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Risk communication successes and limits during sismo-volcanic crisis: the example of Mayotte, France

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Abstract

On 10 May 2018, an active seismic crisis began on French island of Mayotte, which a year later will be shown to be related to offshore volcanic activity. It affects a vulnerable territory exposed to risks of many kinds (poverty, violence, lack of basic resources). In the absence of known events in human memory, the population is naive with regard to seismic and volcanic hazards. The concern is therefore very strong. In spite of a large number of publications, the communication set up by the main actors of the risk chain does not answer the population's concern. To understand why, we analyse a large corpus of the textual communications (press releases, web pages, scientific bulletins, reports, etc.) issued by the authorities and scientists from May 2018 to April 2021. We draw lessons on the communication strategy put in place in the first three years of the crisis; and we issue recommendations for improvement in the future, in Mayotte, but also elsewhere in contexts where comparable geo-crises may happen. We notably stress the importance of ensuring that communication is not overly technical, that it aims to inform rather than reassure, that it focuses on risk and not only on hazard and that it provides clues to possible risk scenarios.

1. Introduction

On 10 May 2018 begins on the island of Mayotte, a very active seismic crisis whose intensity and duration surprises the population, scientists and authorities. Scientists in charge of seismic monitoring in the region describe the situation as *"exceptional beyond anything recorded in Mayotte"* (Director of BRGM in Mayotte, 16 May 2018 AFP dispatch picked up by many media, e.g. Le Point (2018)). Prior to May 2018, regional instrumental seismicity near the islands (blue dots in Figure 1) was indeed moderate, with the largest magnitudes recorded between Mb 5 and 5.5. At the beginning of the 2018 crisis, the island is poorly instrumented, which complicates the monitoring of the seismic crisis, the understanding of its origin, the determination of possible risk scenarios and of preventive measures. Mayotte belongs to the Comoros archipelago, composed of four main islands, which formed as a result of Cenozoic volcanism in a poorly understood geodynamic context (Figure 1). Several hypotheses are put forward: hot-spot volcanism versus rifting volcanism, or a mixture of the two (e.g., Michon, 2016). Karthala, on the westernmost island of Grande Comore (Figure 1), is an active volcano studied by a monitoring network managed by the Karthala Observatory of the CNDRS (Centre National de Documentation et de Recherche Scientifique, in Moroni) in collaboration with the Institut de Physique du Globe in Paris and the University of La Réunion.

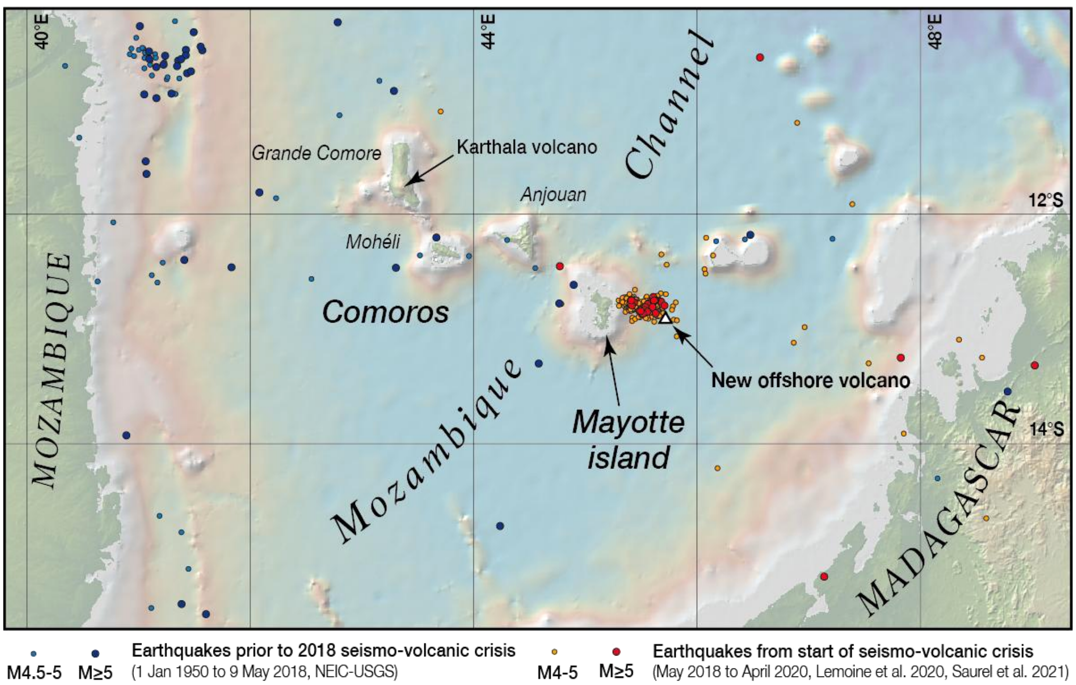

Figure 1. Location of Mayotte, easternmost island of the Comoros archipelago. Blue dots: epicenters of seismic events prior to seismic crisis that started on 10 May 2018 (Magnitude ≥4.5, Jan. 1950 to 9 May 2018, USGS catalog); Red (magnitude ≥5) and orange (4 ≤ magnitude < 5) dots show earthquake epicenters with well-constrained hypocentral depth from 10 May 2018 to April 2020 - locations from Lemoine et al. (2020) between May 2018 and March 2019 and Revosima catalog between April 2019 and April 2020 (Saurel et al., 2021). Most earthquakes of the ongoing seismic crisis as well as the new offshore volcano discovered in May 2019 (Feuillet et al., 2019, 2021) are located 10-50km east of Mayotte island. To avoid problems with mislocated events on this map we excluded epicenters with 10km fixed depth, and only plotted the ones with well-determined hypocentral depths. Topographic and bathymetric visualisation is from GeoMapApp (www.geomapapp.org - CC-BY).

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The seismic crisis is affecting a particularly vulnerable territory, already exposed to risks of many kinds. Mayotte is a French overseas territory and has the status of a regular French department, but is marked by great poverty and strong social inequalities (Roinsard, 2014). Among a population of 256 000 people, 77% live below the poverty line and more than 30% are unemployed, 48% is foreign (and often illegal), 30% have no access to drinking water, and 4 out of 10 people live in informal settlements (2017 Data - INSEE, 2021). Criminality is high, episodes of social unrest follow one another and the population's distrust of the authorities is strong. Mayotte's multiculturalism is a richness that proves difficult for the authorities to manage when the situation requires informing the widest possible audience. 95% of the inhabitants are Muslim (Ministère des Outre-Mer, 2016), 45% are of Comorian origin (INSEE, 2021) and although French remains the official language of communication, ~37% are not speaking French (2007 data - INSEE, 2017). Even when understanding French, a large part of the population speaks Shimaore or Kibushi on a daily basis. One can refer to e.g. Roinsard (2014) or Walker (2019) for more analyses of the economic, political and cultural situations in Mayotte. What is important to keep in mind here is that the absence of seismic and volcanic events known to human memory means that the population is relatively naive with regard to these hazards. A survey conducted by the agency TIFAKI HAZI in 2012 reveals that 75% of the people surveyed consider themselves to be poorly informed and badly sensitized to natural hazards in general (DIRMOM, pers. com.).

- **High public anxiety and a recurring complaint about a lack of information**

Nearly a year elapses between the beginning of the seismic crisis and the announcement, in an inter ministerial press release on 16 May 2019 (e.g., Ministère de la Transition écologique et solidaire, Ministère de l'Enseignement supérieur de la recherche et de l'Innovation, Ministère des Outre-Mer, Ministère de l'Intérieur, 2019) of the discovery of active volcanism off the island of Mayotte (Figure 1). During that first year, the population is shaken by numerous felt earthquakes, some of which slightly damage houses and public buildings such as schools (Sira et al., 2018). Anxiety is very strong, as evidenced by the testimonies of the inhabitants in newspapers and on social networks: *"It's starting to shake strongly, it's frightening"* (Le Figaro, 2018a, 14 May). Thousands of people sleep in the street at night (10 to 20% of the population according to official sources, pers. com.). In the days after the beginning of the crisis, a group of Mayotte inhabitants creates a Facebook group called STTM (for "Signalement Tremblement de Terre de Mayotte") that quickly become very active in the public discussion of earthquake-related issues. People complain of a lack of communication from scientists and authorities about the possible origin of these earthquakes, as well as the dangers and risks associated with them. *"Whether or not we know what's going on at more than 3,000 meters deep, there are facts that are there. Earthquakes that sometimes exceed magnitude 5, cracks in buildings, fires, landslides, etc.... and no real reaction from the State apart from information on the magnitude of the tremors already felt."* (excerpt from STTM Facebook group, 26 May 2018). On 5 June 2018, the deputy of Mayotte, Ms. Ramlati Ali, warn the ministries against a confusing communication and alert on the existence of *"false information fueled by fantasies that have the effect of increasing the anxiety of the Mahoran population, generating a state of panic and even psychosis"* (Ali, 2018). On 27 August 2018, the local newspaper *Le journal de Mayotte* highlight the inability of experts to document the earthquakes felt and headline: *"Earthquakes: It trembles in Mayotte in silence"*, and

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again: "*On the phones, the applications of international sites, downloaded with frenzy last May, have given nothing, just like the BRGM* [the local expert body in charge of seismic monitoring], *while the earth began to shake again this Sunday in Mayotte"* (Perzo, 2018c). The feeling of being left out reinforces an already existing distrust of state services (it should be recalled that at the time of the first earthquakes, Mayotte is just emerging from a hard social crisis that had lasted for many months). On the STTM feed, one can read: "*How much do you want to bet that in a year nothing will have been done? As soon as the crisis passes we play the watch hoping that the next one will come when we leave the island. That's how the administration has managed Mayotte for decades.*" (excerpt from STTM Facebook group, 27 May 2018).

A year later, in may 2019, the discovery of the underwater volcanic activity is described by official sources as exceptional. The unexpected *"birth of a new volcano"* (BBC - Science in Action, 2019) causes enthusiasm in the national and international scientific community, and in the media (e.g., Andrews, 2019; Minassian, 2019; Wei-Haas, 2019). Indeed, the large volumes of lava involved are only comparable to those emitted during the Laki eruption in 1783-1784 (Cesca et al., 2020; Feuillet et al., 2021; Thordarson & Self, 1993) and the underwater nature of the eruption requires innovation in terms of observation, research and monitoring. It marks the beginning of an exciting scientific adventure. If the inhabitants are delighted by the sudden interest of the scientific world for their island, they are also worried about the risks linked to this new activity and they continue asking for more information: *"Say nothing, explain nothing... Can only create confusion... Questions that go around in circles because we don't have the answers! When there is neither answer nor explanation ... One can only wonder ... Why this? What interest or motivation do they have in not giving the information ... They would like the population to worry: they couldn't do better! The sickly inability of administrations to communicate …"* (excerpt from Facebook group STTM, 20 June 2019). The announcement of the birth of the volcanological and seismological observation network of Mayotte (REVOSIMA) in June 2019 only partially meets expectations.

During the first year of the crisis, external observers also point to a lack of scientific information and communication from the authorities and the scientists (Fallou et al., 2020; Fallou & Bossu, 2019). For Fallou et al. (2020), it is this *"information vacuum"* that leads inhabitants to take advantage of social media to develop, by themselves, the *"seismology citizen group"* STTM. The need for information is indeed testified by the very success of the group which soon gathers more than 10,000 members. And, although the sociology of the group is not representative of the entire population of Mayotte (discussions are held mainly in French), it will become a key interlocutor for the local authorities who, a year later, will invite some of its most visible members to the discussion table: *"Earthquakes: the Facebook group STTM received in the Préfecture"* (Journal de Mayotte, 9 August, YD, 2019).

As highlighted by Fallou et al. (2020), among the group itself, discussions revolve a lot around scientific knowledge and uncertainties and around the lack of sufficient information for the population to be able to adapt to the associated risks. The questions asked are relevant with respect to risk management, e.g. *"The schools for example, which accommodate some 80,000 students, have been checked by experts (I hope everywhere in Mayotte) but there has not yet been any feedback to the general public. [...] I would like, for example, in the general interest, that according to such and such a structure, we could say to what extent it will resist to such and such*

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a magnitude (including site effects and other local variables) and also how it will resist to the succession of moderate tremors (in swarm, which is obviously our case)" (excerpt from STTM Facebook group, 27 May 2018). Discussions are informed by publicly available scientific knowledge, in the form of official releases from local authorities, scientific reports from scientific organizations involved in monitoring, and more generally anything that can be found on the Internet. Fallou et al. (2020) point to the absence of a professional scientist who can help the group to translate and contextualize such information.

- **The difficulty of answering populations' need for information**

Informing the population is a fundamental issue at all stages of the risk reduction cycle. Faced with the risk of a disaster, populations are not the passive recipient and executors of decisions taken in a top-down manner by the authorities under the advice of wise scientists. People likely to be affected are the first actors of their own safety and, often, of the safety of their relatives and neighbors (e.g. this principle is included in the French civil protection law since 2004). The recent COVID-19 crisis reminded us of the importance of public understanding and acceptance of protective measures and brought the issue of public information back into focus. It also reminded us how enhanced media interest can complicate risk communication. This complexity stems from the fact that public information about risks emerges as an end product of a complex process at the interface between science, policy and society. And, as shown by science studies, the knowledge governing public decision in the domain of environmental as well as natural risks is determined as much by the scientific method and the social context of scientific knowledge production as by the institutional and wider social and political context (e.g. Jasanoff, 2004; Oreskes, 2004; Brown, 2009; Oreskes, 2015). This observation has motivated the development of a field of research entitled "social volcanology", with counts some important contributions about information dissemination (e.g. Fearnley, 2013; Fearnley & Beaven, 2018; Donovan, Oppenheimer and Bravo, 2012; Donovan, 2019). The present paper follows this line of thought while also borrowing to the literature dedicated to risk communication in the wider field of the *disaster studies* (e.g. Mileti, 1993; Lindell et al., 2006).

With regard to sismo-volcanic risks, Mayotte is currently in a phase that, in the language of risk managers, must combine prevention and preparedness. The information transmitted by the actors of the "risk chain" (from hazard monitoring to risk management) should allow people to understand the risks they face, to implement preventive measures and to prepare for a possible rise in the alert level. The recurrent complaint of a lack of information from part of the population suggests that the communication currently in place is not up to the challenges of this period. According to Lindell et al. (2006), populations' need for information can be broken down into a few key questions: What is the risk? Where is it going to happen? When is it going to happen? What will be the effects? To those, one could also add: How do I prepare my family to face that risk? Mileti (1993) also identified four key steps in the process of efficient risk communication: 1) people need to *receive* the information, 2) people need to *consider* the information available, 3) people need to *understand* the information and 4) the sources of that information must be perceived as credible and legitimate - perceptions that can be strongly altered by poor communication.

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In the case of Mayotte, one can wonder whether the communication of the authorities in charge of risk management - but also of the scientists in charge of monitoring - enabled people to *receive*, *consider* and *comprehend* the information and if it helped them to adapt their response to the seismic crisis and to prepare their potential response to threats associated with the new volcanic activity. Unfortunately, this does not seem to have been the case, as evidenced by the disconnect between the very large number of communications issued by official risk management actors during the first year of the crisis and the sense of lack of information reported by the population on social media (Figure 2).

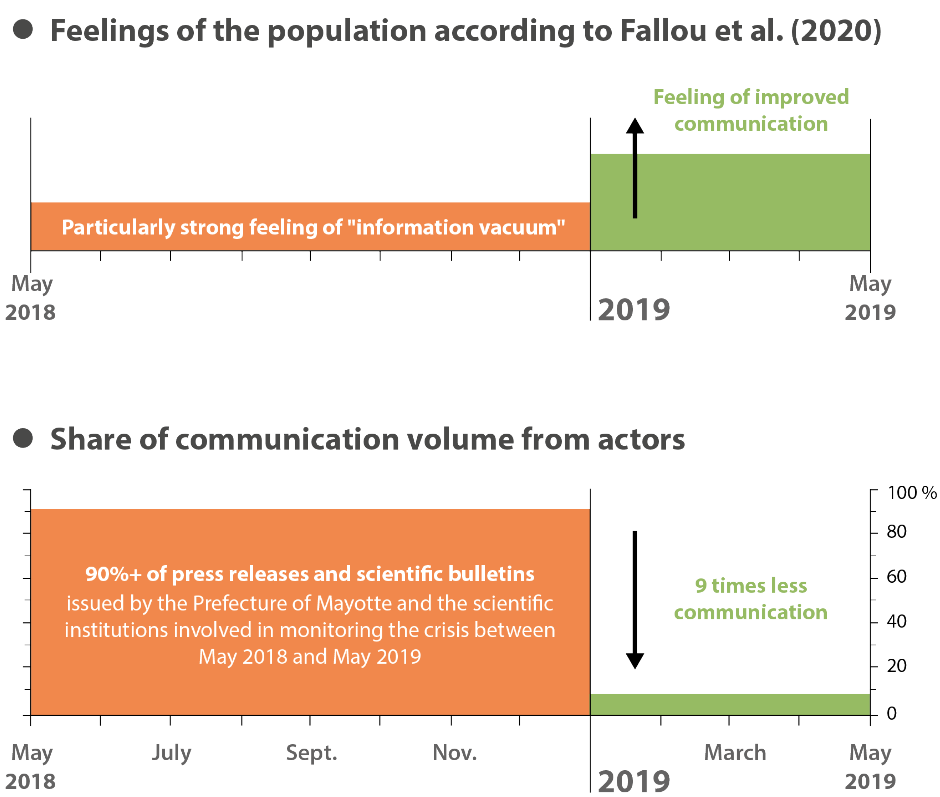

Figure 2. Evolution of the number of communications from the authorities and scientists on the sismo-volcanic crisis of Mayotte in regard to the feeling of "information vacuum" of the population as reported by Fallou et al. (2020). This figure does not cover our whole study period. It illustrates the gap between the perception of the population and the communication efforts made by the actors at the beginning of the crisis, less than a year after the beginning of the seismic crisis and before volcanic activity was discovered. The evolution of this offset throughout the three first years of the crisis is discussed at length in the following sections of the paper.

- **Our study**

The present paper contributes to the effort made by social sciences to identify ways of overcoming the difficulty of answering at risk populations' information need. Our approach is to

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factually analyze the way the scientists and the authorities communicated during the first three years of the crisis, in order to understand what has failed in their strategy of communication. We believe that the lessons learned from the case of Mayotte, in a relatively unprecedented context (risks are perceived indirectly, the underwater volcano remaining invisible, and in a poorly instrumented area), can usefully nourish the reflection carried out in the existing literature (Fearnley, 2013; Fearnley & Beaven, 2018; Donovan, Oppenheimer and Bravo, 2012; Donovan, 2019).

To prevent possible ambiguities, it might be important to specify from the outset that scientists and authorities are not expected to play the same role with respect to risk communication but that their roles are complementary (e.g. Newhall, 1999; Fernley and Beaven, 2018). It is the authorities who are officially in charge of communicating information about risks and decisions taken to protect people (notably prevention, preparedness, alert and protection measures). But, as shown by the analysis of social networks and the press (Devès et al., 2021; Fallou et al., 2020) and by earlier studies, scientists have a role to play in helping the population to comprehend scientific information as the latter is often far too technical for non-specialists. Such a role is essential to maintain the legitimacy and credibility of the information on which public decisions are based (Jasanoff, 2005). In Mayotte, as far as telluric risk is concerned, a disaster has not yet occurred - the seismic crisis, although very worrying for the population, has not caused major damage. But many questions remain unanswered concerning the potential effects of the current activity in the short or medium term: are the earthquakes and/or the deformation associated with volcanic activity likely to generate major tsunamis? Can volcanic activity migrate to the island of Mayotte? The challenges of the current phase are therefore those of scientific research to understand, monitoring to alert, and preparedness to reduce potential impacts, improve emergency management, and foster individual and collective resilience. Each of these relies heavily on scientific knowledge and expertise. It is therefore important to analyze not only the communication strategy adopted by local and national authorities, but also by the scientific institutions involved in monitoring. In the case of Mayotte, was it the content, format or modalities to convey the information that failed to meet the needs of the population and to answer their concerns? How does the science/public risk management interface work in practice and how have actors managed to explain what is not yet known, what is uncertain? How people's information needs, and their feelings about seismicity and hazards, evolve in time? What role played the new information resulting from the offshore observation campaigns that started one year after the beginning of the crisis?

To address these questions, we have built up a large corpus made up of all the communications (press releases, web pages, scientific bulletins, reports, etc…) issued by the authorities and scientists during the first three years of the crisis (section 2). We analyze this corpus by combining qualitative and quantitative approaches. Section 3 proposes a chronological reading of the main stages of monitoring and crisis management. We distinguish 4 main phases (1, 2, 3, 4) which correspond to the different moments of the structuring of the scientific and state response to the crisis. Section 4 focuses more specifically on the communication aspects of risk management. There the analysis leads us to distinguish not four, but three major phases of communication (A, B, C), because of a certain gap between the structuring of the response and communication to the public. Such analysis allows drawing lessons on the communication strategy put in place in the first three years of the crisis and to issue recommendations for

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improvement in the future, in Mayotte, but also elsewhere in contexts where comparable geo-crises may happen (section 5).

2. Material and methods

2.1. A two step-methodology combining quantitative and qualitative approaches

We focus on the first three years of the Mayotte seismic-volcanic crisis, more precisely from 10 May 2018 to 1 April 2021. We build our analysis on the following methodology and datasets.

We searched the archives and in particular the web archives of the scientific and state institutions involved in the monitoring and management of the crisis. We collected and analyzed all the documents made public by the authorities and scientists during these first three years such as press releases, scientific bulletins, news on websites and public notes (table 1). Hereafter, we are citing scientific bulletins and websites as references (including their URL when existing) while authorities' press releases are given in the supplementary dataset (ministerial press releases as well as those from the Préfecture of Mayotte). We also included the academic papers published during our 3 years period of study (Cesca et al., 2020; Famin et al., 2020; Feuillet et al., 2021; Lemoine et al., 2020; Tzevahirtzian et al., 2021). We coded this dataset by date of publication and by publishing institution/author, and quantitatively analysed it to show the time evolution of the publication rate by the different actors of the risk management (see Figure 4). Using the catalog of the felt seismicity provided by EMSC for the period from May 2018 to April 2021 (EMSC-CSEM, 2021), we compare this publication rate to the number of earthquakes felt by Mayotte citizens and its evolution in time (Figure 3, 4). This analysis was made using the R software package. This allows us to quantitatively put the scientist's and authorities' communication effort in perspective with the evolution of the geophysical signal that directly affected the population.

However, to understand people's feeling of a lack of communication and how the communication has been managed by the scientists and authorities as the crisis developed, we also needed more qualitative approaches: i.e. qualitative analysis of the content of the different documents. We thus studied the content of all the documents in the above dataset and the way it has evolved in time. We also aimed to identify the main stages of scientific monitoring and to understand how the circulation and transfer of knowledge has been managed by the different actors. With this objective, we conducted semi-structured interviews with scientists from the main institutions in charge of the geophysical monitoring of the crisis (7 interviews lasting from 1 to 3 hours within BRGM, IPGP, CNRS and REVOSIMA) and with local and national risk managers (6 interviews lasting from 40 minutes to 2 hours within the Préfecture of Mayotte, the DIRMOM, the Ministries of Research, Environment and Interior). We asked questions about the actors involved in the monitoring and their role, about the procedures, contents and formats used to exchange between them, with the media and the public. We also asked what were the most important moments for them in terms of knowledge transfer and to give their view on the effectiveness of hazard and risk communication toward the exposed population. We anonymised the citations taken from these interviews to respect interviewee's confidentiality, and provide here our own

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english translation. We also explored Facebook publication feeds when they existed (i.e. for OVPF-IPGP, REVOSIMA, Préfecture of Mayotte, as well as the STTM citizen group) but without aiming for exhaustiveness as it is difficult to achieve without adequate tools. In particular, we use selected citations extracted from STTM facebook posts to illustrate citizens' feelings about the management of the crisis by the scientists and authorities. Hereafter, we anonymised these facebook excerpts, and provide our own english translation (anonymised French original versions of the facebook posts are given in the supplementary dataset). If this Facebook group gathers more than 10 000 members and has been identified as a key interlocutor by local authorities, it is not representative of the sociology of the whole population of Mayotte. Nevertheless, these excerpts allow us to identify misunderstandings and grasp ways in which communication could be improved.

2.2. Presentation of the key actors of risk communication

Before describing the course of the crisis, it is important to present the actors involved in the monitoring and management of seismic, volcanic and tsunami risks in Mayotte (Table 1). Two main categories of actors can be distinguished according to their function: risk management or scientific monitoring. On the risk management side, our analysis is based on communication from 1) the Préfecture of Mayotte, which is the body representing and implementing government policy at the local level, and 2) the ministries concerned with risk prevention, civil protection, research, and overseas administration, whose actions have been coordinated by an Inter-ministerial Delegation for Major Overseas Risks (DIRMOM) since 24 April 2019. We do not consider the communication put in place by the Mayors of the communes because, in the case of the seismo-volcanic crisis in Mayotte, the communication was mainly orchestrated by the state authorities. On the scientific monitoring side, we consider the institutions that have played a central role in the collection and analysis of data on the hazard and/or associated risks. We also take into account individual researchers who issued key analyses at crucial times during the crisis (Briole, 2018). One must note that not all scientific actors play a similar role and that the number of actors involved in monitoring the crisis has increased over time[1]. To sum up, the *Institut de Physique du*

- [1] The *Bureau de Recherche Géologique et Minière* (BRGM) and the *Institut Français de Recherche pour l'Exploitation de la Mer* (IFREMER) are public industrial and commercial institutions dedicated to, respectively, georessources and marine resources placed under the joint authority of the Ministries in charge of ecology, research and, respectively, economy or agronomy. The *National Institute of Geographic and Forest Information* (IGN) is a public administrative establishment placed under the joint authority of the Ministries in charge of ecology and forestry.

- The *Institut de Physique du Globe de Paris* (IPGP) is an institution for higher education and research in geosciences which is in charge of certified observation services in volcanology, and seismology through its permanent volcanological and seismological observatories like the one in La Réunion island (OVPF for Observatoire Volcanologique du Piton de la Fournaise). It operates the Volcanological and Seismological Monitoring Network of Mayotte (REVOSIMA).

- The *School and Observatory of Earth Sciences* (EOST) is an institution under the supervisory authority of the University of Strasbourg and the CNRS (French National Center for Scientific Research) in charge of education, research, and observation in Earth Science. The IPGP and EOST equip and maintain global geophysics networks that monitor seismic activity (GEOSCOPE network) around the globe. EOST is sometimes referred to as the Institut de physique du Globe de Strasbourg (IPGS), the two bodies having intimate links. The EOST pilots the BCSF-RéNass, *Bureau central sismologique français - Réseau national de surveillance sismique*, which is in charge of centralising, archiving and distributing national seismic data. The BCSF-RéNass issues a bulletin after each event and collects public testimonies of felt earthquakes (www.franceseisme.fr). It also provides assistance to the public authorities by sending a task force of seismologists (GIM for Groupe d'intervention macrosismique) to estimate impacts after significant earthquakes in French territories.

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Globe de Paris (IPGP), the *School and Observatory of Earth Sciences* in relation with *the École et observatoire des sciences de la terre / Institut de Physique du Globe de Strasbourg* (hereafter referred as EOST), the *Bureau de Recherche Géologique et Minière* (BRGM) and the *Institut Français de Recherche pour l'Exploitation de la Mer* (IFREMER) are the scientific actors directly involved in monitoring the sismo-volcanic activity of Mayotte. The REVOSIMA brings together these different scientific actors. It is operated by the IPGP from its closest observatory of the Indian Ocean region, i.e. the *Observatoire volcanologique du Piton de la Fournaise (OVPF)* in Reunion Island, and with the support of the antenna of BRGM in Mayotte. The *Bureau central sismologique français - Réseau national de surveillance sismique* (BCSF-RéNass), the *European-Mediterranean Seismological Centre* (EMSC) and the *National Institute of Geographic and Forest Information* (IGN) centralise, distribute or provide data. Table 1 lists the preferred publication format and volume of communication of each actor during our period of study. We do not count the numerous automatic bulletins emitted by REVOSIMA (daily automatic bulletin are emitted since march 2020), BCSF-RéNass and EMSC but we count the report published by the BCSF-RéNass's Groupe d'intervention macrosismique (GIM) and a web article from the EMSC that aims at providing a global view of the seismic crisis. We include in our database the five academic papers (one is a preprint version of a submitted paper) dedicated to the crisis that were published during our period of study (Cesca et al., 2020; Famin et al., 2020; Feuillet et al., 2021; Lemoine et al., 2020; Tzevahirtzian et al., 2021) and commented by the press and/or the members of STTM facebook group.

3. Description of the phases of the crisis from a monitoring and risk management perspective

The seismic crisis starts on the night of 10 to 11 May 2018 with an earthquake of magnitude M_L4.3 being felt by the population. It intensifies on 15 May 2018 with several earthquakes of magnitude M_L greater than 4 and an earthquake of M_L5.8 (M_W 5.9) that slightly damages buildings (Lemoine et al., 2020). One month after the beginning of the crisis, 140 earthquakes with magnitudes M_L>4 have been recorded (Lemoine et al., 2020). For weeks, the people of Mayotte feel several earthquakes a day. During the first month of the crisis, the EMSC catalog (EMSC-CSEM, 2021) reports ~10 to 20 felt earthquakes per week (i.e. seismic events with at least 4 online citizen testimonies, which EMSC call "felt reports"). Mayotte citizens testify largely after earthquakes of the largest magnitudes: EMSC catalog lists ~200 to more than 500

- The *French National Centre for Scientific Research* (CNRS) is an interdisciplinary public research organisation under the administrative supervision of the French Ministry of Higher Education and Research. A significant part of French researchers belong to CNRS and work within laboratories which are placed under the joint authorities of the CNRS and the local university. The *National Institute for Universe Sciences* from CNRS (INSU) has the mission to develop and coordinate French research in astronomy and Earth sciences, as well as ocean, atmospheric, and space sciences.

- The *European-Mediterranean Seismological Centre* (EMSC) runs an Earthquake Alert System for potentially damaging earthquakes in the Euro-Mediteranean region. As BCSF-RéNass, EMSC collects testimonies through its Lastquake application (e.g., Bossu et al., 2019). Within the hour following the occurrence of an earthquake, EMSC publishes a web page with its epicentre and magnitude, and the collected testimonies.

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felt reports for each M_L>5 events that occurred in May and June 2018. Between May 2018 and May 2019, the seismic networks record about 1900 events with M_L≥3.5 (Cesca et al., 2020; Lemoine et al., 2020). However, there is a sharp decrease in the number of felt earthquakes after June 2018 (Figure 3), with only ~4 felt events per month until the end of 2018, and then a moderate recovery in the number of felt events between February and June 2019 (~9 felt events per month on the average). The seismic crisis is still ongoing at the time of writing, 3 years after its start.

The interviews conducted with monitoring and risk management actors led us to distinguish four main phases in the course of the crisis. The first phase goes from the recording of the first earthquakes to the recording of the first unambiguous signals of a volcanic component. The second phase corresponds to the mobilization of scientists, and funding agencies in relation to ministries, to get the financial means to instrument the area. The third phase runs from the first measurement campaigns to the proof of the volcanic activity which signed the official setting up of the seismo-volcanic monitoring network of REVOSIMA. The fourth phase begins with the official creation of REVOSIMA and ends with our windows of study. Figure 3 summarizes the key events that marked each of these four phases. In addition to the events linked to monitoring, we show some key events in the response of scientists, authorities and inhabitants of Mayotte. The following description illustrates the role of these different actors and the timing and context of their involvement phase by phase.

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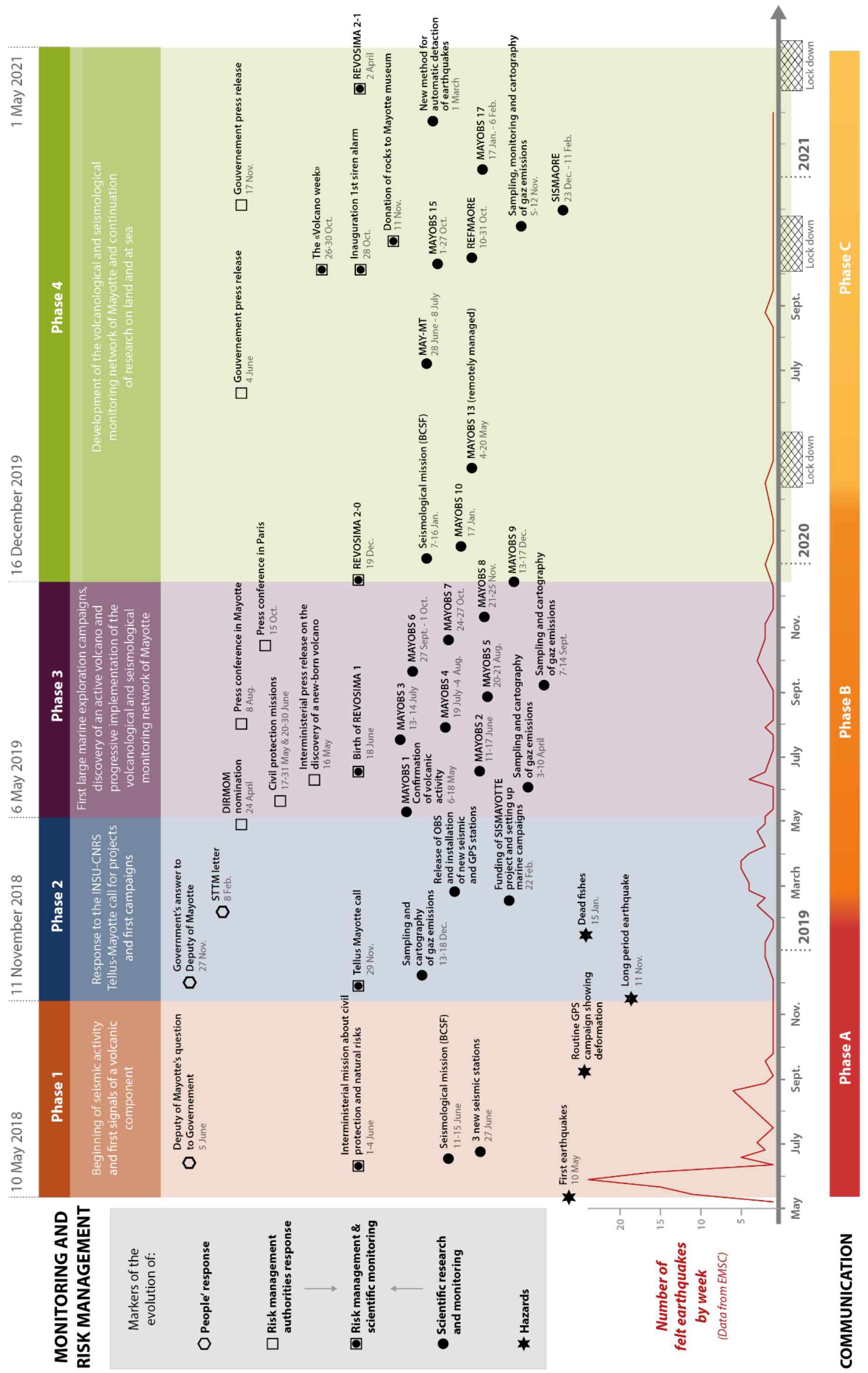

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Figure 3: Major phases and markers of the management of the seismic-volcanic crisis in Mayotte from 10 May 2018 to 1 April 2021, end of our period of study.

- **Phase 1: 10 May 2018 to 10 November 2018**

During the **first phase of the crisis**, the French Geological Bureau (BRGM) plays a central role. It is the only geo-scientific institution with a permanent office in Mayotte and, at the beginning of the seismic crisis, it is in charge of maintaining the only 3 accelerometric seismic stations installed on the island (which was not known to be particularly active seismically). In this context, at the beginning of the crisis, BRGM Mayotte is the authorities' natural interlocutor for decision support. It should however be noted that, for BRGM, as for the other scientific organizations involved in monitoring before the creation of REVOSIMA, real-time data processing is organized thanks to scientists' voluntary commitment. But the situation is difficult as crucial data are missing. Only the largest magnitude earthquakes (M>5) are reported by global seismic networks while the existing local network – the few accelerometric stations in Mayotte completed by few regional stations in Comoros and in Madagascar – does not allow a good record of the surge of moderate magnitude earthquakes felt by the population. Because of this inadequate network the BRGM operators initially encountered difficulties in accurately locating the earthquakes and assessing their epicentral depths.

In June 2018, the persistence of the seismic crisis leads other actors to become involved. Ministries in charge of civil protection and disaster risk prevention send an interministerial mission. Mid-June 2018, a team of seismologists from BCSF-RéNass is sent to *"estimate the levels of damage induced by this seismic swarm according to the vulnerability of the buildings at the date of the field analysis"* (Sira et al., 2018). 3 more seismic stations are installed (two short-period RaspberryShake velocimeters by the BCSF, one broad-band velocimeter in the frame of the 'Sismo à l'École' network). During the summer, scientists from IPGP and EOST help the BRGM team to monitor the activity as its intensity decreases.

In September 2018, seismic activity intensifies again. The French scientific community starts organising to seek funding to instrument the area, notably at sea. A note is sent to the French National Centre for Scientific Research (CNRS) to attract funding agencies' attention to Mayotte's issues. As surveys have to be done mostly offshore using research vessels and heavy human and technical logistics, the funding to be mobilized is typically of the order of several million euros per year. In parallel, one also have to deal with vessel's availability for their work programs are often planned years in advance. At the same moment, routine GNSS measurements led by the IGN reveal strong displacement anomalies affecting stations on the Mayotte island. Researchers from the Ecole Normale Supérieure (ENS) Geoscience Lab. analyze the GNSS data, tracing the onset of surface deformation back to July 2018. They explain it by the deflation of a huge magmatic chamber located off the coast of Mayotte. These results are published in the form of notes on the public website of the laboratory in October 2018 (Briole, 2018). The lack of geological observations offshore Mayotte still prevents a good understanding of the phenomenon but the scientific community urges public authorities to fund geophysical instrumentation and surveys in the region.

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- **Phase 2: 11 November 2018 to 5 May 2019**

The **second phase of the crisis** starts on 11 November 2018 with a long period earthquake with peculiar characteristics (a very long trend of monochromatic seismic waves). The event, not felt by the population because of its long period character, is recorded by global seismic networks. It is much discussed on social networks and appears to be mentioned in the international and soon national and local press (see discussion in Lacassin et al., 2020). It supports the volcanic hypothesis (Cesca et al., 2020; Lemoine et al., 2020). Mid-november, a meeting is organised with representatives of the four ministries, scientists and institutional stakeholders like CNRS-INSU. On 29 November, public authorities set up a call for projects to fund observation and research in the area. The call, named *"Tellus-Mayotte"*, is coordinated by the CNRS-INSU and co-financed by the Ministry in charge of disaster risk prevention (MTES).

In January 2019, fishermen report dead deep sea fishes at the surface of the ocean east of Mayotte (Perzo, 2019a). On 22 January, three projects are eventually selected on the Tellus Mayotte call, involving 11 laboratories and 44 scientists from CNRS, IPGP, EOST, BRGM, Ifremer and IGN. On 22 February, CNRS, IPGP, BRGM and EOST announce the launch of the first major monitoring missions. Between February and March 2019, 6 OBS are deployed at sea in the frame of these Tellus-Mayotte projects, and new seismic and GNSS stations are installed on land (by OVPF-IPGP, BRGM, EOST). A team from the University of Réunion associated with OVPF-IPGP carry out field missions to consolidate knowledge of the tectonic and volcanic history of Mayotte.

- **Phase 3: 3 May 2019 to 5 December 2019**

The third phase of the crisis starts with the first MAYOBS marine campaigns on the scientific ship *Marion Dufresne* (MAYOBS 1 on 6-18 May 2019 and MAYOBS 2 on 11-17 June). The campaigns are led under the auspices of the CNRS and involves scientists from BRGM, IPGP, EOST, IFREMER, the University Clermont Auvergne, the University of La Rochelle with the support of IGN, the Centre nationale d'études spatiales (CNES) and the Service Hydrographic and Oceanographic Marine Observations (SHOM). The OBSs deployed in February are retrieved and new ones are released. The data allow relocating the earthquakes and specifying the location of the seismic swarms (Deplus et al., 2019; Feuillet et al., 2019, 2021; Jacques et al., 2019; Saurel et al., 2019). Scientists are also acquiring high-resolution marine geophysical data, studying the water column and carrying out rock dredging operations on the seafloor. An ongoing deep sea volcanic activity is discovered with a new ~800m high underwater volcano, confirming the already suspected volcanic hypothesis. The discovery is announced by an official press release signed by four ministries (e.g., Ministère de la Transition écologique et solidaire, Ministère de l'Enseignement supérieur de la recherche et de l'Innovation, Ministère des Outre-Mer, Ministère de l'Intérieur, 2019) and relayed by the scientific institutions involved in the campaign on their websites. The Préfecture and vice-rectorate of Mayotte launch a competition among primary and secondary schools to name the new-born volcano.

Numerous other marine campaigns will follow that will allow refining the understanding of the phenomenon (see Feuillet et al. (2019) to access the MAYOBS campaigns' reports). On 18 June 2019, an inter-ministerial meeting sets up a scientific and technical committee of crisis monitoring and officializes the creation of the Volcanological and Seismological Monitoring Network of Mayotte (REVOSIMA) with the implementation of *"a monitoring of volcanological and seismological activity in real time and continuously"* (IPGP, 2019b, published on 27 August 2019,

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translation by the authors). Several phases are envisaged for the implementation of this network. In a first phase, the REVOSIMA (called REVOSIMA 1 by the actors) is supported by a 2.5 million euros fund in order to establish a monitoring network and to guarantee a scientific follow-up of the phenomenon with the implementation of new oceanic campaigns aiming at deploying and recovering OBS. The monitoring mission is entrusted to the IPGP, already in charge of the other French volcanological and seismic observatories. IPGP operates this network through the Observatoire volcanologique du Piton de la Fournaise (OVFP-IPGP) in co-responsibility with the BRGM and its regional direction in Mayotte. The REVOSIMA is expected to set up specific scientific actions in order to : *"i) monitor the seismo-eruptive dynamics on land and at sea, in particular in connection with offshore campaigns and underwater instrumentation to monitor the possible migration of seismicity and volcanism, ii) monitor marine deformation and submersion, iii) characterize and monitor gravitational instabilities and tsunami hazard, iv) improve knowledge of the tectonics and geodynamic context of Mayotte, v) monitor the geochemistry of volcanic fluids."* (IPGP, 2019b, published on 27 August 2019, translation by the authors). In October 2019, a “pickathon” is organised by the geoscientists of REVOSIMA in order to speed up the process of relocation of the seismicity.

- **Phase 4: 16 December 2019 to 1 April 2021**

The fourth phase of the crisis corresponds to the perpetuation of the volcanological and seismological monitoring network of Mayotte which allows the development of new research on land and at sea (there has been more than 8 research and monitoring campaigns since december 2019). In December 2019, a new interministerial meeting ratifies the perpetuation of the surveillance network and the release of 4.5 million Euros funding. REVOSIMA 2 is launched at the beginning of 2020. In January 2020, seismologists of BCSF-RéNass come back to Mayotte to trace the evolution of damages due to the earthquakes from June 2018 and a second pickathon is organised to relocate seismicity. From March 2020 onwards, the actors have to deal with disruptions due to the international pandemic of COVID-19. A double maritime campaign (MAYOBS 13-1, MAYOBS 13-2) is nevertheless organized in May with the support of the French Navy. The second mission is remotely operated by scientists from IFREMER, IPGP, BRGM and CNRS located in metropolitan France. It is followed, in June, by a magnetotelluric campaign (MAY-MT) and, in October, by a seismic-refraction campaign (REFMAORE), both coordinated by BRGM. The oceanographic campaigns have continued at a steady pace since then, despite the second and third COVID-19 lock down. The only notable change, at the end of our study period, is the improvement of the automatic earthquake location method announced by REVOSIMA in March 2021.

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4. Analysis of the scientific and official communication

Table 1. Format and volume of the documents made public by the main actors involved in the scientific monitoring and risk management of the sismo-volcanic crisis in Mayotte during our period of study. As discussed in the text, we only count a report and a web article for, respectively, the BCSF-RéNass and the EMSC, and not their automatic reports. We do not count the daily automatic bulletin from REVOSIMA. We include the five academic articles dedicated to the understanding of the phenomena occurring in Mayotte that were published during our study period.

	Scientific bulletins	**Press releases**	**News on website**	**Public notes**	**Academic papers**	***TOTAL***
Scientific monitoring						
BRGM	104		22			**126**
REVOSIMA	40	1				**41**
IPGP		1	15			**16**
IFREMER			10			**10**
Researchers				4	5	**9**
EOST			8			**8**
CNRS/CNRS-INSU		2	1			**3**
IGN			1			**1**
EMSC			1			**1**
BCSF-RéNaSS	1					**1**
Risk management						
Préfecture of Mayotte		100				**100**
Ministries/Gouvernement		4				**4**
TOTAL	**145**	**108**	**58**	**4**	**5**	**320**

The number and frequency of publications vary greatly over time and among actors (Figure 4). Communication is particularly intense during the first six weeks of the crisis and continues with some regularity throughout 2018. The average number of communications per day is 6,8 during the first phase of the crisis (phase 1), compared to 1,3 (phase 2), 1,2 (phase 3) and 1,0 (phase 4) during subsequent phases (Figure 4). As mentioned in the introduction, Fallou et al. (2020) show that, during phase 1, at the same time communication rate was very high, the population perceived a lack of information on the part of authorities and scientists. This finding deserves an in-depth analysis to understand the discrepancy between the initial high

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communication rate and the *"information vacuum"* felt by local people. Hence, hereafter, we analyze in some detail not only the frequency but also the content and modalities of the information circulation during the different phases of the sismo-volcanic crisis.

Focussing on the communication of scientists and authorities, three main phases can be distinguished (A, B, C) that can be discussed in regard to the major phases 1, 2, 3, 4 of hazard monitoring and risk management (Figures 3, 4).

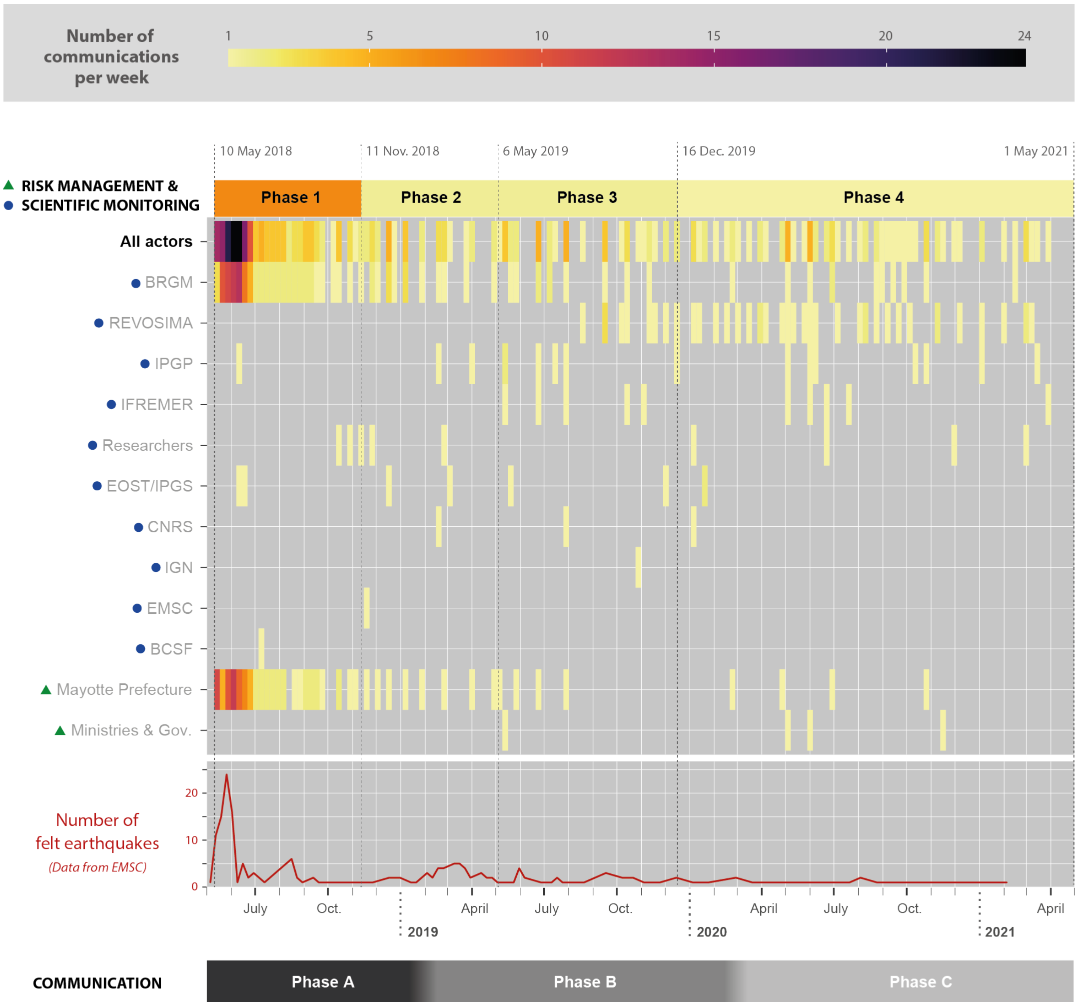

Figure 4. Number of documents made public per week by the main actors in charge of monitoring and risk management. The average number of documents published per day is indicated for each of the phases identified in Figure 3.

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- **Phase A: from the beginning of the crisis to February 2019**

Between the beginning of the seismic crisis and February 2019, the modalities of communication do not vary much. The local stakeholders in charge of monitoring and risk management, BRGM and the Préfecture of Mayotte, are the main contributors. Other scientific actors, such as the IPGP and the EOST who are gradually getting involved in monitoring from the first months of the crisis, are only communicating punctually to report on the geodynamic context of the activity and/or on their involvement in the collect and treatment of data: e.g., on 11 June 2018, EOST announces the dispatch of the macroseismic response mission (GIM) to Mayotte (EOST, 2018a); on 12 June, IPGP publishes an information brief on the ongoing crisis in Mayotte (IPGP, 2018).

The first communication to the public is a press release from the Préfecture of Mayotte on 14 May 2018. Referring to the monitoring undertaken by the BRGM since 10 May 2018, it mentions a *"swarm of earthquakes"*, distinguishes it from seismic aftershocks and recalls the safety instructions to be followed in case of earthquakes. Three press releases are published on 15 May that list the time and magnitude of felt earthquakes and specify that *"all the earthquakes take place in the same sector (around 50km off Mayotte) and, although located at sea, are too weak to generate a tsunami"*. The experts appear as puzzled by this unusual seismic activity as the people of Mayotte and the authorities. In an interview given to the French national press, the director of BRGM Mayotte declares: *"Unfortunately, we are in the unknown"* (15 June, Le Figaro, 2018b). Confronted with the repetition of felt earthquakes, the Préfet of Mayotte activates a crisis unit on 16 May 2018. From then on, the Préfecture publishes press releases on a daily basis (sometimes more) while the BRGM, which switched to "crisis monitoring", publishes daily reports. As testified by several interviewees, during that first phase of the crisis, the local branch of BRGM is put under strong pressure *"to be able to inform, almost 'day and night', the authorities on the magnitude, on the location of the earthquakes, a more precise location than the one announced by the international networks which were not reliable because of their distance"* (anonymous, interview May 2020). It is important to outline again that, before the creation of REVOSIMA, real-time data processing is organized through the voluntary commitment of scientists.

During the first weeks of the crisis, the scientific reports and official press releases follow one another within a few hours. BRGM publishes its bulletins on the BRGM website[2], while the Préfecture sends press releases to the press and publishes them on Facebook. These official press releases generally reproduce the elements communicated by the expert body. They remain often very technical, recalling the number of earthquakes recorded per day, their magnitude, the time at which they were detected and their distance from the island (the reports mention uncertainties of the order of 10-15 km). The Préfecture's press releases can contain additional elements about impacts (injuries, building damage) and often recall safety instructions. They also provide information about the decisions taken by the Préfecture to support the inhabitants of the island (e.g. with the setting up of a toll-free phone number and the opening of a psychological

[2] https://www.brgm.fr/fr/actualite/dossier-thematique/volcan-seismes-mayotte-brgm-fortement-implique

support unit ; the demand for (and arrival of) a support mission of civil protection and natural risks in June 2018).

But, despite significant effort from all parties, a careful read shows that the communication of the first weeks is overall marked by a sense of surprise, uncertainty and even sometimes inaccuracy. Two anecdotes have been quite commented upon within the scientific community. The first public scientific bulletin, published on 16 May 2018, indicates that *"in all rigor and given the limited knowledge in the region, a tremor of magnitude greater than those already observed cannot be excluded"* and outlines again that *"these earthquakes do not produce damage and, although at sea, are too weak to generate tsunamis"* (bulletin of 16 May, BRGM, 2018a). This is taken up word for word by the officials and the Minister of Outremers declares the same day that *"there is no risk of damage on land, nor a tsunami at sea"* (quote from the Minister of Outremers in *L'express de Madagascar*, 16 May 2018). Retrospectively, such statements seem inappropriate, especially because the tsunami risk is the focus of recent monitoring and warning systems developments. Another unfortunate example occurs on 1 June 2018. After a public press briefing with civil protection experts and seismologists (Perzo, 2018b), the Préfecture posts on Facebook and Twitter that *"there will be no earthquake of a higher magnitude than what we have already known"*, a seismologically inexact prediction, which has been commented as an inappropriate attempt to reassure the population. Beyond these missteps, it can be noted that the technicalist and minimalist tone adopted in official communications is at odd with the statements that are made by scientists and officials who insist on the unprecedented and *de facto* very uncertain nature of the activity (e.g. the press release of 3 June 2018, which states that *"seismic activity remains abnormal and continues"*).

The arrival of the interministerial mission composed of civil protection experts and seismologists in early June 2018 is an opportunity to take a step back from the situation (e.g., Mayotte la 1ère, 2018; Perzo, 2018b). The experts conclude that i) the impact of the earthquakes mainly resulted in an aggravation of disorders on buildings that were already vulnerable (widening, elongation of cracks) and that ii) about thirty people got minor injuries, often linked to misbehaviour in stressful situations during the earthquakes (e.g. falling down stairs). They also outline that the repetition of shaking causes a feeling of anxiety and fear among the population, all the more marked as this seismic swarm phenomenon was unknown in Mayotte until then. Despite several attempts to address the problem of anxiety (notably with the opening of a toll-free phone number and of a psychological support unit at the local hospital), the dialogue between the authorities and the people remains difficult. Mid-June 2018, the BRGM publishes a Frequently Asked Questions (FAQ) on its website explaining in a more educational way the state of knowledge and the main uncertainties. The attempt is virtuous but not sufficient. As written a few months later by the Ministry of Interior in its answer to the deputy of Mayotte, *"the most inventive explanations have found an echo in part of the population (conspiracy, actions of evil spirits, etc.) and communication is proving difficult. The State has obviously been concerned about this situation since the beginning of the event, and everything possible is being done to inform the population in a reliable manner"* (Question à l'assemblée nationale n°8992, 27 November 2018, Ali, 2018). Among the explanations that have emerged, a popular one is that the earthquakes are caused by oil exploration off the coast of Mayotte (Fallou et al., 2020). The hypothesis of a

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volcanic cause has also surfaced: it is discussed on the websites of national scientific laboratories (EOST, 2018b; IPGP, 2018) and in the local press (e.g., YD, 2018) as early as May-June 2018.

From the end of june 2018, the number of communications decreases with the decrease in seismic activity (2 BRGM bulletins per week from 29 June 2018). In September 2018, BRGM announces that *"the swarm is still running [but that] the lull observed since the end of June justifies the change from "crisis" monitoring to "routine" monitoring"* (bulletin of 17 Sept, BRGM, 2018a). From then on, BRGM publishes bulletins twice a month, with exceptional bulletins in case of felt earthquakes. In October 2018, analysing the routine GNSS measurements led by the IGN, a geophysicist from the Ecole Normale Supérieure suggests that the seismicity could be related to the deflation of a deep magma chamber. He publishes two notes explaining his results on his laboratory blog (Briole, 2018); two more notes are published in november and december. In the opinion of several scientists we interviewed, the *"wild"* publication of his results played an important role in raising awareness of the importance of this seismic crisis among scientists and authorities in charge of risk management. On 7 November 2018, a press release from the Préfecture of Mayotte mentions that the IGN measured a shift of the island eastward as well as a *"slight downward shift"*. The risk implications are not specified but it is the first time the volcanological component is officially mentioned, 6 months after the hypothesis circulated among experts and in the press. The infrasound signal of November 11, 2018, which occurrence supports the volcanic hypothesis, give rise to intense discussions among the international scientific community (Lacassin et al., 2020). It is mentioned by the BRGM in a news item summarizing current knowledge on the understanding of the ongoing activity published on its web site on 17 December 2018 (BRGM, 2018b) .

From January 2019, the frequency of BRGM bulletins continues to decrease to reach a frequency of one bulletin every 20-30 days.

- **Phase B: from February 2019 to February 2020**

On 8 February 2019, following the initiative of the STTM group of Mayotte, 140 inhabitants of Mayotte sign an open letter addressed to the Préfet of Mayotte, the local administration, the BRGM and the local media. Pressing them for more information (Picard, 2019, on change.org), they write: *"You are not unaware that, for almost 9 months, a large majority of "your" population has been living in anxiety, incomprehension ... Even anguish! The most "basic" questions in terms of security of people, conduct to hold and even projection in the near future ... Are found without any answer! You are certainly convinced that you are doing the maximum so that the panic does not reach your "constituents"? BUT this is not the reality on the ground."* Expectations are particularly high toward scientists, who are expected to provide explanations and guidance with respect to risk scenarios. But, in the absence of offshore observations, the scientific advances are still poor.

February 2019 is an important tipping point, however, as the scientific community finally receives the funding to work in the area. On 22 February 2019, CNRS issues a press release with the laureates of the Tellus-Mayotte call for tenders (CNRS, 2019). With the launch of the Tellus Mayotte program, communication opens up to new scientific actors. IPGP and EOST announce their involvement in the up-coming missions on their website. BRGM scientists publish the first

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public catalog of the seismic data collected since the beginning of the crisis (Bertil et al., 2018; Lemoine et al., 2019).

BRGM continues to publish a monthly bulletin dedicated to the monitoring of the seismicity but communication from the Préfecture of Mayotte becomes more episodic. It focuses on relaying BRGM's situation points (with the list of events - among which the felt ones - in the past months) and on announcing the arrival of Tellus Mayotte scientific campaigns. It is worth pointing out that the press release of 3 April 2019 mentions a *"scientific volcanological mission"* which aims at *“consolidating knowledge of the tectonic and volcanic history of Mayotte and at highlighting the tectonic structures of the island by means of dating of magmatic rocks, or analyses of the composition of soil gases"*.

One year after the beginning of the seismic crisis, it's time to take stock of the situation. In a press release published on 10 May 2019, the Préfecture of Mayotte reviews the actions undertaken, both from a scientific and risk management point of view, during the past year, and concludes that *"the latest data collected by the experts and the modeling of the phenomenon [now] suggest a volcanic origin, possibly linked to a large-scale underwater eruption, or even to an origin combining both tectonic and volcanic phenomena"*. When the scientists of the MAYOBS campaign arrive at the dock on 16 May 2019, they are accompanied with an inter-ministerial press release (e.g., Ministère de la Transition écologique et solidaire, Ministère de l'Enseignement supérieur de la recherche et de l'Innovation, Ministère des Outre-Mer, Ministère de l'Intérieur, 2019) announcing the discovery of a newborn volcano at the origin of the abnormal seismicity endured by the Mahorais for the past year. The government, through the voice of 4 of its ministries, commits to reinforce monitoring and prevention measures. IPGP relays the press release on its web site on the very same day (IPGP, 2019a), IFREMER, EOST and BRGM follow soon after. The announcement is relayed on Twitter, with a spectacular picture of the underwater volcanic edifice and of the rising plume above it (Lacassin, 2019), which raises the interest of international scientists and of media such as National Geographic, Science, or the BBC (BBC - Science in Action, 2019; Pease, 2019; Wei-Haas, 2019). There are similar surges of communication after the return of the next marine campaigns MAYOBS 2 to 4 in June and July 2019, but much less communication afterwards[3]. The effort of communication will resume again in May 2020 after the MAYOBS13 campaign.

From the discovery of the underwater volcanic activity, the Préfecture of Mayotte and the BRGM are no longer the only two central actors regarding risk communication. On 28 May, 2019, BRGM publishes its latest seismic bulletin on its own and the Préfecture of Mayotte publishes its latest press release only dedicated to the seismic crisis. Monitoring falls in the hand of the newly born REVOSIMA. Communication is now discussed at a more centralised level by the DIRMOM who reports directly to the prime minister cabinet. The Préfecture works closely with the DIRMOM to elaborate new communicational tools such as information leaflets. Early August, the Préfet organizes a press conference during which scientists present the results of the last campaigns to elected officials and local dignitaries.

[3] Reports and press releases following MAYOBS campaigns are listed on this dedicated IPGP web page: https://www.ipgp.fr/fr/revosima/rapports-communiques-de-presse-missions-mayobs

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On 27 August 2019, the first web news concerning the creation of REVOSIMA is published on the IPGP website (IPGP, 2019b). Entitled *"Volcanological and Seismological Monitoring Network of Mayotte"*, it presents the mandate of the IPGP and its partners in monitoring the seismic-volcanic crisis in Mayotte. REVOSIMA issues its first scientific bulletin at the end of August 2019. It corresponds to the bulletin of July 2019, the two bulletins for August follow in September creating an apparent surge of communication on Figure 4. From now on, two scientific monitoring bulletins are published every month (it will be reduced to one per month in March 2020)[4].

A scientific conference is organized at IPGP in Paris on 15 October 2019. It aims to present the obtained scientific results on the ongoing seismic-volcanic crisis, and to discuss the challenges of its future monitoring. It is followed by a public conference and a question-and-answer session in the presence of state representatives and of the media. It is covered by national media, which are stoned by the unprecedented nature of the activity (e.g., Vey, 2019), and the local press, which is proud to see a local scientist, Said Said Hachim, invited (Perzo, 2019b). In October 2019, the Préfecture set up a *"stakeholder committee"* that brings together *"all the notables, heads of department, politicians, around a table"* and to whom scientists should present, about every six months, *"the assessment of the crisis and the scientific findings"* (anonymous, interview May 2020). In November 2019, the Préfecture organises public meetings in several communes of Mayotte but with a sparse audience (a few tens of people, anonymous, interview May 2020).

In December 2019, the American Geophysical Union fall meeting hosts a special session dedicated to the Mayotte new volcano discovery where the scientific results from the first MAYOBS campaigns are presented (e.g., Deplus et al., 2019; Feuillet et al., 2019; Jacques et al., 2019; Saurel et al., 2019). From our interviews, we understand that some tensions emerge between the authorities and the scientists about one of the communications (Poulain et al., 2019), which mentions a delay of a few minutes between a triggering event due to the volcanic activity and the arrival of a tsunami on land. The authorities do not want such information to be communicated without having thought beforehand about the protection measures to be put in place. Scientists defend their academic freedom. But the case is quickly closed.

At the end of 2019, EOST also announces the arrival of the second mission of the BCSF-RéNaSS macro-seismic intervention group in Mayotte. The continuation of REVOSIMA decided at the December 2019 interministerial meeting is not really announced, at least publicly.

In January 2020, a team of French and German researchers, not members of REVOSIMA, publishes in *Nature Geoscience* the first academic paper analysing the time evolution and the dynamics of the ongoing volcanic activity (Cesca et al., 2020). This paper, mostly based on seismic data acquired by worldwide seismic networks, mentions the discovery of the new volcano before its publication by the scientists directly involved in the survey campaigns and the close monitoring of the crisis. The CNRS and the University of Toulouse, which hosts the second author of this paper, publishes a press release in French (CNRS & Université de Toulouse III, 2020)

[4] All REVOSIMA bulletins and reports are listed and accessible from the following IPGP web page: https://www.ipgp.fr/fr/revosima/actualites-reseau

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bearing a sketch section of the proposed magmatic plumbing system, which is largely commented by the STTM group: “*So much questions !!! In particular on the position of the magma chamber […] One or Two? 1 or 2 chambers? The island is moving east, towards the supposed chamber near the volcano??? And there's another one just below under the doormat on our front door”, “Silly question, but does that portend a big disaster for us?”* (excerpts from STTM Facebook group, 8 Jan 2020)

In January, EOST also announces the results of the GIM mission and of a pickathon organized by the REVOSIMA to get help in relocating earthquakes. In February, the BRGM and the Préfecture of Mayotte announce the future launch of seismic-refraction and magnetotelluric surveys (MAY-MT and REFMAROE).

- **Phase C: From March 2020 to April 2021**

From the beginning of 2020, with the perpetuation of REVOSIMA, the number of actors communicating diminishes. REVOSIMA refocuses the communication effort. From March 2020, the frequency of its scientific bulletins becomes monthly and automatic bulletins are released every day. The monthly bulletins, consisting of about ten to twenty pages, are particularly appreciated by the scientific community because they contain details on scientific hypotheses, instruments, methods and results as well as the related uncertainties. Despite a first summary page aimed at popularizing the contents of the bulletin, the monthly bulletin remains nevertheless difficult for the lay public to access as it is testified of by discussions within the STTM group: *"Gee.... a REVOSIMA bulletin of 21 pages, we didn't expect so much.....I don't understand everything, so I count on THE scientists to tell me if there is something new..."*, and in response, *"Sorry but I can't stand these bulletins anymore! I force myself to read them ? Why : 89 % of repetitions and reminders of the facts ... I haven't read this one yet (the 25th) ! I think that the objective is reached ! To make the "average" readers like us run away ! Impossible a short, sharp and clear bulletin ??? Saying : "since the last time…"* (excerpts from STTM Facebook group, 5 Jan 2021). Shorter exceptional bulletins are issued in case of felt earthquakes. REVOSIMA monthly and daily bulletins and exceptional press releases (in case of felt earthquake) are the main supports for information. They are made accessible to the public on a dedicated facebook feed and are regularly commented on, in the STTM facebook group as well as in the local press. The Préfecture continues to inform the population about new scientific campaigns.

The COVID 19 pandemics, the related lockdowns and travel restrictions complicate the scientific survey of the crisis. A part of it has to be remotely managed, including the MayOBS13-2 bathymetric survey in May 2020, operated by a commercial survey vessel while the scientific team worked on it from their homes. The objectives of these missions are announced by a press release from the Préfecture of Mayotte (2 May 2020) relayed on the websites of REVOSIMA partner institutions (IPGP, IFREMER, BRGM). The information is backed up by a government press release (6 May 2020) which recalls *"the State's permanent commitment to protecting the population of Mayotte"* and states that, as such, *REVOSIMA "continues to carry out its land and sea monitoring missions, including in the current health context, with all due precautions"*. Two information leaflets are also issued that describe the release and recovery of OBS (MAYOBS 13-1) and the acquisition of underwater acoustic data (MAYOBS 13-2). While surprisingly, no press release followed the MayOBS 5 to 12 missions, REVOSIMA issues in May 2020 a detailed report about MayOBS13 results (REVOSIMA, 2020), which is relayed on the websites of partner institutions (IPGP, BRGM, IFREMER) on 4 June 2020. The same day, the government publishes a press release that summarizes the main scientific results and thanks all the staff for their commitment in these missions.

Two more scientific papers are published in June 2020, one on the volcanological and seismotectonic context of the seismo-volcanic crisis (Famin et al., 2020), the other one, led by BRGM scientists, analyses the seismic and GNSS data from the first year (2018-2019) of the seismo-volcanic episode (Lemoine et al., 2020). It should be noted that a preprint preliminary version of the latter was publicly available in February 2019 (Lemoine et al., 2019).

The following months are marked by more scattered communications from the REVOSIMA partner institutions (in addition to the monthly REVOSIMA bulletin), aiming to summarize the knowledge acquired since the beginning of the crisis (e.g. “two years of seismic crisis and the birth of an underwater volcano in Mayotte”, August 25th, Paquet, 2020). There is a new surge of communication in October 2020 with the preparation of the MAYOBS-15 campaign. IPGP presents the campaign’s objectives on its website on 13 October, 2020 and publishes a preliminary assessment of the mission on 29 October (IPGP, 2020). The Préfecture of Mayotte issues a press release presenting MAYOBS-15 results on 28 October. Some of the scientists of the campaign remain in Mayotte to participate in the "volcano week". Organized by the Préfecture of Mayotte, in close collaboration with the DIRMOM and REVOSIMA, this "volcano week" aims to raise awareness of the volcano among the inhabitants of Mayotte. Local personalities and scientists take turns talking about the ongoing telluric crisis. The scientists present their understanding of the ongoing volcanic activity without dwelling on the possible scenarios. Only the tsunami risk is presented in some detail. Alternative scenarios are shared to the public recalling that a working group is already working to identify possible evacuation routes and that a program has been launched to work on a network of sirens and, in the longer term, a mass alert system by telephone operators. But the information shared during that week remains quite light on the overall topic of risks and the reactions posted live on the facebook feed of the Préfecture during the presentations are pretty skeptical. The tsunami risk will be commented in the local press as being eventually "quite limited" (Journal de Mayotte, 2 November, YD, 2020). Two presentations by scientists from REVOSIMA are also organized by the education authority for high school students and 160 science teachers in Mayotte. During the same week, the Préfet of Mayotte inaugurates the first tsunami warning siren in Dembeni and scientists symbolically hand over volcanic rocks to the Museum of Mayotte. The government issues a press release on 17 November 2020 that reviews the results of the MAYOBS-15 campaign and the outputs of the "Volcano Week."

In January 2021, IPGP announces to be laureate of a major instrumentation project in Mayotte (Programme Investissement d’Avenir 3, MARMOR project). Led by IFREMER, the project brings together the core partners of REVOSIMA and prefigures a restructuring of the governance of research and observation in the region. This change in governance will be all the more important in the months to come as the DIRMOM's mission ends at the beginning of May 2021, leaving room for a reorganization within the State services themselves. This reorganization is underway at the time of writing and is therefore beyond the scope of this paper. However, it is

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interesting to note that our study period, which covers the first three years of the crisis, corresponds to the first major stage of volcanic risk management in Mayotte.

In March 2021, the researchers involved in the first MAYOBS campaigns and in REVOSIMA publicly release a preprint of their paper submitted to Nature Geoscience (Feuillet et al., 2021). This paper was initially submitted to Nature in September 2019, then transferred to Nature Geoscience in June 2020, but remained confidential until March 2021. It is still under review after revision at the time of writing. The preprint describes the new offshore volcano and its activity, the evolution of the crisis from the initial deep fracturation processes to the upward migration of magma across the lithosphere, and discusses the geodynamic context, but does not discuss future scenarios of evolution and related hazards. Local press summarizes its main results using a lithospheric-scale cross-section from the preprint that illustrates the processes at work and the location of the seismicity and of magma chambers (YD, 2021). On 15 March 2021, the online media from the Cité des Sciences et de l'Industrie (a science museum in Paris) publishes a webdoc summarizing in a popularized way all main results obtained so far on the Mayotte seismo-volcanic crisis (Minassian, 2021).

5. Overcoming the gap between risk actors and populations: the role of scientific explanation and risk scenarios

The previous analysis, based on a quasi exhaustive documentation, shows that the communication strategy of the authorities and scientists has become more structured and more centralised from the summer 2019, with the establishment of a dedicated monitoring body (REVOSIMA) and with a support of a inter ministerial mission dedicated to risk reduction in the overseas (DIRMOM). Before and after that, our analysis also shows a constant commitment of scientific and state actors to understand and monitor the crisis and a care to communicate their progress publicly. But despite this, there is a persistent discontent among the population. Our study of how information circulates from its place of production to its communication in public scientific or official documents allows drawing a few lessons, which could help to improve future communication strategies. The question that arises is: why does the population of Mayotte complain about a lack of information when, objectively, the volume of documents made public by the main risk actors is significant, corresponding to a real effort to communicate on their part? We will attempt to answer that question by taking into account the specific issues at stake in each of the four scientific monitoring phases 1, 2, 3 and 4, the adaptation of the communication strategies between phases A, B and C and the evolution of the population's information needs.

5.1. Two factors determining the evolution of population's need for information

In the case of Mayotte, the evolution of the population's need for information seems to be a modulation of two main factors: 1) a need for "basic" information that is typical of all populations at risk and well known to disaster studies (see for instance Lindell et al., 2006; Mileti, 1993), and

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2) a need for information that adapts to the level of perceived danger, i.e. to the evolution of the hazard.

Regarding the first factor, Lindell et al. (2006) report 8 typical questions people ask themselves before making any decision when they receive a warning message from the authorities: Is there a real threat that requires my attention? Do I need to take protective action? What can I do to achieve protection? What is the best method of protection? Do I need to take protection action now? What information do I need to answer my questions? Where and how can I obtain this information? Do I need the information now? In the case of Mayotte, we are not strictly in the case of receiving a warning message, but feeling earthquakes warns people in a very efficient manner and one can suppose that similar questions arise. Mileti (1993) points out that it is important for risk actors to answer four main questions people face: What is the risk? Where will it happen? When will it happen? What will be the effects?

Regarding the second factor, it is important to recall that the inhabitants of Mayotte perceive the existence of offshore volcanic activity only indirectly, mainly through felt earthquakes and, secondarily, through stories told on social media and in the press or reported, for instance, by fishermen who observe dead fishes coming up from deep seas. Numerous studies have shown that experiencing the effects of a hazard increases the attention paid to information about that hazard (e.g., Sorensen, 2000). From this point of view, it seems reasonable to consider that the thirst for information of the inhabitants of Mayotte has evolved during the crisis, in response to the evolution of the seismicity (Figure 3). The beginning of the crisis was marked by repeated and strongly felt earthquakes, which goes hand in hand with a strong demand for information (Fallou et al., 2020). This interest in the topic of earthquakes is further evidenced by a peak in the number of articles published in the local press at the beginning of the crisis (Devès et al., 2021). The number of felt earthquakes decreased thereafter and so did interest in earthquake-related news. This is shown by a significant drop in the number of articles in the local press. Inhabitants of Mayotte report that, today, the risks associated with the seismic or volcanic activity are barely mentioned in everyday discussions (anonymous, interview). Indeed, people are exposed to a variety of risks, some of which are more immediate than those associated with the seismic-volcanic crisis: financial insecurity, energy insecurity, risk of being expelled from the country, daily struggle for access to water, food, and among the natural hazards, flooding, which is far more frequent.

5.2. The role of the evolving available information content

The need for information also changes according to the content of the information that is disseminated. Regarding this issue, we have identified three main phases of communication (A, B, C).

5.2.1. The technicalist biais

From the beginning of the seismic crisis in May 2018 to the launch of the first scientific campaigns in February/March 2019 (phase A), the communication is overall characterized by a frequent but minimalist and technicalist discourse (i.e. many lists of earthquakes with magnitude and location). The effect of surprise, and the lack of proper instrumentation to monitor and understand the seismic crisis, creates a context of strong uncertainties that leads to some

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confusion. We already illustrated that point earlier. A final example can be given about the uncertainties linked to the initial setup of the seismic network. As reported by Fallou et al. (2020), the fact that some of the felt earthquakes are not reported in the scientific bulletins fuels a sense of distrust among the population. Scientists in charge of monitoring take care to publish a note explaining the limitations of the seismic network and the difference with international networks (22 May, BRGM, 2018a). But the efforts made to explain these uncertainties are challenged by the publication of real-time data, albeit of lower quality, by web applications accessible to all. The Préfecture tries to bridge the gap by communicating immediately after earthquakes of magnitude greater than 5 using the data issued by international networks while recalling that *"the estimates of international measurement centers are relayed [...] [waiting for] the BRGM to refine its results"* that will be *"more accurate because the sensors [are] located in Mayotte and in the area"* (Press release, 5 June 2018). Unfortunately, this strategy, which is legitimate from a scientific point of view, tends to make it even more difficult to understand data uncertainties. It seems paradoxical to say that the data is of poor quality when they are de facto used in official communication without waiting to be improved.

5.2.2. The reassuring biais

Beyond the fact that it remains essentially focussed on the seismic hazard, the first phase of communication is marked by the propensity of the various actors of the risk chain (the authorities, but also the scientists and the local press) to try "reassuring" the population in order to "avoid panic". The local Journal de Mayotte reports that "the mayor of Mamoudzou is calling people to calm down and not to give in to any form of panic" (Journal of Mayotte, 23 May, Perzo, 2018a). Coming back onto that stage of the crisis, a scientist explains: "At the beginning, we talked a lot about the seismic risk to minimize it in the sense that these were only moderate earthquakes, 5.8 was the larger and afterwards we stayed on moderate earthquakes, we communicated quite a lot saying that to have a lot of damage it was necessary to have high enough magnitudes, that it was, maybe, not in the functioning of the system that we knew" (anonymous scientist, interview). And thus, in the local press, one could read that "Mayotte [was] indeed in a seismic zone, but the tremors [were] not of a nature to worry the scientists" (Journal de Mayotte, 2 June, Perzo, 2018b). This desire to reassure the population in order to avoid disturbances of public order is not specific to the case of Mayotte. It has been observed in other crises – like industrial accidents (e.g., Borraz, 2019) or other earthquake sequences (e.g., L'Aquila, see discussion in Cocco et al., 2015; Jordan, 2013) – even though mass panic is a rare phenomenon, considered highly unlikely by disaster specialists who have shown that it only occurs in very specific settings - such as crowds trapped in a confined and restricted space (Quarantelli, 2008).

On the contrary, communities facing disaster risks tend to react by reinforcing social control mechanisms (Solnit, 2010). In Mayotte, people like the members of the STTM facebook group cope pretty well with the stressful nature of the situation. By sharing experiences, emotions and information, they collectively increase their capacity for resilience. But coping also means, for them, understanding what causes seismicity. In order to achieve that goal, they then work at describing the phenomenon as accurately as possible (following the group, you could know whenever an earthquake was felt, with which intensity and what impact from place to place). To that respect, the expectations are very high toward scientists who are seen as the ones who can

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understand and explain. Among the scientists we interviewed, most argue that "it's not worth worrying people about things that are still hypothetical so [given the uncertainties] we chose to remain very factual" (anonymous, interview). But has this "factual" communication only dedicated to seismic hazards, and taking the form of lists of events, enabled people to understand "the big picture", i.e. what was happening and what could happen next? Has the great caution adopted by the scientists and the authorities to communicate on certainties rather than on hypotheses and means answered the basic information needs of the exposed population? We tend to believe that it adds confusion by delaying the sharing of robust information. The fact that the Préfecture mentioned the volcanic hypothesis 6 months after the local press undoubtedly contributed to the population's feeling of a lack of information, and also facilitated the emergence of complotism. It is true that, given the uncertainties, some questions could not be answered but, as suggested by Lindell et al. (2006), one might have explained earlier what was known and not known, and what will be done to address that lack of knowledge. As noted by Sharma & Patt (2012), recent empirical studies tend to show that *"lay people do understand uncertainty and, under conditions of good communication, even understand probabilistic forecasts. Therefore, there may be value in communicating uncertainty from the point of view of improving the credibility of the message. This is particularly important as the experience about the credibility of the message in the current hazard event would most likely affect the response to warning in the next future event."*

5.2.3. The hazard biais and the lack of risk scenarios

From the launch of the first scientific campaigns in February/March 2019 to the creation and perpetuation of the REVOSIMA (phase B), the format and the nature of communication changes. At first, it is distributed among much more actors and then changes scale with a resumption of communication by national actors (major scientific institutions, CNRS, ministries and government through the DIRMOM). But it remains relatively coherent as each of these actors refers to the joint Tellus Mayotte work program. The discoveries made during the MAYOBS1-2 and MAYOBS 3-4 missions constitute an important turning point in the information that is shared. From May 2019, communications no longer focus only on seismic hazard but start drawing a more general explanatory framework attributing earthquakes to an offshore, and unexpected, volcanic activity. But despite this important change, the communication remains centered on hazards rather than on risks, which still does not allow answering the population information needs. Reading the press and the STTM facebook feed, one realizes that people are very excited by the unprecedented scientific mobilisation around their island and expect to learn a lot from scientists. But after the first campaigns, given the extent of the discovery that makes fear of potentially high associated risks, the authorities become very cautious about communication. They ask the scientists to refine their scenarios before sharing openly information about risks with the population (we mentioned earlier some tensions in AGU). A scientist reports that *"today [a year after the discovery of the volcano] we are starting to talk about all the risks. But we are talking about it with frilosity. But it is not the scientists who talk about it with frilosity, I think that the authorities have locked up this subject a little."* (anonymous, interview in May 2020). Some of the scientists actually share the frilosity of the risk managers pointing out that *"I prefer to publish, and to get a peer-to-peer validation of my hypotheses, before sharing them publicly [...] I don't want to panic people"* (anonymous, interview in July 2020). Hence, the scientific as well as the official communication settles for highlighting the unprecedented nature of volcanic activity and the prowess scientists must deploy to study it. Little is said about the possible evolution of the hazard although, as recalled by another scientist, *“we identified [coarsely] the possible scenarios probably from May-June 2019”* (anonymous, interview in May 2020). The population feels abandoned. *“[…] The State gives up a lot of money and resources... But no respect for the population! No info (the same for 2 years! True!) No listening to people and their requests! No explanation in the villages […] And when they give a conference (scientific or press) it is to repeat the same information over and over!” (*excerpt from STTM Facebook group, 5 Jan 2021). The feeling prevails that communication does not answer the important questions, which are intimately linked to the issue of risk scenarios.

So far, i.e. three years after the beginning of the seismic crisis, scenarios have only been communicated orally, in the form of a listing of potential hazards, indicating that scientists are still working to refine their assessment of the associated risks. But this strategy is debated among scientists. Some argue that *"these are still scenarios, so we must be very careful [in communicating] [...] I understand that some scientists are a little confused because a lot of work has been done and not all the information has been passed on to the general public, but I think that the general public does not need to know certain information either, because it is all just hypotheses and then you take a sentence out of context and it's panic. I understand that”* (anonymous, interview in May 2020). Others respond: *“I think it's better [...] that people are aware that one day there could be a mudslide in their garden or a tsunami than not to know. I know that Mayotte is maybe more complicated because, I don't know, they have other problems but it's not a reason to hide it from [people]...”* (anonymous, interview in June 2020). Between the supporters of a communication based on certainties and quantitative assessment, which is structurally close to the strategy adopted by the authorities, and the supporters of a certain level of academic freedom in communicating hypotheses at work and not just confirmed results, the debate is still open.

Both strategies have advantages and caveats. Davies et al. (2015) argue that *“quantitative risk assessment and risk management processes”* are *“of value at regional or larger scales by governments and insurance companies”* but do not provide *“a rational basis for reducing the impacts at the local (community) level because in any given locality disaster events occur too infrequently for their future occurrence in a realistic timeframe to be accurately predicted by statistics”*. They suggest, instead, that *“communities, local government officials, civil society organisations and scientists could form teams to co-develop local hazard event and effects scenarios, around which the teams can then develop realistic long-term plans for building local resilience”*. As outlined by earlier studies, as providers of the primary information about the hazards, scientists are - whether they like it or not - at the heart of the risk reduction process (e.g. Donovan, Oppenheimer & Bravo, 2012; Fearnley and Beaven, 2018; Donovan, 2021). They cannot wait for the very last quantitative results to share their knowledge, i.e. their hypothesis, their methods and their results (that can be negative ones proving that an hypothesis does not hold). They have a moral, if not legal, responsibility to respond to the demand for information from different audiences (authorities, people likely to be affected, journalists, etc.) and at all times (times of larger or smaller uncertainties). Jasanoff (2005) speaks about “civic epistemology” as “the institutionalized practices by which members of a given society test knowledge claims used as a basis for making collective choices”. Scientists’ role is indeed all the more central as their opinions not only inform, but also legitimize the decisions taken by the authorities in charge of

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civil protection. Of course, such a posture is not easy to adopt, notably because there is a bounded understanding of the scientific approach in our societies (e.g., Bromme & Goldman, 2014). During our interviews, we were said that the comments posted on STTM hurted some scientists. Referring to the criticisms read on the Facebook of the STTM group, one of them says: *"What they did not understand is that we did not understand what was happening either [...] Because there is no analog [...] We started from an area considered as [inactive]. We find ourselves in an unknown zone to manage a phenomenon without analogue while having to organize missions involving unprecedented means [i.e. large scientific boats that should be booked months in advance] [...] Our role is to make scientific reports [but] I think these have a limited impact [because] there is no one on the ground [who can translate what we do]."* (anonymous, Interview in July 2020). That such knowledge *"translation"* has to be done by concerned scientists actively engaged in science communication and in answering people's concerns, or by professional *"knowledge brokers"* (Hering, 2016), is an open question.

The publication of an article by REVOSIMA researchers on EarthArxiv (Feuillet et al., 2021) in march 2021 gives rise to mixed feelings in the STTM feed. The fact that the publication is not associated with a document in French and addressed to the lay public is not much appreciated: *"they are seriously starting to get on my nerves! A choice to address only peers! And damn for a minimum of popularization and "simple" explanations. Afterwards, they are surprised that some and others tell everything, anything! or blame them for their "Height""* (excerpt from STTM Facebook group, 17 March 2021). The intuitive interpretations they make of the article, from the point of view of risks, are rather accurate: *"I learn from this cross-section that the volcano's chimney is 15km from Mamoudzou and not 50, where the underwater volcano is formed. Not reassuring. Moreover, the last activities mentioned are in the main volcano, so very close to us."* (excerpt from STTM Facebook group, 17 March 2021). People have clearly understood that it is not the new volcano that poses a significant risk to them. They are very concerned about the seismicity located closer to the island, especially since the publication of the cross-sectional diagrams of Cesca et al. (2020) and Feuillet et al. (2021). They ask themselves questions about a future eruption very close, and/or collapse on the outer-reef slope generating tsunamis, which corresponds more or less to the scenarios considered by scientists. To this respect, it seems rather vain not to communicate on scenarios, at least towards the part of the population who is able to understand, with only a little help, how science works and what are the hypotheses and uncertainties.

5.2.4. The complexity of multiculturalism

To conclude this discussion, it is important to come back to an essential fact about risk reduction in Mayotte in its communication aspect. Lindell et al. (2006) emphasize that for individuals to effectively adapt their response to a risky situation, they must not only receive information, but also consider and understand it. It is clear that individuals comprehend information only if it is provided in a language they understand, at a time and in a format they are accustomed to use. The above discussion shows that even if information is shared publicly, it is not properly formatted to be understood even by the educated part of the population. The fact that written communication to date has been primarily in French, an official language but one that is far from being well understood by the majority of the population, is a major problem. Efforts have been made to translate some of the communication materials, including the seismic safety

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guidelines, into Shimaoré in May 2020, but this is far from sufficient. Identifying the various habits of the population with respect to communication (not only language but also practices, who listens to who?) would also be important to adapt both format and contents. As pointed out by the Senator of Mayotte, Thani Mohamed Soilihi, orality plays an important role in Mayotte and written formats would gain to be accompanied orally (radio, animated movies but also neighborhood meetings and informal discussions with prominent members of the various social groups composing Mayotte (associations, cadis), etc.) (interview excerpt in the Report of activity of the DIRMOM, May 2019 - July 2020).

6. Conclusions

As pointed out by Stewart and Lewis (2017), *"scientists' attention to technical accuracy and their emphasis on professional consensus may do little to influence multiple publics whose worries instead root into their sense of place, trust and governance, as well as equity and ethics."* The work done on the circulation of information from its place of production (the laboratory, the boat, the field) to different publics (authorities, media, population) during the first three years of the Mayotte seismo-volcanic crisis supports this observation. There is a real gap between the culture of the scientists and authorities in charge of monitoring and risk management, and that of the local populations. The efforts made by the risk chain actors to share information are undeniable, as well as the knowledge built up over time at the cost of a high level of commitment (from the Prime Minister's office to ship technicians). This is reflected in a significant volume of publications that take various forms, from press releases to scientific bulletins, web news or communication events. But the effort is insufficient insofar as it does not allow to cross *"the last mile"* (e.g., Shah, 2006) towards the populations. Many factors come into play here, some of which are well known to the social sciences, and some of which have to do with the complicated relations between metropolitan France and the overseas territories.

In terms of communication there are several levers that could be pulled to gain efficiency. The first lever consists in establishing a real strategy of research and expertise dedicated not only to hazards monitoring but more broadly to the reduction of risks, the latter being considered in their technical dimension but also in their human and social aspects. The second lever is to work on the content and formats of information sharing. As emphasized by Oreskes (2015) about seismic risk, *“earthquake safety has never been simply a matter of geophysics, but most earthquake scientists, acting qua scientists, have traditionally understood their job to be to study how, when, and why earthquakes happen, and only to a lesser extent (if at all) how to communicate that knowledge to engineers and officials responsible for mitigation, or to the general public [...] But in the contemporary world, the inter-relationship between knowledge and safety is not easily disentangled. Seismology is no longer simply a matter of geophysics, if it ever was. It involves consideration of ethics, values, and monetary and social costs. [The trial of] L’Aquila shows that scientists can no longer ignore the social factors that affect and even control how damaging a particular earthquake may be. Earthquake prediction is a social science.”* The reasoning applies to the assessment of other *“natural”* risks. If scientists' main job is not to communicate, they are nevertheless the only ones able to appreciate the robustness of the science-based information. As such, they are expected to take the time to present it in a way that can help risk managers, elected officials, but also journalists and the wider population to act

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effectively. From this point of view, it seems important to work at clarifying the frontier between the communication of scientific advances on hazard understanding, and the communication of operational risk management measures. That frontier seems particularly blurry in the case of Mayotte. The advantage of this clarification would be twofold. Allowing scientists to explain their hypotheses, results and uncertainties would lead to an improvement of the population's scientific culture while reinforcing the credibility of the scientific expertise. The latter is a pillar of any science-based risk governance process, as one may adhere to decisions made by authorities only if he/she believes their scientific basis to be credible. The adhesion to the scientific approach is thus a prerequisite to the adhesion to the risk reduction approach carried out by the other actors of the chain. The third lever is the association of local personalities, elected officials, local NGOs, to the reflection on the risk scenarios and adaptation strategies. The international Sendai Framework for Disaster Risk Reduction calls for a more integrated practice. The signatory countries reckon that, in order to reduce efficiently the risk of disasters, *"there is a need for the public and private sectors and civil society organizations, as well as academia and scientific and research institutions, to work more closely together and to create opportunities for collaboration […]"* (Sendai framework page 7 - UNISDR, 2015). Following Ismail-Zadeh et al. (2017), Stewart, Ickert and Lacassin (2018) emphasize that the willingness for greater integration defines a *"new social contract between hazard scientists and the wider public [...] that encourages the scientific community to endeavour, alongside their existing technical expertise, to '... support action by local communities and authorities; and support the interface between policy and science for decision-making' (Sendai framework page 22 - UNISDR, 2015)"*. As shown in this paper, this change of expectations creates new challenges for scientists, notably on the issue of communication. We hope that this work will contribute to open new avenues for transdisciplinary research drawing on geosciences, social sciences and humanities that can improve the effectiveness of the science-society nexus for disaster risk reduction.

Data availability

EMSC data on the felt seismicity are available from https://doi.org/10.5281/zenodo.4734032. Instrumental seismicity plotted on Figure 1 is from Lemoine et al. (2020) dataset, and from REVOSIMA catalog (not yet available for distribution, these data will be included in Saurel et al., 2021). Press releases from the Préfecture de Mayotte and French ministries are given in supplementary dataset. French version of STTM post excerpts are also given in supplementary dataset. Full verbatim of interviews from which we extracted cited excerpts are not public for confidentiality. All other data used in this paper are available from cited references.

Author contribution

MHD was responsible for the conceptualization of the study, project administration, methodology and writing the original draft of the paper. MHD and RL undertook the revision and editing of the final paper in concert with all co-authors. MHD and GR were responsible for data curation and investigation. RL curated the STTM Facebook threads and selected relevant excerpts. MHD and

GR conducted and transcribed the interviews. MHD, RL and GR undertook the formal analysis. MHD and RL carried out the validation. HP, RL and MHD were responsible for the figures.

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Competing interests

The authors declare that they have no conflict of interest.

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