/Twitter_Usage_in_Indonesia-_CMU-ISR-15-109.pdf (accessed July 5, 2022).

Carvajal, M., Araya-Cornejo, C., Sepúlveda, I., Melnick, D., and Haase, J. S. (2019). Nearly instantaneous tsunamis following the Mw 7.5 2018 Palu earthquake. *Geophy. Res. Lett.* 46, 5117–5126. doi: 10.1029/2019GL082578

Contreras, D., Wilkinson, S., Fallou, L., Landès, M., Tomljenovich, I., Bossu, R., et al. (2021). Assessing emergency response and early recovery using Sentiment Analysis (SA). The case of Zagreb, Croatia. In *1st Croatian Conference on Earthquake Engineering (1CroCEE) 2021*. England, Newcastle University.

Earle, P. S., Bowden, D., and Guy, M. (2011). Twitter earthquake detection: earthquake monitoring in a social world. *Annal. Geophys.* 54, 708–715. doi: 10.4401/ag-5364

Eriksson, M. (2018). Lessons for crisis communication on social media: a systematic review of what research tells the practice. *Int. J. Strat. Commun.* 12, 526–551. doi: 10.1080/1553118X.2018.1510405

Fallou, L., Bossu, R., Landès, M., Roch, J., Roussel, F., Steed, R., et al. (2020). Citizen seismology without seismologists? Lessons learned from Mayotte leading to improved collaboration. *Front. Commun.* 5, 49. doi: 10.3389/fcomm.2020.00049

Fallou, L., Corradini, M., Bossu, R., and Cheny, J. M. (2022b). Preventing and debunking earthquake misinformation: insights into EMSC's practices. *Front. Commun.* 7, 28. doi: 10.3389/fcomm.2022.993510

Fallou, L., Marti, M., Dallo, I., and Corradini, M. (2022a). How to fight earthquake misinformation: a communication guide. *Seismol. Soc. Am.* 93, 2418–2422. doi: 10.1785/0220220086

Fallou, L., Petersen, L., Bossu, R., and Roussel, F. (2019). *Efficiently Allocating Safety Tips After an Earthquake-Lessons Learned From the Smartphone Application LastQuake. In ISCRAM*. Available online at: http://idl.iscram.org/files/laurefallou/2019/1943_LaureFallou_etal2019.pdf (accessed July 6, 2022).

Guérin-Marthe, S., Gehl, P., Negulescu, C., Auclair, S., and Fayjaloun, R. (2021). Rapid earthquake response: the state-of-the art and recommendations with a focus on European systems. *Int. J. Disaster Risk Reduc.* 52, 101958. doi: 10.1016/j.ijdrr.2020.101958

Hofeditz, L., Ehnis, C., Bunker, D., Brachten, F., and Stieglitz, S. (2019). "Meaningful use of social bots? Possible applications in crisis communication during disasters," in *Twenty-Seventh European Conference on Information Systems (ECIS2019)* (Stockholm; Uppsala). Available online at: https://www.researchgate.net/profile/Lennart-Hofeditz/publication/332842989_MEANINGFUL_USE_OF_SOCIAL_BOTS_POSSIBLE_APPLICATIONS_IN_CRISIS_COMMUNICATION_DURING_DISASTERS/links/5d073b30458515b055d8e814/MEANINGFUL-USE-OF-SOCIAL-BOTS-POSSIBLE-APPLICATIONS-IN-CRISISCOMMUNICATION-DURING-DISASTERS.pdf

Hubbard, J. (2022). *You Might Hear a Geologist Say: "We Can't Predict Earthquakes.* Available online at: https://twitter.com/JudithGeology/status/1485813279653908480 (accessed February 10, 2023).

Julien-Laferrière (2019). *Earthquake Qualitative impact Assessment: Performance evaluation. SERA project report pp 29*. Available online at: http://sera-cms.ethz.ch/export/sites/sera/home/.galleries/pdfs/Performance_analysis_EQIA.pdf (accessed July 7, 2022).

Khaund, T., Al-Khateeb, S., Tokdemir, S., and Agarwal, N. (2018). *Analyzing Social Bots and Their Coordination During Natural Disasters. International Conference on Social Computing, Behavioral-Cultural Modeling and Prediction and Behavior Representation in Modeling and Simulation*. Cham: Springer, 207–212.

Lacassin, R., Devès, M., Hicks, S. P., Ampuero, J. P., Bossu, R., Bruhat, L., et al. (2020). Rapid collaborative knowledge building *via* Twitter after significant geohazard events. *Geoscie. Commun.* 3, 129–146. doi: 10.5194/gc-3-129-2020

Markuši,ć, S., Stanko, D., Penava, D., Ivanči,ć, I., Bjelotomić Oršuli,ć, O., Korbar, T., et al. (2021). Destructive M6, 2. petrinja earthquake (Croatia) in 2020—Preliminary multidisciplinary research. *Remote Sensing* 13, 1095. doi: 10.3390/rs13061095

Markušić, S., Stanko, D., Korbar, T., Belić, N., Penava, D., Kordić, B., et al. (2020). The Zagreb (Croatia) M5, 5. Earthquake on 22 March 2020. *Geosciences* 10, 252. doi: 10.3390/geosciences10070252

Martin, S. S., Bossu, R., Steed, R., Landès, M., Srinagesh, D., Srinivas, D., et al. (2021). When Punjab cried wolf: how a rumor triggered an "earthquake" in India. *Seismol. Soc. Am.* 92, 3887–3898. doi: 10.1785/0220210130

Mustać, M., Dasović, I., Latečki, H., and Cecić, I. (2021). The public response and educational outreach through social media after the Zagreb earthquake of 22 March 2020. *Geofizika* 38, 215–234. doi: 10.15233/gfz.2021.38.7

Ogie, R. I., and Forehead, H. (2017). Investigating the accuracy of georeferenced social media data for flood mapping: The PetaJakarta.org case study. In *2017 4th International Conference on Information and Communication Technologies for Disaster Management (ICT-DM)*. New York, NY, IEEE, 1–6.

Oreskes, N. (2015). How earth science has become a social science. *Historical Soc. Res.* 1, 246–270. doi: 10.12759/hsr.40.2015.2.246-270

Peng, Z. (2020). Earthquakes and coronavirus: how to survive an infodemic. *Seismol. Res. Letters* 91, 2441–2443. doi: 10.1785/0220200125

Quigley, M. C., and Forte, A. M. (2017). Science website traffic in earthquakes. *Seismol. Res. Lett.* 88, 867–74. doi: 10.1785/0220160172

Saathoff, G., and Everly, J. G. (2002). Psychological challenges of bioterror: containing contagion. *Int. J. Emerg. Mental Health* 4, 245–252.

Saroj, A., and Pal, S. (2020). Use of social media in crisis management: a survey. *Int. J. Disaster Risk Reduc.* 48, 101584. doi: 10.1016/j.ijdrr.2020.101584

Schwarz, S. (2004). Cyberseismology and teachable moments. *Seismol. Res. Lett.* 75, 749. doi: 10.1785/gssrl.75.6.749

Stallings, R. A. (1986). Reaching the ethnic minorities: earthquake public education in the aftermath of foreign disasters. *Earthquake Spectra* 2, 695–702. doi: 10.1193/1.1585406

Steed, R. J., Fuenzalida, A., Bossu, R., Bondár, I., Heinloo, A., Dupont, A., et al. (2019). Crowdsourcing triggers rapid, reliable earthquake locations. *Sci. Adv.* 5, eaau9824. doi: 10.1126/sciadv.aau9824

Steelman, T. A., McCaffrey, S. M., Velez, A. L. K., and Briefel, J. A. (2015). What information do people use, trust, and find useful during a disaster? Evidence from five large wildfires. *Natural Hazards* 76, 615–634. doi: 10.1007/s11069-014-1512-x

Supendi, P., Nugraha, A. D., Widiyantoro, S., Pesicek, J. D., Thurber, C. H., Abdullah, C. I., et al. (2020). Relocated aftershocks and background seismicity in eastern Indonesia shed light on the 2018 Lombok and Palu earthquake sequences. *Geophys. J. Int.* 221, 1845–1855. doi: 10.1093/gji/ggaa118

Woods, R. J., McBride, S. K., Wotherspoon, L. M., Beavan, S., Potter, S. H., Johnston, D. M., et al. (2017). Science to emergency management response: Kaikoura earthquakes 2016. *Bullet. Soc. Earthquake Eng.* 50, 329–337. doi: 10.5459/bnzsee.50.2.329-337

Zhou, C., Xiu, H., Wang, Y., and Yu, X. (2021). Characterizing the dissemination of misinformation on social media in health emergencies: an empirical study based on COVID-19. *Inf. Proc. Manage.* 58, 102554. doi: 10.1016/j.ipm.2021.102554