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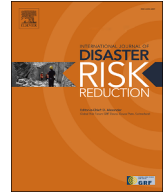
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Crisis exercise in the framework of coastal geohazards: Experience in the Balearic islands (Spain)

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ABSTRACT

Within an international cooperation network (France, Spain and Portugal) involving researchers, first responders and civil protection authorities, a crisis exercise was held simultaneously in Mallorca and Ibiza (Balearic Islands, Spain). The objectives were to test crisis management procedures defined by operational actors, integrating new developed scientific tools related to landslides and rockfalls, as well as the internal relationship with the new created Technical Advisory Committee. The initiative included a training module for all stakeholders before the exercise explaining the scientific tools used for supporting the decision-making process during the exercise, as well as a field trip in the Tramuntana range in Mallorca to gain first-hand knowledge of the geological hazards threatening the region, mainly rockfalls. More than 70 people were involved in the training exercise, including researchers, civil protection, civil guard, municipalities, representatives of the autonomous regions, local and regional crisis management managers from different French and Spanish entities, etc. At the end of the exercise, a joint analysis was made of the strengths and weaknesses found during the development of the exercise and propositions of improvements were made. Local and regional authorities concluded that, thanks to the exercise, they are better prepared to deal with georisks induced by extreme weather, mainly landslides and rockfalls. The scientific community understood the type of operational products they should develop for decision support during disaster risk crises. This experience emphasizes the need to create stronger links between the scientific community and civil protection stakeholders.

1. Introduction

Coastlines are highly vulnerable to the effects of climate change. Low-lying coastal systems are increasingly experiencing destructive impacts such as submergence, erosion and coastal flooding due to extreme events such as storm surges, tsunamis and flash floods [1]. Steep coasts may be considered a priori less vulnerable since they are normally not subject to marine submersions, but it is not

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that simple. Global warming also impacts steep coasts by more recurrent downpours, increasing slopes instability which induce quicker variations of the coastline [14]. Thus, as destructive coastal hazards affect periodically many of the world coasts, entire coastlines can be labelled as “high risk” [34,43,44].

In the meantime, anthropic pressure is rapidly increasing in coastal areas [8]. Coastal areas with an altitude lower than 10 m represent only 2 % of the Planet’s land area but contain 10 % of the world’s population [28]. The intergovernmental panel for climate change (IPCC) suggests that adaptation can substantially reduce the risks due to climate change impacts [1]. Still, the rate and magnitude of climate change are so high that even the adaptation limits are likely to be exceeded [10].

Disasters cannot be properly understood, or indeed prevented, without paying attention to the critical role of human agency and societal processes [35]. Moreover, as pointed out by Ref. [13]; an important factor to avoid a hazard to turn into a disaster is to include local knowledge in technical and scientific solutions. That is why participatory approaches to natural disaster risk management are of great importance in public policies.

Risk prevention policy is often described as based on 7 pillars [29] that are synthetized on Fig. 1: 1) understanding and assessing risks, 2) forecasting and early warning system, 3) educating people to risk awareness, 4) integrating risks in land use planning, 5) reducing vulnerability, 6) preparing and managing crisis, 7) organizing feedback.

Scientists can and should intervene in all those 7 pillars. They have a key role to play in the first 2 pillars: understanding, assessing and risks forecasting [32]; [46] and early warning system supporting [5]; [6]), but they also should be involved in the other pillars [11]. exposed a simulation game in which families were involved to be better prepared to face landslides. Scientists can also help to develop new methods and tools to better design scenarios [15]; [16] [9]. exposed a crisis exercise in the French riviera where they used scientific research to propose a flood scenario as realistic as possible.

Emergency management exercises are part of risk prevention policy. They can contribute to several of those seven pillars. They help improving the management of crisis (pillar 6) and providing feedback (pillar 7), but they also can help to test early warning system (pillar 2), be used as educational and risk awareness (pillar 3) and, with the feedback review of the exercise, improve the integration of risk in land use planification (pillar 4). Moreover, exercises are used to identify possible improvements to plans and to develop necessary individual and collaborative skills [12]. Finally, the general assumption is that emergency management exercises provide areas for learning and knowledge sharing [3].

In many countries, the obligation to organize exercises is fully integrated into the emergency management planning system. These exercises can be organised at different decision-making levels: local, regional, national, international [33]; etc. The frequency of these exercises, their objectives (testing plans, training teams or evaluating resources for instance) have to be discussed with the involved actors before conducting the exercise. Fig. 2 presents a general overview of emergency management exercise actors. All of them, or only part of them, can be mobilized depending on the type and the goals of the exercise. Indeed, emergency management exercises can take various forms. *Tabletop* exercises [45] and *command post* exercises [48] intend to test the internal procedures of the authorities contributing to the emergency response, without deploying resources in the field. *Full-scale* exercises [11]; with the involvement of the population can test, for instance, the triggering of warning systems, evacuation and sheltering measures or raise public awareness of risk culture.

In this paper we focus on a table-top emergency management exercise recently conducted (2022) in Mallorca and Ibiza (Balearic Islands, Spain) with a focus on the role played by the scientific community in the exercise. Specifically, we aim to investigate whether

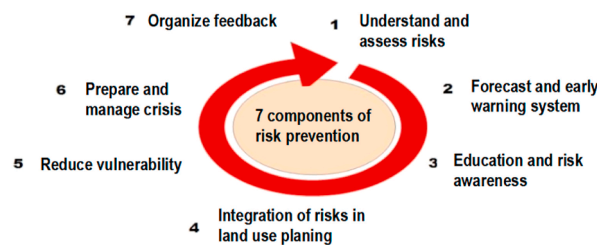


Fig. 1. Seven components of risk prevention.



Fig. 2. Actors of emergency management (Cerema, 2021).

the information and maps they created for the exercise were effectively utilized and in what manner they contributed to the emergency management.

2. TEST SITES – description and emergency management

2.1. The Balearic islands

The Balearic Islands (Spain) are located in the Western Mediterranean Sea, near the Iberian Peninsula's eastern coast (Fig. 3). The Balearic Archipelago (almost 5000 km² in extension) comprises four major islands (Mallorca, Menorca, Ibiza and Formentera) and several other islets. Mallorca is the largest island, spanning 3640 km². The climate of the Balearic Islands is of the maritime Mediterranean type, with mild winter temperatures and very hot summers. Rainfall tends to be torrential, especially after the summer months, when "cut-off low" meteorological phenomenon occurs. During these events, heavy rainfall takes place with precipitation values of up to 300 mm/24 h [20].

The word 'Balearization' is one of the known international synonyms for mass tourism and intensive coast urbanization. This unplanned urban development began with the 1960's boom and was encouraged by the European investors dynamism. The Balearic archipelago became one of the main tourist destinations on the world. Nowadays, tourism business has become the main source of revenue for the island (45.5 % of its GDP). With a population of approximately one million people, the archipelago received 16.5 million visitors in 2022. Mallorca itself welcomed nearly 12 million tourists and Ibiza and Formentera received around 3.4 million visitors in that year. Over the last decade, the Balearic Islands have had the highest occupancy rate of coastal territory among Spanish regions [24].

Geological and geographical contexts of the Balearic Islands as well as precise descriptions of the test sites (red dots in Fig. 3) are given in Appendix 1.

2.2. Emergency management and organisation in Balearic islands

The Balearic Islands is one of the 17 Spanish Autonomous Communities. Each Spanish Communities can have its own political organization under the supervision of the central government. For example, the Balearic Islands have an island-government called "Consell" to manage the citizens' security (the Consell of Mallorca has its own fire brigade). A general presentation of geohazards management in the legal framework of the Balearic Islands is given in Appendix 2.

To prepare an emergency management exercise, it is important to precise how the general map of actors (presented formerly in Fig. 2) is translated in the area under study. The regional organisation and the actors of emergency management in the Balearics Islands, synthetized in Fig. 4, are presented below:

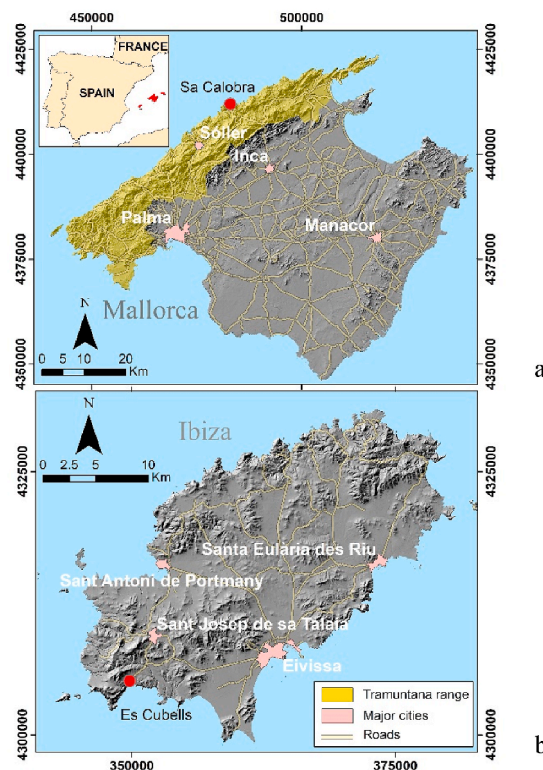


Fig. 3. Test-sites located with red points on a- Mallorca and b- Ibiza. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

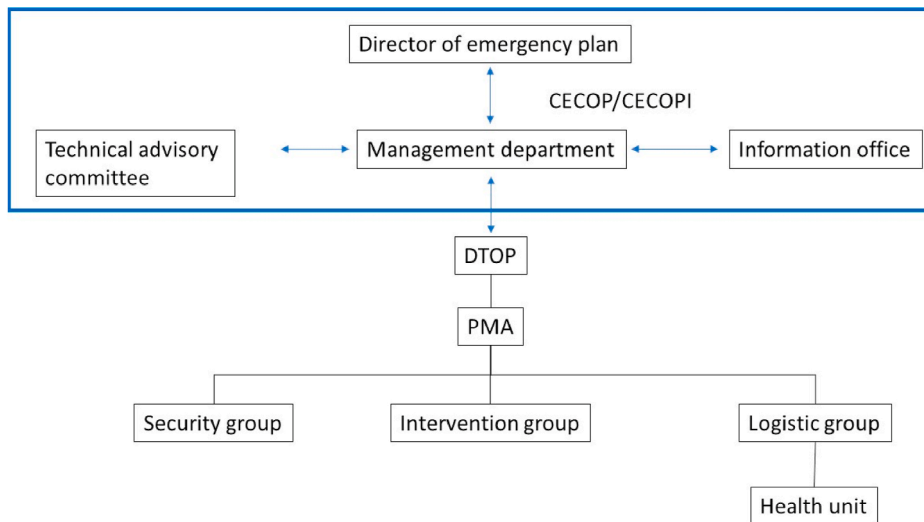


Fig. 4. Emergency management in the Balearic Islands.

The Territorial Civil Protection Plan of the Balearic Islands (PlaTerBal) is implemented by CECOP (Operational Coordination Centre) and CECOPI (Integrated Operational Coordination Centre for Scientific Functions). They are also responsible for all strategic decision in the real life or during exercise.

The **Director of emergency plan** leads the CECOP. His/Her main functions are to appoint the technical director of operations for each operational shift, the members of the technical advisory committee and the information office. During emergency, he/she has the responsibility to declare the activation of the plan and the changes of emergency phases or levels that are anticipated, to appoint the CECOP, and to decide the end of the emergency situation and deactivate the plan. Outside emergency situation, he/she ensures the maintenance of the plan's operation as well as its review and updates, convenes the technical advisory committee and the information office, transmits the decisions made to the DTOP so that they can be executed. He/she also guarantees coordination with the administrations or entities involved in the emergency, determines and coordinates information to the population, the media and other administrations, requests the participation of state media or other communities and finally proposes regulatory, preventive and compensatory measures.

The **PMA** (Advanced command post) and WFP (Forward Command Post) are responsible of the tactical coordination of the response on the site directly affected by the impact of the accident or disaster. Depending on the situation and of the number of impacted sites more than one PMA can be needed.

DTOP (technical director of operations) leads the PMA. DTOP has the maximum technical responsibilities and the direction authority of operations in the ground. Its functions are to delegate the remaining technical responsibilities to the organizational structure, exercise technical operational direction of emergency actions, to determine the deployment of the permanently activated organizational structure, to coordinate actions to be carried out by all administrations, other public entities or private and affected citizens. DTOP has also to provide the technical advisory committee with the information required for decisions-making, and proposes to the Director the activation and deactivation of the plan, the constitution of the CECOP, the adoption of regulatory, preventive and compensatory measures, the request for extraordinary measures, and the information lines intended for the population, the media and other administrations.

The **Technical Advisory Committee (TAC)** is an advisory committee, not systematically mobilized, that supposed to help to take decisions. Its functions are to assess emergency situations from a scientific and technical point of view, to anticipate the evolution of emergency situations and to propose preventive measures. TAC must therefore propose to the management department measures to control the emergency and restore normality. It also issues technical reports.

3. Objectives of the exercise and methods

The main objective of this work is to identify the strengths and weaknesses that exist when applying the tools developed by scientific teams during an emergency. Usually, these tools are developed during earlier planning and prevention stages, but not for actual application in a concrete emergency case [9]. Additionally, our work aims to identify the type of relationships established among the different actors involved in the emergency, whether they endure over time, how they coordinate, which protocols are applied, and the real effectiveness of the tools finally used. Another aspect to consider is the importance of prior training, where emergency managers have firsthand knowledge of the processes they face and the cascading effects they can generate, as well as the products and tools offered by the scientific community. Another objective of this work is to identify and evaluate the ways of informing and communicating with society about what is happening. This includes assessing the transparency of the information conveyed, the media used, and, above all, determining who should be the spokesperson for the media, as pointed out in *Exercise report - by the Paris Resilience Group* (2016).

Preparation an emergency management exercise usually follows precise steps.

- Definition of desired objectives (testing a plan, raising awareness in the population, etc.).
- Definition of the actors who will be mobilized during the exercise.
- Development of a detailed scenario and a timeline.
- Scientific material for the exercise.
- Analysis of the exercise

3.1. Objectives of the exercise for the emergency authorities and for scientists in charge of hazard and risk quantification

The Balearic authorities wanted to test the coordination between the different bodies and services included in the PlaTerBal, improving response to a possible risk of rockfall or landslide in their territory. More specifically, the Civil Protection services wished to analyse and evaluate the role of TAC in its transmission to the PMA and at the different levels of the emergency and organizational structure in the Emergency Management System. More precisely, the five objectives of the local authorities were to.

1. Implement the activation, employment and deactivation procedures of the different agencies and services, according to their specific protocols.
2. Put into practice the coordination between the State, Autonomous Community and Local Administrations responsible for resolving the emergency according to its level of severity.
3. Practise planning and decision-making within the TAC based on the information provided by each intervening body in the event of particularly complex or extreme situations (evacuation of a large number of affected personnel, care of victims, rescue, etc.).
4. Increase mutual knowledge between the different actors involved in the emergency.
- 5 Thoroughly analyse whether the maps and tools generated by the scientists held tangible value, clearly identify the information that was utilized and that which was disregarded during the emergency, and discuss the underlying reasons for these decisions.

3.2. Definition of the actors involved

In section 2.3 we described general actors needed in crisis management. Here we focus on the actors of the exercise.

o TAC

For the exercise, TAC was composed by 3 women-scientists: the director of AEMET (State Meteorological Agency), the general director of the road Maintenance Service of Mallorca and the head of the Department of Natural Hazards at IGME-CSIC (Spanish Geological Survey). They had at their disposal all the tools and maps previously created for their use during the exercise.

o PMA

The PMA was represented by the emergency truck (no inside photos were allowed).

o PlaTerBal Committee

The PlaTerBal committee was composed of the TAC (see above) and the command post, itself composed of the General Direction of Emergencies and Interior (DGEI) for the regional government, the Consell of Mallorca, the Consell of Ibiza, the national Government Delegation, of the Guardia Civil, and the Town Council of Escorca and Sant Josep de Sa Talaia. Indeed, the regional government is responsible for emergency technicians, 112 phone managers, press, etc., Consells are responsible for road-operations, fire brigade, firemen, etc., the national Government Delegation is responsible for National Civil Protection.

o Animation TEAM

The direction of animation (DIRANIM) was in charge of introducing a series of situations, events or incidents that the players will have to deal with. DIRANIM had to prepare the setting and incidents, control the timing of the exercise (greater or lesser stress on the planning teams) and, if necessary, represent the various non-participating organizations, so as to work in an environment as realistic as possible. DIRANIM has a right to feed the scenario with additional incidents during the exercise, after exchanges with the observers that are placed between the players.

The incident reporting system could be either by email, phone, or physically on paper (by hand at the emergency PMA). Weather bulletins, radar images and rainfall data are sent by email by DIRANIM to the municipalities and stakeholders at the addresses indicated in the yearbook of the exercise. The presence of media was interpreted in a fictitious way by the DGEI's communication service.

o Observers Team

Observers are supposed to follow the progress of the activities in both PMA and PlaTerBal committees, to collect and facilitate feedback from the experience. They are briefed before the beginning of the emergency management exercise with an overview of the exercise schedule and the key elements to evaluate. Each observer received a generic evaluation form as well as specific observation objectives. The code of behaviour to be followed during the observation (avoid disturbance and interaction with the players) is remind. During the exercise, observers filled the evaluation form, integrating hourly feedback provided by each member of DIRANIM. The observers had the possibility to interact by telephone with DIRANIM, if needed. After the exercise, observers debriefed quickly, and the most relevant remarks were summarized, before joining the overall debriefing.

3.3. Definition of scenarios

The definition of the scenario is defined considering the objectives of the exercise and tailored on some key components. The scenarios considered the crisis management organisation thus coordination activities were carried out in two centers at different levels.

1. CeCOPI, responsible for strategic decision making and implementation of the PlaTerBal and responsible for strategic decisions for the two exercise sites.
2. PMA, responsible for the tactical coordination of interventions in the area directly affected by the impact of the accident or disaster, for each site of interest.

The Palma de Mallorca PMA was linked to CECOPI through the DTOP.

The simulated scenario in Mallorca, developed as a command exercise, made it possible to identify key measures during an exceptional weather event, which produced rockfalls on a section of the Sa Calobra road (Ma-2141), that goes all the way through the mountain range of the Serra de Tramuntana to the cove of Sa Calobra. On this occasion, the PMA and the CeCOP with TAC, were put into operation and tested.

Fig. 5 presents the chronological unrolling of the emergency management exercise detailed below.

At the beginning of the emergency exercise (orange timeline in Fig. 5), all the command posts of the agencies and services as implicit in the figure were already set up and operational in the area, simulating the PMA deployment. The Emergency management Director engaged the first responders' teams, according to the level of alert, the resources available, or the severity of the situation. The operational units of each agency in the field were simulated. Fictitious weather forecasts and meteorological bulletins were created, over several days, based on events already experienced in the Balearic Islands, to provide information about potentially dangerous conditions, concerning landslides and rockfalls occurrences.

- 7 days before the exercise: a weather report is received from the State Meteorological Agency (AEMET) with a yellow warning for the islands of Ibiza and Mallorca with an additional note warning that 800 mm of rainfall has already accumulated in recent weeks, the rockfall triggering value estimated in Ref. [21].
- 6 and 5 days before the exercise: the State Meteorological Agency forecasts were confirmed, with no notable incidents and no need for action from the new (2022) Special Flood Risk Plan (InunBal) where landslide risk is contemplated.
- 3 to 1 days before the exercise: anticyclonic situation of atmospheric stability with low temperatures in the Tramuntana range was announced. The climatic situation is very similar to what happened during the period 2008–2010 when more than 35 slope movements took place [21]. Again, significant accumulated rainfall and low temperatures are combined, that might trigger rockfalls.

On "D-day", the emergency exercise started when the 112 received simulated calls informing of rockfalls, in both exercise sites (Mallorca and Ibiza). Then, meteorological data from the previous days, as well as landslides and rockfalls put the DGEI on alert and they proposed to the Plan Directorate an urgent meeting of TAC and the activation of PlaTerBal level 0, and level 1. The TAC is activated to help decision making. The exercise was declared completed when all safety measures foreseen in PlaTerBal were effective.

• Mallorca

More precisely, in the case of Mallorca, the 112 received a simulated call by a bus driver on his way to Sa Calobra. He informed that the road was blocked by rockfalls. Then local police sent alerts of fall of a large rock and several small ones that prevent the passage of vehicles near La Calobra before reaching the turnoff for Cala Tuent. There are at least 5 coaches full of tourists going down to Calobra and numerous cars. In the Sa Calobra and Cala Tuent areas, the exact number of present people is unknown but there are at

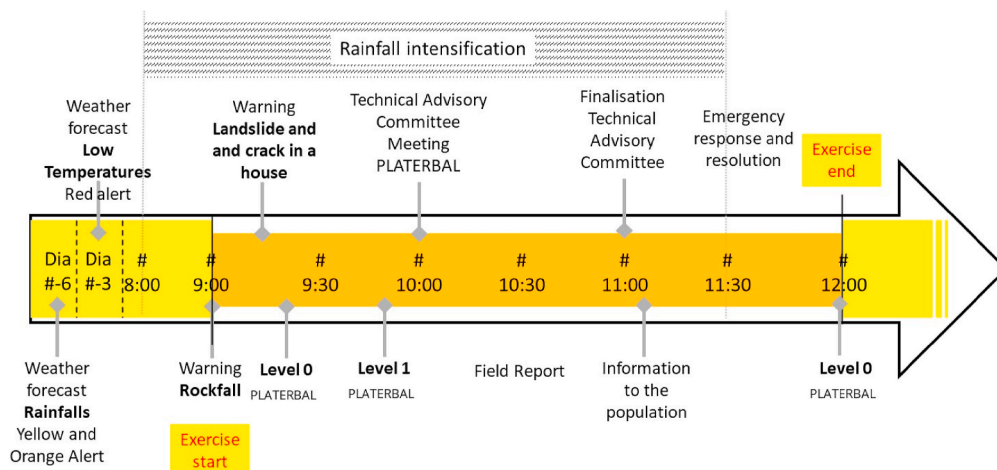


Fig. 5. Chronological unrolling of the exercise.

least 2 coaches and about 30 vehicles. At that moment, an unknown number of people doing the excursion of the Torrent de Pareis is present, unaware of the situation.

Later, Plan Direction is informed that 5 coaches with 205 people and between 30 and 40 family vehicles with about 100 people are present on site. Most tourists don't know what's going on and are nervous. Highway technician needs one day to clear the road of vehicles to be able to carry heavy machinery to remove the rocks. It is requested to know if the area is safe for the people who are trapped and for carrying out rock removal works.

- Ibiza

In the case of Ibiza, the simulated call came from a resident of Es Cubells who had found a 5 cm wide crack in the living room wall of his house near the road (Fig. 6), that was not there the day before. In the scenario, local authorities learnt that the crack has length of about 2 m and that small stones on the road have been observed. The house is currently vacated. These facts conduct local municipalities to request the Plan Director to know the possibility of a landslide occurring in order to proceed to implement the appropriate measures to protect people.

3.4. Hazard maps and tools developed for the exercise

For the crisis exercise, adaptation of existing tools or development of new ones were carried out. The tools are based on remote sensing data (satellite/drones and/or terrestrial) or mathematical simulations to support early warning systems for different types of geohazards and especially for landslides/rockfalls. We show the different products for each test-site that were shown and explained during the training day.

3.4.1. Sa Calobra (Tramuntana range, Mallorca)

Six maps were prepared to support the exercise in Sa Calobra.

- *Maps of estimated annual rainfall in dry, medium and wet type-years* [17] on the island of Mallorca. The rainfall thresholds for triggering landslides on the Tramuntana range was established in 90 mm/24 h [19] and implemented in the new Balearic Special Plan for flooding (INUNBAL, 2022). INUNBAL also establishes as rockfall-trigger rainy and cold periods, when several freeze-thaw cycles are recorded.
- *Rockfall inventory in the Tramuntana Range.* Since the XVIII century, a total of 965 landslides have been recorded in the region: 648 rockfalls; 234 landslides; 40 flows; 25 lateral spreadings and 18 karstic collapses (<https://info.igme.es/BDMOVES/>).
- *Rockfall hazard map of the Tramuntana range* based on a rockfall susceptibility map and probability maps of temporal and rockfall magnitude. The rockfall susceptibility map was elaborated by rockfall modelling using STONE [47] and applying criteria developed by Ref. [22]. The final result is a map of rockfall trajectories (Fig. 7) which was crucial to elaborate the scenario of the crisis exercise.
- *Map of social vulnerability in the Tramuntana range*, by municipalities. This map is the product of: (1) the criticality map, which takes into account several parameters related to the population: population density, foreign population, age of population, gender, educational level, housing density and housing occupancy rate; and (2) the bearing capacity map related to critical infrastructures in the municipality: road network, supermarkets, health services, hotels, police station, petrol station, educational and sport centers.



Fig. 6. Location (in red) of the fictive damaged house in Es Cubells located on a landslide (after GoogleMaps). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

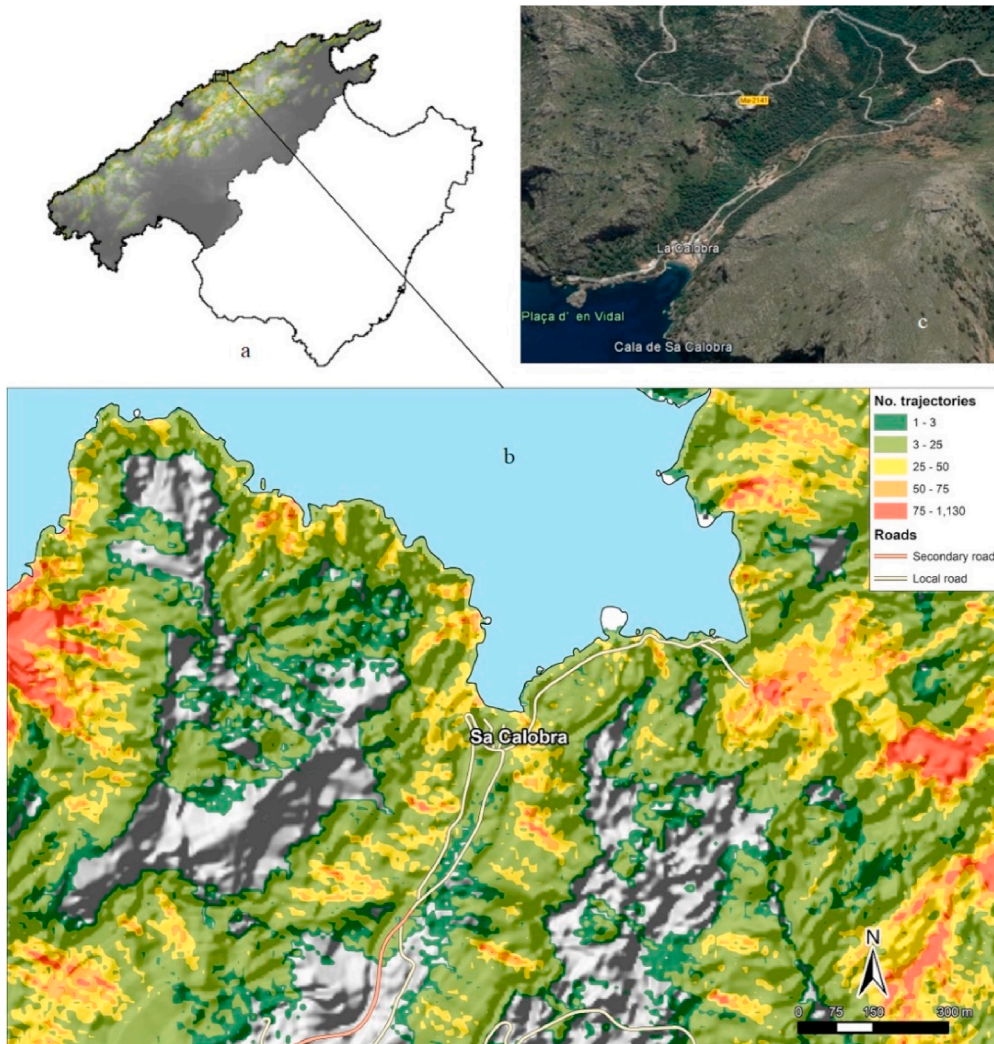


Fig. 7. a- Rockfall simulation by STONE in the Tramuntana range of Mallorca, b-zoom around Sa Calobra, c-google map view of Sa Calobra.

- *Population exposure maps* for the low (November to February), medium (March, April, May and October) and high (June to September) tourist season. These maps were elaborated taking into account the population census of the municipality and the number of people hosted during each tourist season.
- *Rockfall risk maps* for the low, medium and high tourist season by combining the rockfall hazard map and the population exposure maps for each season. This type of map is of particular importance considering the evolution of population along the year.

Detailed description of the elaboration of those last 3 maps can be found in [38]

3.4.2. Es Cubells (Ibiza)

On Ibiza we have applied the InSAR techniques to provide an integrated solution capable of absorbing data from different sensors and generating maps that can be used to support geohazard prevention and warning. The resulting maps presented during the exercise have been developed using images acquired by the Sentinel-1 satellite pair (A and B), processed partly through the Geohazard Exploitation Platform (GEP) and partly with the processing chain (PSIG) both developed at CTTC [2,7,30,31,40–42][2,42,30,31][40,41]. Sentinel-1 data cover areas of $250 \times 250 \text{ km}^2$, allowing to cover areas on a regional scale. Sentinel-1 acquire an image every 6 days, have a nominal resolution of $4 \times 14 \text{ m}^2$ and is completely free of charge. The three maps developed are.

- *Map of velocity deformation over Ibiza* (11/2016-04/2020). Fig. 8 presents the map of velocity deformation over Ibiza. It is obtained by using Sentinel-1 Persistent Scatterer Interferometry techniques (PSI) (see [2], to have more information on the methodology). Each point of the map represents a displacement measurement, and the colours refer to the displacement velocity estimated along the measured period. This result has been obtained by using 171 Synthetic Aperture Radar (SAR) images

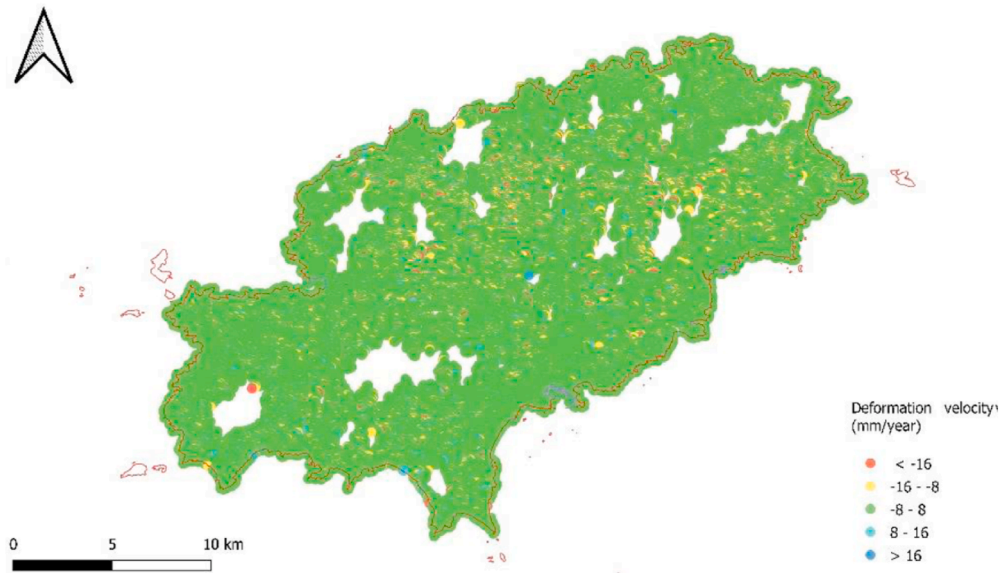


Fig. 8. Map of velocity deformation over Ibiza.

acquired by the Sentinel-1 European Space Agency constellation. The covered period ranges from January 2017 to February 2022.

- *Map of active deformation over Ibiza based on DInSAR data.* Maps of active deformation is a secondary product generated by an automatic detection of those areas where movements have been detected. The result shown in the map represents all the detected moving features. This is then filtered to prioritize the most reliable ones. The approach to detect the active deformation areas (ADA) is described in Ref. [2].
- *PSI map of deformation and times series of deformation over Es Cubells (11/2016-04/2020).* The PSI results also include the temporal evolution of the displacements (TS) for each measured point. Fig. 9 presents a focus of the accumulated displacement along the analyzed period at each of the 171 acquisition times of the satellite around Es Cubells. Deformation velocities 16 mm/yr are identified in the site (blue points) which corresponds with an active landslide that also shows clear evidence in a dwelling.

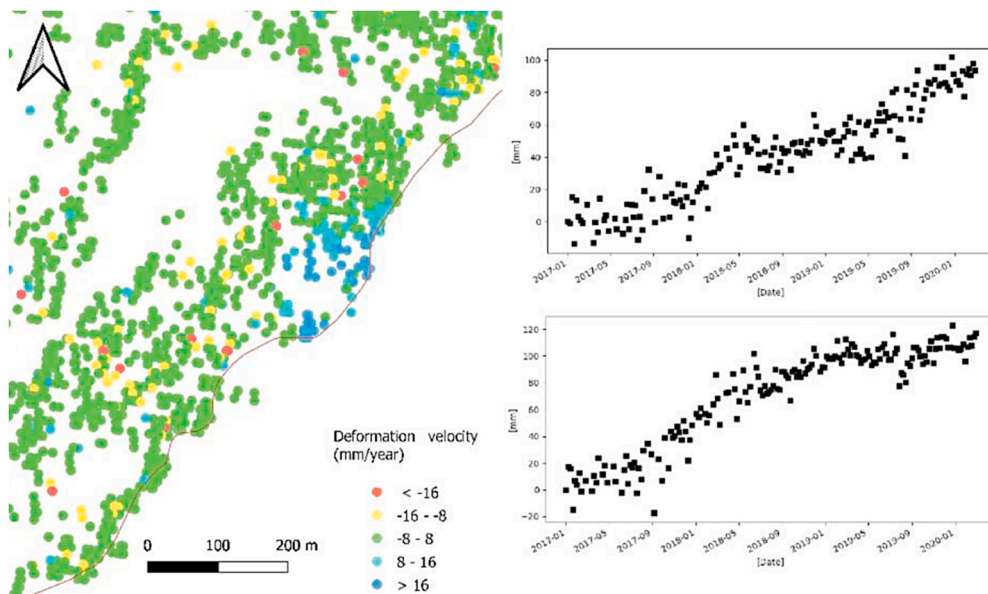


Fig. 9. Times series of deformation over Ibiza Island near Es Cubells.

It is worth noting that the maps developed for the exercise can now be obtained directly by using the data provided by the EGMS Copernicus Service (<https://egms.land.copernicus.eu/>) which was not the case 2 years ago.

3.5. Trainings about geohazard maps and tools for emergency services

Since one of the aims of the table-top exercise was to assess the value of having scientists in the TAC and to improve the use of new maps and tools, the exercise was planned on the third day of a 3-day period composed by a training day, a field trip, and the exercise itself. The training day was organised for local agents from emergency services, civil security, military forces, firefighters, scientific community, etc. It was dedicated to show and explain the tools (maps, radar images, rockfall simulations, etc.) that can be used within the exercise or during real crisis. The field trip in the Tramuntana range was organized to visualize the most hazardous zones, in particular Sa Calobra area.

3.6. Analysis of hot and cold feedback

The “hot” debriefing feedback is conducted by one of the animators and consist in an open interview with representatives of each group of stakeholders in the exercise, concerning.

- Strengths and weaknesses in the activity of the group concerned.
- The most disruptive or blocking elements in the functioning of the unit.
- The most useful available data, and what was still missing.
- the exercise design and management: readability of the documents provided, pace, difficulties, logistics.
- the exercise objectives: effectiveness of the teams to apply the PlaTerBal procedures, of the newly developed products, quality of information management and transfer, strengths and weaknesses of the last modifications to PlaTerBal.

The cold feedback is realized a few weeks later. All participants receive an online survey and are asked to send written feedback about their recollection of the exercise, whether positive or negative. The survey has been defined according to the standards [18]. Some major topics are addressed through the survey (detailed in Appendix 3).

- identification of respondents, including the role they played during the exercise.
- assessment of overall satisfaction.
- evaluation of the functioning of the cells.
- evaluation of the contribution of the new "tools" developed.
- the animators' point of view.

All these elements are used to improve the emergency management, the plans, and organization of the participants. They are also used to improve the tools developed to make them more relevant, more operational, and more useable by the actors of disaster risk crisis management.

4. Results

Table 1 synthetize the number of participants in each specific day.

4.1. Trainings about geohazard information and maps

About 50 local agents from emergency services, civil security, military forces, firefighters, scientific community, etc. attempt the training day. They found very useful to be able to discuss together with scientist who developed the tools and understand how maps

Table 1
Summary of participants.

	nb	
Training day		
Scientists (trainers)	12	IGME, CTTC, CEREMA
“students”	62	Firemen, Guardia Civil, Civil Protection, AEMET, etc.
On field trip		
Scientist	24	IGME, CTTC ^a , CEREMA ^b , BRGM ^c , UGR, IGOT ^d
Other	5	Civil Protection
Exercise		
Committee	people	Many organizations
TAC	3	AEMET, IGME, the Road Maintenance Service of Mallorca
PlaTerBal comm.	8 + TAC	DGEI, 2 Consells, National Gov. Delegation, Guardia Civil, 2 town Councils
DIRANIM	3	CEREMA, DGEI, CTTC
Observers	5	BRGM, CEREMA, Civil servants of Bidart (France) and Barcelona (Spain), Italian Department of Civil Protection
Players (own role)	~30	Firemen, Guardia Civil, Civil Protection, etc.

^a Catalonia Technologic Centre for telecommunications (Spain) www.cttc.cat.

^b Centre for Studies on Risks, the Environment, Mobility and Urban Planning (France) www.cerema.fr.

^c French Geological Survey www.brgm.fr.

^d Geography and Spatial Planning Institute of Lisbon University.

are obtained. In the meantime, scientist found it very interesting to be able to discuss with end-user and some mentioned that it was helpful to understand how to improve the tools to make them more useable.

About 25 scientists involved in the development of the new tools were in the field trip, together with 6 local agents from the Emergency Services (Fig. 10). Scientists were interested in observing the on-field reality, especially important when working on satellite images.

4.2. The table top exercise

The exercise lasted 2.5 h between 9.30 h and 12:00 h and was immediately followed by the hot feedback that lasted about 45 min. Fig. 11 displays photos realized during the exercise.

Five crisis management experts were involved as observers (see Table 1). This panel permits to consider the various approaches to emergency management in both countries (France and Spain).

4.3. The hot feedback

As mentioned, the hot feedback is a critical review meeting during which positive points to remember, points to be improved, etc. are discussed with a representant of all type of participants (players and observers). The observations and comments of the simulation showed that PlaTerBal was respected and correctly applied. The level of means and resources made available to CeCOPI and PMA was generally satisfactory. Exchanges and updates of PMA data showed good structuring. Particular attention was paid to the public information exercise. CeCOPI has planned improvements to make situation points and prioritization of elements more specific and efficient.

It was observed that only part of the new tools developed for the exercise (and described above), were used by TAC integrated in CeCOPI. In addition, PMA had other types of geospatial reference data, such as orthorectified aerial imagery and road network data, stored on the server installed in its mobile unit.

In the case of Sa Calobra, the map of simulated rockfall trajectories was extremely useful. This map was used to decide the safest area to shelter people trapped in the bus. For this purpose, an area not too far away from the bus and far from the reach of any trajectory was decided upon. Here the people were kept waiting for their final evacuation to be decided.

In the case of Es Cubells, Ibiza, the use of satellite data and data derived from landslide modelling made the exchange and coordination between the technical and operational levels and the TAC more effective, although it was noted that there was a need to improve the functioning of DTOP due to the risk of interference between decision-making and information transfer by PMA crisis managers during the exercise. Sometimes their information was returned in too much detail and without taking full advantage of the new types of data made available by the Scientific Committee.

The availability of the newly developed tools on the PMA servers would allow for more effective use of their potential in order to understand the possible evolution of threats, as well as more effective information sharing between PMA and the TAC.

4.4. The cold feedback

Cold feedback was realized a few weeks after the exercise by web-based survey. A form (see Appendix 3) to be filled on a voluntary basis was sent to all participants (players and observers). Around half of the actors answered. The 9 interviewees were mostly representatives of the local authorities in charge of civil protection for the Balearic Islands (BI), as well as a member of the IGME-CSIC (Spain). Six of them performed their own roles in the exercise, i.e., 4 in CeCOPI and 2 for PMA, while the others played an animation role (Fig. 12).



Fig. 10. Field trip. Participants at the Son Cocó rockfall (Tramuntana range).



Fig. 11. pictures of the exercise. a-during the exercise, players are around the maps to discuss important issues, b-scientists, as non-official observers, are gathered in a tent to follow in a screen what is going on without disturbing the players, c- TAC during the exercise, and d-, official observers discussing together at the end of the exercise, before the hot feedback.

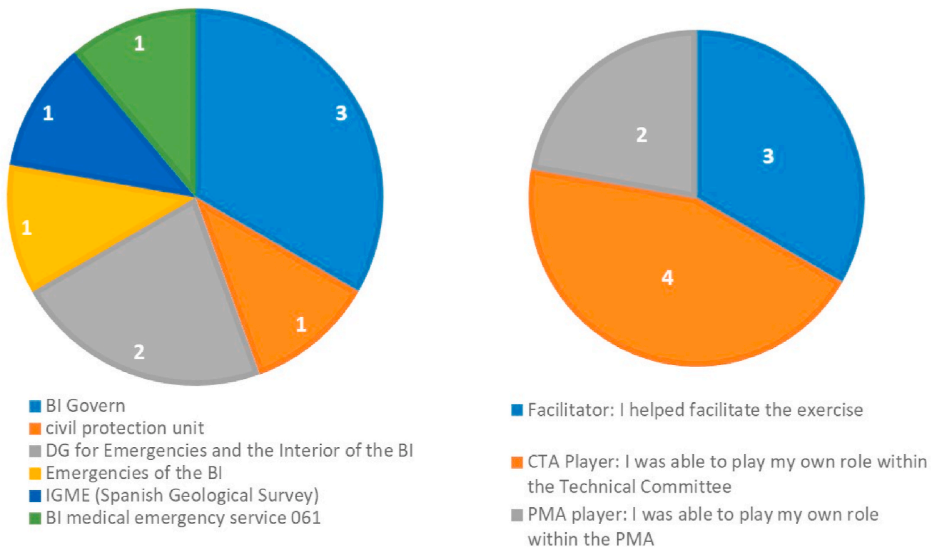


Fig. 12. Profile of respondents, according to the entity to which they belong (left) and their role during the Mallorca exercise (right).

4.4.1. Overall satisfaction of participants

All respondents to the questionnaire were satisfied with their participation in the Balearic Islands simulation. They highlighted the 3 main strengths: good preparation of the exercise, realism of the considered scenario and good collaboration between players. However, some participants regretted that the relatively short format chosen for the exercise did not allow the injected events and the actions performed by the players to develop fully, due to a limited time span.

4.4.2. Cells functioning

The simulation exercise involved the two crisis management cells: CECOPI TAC and the PMA. Although the participants have a positive perception on the composition and functioning of TAC and PMA, a detailed examination of the responses shows that opinions were divided, particularly regarding the exchange of information between the two units, which seems to be an important area for improvement. Regarding TAC (Fig. 13), although the organisation of formal progress reports seems to have been lacking, the use of newly developed maps by the Committee's scientific experts was highly valued, as was the composition and management of the unit.

There were various responses to the open questions on TAC: "Need for a clearer distinction between "scientific" and "operational" functions to improve dialogue without the technical-operational staff taking up too much space in the TAC". Moreover, as usual in exercises, TAC members were already together at the beginning of the exercise, whereas in a real life this would not be the case. Therefore, it must be taken into account that in a real life there would be a time lag, implying a different TAC functioning.

TAC conclusions did not clearly reach PMA. Their recommendations and opinions were not sufficiently documented to allow them to be compared and evaluated. They were only followed by DTOPT when explained orally, which subjectified and summarized them, thus missing technical aspects. This prevented the rest of PMA from making a full assessment for application to the emergency.

For PMA, Fig. 14 confirms the difficulties encountered with TAC on the organization of situation points. However, leading the PMA and taking into account the views of the experts seem to have been more difficult than dealing with TAC.

Among the different responses to the open questions on PMA, the following points can be noted.

- Some participants lacked knowledge of the "pyramid of command".
- Some decisions were taken in haste without considering the TAC conclusions.
- As in the case of TAC, the exercise was conducted with PMA already operational at the time of the emergency. It should be noted that in a real life this would not be the case.
- It appears there had been difficulties related to some actions played in real time and others in compressed time. For example, events were injected while DTOPT was meeting with the advisory committee, which left PMA at times without direction, and there was no internal communication to solve the problem.

Concerning the contribution of the "tools" developed, only three of the nine respondents indicated that they had been able to consult rockfall maps of Ibiza area, including two animators and only one TAC player. Whereas this one player considered this type of map to be useless, the two animators considered it to be very useful, especially to support decision-making concerning speed and moving area.

Five respondents, including two animators and three TAC players, consulted the fall trajectory maps in the Tramuntana range. Apart from one respondent who considered these maps completely useless (the same person who had considered the previous maps useless), the other four respondents were very positive and considered this type of map to be very useful, especially for locating refuge areas where victims could take shelter.

In general, respondents found the integration of data into the TAC database. Moreover, beyond the tools themselves, the scientific experts' contributions were highlighted with particular regard to the ability of contextualising and explaining technical elements to operational actors.

5. Discussion

Considering the exercise feedback, gathered with other feedback from other partners involved in emergency and/or urban and territorial planning, we were able to outline some strengths and weaknesses of the coastal geohazards management and stress the importance of involving scientific teams.

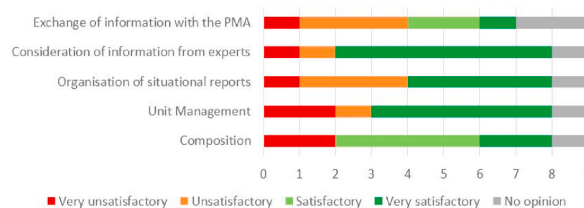


Fig. 13. Satisfaction level with the composition and functioning of the TAC.

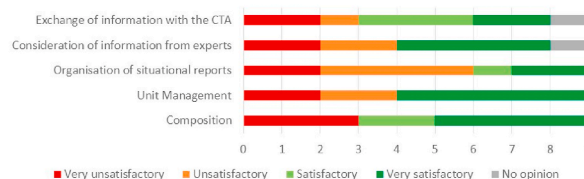


Fig. 14. Level of satisfaction with the composition and functioning of PMA.

5.1. Strengths

The relationship with the Civil Protection services is smooth and usually occurs within the framework of joint research projects or through dedicated agreements on specific cases. Scientific institutions participate in the development of tools to support civil protection, as well as land management/urban planning. Tools consist mainly methodologies and databases, followed by geo-maps and methodologies to support early warning systems. The scientific community is aware of a need for applied science, which supports and improves the management of geological risks on coasts. Most Civil Protection services value the importance of a scientific advisory committee (TAC) in an emergency situation and the information provided is used effectively. Civil protection specialists say that their experience of working with natural hazard experts is useful or very useful and helps them solve problems during an emergency. The affirmation is reciprocal. The Civil Protection services have an established interlocutor to interact with scientific experts. Experts in urbanism/territory management consider that all geological hazards should be taken into account when it comes to territorial planning and urbanism: landslides, earthquakes/tsunamis, floods, erosion, and retreat beaches. This community of experts has a good perception of risk. European Directives oblige to consider flooding in urban planning. The existence of clear and forceful legislation greatly favours not only collaboration between the institutions, but also the efforts devoted to specific problems. Most managers acknowledge having specific guidelines for designing geological hazard maps for application in urban planning. Urbanism/territory managers consider maps useful and easy to interpret and use them as a priority. The relationship between the three actors: Scientific Community, Civil Protection and Urban Planning Managers is generally considered to be fluid and mutually beneficial. The outputs generated by the scientific community, especially the maps dedicated to susceptibility, hazard, vulnerability and risk are of enormous interest for Civil Protection and Urban Management. Solid institutional relationships are nurtured through joint research projects or through specific agreements.

5.2. Weaknesses

Some weaknesses were identified and are described below together with proposed improvements or actions that could be realized.

1. A lack of legal framework has been identified for collaborations between the parties (scientific community, emergency managers, territorial/urban planning). Cooperation is carried out through specific agreements, provision of technical consulting services and research projects, which are usually a one-off agreement. But there is still some confusion between the missions of each party: even during this exercise, the survey answers outlined some difficulties in sharing information and decisions between TAC and PMA.
 - ⇒ *Proposed improvements:* protocol implementation for permanent collaboration under legislative guidance. Scientific advice should be officially part of administrative process and performance protocol.
2. The most expected geological hazards in territorial and urban planning are regulated by specific legislation, such as floods, (cf. the European Floods Directive 60/2007); whereas coastal risks (such as coastal erosion, marine invasion and the retreat of beaches and cliffs), derived from climate change and are usually not enough considered.
 - ⇒ *Proposed improvements:* There is a need to adapt and improve legislation to climate change risk scenarios. Climate change adaptation plans in coastal territories should be mandatory. The risk mapping is lacking a unique set of documents, harmonized charts with common criteria to promote management. An improvement in protocols for cascading effects on the coast is highly needed.
3. Emergency managers, as well as experts in spatial planning/urban planning, require a more practical scientific information, such as maps or specific reports.
 - ⇒ *Proposed improvements:* The response of the scientific community must be faster, as well as more practical and less theoretical. Hazard and risk legislation should be standardised within a common conceptual framework. Methodological procedures to produce risk maps for spatial planning and emergency planning should be recorded and harmonized. Scientific publications (specialized journals, books and chapters of technical books) rarely provide direct, useful and understandable information to those responsible for land management and emergencies. Scientists focus more on understanding the dynamics of past events, whereas policymakers need more models to anticipate future events. The scientific community needs to do more work on developing early warning tools. For a correct application, documents produced by the scientific community must be clear and easy to interpret by non-earth science people. Susceptibility, hazard, and risk maps must be accompanied by regulations with the definitions of compatible uses, to ensure their full effectiveness.
- 4 Communication to public is crucial, especially in the means of how scientific aspects are transmitted. Differing opinions can seriously harm the management of emergencies and end up misinforming the population.
 - ⇒ *Proposed improvements:* Interactions with the media and the public need to be more consensus-based. Having one single point-of-contact is essential. The scientific community should be more actively involved in communicating and disseminating information to the public.
5. Civil Protection draws attention to the inappropriate role of the media, which can hinder emergency management, by transmitting unclear and unofficial information. This calls for the need to act jointly and more collaboratively.
 - ⇒ *Proposed improvements:* Common action and organization plans involving the scientific community, civil protection, territory/urban managers and journalists are needed. Greater training in scientific communication for all actors involved in emergencies.
6. A high proportion of respondents consider that natural hazards are NOT well considered in urban planning.

- ⇒ Proposed improvements: It is necessary to homogenize methodologies and cartographies, in terms of contents, scales and procedures. There is a need to include all geological hazards that may affect a territory. We must produce a multi-risk cartography and include the opinion of the experts in the final approval of the urban plans.
- 7. Greater joint training and the need to create frameworks for connection and collaboration.
 - ⇒ Proposed improvements: The scientific community is not always aware of the protocols of action and lacks -to a large extent- knowledge about the current legislation. Experts can be unaware of the actual application of their products Emergency and town planning managers need continuous training on the scientific progress they can apply to their fields of work, especially new monitoring techniques.
- 8 Preventive measures are rarely implemented. Action is taken only once the problem has occurred and the corrective actions are only structural in most cases. There are hardly any known initiatives with natural-based improvements.
 - ⇒ Proposed improvements: Together with the scientific community, identify the problem upstream, when it is still at the risk prevention level, and have the disaster management procedure updated accordingly. Invest in land management, measures to prevent risks including those related to climate change, towards natural measures with environmental respect, both at the prevention and mitigation stages.

Although there is a long way to go in terms of a legislation on risks, countries should be more forceful in pursuing common legislation that includes geological risks – as a whole – not only in emergency management, but also in territorial and urban planning. In the coastal areas, natural spaces play a fundamental role in the balance of coastal dynamics. Their modification or occupation generate a greater exposure of the population to risk. Coastal strips are highly coveted by urban planning, and that is why its regulation must be well established.

5.3. The real use of scientific information

Regarding the utility of the tools and maps developed for the exercise, only two of them were ultimately employed by the Scientific Committee: the rockfall trajectories map of the Tramuntana range in Mallorca (Fig. 9) and the PSI map depicting deformation and time series of deformation in Es Cubells-Ibiza (Fig. 11). The primary rationale behind this selection is that these are the sole products that facilitated detailed work and provided the essential information needed for decision-making.

The rockfall trajectories map was used in Sa Calobra to determine a secure area for the evacuation of bus passengers. A level area near the bus, well clear of any potential rockfall paths, was chosen.

The PSI map and the time series of deformation in Es Cubells (Ibiza) were employed to confirm the activity of the landslide upon which the damaged house was situated. In the event of a rapid movement of the landslide, it could dislodge an upper rock escarpment, leading to a significant rockfall. This analysis prompted the evacuation of the house's occupants and the closure of access to the area.

No other maps or information were consulted or used during the exercise. Notably, the maps depicting social vulnerability and population exposure at the scale of the Serra de Tramuntana were prominent. Despite the substantial effort invested in their preparation, these maps were disregarded by the participating actors. The chosen scale was deemed inappropriate, and the scenarios designed for low, medium, and high tourist seasons lacked relevance compared to the actual conditions of the time and location.

6. Conclusions

Within an international cooperation network (France, Spain, Portugal) a crisis exercise was held simultaneously in Mallorca and Ibiza (Balearic Islands, Spain). The aim of the exercise was to test new tools developed in order to better understand geological hazards, but also to test the opportunity of the presence of a technical scientific committee (TAC) during a crisis. Strength and weaknesses were identified. Improvements were proposed to reduce the identified weaknesses.

This experience in Mallorca and Ibiza underscores the fact that maps and products on a regional scale are ineffective in emergency situations. There is a pressing need for tools that can be tailored to a small, detailed scale of work and are genuinely valuable for decision-making at specific locations and times. Consequently, it is essential to enhance links between scientific community and first/second responders promoting user-targeted research and faster transfer of science results and products into best practices. Joint work must be done for common technical standards of alert and impact forecasting systems that cope more efficiently geological disasters. The scientific community must make efforts to adapt its research to obtain products more understandable by non-experts, to be more useful for society, especially maps and methodologies at the appropriate scales.

The first day of training and the field trip were of enormous importance. It provided a unique opportunity for the scientific community to explain various processes and their approach. There was a particular focus on the utilization of new technologies, including Earth Observation from space. During the exercise, special attention was given to the proper use of DiNSAR information in managing the Ibiza emergency. Moreover, new applications were introduced, such as rockfall modelling. This proved to be a fundamental tool in effectively managing the evacuation in Sa Calobra on the day of the exercise.

These kind of collaboration experiences allow the identification of needs and opportunities for transferring advanced scientific results into enhancement in disaster logistics and responses. Education and training programmes are vital for emergency management teams, as well as the adoption of novel technologies such as advanced Earth Observation space capabilities.

Climate change drives new challenges in the management of geological risks. Extreme weather events are becoming more frequent and widespread. Maritime storms, DANAs and strong storms usually bring cascading effects on the coast: landslides, rockfalls, beach erosion, floods, sea invasion etc. Geological hazards cannot be addressed separately, but as a whole, as they are interrelated. Civil Pro-

tection and territory/urban managers must take into account these new scenarios and work, together with the scientific community, in the development of new protocols and tools that fundamentally support the prevention stage.

Finally, the three agents must act together when interacting with the media, providing transparent, pedagogical, scientific and contrasted information. The excess of information generates confusion in the population, which loses confidence in managers and becomes much more vulnerable.

CRediT authorship contribution statement

Muriel Gasc-Barbier: Writing – original draft, Supervision, Project administration, Funding acquisition, Conceptualization. **Rosa Maria Mateos:** Writing – review & editing, Investigation, Conceptualization. **Christian Iasio:** Writing – original draft, Methodology, Data curation, Conceptualization. **Anne Chanal:** Writing – original draft, Methodology, Formal analysis, Conceptualization. **Arnaud Villatte:** Resources, Investigation. **Séverine Bernardie:** Writing – review & editing, Supervision, Funding acquisition. **Cristina Reyes-Carmona:** Data curation. **Roberto Sarro:** Visualization, Resources, Data curation. **Monica Martínez-Corbella:** Data curation. **Juan Antonio Luque:** Data curation. **Juan López Vinielles:** Data curation. **Oriol Monserrat:** Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix 1. The Balearic Islands: Geological and geographical contexts

A1.1. Geological and geographical contexts

From the geological point of view, the Balearic Islands constitute the emerged part of the Balearic Promontory that extends 440 km in a NE direction in the middle of the Western Mediterranean. The Balearic Promontory corresponds to the northeast offshore prolongation of the Betic Cordillera of mainland Spain. The geological structure of the archipelago is the result of an evolution of different stages, outstanding the contractional Oligo-Miocene orogenic stage that configures the main ranges of the islands with an imbricate NW thrust system [37]. The Balearic Islands have 1573 km of coastline, 79 % of which correspond to rocky coasts. The Serra de Tramuntana range in Mallorca, the northern region of Menorca and the island of Ibiza are territories with a predominantly step and rugged coastline, with small beaches (coves) interspersed. Considering the climatic and landscape conditions, flash floods, landslides and rockfalls are the main geohazards in the Balearic Islands.

Considering all those observations and previous works, we choose to localize the emergency exercise on two sites: one in Sa Calobra (Mallorca), a small coastal cove in the Tramuntana range (Escorca) and the other one in Es Cubells, on the SW coast of Ibiza; both places not only represent ones of the most hazardous areas for landslides in the archipelago, but they are also very popular sites for tourism.

A1.2. Sa Calobra (Tramuntana range, Mallorca)

The Tramuntana range is the main mountainous alignment of the Balearics (Fig. 3a). This region encompasses 16 municipal districts with a total population of 125,000 inhabitants, with the northern face much more heavily populated and urbanised. The steep topography of this chain, linked to its geological complexity and Mediterranean climate, determines intense slope dynamics with consequent movements of all categories [19,25]. The vast urban development that the Tramuntana region has undergone in the past 40 years has considerably increased risks originating from mass movements.

During the years 2008–2010, Mallorca experienced one of the coldest and wettest winters in living memory, with the highest rates of intense rainfall (up to 296 mm/24 h). The result was 34 mass movements triggered, along the Tramuntana Range [26]. Fortunately, there were no deaths but there were numerous cases of damage to dwellings, holiday apartment blocks, barns and power stations, and especially the road network in the Range (a), which caused significant economic losses in the different tourist resorts. A complete landslide inventory is continuously updated in the Tramuntana Range by the Geological and Mining Institute of Spain (<https://info.igme.es/BDMOVES>) based on numerous studies on slope movements [4,17,19,21–23,36,39].

Sa Calobra is one of the most visited natural places in Mallorca that can only be reached in two ways, either by a very narrow serpentine 12.5 km long road, with set shifts for getting on and off, or by boat. During the summer, an average of 50 tourist buses a day reach Sa Calobra and it is also one of the most popular cycling routes in Europe. Recently, the small touristic place of Sa Calobra was affected by rockfalls during a rainy event in November 2019 (b) and the access road has been closed on numerous occasions due to this type of process (figure A1).



Fig. A1. a) Gorg Blau rockfall (Tramuntana range) occurred at the end of 2008 after heavy rains and low temperatures. The main road of the region (Ma-10) was blocked during almost 3.5 months. b- Rockfalls at Sa Calobra during the rainy event in 2019.

A1.3. Es Cubells (Ibiza)

The coast of Ibiza is characterized by a large number of small coves and pocket beaches, impended by cliffs carved in relatively weak rocks such as calcarenites and marls. Due to its structural, geomorphological and lithological characteristics these cliffs are subjected to widespread occurrence of landslides and rockfalls which represent a major threat to the safety of tourists during the long touristic season of the island (April to November). This threat has increased in the last decades, as the island of Ibiza has become one of the major tourist destinations in Europe.

In August 2017, a heavy rainfall episode took place in Es Cubells, Ibiza (b). This rainfall event (> 40 mm in 1 h) caused extensive damage to the access road to coastal housing estates, impacts of rock blocks on homes and vehicles (figure A2) and people had to be evacuated by sea.



Fig. A2. Es Cubells (Ibiza), damages caused by the heavy rainfall event in August 2017. ©Emergency Service from the Balearic Islands.

Appendix 2. Geohazards in the legal framework of the Balearic Islands

The Balearic Islands are composed of 4 main islands, Mallorca, Menorca, Ibiza and Formentera. They represent one of the 17 Spanish autonomous communities. Spain is a highly decentralized unitary state, thus, land-use and civil protection planning in Spain de-

pend on decentralized public authorities and a transfer of powers to the autonomous communities. Town councils are in charge of urban planning but the final acceptance of the areas subject to urban development depends on the autonomous community decision. As developed by Ref. [27]; geohazards are contemplated in the Spanish legislation in two well-defined areas: (1) the Land and Urban Rehabilitation bill and (2) the Basic Civil Protection regulation.

The Land and Urban Rehabilitation bill, approved in 2015, includes the requirement to draw up natural-risk maps within the ambit of land-use planning. Two articles are of major importance considering natural hazards: Article 21 “non-developable lands are considered to be those with natural or technological risks, including flood or other serious accidents” and article 22.1 “the environmental sustainability reports of urban development planning have to include a map of natural risks in the area to be managed”. Based on this regulation, geohazard maps are incorporated in environmental studies of the territory and the corresponding autonomous communities are responsible for their approval, but no mandatory guidelines are imposed. As a result, maps are elaborated in most cases by architects in urban areas, or by environmental experts in no urban areas. It leads to a large heterogeneity of mapping scales, methods and contents as well as a great confusion of concepts regarding susceptibility, vulnerability, hazard and risk, and thus a large heterogeneity in approaches to geohazard mapping [27]. A methodological guideline to draw up risk maps of the natural hazards, including floods, landslides, land subsidence, expansive clays and others, was elaborated in 2008 by the Spanish Professional Association of Geologists (ICOG), but this guide is still not mandatory.

With regard to Spanish Civil Protection, the reference text is Law 17/2015, of July 9, 2015, about Civil Protection National System. Art. 5 outlines the right to protection in the event of a disaster. It describes the Civil Protection System, rights and duties of the people and administrations; Art.14 precises that every administration with responsibilities in Civil Protection has to prepare and approve plans to be used in case of a disaster in order to organize the response, coordinate the administrations and mobilize the different human and material resources.

The Basic Civil Protection (BCP) regulation establishes the drafting of territorial emergency plans for each autonomous community. In addition to these territorial plans, the BCP regulation establish the possibility of producing special plans focusing on particularly significant hazards in each autonomous community [27]. These special plans are of great importance as they involve in-depth knowledge and characterization of geohazards prior to the operational structure in case of an emergency. They are based on thorough scientific research, applying proper methodologies to study hazard and vulnerability. Results are used for spatial zoning of risk, usually at a reconnaissance scale. Although territorial plans have been approved by all the autonomous communities, special plans are emerging more slowly and gradually. Most of the regions have already approved special plans for flooding and seismic hazard. The Canary Islands have implemented the Special Plan for Volcanic Hazards (PEVOLCA), activated during the El Hierro eruption in 2011 and the Cumbre Vieja eruption in 2021. Again, there is a great heterogeneity in the geohazard maps elaborated for special plans, with no common methodology and a huge confusion of concepts regarding susceptibility, hazard, vulnerability and risk.

In the case of landslides, few regions include special plans for this type of risk. In the case of the Balearic Islands, after the terrible flash flood of Sant Llorenç des Cardassar in Mallorca in October 2018, which caused 13 fatalities [24]; a new special plan for flooding was adopted in 2022 (INUNBAL) which includes landslide and rockfall risk related to extreme meteorological events.

In parallel, many national and regional Spanish research centers have prepared documents and maps related to geohazards and keep an extensive collection of literature on this topic. Nevertheless, much of this information is unknown to the land-use/urban/civil protection as well as civil protection managers. One of the objectives of the emergency management exercise in the Balearic Islands was to diffuse such type of knowledge to the civil protection and emergency teams.

Appendix 3. on-line survey for the cold feedback

Page 1: Identification

1. Last Name
2. First Name
3. Entity Represented
4. E-mail address
5. What exercise did you take part in? (There is only one possible answer. If you have taken part in both exercises, please complete the questionnaire separately for each.)

Exercise in Mallorca, Spain, April 2022

Exercise in Bidart (France), May 2022

6. What was your role during the exercise?

TAC player: I was able to play my own role in the Technical Committee

PMA Player: I was able to play my own role in the Forward Command Post

TAC Observer: I was able to observe the work of the Technical Committee

PMA observer: I was able to observe the work of the Forward Command Post

Facilitator: I contributed to the facilitation of the exercise

Other

Page 2:

7. On a score of 1 (very unsatisfactory) to 5 (very satisfactory), what is your level of satisfaction with participating in the exercise?
8. What would you say were the highlights of this exercise?

9. What do you think were the weak points of this exercise?

Page 3:

10. Cell Composition

	Highly unsatisfactory	Rather unsatisfactory	Somewhat satisfying	Very satisfying	No opinion
TAC					
PMA					

11. What is your feedback on the composition of the TAC?

Observations, suggestions for improvements, etc.

12. What is your feedback on the composition of the PMA (Forward Command Post)?

Observations, suggestions for improvements, etc.

13. Functioning of the TAC

	Highly unsatisfactory	Rather unsatisfactory	Somewhat satisfying	Very satisfying	No opinion
Piloting/management of the cell					
Organization of situation updates					
Taking into account information from experts					
Exchange of information with the TAC					

14. Functioning of the PMA

	Highly unsatisfactory	Rather unsatisfactory	Somewhat satisfying	Very satisfying	No opinion
Piloting/management of the cell					
Organization of situation updates					
Exchange of information with the TAC					
Taking into account information from experts					

15. What is your feedback on how the TAC works?

Actions taken by the departments involved, observations, proposals for improvements, etc.

16. What is your feedback on the functioning of the PMA?

Actions taken by the departments involved, observations, proposals for improvements, etc.

17. Do you have any other feedback to share regarding TAC or PMA?

Actions taken by the departments involved, observations, proposals for improvements, etc.

Page 4:

18. Have you been able to consult the maps with travel statistics in the territory of Ibiza?

Yes/No if yes questions 19, 20 appear.

19. On a scale of 1 (not at all) to 5 (absolutely), how do you rate the usefulness of this information of travel statistics on the territory of Ibiza?

20. Can you elaborate on how this information was used?

Page 5:

21. Have you been able to consult the maps of the trajectories of the falls on the territory of Mallorca?

Yes/No if yes questions 22, 23 appear.

22. On a scale of 1 (not at all) to 5 (absolutely), how do you assess the usefulness of these maps of the trajectories of falls on the territory of Mallorca?

23. Can you elaborate on how these maps were used?

Page 6:

24. Do you think it would be useful to integrate the new tools developed into the accessible TAC database?

Yes

No

No notice

Page 7:

25. Did you have an animation function during the exercise?

Yes/No if yes question 26 appears.

26. Do you have any feedback to share about your role as a facilitator, or any interactions you have had with the players?

Organisational difficulties, players' understanding of the exercise agreements, actions taken by the departments involved, observations, proposals for improvements, etc.

References

- [1] M. Ashiq Ahmed, B. Sridharan, N. Saha, S.A. Sannasiraj, S.N. Kuiry, Assessment of coastal vulnerability for extreme events, *Int. J. Disaster Risk Reduct.* 82 (2022) 103341, <https://doi.org/10.1016/J.IJDRR.2022.103341>.
- [2] A. Barra, L. Solari, M. Bejar, O. Monserrat, S. Bianchini, G. Herrera, M. Crosetto, R. Sarro, E. Alonso, R. Mateos, S. Ligierzana, C. Lopez, S. Moretti, A methodology to detect and update active deformation areas based on Sentinel-1 SAR images, *Rem. Sens.* 9 (2017), <https://doi.org/10.3390/rs9101002>.
- [3] R.J.J. Beerens, H. Tehler, Scoping the field of disaster exercise evaluation - a literature overview and analysis, *Int. J. Disaster Risk Reduct.* 19 (2016) 413–446 <https://doi.org/10.1016/j.ijdr.2016.09.001>, ISSN 2212-4209.
- [4] S. Bianchini, G. Herrera, R.M. Mateos, D. Notti, I. Garcia, O. Mora, S. Moretti, Landslide activity maps generation by means of persistent scatterer interferometry, *Remote Sens* 5 (2013) 6198–6222, <https://doi.org/10.3390/rs5126198>.
- [5] M.-A. Chanut, M. Gasc-Barbier, L. Dubois, A. Carotte, An integrative approach to study deformation of landslides using only terrestrial images, *Landslides* (2021), <https://doi.org/10.1007/s10346-021-01709-2>.
- [6] Chanut MA., Courteille H., Lévy C., Cunha de Barros G., Gasc-Barbier M., Atto A., Meignan L. Trouvé E. Can Machine Learning Help for the Operational Management of Rockfall Hazard on Linear Stakes? Preprint. DOI: 10.2139/ssrn.4635528.
- [7] N. Devanthery, M. Crosetto, O. Monserrat, M. Cuevas-González, B. Crippa, An approach to persistent scatterer interferometry: the PSIG chain, *Rem. Sens.* (2014) 6662–6679, <https://doi.org/10.3390/rs6076662>.
- [8] R.B. Domingues, S.N. de Jesus, Ó. Ferreira, Place attachment, risk perception, and preparedness in a population exposed to coastal hazards: a case study in Faro Beach, southern Portugal, *Int. J. Disaster Risk Reduct.* 60 (2021) 102288, <https://doi.org/10.1016/J.IJDRR.2021.102288>.
- [9] Y. Dorigne, M. Abily, P. Gourbesville, Natural hazard crisis management Exercise at metropolis scale: methodology for Holistic involvement of municipalities, in: P. Gourbesville, G. Caignaert (Eds.), *Advances in Hydroinformatics*, Springer Water. Springer, Singapore, 2020, https://doi.org/10.1007/978-981-15-5436-0_15.
- [10] G.S. Dwarakish, S.A. Vinay, U. Natesan, T. Asano, T. Kakinuma, K. Venkataramana, B.J. Pai, M.K. Babita, Coastal vulnerability assessment of the future sea level rise in Udipi coastal zone of Karnataka state, west coast of India, *Ocean Coast Manag.* 52 (2009) 467–478, <https://doi.org/10.1016/J.OCECOAMAN.2009.07.007>.
- [11] S. Endang, Y. Siswari, A.R. Surya, Family heads' preparedness facing landslides: simulation game method and focus group discussion, *Disaster Advances Vol. 15* (5); 20-25 (2022), doi: <https://doi.org/10.25303/1505da020025>.
- [12] T. Grunnan, H. Fridheim, Planning and conducting crisis management exercises for decision-making: the do's and don'ts, *Int. J. Disaster Risk Reduct.* 5 (2017) 79–95 <https://doi.org/10.1007/s40070-HeumüllerE.,Richter, S., Lechner U. 2012. Towards a framework for command post exercises. Proceedings of the 9th International ISCRAM Conference – Vancouver, Canada, April 2012 L. Rothkrantz, J. Ristvej and Z. Franco>.
- [13] L. Hiwasaki, E. Luna, Syamsidik, R. Shaw, Process for integrating local and indigenous knowledge with science for hydro-meteorological disaster risk reduction and climate change adaptation in coastal and small island communities, *Int. J. Disaster Risk Reduct.* 10 (2014) 15–27, <https://doi.org/10.1016/j.ijdr.2014.07.007>.
- [14] A. Koroglu, R. Ranasinghe, J.A. Jiménez, A. Dastgheib, Comparison of coastal vulnerability index applications for parcelana Province, *Ocean Coast Manag.* 178 (2019) 104799, <https://doi.org/10.1016/J.OCECOAMAN.2019.05.001>.
- [15] P. Limousin, J. Tixier, A. Bony-Dandrieux, V. Chapurlat, S. Sauvagnargues, A new method and tools to scenarios design for crisis management exercises, *Chemical Engineering Transactions* 53 (2016) 319–324, <https://doi.org/10.3303/CET1653054319>.
- [16] P. Limousin, A. Bony-Dandrieux, J. Tixier, S. Sauvagnargues, Improving crisis exercises and managers' skills through the development of scenario design, in: Sophie Sauvagnargues. *Decision-Making in Crisis Situations: Research and Innovation for Optimal Training*, ISTE, 2018, pp. 59–78 978-1-119-55782-1.
- [17] J.A. Luque-Espinar, R.M. Mateos, I. García-Moreno, E. Pardo-Igúzquiza, G. Herrera, Spectral analysis of climate cycles to predict rainfall induced landslides in the western Mediterranean (Majorca, Spain), *Nat. Hazards* 89 (2017) 985–1007, <https://doi.org/10.1007/s11069-017-3003-3>.
- [18] M. Magnusson, L.M. Öberg, Crisis training software and user needs: research directions, in: *Proceedings of 12th International Conference on Information Systems for Crisis Response and Management (ISCRAM '15)*, 2015 Kristiansand, Norway.
- [19] R.M. Mateos, Slope movements in the Majorca island (Spain), in: G. Robin, McInnes, Jenny Jakeways, Thomas Telford (Eds.), *Hazard Analysis. Instability, Planning and Management. Seeking Sustainable Solutions to Ground Movements Problems*, 2002, pp. 339–346 London, 2002. Ventnor, UK. May 2002.
- [20] R.M. Mateos, J.M. Azañón, R. Morales, J.M. López-Chicano, Regional prediction of landslides in the Tramuntana Range (Majorca) using probability analysis of intense rainfall, *Zeitschrift für Geomorphologie*, N° 51 (3) (2007) 287–306.
- [21] R.M. Mateos, I. García-Moreno, J.M. Azañón, F. Rodríguez-Fernández, F.J. Roldán, M. Rodríguez-Peces, Procesos de expansión lateral en la franja costera de la Serra de Tramuntana (Mallorca). *El caso de Bàltx, Geotemas*, Madrid, 2012, pp. 1423–1426.
- [22] R.M. Mateos, I. García-Moreno, P. Reichenbach, G. Herrera, R. Sarro, J. Rius, R. Aguiló, F. Fiorucci, Calibration and validation of rockfall modelling at regional scale: application along a roadway in Mallorca (Spain) and organization of its management, *Landslides* 13 (2016) 751–763, <https://doi.org/10.1007/s10346-015-0602-5>.
- [23] R.M. Mateos, P. Ezquerro, J.M. Azañón, B. Gelabert, G. Herrera, J.A. Fernández-Merodo, D. Spizzichino, R. Sarro, I. García-Moreno, M. Béjar-Pizarro, Coastal lateral spreading in the world heritage site of the Tramuntana range (Majorca, Spain). The use of PSInSAR monitoring to identify vulnerability, *Landslides* 15 (2018) 797–809, <https://doi.org/10.1007/s10346-018-0949-5>.
- [24] R.M. Mateos, R. Sarro, A. Díez-Herrero, C. Reyes-Carmona, J. López-Vinielles, P. Ezquerro, M.-C. Monica, G. Bru, J.-A. Luque, A. Barra, P. Martín, A. Millares, M. Ortega, A. López, J.-P. Galve, J.-M. Azañón, S. Pereira, P. Santos, J.-L. Zêzere, E. Reis, R. Garcia, S. Cruz Oliveira, A. Villatte, A. Chanal, M. Gasc-Barbier, O. Montserrat, Assessment of the socio-economic impacts of extreme weather events on the coast of Southwest Europe during the period 2009 – 2020, *Appl. Sci.* 13 (2023), <https://doi.org/10.3390/app13042640>.
- [25] R.M. Mateos, J.M. Azañón, Los movimientos de ladera en la Sierra de Tramuntana de la Isla de Mallorca: tipos, características y factores condicionantes, *Rev. Soc. Geol. Espana* 18 (1–2) (2005) 89–99.

- [26] R.M. Mateos, I. García-Moreno, J.M. Azañón, Freeze-thaw cycles and rainfall as triggering factors of mass movements in a warm Mediterranean region: the case of the Tramuntana Range (Majorca, Spain), *Landslides* 9 (2012) 417–432, <https://doi.org/10.1007/s10346-011-0290-8>.
- [27] R.M. Mateos, Geohazards into the land-use planning and urban development policies. Spanish experience and European overview, *geonovas* 30 (2017) 11–20.
- [28] G. McGranahan, D. Balk, B. Anderson, The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones, *Environ. Urban.* 19 (2007) 17–37, <https://doi.org/10.1177/0956247807076960>.
- [29] M.E.S.T.(French, French policy to reduce the risk from disasters. Ministry of Ecology, Sustainable Development, Transport and Housing), 2011. <https://www.preventionweb.net/publication/.france-french-policy-reduce-risk-disasters>.
- [30] J.A. Navarro, M. Cuevas-González, A. Barra, M. Crosetto, Detection of Active Deformation Areas based on Sentinel-1 imagery: an efficient, fast and flexible implementation. Proceedings of the 18th International Scientific and Technical Conference, 2018 Crete, Greece.
- [31] J.A. Navarro, R. Tomás, A. Barra, J.I. Pagán, C. Reyes-Carmona, L. Solari, J.L. Vinielles, S. Falco, M. Crosetto, ADAtools: automatic detection and classification of active deformation areas from PSI displacement maps, *ISPRS Int. J. Geo-Inf.* 10 (2020) 584 9.
- [32] A.-T. Nguyen, V. Merrien-Soukatchoff, M. Vinches, M. Gasc-Barbier, Grouping discontinuities of fractured rock mass into main sets: consequences on the stability analysis of a slope cutting (Ax-les-Thermes diversion in southern France), *Bull. of Engineering Geology and the Environment* 75 (4) (2016) 1429–1444, <https://doi.org/10.1007/s10064-015-0822-x>.
- [33] O. Pediconi, S. D'Albenzio, G. Gkrintzali, P. Calistri, M. Georgiev, Crisis preparedness exercise on flit valley Fever introduction into Europe under a one health approach, *Microorganisms* 10 (2022) 1864, <https://doi.org/10.3390/microorganisms10091864>.
- [34] J. Pile, C. Gouramanis, A.D. Switzer, B. Rush, I. Reynolds, J.L.A. Soria, Can the risk of coastal hazards be better communicated? *Int. J. Disaster Risk Reduc.* 27 (2018) 439–450, <https://doi.org/10.1016/j.ijdrr.2017.11.008>.
- [35] R.J. Eiser, A. Bostrom, I. Burton, D.M. Johnston, J. McClure, D. Paton, J. van der Pligt, M.P. White, Risk interpretation and action: a conceptual framework for responses to natural hazards, *Int. J. Disaster Risk Reduct.* 1 (2012) 5–16, <https://doi.org/10.1016/j.ijdrr.2012.05.002>.
- [36] M. Rossi, R. Sarro, P. Reichenbach, R.M. Mateos, Probabilistic identification of rockfall source areas at regional scale in El Hierro (Canary Islands, Spain), *Geomorphology* 381 (2021), <https://doi.org/10.1016/j.geomorph.2021.107661>.
- [37] F. Sàbat, B. Gelabert, A. Rodríguez-Perea, J. Giménez, Geological structure and evolution of Majorca: implications for the origin of the Western Mediterranean, *Tectonophysics* 510 (2011) 217–238.
- [38] Santos P.P. Reyes-Carmona C., Pereira S., Sarro, R. Martínez-Corbella M., Coll-Ramis M.A, Zêzere JL, Mateos R.M., Seasonal Rockfall Risk Analysis in a Touristic Island: Application to the Tramuntana Range (Mallorca, Spain) *International Journal of Disaster Risk Reduction*. Volume 101, 1 February 2024, 104264. <https://doi.org/10.1016/j.ijdrr.2024.104264>.
- [39] R. Sarro, R.M. Mateos, I. García-Moreno, G. Herrera, P. Reichenbach, L. Laín, C. Paredes, The Son moc rockfall (Mallorca, Spain) on the 6th of March 2013: 3D simulation, *Landslides* 11 (2014) 493–503, <https://doi.org/10.1007/s10346-014-0487-8>.
- [40] L. Solari, A. Barra, G. Herrera, S. Bianchini, O. Monserrat, M. Béjar-Pizarro, M. Crosetto, R. Sarro, S. Moretti, Fast detection of ground motions on vulnerable elements using Sentinel-1 InSAR data, *Geomatics, Nat. Hazards Risk* 1 (2018) 152–174 9.
- [41] L. Solari, S. Bianchini, R. Franceschini, A. Barra, O. Monserrat, P. Thuegaz, D. Bertolo, M. Crosetto, F. Catani, Satellite interferometric data for landslide intensity evaluation in mountainous regions, *Int J of Applied Earth Observation and Geoinformation* 87 (2020) 102028.
- [42] R. Tomás, J.P. Pagán, J.A. Navarro, M. Cano, J.L. Pastor, A. Riquelme, M. Cuevas-González, M. Crosetto, A. Barra, O. Monserrat, J.M. Lopez-Sanchez, A. Ramón, S. Ivorra, M. Del Soldato, L. Solari, S. Bianchini, F. Raspini, et al., Semi-automatic identification and pre-screening of geological–geotechnical deformational processes using persistent scatterer interferometry datasets, *Rem. Sens.* 14 (2019) 1675 11.
- [43] H. Tribak, M. Gasc-Barbier, A. El Garouani, A ground instabilities inventory between Tetouan and Jebha (Morocco): mapping , description and analysis, *Bull. Eng. Geol. Environ.* (2023), <https://doi.org/10.1007/s10064-023-03161-z>.
- [44] H. Tribak, M. Gasc-barbier, A. El Garouani, Assessment of ground instabilities` mausative factors using multivariate statistical analysis methods : case of the coastal region of northwestern tif , Morocco, *Geosci.* (2022) 1–24.
- [45] B. Zhou, G. Sun, X. Zhang, J. Xu, J. Lai, X. Du, M. Hosokawa, H. Hayashi, R. Kimura, Y. Sakurada, Development of web-based Tabletop emergency earthquake exercise system, *J. Disaster Res.* 10 (2) (2015) 217–224.
- [46] V. Merrien-Soukatchoff, M. Gasc-Barbier, The Effect of Natural Thermal Cycles on Rock Outcrops: Knowledge and Prospect, *Rock Mech. Rock Eng.* 56 (2023) 6797–6822. <https://doi.org/10.1007/s00603-023-03420-1>.
- [47] F. Guzzetti, G.B. Crosta, R. Detti, F. AgliardiISTONE: a computer program for the three-dimensional simulation of rock-falls *Comput. Geosci.*, 28 (2002), pp. 1079–1093, 10.1016/s0098-3004(02)00025-0.
- [48] E. Heumüller, S. Richter, U. Lechner (Eds.), Towards a framework for command post exercises. Proceedings of the 9th International ISCRAM Conference – Vancouver, Canada, April 2012 L. Rothkrantz, 2012.