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Preventing and debunking earthquake misinformation: Insights into EMSC's practices

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Misinformation spreads fast in times of crises, corroding public trust and causing further harm to already vulnerable communities. In earthquake seismology, the most common misinformation and misleading popular beliefs generally relate to earthquake prediction, earthquake genesis, and potential causal relations between climate, weather and earthquake occurrence. As a public earthquake information and dissemination center, the Euro-Mediterranean Seismological Center (EMSC) has been confronted many times with this issue over the years. In this paper we describe several types of earthquake misinformation that the EMSC had to deal with during the 2018 Mayotte earthquake crisis and the 2021 La Palma seismic swarm. We present frequent misinformation topics such as earthquake predictions seen on our communication channels. Finally, we expose how, based on desk studies and users' surveys, the EMSC has progressively improved its communication strategy and tools to fight earthquake misinformation and restore trust in science. In this paper we elaborate on the observed temporality patterns for earthquake misinformation and the implications this may have to limit the magnitude of the phenomenon. We also discuss the importance of social, psychological and cultural factors in the appearance and therefore in the fight against misinformation. Finally, we emphasize the need to constantly adapt to new platforms, new beliefs, and advances in science to stay relevant and not allow misinformation to take hold.

KEYWORDS

misinformation, earthquake, science communication, risk communication, information system, earthquake predictions, people-centered risk communication

1. Introduction

Earthquake predictions, rumors that animals can predict earthquakes, that there is a significant link between weather and seismic activity, or even belief in the ability of some governments to intentionally create earthquakes... earthquake misinformation is numerous and disparate.

Misinformation through gossip and rumors has always existed, including in relation to earthquakes. In 1990 for instance, the self-proclaimed climatologist Iben Browning made the prediction that a major earthquake would occur on the New Madrid

Fault around December 2nd and 3rd. Ignored by the scientists, the information was nonetheless relayed in the media, causing fear and anxiety among the potentially affected residents of the region who had already experienced damaging earthquakes in the past (Gori, 1993). Another well-documented example of misinformation spreading appeared following the 2010 M8.8 Maule earthquake and tsunami in Chile. The earthquake caused more than 500 casualties, and rumors of volcanic activity and of the death of famous people quickly spread on Twitter, adding confusion to the crisis response process (Castillo et al., 2013). Last but not least, Flores-Saviaga and Savage (2021) studied how, after the 2017 M7.1 Puebla earthquake in Mexico, citizens created a specific hashtag on Twitter to make verified information visible.

Earthquake misinformation has taken on larger significance within the last few years because of the rise of social networks and the development of new informational products in seismology. Misinformation is indeed more visible, more numerous, more shared and this has had tangible consequences. While it has been widely demonstrated that social networks can have a positive impact on crisis management (Reuter and Kaufhold, 2018) and on scientific research (Lacassin et al., 2019), their use can present certain pitfalls, including the circulation of false information that can turn viral. With the use of social networks, the false information that already existed before has become more visible and can circulate more quickly (Fallou et al., 2022). In addition, the communication from seismological institutes has expanded and now almost systematically includes a presence on social networks. However, this presence implies greater interaction with individuals on these platforms and the public has developed strong expectations regarding institutional communication through social media (Petersen et al., 2017; Bossu et al., 2020). Because of their growing presence on social media, seismic institutions have increasingly become aware of the misinformation phenomenon to such an extent that they cannot ignore it anymore. Recent developments in seismology research and informational products are the second conducive cause to the flourishing of misinformation. With the current state of knowledge, seismologists are not able to predict earthquakes - that is to say, they cannot say precisely when, where and with what degree of energy an earthquake will occur. Earthquake Early Warning (EEW) is often confused by the public with earthquake predictions, and such a misunderstanding raises doubts about what science can or cannot do (Elizabeth Cochran et al., 2018; Fallou et al., 2021; Dallo et al., 2022). Operational Earthquake Forecast (OEF) – which is communicated through calculated probability for the next tremors- are developing. However, this type of information is complex to communicate and to be understood by the public and the probabilities themselves can evolve rapidly making prior information outdated (Nigg, 1982; Gigerenzer et al., 2005; Marti et al., 2019; Mcbride et al., 2019).

The problem of earthquake misinformation is far from being trivial and has important tangible and intangible consequences. Ill-informed people make decisions that can be dangerous for them or prevent the smooth running of relief activities, jeopardizing preparedness and awareness efforts (Chen et al., 2018; Mero, 2019; Peng, 2020; Zhou et al., 2021). Some of the consequences are more elusive but perhaps even more dangerous in the long term. The dissemination of misinformation can decrease trust in science or in the authorities (Appleby et al., 2019; Fallou et al., 2020; Zhou et al., 2021). Faced with the consequences of misinformation, it is the social and ethical responsibility of seismology institutes to act (Peppoloni and Di Capua, 2012). Yet, they are not the only actors to have a role to play in this fight against earthquake misinformation: researchers, science communicators, political authorities or the media have also their share to do, since their scientific and risk communication actions often place them in the front line in this fight. While research is gradually addressing the issue of misinformation and providing advice and good practices to guide seismological institutes in the fight against misinformation (Dallo et al., 2022; Fallou et al., 2022), there is currently no work that documents the concrete practices of these actors of earthquake science and risk communication.

As a global seismological and public information institution, the Euro-Mediterannean Seismological Center (EMSC) is regularly confronted with earthquake misinformation on social media, mostly on Twitter *via* its @lastQuake account (223 K followers in September 2022). Over the last years the EMSC has therefore gained empiric experience in the field of misinformation, especially on ways to respond to them (debunk) but also to ensure that they don't appear in the first place (prebunk).

The present paper collates EMSC's experiences related to earthquake misinformation and sets up solutions to tackle the issue. By doing so we seek to research what a global seismic institution can do to help fight earthquake misinformation. In order to do so we will first give elements of context regarding the state of the research on combatting earthquake misinformation. We then document the two main categories of earthquake misinformation that the EMSC is regularly facing, namely:

(1) Misconception and misunderstanding of the EMSC information system (e.g., how the EMSC publish information);
(2) Earthquake predictions.

We then expose how, based on desk studies, users' surveys and 10 years' of empirical experience, the EMSC has progressively improved its communication tools and communication strategy to efficiently fight earthquake misinformation and restore trust in science.

2. Earthquake misinformation: A state of the art

2.1. Defining earthquake misinformation

The term "misinformation" sometimes appears as a catch-all (Baines and Elliott, 2020). Here, we define it as any kind of information that is considered false with regard to the knowledge commonly agreed on or known at a given time (Komendantova et al., 2021). Unlike disinformation, which is a deliberate act of spreading false information most often with the aim of causing harm, misinformation is never intentional. It follows that spotting misinformation requires the ability to discern what is true and what is false. Yet, there are cases where true and false information are not obviously separated and assertions are to be nuanced or conditioned. Science, quite surprisingly, is not always able to discriminate what is true or false: as the scientific field is constantly evolving, consensuses are not always established and controversies appear regularly (Dryhurst et al., 2022).

2.2. Why do people believe and share misinformation?

Reasons why individuals believe and share false information relates as much to the socio-technical properties of the technology platforms, as to social and psychological issues of the communities concerned.

Due to their business model (Deibert, 2019), platforms are designed to promote content that has the greatest chance of engaging users, such as sharing, liking or leaving a comment (Marwick, 2018). Content is created and circulates very quickly but is often not moderated, which allows the circulation of unverified content, sometimes in a viral manner. Research has found that, on social media, fake news is about 70% more likely to be shared than real news and it takes on average 6 times longer for real information to reach 1,500 people (Vosoughi et al., 2018).

Crises are a particularly fertile ground for misinformation. The need for information for affected or concerned people is very high and must be satisfied quickly. At the same time, information is rare, sometimes confusing and not always verified (Palen and Hughes, 2018). False information especially propagates when authoritative information is lacking or when it is ambiguous, triggering additional fear and anxiety (Fallou et al., 2020; Peng, 2020; Zhou et al., 2021). Besides, during crises, anxiety and physical or emotional vulnerability reinforce the propensity to believe and share false information (Abdullah et al., 2015). The feeling of certainty conferred by receiving information, albeit false, participates in the collective sense-making process that people affected by a crisis need (Huang et al., 2015; Starbird et al., 2016). Psychological factors are also at play regarding beliefs in earthquake predictions. In their study related to beliefs in the 1990 Iben Browning earthquake prediction, Atwood and Major (2000) show that pessimistic people felt more at risk and were more likely to believe in the prediction. Inversely, optimistic people sought less information about prediction and risk, which led them to a risk denial.

In the case of earthquakes, the lack of scientific literacy increases the risk of misinformation and confusion. Seismology is a relatively young science and is rapidly evolving; conversely the public literacy level for this science is often low. Indeed, interest in seismology grows with experience... and on a lifetime scale, the number of earthquakes typically experienced for which a person feels concerned is relatively small (in regions where the hazard is moderate and outside of aftershock periods). Additionally, even for a given earthquake, the window of interest is often quite short in time (from a few minutes to a few days). For these reasons, communications related to earthquake risk and science only benefit from few and short moments to be efficient and reach their audience (Camilleri et al., 2020). As a result, at an individual scale, people are not often exposed nor attentive to earthquake science messages and therefore may have inaccurate belief about what seismology can and cannot do and about when scientific information is available (Scheufele et al., 2021).

Overall, earthquake misinformation is fueled by uncertainties, misunderstandings, cognitive biases, lack of science literacy or even lack of science consensus (Dryhurst et al., 2022). All of these causes ultimately contribute and reinforce beliefs in misinformation (Dallo et al., 2022).

2.3. What can be done to fight misinformation?

Solutions to fight misinformation in general are traditionally 2 fold according to the literature:

(a) Technical strategies, that use algorithms seek to detect misinformation and limit its spread (Calfas, 2017; Elgin and Wang, 2018; Van der Linden and Roozenbeek, 2020).
(b) Fact-checking methods, also known as debunking (Cook and Lewandowsky, 2020), counteract misinformation by showing how it is false. Although highly necessary, debunking may not be sufficient and, for some, even add to the initial suspicion (Jang et al., 2019).

Research therefore advocates for pre-bunking techniques, which consist in preventing the appearance of false information in advance (Compton, 2013; Van der Linden and Roozenbeek, 2020), including through gamification approach (Roozenbeek and van der Linden, 2019; Basol et al., 2020). States can also intervene by legislating (Koulolias et al., 2018): During crises, citizens themselves can mobilize and contribute to the effort in fighting misinformation by helping to identify, reporting, and labeling false information or even by educating their peers on the subject (Flores-Saviaga and Savage, 2021).

Communicating better is essential for the earthquake misinformation fight. This includes communication on what information is available at what time, with what level of certainty, and what are the risks for the population (Dallo et al., 2022). To be efficient, this information must be tailored to the public in terms of content, format, and medium (Lamontagne and Flynn, 2014). Communication decreases anxiety during crises, while anxiety is an aggravating factor in the spread of misinformation (Fearn-Banks, 2016). Since different types of misinformation can spread at different stage of the earthquake cycle, communicating in order to pre-bunk and debunk is a permanent task in seismology (Fallou et al., 2022).

With the development of new seismic information products, misinformation has become a timely topic. To prepare scientifically based answers to misinformation that could be used by all actors, Dryhurst et al. (2022) evaluated the existence or the absence of scientific consensus among seismologists on a dozen assertions that are controversial or confusing to the public. They also compiled recommendations to better communicate and fight three of the most common types of earthquake misinformation, namely the earthquake prediction, the earthquake creation, and the potential link between earthquakes, climate, and weather. This resulted in a communication guide (Dallo et al., 2022), where the authors underlined the importance of getting to know the audience and establishing with them a trust relationship, to better understand their needs and concerns (Goulet and Lamontagne, 2018).

3. The EMSC and the earthquake misinformation problem

The EMSC operates LastQuake, a multi-component public earthquake information and crowdsourcing system, comprising websites, a mobile application (900 K users in September 2022), and a twitter account (223 K followers in September 2022). It is completed by an online presence on other social media (Facebook, LinkedIn, and Telegram) (Bossu et al., 2015, 2018). LastQuake focuses on felt earthquakes as they are the ones that matter for the public. On the one hand it monitors online reactions of eyewitnesses to detect felt earthquakes (e.g., Bossu et al., 2019) and collects geo-located felt reports, comments, pictures or videos from eyewitnesses. On the other hand it provides earthquake parameters (magnitude, location) and aggregation of citizens' observation such as map of the reported effects (Bossu et al., 2018). Citizens can share their experience, comments and pictures through the app, the mobile website and the desktop website. They can also access all seismic information on these three platforms. The twitter account (@LastQuake) is primarily a bot but also contains manual tweets used to answer users' questions (especially after damaging earthquakes). It is a relay for the three other channels were eyewitnesses can effectively share their experience. LastQuake also includes tools to contribute to risk reduction such as safety tips and safety checks (Fallou et al., 2019). As it targets a global audience, the EMSC makes intensive use of visual communication in order to be universally understandable (Fallou et al., 2019). Yet, the EMSC publications on Twitter are mostly in English, which restricts the audience to English speakers or to those willing to translate the tweets through the integrated translation tool.

Because of its intensive presence on social media and constant communication with the public, the EMSC has been confronted with many cases and types of misinformation. Some of this misinformation occurs occasionally, outside of crisis periods, and thus gets relatively little attention. However, the most frequent type of misinformation occurs right after major earthquakes and is linked primarily to earthquake prediction and, to a lesser extent, to misconceptions about the EMSC system. The fact that certain earthquakes, destructive or shocking for the population, have led to misinformation makes it possible for us to deduce a geographical and a temporal framework of vulnerability of the population toward false information: it is in the few hours to days that follow the earthquake onset that the eyewitnesses, and anyone affected by the seismic event, are vulnerable to misinformation. This spatio-temporal framework allows us to target our action.

In the following sections we present two different categories of misinformation illustrated by examples. Contrary to the classification established by Dallo et al. (2022), the "misinformation categories" we present in our paper are not strictly based on the content of the false information. Rather, our categories sort misinformation by its nature, since it is the nature of the misinformation, not its content, which determines the type of response. The first "misinformation category" brings together misinformation that is linked to a misconception or misunderstanding of the EMSC information system. The second tackles online earthquake predictions.

3.1. First misinformation category: Misconception and misunderstanding of the LastQuake system

The LastQuake information system has been designed to offer easily understandable messages for global eyewitnesses who just felt an earthquake, who may be new to earthquakes and seismology, and who, above everything, may be anxious. The way the information is produced and displayed through LastQuake has nonetheless generated some misunderstandings, which have led to misinformation. We present here two emblematic cases.

The 2018 Mayotte earthquake crisis

On the 10th of May 2018, a series of widely felt earthquakes started to hit Mayotte, a French island located in the Indian Ocean. This earthquake swarm was first left unexplained from a scientific point of view due to a lack of seismic sensors in the area (Lacassin et al., 2019; Lemoine et al., 2020). This information void generated anxiety, frustration, as well as feelings of abandonment and suspicion, which fueled the circulation of false information and even conspiracy theories. For instance, beyond animist and religious beliefs that for some people contributed to account for the phenomenon, rumors attempted to explain the seismic swarm as originating from secret oil drilling. Similarly, rumors that the earthquake magnitudes were systematically being underestimated started circulating. In a second stage of the seismic swarm, when scientific information started being available, the communication, poorly adapted to the expectations of the public and to the socio-cultural context, struggled to achieve its goals. Science communication was not heard, understood, and not even trusted by the public (Fallou et al., 2020; Devès et al., 2021, 2022).

The Mayotte case has been studied in detail in Fallou et al. (2020). Here, we only focus on the aspects of that misinformation and its implications for the EMSC. In a context of general distrust of information, such as the one in Mayotte, the perception of the EMSC and its LastQuake application was ambivalent. On the one hand, LastQuake was very popular and appreciated for the information it could provide. On the other hand, a misunderstanding of the system and the absence of seismic confirmation for certain events generated strong dissatisfaction among users. It also cast doubt on the reliability of the system and on a potential participation of the EMSC in the so-called plot. Originally, the LastQuake information system used to collect felt reports for all the crowdsourced detections that it recorded but published these testimonies only when the seismic activity had actually been confirmed by seismic data from partner institutes. In the case of Mayotte swarm, not enough sensors were there to seismically confirm the information of the system. Despite the testimonies collected, the earthquakes of the Mayotte swarm were not being displayed – a very frustrating user experience! As a matter of fact, earthquake eyewitnesses were able to report their experience for the first 15 min from the shaking and associate it to the crowdsourced detection displayed on the LastQuake app. However, after 15 min, since no seismic confirmation would arrive to the EMSC, the crowdsourced detection disappeared from the app - and the users were not aware of such limits of the system (Fallou et al., 2020). In this specific case, the lack of both the scientific information and the understanding of the system were the driving force behind the dissemination of false information.

The 2021 Las Palmas seismic swarm

On 19 September 2021, the Cumbia Vieja volcano started erupting on La Palma Island. The eruption garnered seismic activity in the form of a swarm, particularly active in October 2021. An interactive map on the EMSC website unintentionally became "evidence" for false information and even conspiracy theories. Indeed, the local seismicity map, when zoomed, displayed a grid shape (Figure 1).

Theories would then explain that these earthquakes were artificial, linked to military activities of the United States of America (including the HAARP system[1]) or heralded a giant tsunami (Figure 2). In reality, this "grid" of earthquake locations was an artifact, due to the fact that the EMSC rounds longitude and latitude coordinates to two decimal points, resulting in a less-granular, less-defined dataset.

This artifact is not unique to La Palma. It may occur on EMSC maps whenever there is a huge zoom on a very small area. In La Palma, the artifact was made visible to many users because of the very small size of the island, which made them zoom in a lot and see the grid shape.

The EMSC only discovered this misinformation after the USGS issued a clarification about the situation[2] and copied it to the EMSC account. The rumor had spread outside our field of vision on these platforms, but as soon as we saw it, we were able to explain the reasons for this artifact through several publications on social networks and the EMSC's forum LastQuakers. The debunking effort became collective with help from news media[3] and other Twitter users even using humor to denounce the incongruity of the theories. The EMSC decided not to change its digit rounding system in order not to fuel conspiracy theories. Indeed, it may have seemed suspicious that we changed the system immediately, and some could have seen it as a proof that we had something to hide. Even though this was a rare case of noticeable grid pattern, and in order to comply with new standard, the EMSC will add a third digit on the new version of its website. After a few days of debunking, believing that those who would like to find the information were able

1 HAARP stands for High-frequency Active Auroral Research Program and relates to a military research program funded by USA to analyze the ionosphere. HAARP is often a mentioned by conspiracy theorists as a tool capable of "weaponizing weather".

2 Available online at: https://twitter.com/USGSVolcanoes/status/1452446024845299712?s=20&t=NWQG3MrQoVuujq3D5faQ4A (accessed May 21, 2022).

3 See for instance USA Today Available online at: https://eu.usatoday.com/story/news/factcheck/2021/11/07/fact-check-la-palma-earthquake-grid-represents-natural-quakes/6186214001/ or https://leadstories.com/hoax-alert/2021/10/fact-check-seismic-activity-grid-pattern-on-map-is-not-evidence-the-lapalma-eruption-and-earthquakes-are-an-artificial-attack.html (accessed May 21, 2022).

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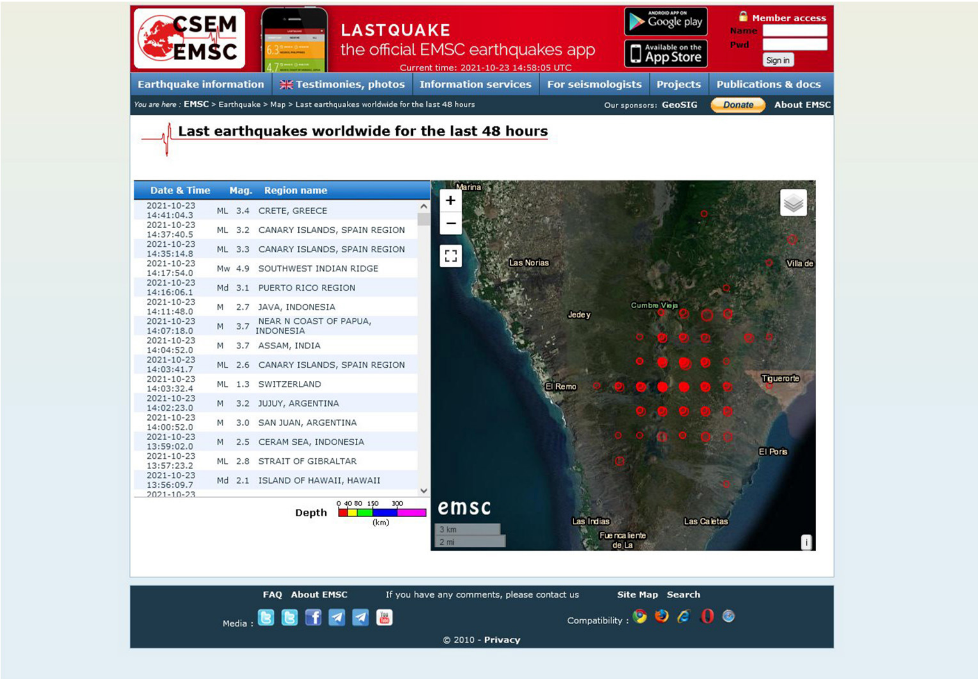

FIGURE 1
Screenshot of the EMSC website displaying the earthquake map with the grid pattern (Screenshot 17 June 2022).

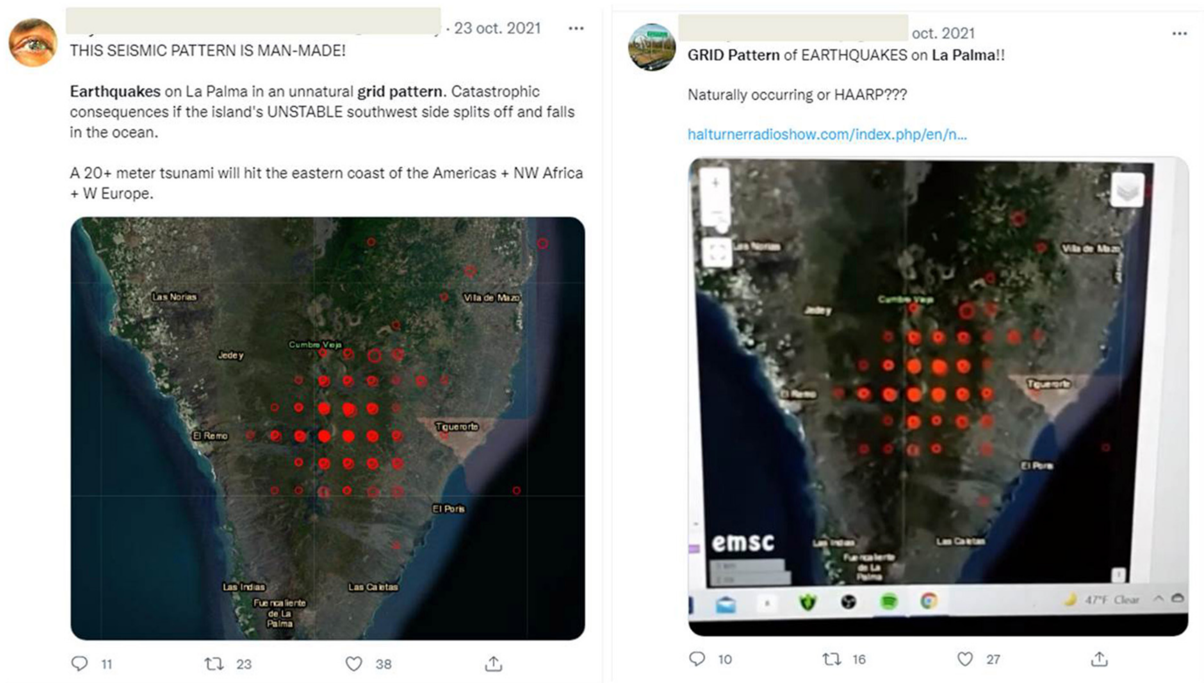

FIGURE 2
Screenshots of Twitter users posting the EMSC map to support misinformation about the earthquake grid pattern (Screenshot 17 June 2022).

to find it, we stopped broadcasting the explanatory messages. In fact, some were still not convinced and rejected this simple explanation to stick to their more complex and sometimes conspiratorial explanations such as military activity or HAARP. For those, we felt that we would not be able to convince them with our arguments.

In this case study, we observed that conspiracy theories are often not believed by everyone. Yet, here they have set light on a tool (the interactive map) that, because of the incongruity of its visualization, sowed doubt and confusion and raised legitimate questions. This is what made the misinformation visible, and to a certain extent, viral.

Beyond the specific cases of Mayotte and La Palma, the EMSC is confronted with examples of misunderstanding of seismology in general. Among the most recurrent: magnitude discrepancy between agencies, the confusion between magnitude and intensity which leads to people questioning of the magnitude of earthquakes or even the doubt generated by the evolution of a magnitude on a given earthquake. These questions and these doubts coming from the public are not directly linked to our tools or informational products. They are a reflection of (1) the public's lack of knowledge in seismology, (2) a lack of awareness on the mode of production of seismological data, and (3) largely spread scientific misconceptions (Coleman and Soellner, 1995; Francek, 2013).

3.2. Second misinformation category: Earthquake predictions

Contrary to some other natural hazards, earthquakes are unpredictable in the sense that it is not possible to know in advance and with precision, when, where and how strongly earthquakes will happen. Defining the terminology is important here since if it is not possible to predict shaking, products such as OEF and EEW systems can spread semantic and conceptual confusion (Jordan et al., 2011; Dallo et al., 2022). Suffice to say that in some languages the words "prediction" and "forecast" are equivalent or even the same word.

The need and desire for prediction is great among the population (and to a lesser extent among scientists). This desire for prediction is especially high right after an earthquake, when eyewitnesses' first and main question asked on Twitter is "what will happen next?". As legitimate this question may be, scientists are not in a position to provide a precise answer. This leaves eyewitnesses either confused by the sometimes-misinterpreted earthquake forecasts, or vulnerable to unscientific answers that predict the future. In fact, the EMSC is confronted with two types of prediction problems: earthquake predictors and earthquake predictions that arise after significant or damaging earthquakes.

Earthquake predictors

The first type of earthquake predictions occurs regularly and are often produced by seismology enthusiasts or self-proclaimed scientists who often use seismic data produced by the EMSC or other well-known seismic centers to predict earthquakes. Some of them use EMSC's notoriety and audience to give visibility to their predictions by mentioning the EMSC account. For example, a person[4] publishing content on Twitter regularly uses EMSC and USGS data to make videos in which he makes and comments on earthquake predictions. He now has a large community on Twitch (50 K followers) and YouTube (530 K followers). This type of prediction occurs throughout the earthquake cycle since these "experts" constantly monitor the seismic situation on a local or global scale. The number of views generated by these contents suggests that it could be a source of income for their authors (Mathew, 2022).

Earthquake predictions after earthquakes

The second type of prediction faced by the EMSC is more localized and occurs mainly after a significant earthquake (Dallo et al., 2022). The case of the Albania earthquake is particularly interesting here. On September 21, 2019, an earthquake of Mw 5.6 hit Albania and was widely felt in Tirana. The earthquake was followed by numerous aftershocks greatly increasing the level of anxiety among the population. Thanks to the LastQuake system, the EMSC became an important source of information for people affected by the earthquake. The next day, an aftershock hit the town again, but what created panic was a media posting asserting that "A Greek seismographer says stay away from your homes, a major earthquake is expected around 11:30 pm" (Erebara, 2019). This prediction, endowed with great precision and credited with a credibility factor (it quotes a seismologist and the information emanated from journalists) only added anguish. As a consequence, many people decided to share the news with their relatives and to leave the city, creating traffic jams for several hours. Subsequently the journalists who had relayed this prediction were arrested by the police.

Most often, these kinds of predictions do not directly affect the EMSC because we are not the origin or the recipients. They occur after strong earthquakes when the population is anxious and, looking for information. In this case, the EMSC is particularly concerned since the eyewitnesses who use our services are in search of information, in a state of shock and therefore potentially vulnerable to false information. Therefore, educating them on the impossibility of making predictions is essential, as well as not giving them visibility.

4 In order not to give him publicity we will not mention his name here.

4. EMSC's solutions to fight frequent earthquake misinformation

4.1. Fighting the misconception and misunderstanding of the LastQuake system

The EMSC developed two strategies to face the information system misunderstanding problem, a technical one and an informational one.

Technical improvements

After the beginning of the Mayotte crisis, which lasted for several months, the LastQuake system evolved technically to better integrate cases when the information is incomplete. Thanks to a sociological survey (Fallou et al., 2020), we were able to take full measure of the frustration linked to the lack of information. A few months after the beginning of the swarm, we thus modified the system, which now makes it possible to publish the events for which we have collected testimonies but that have not been seismically confirmed to us, normally due to a lack of sensors in the region. We display, in a specific color and without magnitude or location, these particular events (Figure 3). This system developed in 2018, has since proven itself and seems to satisfy users, not only in Mayotte but also in other parts of the world. With this new system we therefore publish, in complete transparency and quickly, all the verified information available to the EMSC.

Informational improvements

The EMSC has become aware of the importance of explaining to the public how the LastQuake information system works in order to limit false information. We created a short explanatory video of the system without including any text, so that it is understandable and accessible to as many people as possible. The video is permanently pinned to the EMSC's Twitter account @LastQuake and it serves as an educational presentation. In parallel we created a repository of answers for our Frequently Asked Questions. The questions are organized around 6 mains categories: (1) about the Site (2) about LastQuake, (3) about earthquakes, (4) I felt an earthquake, (5) data and confidentiality, and (6) citizen seismology.

The answers to these questions meet users' expectations in a precise, sourced, and comprehensive way. The FAQ page is permanently accessible on the EMSC mobile and desktop website, and will soon be integrated into the mobile application. They also allow the EMSC team to refer to them and redirect the public if needed, especially after a significant earthquake when questions arise.

4.2. Fighting earthquake predictions

Social media moderation

In order not to give visibility to predictions made by earthquake predictors, EMSC's policy is to systematically block accounts related to predictions on social media. This allows EMSC not to be the target of negative or even insulting comments. Indeed, a few years ago the EMSC was the target of "raids" on social networks, where dozens of people wrote tweets in a synchronized way, mentioning the EMSC in order to support the predictions and alter the credibility of the institution (Bossu et al., 2022).

Conversely, in order to maximize the credibility of its overall content, the @LastQuake account is now certified by Twitter. This certification indicates to users the authenticity of a public interest account. Although this certification was not specifically requested in the context of the EMSC misinformation fight, it nevertheless shows users that the content is, a priori, reliable. The EMSC mostly publishes in English on its Twitter account. While this has allowed gaining a certain visibility, it only permits reaching an English-speaking public and therefore considerably reduces the scope of these actions to fight against misinformation.

Educational messages on the EMSC social media channels

The problem of predictions is particularly visible for the EMSC on social networks and in particular on Twitter, which allows easy, direct and timely conversation with the public. It is therefore primarily on this social network that the EMSC tested a tool to prevent the appearance and spread of misinformation concerning predictions.

First developed in 2012, the robot currently has more than 200 K followers worldwide; making it one of the most widely used seismological information channels at the international level. Although widely appreciated and used, the robot has over time shown rooms for improvement to better adapt to changes both in the platform and in the way citizens searches and share information in the event of an earthquake (Bossu et al., 2022).

In 2022 the EMSC redesigned its @LastQuake robot. This is further detailed in a sister paper (Bossu et al., 2022). A series of tweets was set up with the purpose of fighting against misinformation and fake news -particularly those related to earthquake prediction (Table 1). This evolution has actually automated what was manual before. Indeed after each damaging earthquake the questions about the predictability of the earthquakes (or even predictions as such) systematically flourished and we had to answer them manually on social media.

The new robot is now composed of a series of educational tweets as well as tweets debunking most common fake news and misconceptions, including predictions. New tweets, addressing emerging topics in earthquake misinformation, can also be

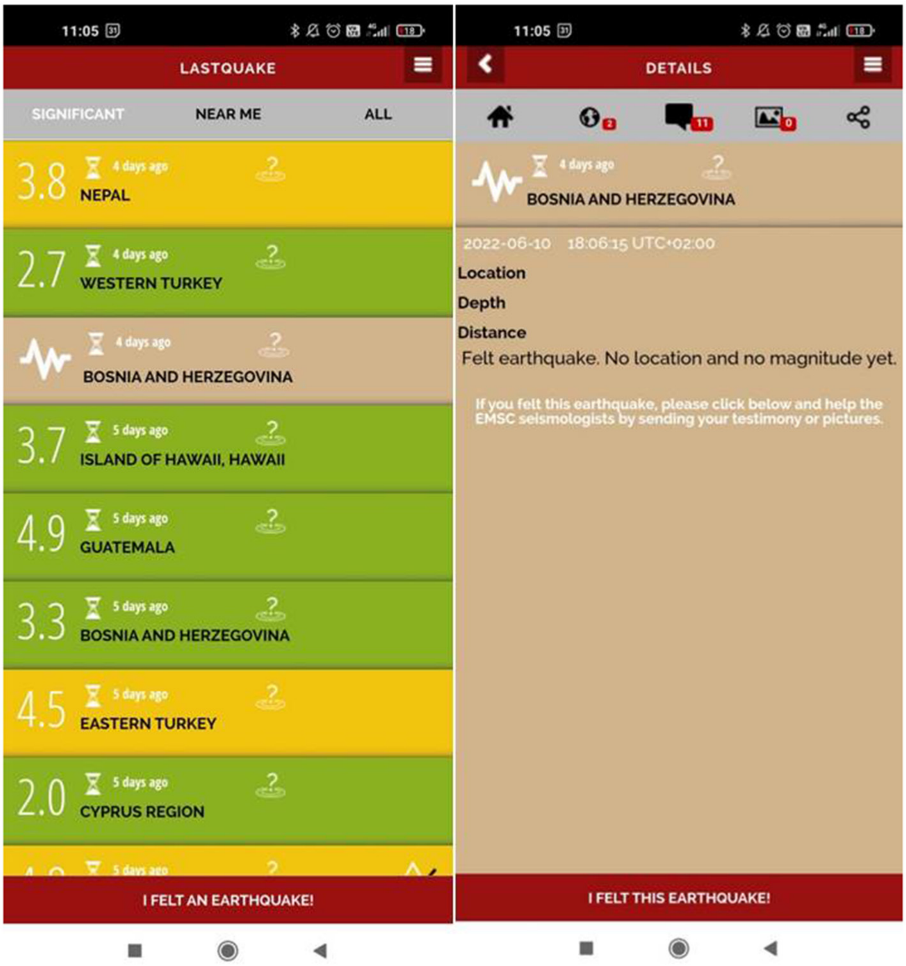

FIGURE 3
Display of the new event type in the LastQuake application.

added to the automatic system if required. The robot is versatile and adaptable in the long term.

To pre-bunk and debunk misinformation, we prepared a series of educational tweets which are published after widely felt non-damaging earthquakes to exploit the teachable moment they open. The ones against prediction are systematically published after damaging earthquakes. Generally, misinformation arises in the case of a large ($M > 4.5$) earthquake, especially if the seismic event retains the interest of the public and/or the media. It is in these circumstances that we publish our educational tweets to prevent the misinformation to arise and spread.

In the new robot we have therefore implemented a communication strategy that takes into account the perception, the prior knowledge, and the psychological state of the users. In particular, people better seize messages that are clear, short, compassionate, and positive. Hence, our wording and tone are carefully chosen to provide reliable and empathetic communication.

The EMSC will monitor the reactions to these educational tweets, whether automatic or manual (Bossu et al., 2022). Additionally, because twitter is only used by a small proportion of the population, the EMSC will study the opportunities to pre-bunk predictions on its other channels such as the app and its websites.

5. Discussion

After an earthquake, the vulnerability of those affected is not only physical and emotional but also informational. We posit that seismological institutes, among other actors, must be particularly vigilant on this aspect precisely because the propensity to believe and share false information is especially

TABLE 1 EMSC's educational tweets about earthquake prediction.

#	EMSC's educational tweet about earthquake prediction
1	❓Can #earthquakes be predicted? No. Seismologists can estimate the seismic hazard (the probability of ground shaking due to earthquakes) in time windows of decades that are used by engineers to design safe buildings. Educational video by @IRIS_EPO 👇 Available online at: https://youtu.be/MQNKpS0xrwM
2	❓Do you have an #earthquake prediction? The Collaboratory for the Study of Earthquake Predictability (https://scec.org/research/projects/CSEP/scec3.html) accepts predictions and evaluates them. Careful though: saying you did predict after the earthquake happens means nothing 🙂
3	❓Why can't seismologists predict #earthquakes? Find it out in this educational video from @IRIS_EPO 👇 Available online at: https://youtu.be/q8Ot3ToO_54
4	👉For an #earthquake prediction to be meaningful, it has to specify a time, location, and magnitude range that is unlikely to occur randomly. This is currently impossible. Learn more in this video from @IRIS_EPO 👇 Available online at: https://youtu.be/F4Ypv0PmDDE
5	"Earthquakes do their best to be as unpredictable as possible" - watch this video from @geosociety where seismologist Ross Stein explains why earthquakes cannot be predicted at present 👇 Available online at: https://youtu.be/ekTG-qjVHxc
6	To our friends and users: we hope you are safe 🙏. In the next hours you are likely going to hear about earthquake prediction. 👉 Earthquake prediction does not exist at present ☐. Please, only trust official sources and follow national authorities' directives.

#Indicate the number of the tweet.

high when one has just felt an earthquake. From the experiences recounted in this article, the tools developed over the years, and the research on earthquake misinformation, we can draw a number of lessons:

1. We observe three different types of patterns for earthquake misinformation, based on the timing of their appearance and the attention they generate. The first pattern concerns misinformation that is constantly present but captures relatively little attention. These are, for example, people who publish prediction bulletins on a regular basis. The second type appears more occasionally but almost systematically after strong earthquakes, these are the predictions of aftershocks and sometimes false information on the damage. These can be anticipated. The third pattern concerns false information which is also generated after earthquakes but which is more unprecedented and less predictable, as was the case in La Palma for example. Considering these three patterns of misinformation makes it possible to better prepare to act against this false information. Indeed, for the first type, constant but light attention is necessary, by simply not making this information more visible, or by systematically blocking the associated content. For the second type, pre-bunking activities can be effective since they aim to capture the attention of eyewitnesses and warn them against this misinformation likely to appear, according to our experience. Finally, the third type is more complex to manage since it is less predictable. It is therefore necessary to be attentive, not only rely on automatic tools and to be trained, to detect this misinformation quickly and respond to it by taking into account the local context. Institutions should provide trainings for professionals which cultivate their skills in scientific and/or crisis communication (Lamontagne, 2022).
2. Social and psychological aspects are key in the spread of misinformation. We must always keep in mind the reasons that lead people to believe and share false information. Anxiety, lack of knowledge, loss of bearings and the need to make sense of what is happening must be taken into account when establishing communication strategies. As pointed out by Dallo et al. (2022), people who believe in earthquake misinformation are not stupid, they need to make sense of what is happening to them and find answers to their questions, especially about what is going to happen next. Because they are the most vulnerable to misinformation, specific attention to eyewitnesses should be given after an earthquake. It is therefore important to fill in the information void and answer eyewitness's questions, even if the only information is "we don't know". Based on EMSC's experience the public generally accepts this information and is thankful for it.
3. The fight against misinformation is as much a matter of communication as of tools design. Seismic informational products should be designed so that information production methods are explicit, understandable and transparent in case users want to learn more. They can be explained in FAQs for instance or through explanatory documentation. This may not completely avoid misunderstanding and misconceptions of the system but it will help get ready explaining it when misinformation actually appears.
4. Preventing misinformation is a long-term task involving team work. The mutual support of seismology institutes, local partners, and fact-checkers is vital as proven by the La Palma example. We need to join forces by sharing resources, best practices and specific knowledge about the cultural context in which misinformation takes place and proliferates. Also, partnership with social media platforms could be useful to report more efficiently problematic content. This issue here is to dilute the visibility of misinformation by improving the findability and trustworthiness of verified and scientific information. It is important to ask ourselves the question of the audiences that we do not yet reach, the most vulnerable (McBride et al., 2022), those who do not speak English, or who do not have accounts on social networks. Yet we must remain humble in our ambitions. While we can work to limit the appearance and effects of earthquake misinformation, it

is likely that we will never be able to completely stem the phenomenon, i.e., convince each person individually of the veracity of certain information. This is all the more important since earthquake misinformation is not separated from the socio-cultural context. Beliefs can be rooted into other social phenomena (e.g., the political or religious context, or the willingness of the individual to trust in science) over which we have little control.

5. Taking into account the cultural context is one of the most challenging elements in the future of the fight against misinformation, as it reaffirms that we cannot rely solely on content automation to pre-bunk and debunk misinformation. If the EMSC Twitter robot can in part prevent certain misinformation, it will not be sufficient on its own to adapt to all the cultural variations of the same information. For example, from one earthquake to another, the so called creators of the earthquakes are not the same (local or foreign governments, private companies…). The Twitter bot publication is essentially in English and only reaches English speakers in that moment, which is currently a strong limit for the EMSC tool. Although we use the word "earthquake" in the local language and Twitter allows user to translate content this may not be sufficient. We must therefore further adapt our response and pursue with a combination of automatic and manual tweets. We will also study the opportunity to have language specific channels on other platforms.
6. Tools and response strategies to misinformation must be constantly adapted to the type of misinformation and enacted in a timely fashion. For instance, if sometimes, misinformation shows itself through regular patterns, responding to it can be done through some form of automation, however, automatic tools are never completely sufficient. Besides, they are not suitable for other types of misinformation that do not follow any pattern. Moreover, misinformation, science, and the means of communication are constantly evolving and we must keep up to always respond as well as possible. Technology will quickly interfere in the debate since messaging apps are becoming more and more important, not only in terms of uses but also in the role they play in the spread of misinformation (Resende et al., 2019). How it is possible to spot and respond to this misinformation circulating on private networks where it is difficult to speak to everyone and in a visible way? For now, we can already focus on ways to improve the communication that is done on traditional social networks, such a Twitter and Facebook. Part of this work includes constantly improving the content, as well as the tone of the messages, i.e., by making better use of humor (Simis-Wilkinson et al., 2018; McBride and Ball, 2022).
7. Both at the individual and at the institutional level, the fight against misinformation seems disarming. It can paralyze some, leaving the impression that the problem is too vast and that the fight is lost in advance. Legal aspects may also come into play and the L'Aquila case is known to have affected the seismological community by making it more hesitant to communicate directly with the public (Alexander, 2010; Jordan, 2013). The EMSC benefits here from the freedom to set up its own communication and moderation strategy (Bossu et al., 2022). For example, we make sure not to encroach on the communication of the national institutes in the event of an earthquake. On the contrary, we support them if necessary. The experience of the EMSC (e.g., the explanation of the production and dissemination of data and information, the attempts at pre-bunking and debunking, or the establishment of networks of experts to better spot and respond to misinformation, etc.) shows that solutions exist, but they deserve to be further improved and to be even more coordinated with partners such as the authorities, education professionals, and the media.

Presenting the case studies the EMSC has encountered, the examples of misinformation it has faced, and the ways it has attempted to respond to it is not paradigmatic here. The implementation of recommendations and measures to combat misinformation has been adapted to the context of the EMSC. Its independence and the multicultural and global dimension of its audience are parameters that influence the implementation of these communication tools. Presenting our fight against misinformation is a way of taking a critical look at what has already been done and what remains to be done. We are confident our experience will be useful to other seismological institutions that provide information to the public and to the research addressing misinformation and ways to fight it.

Wherever possible, the effectiveness and usefulness of these tools will be assessed through quantitative and qualitative data. This will be the subject of future research for EMSC. However, we face a well-known problem in the world of risk management and communication: while it is possible to know when tools have been seen or used, it is almost impossible to know with certainty whether the messages spread have actually prevented the appearance or dissemination of false information, since, precisely they have not appeared and we have no way to know if they would have had without our actions.

6. Conclusion

The practical case of the EMSC's fight against misinformation shows the extent of the challenges seismology institutes face for this growing issue. Earthquake predictions and misconceptions about what science can and cannot do should not be considered inevitabilities. Actions are possible to counter them, and they can prove efficient. The EMSC example shows that fighting misinformation means putting people at the center of science and crisis communication.

That is, understanding their expectations but also anticipating what they might misunderstand or not believe. Considering these questions in advance, before misinformation even appears, is more effective than having to do it afterwards. The actions of the EMSC to combat misinformation are also an illustration of the phenomenon that Naomi Oreskes described in her 2015 paper "any major questions in earth science research today are not matters of the behavior of physical systems alone, but of the interaction of physical and social systems" (Oreskes, 2015). If scientists want their information to be understood, they must then also care about the public. It is therefore a collective work, from scientists and science communicators which must allow, for example, to develop scientific practice and its general understanding by the public, and to restore confidence in science.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

LF and MC took part in the earthquake misinformation working group and reviewed the literature. LF and RB analzsed the case studies and reflected on the solutions and worked on the redesign of the information system after the Mayotte case, along with other members of the EMSC staff. MC, J-MC, and RB worked on the redesign of the Twitter bot along with other members of the EMSC. LF wrote the first draft of the paper. RB, MC, and LF amended it and debated over the discussion section. 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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