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Public earthquake communication in Italy through a multi-source social media platform: The INGVterremoti experience (2010–2022)

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Communicating scientific information about earthquakes is an important and delicate issue in countries like Italy, where seismic risk is high. Furthermore, continuous and scientifically sound communication is needed, especially in recent times when social media have amplified the risk of being biased by misinformation, fake news and conspiracy theories. For this reason, we have developed a communication strategy for earthquake science and risk in Italy, mostly based on social media. The INGVterremoti platform was born between 2010 and 2012 with the goal of increasing scientific information released to the public, and also establishing a two-way communication channel between scientists and citizens. In the past 12 years, the INGVterremoti platform has gained trust and popularity, increasing the number of involved people, which amounts today to several hundred thousand. The platform consists of a coordinated suite of social media channels and a blog-magazine, where updates on ongoing earthquake sequences and posts on scientific topics are continuously published. Our end users are mostly citizens, but also authorities and media. Special attention has been given to interactions with the public, especially on our Facebook page, in order to understand their information needs, identify rumors and fake news, particularly in areas affected by seismic sequences, and address the most pressing requests. In this paper we describe the INGVterremoti strategy, the different media that we use, focusing on their strengths and weaknesses. We concentrate on the experience, carried out in the last few years, of the publication of provisional information on ongoing earthquakes, a long-standing issue strongly requested by our followers. The INGVterremoti platform has played a fundamental role in many seismic sequences of the past 12 years in Italy, starting from the Emilia sequence in 2012, to the central Italy one, started with the deadly earthquake of 24 August 2016 and still ongoing. Besides the periods of high attention after strong earthquakes, we used the INGVterremoti social media as a tool for releasing continuous and sound information to the public, and as a way to involve citizens in the communication arena.

KEYWORDS

Earthquakes, tsunami, social media, surveillance, communication, Italy, INGVterremoti, risk reduction

1 Introduction

According to some studies (Eraybar et al., 2010; Crescimbene et al., 2014), people's perception of seismic risk is generally low in countries, like Italy or Turkey for instance, where earthquakes or seismic sequences are frequent; therefore, communicating scientific information on earthquakes is very important. After the 2009 deadly earthquake in L'Aquila (Abruzzo) and the long series of social and judicial events that followed it (Amato et al., 2015; Cocco et al., 2015), the involvement of scientists in the communication arena was thought to be at risk. Indeed, the fear of being misunderstood or even caught in legal actions, as happened in the L'Aquila case, could have been a deterrent to scientific and risk communication during seismic crises or even before they occurred. It is known that the earthquake's unpredictability makes it very difficult to have correct, balanced communication to media and to the public, especially when people's fear increases, as after a felt earthquake, and even more during a long sequence of shocks affecting a region. An effective strategy for dealing with such a delicate issue cannot be limited to emergency communication but must include a long-term communication plan during "peaceful" periods, to build trust and possibly establish a two-way communication channel between scientific institutions and citizens. For this reason, after the L'Aquila case, the efforts of scientists have multiplied, both in quantity and in the diversification of tools and strategies, also thanks to the wide diffusion of social media. The potential of social media for managing emergency communication and actions and for disaster preparedness and response, has been widely demonstrated since the early phase of the first social media such as Twitter and Facebook (Peary et al., 2012).

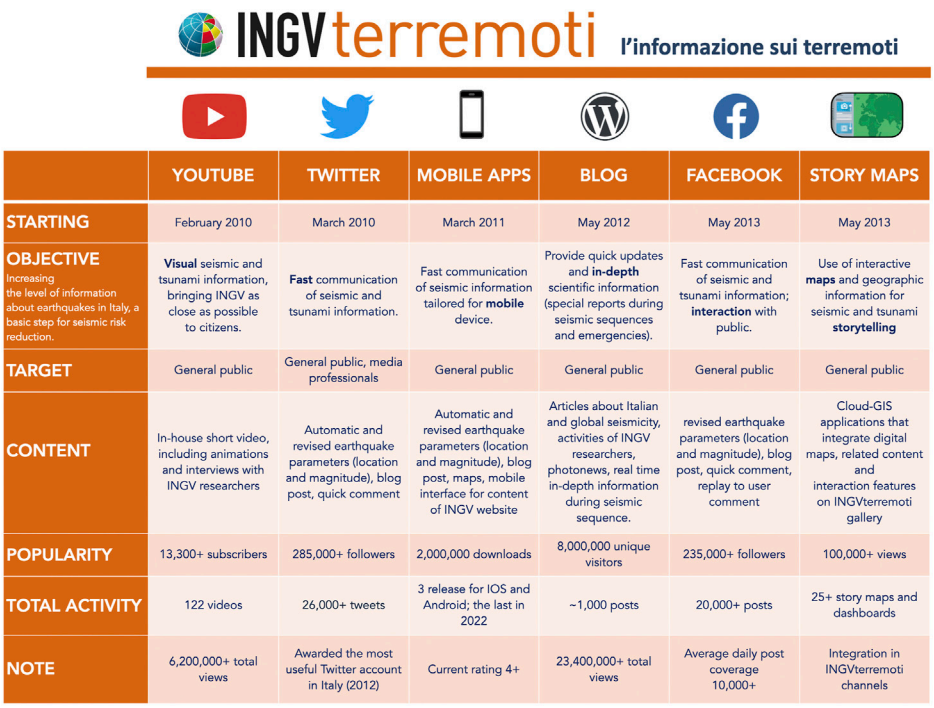
The INGVterremoti communication platform was born in 2010 with the main goal of getting closer to citizens, providing them updated and reliable scientific information on earthquakes, understanding their needs, and giving voice to their questions and fears. During the past 12 years, the INGVterremoti team has been working to diversify the information offer and broaden the audience using different social media channels (Youtube, Twitter, apps for mobile phones, Facebook, a blog and a suite of story maps) and adapting the information to the channel used. Moreover, we have been able to maintain a high publication rate during the whole period 2012–2022, as described in the following sections. This allowed the platform to gain trust and popularity, both on the web and on social media, increasing the number of involved people, which amounts today to several hundred thousand. Our end users are mostly citizens, but also authorities and media: the INGVterremoti tweets on earthquake activity appear often in the first pages of web and TV news magazines a few minutes after an event. Special attention has been given to interactions with the public, especially on our Facebook page, in order to understand their information needs, identify rumors and fake news, particularly in areas affected by seismic sequences, and address the most pressing requests. Among these, a special attention has been given to the rapid release of automatic locations/magnitudes for earthquakes in Italy, that from 2018 are released after a couple of minutes from the earthquake occurrence. The INGVterremoti platform played a fundamental role in many seismic sequences of the past 12 years in Italy, including the seismic sequence that began with the 20 May 2012, Emilia earthquake, and the one in central Italy that started with the deadly earthquake of 24 August 2016 (Pignone et al., 2016).

2 The INGVterremoti activities

In 2010, INGVterremoti team started to reorganize its communication strategy, thanks to a cooperation with Sissa Medialab, a company specialized in science communication. After a series of courses, attended by several tens of INGV researchers, a communication strategy was outlined (Cerrato et al., 2011). In the following 2 years, the cooperation between INGV and Sissa Medialab continued with a thorough analysis of strengths, weaknesses, opportunities and threats of the current communication activities at INGV, leading to a well structured proposal for a communication plan for the Earthquakes Department, in particular for INGVterremoti. (Balli et al., 2013).

The basic points outlined in the report were 1) the definition of the brand identity for INGVterremoti, 2) the objectives (which should be well defined according to the INGV mission), 3) the key themes to specific target audiences, and 4) the vehicle through which delivering the messages (different media for different audiences), and lastly, 5) the budget. Although not all the possible activities and channels could be implemented in the following years, the main idea of having a coordinated suite of web and social media channel for INGVterremoti was pursued, trying to follow the basic literature of science and risk communication (e.g., Renn, 2009, and references therein).

During 2010–2013 the social channels of the INGVterremoti platform were launched in succession (Figure 1). At national level, some of these experiences were pioneering in the area of communication of a scientific institution connected with civil protection, but even at the international level there were not many reference seismological experiences to draw from. At that time, all scientific institutions tried to exploit social channels to bring research closer to the public by skipping the interpretation of traditional media. A temptation that over time proved



	YOUTUBE	TWITTER	MOBILE APPS	BLOG	FACEBOOK	STORY MAPS
STARTING	February 2010	March 2010	March 2011	May 2012	May 2013	May 2013
OBJECTIVE Increasing the level of information about earthquakes in Italy, a basic step for seismic risk reduction.	**Visual** seismic and tsunami information, bringing INGV as close as possible to citizens.	**Fast** communication of seismic and tsunami information.	Fast communication of seismic information tailored for **mobile** device.	Provide quick updates and **in-depth** scientific information (special reports during seismic sequences and emergencies).	Fast communication of seismic and tsunami information; **interaction** with public.	Use of interactive **maps** and geographic information for seismic and tsunami **storytelling**
TARGET	General public	General public, media professionals	General public	General public	General public	General public
CONTENT	In-house short video, including animations and interviews with INGV researchers	Automatic and revised earthquake parameters (location and magnitude), blog post, quick comment	Automatic and revised earthquake parameters (location and magnitude), blog post, maps, mobile interface for content of INGV website	Articles about Italian and global seismicity, activities of INGV researchers, photonews, real time in-depth information during seismic sequence.	revised earthquake parameters (location and magnitude), blog post, quick comment, replay to user comment	Cloud-GIS applications that integrate digital maps, related content and interaction features on INGVterremoti gallery
POPULARITY	13,300+ subscribers	285,000+ followers	2,000,000 downloads	8,000,000 unique visitors	235,000+ followers	100,000+ views
TOTAL ACTIVITY	122 videos	26,000+ tweets	3 release for IOS and Android; the last in 2022	~1,000 posts	20,000+ posts	25+ story maps and dashboards
NOTE	6,200,000+ total views	Awarded the most useful Twitter account in Italy (2012)	Current rating 4+	23,400,000+ total views	Average daily post coverage 10,000+	Integration in INGVterremoti channels

FIGURE 1
The INGVterremoti platform: a coordinated suite of social media channels, including YouTube, Twitter, apps for iOS and Android mobile phones, a blog-magazine on WordPress, Facebook and a gallery of story maps.

simplistic and gave way to a more complex integration. Also Twitter was rising in that period, with major scientific institutions, - for example, U.S. Geological Survey (USGS), Geological hazard information for New Zealand (Geonet) and Euro-Mediterranean Seismological Center (EMSC) - opening their own channels (@Geonet, the Geonet account, joined on January 2009; @USGSted, the USGS account on June 2009; @INGVterremoti, the INGV account, on March 2010; @LastQuake, the EMSC account on October 2010) not only to communicate earthquake locations quickly, but, in some cases, also to use the information produced online by citizens to develop a crowd-sourced earthquake detection algorithms. This integration underlies the work of LastQuake (i.e. Bossu and Earle, 2011; Bossu et al., 2018), a multichannel rapid information system by EMSC, comprising websites, a Twitter quakebot, and a smartphone app for global earthquake eyewitnesses.

After 2013, INGVterremoti activity has grown, both in the number of posts, tweets, *etc.*, and in the variety of topics, researchers involved, and so on. Several choices have been made always looking at similar experiences carried out by similar agencies' best practice, including USGS, New Zealand Institute of Geological and Nuclear Science (GNS Science), and EMSC. Both USGS and GNS Science have a section of their websites dedicated to analyses and insights on specific themes (not only on earthquakes), although the number of posts dedicated to seismological topics is much more limited than what is done by INGVterremoti. Most efforts of USGS, GNS Science, and EMSC experts are devoted to post-event assessment and seismic sequence communication management and problems (Wein et al., 2015; Bossu et al., 2018; Becker et al., 2019; Wald, 2020; Ruan et al., 2022). An interesting analysis on the impact of INGV communication on the media comparing the two main seismic sequences of the last decade (the 2012 Emilia earthquake, the 2016 central Italy seismic sequence) has been carried out by Cerase (2017). A specific attention has been devoted in past years to the issue of contrasting misinformation on earthquake science (see, among many others, Kwanda and Lin, 2020; Dallo et al., 2022, for a recent review and references therein): some of the posts that have been published are related to unreliable or controversial information circulating on the web (e.g., swarms of small earthquakes inhibit the occurrence of large ones, confusing magnitude and intensity scales, induced seismicity, *etc.*). Moreover, the publication of automatic and provisional solutions described in Section 4 had among its goals that of limiting the spreading of false news about earthquakes in the minutes preceding the publication of revised solutions (wrong magnitudes, locations, *etc.*).

Today, INGVterremoti communication moves on two main lines: 1) "peacetime" activities: in the absence of seismic crises,

INGVterremoti team operates to promote a better scientific culture, also in view of the Italian people's inevitable coexistence with natural hazards; 2) "times of emergency", i.e., in the presence of damaging earthquake sequences going on, or even in case of attention by the media due to fear and anxiety in the population, as often happens during long seismic sequences, INGVterremoti responds to the citizens' information needs. Through the years, we succeeded in maintaining a continuous and high level of published contents, spread on the different channels of the platform. This has contributed to increase people's trust in our communication. Italy is a country where a large percentage of the population lives in regions with many natural hazards and related risks, therefore the relevance and the social impact of the research carried out by INGV are very high. Its institutional mission - stated in the INGV statute - includes constant and conscious communication, aimed at spreading a scientific culture of the territory and its characteristics, and the risks associated with them, including seismic, tsunami, volcanic, and environmental risks. The main objective of INGVterremoti towards the public is communication and information on issues related to earthquakes and tsunamis through all communication channels developed, also in case of seismic and tsunami emergencies. Since July 2018, the INGVterremoti on-call service has been activated to manage communication in case of emergencies and to provide 24/7 operation when a magnitude $M \geq 4.0$ seismic event happens in the national territory, as well as for other relevant emergencies.

3 The INGVterremoti platform

The INGVterremoti platform consists of a coordinated suite of social media channels, including Twitter, Facebook, YouTube, apps for iOS and Android mobile phones, some story maps and a blog-magazine on WordPress (Figure 1) where updates on ongoing earthquake sequences and posts on scientific topics are continuously published (Amato et al., 2012; Nostro et al., 2012; Pignone et al., 2016). In the first years of activities, each social channel has had its own history and specific development, until a general coordination among the different channels has been completed. In the following sections, we describe the evolution and the performance of the different social media; afterwards we discuss the main issues of the platform, with a specific focus on the interaction with citizens.

3.1 YouTube

YouTube was the first open social channel of the INGVterremoti platform and was inaugurated in February 2010, with the goal of increasing the level of information about earthquakes in Italy, which represents a basic step for seismic risk reduction (Amato et al., 2012). The main objectives of this initiative, which started a few months after the 2009 L'Aquila earthquake, were to inform the public about the seismic activity in Italy, in the Euro-Mediterranean area and in the world, to communicate the results of scientific research in seismology, and to increase the knowledge of the seismic hazard. The choice was to publish short films (lasting less than 5 min) intended for the general public, including interviews with INGV researchers using simple and immediate language with the goal of bringing the INGV as close as possible to citizens. Over 120 videos have been posted to date, most of which have been produced with "in-house" resources and non-professional equipment and software. Although this sometimes results in low-quality technical content (e.g. audio, lights), we have preferred to focus on the scientific content rather than spending too much time on the various aspects of film-making. The videos published on the channel are organized in 16 different thematic playlists on earthquakes in Italy, seismic hazard in Italy, seismic monitoring, world earthquakes, tsunamis, and some relevant seismic sequences (the 2016 central Italy seismic sequence, the 2012 Emilia earthquake, the 2009 L'Aquila earthquake).

The YouTube/INGVterremoti channel has been integrated into the INGVterremoti blog since its publication in 2012. As described in Section 3.4, in the first months of the blog's activity, during the seismic sequence in Emilia in 2012, we have introduced the videos within the posts in order to get a better dissemination and understanding of the message. An emblematic example is the video "the Po Plain Seismic Sequence on May 2012 - The Buried Faults", published on 8 June 2012 and inserted in the post published the same day. This video was seen by more than 72,000 people, about one-half of which has reached it from the blog post, demonstrating a proficuous interaction of the two communication tools. Also in the following periods, the YouTube/INGVterremoti channel published many new videos, integrating them all with posts and some static pages of the blog. The development of the blog, the YouTube channel, and the sharing of content on the various social channels was useful for strengthening the dissemination of authoritative information, both during small and large seismic emergencies, and to narrate the research activity on earthquakes and tsunamis. Even during the 2016 emergency in central Italy, the constant presence of timely information through the INGVterremoti blog and social media has favored the release of a correct information on national media, reducing the need of looking for alternative sources by TV and newspapers.

The YouTube/INGVterremoti channel has been very important as the main information hub during the information crisis following the fake prediction of a destructive earthquake that was supposed to hit Rome on 11 May 2011. The story of the prediction and of the countermeasures taken by INGVterremoti is described in Nostro et al. (2012), whereas the long series of videos

published before, during, and after that long day is still visible in a specific playlist.

In 2013, one of the videos on the INGV-Rome Control Room was selected by AGU for the session "AGU Cinema 2013" and projected during the whole duration of the fall Meeting. From February 2010 to April 2022, all the videos posted on the channel had a total of more than 6,260,000 views and the video "Tsunami" (in English), the most watched since the opening of the channel, had about 2,740,000 views. Several videos were seen by more than 100,000 people worldwide, with a majority in Italy (most of the videos are in Italian). The audience numbers described in this study are encouraging and confirm a growing interest, as evidenced by the number of shared videos and the comments of the 13,300 subscribers. Between the 10 most viewed videos, five places are occupied by shakemovie animations, the visualizations of 3D high-resolution simulations of seismic wave propagation for earthquakes in the Italian region with magnitude $M_w \geq 5$, nearly automatically generated within a few hours of their occurrence (Casarotti et al., 2016). Each video has hundreds of thousands of views and has been picked up not only by social media but also by more traditional systems such as news broadcasts. The reason for this large audience is to be found in the readiness with which these videos are released. Our motivation for creating a quasi-automatic system for generating these animations is to meet the demand for rapid scientific information but also to help the visualization of a natural phenomenon that we only visually perceive for its catastrophic aftermath.

3.2 Twitter

The INGVterremoti account on Twitter started its activity in March 2010 to provide constant and timely messages about seismic events localized by the seismologists working at the INGV-Rome Control Room which provides seismic surveillance and tsunami alert services (Amato et al., 2021; Margheriti et al., 2021): earthquakes in Italy with magnitude equal to or greater than 2.5 (M2.5+), in the Euro-Mediterranean area with magnitude equal to or larger than 5.0 (M5.0+) and in the world (M6.0+). Most of the tweets are basic data on ongoing seismicity (events' location, origin time, magnitude, affected areas), but in the last few years more general information has also been published, including links to articles published on the INGVterremoti blog-magazine, *etc.*

In the period 2010–2018, the INGVterremoti account on Twitter provided only tweets with locations and magnitudes after the manual revision by seismologists on duty at the INGV Control Rooms in Rome, Naples and Catania, available within 30 min of the earthquake occurrence (most often within 20 min). This procedure was adopted because it warrants the production of only official and validated information about an earthquake, thereby helping stem potential rumors or misinformation related, for instance, to the earthquake's magnitude, in case of initial under- or over-estimation. However, timing has always been a critical element for this communication, particularly in the past few years due to the diffusion and speed of social networks (Figure 2) In fact, revision of a seismic event by on-duty seismologists includes waveforms' re-picking for P and S-waves identification at several seismic stations, computing hypocentral parameters and local magnitude, checking of the results, *etc.*, an operation that generally takes several minutes, typically 8 to 20, with more time needed for large earthquakes. Undeniably, mobile internet, social network sites, and Twitter in particular require a more rapid and "real-time" reaction, due to a large number of comments and questions coming out in the immediate wake of a felt earthquake. So in the following years (2012–2018) we have worked for the release of provisional but rapid information and thanks to a specific study (see Section 4) we have identified the necessary conditions to limit the diffusion of false or wrong seismic event locations and, also, to define the correct syntax of the tweet text with the provisional location. In Section 4, we describe in detail how we faced this problem, moving to the publication of fast, preliminary, unrevised information with locations/magnitudes for earthquakes in Italy with magnitude larger than 3.0, released after a couple of minutes, initially only on Twitter @INGVterremoti, later also on the INGV earthquake list web page and also on the iOS/Android apps.

Among the followers, besides citizens, students, teachers, scientists, and journalists, there are several media agencies at national and local levels, including mainstream TV channels that publish the tweets as soon as they are available online. In 2012, after the Emilia seismic sequence, this account was voted as the Italian "Most useful Twitter account" at the "Macchianera" social media national award. In the period March 2010 - October 2022, @INGVterremoti has issued about 27,000 tweets (about 2,000/year) increasing its followers to more than 292,000. For comparison, the @USGS_Quakes account has 248,800 followers and the EMSC @LastQuake account has 225,100 followers (both on 18 October 2022).

3.3 Mobile apps

Since 10 March 2011 (1 day before the 2011 Tōhoku earthquake), the INGVterremoti app for iOS has been distributed in the App Store. It was the first native seismological app released by a scientific institution. The goal was to provide fast communication about seismic information tailored to mobile users, an audience that was beginning to be dominant. This app shows data on the most recent earthquakes occurring on Italian territory and, is limited to the strongest events, in the rest of the world. They also make it possible to view Italian seismicity from 2005 onwards, *via* the Search section. Special attention has been paid to scientific information

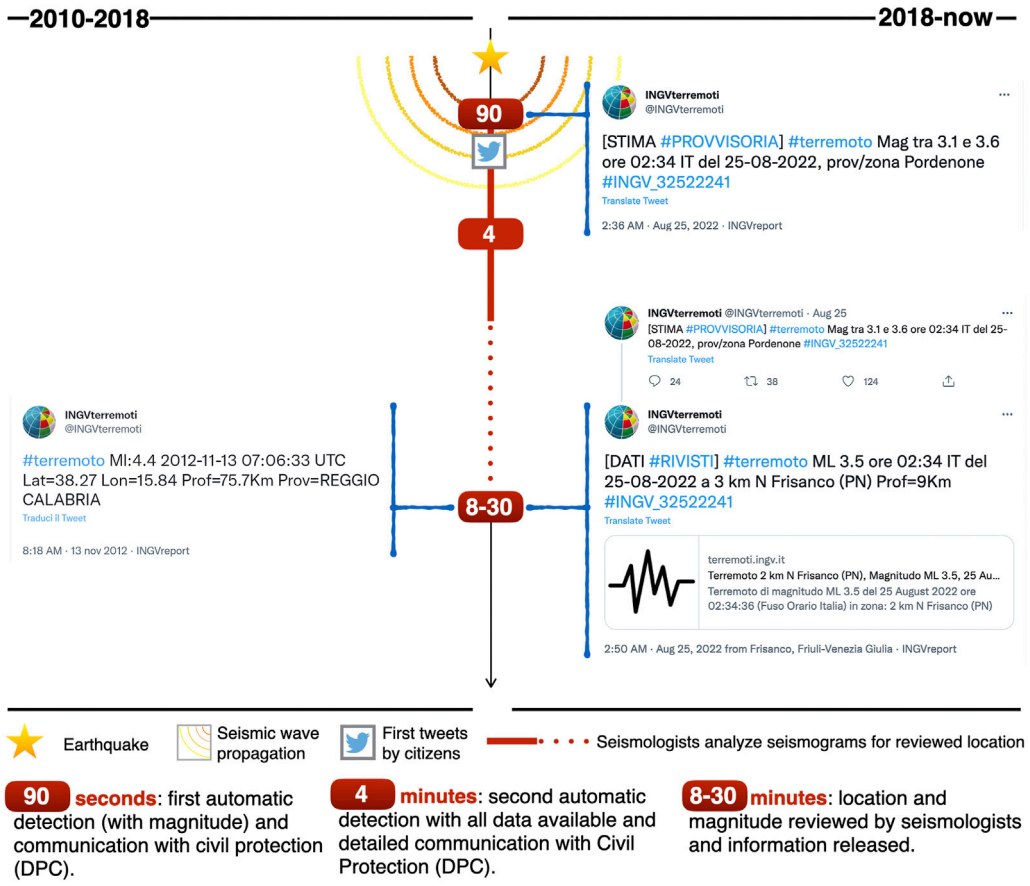


FIGURE 2
Timing of the localization of an earthquake with the systems of the INGV-Rome Control Room; the temporal sequences described above are pre-2018 on the left and the current one on the right, after the publication of the automatic solutions starting on September 2018. Seismologists can review preliminary data strictly within 30 min of the event. In 95% of cases, communications of revised data are made between 8 and 20 min after the earthquake. In addition, the figure shows some examples of tweets according to the sintax and the rules valid before 2018 (left side) and now (right side).

regarding earthquakes with sections linked to the INGVterremoti blog-magazine. When the app was first released, the mobile app market was in its infancy, at least in Italy. Therefore, due to the novelty and the efficiency of a product released by a renowned scientific institution, during the seismic crises ranging between March 2011 and July 2013 the INGVterremoti app repeatedly ranked in the top 10 positions among the most downloaded apps in the Apple App Store (Italy). This app has been constantly updated (3 main releases) both due to the evolution of the technological platforms in which they operate, and due to the changes of the INGV seismicity information service of which they are an integral part. In 2011, the main feature of the original release was that the entire Italian seismic INGV catalog since 2005 was downloaded to the device during the installation to allow the app to function without data connection (e.g., in remote areas or during an earthquake emergency). The improvement of the mobile data coverage in Italy and the creation of APIs to programmatically access the INGV earthquake database have made the presence of the entire catalog within the app a feature no longer necessary in the following releases of the app. Therefore, in 2016 a completely new version of INGVterremoti app has been developed and distributed, not only for iOS but also for Android. Since 2021, the apps show even the provisional earthquake location with the features and limitations described in Section 4. In 2022, the iOS version has been completely rewritten, deeply graphical renovated and released in the App Store. The main feature requested by users but still missing is the presence of a push notification service. This feature has not yet been implemented due to concerns about releasing a notification service that is impeccable in timeliness and robustness, linked directly to INGV, which is the authoritative institution for seismicity for the Italian government. However, the next version of the app will have this feature and is at an advanced stage of testing.

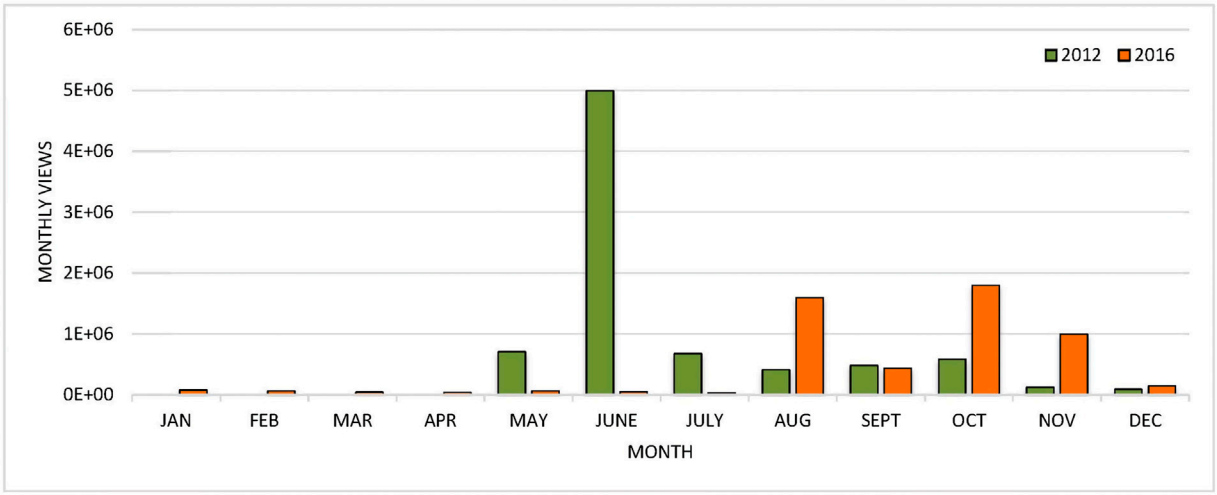


FIGURE 3
Number of the INGVterremoti blog monthly views in 2012 and 2016.

3.4 Blog-magazine

Even if the INGV websites for many years have provided information in quasi real-time about all the earthquakes in Italy, the strongest events in the Mediterranean and in the world, we know that this is not enough. Soon after an earthquake, people look for more news, more specific and detailed information on the region, on previous earthquakes, on the seismic hazard, and on the evolution of the seismic sequence, on the web and social media. For this reason, in the days after the 20 May 2012, Emilia main shock (M_w 5.8), we opened a new blog on WordPress, also called INGVterremoti, to provide quick updates and in-depth scientific information (Pignone et al., 2012). Providing continuous and timely information is particularly important when seismic sequences last for several weeks or months and are characterized by several felt earthquakes, also to counter the bad information, and to fight rumors and fake news that always arise during seismic crises. All the information published on the blog is shared on the other INGVterremoti social media (Twitter and Facebook) and also through the iOS/Android apps.

The blog has continuously released information with three different types of posts:updates on seismic activity; information on the activities carried out by INGV groups in the epicentral area; insights with an increasingly accurate analysis of the available data and the specific results obtained.

In the first 8 months of activity (May - December 2012) 92 out of the 132 articles published on the INGVterremoti blog were dedicated to the Emilia seismic sequence.

The INGVterremoti blog played a central role in the communication also during the long 2016–2017 seismic sequence in central Italy. This seismic sequence began on 24 August 2016 with the deadly M_w 6.0 earthquake affecting the town of Amatrice and other towns and villages of the Rieti province. 109 posts were published in the first 24 months of the sequence. In particular, of the 119 posts published in 2016, 83 are related to the seismic sequence in central Italy and stand out among the most viewed articles in 2016. All blog posts were shared in real-time on the other social media of the INGVterremoti platform (Facebook, Twitter, and iOS/Android apps) and also on the INGV main home page. Even the INGV real-time data portal has published the contents of the blog on dedicated pages that have been automatically fed. The day-to-day work carried out on the INGVterremoti blog during the emergency in central Italy was shared with the INGV Press Office which drafted several press releases based on the contents of the blog.

If we compare statistics of the monthly views in 2012 and 2016 (Figure 3), we note that the blog had the peak of monthly views (5 million) in June 2012 due to the Emilia, 3 June 2012 earthquake (magnitude M_L 5.1). Thanks to the 83 articles published on the seismic sequence in central Italy, in 2016 the blog had a total of more than 5.4 million views and 2.9 million visitors (Figure 4). The peak in the number of views, which was over 830,000 in a single day, was recorded on 24 August 2016, after the M_w 6.0 earthquake that started the sequence.

The INGVterremoti blog has maintained the 2012 original setting until March 2020, where the home page had the timeline of the latest articles and some static pages on general topics: Earthquake in Italy, Seismic Risk, Seismic monitoring, FAQs and Glossary, Story Maps. From May 2012 to March 2020, we published 685 articles, about 85/year on average, 1.6/week, highlighting one of the key performance indicators regarding perseverance. Most of the post are in the “Earthquakes in Italy”

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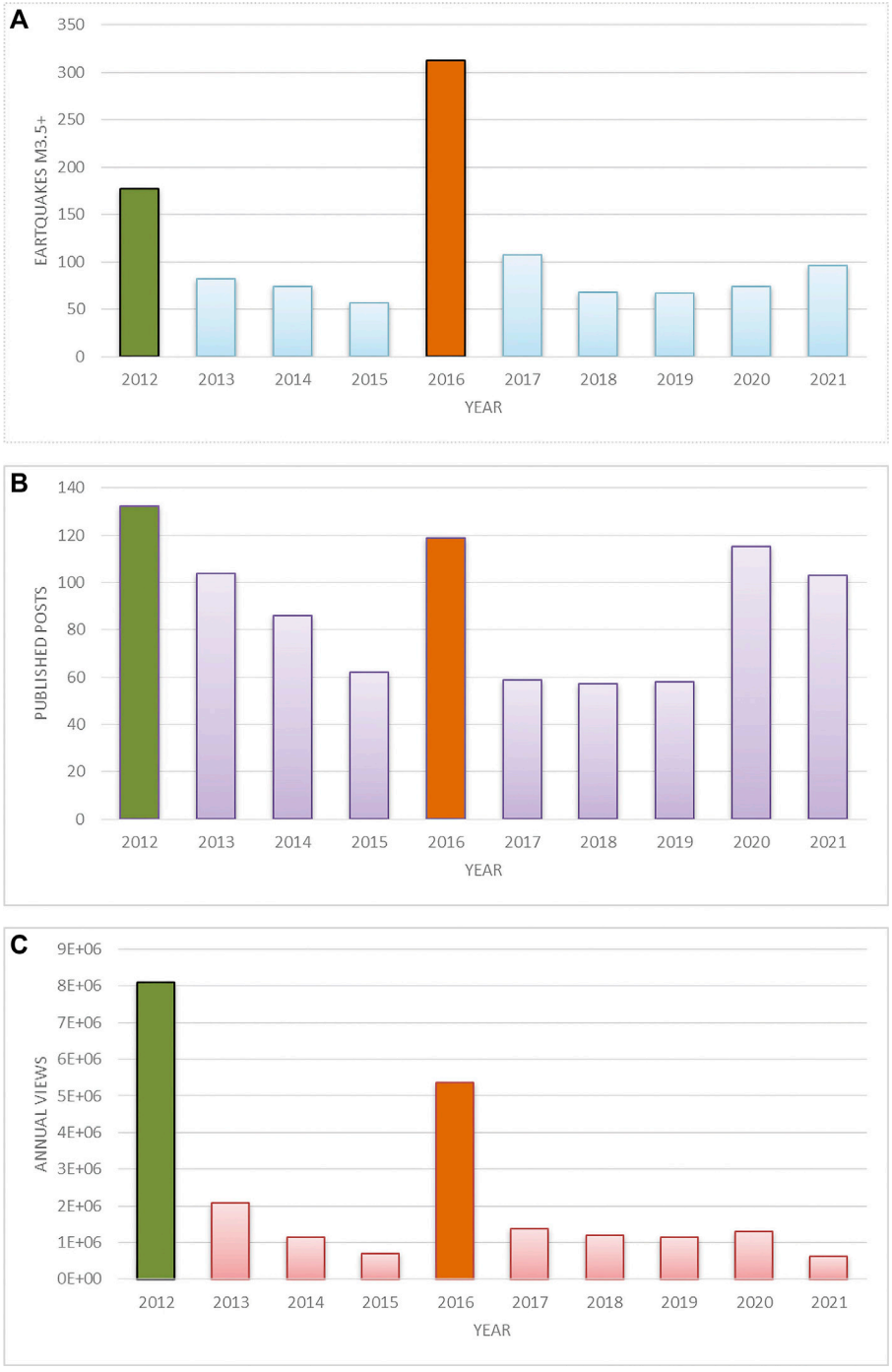

FIGURE 4
Comparison between: **(A)** annual number of earthquakes with magnitude M3.5+ in the area that also includes Italy (lat. 35–49; long. 5–20); these are events that also occur outside the national territory; **(B)** annual number of articles published on the blog; **(C)** annual number of blog views. We note that the blog had the peak of monthly views (5 million) in June 2012 for the Emilia, 3 June 2012 earthquake (magnitude M_L 5.1). This is probably due to the fact that INGV websites in 2012 had many difficulties in being reached by a huge number of users such as those involved in the Po Valley area. The reachability problem of INGV websites was solved in the following years, and the sharing of earthquake data on different INGVterremoti social media was implemented considerably, so the blog in 2016 had a lower views number than in 2012, even if still relevant: 1.6 million in August 2016, 1.8 million in October 2016 e 1.0 million in November 2016.

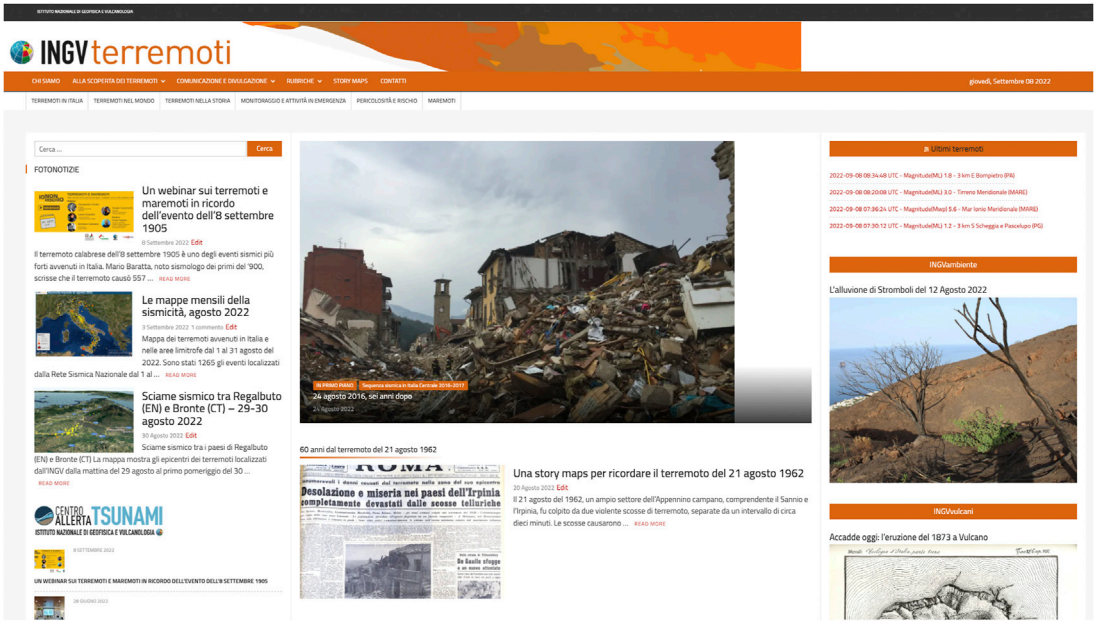

FIGURE 5
Home page of the blog-magazine INGVterremoti in 2022. The INGVterremoti blog menu reflects the new organization of static content and article categories.

category and therefore related to the seismic activity in Italy. In particular, 15 main seismic sequences have occurred from 2012 to 2020 in different regions of Italy (Campania, Toscana, Abruzzo, Umbria, Molise, Lazio, Calabria).

In March 2020 the new INGVterremoti blog-magazine was published, after a 1-year long phase in which a new interface was designed, in coordination with the three INGV departmental blogs (INGVterremoti, INGVvulcani and INGVambiente). A huge work has also been done to achieve a common reorganization of the contents for the three INGV departmental blogs in collaboration with a specialized company through specific on-the-job training. The following points were addressed:

- the analysis of the communication of the three blogs,
- the evolution of communication from blog to e-magazine,
- choice of a new theme, migration from the old to the new one.

A new theme, common to the three blogs, was chosen in order to move from a traditional communication format of blogs (a single chronological time-line for articles) to an interface closer to an e-magazine with a multi-home content management and a greater integration with the social channels of the INGV departmental platforms (Pignone et al., 2020). The new theme allowed blog managers to create various "thematic" time-lines of articles on the INGVterremoti.com homepage, choosing from the various Categories. The new Home page (Figure 5) is much more complex than the previous one and places a slider with the most recent article in the center at the top, immediately below the double menu of the static pages and categories, which reflects the new content organization. On the side, there are the timelines of the articles of the category Photonews ("Fotonotizie"). Photonews is a novelty of this theme, "mini" articles structured with an image and a dozen lines of comment: a faster way to update the magazine with more dynamic and lighter content.

In the vertical development, the structure accepts different timelines to be assigned to a specific theme by selecting the articles of some Categories or Subcategories. Some widgets have been inserted on the right bar: among them there is a link to the last article of the other two INGV departmental blogs. The result of the restructuring perfectly reflects the original idea that prompted the revision and reorganization of the three blog-magazines that today have the same interface and structure. The new version of the INGVterremoti blog-magazine was online at the beginning of March 2020 with the new web address: http://ingvterremoti.com.

This new web page structure facilitated the creation of contents: 115 (68 articles and 47 photonews) and 103 (55 articles and 48 photonews) posts were published in 2020 and 2021, respectively, numbers very similar to those of the years with large seismic sequences. In 2020 there were 1,3 million page views and in 2021 about 623,000. It is

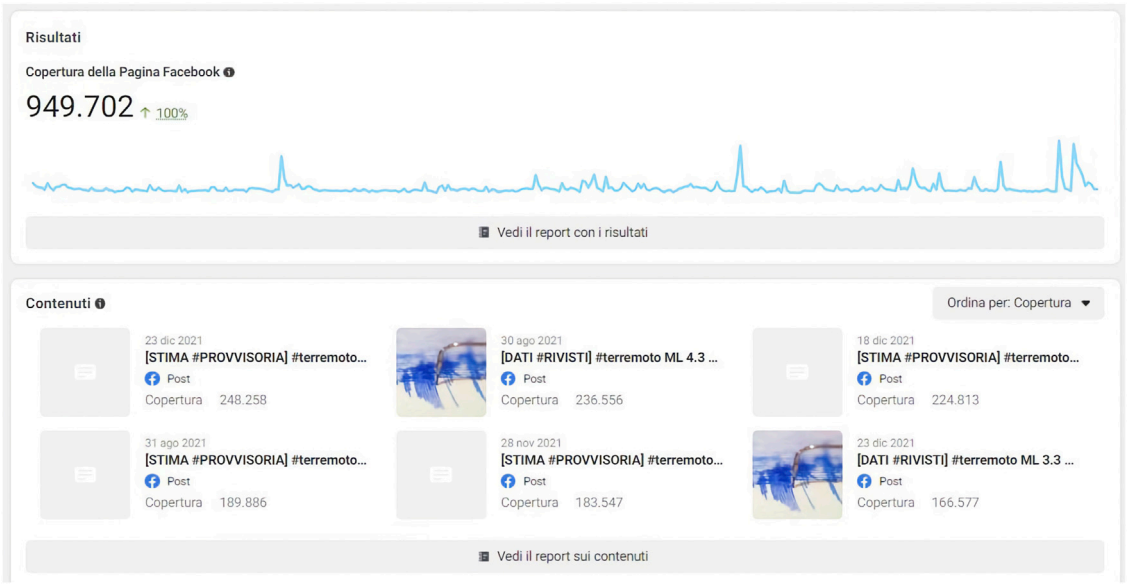

FIGURE 6
The 2021 statistics for INGVterremoti Facebook page, where "Copertura" is Post reach.

important to note the larger number of articles compared to previous years, also considering that no major seismic emergencies occurred. Coherently, among the most viewed articles of the last 2 years, there are not only those related to ongoing seismicity but also in-depth articles (such as, for example, one on the 1908 tsunami and some of those published for the 40th anniversary of the 1980 earthquake in Irpinia-Basilicata, as well as others on the seismic surveillance and monitoring activities during the lockdown due to the COVID-19 health emergency.

In 2022, the blog's homepage was lightened to facilitate consultation from the mobile phone. Indeed, the analysis of accesses to the blog-magazine revealed that mobile phones represent 80% of the devices through which the blog is viewed.

3.5 Facebook

After the 2012 Emilia earthquakes, in 2013 we opened the INGVterremoti page on Facebook to publish, in a similar way to what was already happening on the Twitter channel, data about seismic events in Italy with magnitude equal to or greater than 2.5, quick updates on seismic sequences and to open two-way communications with users. In addition to locations of the M2.5+ events in Italy, M5+ earthquakes in the Euro-Mediterranean area and M6+ global events are automatically published on the Facebook page. The aim is to reach the broad public using Facebook as its only or preferred social media. Furthermore, all the posts that come out on the INGVterremoti blog-magazine (Section 3.4) are published automatically on Facebook page. On the occasion of some of the most significant earthquakes, provisional estimates of the locations of the INGV-Rome Control Room have been published since August 2018, with manual intervention by the page managers (who are part of the INGVterremoti team), to respond to users' requests to know where a felt earthquake has occurred, and how strong it was. In these cases, it has been observed that the post with the provisional estimate ([STIMA #PROVVISORIA]) has great resonance, far superior to that of the post with the revised location. If we look at the 2021 statistics (Figure 6), the posts with the largest coverage are those related to preliminary locations. The post related to the provisional estimate of the 23 December 2021, M_w 4.3 earthquake in the province of Catania (Sicily) had over 263,000 impressions, 248,000 reach, 475 shares (see Facebook notes), while the one with the revised data of the same earthquake had over 27,000 impressions, 26,000 reach, 26 shares (Figure 7).

Since 2013, more than 20,000 posts have been published (including location revised by seismologists, preliminary locations/magnitudes and blog articles), with average daily post coverage close to 10,000–15,000 people and peaks over 100,000 during a seismic sequence or when a relevant earthquake occurs. Currently, the INGVterremoti Facebook page has more than 235,000 followers and is the only social network that provides two-way communication with our users. In Section 5 we describe the interactions with followers, a very heterogeneous audience that includes people of all ages and education levels. In the coming months, provisional estimates

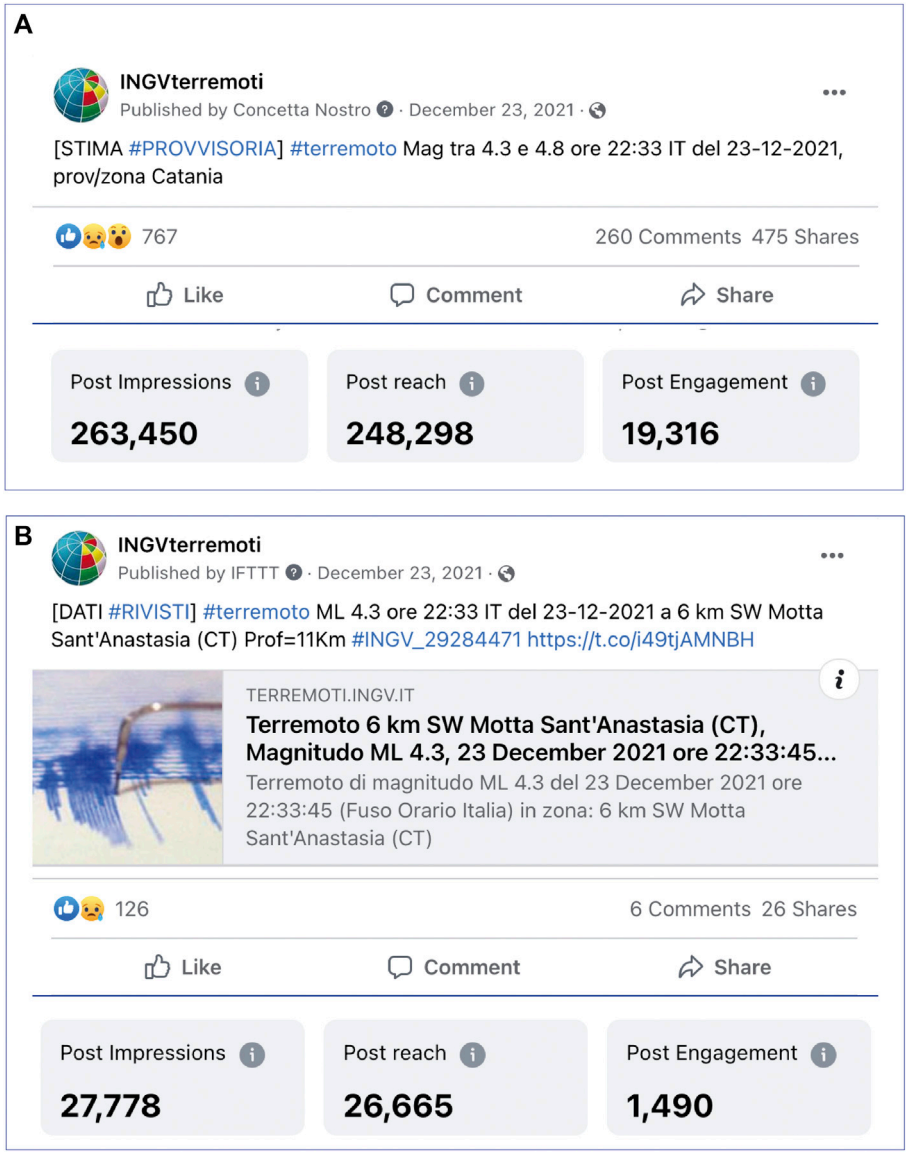

FIGURE 7
The post with the greatest coverage in 2021 is the one related to the preliminary location **(A)** of the 23 December 2021, M_w 4.3 earthquake in the province of Catania (Sicily). **(B)** Post with the manual revision by seismologists on duty at the ONT-Rome control room.

will also be published on the Facebook page with a procedure linked directly to the notification systems of seismic events, in a similar way to what already happens for Twitter.

3.6 Story maps

Since 2013, INGVterremoti has used story maps as a new communication and information channel on seismicity and seismic risk of the national territory. Numerous story maps have been developed to tell the various aspects of the earthquakes that have struck in the past, and in recent years, our country by integrating descriptive, photographic and multimedia information with georeferenced data from the INGV seismological and seismotectonic databases (Pignone, 2015). A story maps is an integrated set of digital maps, related content (legend, text, photos, videos, *etc.*) and interaction features (pan/zoom, pop-up, query, select, *etc.*) that make it an easily understandable and an immediate information and communication product. For this reason they have also

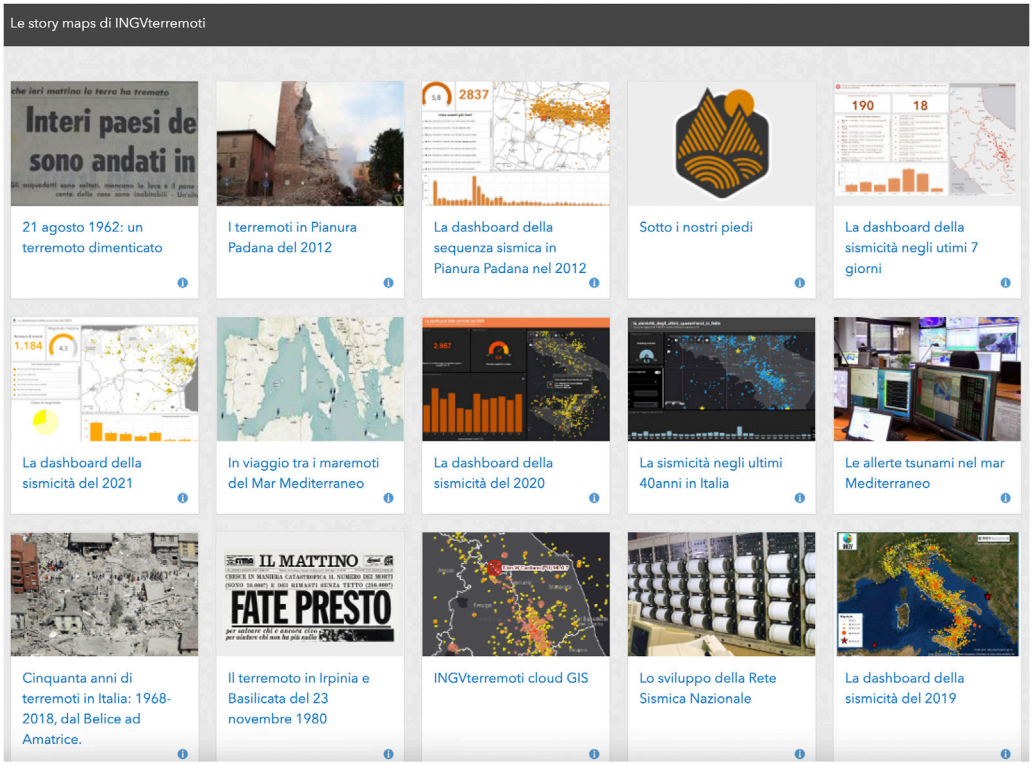

FIGURE 8
ESRI ArcGIS online gallery with the latest published INGVterremoti story maps and dashboards.

become a very valid tool in the outreach public events that INGVterremoti promotes through the use of touch screens that allow you to create real exhibits with which to interact with the public, demonstrating the potential of geographic information in risk communication. After the creation of the story maps, it was decided to also use the web applications of the dashboards type that allow you to make various tools for viewing the datasets and related attributes available, in order to create simple info-graphics, very effective for communication and information for inexperienced users. From 2013 to today, over 25 story maps and dashboards (Figure 8) have been created to describe some of the most important earthquakes and tsunamis of the past in Italy and in the Mediterranean area, and to analyze some of the recent seismic sequences that have affected the Italian territory. There were overall about 110,000 views of the published story maps and dashboards.

Story maps and dashboards are published in a thematic gallery available on ESRI-ARCGIS.com and have been easily integrated into the INGVterremoti web and social communication channels. These web applications represent a useful tool for information on seismicity in progress, on the most important seismic sequences in Italy, on the earthquakes and tsunamis of the past. A section is available on the INGVterremoti blog-magazine which collects the main story maps and dashboards published in recent years.

4 From "slow" revised information to fast automatic data

As a result of the "real-time" nature of social network sites, the time gap between the immediate conversations about an earthquake that takes place on social media, and the official INGV communication, was causing public dissatisfaction, failing to fulfill the need for timely information. Nevertheless, in Italy, the communication of automatic detections, including hypocentral locations and magnitudes, as done by other seismological agencies (e.g. CSEM, Geonet) raised doubts not only from emergency communication experts and civil protection workers but also among INGV seismologists. Among the issues raised was that the public would not understand the provisional nature of this communication. Monitoring the conversation on social networks showed that "evolving" values of earthquake parameters could be seen as: "errors due to ineptitude", "you are hiding the truth", and "conspiracy". Tweeting the automatic detection could increase the risk of unfruitful debates around magnitude or conspiracy

theory (e.g. the history of the fake news of the magnitude of the M_w 6.5 30 October 2016 Norcia earthquake documented by valigiablu. it).

It is important to consider that the issue of misinformation is critical in Italy. Differently from other countries, such as New Zealand (see, for instance, (Wein et al., 2015); (Becker et al., 2019)) where the public acceptance of uncertainties and revised estimates seems to be higher, a change in seismic parameters, as, for example, a revision bringing to a magnitude lower than the initial one, is immediately interpreted by many as a fraudulent attempt of minimizing the risk. It happened that after the 2009 L'Aquila earthquake, for which the magnitude Mw was estimated between 6.1 and 6.3, but the Richter magnitude was calculated as 5.9, that this latter value (still present in the INGV website) was criticized because it was erroneously confused with the threshold of the Mercalli (MCS) scale according to which only municipalities with observed degree six or above had the right to be refunded by the State. This and other similar issues still happening today after any relevant earthquake often hold the stage for a long time after an earthquake even on national TV channels and newspapers.

For this reason, INGVterremoti always tries to be fast in releasing earthquake information, but at the same time takes particular attention to the accuracy. To address this issue, the INGV planned the communication of the provisional locations and magnitudes *via* Twitter after a quantitative assessment of user understanding - through an online survey - also exposing the degree of uncertainty of the automatic estimates (Comunello et al., 2015). This assessment is the result of collaboration between domain scientists and communication experts through the PRIN Shakenetworks project led by CORIS (Department of Communication and Social Research, Sapienza University of Rome) (Comunello and Mulargia, 2018). In particular, during the summer of 2014, INGV carried out a quali-quantitative study (through in-depth interviews and a 51-question web survey) in order to evaluate the best format to deliver automatic information involving the Twitter followers and citizens in general. The goal was to improve the comprehension of @INGVterremoti tweets and timeline, focusing on selecting words, structure, and information of automatic detection tweets. This survey is the first experiment to involve citizens and the media to consider earthquake parameters as evolving estimates as long as new data become available and analyses results become more reliable. The survey obtained 1,224 completed responses and the results are detailed in Comunello et al. (2015). Here we highlight that respondents place great importance on official information within 2 min of a seismic event. Respondents' preferences on the information they value most drove both syntax and wording, as well as the order of topics within the tweet, with the most relevant information at the beginning of the text. Local time was inserted, substituting the previously used UTC time; the label [STIMA #PROVVISORIA] ("provisional estimate") was chosen. We valued the concept of provisional estimate as the most important information to be conveyed, in order to avoid misunderstandings in case of differences between the automatic and the reviewed parameters. The automated tweet is always followed by a second tweet as a reply to it, containing the parameters reviewed by the seismologist, in order to show the evolution of the estimates. The quantitative analysis of user comprehension has laid a solid foundation both for reducing misunderstandings and to face possible criticisms. In order to satisfy the need to communicate "provisional estimate" within 2 min of a seismic event, we explored a set of parameters to define the reliability of automatic detections, balancing timeliness with the robustness of information. The goal is to communicate provisional estimates for as many events as possible, avoid false alarms (events that are reported but did not actually occur) and reduce cases where automatic parameters differ substantially from those reviewed by seismologists. Thus, analyzing the solutions provided by the seismic monitoring room for the Italian territory, four reliability thresholds were defined. Automatic localization of a seismic event is then considered for open communication only if all the following conditions are true: 1) magnitude M greater than or equal to three calculated on a number of channels greater than 10·M; 2) more than six observations; 3) root mean square $<$ 1.5 and error in depth $<$ 10.0 km; 4) azimuthal gap between seismic stations $<$ 180°, distance from first station $<$ 100.0 km. Thus, applying the previous conditions to the seismicity that occurred in the Italian territory from 1 January 2013, to 1 September 2018, we found that 78% 1,432) of earthquakes with a magnitude greater than three were judged reliable (Figure 9). In contrast, there would have been six false alarms (0.3%), in general, due to temporary technical problems or simultaneous events or deep events.

Based on these results and supported by the user comprehension survey, we decided to provide the provisional magnitude estimate as a range of values (precisely -0.3 and +0.2 from the central value). Considering this range of values for reliable earthquakes, we observe that 5% of these have revised parameters that visibly deviated from the provisional magnitude range (Figure 10) or from the spatial location by more than 20 km. Expressing a range of values in which the magnitude is included is a choice that highlights the associated uncertainty.

These analyses were adequate to allow Dipartimento della Protezione Civile (DPC) and INGV representatives to shift the communication paradigm from immutable over time, monolithic localization parameters, to prompt estimates including uncertainties, that evolve with improved analysis and new data availability. Since September 2018, first on the Twitter account, then on the INGV earthquake list website and on the iOS and Android apps, automatic solutions are posted through the syntax shown in Figure 2. In Figure 11 we show the geographical distribution of earthquakes (since September 2018)

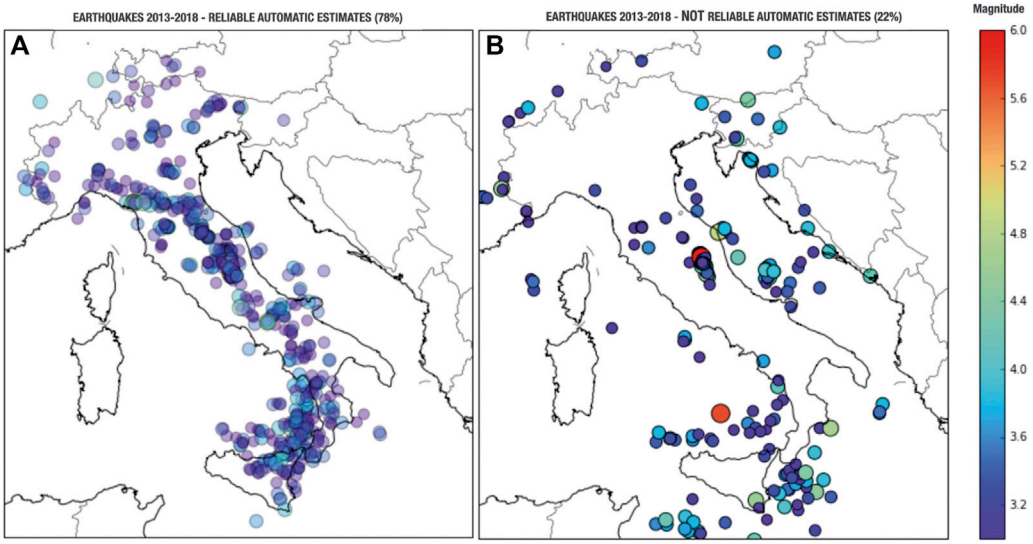

FIGURE 9
Earthquakes with M ≥ 3 recorded from 1 January 2013 to 1 September 2018 in Italy and surrounding regions **(A)** reliable automatic estimates (78% of all the events with M ≥ 3) that satisfy all the following conditions: a) magnitude M ≥ 3 calculated on a number of channels greater than 10·M; b) more than six observations; c) root mean square < 1.5 and error in depth < 10.0 km; d) azimuthal gap between seismic stations < 180°, distance from first station < 100.0 km **(B)** automatic estimates that don't satisfy the conditions of reliability The unreliability of the automatic solutions increases during important seismic sequences (i.e., the 2016 central Italy sequence) since waveforms from several earthquakes could be overlapping.

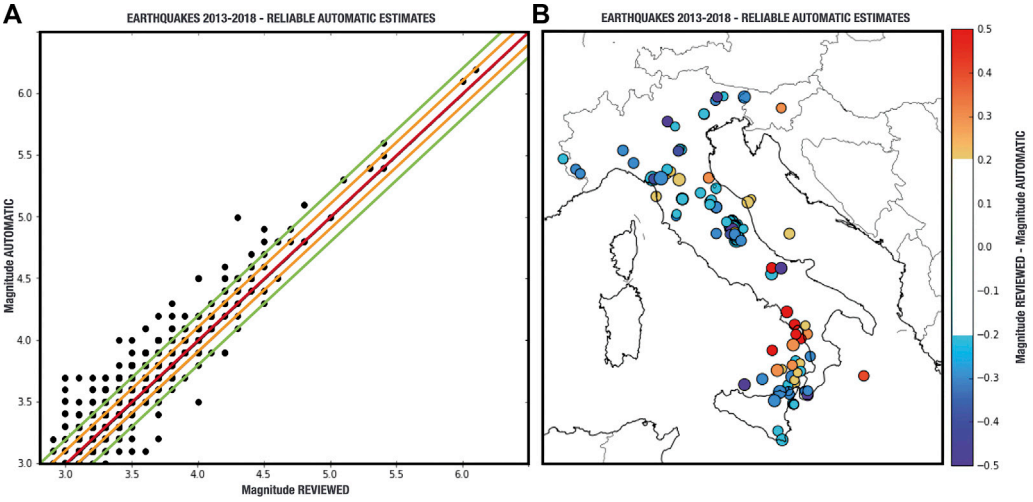

FIGURE 10
Analysis of the difference between automatic and manually revised magnitude for reliable automatic estimates **(A)** Distribution of reviewed magnitude of reviewed M_L vs. automatic M_L, the lines highlights difference with 0.1 step **(B)** map of automatic reliable estimates with difference in magnitude greater than 0.2, higher differences correspond to deep events located on the subduction of the Calabrian Arc that usually shows higher error in the automatic location.

for which provisional parameter estimates were reported, together with those that failed the reliability thresholds.

As can be seen, comparing Figure 9 and Figure 11, earthquakes located in the Adriatic Sea and at the edge of the national seismic network have increased during these years, thanks to the improved station coverage and network sensitivity. However, given the unfavorable station geometry, the manual revised solutions with at least one parameter outside

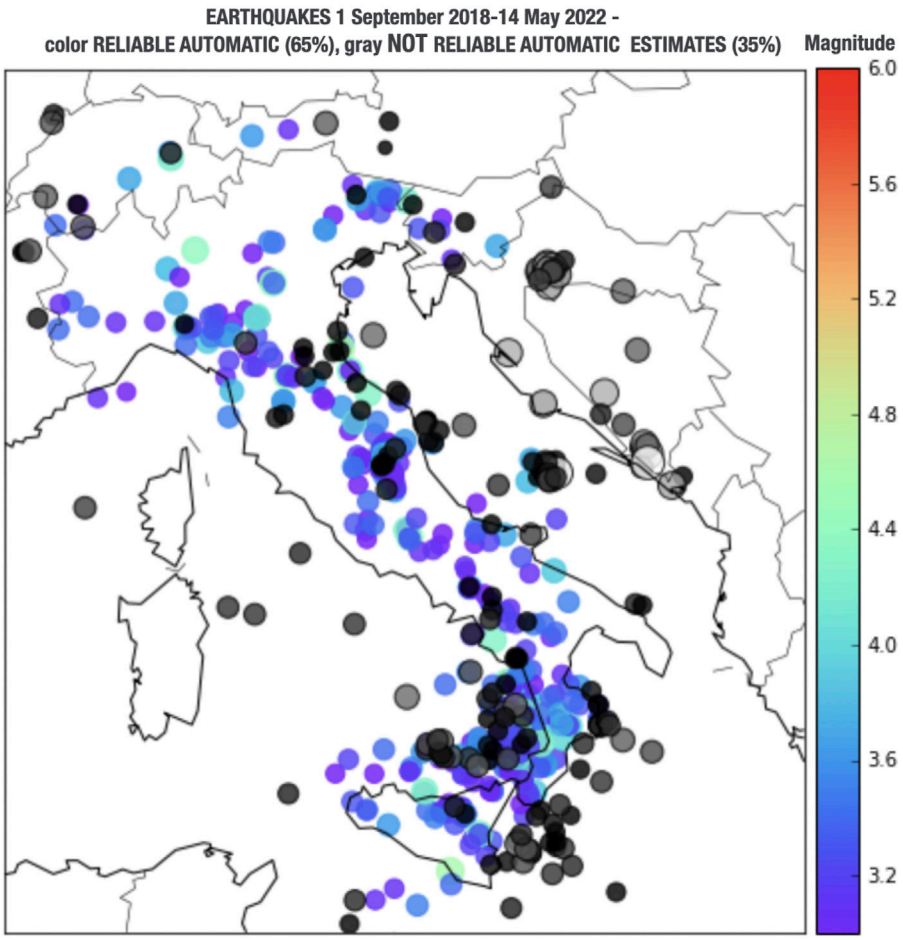

FIGURE 11
Geographical distribution of earthquakes (1 September 2018–14 May 2022) for which provisional parameter estimates were reported (color), together with those that failed the reliability thresholds (gray).

the reliable provisional estimates (magnitude out of the uncertainty range and epicenter coordinates different more than 20 km) are increased with respect to the previous period (7% vs. 5%). In Figure 12 we report such events, highlighting that the revised parameters differed from those of the provisional estimate in a way that made the communication "wrong".

A first and relevant communicative effect of this paradigm shift was the reduction of controversy after an earthquake. Unfortunately, this remains when reliability criteria are not fulfilled and the only official communication remains the one related to seismologist-revised parameters, that is released some minutes later. It is remarkable that the most relevant national online media, such as Repubblica. it or Corriere. it, in the commitment to reducing fake news and unreliable information, have started to embed our automatic tweets directly on their page, confirming that it is an important and awaited tool for journalists and citizens. According to Twitter analytics, the statistics of the automatic tweet scales significantly fast (Bossu et al., 2015) after events that are felt in densely populated areas, reaching tens of thousands of impressions in less than 5 min. The information included in the automatic tweet, if timely provided (i.e., within 2–3 min from the earthquake origin time), is enough to meet the demand of citizens: in fact, the statistics for tweets with the revised parameters are substantially lower (fewer retweets, fewer likes, fewer comments), even when they are available a few minutes after the one with the automatic estimates. This lower popularity of the tweet with the most reliable information could also be due to Twitter's algorithms that display more frequently in user timelines tweets that quickly become popular. Obviously, we observe a proportional relationship between the number of impressions and the earthquakes' magnitude, modulated by the population density of the impact areas. We underline that the tweet issued after the largest Italian event of the last 20 years - the 30 October 2016, M_w 6.5 Norcia earthquake - has got 440,000 impressions (at that time only the revised solution was published). Nevertheless, after the

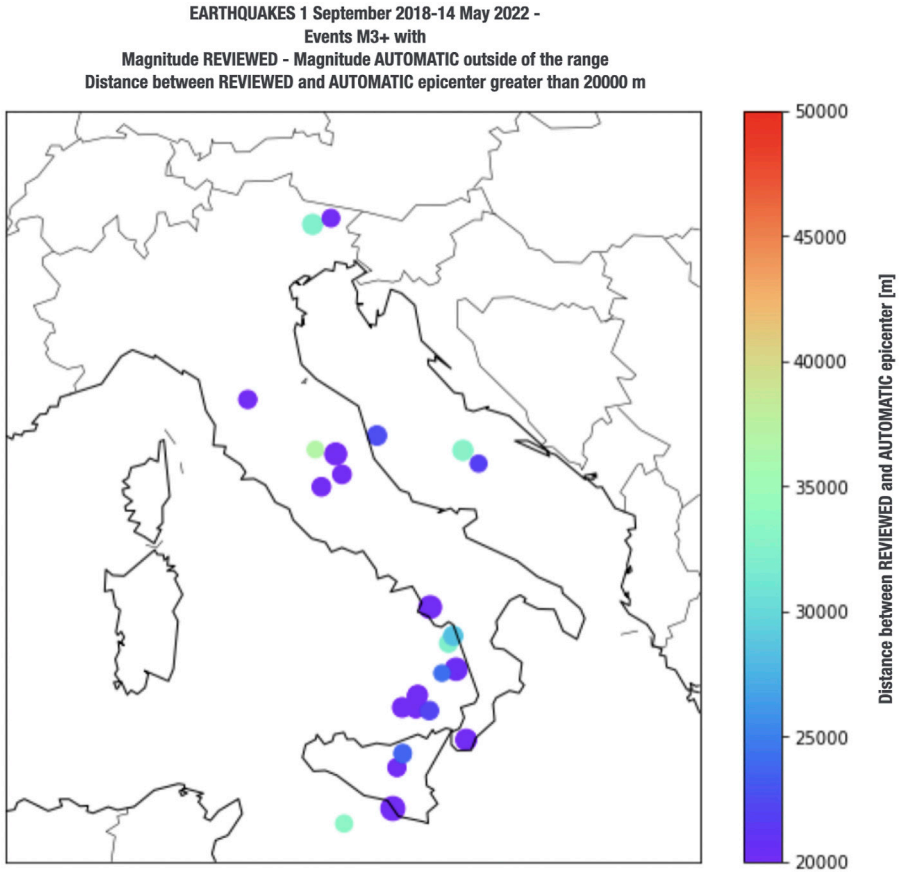

FIGURE 12
Geographical distribution of earthquakes (1 September 2018–14 May 2022) for which the revised parameters differed from those of the provisional estimate in a way that made the communication "wrong" (magnitude out of the uncertainty range and epicenter coordinates different more than 20 km).

introduction of the provisional parameters, Twitter Analytics shows that the most viewed tweet has been the automatic data of the earthquake M_w3.9 occurred on 18 December 2021, 37 km NE to Milan (a very densely populated area) with more than 800,000 impressions, emphasizing the importance of the fast release of information after a felt shock.

5 Interaction with citizens

All our social media are followed by the INGVterremoti team to check the reactions after the publication of the posts, and possibly engage with citizens, providing feedback and answers to specific requests. In general, we observe the greatest number of reactions and comments on the Facebook page, where the number of reactions is directly related to the magnitude of the earthquake and to the population that felt it (with additional secondary factors such as the anxiety level, if a sequence is ongoing, the time of the day). For the earthquakes in central Italy in 2016, there were thousands of comments for each shock of high magnitude. On the contrary, reactions on the Twitter channel are much more limited, although the channel is considered an important source of information, as shown by the automatic locations often published by many newspapers or websites. This is probably due to the type and the attitude of the public participating in the two social media.

For this reason, we have decided to have an active role in the Facebook page only, albeit not an invasive presence. We respond to private messages from individual users, and reply to public comments from the followers of the page that in our opinion require useful clarifications for our audience. It was necessary to explain to users that the page is not followed 24 h a day and therefore it is not always possible to reply quickly.

Through private messages, we receive requests for information on newly felt earthquakes to which we reply with preliminary location information, if available. Many requests are related to seismic sequences in progress. These create apprehension in the population affected and generally the

request is something like: "What will happen next?", or "I know that earthquakes cannot be predicted, but should we expect stronger quakes?". We also receive many reports of phenomena for which we are asked for explanations, such as cracks in the ground, gas emissions, variations in some springs' flow rate, *etc.* These messages are always answered, receiving thanks for the work done by INGV.

As for the public comments made to the posts, therefore visible to all, we note different types of comments. In absolute terms, the INGVterremoti posts that receive more comments in a very short time are those related to the provisional locations of earthquakes of magnitude greater than 3. These posts respond to the request for timely information when an earthquake is felt, and many people write indicating where they felt the shaking, how it was, how long it lasted, *etc.* The comments are very numerous when major cities are concerned, especially Rome, Milan, Bologna, Florence, *etc.* We receive many hundreds of comments within minutes. After the first few minutes, we receive other kinds of comments: requests for explanations of the phenomenon, for information on the evolution of seismicity, on the fault that generated the earthquake, *etc.* In this case, we observe that sometimes the answers to these requests are given by our own followers, that include geologists who answer correctly; otherwise, or if there is no answer, we comment directly so as not to leave the questions unanswered or with wrong answers. In all these years, rarely on our Facebook page, there have been exchanges of comments that have turned into insults among users. Only 2–3 times were we forced to remove users' comments. Some of the requests posted during a seismic sequence have been useful to decide the preparation and publication of new posts on some specific topics. A typical example is the explanation of the possible (unknown) evolution of ongoing seismic sequences. In such cases, we try to explain what has happened, providing some information on the possible evolution, based on previous cases and on the statistical assessment of aftershock distribution. An important point we always try to stress is the uncertainty affecting any estimate of possible future evolution. We also take advantage of the high attention raised by a local increase in seismic activity to remind the importance of reducing buildings' vulnerability if one wants to reduce seismic risk.

6 Conclusion

In the past 12 years, the INGVterremoti platform has continuously provided quick updates on the ongoing seismic activity in Italy and worldwide, and scientific insights on several topics regarding earthquake science. These include articles on specific historical earthquakes and tsunamis, on seismic and tsunami hazards, geological interpretations, source models from different types of data, surface effects, and so on. This has been possible thanks to the involvement of more than one hundred colleagues (geologists, seismologists, *etc.*) belonging to the INGV Earthquakes Department and in some cases with contributions from University researchers. The hundreds of articles published in these 12 years are often used and have revealed precious even years after their publication when another earthquake or sequence affects a specific region, and there is the need to explain what is going on, which particular geological phenomenon lies behind that earthquake, and so on. A key issue of our communication strategy through the years is the perseverance of publishing a good number of articles every month (5–10 posts/month on average, except in 2012 when the average was 19 articles). This allowed us to maintain a continuous and active communication with the public, also increasing the number of people interested in earthquake and tsunami science, and in risk reduction.

As far as the rapid information after relevant earthquakes is concerned ($M \geq 4$ in Italy and for large earthquakes worldwide), the INGVterremoti teams is ready to respond 24h7, publishing a first post with the basic information on the ongoing seismicity in less than 1 hour, and then deepening the information publishing additional posts in the following few hours, with the help of specific experts of that area or of that phenomenon. The coordinated use of several social communication channels represents an opportunity to spread information to different segments of the population, both during emergencies and in quiet times. These technologies have the potential to prevent communication breakdown through reliance on just one platform and thereby to reinforce the diffusion of authoritative information. The use of social media channels has allowed us to interact with the public, listen to citizens' curiosity, needs and fears, trying to establish a continuous and virtuous relationship. This has allowed us to respond to people's needs in quasi-real time, answering directly to questions, and doubts, or preparing some specific articles on a debated matter. We have seen several times that the attention of the public on earthquake risk is very high when there is some ongoing activity with felt earthquakes, but it vanishes quite soon when the activity ends. We have tried to use those moments to raise people's awareness and preparedness to future earthquakes, but at the moment we could not evaluate if we succeeded in this, and to what extent.

For the future, we are evaluating how to improve our communication strategy and to increase the quality and quantity of information both on ongoing seismicity and on the hot research topics in earthquake science. We will do this both through the social media already used and by trying to open new ones. Possible developments therefore include the opening of new social media, such as Instagram and possibly TikTok, in order to reach a broader and younger audience and involve them in the scientific dialogue and in risk reduction. Future generations are the main resource for a cultural change in Earth system management, both for climate change countermeasures and for natural risks reduction. More in general, we saw that story maps and storytelling are two important tools to reach more attention from the public and from the media. Another important element to be taken into account is the prevalence of access to our channels from mobile phones (80%) with respect to PCs. This will guide the way in which

we will offer contents to the public: we would probably need shorter contents, infographics, and an improved interface more suitable for mobile devices. Other possible improvements include the continuous monitoring and assessment of our communication strategy with specific surveys on targeted audiences.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: http://terremoti.ingv.it/https://ingvterremoti.com/.

Author contributions

MP, AA, CN, EC and CM contributed to conception and design of the work. AA, CN, EC wrote the first draft of the manuscript. MP wrote the section of the manuscript about the blog, CM the section about the Facebook page. All authors contributed to manuscript revision, read, and approved the submitted version. EC performed the statistical analys-is for the communication of automatic earthquake detection. Since the INGVterremoti platform consists of a coordinated suite of social media channels, including Twitter, Facebook, Youtube, iOS/Android apps and a blog-magazine, each author of this work contributes specifically to the different activities that we specify as follows: AA, CN, EC, CM and MP are content creator and manager the whole suite. MP is the blog administrator and web designer and, together with AA, CN, EC and CM, take care of the development. EC and VL are the managers of @INGVterremoti on Twitter. CM, MP, CN and EC are the managers of the Facebook page. EC, MP and VL are the app managers. AA, MP and CN are the YouTube managers. VL and MQ have been working on the technical development of the online publishing of seismic events.

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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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