REVIEWED OPINION
doi:10.26443/seismica.v2i2.470
SEISMICA

The need for open, transdisciplinary, and ethical science in seismology

Irina Dallo *[1], **Marcus Herrmann** [2], **Mariano Supino** [3], **José A. Bayona** [4], **Asim M. Khawaja** [5], **Chiara Scaini** [6]

[1]Swiss Seismological Service at ETH Zurich, Switzerland, [2]Università degli Studi di Napoli 'Federico II', Naples, Italy, [3]Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy, [4]School of Earth Sciences, University of Bristol, Bristol, United Kingdom, [5]GFZ German Research Centre for Geosciences, Potsdam, Germany, [6]National Institute of Oceanography and Applied Geophysics, Trieste, Italy

Author contributions: *Conceptualization*: ID, MH. *Methodology*: ID, MH. *Investigation*: ID, MH, MS, JB, AK, CS. *Resources*: ID, MH, MS, JB, AK, CS. *Writing - original draft*: ID, MH, MS, JB, AK, CS. *Writing - review & editing*: ID, MH, MS, JB, CS. *Visualization*: MH.
ID and MH share first authorship and contributed equally to this opinion paper.

Abstract Reducing the seismic risk for societies requires a bridge between scientific knowledge and societal actions. In recent years, three subjects that facilitate this connection gained growing importance: open science, transdisciplinarity, and ethics. We outline their relevance in general and specifically at the example of 'dynamic seismic risk' as explored in a dedicated workshop. We argue that these reflections can be transferred to other research fields for improving their practical and societal relevance. We provide recommendations for scientists at all levels to make science more open, transdisciplinary, and ethical. Only with a transition can we, as scientists, address current societal challenges and increase societies' resilience to disasters.

Production Editor:
Gareth Funning
Handling Editor:
Samantha Teplitzky
Copy & Layout Editor:
Hannah F. Mark

Signed reviewer(s):
Iryna Kuchma
Carmine Galasso

Received:
10 March 2023
Accepted:
11 July 2023
Published:
1 August 2023

1 Introduction

The devastating 2023 M7.8 Türkiye–Syria earthquake sequence once again highlighted the gap between scientific knowledge and action (e.g., Toomey, 2016): Although the impacted region is known to be at high seismic risk (i.e., highly seismically active, densely populated, and high physical and social vulnerability), the political and societal conditions have complicated and delayed protective measures (e.g., Hussain et al., 2023). To reduce the seismic risk and prepare local communities, experts from different disciplines must collaborate effectively in redesigning the built environment and engaging the construction companies, politicians, residents, etc. in risk education and management (Comfort et al., 2023).

In recent years, three subjects have become increasingly relevant to build that needed bridge between scientific knowledge and societal action, namely open science, transdisciplinarity, and ethics (see Figure 1). These subjects have influenced scientific discussions on how to transition from purely scientific research to practical and societally relevant applications that increase societies' resilience to disasters (e.g., Marti et al., 2022) – just as envisioned by several initiatives around the world, including the EU Horizon 2020 programme, the US National Science Foundation, and the UK Research and Innovation funding agency

We, along with other early career scientists of RISE (Real-time earthquake rIsk reduction for a reSilient Europe; EU Horizon 2020 project), identified these three subjects in several virtual discussions while reflecting on our needs to make our research efforts more societally meaningful and effective. Eventually, together with senior scientists, we discussed and evaluated these subjects during a three-day workshop in Naples (Italy), October 26-28, 2022, under the theme "Bringing research to practical applications that increase society's earthquake resilience" (Supplement 1). This theme resembled RISE's overall goal of advancing the scientific and societal knowledge on dynamic seismic risk, the overarching topic we additionally wanted to explore. First, keynotes from experts gave us a background on the three subjects, and lightning talks by all participants revealed the range of our expertise. Second, we drew a rich picture for the overarching topic and each subject following the Soft Systems Methodology (Pohl, 2020): separate groups sketch and express their ideas as mental models, receive feedback from the other groups, and revise it accordingly (see Supplement S2a-d for the evolution of the rich pictures). This approach allowed us to integrate all our expertise on the topic and subjects.

In the following, we provide the conceptual back-

*Address correspondence to Irina Dallo, ETH Zurich, Swiss Seismological Service, Sonneggstrasse 5, 8092 Zurich, Switzerland, irina.dallo@sed.ethz.ch

ground of the three main subjects, stress their relevance in current research, and illustrate their link to dynamic seismic risk (Figure 1). We believe that these reflections can be transferred to any other research field since the subjects affect various disciplines.

2 The three subjects in the light of dynamic seismic risk

To assess the impact of earthquakes on the built environment and people's well-being, seismic risk combines the knowledge about the potential ground shaking due to future earthquakes (seismic hazard) with the knowledge about the exposure and vulnerability of buildings, infrastructure, and communities. However, seismic risk is not constant but dynamic (varying in time, space, and context) due to changes in short- and long-term temporal variation of the hazard (e.g., occurrence of earthquake sequences, secondary effects such as tsunamis, fires or landslides), exposure (e.g., population growth and displacements, time of the day), and vulnerability (e.g., retrofitting, structural degradation) as well as complex interactions between individual and social vulnerabilities (e.g., Orru et al., 2022). To address these dynamics and related challenges, different approaches are needed in different phases of the disaster cycle (i.e., before, during, and after an earthquake sequence) such as operational earthquake forecasting (Jordan et al., 2011), dynamic exposure and vulnerability modelling (Schorlemmer et al., 2020; Orlacchio et al., 2021; Pittore et al., 2016), earthquake early warning (Allen and Melgar, 2019; Cremen and Galasso, 2020), rapid loss assessment (Erdik et al., 2011), and recovery and rebuilding efforts (Miles and Chang, 2006); see also Supplement S2a.

The data, models, products, and services (hereafter referred to as assets) that have been produced in RISE contribute to all phases of the disaster cycle (Carr, 1932) and, taken together, address dynamic seismic risk (Alexander, 2018). As outlined in the following three sections, these assets can only be combined meaningfully if interdisciplinary research groups openly share and document their inputs and outputs (Section 2.1), actively involve societal stakeholders (Section 2.2), and appropriately consider ethical issues (Section 2.3). For every subject, we dedicate three paragraphs: (§1) the theoretical concepts and advantages, (§2) their specific relevance for dynamic seismic risk, and (§3) solutions and good practices to implement them in future research.

2.1 Open science

Open science envisions transparent and accessible knowledge that is shared and developed collaboratively (UNESCO, 2022). It encompasses practices such as making research outputs open (e.g., open access publications, open data, and open source software), verifiable, and reproducible, as well as openly designing experiments, methods, and analyses. This openness provides many benefits, for instance making it easier to disseminate and communicate scientific knowledge, expedite the scientific process by saving time for re-inventing methods, receive constructive feedback from the scientific community, and promote collaborative, cross-disciplinary, and inclusive research practices. Moreover, open data can help identify systematic data misuse (i.e., a potentially adverse use that was not originally intended), particularly when issues in data analysis arise (e.g., geographical correlation associated with causality; Flaherty et al., 2022). Open science is further guided by the FAIR principles (Wilkinson et al., 2016), ensuring Findability, Accessibility, Interoperability, and Reuse of digital assets. For instance, a Digital Object Identifier (DOI; Paskin, 2010) is key to guarantee correct attribution and access of an asset in the long term (Schymanski and Schymanski, 2023). Moreover, open licenses (see Table 1) ensure an unrestricted use of data, models, or other outputs while appropriately crediting the creator. By complying with these standards and principles, cross-disciplinary efforts are possible (COAR et al., 2021).

Dynamic (seismic) risk assessment requires linking information from different assets and different phases of the disaster cycle, therefore significantly benefiting from an open approach. For example, the European Plate Observing System (EPOS) positioned itself to facilitate the open and FAIR data transfer between institutions and multiple disciplines within solid-earth sciences (Bailo et al., 2022; Marti et al., 2022). The EPOS Thematic Core Service for Seismology (Haslinger et al., 2022) enables homogenized monitoring efforts and collaboration based on seismic waveform data (ORFEUS), rapid earthquake information (EMSC), and expertise in seismic hazard and risk assessments (EFEHR); thus connecting the different assets along the disaster cycle. Also in RISE, some open science assets have been created, such as the pyCSEP toolkit, an open source software for developing and testing probabilistic earthquake forecasts (Savran et al., 2022a,b), so-called reproducibility packages that contain code, data, and other resources to reproduce research outcomes without additional effort (e.g., Bayona et al., 2022, 2023; Khawaja et al., 2023), an open sensor firmware platform that supports creating real-time monitoring networks (quakesaver.net), and a dynamic exposure model based on crowd-sourced/citizen-science building data (Schorlemmer et al., 2020). These developments set an example for making the fundamental assets of dynamic (seismic) risk assessment available. For the 2023 Türkiye–Syria earthquake sequence, in particular, various initiatives (e.g., EERI, 2013; GDACS, 2023; GSLN, 2023) collected open data and reports to facilitate scientific investigation, understanding, and dynamic risk reduction strategies.

To date, several challenges restrict the dissemination and development of open science (see also National Academies of Sciences, Engineering, and Medicine, 2018). Here we emphasize four of them: (i) Open science is not yet fully recognized as a part of science education, therefore authorities (e.g., universities, science ministries, research centers, funding bodies) responsible for overseeing science should put more emphasis on open science; (ii) The tools and technologies being used for open science are either unfamiliar or unavail-

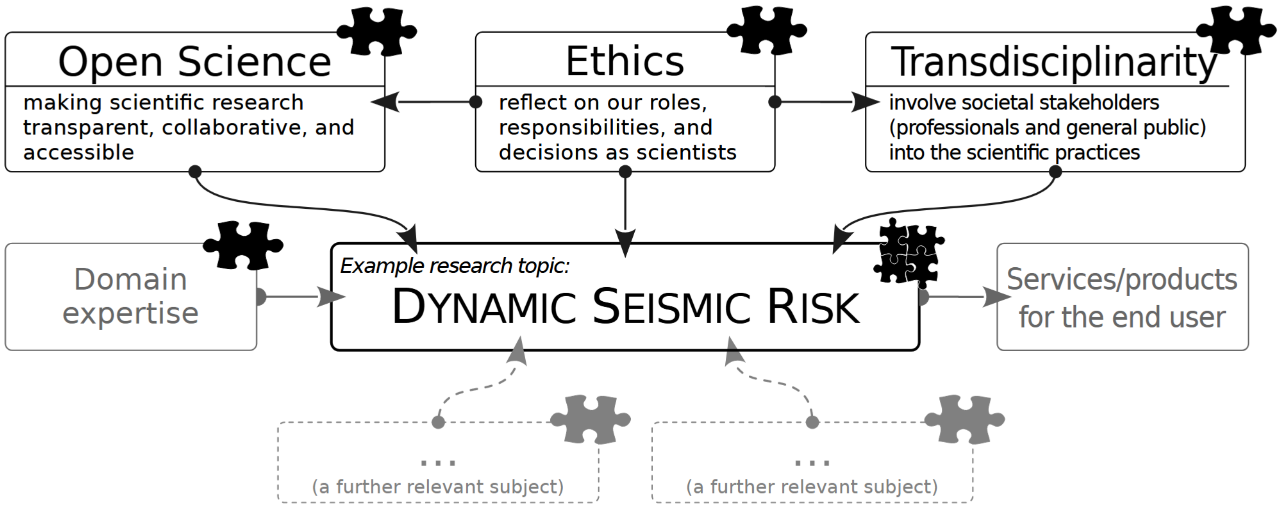

Figure 1 Overview of the three subjects (open science, ethics, and transdisciplinarity) and their relevance in dynamic seismic risk to co-design user-centered services and products. Ethics not only influence dynamic seismic risk, but also open science and transdisciplinarity (see Section 2.3 §2).The two empty dashed boxes at the bottom indicate further important subjects that were not addressed but are similarly relevant (e.g., legality, equity, diversity, inclusivity; Klinkhamer, 2022).

able to many scientists, thereby creating barriers to conducting open science. Training and open tools for the collaborative development of code, data, and methods should be provided to researchers early in their careers; (iii) Open science demands time, which is not yet considered in the researchers' evaluation process. Efforts for open science should be rewarded during the evaluation process of a researcher, for example through qualitative assessments (e.g., Hicks et al., 2015); (iv) The costs of open access publishing are usually high (in particular for journals of repute, which not all research institutions can afford; Sample, 2012), potentially discrediting research, leading to inequity (favoring those who have the funds), and fueling 'predatory' journals (Pourret, 2022); diamond open access journals like this one support a transition in open access publishing (Rowe et al., 2022).

2.2 Transdisciplinarity

Addressing current societal challenges requires transdisciplinary approaches (Peek et al., 2020; Vienni Baptista et al., 2020), that is, integrating knowledge from different scientific disciplines (interdisciplinary) and considering the values, knowledge, and needs of stakeholders in the society, including the public and private sectors, the general public, etc. (stakeholder engagement). Transdisciplinary approaches acknowledge the societal and scientific complexity of a problem (Hirsch Hadorn et al., 2008), co-create knowledge and practices (Pohl et al., 2021), tailor general scientific concepts to the local context (Stablein et al., 2022), and develop user-centered assets to contribute to disaster risk reduction (Dallo, 2022; Raška, 2022). Fostering transdisciplinarity is indispensable because we, as scientists, have a societal responsibility (Di Capua and Peppoloni, 2021) since our scientific outputs can have a direct or indirect impact on people's lives (Marti et al., 2022).

Transdisciplinary efforts to assess risk perception and awareness across communities and stakeholders are essential for disaster risk reduction (UNDRR, 2022a). The dynamic seismic risk framework develops products for different stakeholders who actively participate in all phases of the disaster cycle. In RISE, for example, interdisciplinary groups (consisting of engineers, seismologists, IT specialists, and communication experts) co-designed products and services by involving civil protection, authorities, and the general public through focus groups, interviews, and surveys (Fallou et al., 2022; Marti et al., 2023). It became apparent that a key factor in improving risk mitigation strategies is strengthening the relationship between scientists and stakeholders to better understand societies' needs and concerns.

Transdisciplinarity is not yet fully practiced by scientists involved in disaster risk reduction activities, and is not included in current discipline-specific academic education programs despite the desire of early career scientists (Bridle et al., 2013, Supplement 3). Two main challenges are (i) building interdisciplinary groups and ensuring effective interactions between the disciplinary experts, and (ii) engaging with civil society (a structured and sometimes lengthy process) by building trust between scientists and stakeholders (UNDRR, 2022b). Research infrastructures can foster the development of a transdisciplinary research community in the field of disaster risk (Peek et al., 2020) and provide powerful tools (e.g., data, codes, expertise) to research groups (e.g., Folch et al., 2023; Calatrava et al., 2023; Dañobeitia et al., 2020). Access and interaction with research infrastructures should therefore be promoted and encouraged among the disaster risk community to exploit these opportunities. Further, developing effective risk-related communication, in particular for the general public, is also challenged by potential misinformation, disinformation, and/or misunderstandings. This has been again observed in the 2023 Türkiye–Syria earthquake sequence (e.g., Panjwani, 2023). Thus, communication experts must be aware of these dynamics and continue to provide useful, understandable, and evidence-based recommendations to combat earthquake misinformation (Dallo et al., 2022a), help design and implement strategies for efficiently communicating earthquake early warnings and forecasts (Dryhurst et al., 2021; Freeman et al., 2023), and foster multi-hazard communication among different stakeholders (Dallo, 2022).

2.3 Ethics

Ethics is relevant to data collection, use, and processing, as well as to data-driven decision-making – it must be consciously considered by researchers. In general, experts differentiate between internal and external (research) ethics (ALLEA, 2013). Internal ethics refer to good research practices such as complying with GDPR and FAIR data principles, reflecting on conflicts of interest or embracing the duty to produce open science (Di Capua and Peppoloni, 2021; Wilkinson et al., 2016). External research ethics refer to the relations between science and society such as the potential misuse of information, the responsibility towards society, legal consequences (e.g., L'Aquila trial in 2009), or inclusive research cultures (ALLEA, 2013). These relations have a long history, starting with defined ethical standards after World War II (Evers, 2001). Even though international, European, and national ethical guidelines have been established (e.g., AGU, 2017), their practical implementation is still in its early stages (Di Capua and Peppoloni, 2021).

An assessment of ethical implications is required when personal data (e.g., socio-economic data) are used to assess social vulnerability (Ferreira et al., 2015) and/or consequences of disasters (Mezinska et al., 2016; Louis-Charles et al., 2020). Ethical issues could arise if outcomes of such assessments identify vulnerable or minority groups which can be targeted for other purposes (e.g., insurance plans). Granting public access to data, models, or products of a dynamic risk framework may lead to potential misuse by third parties, which should be considered by the providers and/or scientists beforehand, e.g. by clarifying the responsibility of any consequences. For example, an open earthquake forecasting (or risk) model could either be incorrectly used or its results misinterpreted, which may eventually reduce the trust in those models; or be intentionally manipulated to provide exaggerated forecasts, which may create fear and panic among the public. Ethics also matters when communicating certain information: in the workshop we discussed whether we could simply release probabilistic earthquake short-term forecasts to the public (and if yes, how?). Although those probabilities are produced by several institutions, not every scientist may advocate their public release for ethical reasons (e.g., potential misinterpretation, unintended panic, missing knowledge on translating the probabilities into mitigation actions) – yet, our internal majority voted for an unconditional public release, arguing that some information is more useful for (personal) decision-making than no information. Currently, a few institutions publicly release earthquake forecasts only after a large earthquake occurred (e.g., USGS and GNS). But for making (personal) decisions, people want actionable information, not probabilities (Dallo et al., 2022b).

But ethically, who decides what is actually considered right or wrong? We identified three possible categories: (i) 'agreed upon', where the necessary action to undertake is obvious, such as doing open science, involving more reviewers in the review process to reduce bias, or improving education; (ii) 'subjective', where a consensus is needed (such as publicly releasing forecasts), which can be obtained via voting (democratic) or providing and discussing arguments; and (iii) 'I do not care', where ethical implications are ignored or considered irrelevant (which we think is not a solution, but we have had experiences where scientists had this attitude). For the second category, which is the most difficult one, one may not find a consensus easily and may need to wait for more information or better arguments. Interestingly, a democratic approach to consensus building may in itself be considered unethical because minorities are not adequately represented. Therefore, evaluating ethical implications in practical applications of research results is not trivial – potential unethical situations must be carefully considered and reflected upon.

3 So, what can we do now?

On all levels – individually, within labs, institutionally, nationally, and internationally – more efforts are needed to foster open science, shift from discipline-specific or interdisciplinary research to transdisciplinary research, and jointly discuss the ethical implications of our research. Transdisciplinarity, in particular, is not sufficiently rewarded and encouraged within the academic sector (Müller and Kaltenbrunner, 2019), and all three subjects presented here are, at best, only partially addressed during academic training and career development.

In Table 1 we provide some practical guidelines and general suggestions on how to better address these three subjects. We advocate that research institutes and supervisors integrate them in their training programs for early career scientists, go beyond purely discipline-oriented training, motivate other scientists to consider these subjects in their projects, and bring them up in discussions with colleagues (from other disciplines) or outside academia. Specific programs for short visiting periods or fieldwork might enforce transdisciplinary connections and could be supported financially.

We further suggest that researchers' activities and projects should also be evaluated based on their contributions in terms of transdisciplinarity, openness, and ethical compliance to promote excellence and fairness. Finally, on an university, institutional, or project level, we argue that sessions with practical guidelines are needed to ensure that current and future research excellence considers the three subjects. We are aware that a fixed set of practices and guidelines are not sufficient; for instance, achieving openness in science is also a process of negotiation and dialogue with atten-

The subjects	Practical guidelines	General suggestions
Open Science	• FAIR Principles • OpenAire Open Science Guides • Open Science Training in TRIPLE (Provost et al., 2023) • Ten rules for implementing open and reproducible research practices (Heise et al., 2023) • FOSTER: Open Science Toolkit • Open Science: A Practical Guide for Early-Career Researchers • Open Data Commons Licenses • Creative Commons Licenses • Open Source Initiative – Licenses Overview • EC's Joinup Software License Assistent	• Provide training and use open tools for a collaborative development of code, data, and methods. • Incentives to focus on open science, e.g., publishing software packages should be acknowledged in performance evaluations (Journal of Open Source Software Merow et al., 2023) • Incentives for qualitative evaluations of researcher output, e.g., DORA, Leiden Manifesto, CoARA. • Preferentially publish in (diamond) open access journals
Transdisciplinarity	• td-net toolbox • What is transdisciplinary research? • Ten steps to make your research more relevant • EU action catalogue • Participatory methods • Communication Guide: How to fight misinformation about earthquakes? (Dallo et al., 2022a) • Research Culture – creating an inclusive research environment (e.g., Royal Society)	• Professors should actively share their knowledge about stakeholders' decision-making processes with their junior scientists, e.g., by dedicated seminars. • Training activities (e.g., workshops) where researchers can directly apply transdisciplinarity methods, which they can use for their research. • Real-world laboratories to facilitate the co-production between scientists and stakeholders (Pärli et al., 2022). • Promote more inter- and transdisciplinary interactions (Bridle et al., 2013). • Align incentives (e.g., promotion criteria, tenure, job applications, funding for visiting, and fieldwork). Recognize the value of transdisciplinary journals.
Ethics	• Ethics Education in Science • Artificial Intelligence & Ethics • Code of Conduct for Scientific Integrity • What is Ethics in Research • International Association for Promoting Geoethics	• Claim support for assessing ethical implications of research activities (e.g., ethical review specialists). • Improve review mechanisms to avoid bias and subjectivity. • Build consensus by considering diverse perspectives. • Foster practices and approaches for fieldwork (Ryan-Davis and Scalice, 2022).
All three subjects	• The Turing Way: Practical handbook with focus on reproducible, collaborative, and ethical research • Best practices for transparent, reproducible, and ethical research (de la Guardia and Sturdy, 2019).	• Training courses for early career scientists, seniors, supervisors, etc. (at the institutes) (Nature, 2023). • Project workshops discussing these subjects in the light of the overall project theme or subtasks (as we did, see Supplement S1). • Build reward mechanisms for research that adopts transdisciplinarity, comply with open access principles, and/or covers ethical aspects. • Supervisors should be role models (Haven et al., 2022). • Engage in knowledge transfer and dissemination activities to the society. • Foster interaction with research infrastructures (both at individual level and for research groups).

Table 1 A selection of practical guidelines for each of the three subjects (middle column) and general suggestions to proactively address them (right column). The last row refers to all three subjects.

tion to socio-cultural contexts and diverse perspectives (Leonelli, 2023) – i.e., the interaction of three subjects outlined here. Likewise, open and transdisciplinary approaches can help with a better training in the 'ethical dimension' of science. Only by embracing this open and inclusive system of knowledge production can we, as scientists, help address current societal challenges and ultimately contribute to increasing societies' resilience to disasters.

Acknowledgements

The authors thank Max Werner, the handling editor, and the two reviewers, Carmine Galasso and Iryna Kuchma, for their valuable comments to improve our opinion article. The authors would like to thank all workshop participants for their active contributions: Jedidiah Aguirre, Emanuele Biondini, Laura Cataldi, Marta Han, Marius Paul Isken (and his keynote), Russell Azad Khan, Simone Mancini, Aron Mirwald, Sam Stockman, Nadja Valenzuela, Tara Evaz Zadeh, Paolo Bergamo, Laura Gulia, Valerio Poggi, and Stefan Wiemer (project leader). We sincerely appreciated the keynote talks of Warner Marzocchi, Silvia Peppoloni, and Angelo Strollo for inspiration and valuable insights. We are also grateful to Jamal Dabbeek, Laure Fallou, Pablo Iturrieta, Mabel Orlacchio, Yves Reuland, and Francesco Serafini for the initial virtual brainstorming. This investigation was supported by the 'Real-time Earthquake Risk Reduction for a Resilient Europe' (RISE) project, which received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 821115. Opinions expressed in this article solely reflect the authors' views; the EU is not responsible for any use that may be made of information it contains.

Data and code availability

The outputs of the RISE ECS Workshop are available in the Supplement (Dallo and Herrmann, 2023).

Competing interests

The authors declare no conflicts of interest.

References

AGU. *The responsibilities and rights of scientists. Position statement.* American Geophysical Union, 2017.

Alexander, D. E. L'Aquila, central Italy, and the "disaster cycle", 2009-2017. *Disaster Prevention and Management: An International Journal*, 28(4):419–433, Aug. 2018. doi: 10.1108/dpm-01-2018-0022.

ALLEA. Ethics education in science. ALL European Academies - Permanent Working Group on Science and Ethics, 2013. https://www.allea.org/wp-content/uploads/2015/07/Statement_Ethics_Edu_web_final_2013_10_10.pd.

Allen, R. M. and Melgar, D. Earthquake Early Warning: Advances, Scientific Challenges, and Societal Needs. *Annual Review of Earth and Planetary Sciences*, 47(1):361–388, May 2019. doi: 10.1146/annurev-earth-053018-060457.

Bailo, D., Jeffery, K. G., Atakan, K., Trani, L., Paciello, R., Vinciarelli, V., Michalek, J., and Spinuso, A. Data integration and FAIR data management in Solid Earth Science. *Annals of Geophysics*, 65 (2):DM210, Apr. 2022. doi: 10.4401/ag-8742.

Bayona, J., Savran, W., Iturrieta, P., Gerstenberger, M., Graham, K., Marzocchi, W., Schorlemmer, D., and Werner, M. Are Regionally Calibrated Seismicity Models More Informative than Global Models? Insights from California, New Zealand, and Italy. *The Seismic Record*, 3(2):86–95, Apr. 2023. doi: 10.1785/0320230006.

Bayona, J. A., Savran, W. H., Rhoades, D. A., and Werner, M. J. Prospective evaluation of multiplicative hybrid earthquake forecasting models in California. *Geophysical Journal International*, 229(3):1736–1753, Jan. 2022. doi: 10.1093/gji/ggac018.

Bridle, H., Vrieling, A., Cardillo, M., Araya, Y., and Hinojosa, L. Preparing for an interdisciplinary future: A perspective from early-career researchers. *Futures*, 53:22–32, Sept. 2013. doi: 10.1016/j.futures.2013.09.003.

Calatrava, A., Asorey, H., Astalos, J., Azevedo, A., Benincasa, F., Blanquer, I., Bobak, M., Brasileiro, F., Codó, L., Cano, L., Esteban, B., Ferret, M., Handl, J., Kerzenmacher, T., Kozlov, V., Křenek, A., Martins, R., Pavesio, M., Rubio-Montero, A., and Sánchez-Ferrero, J. A survey of the European Open Science Cloud services for expanding the capacity and capabilities of multidisciplinary scientific applications. *Computer Science Review*, 49: 100571, Aug. 2023. doi: 10.1016/j.cosrev.2023.100571.

Carr, L. J. Disaster and the Sequence-Pattern Concept of Social Change. *American Journal of Sociology*, 38(2):207–218, Sept. 1932. doi: 10.1086/216030.

COAR, CoreTrustSeal, European University Association, Science Europe, and World Data System. Joint Position Statement on "Data Repository Selection - Criteria That Matter", 2021. https://zenodo.org/record/4649136. doi: 10.5281/ZENODO.4649136.

Comfort, L., Erkan, B., and Gulkan, P. Earthquake in Turkey exposes gap between seismic knowledge and action - but it is possible to prepare, 2023. https://theconversation.com/earthquake-in-turkey-exposes-gap-between-seismic-knowledge-and-action-but-it-is-possible-to-prepare-199379. The Conversation.

Cremen, G. and Galasso, C. Earthquake early warning: Recent advances and perspectives. *Earth-Science Reviews*, 205:103184, June 2020. doi: 10.1016/j.earscirev.2020.103184.

Dallo, I. *Understanding the communication of event-related earthquake information in a multi-hazard context to improve society's resilience.* PhD thesis, ETH Zurich, 2022. http://hdl.handle.net/20.500.11850/535657.

Dallo, I. and Herrmann, M. Supplement of "The need for open, transdisciplinary, and ethical science in seismology", July 2023. doi: 10.3929/ethz-b-000621044.

Dallo, I., Corradini, M., Fallou, L., and Marti, M. How to fight misinformation about earthquakes? A Communication Guide. 2022a. doi: 10.3929/ETHZ-B-000530319.

Dallo, I., Stauffacher, M., and Marti, M. Actionable and understandable? Evidence-based recommendations for the design of (multi-)hazard warning messages. *International Journal of Disaster Risk Reduction*, 74:102917, May 2022b. doi: 10.1016/j.ijdrr.2022.102917.

Dañobeitia, J., Pouliquen, S., Johannessen, T., Basset, A., Cannat, M., Pfeil, B., M.I., F., Materia, P., Gourcuff, C., Magnifico, G., Delory1, E., Rio Fernandez, J., Rodero, I., Beranzoli, L., Nardello, I., Iudicone, D., Carval, T., Gonzalez Aranda, J., Petihakis, G., Blandin, J., Kutsch, W., Rintala, J.-M., Gates, A., and Favali, P. Toward a Comprehensive and Integrated Strategy of the European Marine Research Infrastructures for Ocean Observations. *Frontiers in Marine Science*, 7, Mar. 2020. doi: 10.3389/fmars.2020.00180.

de la Guardia, F. H. and Sturdy, J. Best Practices for Transparent, Reproducible, and Ethical Research. Technical report, Feb. 2019.

Di Capua, G. and Peppoloni, S. First report on ethical implications of EPOS Services to Society, 2021. https://www.epos-eu.org/sites/default/files/2022-01/First%20report%20on%20ethical%20implications%20of%20EPOS%20Services%20to%20Society.pdf. Deliverable [EPOS SP] 6.1; WP6: Value for Society, Issue 6.1). Instituto Nazionale di Geofisica e Vulcanologia.

Dryhurst, S., Luoni, G., Dallo, I., Freeman, A., and Marti, M. Designing & implementing the seismic portion of dynamic risk communication for long-term risks, variable short-term risks, early warnings, 2021. http://static.seismo.ethz.ch/rise/deliverables/Deliverable_5.3.pdf. Deliverable]. European Horizon-2020 project RISE.

EERI. Earthquake Engineering Research Institute, 2013. https://learningfromearthquakes.org/2023-02-06-nurdagi-turkey.

Erdik, M., Şeşetyan, K., Demircioğlu, M., Hancılar, U., and Zülfikar, C. Rapid earthquake loss assessment after damaging earthquakes. *Soil Dynamics and Earthquake Engineering*, 31(2): 247–266, Feb. 2011. doi: 10.1016/j.soildyn.2010.03.009.

Evers, K. Standards for ethics and responsibility in science, 2001. https://council.science/wp-content/uploads/2017/05/SCRES-Background.pdf. The Standing Committee on Responsibility and Ethics in Science (SCRES), 149.

Fallou, L., Marti, M., Dallo, I., and Corradini, M. How to Fight Earthquake Misinformation: A Communication Guide. *Seismological Research Letters*, 93(5):2418–2422, June 2022. doi: 10.1785/0220220086.

Ferreira, R., Buttell, F., and Ferreira, S. Ethical considerations for conducting disaster research with vulnerable populations. *Journal of Social Work Values and Ethics*, 3:379–384, 2015.

Flaherty, E., Sturm, T., and Farries, E. The conspiracy of Covid-19 and 5G: Spatial analysis fallacies in the age of data democratization. *Social Science & Medicine*, 293:114546, Jan. 2022. doi: 10.1016/j.socscimed.2021.114546.

Folch, A., Abril, C., Afanasiev, M., Amati, G., Bader, M., Badia, R. M., Bayraktar, H. B., Barsotti, S., Basili, R., Bernardi, F., Boehm, C., Brizuela, B., Brogi, F., Cabrera, E., Casarotti, E., Castro, M. J., Cerminara, M., Cirella, A., Cheptsov, A., Conejero, J., Costa, A., de la Asunción, M., de la Puente, J., Djuric, M., Dorozhinskii, R., Espinosa, G., Esposti-Ongaro, T., Farnós, J., Favretto-Cristini, N., Fichtner, A., Fournier, A., Gabriel, A.-A., Gallard, J.-M., Gibbons, S. J., Glimsdal, S., González-Vida, J. M., Gracia, J., Gregorio, R., Gutierrez, N., Halldorsson, B., Hamitou, O., Houzeaux, G., Jaure, S., Kessar, M., Krenz, L., Krischer, L., Laforet, S., Lanucara, P., Li, B., Lorenzino, M. C., Lorito, S., Løvholt, F., Macedonio, G., Macías, J., Marín, G., Montesinos, B. M., Mingari, L., Moguilny, G., Montellier, V., Monterrubio-Velasco, M., Moulard, G. E., Nagaso, M., Nazaria, M., Niethammer, C., Pardini, F., Pienkowska, M., Pizzimenti, L., Poiata, N., Rannabauer, L., Rojas, O., Rodriguez, J. E., Romano, F., Rudyy, O., Ruggiero, V., Samfass, P., Sánchez-Linares, C., Sanchez, S., Sandri, L., Scala, A., Schaefer, N., Schuchart, J., Selva, J., Sergeant, A., Stallone, A., Taroni, M., Thrastarson, S., Titos, M., Tonelllo, N., Tonini, R., Ulrich, T., Vilotte, J.-P., Vöge, M., Volpe, M., Wirp, S. A., and Wössner, U. The EU Center of Excellence for Exascale in Solid Earth (ChEESE): Implementation, results, and roadmap for the second phase. *Future Generation Computer Systems*, 146:47–61, Sept. 2023. doi: 10.1016/j.future.2023.04.006.

Freeman, A., Dryhurst, S., and Luoni, G. Good practice recommendations: Earthquake forecast communication, 2023. http://rise-eu.org/dissemination/good-practices/oef-communication. European Horizon-2020 project RISE.

GDACS. Global Disaster Alert and Coordination System, 2023. https://www.gdacs.org/report.aspx?eventid=1357372&episodeid=1487096&eventtype=EQ. M 7.8 in Türkiye on 06 Feb 2023 01:17 UTC. Webpage.

GSLN. Geohazard Supersites and Natural Laboratories, 2023. https://geo-gsnl.org/supersites/event-supersites/active-event-supersites/kahramanmaras-event-supersite.

Haslinger, F., Basili, R., Bossu, R., Cauzzi, C., Cotton, F., Crowley, H., Custodio, S., Danciu, L., Locati, M., Michelini, A., Molinari, I., Ottemöller, L., and Parolai, S. Coordinated and Interoperable Seismological Data and Product Services in Europe: the EPOS Thematic Core Service for Seismology. *Annals of Geophysics*, 65 (2):DM213, Apr. 2022. doi: 10.4401/ag-8767.

Haven, T., Bouter, L., Mennen, L., and Tijdink, J. Superb supervision: A pilot study on training supervisors to convey responsible research practices onto their PhD candidates. *Accountability in Research*, pages 1–18, May 2022. doi: 10.1080/08989621.2022.2071153.

Heise, V., Holman, C., Lo, H., Lyras, E. M., Adkins, M. C., Aquino, M. R. J., Bougioukas, K. I., Bray, K. O., Gajos, M., Guo, X., Hartling, C., Huerta-Gutierrez, R., Jindrová, M., Kenney, J. P. M., Kępińska, A. P., Kneller, L., Lopez-Rodriguez, E., Mühlensiepen, F., Richards, A., Richards, G., Siebert, M., Smith, J. A., Smith, N., Stransky, N., Tarvainen, S., Valdes, D. S., Warrington, K. L., Wilpert, N.-M., Witkowska, D., Zaneva, M., Zanker, J., and Weissgerber, T. L. Ten simple rules for implementing open and reproducible research practices after attending a training course. *PLOS Computational Biology*, 19(1):e1010750, Jan. 2023. doi: 10.1371/journal.pcbi.1010750.

Hicks, D., Wouters, P., Waltman, L., de Rijcke, S., and Rafols, I. Bibliometrics: The Leiden Manifesto for research metrics. *Nature*, 520(7548):429–431, Apr. 2015. doi: 10.1038/520429a.

Hirsch Hadorn, G., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., and Zemp, E., editors. *Handbook of transdisciplinary research*. Springer, 2008.

Hussain, E., Kalaycıoğlu, S., Milliner, C., and Çakir, Z. Preconditioning the 2023 Kahramanmaraş (Türkiye) earthquake disaster. *Nature Reviews Earth & Environment*, 4(5):287–289, Apr. 2023. doi: 10.1038/s43017-023-00411-2.

Jordan, T. H., Chen, Y.-T., Gasparini, P., Madariaga, R., Main, I., Marzocchi, W., Papadopoulos, G., Sobolev, G., Yamaoka, K., and Zschau, J. Operational Earthquake Forecasting: State of knowledge and guidelines for implementation. *Annals of Geophysics*, 54(4), Aug. 2011. doi: 10.4401/ag-5350.

Khawaja, A. M., Hainzl, S., Schorlemmer, D., Iturrieta, P., Bayona, J. A., Savran, W. H., Werner, M., and Marzocchi, W. Statistical power of spatial earthquake forecast tests. *Geophysical Journal International*, 233(3):2053–2066, Jan. 2023. doi: 10.1093/gji/ggad030.

Klinkhamer, L. Equity, diversity and inclusivity in open research. *BMJ Open Science*, 2022.

Leonelli, S. Philosophy of open science, 2023. https://philsci-archive.pitt.edu/21986.

Louis-Charles, H. M., Howard, R., Remy, L., Nibbs, F., and Turner, G. Ethical Considerations for Postdisaster Fieldwork and Data Collection in the Caribbean. *American Behavioral Scientist*, 64 (8):1129–1144, July 2020. doi: 10.1177/0002764220938113.

Marti, M., Haslinger, F., Peppoloni, S., Capua, G., Glaves, H., and Dallo, I. Addressing the challenges of making data, products, and services accessible: An EPOS perspective. *Annals of Geophysics*, 65(2):DM212, Apr. 2022. doi: 10.4401/ag-8746.

Marti, M., Dallo, I., Roth, P., Papadopoulos, A., and Zaugg, S. Illustrating the impact of earthquakes: Evidence-based and user-centered recommendations on how to design earthquake scenarios and rapid impact assessments. *International Journal of Disaster Risk Reduction*, 90:103674, May 2023. doi: 10.1016/j.ijdrr.2023.103674.

Merow, C., Boyle, B., Enquist, B. J., Feng, X., Kass, J. M., Maitner, B. S., McGill, B., Owens, H., Park, D. S., Paz, A., Pinilla-Buitrago, G. E., Urban, M. C., Varela, S., and Wilson, A. M. Better incentives are needed to reward academic software development. *Nature Ecology & Evolution*, 7(5):626–627, Feb. 2023. doi: 10.1038/s41559-023-02008-w.

Mezinska, S., Kakuk, P., Mijaljica, G., Waligóra, M., and O'Mathúna, D. P. Research in disaster settings: a systematic qualitative review of ethical guidelines. *BMC Medical Ethics*, 17(1), Oct. 2016. doi: 10.1186/s12910-016-0148-7.

Miles, S. B. and Chang, S. E. Modeling Community Recovery from Earthquakes. *Earthquake Spectra*, 22(2):439–458, May 2006. doi: 10.1193/1.2192847.

Müller, R. and Kaltenbrunner, W. Re-disciplining Academic Careers? Interdisciplinary Practice and Career Development in a Swedish Environmental Sciences Research Center. *Minerva*, 57 (4):479–499, Apr. 2019. doi: 10.1007/s11024-019-09373-6.

National Academies of Sciences, Engineering, and Medicine. *Open Science by Design: Realizing a Vision for 21st Century Research*. National Academies Press, Aug. 2018. doi: 10.17226/25116.

Nature. PhD training is no longer fit for purpose—It needs reform now. *Nature*, 613(7944):414–414, Jan. 2023. doi: 10.1038/d41586-023-00084-3.

Orlacchio, M., Chioccarelli, E., Baltzopoulos, G., and Iervolino, I. State-Dependent Seismic Fragility Functions for Italian Reinforced Concrete Structures: Preliminary Results. In *Proceedings of the 31st European Safety and Reliability Conference (ESREL 2021)*. Research Publishing Services, 2021. doi: 10.3850/978-981-18-2016-8_660-cd.

Orru, K., Klaos, M., Nero, K., Gabel, F., Hansson, S., and Nævestad, T.-O. Imagining and assessing future risks: A dynamic scenario-based social vulnerability analysis framework for disaster planning and response. *Journal of Contingencies and Crisis Management*, Nov. 2022. doi: 10.1111/1468-5973.12436.

Panjwani, A. False social media posts are hindering earthquake relief efforts in Turkey. You can help stop that. *The Guardian*, 2023.

Paskin, N. Digital object identifier (DOI®) system. *Encyclopedia of library and information sciences*, 3:1586–1592, 2010. doi: 10.1081/E-ELIS3-120044418.

Peek, L., Tobin, J., Adams, R. M., Wu, H., and Mathews, M. C. A Framework for Convergence Research in the Hazards and Disaster Field: The Natural Hazards Engineering Research Infrastructure CONVERGE Facility. *Frontiers in Built Environment*, 6, July 2020. doi: 10.3389/fbuil.2020.00110.

Pittore, M., Wieland, M., and Fleming, K. Perspectives on global dynamic exposure modelling for geo-risk assessment. *Natural Hazards*, 86(S1):7–30, June 2016. doi: 10.1007/s11069-016-2437-3.

Pohl, C. Soft systems methodology, 2020. https://zenodo.org/record/3717356. doi: 10.5281/ZENODO.3717356.

Pohl, C., Klein, J. T., Hoffmann, S., Mitchell, C., and Fam, D. Conceptualising transdisciplinary integration as a multidimensional interactive process. *Environmental Science & Policy*, 118:18–26, Apr. 2021. doi: 10.1016/j.envsci.2020.12.005.

Pourret, O. Stop paying to be published Open Access – a French perspective. *European Science Editing*, 48, Aug. 2022. doi: 10.3897/ese.2022.e90113.

Provost, L., Donato, F., Tóth-Czifra, E., Dumouchel, S., Blotière, E., and Chen, Y. Open Science Training in TRIPLE. *Open Research Europe*, 3:39, Feb. 2023. doi: 10.12688/openreseurope.15430.1.

Pärli, R., Stauffacher, M., Seigo, S., Probst, M., and Pearce, B. Designing interventions for sustainable change in a real-world laboratory. *Environment, Development and Sustainability*, Sept. 2022. doi: 10.1007/s10668-022-02659-y.

Raška, P. On Epistemic Dissonance: Contesting the Transdisciplinary Disaster Risk Reduction Education, Research, and Practices. *Frontiers in Earth Science*, 9, Jan. 2022. doi: 10.3389/feart.2021.818361.

Rowe, C., Agius, M., Convers, J., Funning, G., Galasso, C., Hicks, S., Huynh, T., Lange, J., Lecocq, T., Mark, H., Ragon, T., Rychert, C., Teplitzky, S., Den Ende, M., and Okuwaki, R. The launch of Seismica: A seismic shift in publishing. *Seismica*, 1(1), Nov. 2022. doi: 10.26443/seismica.v1i1.255.

Ryan-Davis, J. and Scalice, D. Co-Creating Ethical Practices and Approaches for Fieldwork. *AGU Advances*, 3(6), Dec. 2022. doi: 10.1029/2022av000762.

Sample, I. Harvard University says it can't afford journal publishers' prices. *The Guardian*, 24(1):20–32, 2012.

Savran, W., Bayona, J., Iturrieta, P., Asim, K., Bao, H., Bayliss, K., Herrmann, M., Schorlemmer, D., Maechling, P., and Werner, M. pyCSEP: A Python Toolkit for Earthquake Forecast Developers. *Seismological Research Letters*, 93(5):2858–2870, July 2022a. doi: 10.1785/0220220033.

Savran, W., Werner, M., Schorlemmer, D., and Maechling, P. pyCSEP: A Python Toolkit For Earthquake Forecast Developers. *Journal of Open Source Software*, 7(69):3658, Jan. 2022b. doi: 10.21105/joss.03658.

Schorlemmer, D., Beutin, T., Cotton, F., Ospina, N. G., Hirata, N., Ma, K.-F., Nievas, C., Prehn, K., and Wyss, M. Global Dynamic Exposure and the OpenBuildingMap - A Big-Data and Crowd-Sourcing Approach to Exposure Modeling. Mar. 2020. doi: 10.5194/egusphere-egu2020-18920.

Schymanski, E. L. and Schymanski, S. J. Water science must be Open Science. *Nature Water*, 1(1):4–6, Jan. 2023. doi: 10.1038/s44221-022-00014-z.

Stablein, M., Gonzalez Cruz, J., Fidan, E., Talbot, J., Reed, S., Walters, R., Ogunyiola, A., Fernández Frey, M., Ramirez, M., Rosado Casanova, B., Heemstra, J., Marshall, A., and Rodríguez, L. Compound[ing] disasters in Puerto Rico: Pathways for virtual transdisciplinary collaboration to enhance community resilience. *Global Environmental Change*, 76:102558, Sept. 2022. doi: 10.1016/j.gloenvcha.2022.102558.

Toomey, A. H. What happens at the gap between knowledge and practice? Spaces of encounter and misencounter between environmental scientists and local people. *Ecology and Society*, 21 (2), 2016. doi: 10.5751/es-08409-210228.

UNDRR. *Global Assessment Report on Disaster Risk Reduction 2022: Our World at Risk: Transforming Governance for a Resilient Future*. United Nations, May 2022a. doi: 10.18356/9789210015059.

UNDRR. Prospects and challenges of transdisciplinary research approaches for managing and communicating climate-related risks. In *United Nations Office for Disaster Risk Reduction (UNDRR)*. Geneva, Switzerland, 2022b.

UNESCO. Open Science, 2022. https://www.unesco.org/en/natural-sciences/open-science.

Vienni Baptista, B., Fletcher, I., Maryl, M., Wciślik, P., Buchner, A., Lyall, C., Spaapen, J., and Pohl, C. Final report on understandings of interdisciplinary and transdisciplinary research and factors of success and failure (SHAPE-ID), 2020. https://

zenodo.org/record/3824839.

Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L. B., Bourne, P. E., Bouwman, J., Brookes, A. J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C. T., Finkers, R., Gonzalez-Beltran, A., Gray, A. J., Groth, P., Goble, C., Grethe, J. S., Heringa, J., 't Hoen, P. A., Hooft, R., Kuhn, T., Kok, R., Kok, J., Lusher, S. J., Martone, M. E., Mons, A., Packer, A. L., Persson, B., Rocca-Serra, P., Roos, M., van Schaik, R., Sansone, S.-A., Schultes, E., Sengstag, T., Slater, T., Strawn, G., Swertz, M. A., Thompson, M., van der Lei, J., van Mulligen, E., Velterop, J., Waagmeester, A., Wittenburg, P., Wolstencroft, K., Zhao, J., and Mons, B. The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data*, 3(1), Mar. 2016. doi: 10.1038/sdata.2016.18.