Deliverable

D5.5: Good practice recommendations report on OEF (or OELF) communication

Deliverable information	
Work package	WP5: Society: Data Gathering and Information Sharing with the Public and Policy-makers
Lead	University of Cambridge
Authors	Alexandra LJ Freeman, Sarah Dryhurst, Giulia Luoni Winton Centre for Risk & Evidence Communication, University of Cambridge
Reviewers	Irina Dallo, ETH Zurich; Rémy Bossu, EMSC
Approval	Management Board
Status	Final
Dissemination level	Public
Will the data supporting this document be made open access? (Y/N)	Y
If No Open Access, provide reasons	
Delivery deadline	[28.02.2023]
Submission date	[15.02.2023]
Intranet path	[DOCUMENTS/DELIVERABLES/File Name]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821115

Table of contents

Guidelines

This good practice report aims to summarise, in a practical and easy-to-read manner, advice on how to communicate Operational Earthquake (and/or Loss) Forecasts (OEFs or OELFs). This advice is the result of our review (literature and interviews with experts) of best practice in communicating dynamic risks in other domains (deliverable D5.1), interviews and focus groups with over 100 people: public, seismologists, first responders, journalists, civil protection etc, including views on draft OEF communications (deliverables D5.2, D5.3), and quantitative studies using 8,196 members of the public across three countries (the U.S., Italy & Switzerland) (deliverable D5.4).

We present 13 points of advice, and the evidence to support it in the appendices of the document.

Before you start communicating OEF:

1) Be clear about the difference between a forecast and a warning; between information and advice.

This is about understanding the aims of your communication, because you can't achieve your aims unless you are clear about them in your own mind. A warning aims to change people's behaviour, through clear advice and messaging – a forecast aims only to give people information which they can use in their own decision-making: there is no advice or message. The two require different communication techniques and would be evaluated very differently.

Evidence base: Appendix 1

2) Build relationships with those who might use your forecasts, and those who might help disseminate them.

This will help you understand the needs of your audiences so that you can provide them with the information that they want and need, and not just the information that you want to give them or assume that they want. Different audiences might want different things, so you may have to prepare different outputs for them. You may also want to work with audiences to help them know how to respond to the forecast – what actions they may consider. This is particularly advised in schools, but also with others, such as infrastructure managers. When communicating to the public, use the channels that they are already used to using for similar information rather than trying to invent your own: work with journalists in all media, weather forecasters etc. They will also likely know their audiences well and be able to help. Regular meetings with those who are going to try to interpret and disseminate forecasts can also help ensure that any new people are familiar with the format and ready to help their audiences.

Evidence base: Appendix 2

When communicating OEF:

3) Make the purpose of the forecast, and its limitations, clear to the audience

Just as you as a communicator had to decide what the aim of your communication is, so your audience also needs to know this aim. If the audience are expecting a warning with a clear behaviour message, they will be confused and unhappy with a forecast that doesn't give them that. Forecast information can help people make all sorts of decisions, depending on their own circumstances – it is useful even when absolute probabilities are low and there is no official 'advice'. For example, people might choose to practice an evacuation drill, test shut down procedures for power stations, identify diversion routes that avoid tunnels or bridges – all depending on their responsibilities. You're not advising people to do any of those things as part of the forecast, but you can give people a sense of decisions that they or others might make. Making it clear why the forecast is being made public and how it might be of use to some people will help the audience know how to respond to it.

Evidence base: Appendix 3

4) Minimise the number of variables that you allow the audience to change

It is tempting to avoid making decisions on behalf of your audiences, and instead to allow every variable to be customised (e.g. the geographical area and time frame of the forecast, the threshold of event size being considered, metrics such as intensity or magnitude). However, if communicating with the public, this is not helpful for most and instead makes the forecast more complex and difficult to understand. Add as little customisation as possible to the main interface: if possible, allow the audience to vary only one thing - the location for which the forecast applies. For more experienced audiences you can allow more customisation via a 'settings' option, but work with these audiences to identify the variables they need to change and keep the customisation via settings only to those.

Evidence base: Appendix 4

5) Ensure that the forecast is given out regularly & frequently, in the same consistent format, to allow the audience to become familiar with it during quiescent times

People find it increasingly easy to interpret formats as they become familiar with them, so it is useful to expose people to a format frequently. Additionally, familiarity with what 'normal' looks like in terms of the likelihood of a seismic event will help people interpret the likelihoods displayed in times where the risk level is higher and so make sense of it (which it is important that they are able to do).

Evidence base: Appendix 5

6) Don't try to communicate forecast information to individuals via a geographical map representation. Only use a geographical map to illustrate the area over which the forecast is valid.

Geographical maps are formats that are very familiar to most audiences, and so they frequently express a liking for information presented in that way. A geographical map can be useful to help them know the area over which a forecast is calculated and valid, but for individuals only interested in the forecast at one particular location, reading absolute risks off a map (illustrated as isolines) seems to be harder than simply displaying the absolute risk probability to them. It may also confuse people into thinking that the isolines on the map represent something other than the likelihood of an event of a set magnitude (e.g. the geographical distribution of intensity of, or damage caused by, a forecasted earthquake, since such maps are often used after an event to illustrate exactly that).

Evidence base: Appendix 7

7) Communicate information about what impact people might expect, as well as the likelihood/probability

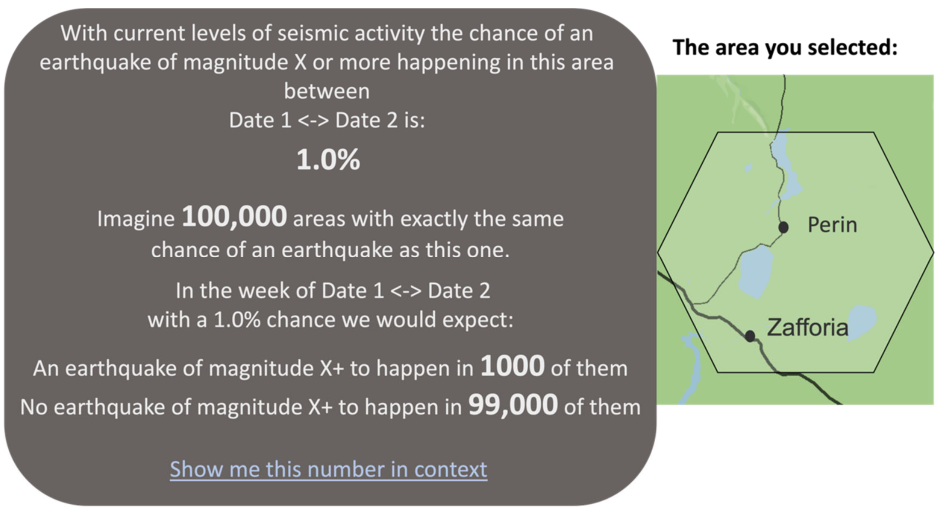
It's easy to concentrate on communicating the difficult aspect of the numbers involved in the likelihood, but forget that the numbers involved in the impact (e.g. magnitude or intensity) also need to be given a context for people to know what this might mean for them. Although an earthquake of the same magnitude or even intensity can have very different effects depending on the types of buildings in an area, just giving people a sense of what sort of effects different levels of earthquake might have, and in a way that references their experience (e.g. giving examples of earthquakes that they might remember reports from) rather than theoretical (e.g. not through a description like 'light damage likely', which people found unhelpful in our interviews).

Evidence base: Appendix 7: Communicating potential impact as well as likelihood

8) Present probabilities of events occurring as both percentages (e.g. 'X% chance of an earthquake') <u>and</u> expected frequencies (e.g. 'out of 100,000 towns with exactly the same chance of an earthquake as this one, we would expect an earthquake to happen in X of them.')

People shown a probability as a more solid and imaginable expected frequency perceive that probability to present a higher chance of happening than when shown a percentage. However, such expected frequencies also help people discriminate between low probabilities, which would have several decimal points if shown as a percentage (and where changes of whole orders of magnitude are difficult for people to discriminate). A percentage, though, even with decimal places, is seen as clearer and easier to read, so presenting the absolute risk as a percentage in a big, bold font as the main output seems sensible, whilst also showing the interpretation underneath as an expected frequency. Graphics such as bar charts or icons are not helpful for the low probabilities most often applicable to seismic events.

Evidence base: Appendix 8



9) Don't give the baseline risk (the average percentage chance of an event occurring) or a relative risk (how many times higher than average the current risk is) in an attempt to help people understand their current risk level.

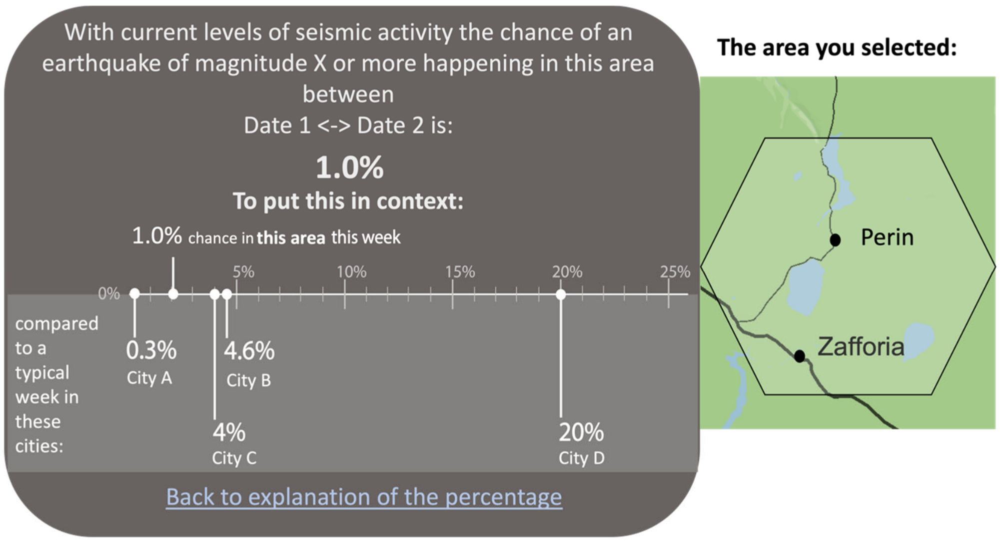
Giving context to the absolute risk of a seismic event is important to help people interpret the (otherwise fairly meaningless) probability of such an event. If they have become used to seeing the forecast regularly (see point 5 above) then they may already have an idea of what 'normal' (baseline) is, but the format should not rely on that knowledge. Experiments where people were given the baseline risk in an area as a piece of context to a forecast gave inconsistent results. Where people were given the relative risk between the current and baseline probabilities (e.g. 'twice as high as average') people had a higher perception of the risk (if it was elevated above baseline), but it also seemed to inhibit discrimination between different probabilities. We therefore don't recommend using either a baseline or relative risk as a way to add context to an absolute forecast probability.

Evidence base: Appendix 9

10) Allow those who want further context to view a graphic which illustrates the current probability of an event happening in the selected geographical area on a risk ladder, compared with the average probability of the same event happening in a few familiar cities that illustrate a broad range of high to low risk levels.

What does seem to give people useful context to interpret the current probability of a seismic event however, is a graphical comparison of this probability against the average probability in other cities with which they are likely already to have some sense of the likelihood of an earthquake. These cities are likely to be within their country, but may be international in the case of some famously high hazard locations (e.g. Tokyo or Los Angeles). The scale on the risk ladder should be linear, not logarithmic (it can be cut off just above the highest baseline risk). We acknowledge that calculating these comparator risks is complex. Some members of the audience are likely to find the risk ladder 'too much information' – especially alongside both the percentage and expected frequency formats described in point 7 - so it is probably better as optional additional information.

Evidence base: Appendix 10



11) *Allow those who want it to find information about how long events might last for if they happen, and what people might expect in terms of emergency support or communication*

Even if you don't communicate this information as part of your forecast service, work with others who can provide this information to the relevant audiences. People want to know what to expect if an event occurs – how long an aftershock sequence might last, what sort of effects an earthquake might have, how long before things are likely to return to normal, and who has responsibility for different actions.

Evidence base: Appendix 11

12) *Provide some explanation in normal language, and a personal interpretation service for those who want to be able to talk to a 'real person' about the forecast and how to interpret it*

Although an automated forecast service might be cost-effective, in order to really support your audiences you should also provide alongside it a short (1-2 sentences) written explanation for the forecast, and a continually-available personal service for those who need to ring to have an explanation of the forecast. It may be worried members of the public, journalists, or key infrastructure managers or political decision-makers – all will need to be supported by a one-to-one service, staffed by people who understand the technicalities of the forecast but are able to communicate about it at any level required. This is no small undertaking, but an important one.

Evidence base: Appendix 12

13) Consider 'prebunking' misinformation or common misunderstandings without patronising the audience or showing lack of cultural sensitivity

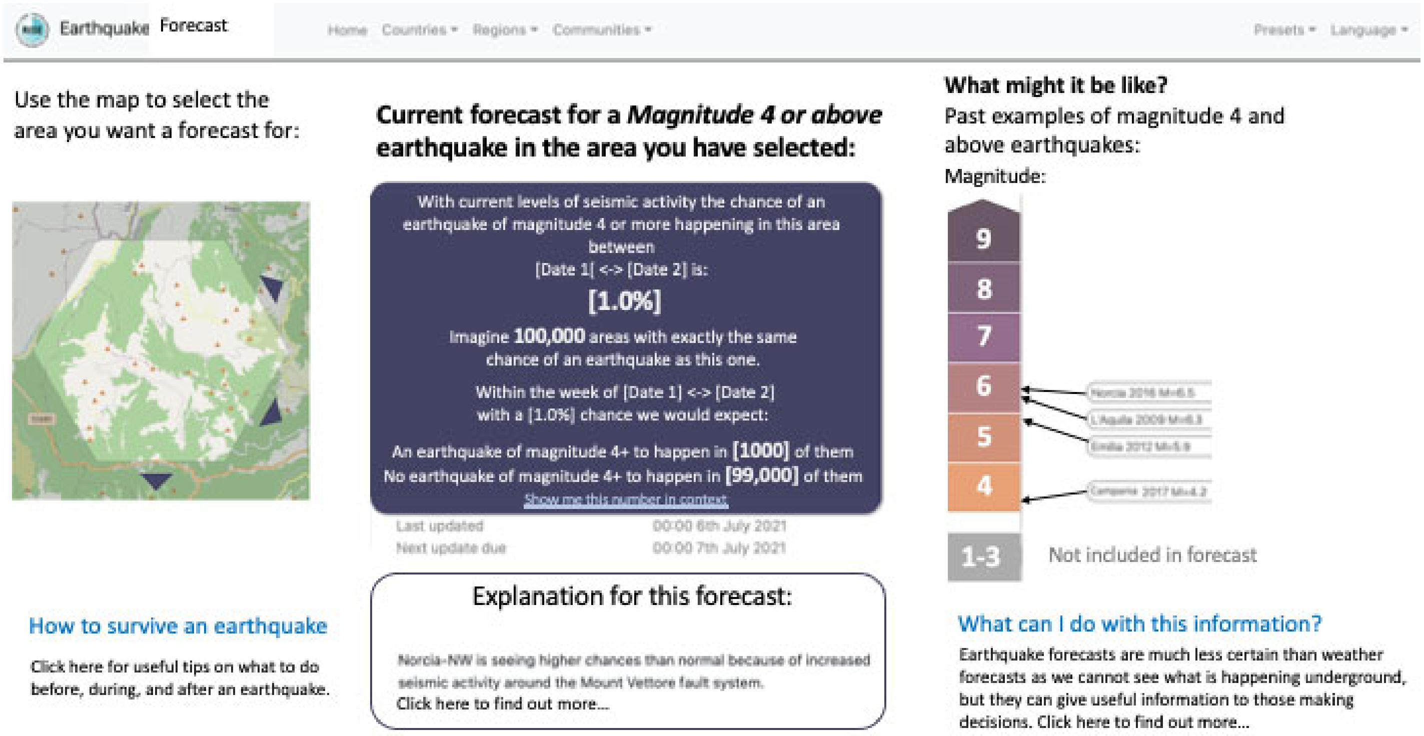
It is helpful to be able to pre-empt potential misunderstandings (such as the difference between a forecast and a prediction, or that large seismic events can happen without warning at any time even in 'low hazard' areas). However, it is important to approach this task with humility. Recognise that there is a great deal not known within the geosciences, and that a lot of information is not 'true' or 'false' but a matter of degree, interpretation or debate. Also recognise that many different cultures have different views on the role of aspects such as fate and that insensitivity to this can easily create barriers between groups and foster mistrust – which can undermine all attempts at communication.

Evidence base: Appendix 13

The guidelines will hopefully allow different regions that are currently exploring the operationalisation of earthquake forecasting to move ahead with greater confidence. Concerns about the uncertainties and potential liabilities involved in forecasting, which we heard several times whilst conducting this research, can be mitigated once these guidelines are followed. Key to this is understanding – and communicating - that it is *information* being given, not a *warning*. It should also be of considerable reassurance that there is an evidence base to suggest that the formats chosen are well understood by the public. This means that forecasters should not feel that they are providing information that might be misunderstood – in fact, it is more of an ethical concern if they are in possession of information which they are *not* sharing publicly.

That is not to say that there are no remaining barriers to OEF. Firstly, we recognise that the probability calculations themselves need to be done, and then decisions and calculations done to create the probability comparators that we suggest. Each region wanting to launch OEF will need to do some user research to choose suitable comparator events and cities for their own local displays, and this is particularly true of regions where there have not been recent local seismic events to give people a reference (e.g. Switzerland).

However, we hope that the Open Source code base (https://github.com/WintonCentre/rise-dashboard) developed to produce a test OEF website demonstrating these guidelines (as well as other findings from user-testing) will be of use and allow relatively rapid implementation of OEF (see http://earthquake-forecast.wintoncentre.uk).



Above is a demonstration OEF website designed to take into account some of the best practice recommendations, including:

- how best to present the probabilities (as percentage and expected frequencies)
- how best to give context to these (by allowing a 'click through' which would reveal the risk ladder)
- giving narrative context which explains the geological activity that has given rise to the forecast (and there should ideally be a phone number for those who want to understand more)
- giving context to the potential impacts (through example earthquakes at different magnitudes), and making it clear why these are being given (to give people a sense of what such an earthquake might be like)
- giving people easy access to information on what they can do before, during and after an earthquake (which may be on a different provider's site)
- making it clear what a forecast is and why it might be useful
- minimising the choices people have to make to get a forecast (choosing their geographical location only)
- Keeping the page clear and free from other, distracting information (although it is accessible via other menus)
- Giving people clear links to things that they can do to prepare for earthquakes in general.

A working version of this design is available at: http://earthquake-forecast.wintoncentre.uk (although you can change map region and language, the examples chosen to give context are designed for an Italian audience).

Appendix 1: Information versus advice

Be clear about the difference between a forecast and a warning; between information and advice.

A warning is a 'message-based' piece of communication which aims to give the audience a piece of advice and influence their behaviour (i.e. make them more likely to do something, or not do something). 'Message-based' communication is very common.

A forecast is a form of 'evidence communication' which aims to give the audience information which they can use (or not) in their own decision-making. It does not give advice or recommendations, or have a take-home message. Instead, it supports autonomy on the part of the audience. Evidence communication is much less common.

To understand how forecast information might be used to inform decision-making very differently by different members of the audience, consider a forecast for rain in an area on the following day. For a local farmer, this might signal an excellent time to sow seed. For an outdoor local event, it might change their decisions around event organisation. For an indoor sports facility, it might have no impact on decision-making at all. The forecast is purely informational – and agnostic to how that information might be used.

Operational earthquake forecasts can be purely informational in the same way as a rain forecast. They do not have to give rise to warning messages. The information they carry might be used by a whole range of audiences to make many decisions about which the communicator is entirely ignorant. What is important is that the communicator is communicating what they know, to allow others to use that information.

Many people during our work have expressed the opinion that operational earthquake forecasts are of no use to anyone because they can very rarely or never give rise to probabilities that would be high enough to warrant a warning. But this ignores the many other decisions that various audiences might be making and into which OEF information – however uncertain – might feed. For example, even with only a slightly increased risk level, those in charge of power generation plants might want to test emergency shut-down procedures; those in charge of road infrastructure might want to inspect bridges and tunnels, and plan alternative route signage; those in charge of schools and places of work may want to practise earthquake safety drills or evacuation procedures; members of the public may want to think through their own emergency preparations. These sorts of decisions do not have to be advised (or mandated) at particular thresholds – a forecaster's job is not necessarily to 'tell people what to do'. But these are examples of decisions that would be influenced by information given in a forecast.

However, 'not telling people what to do' does not mean not giving them information about potential impacts as well as likelihoods. See Appendix 7.

It is also common to hear from users that they would just like to be 'told what to do'. This is natural – it is much easier for all of us not to have to make decisions for ourselves! This is why it is vital to ensure that the audiences know what the forecast aims to do (i.e. give the current state of knowledge so that people can make their own decisions based on it). Once people understand the purpose, use and limitations they will approach the information in a different way. See Appendix 3.

You are likely to need to keep reminding yourself, and your audiences, of this important difference in aims – 'informing' rather than 'giving a message' is a much rarer type of communication.

Appendix 2: Relationships with users and communicators

Build relationships with those who might use your forecasts, and those who might help disseminate them.

Groups working on various forms of forecast communication who might be expected to face similar challenges to earthquake forecasters, such as flood risk forecasters (Morss et al., 2015) and storm risk forecasters (our own interviews, reported in RISE deliverable D5.1 (Dryhurst et al., 2020)) have highlighted the need for close working between forecasters and those who would be communicating and/or acting on any information regarding a raised risk level, in order that everyone understands the information in enough depth, has rehearsed procedures for communicating onwards when necessary, and has understood what decisions others in the communication and action chain are making based on the information being communicated.

Involving relevant stakeholders in the design of communications ensures not only that appropriate and well-understood language and graphics are used, but also that such stakeholders have 'buy in' and that the communications suit their needs. During our interviews (Dryhurst et al., 2020), the UK's flood forecasters told us how important it was that their audiences had good awareness of the hazard, and as forecasters they saw their role as helping people understand the risk, prepare for floods, and ensure that they were prepared to deal with the aftermath of them. They call this suite of skills in the public 'flood resilience', and achieve it through local community work in which 'resilience engagement advisors' work locally with schools, businesses and communities to help people prepare for floods, and to understand the daily forecasts.

We found a similar approach during our interviews with storm forecasters in the US. They explained how, with a fast-onset hazard like a storm, it's vital that the audience already know how to respond to any forecast storm. Like the flood resilience preparation in the UK, training is done in schools in the US in areas where tornados or hurricanes are likely. Evidence suggests that this school training is effective: in one district, when a storm struck, no one of school age or who had left school in the area in the past 5 years was killed, and only one parent of a child who had been in school during that time died. Fatalities were much higher in those who had not received school training, or exposure to it through their child. Given that during a seismically active period, schools may well be closed and (especially in the case of an aftershock sequence) communication lines disrupted, it is important that audiences are familiar with 'what to do' in advance.

Forecasters at the Storm Prediction Center in the US told us that they not only have a contact list of emergency managers, schools, infrastructure managers and broadcasters whom they contact if there is a heightened risk, but twice a year they have a media workshop training journalists and broadcasters on how to interpret forecast information and report it.

These relationships also help identify what information is useful to communicate. Research suggests that there is a gap between what scientists think is useful information and what users actually find useful for their decision making, even in mature forecasting domains such as weather (Klemm & McPherson, 2017; Lemos et al., 2012). There is considerable evidence that services that are co-developed between producers and their audience are those which are most useful (Dilling & Lemos, 2011; Steynor et al., 2016; Vaughan et al., 2016). As such, during the RISE project, we interviewed and held focus groups with over 100 stakeholders, from seismologists to the public; civil protection to journalists, in Iceland, Italy and Switzerland in order to co-design communications of operational earthquake forecasts (see Appendix 14). We also mapped the communication pathways in each of these countries – see deliverable D5.2 (Luoni et al., 2021). Forecasters will need to decide how best their forecasts should be disseminated to the different audiences within the existing communication pathways, although we suggest that it is sensible to have a single central authoritative forecast website to ensure that the public and other communicators always know that there is a trusted source that they can check at any time. Additional communications should then flow from and reflect the content of that site (see Appendix 5).

Appendix 3: Clarity of purpose and use

Make the purpose of the forecast, and its limitations, very clear to the audience

Number one on our list of recommendations was to work out the aim of your communication ("Be clear about the difference between a forecast and a warning; between information and advice.") – but it is then very important to make that aim clear to your audiences.

Someone coming to the forecast expecting a clear warning with a behavioural take-home message will be confused and negative towards a forecast communication that is designed to give information but not advice.

In our focus groups (reported in RISE deliverable D5.3, (Dryhurst et al., 2021)), participants were specifically not told the aim or purpose of the (draft) OEF communications that we were designing and testing, and we found that some participants came with expectations that were not being met:

"I thought [the dashboard] was made to alert people. Curiosity is ok but I am not sure why [the chart] is inserted into the project you are working on." (Participant in public focus group 1)

It's therefore important to set people's expectations clearly at the top of the forecast, and also to explain the point of each piece of information you are giving:

"With this [bar chart] I do not know what information I need to understand. There are 23 earthquakes in January, but I don't know what I can do with this information." (Participant in seismologist focus group 2)

"Knowing the past [earthquakes], I will not know the future ones. It is simply data that is interesting but it does not tell you anything about the future." (Participant from public focus group 2)

This is why we suggest wording such as "to put this chance in context…" when giving contextual information - it lets the audience know why that information is being communicated to them.

It is also important to be very clear about the limitations of forecasting. Some members of the public in our interviews and focus groups expected OEF to provide precise predictions (or at least high probability forecasts) of when and where an earthquake would occur – and expressed desires for the communicator to turn the probabilistic forecast into categorical information and advice:

"It would be nice to have a monthly calendar because if you tell me that within the next week you expect less than one earthquake, it means that you do expect an earthquake but maybe not within the next week, so if you give me the month, I don't know, a widget of the month with a red week, a yellow week, a green week, if you give me an opinion that is updated in time, I know which week I should be more careful, so if I need to choose whether or not to sleep in the car, I choose the initial week instead of the last one." (Participant in public focus group 2)

"It is implied in the concept of forecasting the idea that they can be false, and if the likelihood is 80% you think that tomorrow it will surely rain." (Participant in public focus group 1)

Equally, people who were aware that earthquakes could not be predicted doubted the credibility of the forecasts because they thought they were "predictions".

We all want certainty but converting a chance to an implied certainty to satiate the desires of the audiences rather than respect the limitations of forecasts (and the unpredictable nature of seismic events), will inevitably create problems, as was the case in L'Aquila, where uncertainties were absent from communications. Forecasters must try to set the audiences' expectations of what a forecast can and cannot do, and the sorts of decisions that it can and cannot support. When attempting to set expectations however, beware adding unnecessary information and text, as the more text there is on a page, the more will go unread, which could end up undermining the efficacy and perceived credibility of the communication further.

Appendix 4: Minimising variables

Minimise the number of variables that you allow the audience to change

Designing an informative communication – particularly one as complex as OEF – requires the communicator to make decisions about what to communicate on behalf of the audience: what information do they want or need, and in what format(s)?

For example: what size earthquake is the forecast valid for? Over what geographical area? Over what time frame? Is that size expressed as a magnitude or intensity? Is it better to communicate OEFs or OELFs? How should the probabilities be expressed? Should they be visualized, and if so, how?

There may be strong arguments both for and against different options for these sorts of questions; different audiences might express different preferences; different individual forecasters or audience members might disagree. The result can be that no decisions are made, and that instead the audience is given the option to customize the outputs themselves (e.g. https://www.richterx.com/?go=forecast). Indeed, such broad customisation might be requested during discussions with audience members when they are asked their preferences on difficult decisions like those above. We came across this ourselves during our interviews and focus groups. However, the problem with allowing such customisation is that it makes the communication itself complex and can present barriers to large portions of the audience understanding it at all.

When we started designing OEF communications we gave our audiences multiple options for customisation, but we found that when they were asked what part of the communication they noticed first, different people said different things. This is not a sign of good design. Audience members did not know where to look for the actual forecast on the page. For example:

"I start to ask myself, but where am I, what is the forecast?" (Participant in public focus group 1)

We therefore strongly suggest keeping the main OEF communication as simple as possible, and then giving relatively subtle links to allow people to find more information if they wish:

"I would try to distinguish the topics according to their importance... the order is consequential, so once I was informed about the forecast, then later I looked for information about the history of the earthquakes." (Participant in public focus group 1)

The comment above again highlights the need to make clear why each piece of information within a communication is being provided (in this case a chart of historical events was being given as a means of suggesting the baseline rate of events of that magnitude in the area, but participants often did not understand that – it needed to be labelled clearly to make the purpose salient).

In the case of seismic forecasts, changing the parameters of the forecast (such as the intensity threshold or area over which the forecast is calculated) can create confusion: it is not necessarily intuitive that probabilities increase as areas of interest increase, or time periods increase.

On the basis of our co-design with different stakeholders in different countries we suggest that forecasters:

- Choose a single threshold magnitude (or intensity) to communicate the likelihood of, and make it very clear to participants that it is 'this size or larger' (and what the impacts of such an event might be). Our research suggests that magnitude 4+ is a good threshold for Italy. If you want to allow audiences to vary this threshold, make this a subtle and non-distracting menu option for interested/expert users.

- Choose a single geographical area over which the forecast is valid (e.g. a 20km diameter circle or hexagon, which was frequently mentioned by seismologists in our focus groups as a reasonable size) and illustrate that area with a map. Allowing the user to choose the geographical location of interest to them is, of course, important. Make it clear whether your forecast means the likelihood of an event being FELT within that area, or if it means the likelihood of having an EPICENTRE within that area.

- Choose whether you want to use magnitude or intensity. Audiences (both public and seismologist) were not unanimous during our discussions, although magnitude was more familiar to non-seismologists and was preferred by most. People were easily confused between the two and so we advise avoiding using both. If you choose to communicate intensity, beware people interpreting it as magnitude and also be clear whether you mean the intensity as felt at that geographical location, or the epicentral intensity.

- Give the forecast as the probability of that size of event occurring in that area 'within the next 7 days' (stating the dates of the start and end of that 7 day period). Our different stakeholders were generally in agreement that a 7 day period was the most useful.

- Give the probability as a number, with context given as an optional link (more on this later).

Appendix 5: Regularity, frequency and consistency

Ensure that the forecast is given out regularly & frequently, in the same consistent format, to allow the audience to become familiar with it during quiescent times

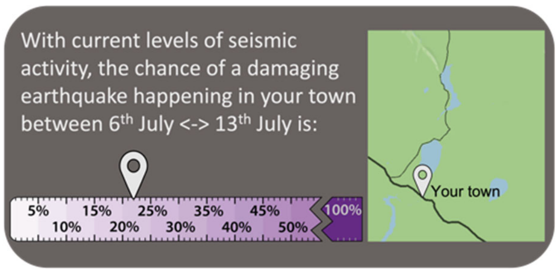
Many seismologists question the usefulness of OEF outside of a period of heightened activity. However, experience from other domains suggests that consistency is important. Audiences need to be used to the format, and how to interpret it, as well as knowing 'what normal looks like'. OEF, remember, is not a warning or message-based communication: it is information. And information is useful at all times.

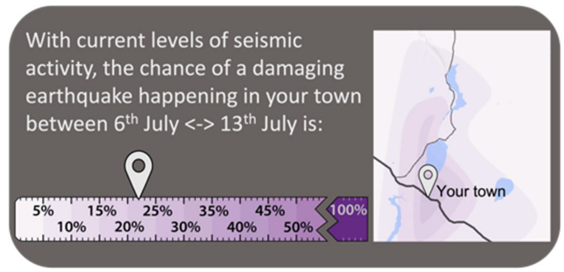
In the UK, for example, the Environment Agency and Meteorological Office's joint flooding website shows the flood forecast for the coming 5 days, every single day, even during drought times (https://check-for-flooding.service.gov.uk/?v=map-outlook). This ensures that everyone knows where to go for flood information, at any time, and can spend time getting used to the system in place.

Appendix 6: Avoiding putting forecast information on a map

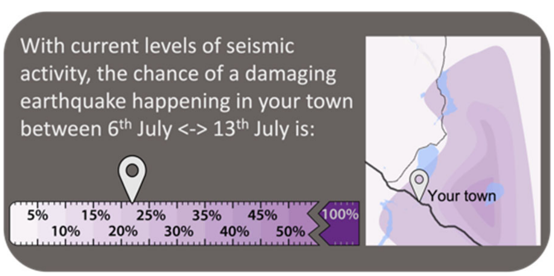
> ***Don't try to communicate forecast information to individuals via a geographical map representation. Only use a geographical map to illustrate the area over which the forecast is valid.***

In previous research on the use of maps in OEF, in New Zealand, Becker et al. (2019) found that displaying OEF probabilities on maps did not help the public in their decision-making. To investigate this further, we carried out a quantitative experiment, with 683 participants per experimental arm in each of three countries: Switzerland, Italy, and USA (California, specifically). We compared people's perception of the risk of an earthquake when the probability was shown as a number pointed out on a coloured scale and only a geographical map (left hand side below), and when that same number on a coloured scale was accompanied by a map showing that same forecast information as coloured isolines (right hand side below) (details in RISE deliverable D5.4 (Dryhurst, Dallo, et al., 2022)):





We found there was no difference between people's perceptions of the risk (at either of two probability levels – 22% and 44%) in these two conditions. This suggests that people were not using the isolines on the map as a cue, and instead were likely to be using the probability they could read off the scale. This is given more credence by the results from a third experimental group shown the same information on the coloured scale, but a different isoline map – again the map did not seem to affect people's perceptions of the risk (except for one hazard level in the Californian group only).



Furthermore, during our interviews with participants, we suspected that some were mistaking isolines on the map we included in our trial OEF communications as representing the forecast epicentre of an earthquake and/or the forecast extent of damage and level of impact, rather than as representing forecast probabilities, since similar-looking maps are often used in the aftermath of an event to indicate exactly that.

Given the potential for misunderstanding, and the fact that audiences don't appear to use an isoline map to read off probabilities when they are given clearly alongside it in another form, we recommend avoiding trying to represent probabilities of forecast events on a map, and instead just use a map to represent the area that the forecast relates to (something that a geographical map is useful for, and which our participants expected).

Appendix 7: Communicating potential impact as well as likelihood

Communicate information about what impact people might expect, as well as the likelihood/probability

It is easy for a forecaster to concentrate on communicating the ever-changing probabilities and forget that their audience also needs help understanding the likely impacts of the forecast event. A classic example of the problem was the winter storm of 1993 in the Eastern US that killed hundreds of people despite strong forecasts and even storm warnings. The public knew from the forecasts that a winter storm was coming. What they didn't know was what the impact of that was likely to be – the fact that driving conditions would be so lethal, the electricity supply would be likely to go down etc. This has also been seen in other fields: while researching flash flooding in Colorado, US, (Lazrus et al., 2016) found that whilst people might hear a forecast for a flash flood, they didn't know what that might mean and what they might do. Research in the aftermath of Hurricanes Sandy and Ike in the US again showed the same (David P. Rogers & Tsirkunov, 2013; Morss & Hayden, 2010). The impact had not been communicated as effectively as the likelihood.

So, although the job of a seismic researcher might not be to give warning messages advising people to do a particular thing in light of the current forecasts, what they can – and indeed probably should – do, is to explain the expected impact of the event they are forecasting, and the sorts of things that people could do to mitigate that impact. This is standard for 'risk communication' which is not about giving warnings but giving information (Mileti & Sorensen, 1987; Tierney et al., 2001).

The desire for information about the impact was clear from some of the participants in our interviews and focus groups:

"What I am saying is that I don't care about the likelihood. This morning a likelihood was given and it is not raining. I want to know the intensity [of the rain forecast] as I want to know the millimetre of water. Because the percentage then can say anything or nothing. It is of little use" (Participant in public focus group 1)

"It is better to have other information, not how likely it is to happen, but if it does happen, what can happen?" (Participant in public focus group 1)

Both these participants' sentiments could be interpreted as wanting more certainty than a forecast can deliver (we all do!), but actually providing clear information about the likely impact of a seismic event above the threshold whose likelihood is being communicated, alongside the probability, would probably help address their needs. Both likelihood and impact need to be communicated, and in a meaningful way i.e. put in an understandable context.

In order to give context to an impact, for example, UK flood forecasters try to relate the forecast event to a recent historical one that the audience might remember. Our attempts at something similar – giving examples of earthquakes of different magnitudes that the audience were likely to be familiar with – seemed to work:

"To me - and I am talking as a person who doesn't really know earthquakes - what helped me the most is the example. Because if you give me 'magnitude 4' - I don't know what it involves. […] But for example, I got an idea of it reading 'Amatrice'." (Infrastructure manager in round 3 interview)

This is called 'impact-based forecasting': talking about the likelihood of what a hazard will be like alongside what a hazard might *do* (Red Cross Red Crescent & UK Met Office, 2018). It's found particularly in meteorology, although seismology has made moves towards it. (e.g. (Chioccarelli & Iervolino, 2016; Iervolino et al., 2015)). We recommend the "Impact Based Forecasting Guide" by the (Red Cross Red Crescent & UK Met Office, 2018). See below for an example of information from this guide which is explicit about impact (although not in this case, likelihood), whilst not giving a message or advice.

Hazard	Forecast	Impact-based forecast for Individuals/ members of public	Impact based forecast for Sector specific users
Flooding	Heavy rain is forecast. 100 to 150mm of rain is expected within a three-hour period.	Flash flooding of the County River is expected. Dwellings, farm buildings and grazing land within 30m of the river channel are expected to flood and be damaged.	The forecast water level in the recreational district is expected to cross the +0.85 alert threshold in 5 days and remain above for a further 3 days. An impact forecast of loss of household assets is over 25% and affected population over 40%.
Tropical Cyclone	A tropical cyclone category 3, windspeed of 125 km/h is expected in the next 48 hours.	A tropical cyclone category 3, windspeed of 125 km/h is expected to make landfall in 12 hours, in X and Y regions, likely to damage critical infrastructure such as bridges, blocking transport from region X to region Y.	A Tropical cyclone, lead time of 30 hours, with wind speed greater than 125 km/h, corresponding to an impact forecast of damage of 25% of housing.

Appendix 8: Using both percentages and expected frequencies

Present probabilities of events occurring as both percentages (e.g. 'X% chance of an earthquake') <u>and</u> expected frequencies (e.g. 'out of 100,000 towns with exactly the same chance of an earthquake as this one, we would expect an earthquake to happen in X of them.')

We expect that forecasters will be presenting the numeric probability of a seismic event happening (rather than trying to use words like 'high likelihood').

Although there is a lot of literature suggesting that people don't interpret probabilities in probabilistic weather forecasts the way that forecasters intend, and in fact that forecasters themselves can differ in interpretation (De Elía & Laprise, 2005; Gigerenzer et al., 2005), many of the issues picked out by those studying weather forecasts are in fact to do with a lack of clarity about what the probability actually refers to rather than misinterpretations of the numerical probability itself (Fischhoff, 1994; Handmer & Proudley, 2007; Joslyn et al., 2009; Juanchich & Sirota, 2016).

Having said that, there is also research suggesting that people can misinterpret probabilities, particularly small probabilities (Hertwig, Barron, Weber, & Erev, 2004; Kahneman & Tversky, 1979; Rottenstreich & Hsee, 2001; Stone, Yates, & Parker, 1994). Indeed, some interviewees in our work expressed concerns about interpreting probabilities, for example:

"*I don't care about the likelihood… the percentage then can say anything or nothing. It is of little use." (Participant in public focus group 1)*

This issue has been tackled in health communication by converting the probability of a one-off event happening in the future into what is called an 'expected frequency': how often an event might be expected to happen out of a large number of opportunities. For example, a 10% probability would be an expected frequency of 10 in 100 times – or, in health terms, we might expect it to happen to 10 out of 100 patients with the same characteristics. For a single or rare event such as an earthquake, the expected frequency format is not quite so easy to construct (or possibly to interpret) as it really involves imagining multiple potential ways in which the future might play out.

However, in order to discover how people reacted to such a format, we constructed two potential phrasings of an expected frequency for a seismic event: *"imagine 100,000 possible ways in which the week could turn out in your town"* (we call this the 'future frequency'), and "*out of 100,000 towns with exactly the same chance of an earthquake as your town"* (we call this the 'geographical frequency'). We investigated whether either of these (on their own, or in combination with the percentage) would help people interpret the probability better than a percentage alone (as reported in RISE deliverable D5.4, (Dryhurst, Dallo, et al., 2022)).

In order to measure how people reacted to the format, we needed to use measures to tell us how people interpreted the probability. Several authors have worked on criteria of success for such information provision (e.g. (Michie et al., 2002; Weinstein, 1999; Weinstein & Sandman, 1993). We looked at measures of subjective feelings of comprehension to compare the formats (for example how easy they thought the format was to understand), along with the ability to be able to tell the difference between two hazard levels ('discrimination').

We showed each of 683 participants five different hazard levels in one of four numerical formats (each participant seeing the five numbers in the same format, in a random order). We did this experiment across three countries: Switzerland, Italy, and USA (California, specifically), changing the formats shown in each country slightly to cover more combinations.

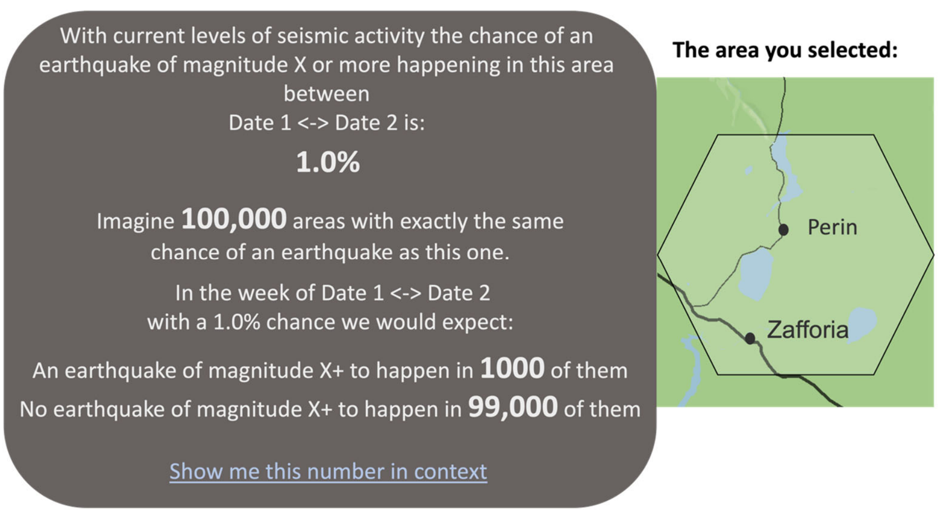
The two expected frequency formats gave participants a higher perception of the risk of each probability than the percentage format, as we expected from the existing literature (Freeman et al., 2021; Peters, Hart, & Fraenkel, 2011): the 'future' frequency format was perceived as slightly less risky than the 'geographical' frequency format – possibly because it is less easy to imagine psychologically (imagining "100,000 ways in which the week could turn out" perhaps feels less concrete than imagining "100,000 towns like your town") (Keller et al., 2006; Siegrist, 1997; Slovic et al., 2000).

This in itself is not necessarily helpful – it is not increasing discrimination of probabilities. However, combining a percentage and an expected frequency apparently did: it heightened discrimination between the lower risks (where the many decimal points made the percentages hard to distinguish).

When it came to subjective comprehension measures[1], the expected frequency formats were rated harder to understand (not surprisingly, as they are quite verbose), but participants that saw both the percentage and the frequency together rated this more easily understood than just the frequency phrasing alone. Given that this combined format has more words on it than any other makes this rating particularly interesting.

Our advice, then, is that an institution providing "only" a percentage, even with several decimal places, is not necessarily serving their audiences poorly as these are relatively well understood. However, given the need for discrimination between low percentages in OEF, we would recommend combining the percentage with an expected frequency format to help audiences interpret the probability.

Our recommended combined percentage and 'geographical expected frequency' format is shown below:



[1] Subjective comprehension measures asked participants how much effort they felt they had to make to understand the information, how easy or hard it was to understand etc. Their objective comprehension of what the information meant is measured via their risk perception: whether they felt a higher level of risk for higher probabilities etc.

Appendix 9: Avoiding either baseline or relative risks as ways of giving context

> ***Don't give the baseline risk (average percentage chance of an event occurring) or a relative risk (how many times higher than average the current risk is) in an attempt to help people understand their current risk level.***

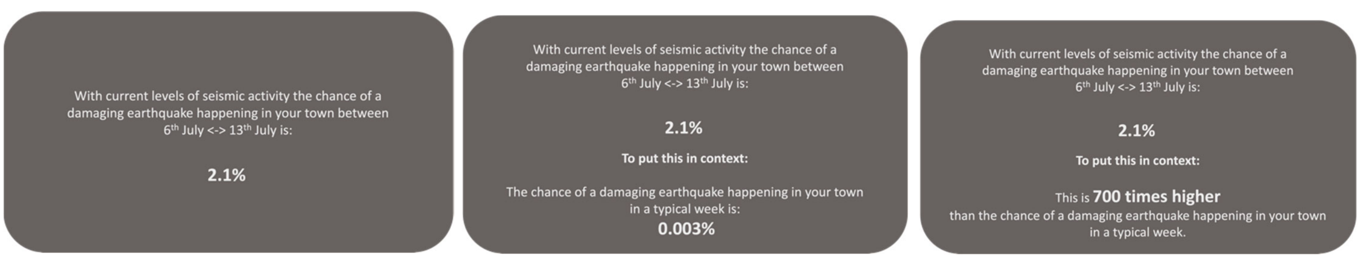
Is a 10% risk high or low? In some contexts, it may be high, in others low. Every number needs context in order to be interpretable. Experts may know the context through experience. Most of the audience of an OEF will not be an expert.

Since the job of a forecaster is often not to interpret the forecast for the audience (in terms of telling them that the risk is 'high' or 'low' in the forecaster's own opinion) which might stray into message-based communication. Instead, it is to provide information to allow the audience to interpret it for themselves. To do that, it can be important to provide context in the form of comparator risks.

Two common ways to do that is either to present the current risk alongside some kind of baseline or average risk for the audience to mentally compare, or to provide a relative risk (how much higher or lower than the baseline or average the current risk is).

Of course, comparing a higher current risk to a lower baseline risk – especially via a relative risk - can make people think the current risk is higher than if they viewed that current risk alone without context (Sandman et al., 1994; Siegrist et al., 2008). Theoretically, this may helpfully aid discrimination, particularly where low percentages with many decimal places are difficult to tell apart. However, in our own experiments (reported in deliverable D5.4 (Dryhurst, Dallo, et al., 2022)), we found that the effects were more complex.

We showed 683 participants (per experimental arm) in Switzerland and Italy four risk levels in a format with either the absolute risks alone, or the absolute risk combined with the baseline. In California, we showed 683 participants per experimental arm three risk levels in a format with either the absolute risks alone, or the absolute risk combined with the relative risk:



It is perhaps no surprise that our results showed that participants seeing the forecast probability represented as both an absolute and a relative risk together ('x times higher') perceived the hazards to be riskier than those who saw the absolute risk alone with no comparators. This combination of absolute and relative risk did not, however, enhance participants' ability to discriminate between risk levels.

The effects of giving the absolute baseline hazard level for comparison alongside the current, forecast absolute risk were more complex. In Italy, it appeared to dampen down risk perception for the higher hazard levels shown; in Switzerland it appeared to give a higher risk perception for all hazard levels. This is probably due to differing perceptions of the risk of earthquakes that we saw in these two countries. In neither case did it enhance discrimination between the different hazard levels.

We therefore do not recommend either of these approaches as useful ways to give context to a probability in OEF communications.

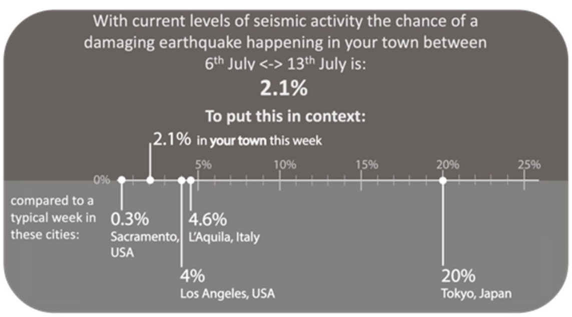
Appendix 10: Using a risk ladder of familiar cities and their seismic hazards for optional context

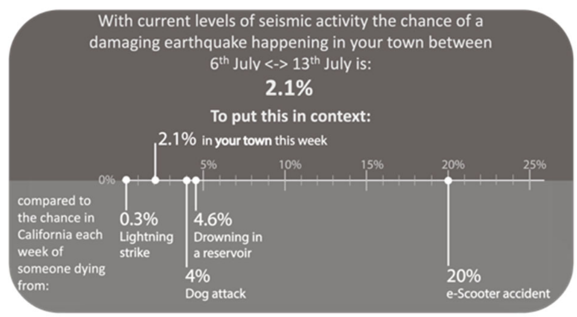
Allow those who want further context to view a graphic which illustrates the current probability of an event happening in the selected geographical area on a risk ladder, compared with the average probability of the same event happening in a few familiar cities which illustrate a broad range of high to low risk levels.

Another possible way to give context to a probability is to provide for comparison a range of probabilities for other events (Covello et al., 1988; Fischhoff et al., 1978; Keller et al., 2006; Kunreuther et al., 2001; Pighin et al., 2013; Wilson & Crouch, 1987). Savadori and colleagues (Savadori et al., 2022) found that comparator risks increased the sensitivity of UK participants to different levels of seismic risk in particular.

A graphical 'risk ladder', positioning the comparator risks along a scale, can help people contextualise the magnitude of the risk (Sandman et al., 1994; Siegrist et al., 2008).

We chose to test risk ladders with two different sets of comparators (reported in deliverable D5.4). One used other fatal risks, similar to (Savadori et al., 2022). The other, based on the experience of Kunreuther et al. (2001) and Freeman et al. (Freeman et al., 2021) used comparators that were closer to the risk being communicated: seismic risks in other areas that the audience might have a sense of. We carried out this experiment on 683 participants per arm in California (U.S.), Italy, and Switzerland.





Neither risk ladder had the effect of increasing discrimination between risk levels reported by Savadori et al. (2022), but instead shifted the risk perception upwards. They were also rated as difficult to understand (not surprisingly, given the amount of information they carry).

When shown a variety of potential ways of putting context around a probability and asked which they preferred, and why, for some people, the risk ladder with comparisons of the seismic hazard in different cities was appreciated as the most informative and suitable contextual addition.

"Comparison is good. You can get a better picture. But only earthquake comparison. One should not compare apples with pears" (Swiss online survey participant)

"I find it especially interesting if you have a comparison. Because otherwise you don't really know how to classify the numbers" (Swiss online survey participant)

Its complexity, though, was noted:

"I would prefer to see a simpler and more immediate graph, less technical" (Italian online survey participant)

"Charts are too complicated, as they take too long to be understood correctly. A more concise information I think can reach more people" (Italian online survey participant)

Out of all the formats that attempted to give context to the probability, this risk ladder probably enhanced people's risk discrimination the most and gave them the most useful context. However, given its complexity and heavy information content, we advise that it is offered as optional, additional content rather than being combined with the absolute risk presentation already advised.

We also advise care is taken over the choice of the comparator cities: they must be as familiar as possible for the chosen audience, but be careful with those with large emotional saliency (such as L'Aquila for Italian audiences). We report the perceived relative hazard levels of different cities for public participants in Italy, Switzerland, and California in deliverable 5.4 (Dryhurst, Dallo, et al., 2022) which may prove useful for the choice of comparator cities in those countries. We realise that identifying the baseline or average probability (and choosing the area over which to calculate it) is a challenge. We also suggest the use of the word 'typical' to describe this probability, after research during interviews with the public in different countries ('average' and 'baseline' were not easily understood).

Appendix 11: Giving links to information on what to expect during an earthquake sequence

Allow those who want it to find information about how long events might last for if they happen, and what people might expect in terms of emergency support or communication

Previous research by Becker and her team (Becker et al., 2019; Wein et al., 2016) has suggested that another piece of information requested by the media and public alongside probability and likely impact of forecast events was a likely duration for any earthquake sequence. Although this is not possible to forecast, it may be useful for audiences to know how long aftershock sequences usually last, and how long they should wait after an earthquake or felt tremor before leaving a place of safety (our interviews revealed that US tornado forecasters were asked this about leaving safety after a tornado as well), or starting emergency support etc. (as was found by USGS in their trials of operational earthquake forecasting).

Another request was for information on what to do during the aftershock sequence, including protective actions people could take (Becker et al., 2019):

Science information	Protective action information	Coping/recovery information
• What had caused the earthquakes (including geological background) • Likely future earthquake locations • Likely future magnitudes or intensities of aftershocks (e.g. *"the aftershocks may be [felt as] as severe[ly] as the initial shock"*) • To know there will be aftershocks • Duration of the aftershock sequence (e.g. "*another six months*"; *"When's going to be the next one?"*) • Context around an aftershock forecast (how it compares to background seismicity, what happened in previous NZ and overseas earthquakes, how do future earthquakes relate to what we have already just experienced?) • Aftershock information to inform longer term decision-making (e.g. future property purchases).	• How to immediately respond to aftershocks (e.g. Drop, Cover, Hold) • What to do next during the aftershock sequence (e.g. look after your friends/family). • How to get prepared (e.g. physical preparedness, develop a family emergency plan).	• Getting to and from school for parents • Commuting to and from work • Whether their house would be liveable • Advice on how to cope with aftershocks.

The information that members of the public requested from OEF, from Table 3 in Becker et al. (2019)

Although for some seismic forecasters, it may feel uncomfortable to stray into the territory of 'giving advice', this is not advice *in the light of the forecast,* but background information about the duration of past events and standard advice about what to do in an emergency. If a forecaster feels unable to carry such information on their own site, they should consider linking to the sites of agencies that do.

Appendix 12: Providing a narrative explanation behind the forecast and access to a person who can be called to explain it

Provide some explanation in normal language, and a personal interpretation service for those who want to be able to talk to a 'real person' about the forecast and how to interpret it

Whilst testing our prototype communications, it became clear that one of the well-appreciated aspects of the later designs was the addition of a sentence under the heading "What's happening here and now?" which gave a single sentence explaining the geological reasons for or evidence behind the forecast (e.g. "*This region is seeing higher chances than normal because of increased seismic activity around the Mount Vettore fault system."* Or *"In the last month this region has seen no seismic activity above the expected normal level. However, an earthquake can always occur with no warning."*). This verbal context was important for some participants to help them interpret the forecast (and could link through to further information), and they advised that it should be prominently displayed:

"*I am very interested in the reason of why there are some problems so the "what is happening here and now" is something very interesting.*" (Italian public, 3rd round)

"The first thing I thought when I read it was how it was possible to connect the … the weekly chance …. And the below information gives me an answer." (Italian public, 3rd round)

"*I would give emphasis to the information regarding the faults, that is an information that normally is not given and that could be of interest to everyone.*" (Engineer, 3rd round)

In our interviews with storm forecasters in the U.S. (reported in deliverable D5.1 (Dryhurst et al., 2020)), they also stressed the importance of providing a 24hr service whereby anyone could ring and speak to an expert who could help interpret the forecast for them. This allows people with potentially vital decisions to make to be able to access the best information possible (note that this is NOT an advice or warning line – just a service to be able to help explain the forecast to anyone who wants the information in more detail or a verbal description).

Appendix 13: Prebunking common misinformation or pre-empting misunderstandings

Consider 'prebunking' misinformation or common misunderstandings without patronising the audience or showing lack of cultural sensitivity

It is easy for people to misunderstand information, especially about topics that they have little background knowledge of. Background knowledge of seismology was relatively high in Iceland, according to our interviews with members of the public, but much lower in Switzerland and Italy. If there are important pieces of information that might be misunderstood (e.g. that earthquakes can happen even where there is no known fault line, or that a damaging earthquake can occur with no pre-warning at all) then it is helpful to pre-empt those misunderstandings clearly and obviously as part of the forecast.

As well as misunderstandings, there can be misinformation. False rumours are a problem around all sorts of events, but research suggests that fast, credible debunking can help (McBride et al., 2020). For example, researchers following false rumours on social media (that evacuation centres were checking people's immigration status as they arrived as Hurricanes Harvey the US coast in 2017) found that government and verified news agencies' corrections were heavily retweeted. The same rumours subsequently had far less traction when, shortly afterwards, they were spread again in advance of Hurricane Irma (Hunt et al., 2020). Similarly, after the Great East Japan Earthquake in March 2011, a false rumour about a chemical contamination event was quickly and overtly refuted by the local City Hall on social media, and the correction ("*After the LPG tanks explosion, there are rumors that harmful chemically contaminated rain may fall. However, the Earthquake Disaster Prevention Division of the City Fire Department confirmed that there is no scientific basis for these rumors. Please be careful not to be confused by the rumors*") was more re-tweeted than the original (Takayasu et al., 2015).

'Prebunking' potential misinformation is something that can be done to help protect people from common rumours (Lewandowsky & van der Linden, 2021; Roozenbeek et al., 2020). However, tone and sensitivity is required: it is important to avoid the tone of 'we know best' and 'you are wrong'. Seismology is a relatively young science and there is much that is still debated within the expert community (Dryhurst, Mulder, et al., 2022). Additionally, attitudes to seismological events are affected by cultural factors such as beliefs in the role of fate. Challenging such beliefs, even unintentionally, may be divisive and undermine trust. See Fallou et al. 2021 for a guide to fighting misinformation in the seismic domain {Formatting Citation}.

Appendix 14: Participants and acknowledgements

This work is based on a series of interviews and focus groups and we would like to extend our thanks to all the participants and those who helped us get in touch with and interview them. We'd especially like to thank our collaborators Irina Dallo & Michele Marti at ETH Zurich.

To understand current communication practices, focus groups/interviews with:

7 experts in communicating dynamic risks in different domains

4 experts on earthquake early warning from 3 countries

6 experts on operational earthquake forecasting from 5 countries

7 experts on rapid loss assessment from 7 countries

3 experts on long term hazard maps from 2 countries

2 experts on seismic risk perception from 1 country

2 experts on ShakeMaps from 2 countries

To understand communication needs and chains of communication and iterative deisgn of the communications, focus groups/interviews with:

Round 1:

6 people from national civil protection in Italy

10 people from regional/local civil protection and emergency response in Italy

9 people from civil protection/emergency response in Iceland

1 journalist from Iceland

11 members of the public from L'Aquila, Italy

10 members of the public from Reggio Calabria, Italy

8 members of the public from Modena, Italy

10 members of the public from Busto Arsizio, Italy

9 members of the public from Iceland

9 members of the public from Basel/Valais, Switzerland

9 members of the public from Zurich, Switzerland

Round 2:

6 seismologists from 4 countries

13 members of the public from Italy

Round 3:

3 seismologists from Italy

3 journalists from Italy

5 first responders/civil protection from Italy

1 engineer from Italy

19 members of the public from Italy

Quantitative studies, online surveys with:

8,196 members of the public across three countries (the U.S., Italy & Switzerland)

References

Becker, J. S., Potter, S. H., McBride, S. K., Wein, A., Doyle, E. E. H., & Paton, D. (2019). When the earth doesn't stop shaking: How experiences over time influenced information needs, communication, and interpretation of aftershock information during the Canterbury Earthquake Sequence, New Zealand. *International Journal of Disaster Risk Reduction*, *34*(November 2018), 397–411. https://doi.org/10.1016/j.ijdrr.2018.12.009

Chioccarelli, E., & Iervolino, I. (2016). Operational earthquake loss forecasting: a retrospective analysis of some recent Italian seismic sequences. *Bulletin of Earthquake Engineering*, *14*(9), 2607–2626. https://doi.org/10.1007/s10518-015-9837-8

Covello, V. T., Sandman, P. M., & Slovic, P. (1988). *Risk Communication, Risk Statistics, and Risk Comparisons: A Manual for Plant Managers*. Chemical Manufacturers Association.

David P. Rogers, & Tsirkunov, V. V. (2013). Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services. In *Book*.

De Elía, R., & Laprise, R. (2005). Diversity in interpretations of probability: Implications for weather forecasting. *Monthly Weather Review*, *133*(5), 1129–1143. https://doi.org/10.1175/MWR2913.1

Dilling, L., & Lemos, M. C. (2011). Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environmental Change*, *21*(2), 680–689. https://doi.org/10.1016/j.gloenvcha.2010.11.006

Dryhurst, S., Dallo, I., Luoni, G., Marti, M., & Freeman, A. L. (2022). *Field evaluation of OEF communications*.

Dryhurst, S., Luoni, G., Dallo, I., & Freeman, A. L. J. (2020). *Communicating seismic forecasts*. http://static.seismo.ethz.ch/rise/deliverables/Deliverable_5.1.pdf

Dryhurst, S., Luoni, G., Dallo, I., & Freeman, A. L. J. (2021). *Designing & implementing the seismic portion of dynamic risk communication for long-term risks, variable short-term risks, early warnings*.

Dryhurst, S., Mulder, F., Dallo, I., Kerr, J. R., McBride, S. K., Fallou, L., & Becker, J. (2022). Fighting misinformation in seismology: expert opinion on earthquake facts vs fiction. *Frontiers in Earth Science*, *10*(December), 1–11. https://doi.org/10.3389/feart.2022.937055

Fischhoff, B. (1994). What forecasts (seem to) mean. *International Journal of Forecasting*, *10*, 387–403.

Fischhoff, B., Slovic, P., Lichtenstein, S., Read, S., & Combs, B. (1978). How safe is safe enough? A psychometric study of attitudes towards technological risks and benefits. *Policy Sciences*, *9*(2), 127–152. https://doi.org/10.1007/BF00143739

Freeman, A. L. J., Kerr, J., Recchia, G., Schneider, C. R., Lawrence, A. C. E., Finikarides, L., Luoni, G., Dryhurst, S., & Spiegelhalter, D. (2021). Communicating personalized risks from COVID-19: Guidelines from an empirical study. In *Royal Society Open Science* (Vol. 8, Issue 4). https://doi.org/10.1098/rsos.201721

Gigerenzer, G., Hertwig, R., Van Den Broek, E., Fasolo, B., & Katsikopoulos, K. V. (2005). "A 30% chance of rain tomorrow": How does the public understand probabilistic weather forecasts? *Risk Analysis*, *25*(3), 623–629. https://doi.org/10.1111/j.1539-6924.2005.00608.x

Handmer, J., & Proudley, B. (2007). Communicating uncertainty via probabilities: The case of weather forecasts. *Environmental Hazards*, *7*(2), 79–87. https://doi.org/10.1016/j.envhaz.2007.05.002

Hertwig, R., Barron, G., Weber, E. U., & Erev, I. (2004). Decisions from experience and the effect of rare events in risky choice. *Psychological Science*, *15*(8), 534–539. https://doi.org/10.1111/j.0956-7976.2004.00715.x

Hunt, K., Wang, B., & Zhuang, J. (2020). Misinformation debunking and cross-platform information sharing through Twitter during Hurricanes Harvey and Irma: a case study on shelters and ID checks. *Natural Hazards*, *103*(1), 861–883. https://doi.org/10.1007/s11069-020-04016-6

Iervolino, I., Chioccarelli, E., Giorgio, M., Marzocchi, W., Zuccaro, G., Dolce, M., & Manfredi, G. (2015). Operational (short-term) earthquake loss forecasting in Italy. *Bulletin of the Seismological Society of America*, *105*(4), 2286–2298. https://doi.org/10.1785/0120140344

Joslyn, S., Nadav-greenberg, L., & Nichols, R. M. (2009). Probability of Precipitation. *Bulletin of the American Meteorological Society*, *90*(2), 185–193. https://doi.org/10.1175/2008BAMS2509.I

Juanchich, M., & Sirota, M. (2016). How to improve people's interpretation of probabilities of precipitation. *Journal of Risk Research*, *19*(3), 388–404. https://doi.org/10.1080/13669877.2014.983945

Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. Econometrika, 47, 263-291. *Econometrica*, *47*(2), 263–292.

Keller, C., Siegrist, M., & Gutscher, H. (2006). The role of the affect and availability heuristics in risk communication. *Risk Analysis*, *26*(3), 631–639. https://doi.org/10.1111/j.1539-6924.2006.00773.x

Klemm, T., & McPherson, R. A. (2017). The development of seasonal climate forecasting for agricultural producers. *Agricultural and Forest Meteorology*, *232*, 384–399. https://doi.org/10.1016/j.agrformet.2016.09.005

Kunreuther, H., Novemsky, N., & Kahneman, D. (2001). Making Low Probabilities Useful. *Journal of Risk and Uncertainty*, *23*(2), 103–120. https://doi.org/10.1023/A:1011111601406

Lazrus, H., Morss, R. E., Demuth, J. L., Lazo, J. K., & Bostrom, A. (2016). "Know What to Do If You Encounter a Flash Flood": Mental Models Analysis for Improving Flash Flood Risk Communication and Public Decision Making. *Risk Analysis*, *36*(2), 411–427. https://doi.org/10.1111/risa.12480

Lemos, M. C., Kirchhoff, C. J., & Ramprasad, V. (2012). Narrowing the climate information usability gap. *Nature Climate Change*, *2*(11), 789–794. https://doi.org/10.1038/nclimate1614

Lewandowsky, S., & van der Linden, S. (2021). Countering Misinformation and Fake News Through Inoculation and Prebunking. *European Review of Social Psychology*, *32*(2), 348–384. https://doi.org/10.1080/10463283.2021.1876983

Luoni, G., Dallo, I., Marti, M., Freeman, A. L., & Dryhurst, S. (2021). *Current communication pathways for seismic information in Italy, Switzerland and Iceland*.

McBride, S. K., Bostrom, A., Sutton, J., de Groot, R. M., Baltay, A. S., Terbush, B., Bodin, P., Dixon, M., Holland, E., Arba, R., Laustsen, P., Liu, S., & Vinci, M. (2020). Developing post-alert messaging for ShakeAlert, the earthquake early warning system for the West Coast of the United States of America. *International Journal of Disaster Risk Reduction*, *50*(May), 101713. https://doi.org/10.1016/j.ijdrr.2020.101713

Michie, Dormandy, Marteau, Michie, S., Dormandy, E., & Marteau, T. M. (2002). The multi-dimensional measure of informed choice: a validation study. *Patient Education and Counseling*, *48*(1), 87–91. https://doi.org/10.1016/S0738-3991(02)00089-7

Mileti, D. S., & Sorensen, J. H. (1987). Natural hazards and precautionary behavior. In *Taking care: Understanding and encouraging self-protective behavior.* (pp. 189–207). Cambridge University Press. https://doi.org/10.1017/CBO9780511527760.012

Morss, R. E., Demuth, J. L., Bostrom, A., Lazo, J. K., & Lazrus, H. (2015). Flash Flood Risks and Warning Decisions: A Mental Models Study of Forecasters, Public Officials, and Media Broadcasters in Boulder, Colorado. *Risk Analysis*, *35*(11), 2009–2028. https://doi.org/10.1111/risa.12403

Morss, R. E., & Hayden, M. H. (2010). Storm surge and "certain death": Interviews with texas coastal residents following hurricane ike. *Weather, Climate, and Society*, *2*(3), 174–189. https://doi.org/10.1175/2010WCAS1041.1

Peters, E., Hart, P. S., & Fraenkel, L. (2011). Informing patients: The influence of numeracy, framing, and format of side effect information on risk perceptions. *Medical Decision Making*, *31*(3), 432–436. https://doi.org/10.1177/0272989X10391672

Pighin, S., Savadori, L., Barilli, E., Rumiati, R., Bonalumi, S., Ferrari, M., & Cremonesi, L. (2013). Using comparison scenarios to improve prenatal risk communication. *Medical Decision Making*, *33*(1), 48–58. https://doi.org/10.1177/0272989X12464433

Red Cross Red Crescent, & UK Met Office. (2018). *IBF: Impact-based forecasting*.

Roozenbeek, J., van der Linden, S., & Nygren, T. (2020). Prebunking interventions based on "inoculation" theory can reduce susceptibility to misinformation across cultures. *The Harvard*

Kennedy School (HKS) Misinformation Review, *1*(2). https://doi.org/10.37016//mr-2020-008

Rottenstreich, Y., & Hsee, C. K. (2001). Money, kisses, and electric shocks: On the Affective Psychology of Risk. *Psychological Science*, *12*(3), 185–190. https://doi.org/10.1111/1467-9280.00334

Sandman, P. M., Weinstein, N. D., & Miller, P. (1994). High Risk or Low: How Location on a "Risk Ladder" Affects Perceived Risk. *Risk Analysis*, *14*(1), 35–45. https://doi.org/10.1111/j.1539-6924.1994.tb00026.x

Savadori, L., Ronzani, P., Sillari, G., Di Bucci, D., & Dolce, M. (2022). Communicating Seismic Risk Information: The Effect of Risk Comparisons on Risk Perception Sensitivity. *Frontiers in Communication*, *7*(March), 1–11. https://doi.org/10.3389/fcomm.2022.743172

Siegrist, M. (1997). Communicating low risk magnitudes: Incidence rates expressed as frequency versus rates expressed as probability. *Risk Analysis*, *17*(4), 507–510. https://doi.org/10.1111/j.1539-6924.1997.tb00891.x

Siegrist, M., Orlow, P., & Keller, C. (2008). The effect of graphical and numerical presentation of hypothetical prenatal diagnosis results on risk perception. *Medical Decision Making*, *28*(4), 567–574. https://doi.org/10.1177/0272989X08315237

Slovic, P., Monahan, J., & MacGregor, D. G. (2000). Violence risk assessment and risk communication: The effects of using actual cases, providing instructions, and employing probability vs. frequency formats. *Law & Human Behavior*, *24*(3), 271–296. https://doi.org/10.1023/A:1005595519944

Steynor, A., Padgham, J., Jack, C., Hewitson, B., & Lennard, C. (2016). Co-exploratory climate risk workshops: Experiences from urban Africa. *Climate Risk Management*, *13*, 95–102. https://doi.org/10.1016/j.crm.2016.03.001

Stone, E. R., Yates, J. F., & Parker, A. M. (1994). Risk communication: Absolute versus relative expressions of low-probability risks. In *Organizational Behavior and Human Decision Processes* (Vol. 60, Issue 3, pp. 387–408). https://doi.org/10.1006/obhd.1994.1091

Takayasu, M., Sato, K., Sano, Y., Yamada, K., Miura, W., & Takayasu, H. (2015). Rumor diffusion and convergence during the 3.11 Earthquake: A twitter case study. *PLoS ONE*, *10*(4), 1–18. https://doi.org/10.1371/journal.pone.0121443

Tierney, K., Lindell, M. K., & Perry, R. W. (2001). *Facing the Unexpected : Disaster Preparedness and Response in the United States*. Joseph Henry Press.

Vaughan, C., Buja, L., Kruczkiewicz, A., & Goddard, L. (2016). Identifying research priorities to advance climate services. *Climate Services*, *4*, 65–74. https://doi.org/10.1016/j.cliser.2016.11.004

Wein, A., Potter, S., Johal, S., Doyle, E., & Becker, J. (2016). Communicating with the public during an earthquake sequence: Improving communication of geoscience. *Seismological Research Letters*, *87*(1), 112–118. https://doi.org/10.1785/0220150113

Weinstein, N. D. (1999). What does it mean to understand a risk? Evaluating risk comprehension. *Journal of the National Cancer Institute. Monographs*, *25*, 15–20. https://doi.org/10.1093/oxfordjournals.jncimonographs.a024192

Weinstein, N. D., & Sandman, P. M. (1993). Some criteria for evaluating risk messages. *Risk Analysis*, *13*(1), 103–114. https://doi.org/10.1111/j.1539-6924.1993.tb00733.x

Wilson, R., & Crouch, E. A. C. (1987). Risk assessment and comparisons: An introduction. *Science*, *236*(4799), 267–270. https://doi.org/10.1126/science.3563505