Workshop on

Advancing Volcanic Hazards in Early Warnings for All

(Geneva, Switzerland, 7-9 July 2025)

Consensual Summary

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This Consensual Summary has resulted from the contribution of all workshop participants (Appendix 1)

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Acknowledgments

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EXECUTIVE SUMMARY

The Advancing Volcanic Hazards in Early Warnings for All workshop, held at World Meteorological Organization (WMO) Headquarters in Geneva (7–9 July 2025) alongside the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) Scientific Assembly, brought together more than 100 experts from volcano observatories, United Nations (UN) agencies, International Organizations (IO), regional disaster risk management authorities, and civil society. Its goal was to strengthen the integration of volcanic hazards and risk into the UN Early Warnings for All (EW4All) initiative and related global early warning frameworks.

Volcanoes produce a wide range of primary hazards, including pyroclastic density currents (PDCs), lava, ashfall, and gases, as well as secondary phenomena such as lahars, tsunamis and aeolian remobilization of ash, affecting sectors from aviation and agriculture to health and infrastructure. Some of these risks are amplified by climate change, while monitoring and preparedness remain uneven, particularly in Small Island Developing States (SIDS) and least-developed countries (LDCs). Over 800 million people and more than 1,100 cities are located within 100 km of active volcanoes, placing populations and critical infrastructure at substantial risk. Globally, volcanic eruptions result in average annual economic losses of approximately USD 1 billion, with major events, such as the 2010 Eyjafjallajökull eruption (Iceland) and the 1991 eruption of Mount Pinatubo (Philippines) producing disruptions exceeding USD 5 billion.

Volcanic hazards, despite their global significance, have received less systematic attention than hydrometeorological hazards in the framework of national and international initiatives and policies. Limited investment in risk knowledge, fragile monitoring infrastructure, and uneven institutional mandates constrain observatory capacity. However, strong collaboration among scientists, authorities, and communities has proven highly effective in reducing risk. In this context, the World Organization of Volcano Observatories (WOVO), a global IAVCEI network, plays a key role by linking observatories worldwide to advance collaboration, data exchange, and shared best practices.

The workshop reviewed progress and challenges across the four EW4All pillars:

- Pillar 1 – Risk Knowledge: Advances include global databases (WOVOdat) and retrospective analyses; however, many volcanoes remain poorly characterized. Opportunities lie in AI-supported hazard and risk modelling, systematic data collection, and community co-production of actionable risk knowledge.
- Pillar 2 – Monitoring and Forecasting: Multi-parameter monitoring and integration with meteorological services are advancing, but can go much further, and monitoring gaps, equipment losses, and staff turnover limit coverage. Shared platforms, Earth Observation (EO), and regional collaboration can improve forecasting capacity.
- Pillar 3 – Warning Dissemination: Mobile connectivity, Common Alerting Protocol (CAP) standard, and layered communication systems enable rapid outreach. Yet

one-third of the global population remains unreached, with trust deficits, fragmented mandates, and ignoring vulnerable groups undermining effectiveness.

- Pillar 4 – Preparedness and Response: Remains fragmented and variable. Although outcomes have improved in (for example) Ecuador, Philippines and St. Vincent, through pre-defined thresholds, anticipatory action protocols, and regular drills; there remain persistent challenges including resource gaps, legal ambiguities, and challenges in large-scale evacuations.

Key Recommendations

Participants identified priority actions for both the volcanology community and UN/IO partners:

- Strengthen disaster risk knowledge through systematic volcanic hazard and risk assessments, integration of probabilistic models/methodologies, and enhanced global databases.
- Expand monitoring of volcanoes with multi-parameter networks, Earth Observation (EO) data, Artificial Intelligence (AI), and equitable support for observatories in high-risk regions.
- Adopt inclusive, multi-channel warning dissemination for hazardous volcanic events (ideally by the mandated national authorities) through the implementation of Common Alerting Protocol (CAP) globally at Volcano Observatories, ensuring redundancy, and fostering trust through community engagement and scenario-based messaging.
- Integrate volcanic hazards into multi-hazard frameworks, aligning observatory expertise with meteorological, civil protection, and humanitarian actors.
- Promote anticipatory action and preparedness by embedding volcanic hazards into EWS protocols, supporting financing mechanisms, and documenting good practices.
- Advocate for volcanology representation at UN level to strengthen visibility, policy support, and funding within EW4All and Sendai Framework Target G.

Path Forward

The workshop fostered new collaborations across disciplines and institutions. Volcanology experts committed to supporting EW4All roadmaps, engaging in UN/IO communities of practice (e.g., CAP, AI, GDACS), and to strengthening IAVCEI's and WOVO's coordination role. EW4All pillar leads are encouraged to formally integrate volcanic hazards into their frameworks, including WMO hazard categories and national-level roadmaps.

By aligning scientific advances with global disaster risk management frameworks, the volcanology community and UN agencies can together ensure that volcanic hazards are no longer overlooked but are fully embedded within the multi-hazard early warning systems needed to safeguard lives and livelihoods worldwide.

1. Introduction

This report presents the outcomes of the workshop on *Advancing Volcanic Hazards in Early Warnings for All*, held in Geneva at the WMO Headquarters between 7–9 July 2025 in association with the 2025 Scientific Assembly of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) with the purpose of establishing a common understanding, identifying opportunities, and outlining a path forward to strengthen the integration of volcanic risk into global early warning systems (https://www.unige.ch/sciences/terre/CERG-C/international-conferences/EW4ALL).

This document is intended for a broad audience, including the international volcanology community, Volcano Observatories, national disaster risk reduction and disaster risk management focal points, regional and global leads of the EW4All pillars, and all stakeholders involved in disaster risk reduction and the implementation of early warning systems. Its primary objective is to present the current state of integration of volcanic hazards into early warning initiatives at global, regional, national, and local levels. The document also identifies key gaps, challenges, and opportunities, and provides prioritized recommendations for targeted actions to enhance the inclusion of volcanic risk in current and future early warning efforts.

Volcanoes produce multiple primary hazards (e.g., pyroclastic density currents - PDCs, lava flows, tephra fall, volcanic gases) and secondary hazards (e.g., debris avalanches, lahars, acid rain, volcanic smog, tsunamis, aeolian ash remobilization, drifting pumices) across a wide range of spatial and temporal scales, leading to impacts that span local, national, regional, and global levels. Volcanic eruptions can disrupt road, rail, aviation and marine transport, damage agriculture and critical infrastructure, affect population health, and in extreme cases, contribute to global food insecurity and climate anomalies. Some of these volcanic hazards are expected to worsen with climate change, due to their interaction with increasing rainfall intensity, glacier melting, sea-level rise, variations in tropopause levels, and shifting weather patterns. Concurrently, a warming climate may exacerbate volcanic risk by increasing the likelihood of eruptions in glaciated regions due to rapid ice melt, promoting secondary hazards such as lahars through rainfall and hydrological changes, and influencing atmospheric conditions that affect plume dispersal. These environmental changes, combined with heightened social vulnerability, such as food insecurity and strained and interdependent infrastructure, can significantly amplify the human and economic impacts of volcanic events.

Despite the severe risks they pose, volcanic hazards have received relatively less systematic attention in the development of early warning systems than hydrometeorological hazards. Operational coordination across borders remains limited, and there is wide disparity in the resourcing and mandate of volcano observatories globally. Some highly active volcanic regions are also among the most vulnerable and least equipped to provide timely warnings.

However, experience shows that with good scientific monitoring and strong collaboration between volcanologists, emergency managers, and local communities, volcanic impacts can be significantly mitigated.

Recognizing this gap, this workshop was convened to explore how volcanic hazards can be more effectively integrated into the Early Warnings for All (EW4All) initiative. Launched by the United Nations at COP27 in 2022, EW4All aims to ensure that everyone on Earth is protected by early warning systems by 2027. Coordinated by the United Nations Office for Disaster Risk Reduction (UNDRR), the World Meteorological Organization (WMO), the International Telecommunication Union (ITU) and the International Federation of Red Cross and Red Crescent Societies (IFRC), EW4All is structured around four interconnected pillars: (1) Disaster Risk Knowledge, (2) Detection, Observation, Monitoring, Analysis and Forecasting, (3) Warning Dissemination and Communication, and (4) Preparedness and Response. Initially focused on weather- and climate-related hazards, the initiative includes geological hazards such as volcanic eruptions, recognizing their severe and often transboundary impacts.

The need for integrated and impact-based approaches for volcanic hazards, aligned with the Sendai Framework and EW4All initiative, was already highlighted by a previous workshop that took place on 5 February 2023 following the IAVCEI Scientific Assembly in Rotorua, New Zealand (*Tupper and Leonard 2024: https://link.springer.com/article/10.1007/s00445-024-01715-x*). Through presentations, panels, and breakout discussions, participants developed a 'vision' and 'roadmap' (key ideas on 'how do we get there?', organised into themes and activities) for multi-hazard operations, emphasizing that aviation-specific arrangements can inform broader hazard management for diverse user groups. Suggestions for future work included integrated volcanic management operations, emerging best practices, and sustainable capacity-building measures, strengthening both aviation and non-aviation warning systems and advancing a globally coordinated approach to reduce risk from volcanic and related hazards.

Building on these important outcomes and 'roadmap', the *Advancing Volcanic Hazards in Early Warnings for All* workshop aimed to share methodologies, case studies, and experiences related to multi-hazard risk research and strategies in order to:

- Understand the impact of volcanoes – how to integrate the scientific leadership of IAVCEI and the knowledge of the volcano observatories into the EW4All programme.
- Identify and prioritize actions to be taken – develop a common understanding of ways to improve volcano early warnings, what is possible now and what is possible if people were better informed or financially assisted to enable action.

- Assess what information is needed – how can the science of monitoring volcanoes be improved to better inform early warnings - sharing methodologies, case studies, and experiences related to multi-hazard risk research and strategies.
- Understand who takes the action – identify the key actors for centralised disaster risk analysis, early warning systems, communication, preparedness and response and how this informs community-led action.

The workshop brought together more than 100 experts from volcano observatories, national and regional disaster risk reduction and management agencies, pillar leads and partners of EW4All, as well as scientists from the volcanology and early warning communities, and representatives from international organizations and civil society (**see Appendix 1**). Their discussions have shaped the key messages and recommendations captured in this report. The program (**Appendix 2**) included more than 20 invited talks aimed at presenting the research state of the art around the 4 EW4All pillars as well as the EW4All pillar lead perspectives. Case studies from different regions were also presented to report on local practices and their integration within global strategies. More than 40 posters were also presented to discuss various aspects of early warning systems worldwide. Finally, participants were divided into 8 breakout groups to discuss: 1) relationships, 2) in-country governance, 3) user needs, 4) best operational practices, 5) multi-hazard capacity building (Spanish speaking group - unpacking EW4Al national roadmaps of Ecuador and Guatemala), 6) multi-hazard capacity building, 7) Innovations, 8) International strategies. The work of these groups was supported by a facilitator and a rapporteur. The outcomes of the groups are reported in **Appendix 3 and Annex 1**.

The workshop provided participants with an opportunity to familiarize themselves with the EW4All initiative, including its key partners, implementation of roadmaps, and strategic products. It fostered a broader understanding of the collective progress made by the volcanological community, encouraging participants to look beyond individual research interests and recognize the value of coordinated, international and interdisciplinary efforts. A central outcome was the commitment to increased collaboration, both within the volcanological field and across sectors, including engagement with other scientific communities, UN agencies, international and regional organizations, and operational stakeholders. The discussions stimulated new ideas and partnerships, particularly aimed at bridging the gap between scientific research and practical implementation in early warning systems. Participants also benefited from a global perspective, enriched by the sharing of local best practices, highlighting the importance of context-specific approaches within a unified global framework.

2. Current state, gaps, challenges and opportunities in volcanology community

Plenary talks, case studies, posters and breakout sessions highlighted the current state, gaps, challenges and opportunities in the volcanology community as follows:

Current state: The global volcanology community has made significant strides in monitoring, early warning, and community preparedness, leveraging multi-parameter observational networks, remote sensing, AI-assisted modelling, and probabilistic hazard and risk mapping. Countries such as Vanuatu and Indonesia have implemented operational multi-hazard EWS with strong institutional coordination, real-time data integration, and multi-channel alert dissemination. Humanitarian organizations, including IFRC, demonstrate effective anticipatory action protocols and community engagement, while ITU highlights near-global mobile network coverage, enabling rapid alerting via cell broadcast and other technologies. Collaborative platforms like WOVOdat and EPOS (European Plate Observing System) provide frameworks for data sharing, and initiatives such as Volcano Ready (St. Vincent) exemplify community-centred preparedness.

Gaps: Despite progress, significant gaps persist. Many volcanoes remain minimally monitored, especially in resource-limited countries. Monitoring infrastructure suffers recurrent damage from climate and environmental hazards, while human resource constraints limit analytical and operational capacity. Global data sharing is uneven, with lack of central archives (e.g. VONA) with limited feedback contributing to the workload at observatories, and EO and advanced remote sensing remain underutilized. Trust and inclusivity in communication remain challenging; a third of the global population remains unreached by early warning systems. Legal ambiguities, fragmented governance, and inconsistent coordination often delay action, while marginalized populations frequently lack access to actionable alerts.

Challenges: Volcanic risk forecasting remains inherently uncertain, particularly for low-frequency, high-impact events. Sustaining engagement during quiescent periods is difficult, while multi-hazard interactions (e.g., rainfall, landslides, lahars) further complicate risk communication. A key gap lies in the limited integration of multi-hazard and impact-based warning systems, linking volcanic, meteorological, tsunami, and other hazard information with near real-time impact estimation. This challenge spans observatories, meteorological services, and agencies, and cuts across organizations such as WMO, IAVCEI, and IOC (Intergovernmental Oceanographic Commission) - UNESCO, underscoring the need for stronger interdisciplinary and inter-agency coordination. Island nations and geographically dispersed countries face additional logistical, resource, and communication barriers. Globally, uneven funding, staffing, and access to advanced monitoring and modelling tools continue to constrain observatory capability and long-term sustainability.

Opportunities: There is strong potential to leverage existing WMO networks, Common Alerting Protocol (CAP), regional data platforms, global multi-hazard awareness systems for the humanitarian aid community (GDACS), and AI-enabled tools for enhanced hazard detection, communication, and anticipatory action. Multi-channel, inclusive alert dissemination can improve public responsiveness, while coordinated efforts with humanitarian agencies can support early action. Co-development of scenario-based risk messaging and continuous community engagement can build trust and preparedness. Regional learning, real-case exercises, and global data standardization offer pathways to strengthen institutional resilience.

Current state, gaps, challenges and opportunities have also been analysed per pillar in order to facilitate the integration of volcanic hazards within the EW4All initiative.

Pillar 1 – Disaster Risk Knowledge

Disaster-risk knowledge remains the least developed and least funded pillar of EW4All, and volcanic risk is particularly under-represented. Yet, understanding volcanic hazards is essential to anticipate impacts, enable impact-based forecasts, and guide anticipatory action (e.g., by setting indexes and hazard thresholds). Volcanic processes are diverse, including gas emissions that can affect climate, ash plumes that disrupt aviation and infrastructure, volcanic mudflows/lahars highly destructive which can be triggered by rain, and pyroclastic flows and lavas that threaten communities with inundation. All of these hazards require robust vulnerability models and risk assessments to underpin preparedness. In addition, strategies to quantify uncertainties across all stages of the risk assessment process.

Case studies presented during the workshop illustrate both advances and persistent gaps. In the US, lahar-detection systems at Mount Rainier and school evacuation drills in Washington demonstrate integration of science into preparedness, though challenges include equipment maintenance and sustained staffing. In Iceland, a multi-hazard monitoring system combines seismic, hydrological, meteorological, GNSS, and infrasound data and supports responses to volcanic, climatic, and related cascading hazards, while stretching the capacity of this small country. In the DRC, the Goma Volcano Observatory faces immense difficulties in monitoring toxic, diffuse CO_2 emissions and damaging lava flows in a conflict zone with scarce resources. Forensic analyses from Tungurahua (Ecuador) and Cordón Caulle (Chile/Argentina) highlight how retrospective studies, trust-building with communities, and “vigía” networks improve long-term resilience and early warning effectiveness.

Gaps include limited global hazard assessments, lack of common methodologies, large uncertainties in eruption style and frequency, and insufficient integration of volcanic data into multi-hazard frameworks. There is no coordinating UN treaty agency for volcanic

hazards, making it more difficult to negotiate common standards, systems and scientific methodologies when compared to the world of meteorology. Challenges remain in bridging observatory knowledge with civil protection/humanitarian aid and meteorological services, sustaining trust during quiescent phases, and fostering equitable capacity across observatories. Opportunities lie in strengthening global databases (e.g., WOVOdat), applying AI and physics-based modelling, and expanding people-centred approaches to risk knowledge through partnerships with local communities.

Pillar 2 – Monitoring and Forecasting

Monitoring and forecasting capacity is growing, with strong case studies from Southeast Asia presented during the workshop. In the Philippines, integration of WOVOdat, multi-parameter monitoring (MultiGAS, CO_2 sensors, GPS baselines), and automated templates for VONA dissemination support timely alerts. Monthly drills with Tokyo VAAC and alignment of early warning systems with institutional missions show how forecasting can be embedded strategically. In Indonesia, CAP-based dissemination is already used for weather and is being expanded to multi-hazard contexts.

Nevertheless, gaps persist. Monitoring infrastructure is highly vulnerable to climate and hazard impacts, with repeated losses of costly equipment and staff exposure to dangerous environments. Human resource constraints, especially high turnover and limited technical staff, weaken continuity and institutional memory. Globally, capabilities remain uneven, with many volcanoes minimally monitored. Earth Observation (EO) and advanced modelling are underutilized due to access and resource constraints.

Opportunities include expanding the use of Artificial Intelligence (AI) for data analysis such as identification of deviation from background, and forecasting potential hazardous events. There is also a clear need and opportunity to better integrate geophysical forecasting with Pillar 1 risk models, enabling progress toward impact-based forecasting, which is increasingly recognized as best practice. Data sharing can be strengthened with shared platforms such as EPOS, by leveraging WMO networks (e.g., WMO Information System 2.0 (WIS2) and WMO Integrated Processing and Prediction System (WIPPS)) and linking to global multi hazard awareness systems for the international humanitarian aid community (GDACS). Regional cooperation has proven successful: the 2024 Ruang eruption in Indonesia demonstrated that effective community engagement and coordination with emergency managers enabled the evacuation of 825 residents despite limited seismic coverage. The challenge remains ensuring consistent investment, structured data-sharing protocols, and empowerment of observatories to contribute to and benefit from global systems.

Pillar 3 – Warning Dissemination and Communication

Our capacity to disseminate early warnings is expanding through both technological and humanitarian channels. IFRC demonstrated anticipatory action through "Early Action Protocols" (EAPs) in Ecuador, distributing livelihood kits and engaging communities directly. These formal plans pre-agreed actions and funding in advance of extreme weather or other hazards, based on forecast-based financing triggers. ITU reported that nearly the entire global population is now covered by broadband cellular networks that enable the use of cell broadcast and SMS. Multi-channel dissemination (including radio, television, mobile apps, and satellite systems) is increasingly recognized as essential for redundancy and inclusivity.

Good practices include the La Soufrière (St. Vincent) evacuation, which succeeded through layered communication and established governance (https://www.youtube.com/watch?v=YthCJEaGrKc), and observatory-driven communication systems such as those in Italy, New Zealand, and the Caribbean, where volcano observatories play a central role. Yet, despite technological reach, UNDRR reports that one-third of the world's population remains outside functional early warning systems. Even where systems exist, trust deficits, poorly tailored messages, and exclusion of vulnerable groups reduce warning effectiveness. Fragmented institutional mandates, as seen in the Whakaari/White Island (New Zealand) tragedy, create ambiguity in responsibility and delays in protective action.

Opportunities lie in leveraging mobile connectivity and CAP to standardize alerts globally, expanding inclusive frameworks (e.g., Volcano Ready, VIGIA), and building two-way engagement to maintain trust during quiescence. There is also significant opportunity to incorporate human-behaviour evidence from social science to optimize message content, structure, and delivery maximizing understanding and action in response to alerts. Volcanic hazard is particularly challenging due to relatively high frequency of false alarms (i.e. unrest not leading to eruption). This applies across all hazard warnings, including volcanoes. Emerging AI- and satellite-based tools can further help bridge last-mile challenges, but sustained community engagement, pre-event scenario planning, and dynamic hazard assessments remain critical.

Pillar 4 – Preparedness and Response Capabilities

Preparedness and response capacities are increasingly integrated within global humanitarian and civil protection frameworks through cluster coordination systems that align the efforts of multiple agencies and stakeholders to ensure coherent, integrated, and effective action in addressing specific risks or sectors. Examples from Ecuador and St. Vincent show how pre-defined EAPs can enable anticipatory response. National examples highlight strengths and gaps: Iceland has established regular exercises and revised hazard

maps for dense populations; the Philippines conducts monthly simulation drills; and Goma relies on local networks and sirens in contexts of limited resources and insecurity.

Despite progress, many volcano observatories lack resources for training, scenario planning, common alert and response protocols, and sustained exercises. Preparedness materials often require updating and dissemination, while legal ambiguity around decision-making hinders timely response. Small island states and conflict-affected regions face specific challenges, from large-scale evacuations under concurrent crises (e.g., COVID-19 in St. Vincent) to security risks limiting field monitoring in the DRC.

Volcano observatories are currently rarely directly involved in humanitarian response, but they play a crucial role in preparing stakeholders for likely eruption impacts and, after an event, in providing critical data, including ash and lahar thicknesses, concentrations of leachable toxic elements in the ash, and information on cascading secondary hazards. Opportunities include closer collaboration between volcano observatories and humanitarian actors (e.g., IFRC), application of anticipatory financing mechanisms, and incorporation of volcanic hazards into multi-hazard preparedness frameworks. Ensuring inclusivity, particularly for marginalized and vulnerable groups, will be key to strengthening resilience.

3. Prioritised recommendations for focused actions to be taken on the integration of volcanic hazards within current and future global, regional, national and local early warning initiatives

Breakout discussions identified a list of priority actions per topic: 1) relationships, 2) in-country governance, 3) user needs, 4) best operations practices, 5) multi-hazard capacity building (Spanish speaking group - unpacking EW4All national roadmaps of Ecuador and Guatemala), 6) multi-hazard capacity building (English speaking group), 7) innovations, and 8) international strategies. (see *Appendix 3* for report of breakout session discussions). Here below we have synthetized all listed actions (as outlined in Appendix 3) into 6 key recommendations for effective integration of volcanic hazards within EW4All and broader early warning initiatives:

1. **Strengthen Monitoring and Data Systems (Pillar 1, 2, 4):**
    a. Expand and maintain multi-parameter, high-resolution monitoring networks, integrating AI and EO technologies.
    b. Prioritize data collection for under-monitored volcanoes and systematically build disaster knowledge at local, national, and global levels.
    c. Support observatories through training, staffing, and resource provision, particularly in Small Island Developing States (SIDS) and least-developed countries (LDCs).

2. **Enhance Multi-Channel and Inclusive Volcanic Hazard Early Warning (Pillar 2, 3, 4):**
    a. Implement the CAP standard globally and ensure redundancy across SMS, cell broadcast, apps, radio, and satellite systems.
    b. Focus on two-way communication, scenario-based messaging, and pre-event engagement to increase trust and comprehension.
    c. Include marginalized groups and vulnerable populations in alert design and preparedness planning.
3. **Promote Institutional Coordination and Multi-Stakeholder Engagement (Pillar 2, 3, 4):**
    a. Foster collaboration among volcano observatories, meteorological services, emergency management authorities, UN-IO agencies, and NGOs.
    b. Integrate volcanic hazards into broader multi-hazard EWS strategies (EW4All, Sendai Framework Target G).
    c. Strengthen anticipatory action protocols, clearly defining triggers, thresholds, and response responsibilities.
4. **Leverage Emerging Technologies and Global Platforms (Pillar 1, 4):**
    a. Use AI, EO, and probabilistic modelling to enhance hazard and risk assessments, forecasting (including impact-based), and decision making support.
    b. Establish shared regional and global platforms for data processing, visualization, and dissemination.
    c. Encourage cross-learning and knowledge exchange through conferences, networks, and capacity-building programs.
5. **Support Community-Centred Preparedness and Risk Knowledge (Pillar 1, 3):**
    a. Engage local communities, including Indigenous populations, in co-producing risk knowledge and preparedness strategies.
    b. Develop and maintain pre-event communication, evacuation planning, and long-term resilience initiatives.
    c. Document and share lessons learned, case studies, and good practices to inform regional and global risk-reduction efforts.
6. **Advocate for UN-Level Volcanology Representation (Pillar 3, 4):**
    a. Strengthen funding, policy support, and recognition of volcanology expertise within UN and global disaster frameworks.
    b. Promote integration of volcanic hazards in international multi-hazard early warning policies and climate adaptation strategies.

Together, these actions can help bridge scientific advances, operational needs, and community resilience, ensuring that volcanic hazards are fully integrated within global, regional, national, and local early warning systems.

4. Path Forward

Building on the prioritized recommendations, the following path forward highlights complementary actions for both the volcanology community and the EW4All pillar leads. These actions emphasize partnership, shared responsibility, and coordinated effort to ensure that volcanic hazards and risk are systematically integrated into global, regional, national, and local EW systems.

4.1 Actions for the Volcanology Community and Observatories

- Present a consensual summary to the inter-pillar group to facilitate the integration of volcanic hazards within current and future early warning initiatives.
- Contribute to the implementation of EW4All, including the development and finalization of key products such as national roadmaps.
- Enhance the governance and coordination role of IAVCEI as the global scientific authority in volcanology, ensuring its leadership extends beyond individual research interests.
- Strengthen the governance and coordination role of the World Organization of Volcano Observatories (WOVO) under IAVCEI to improve the oversight, effectiveness, and societal impact of Volcano Observatories worldwide.
- Continue and deepen engagement between IAVCEI and UN-IO bodies (UNESCO, UNDRR, WMO, IFRC, ITU).
- Initiate dialogue of national volcanological communities with EW4All pillar regional offices and national focal points.
- Establish close collaboration between observatories, national meteorological services, and WMO Permanent Representatives.
- Participate in communities of practice and technical areas (e.g., cell broadcast, CAP, AI, GDACS).

4.2 Actions for EW4All Pillar Leads

- Involve the volcanology community and observatories in the rollout of EW4All at the national level, including the development of national roadmaps.
- Include volcanic hazards in the WMO categories of hazardous events.
- Integrate volcanic hazards beyond aviation ash into EW4All pillar priorities.
- Ensure early warning standards cover meteorological, geological, and other hazards, with coordinated engagement of the responsible organizations.
- Engage the volcanology community and observatories in relevant communities of practice and technical areas (e.g., cell broadcast, CAP, AI, GDACS).

4.3 Joint Call for Action

Strengthening the integration of volcanic hazards into early warning systems requires collective commitment. The volcanology community brings unique scientific expertise and operational experience, while EW4All provides a unifying global framework and multi-stakeholder platform. By working together, both communities can ensure that volcanic risk is not only recognized but systematically addressed, enhancing preparedness, protecting vulnerable populations, and advancing the global goal of making EW4All a reality by 2027.

APPENDICES:

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67. Stephany Julmy	IFRC
68. Fara Katiuscia	Climate Change and DRR consultant
69. Christopher Kilburn	University College London, UK
70. Hayato Komatsu	Japanese Meteorological Agency, Japan
71. Ulrich Kueppers	Ludwig-Maximilians-Universität (LMU) Munich, Germany

72. Jacob Landers	Met Office, UK
73. Jonathan Lemus	University of Geneva, Switzerland
74. Graham Leonard	GNS Science, New Zealand
75. Ian Lisk	WMO Commission for Weather, Climate, Hydrological, Marine, and Related Environmental Services and Applications (SERCOM)
76. John Makario Londoño	Colombia Geological Survey, Colombian
77. Sue Loughlin	British Geological Survey (BGS), UK
78. Fathia Lutfiananda	University of Edinburgh, UK
79. Blaise Mafuko Nyandwi	University of Goma, DRC
80. Domenico Mangione	Italian Civil Protection, Italy
81. Warner Marzocchi	University of Naples, Italy
82. Mario Mejia	Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología - INSIVUMEH, Guatemala
83. Roberto Merida	Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología - INSIVUMEH, Guatemala
84. Virginia Murray	WHO / UKHSA
85. Ailsa Katharine Naismith	Meteorology, Climatology, and Geophysical Agency of Indonesia (BMKG)
86. Fernanda Naranjo	IGEPN, Ecuador
87. Öcal Necmioğlu	UNESCO-IOC
88. Emma Nicholson	University of Waikato, New Zealand
89. Akira Nishijo	Japanese Meteorological Agency, Japan
90. John Junior Niroa	Vanuatu Meteorology and Geo-Hazards Department, Vanuatu
91. Sara Ogburn	USGS, USA
92. Nadia Ortega	IFRC
93. Soledad Osores	Argentina National Meteorological Service and Buenos Aires VAAC, Argentina
94. Michelle M. Parks	IMO, Iceland
95. Maria Paz Reyes Hardy	University of Geneva, Switzerland
96. Christopher Perez	Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) Weather and Flood Forecasting Center, Philippines
97. Jeremy Phillips	University of Bristol, UK
98. Elio Pittera	Centre d'annonce et de suivi de la situation (NEOC/MLZ)
99. Sylvain Ponserre	Independent
100. Heruningtyas Desi Purnamasari	Indonesian Center for Volcanology and Geologic Hazard Mitigation (CVGHM)
101. Agie Wandala Putra	Meteorology, Climatology, and Geophysical Agency of Indonesia (BMKG), Indonesia
102. Danilo Reitano	INGV, Italy
103. Maurizio Ripepe	University of Florence, Italy
104. Richard Robertson	UWI Seismic Research Centre, Eastern Caribbean

105. Joel Ruch	University of Geneva, Switzerland
106. Mario Salgado Galvez	UNDRR
107. Laura Sandri	INGV, Italy
108. Marzia SANTINI	European Commission, Joint Research Centre
109. Anja Schmidt	DLR, Germany
110. Riccardo Simionato	University of Geneva, Switzerland
111. Andrew Colin Spewzoka	UNDRR
112. Johan Stander	WMO
113. Bastian Steinke	University of Auckland, New Zealand
114. Benoit Taisne	Nanyang Technological University, Singapore
115. Yasuhisa Tajima	Nippon Koei CO, Japan
116. Eleanor Tennant	Nanyang Technological University, Singapore
117. Simon Thivet	University of Geneva, Switzerland
118. Carlos Uribe	UNESCO
119. Molly Urquhart	University College London, UK
120. Carmen Jaimes Viera	National Autonomous University of Mexico, Mexico
121. Muhammed Wafid	Indonesian Geological Agency, Ministry of Energy and Mineral Resources, Indonesia
122. Braden Walsh	CTBTO, USA
123. Christiana Widiwijyanti	Nanyang Technological University, Singapore
124. Carlyne Yu	UNDRR
125. Tianyuan Zhu	University of Bristol, UK

2. WORKSHOP PROGRAM

Please check also workshop website for:

- PDFs of oral presentations: https://www.unige.ch/sciences/terre/CERG-C/international-conferences/EW4ALL/program
- Abstracts and PDFs of posters: https://www.unige.ch/sciences/terre/CERG-C/international-conferences/EW4ALL/posters

7 July 2025 - Disaster Risk Knowledge

Talks (20 min + 10 min questions)
Chairs: Matt Hort (AM)/ Andrew Tupper (PM)
Rapporteurs: Mira Markova & Jake Lowenstern (AM)/Costanza Bonadonna & Lara Mani (PM)

08:00-08:30 Registration /welcome coffee

08:30-08:40: Welcome from President of IAVCEI - Costanza Bonadonna (UNIGE)

8:40-9:00: Welcome remarks from WMO Director of Services and UNDRR SRSG - Johan Stander (WMO), Kamal Kishore (UNDRR), and Head of Climate Risk and Early Warning Systems (CREWS) Secretariat - John Harding

09:00-09:30 Opportunities, challenges and gaps of EW4All (with a special focus on volcanic hazard) - Jonathan Stone (IFRC)

09:30-10:00 Volcanoes: a multi-hazard and multi-scale challenge (including climate forcing and impact) - Anja Schmidt (DLR), Sue Loughlin (BGS)

10:00-10:30 Disaster risk knowledge: UNDRR perspective - Loretta Hieber-Girardet (UNDRR)

10:30-11:00 Coffee break

11:00-11:30 Strategies for individual and multi hazard assessment: state-of-the-art and challenges - Laura Sandri (INGV), Daniel Bertin (SERNAGEOMIN)

11:30-12:00 Strategies for exposure, vulnerability and resilience assessment: state-of-the-art and challenges - Sebastien Biass (University of Geneva), Susanna Jenkins (NTU EOS, Singapore), Amy Donovan (University of Cambridge)

12:00-12:30 Strategies for volcanic risk assessment/Risk Ranking: state-of-the-art and challenges - Natalia Deligne (USGS), Julia Crummy (BGS), Costanza Bonadonna (University of Geneva)

12:30-13:30 Lunch

13:30-14:00 Case study 1 (risk assessment/stakeholder requirement): the example of US volcanoes - Jake Lowenstern (United States Geological Survey)

14:00-14:30 Case study 2 (risk assessment/stakeholder requirement): the example of Iceland - Sara Barsotti (Icelandic Meteorological Office)

14:30-15:00 Case study 3 (risk assessment/stakeholder requirement): the example of Goma - Charles Balagizi (Goma Volcano Observatory, DRC), Blaise Mafuko Nyandwi (University of Goma, DRC)

15:00-15:30 Coffee break

15:30-16:00 Case study 4 (forensic analysis of impact) - Lucia Dominguez (University of Geneva, Switzerland), Jeremy Phillips (University of Bristol, UK)

16:00-17:00 Breakout sessions

17:00-18:00 Poster session

8 July 2025 - Detection, observation, monitoring, analysis, and forecasting

Talks (20 min + 10 min questions)
Chairs: Costanza Bonadonna (AM)/ Jake Lowenstern (PM)
Rapporteurs: Jonathan Stone & Matt Hort (AM)/Path Joseph & Andrew Tupper (PM)

08:30-09:00 Arrival and coffee

09:00-09:30 Detection, observation, monitoring, analysis, and forecasting: WMO perspectives - Cyrille Honoré (WMO), Ian Lisk (UK-Met Office)

09:30-10:00 Volcano monitoring: a multi-hazard and multi-scale challenge - Nico Fournier (GNS - WOVO Chair), Jake Lowenstern (USGS), Laura Sandri (INGV), Sara Barsotti (IMO), Benoit Taisne (NTU EOS, Singapore)

10:00-10:30 State of volcanic eruption forecasting: needs, challenges and opportunities - Warner Marzocchi (INGV), Graham Leonard (GNS Science), Kyle Anderson (USGS)

10:30-11:00 Coffee break

11:00-11:30 State of volcanic hazard forecasting: needs, challenges and opportunities - Mattia de Michieli Vitturi (INGV, Italy), Soledad Osores (Servicio Meteorológico Nacional, Argentina), Öcal Necmioğlu (UNESCO)

11:30-12:00 State of volcanic hazard data access and sharing (local to global): needs, challenges and opportunities - Danilo Reitano (INGV, EPOS), Benoit Taisne (NTU EOS, Singapore), Christina Widiwijayanti (NTU EOS, Singapore), Sara Ogburn (USGS)

12:00-12:30 Case study 1 (country centric capabilities and challenges): the example of Vanuatu - Levu Antfalo Boaz (Vanuatu Meteorology and Geo-Hazards Department), John Junior Niroa (Vanuatu Meteorology and Geo-Hazards Department)

12:30-13:30 Lunch

13:30-14:00 Case study 2 (country centric capabilities and challenges): the example of Philippines - Mariton Bornas (PHIVOLCS), Christopher Perez (PAGASA Weather and Flood Forecasting Center, Philippines)

14:00-14:30 Case study 3 (country centric capabilities and challenges): the example of Indonesia - Agie Wandala Putra (Meteorology, Climatology, and Geophysical Agency of Indonesia - BMKG), Muhammed Wafid (Indonesian Geological Agency, Ministry of Energy and Mineral Resources), Heruningtyas Desi Purnamasari (Indonesian Center for Volcanology and Geologic Hazard Mitigation - CVGHM)

14:30-15:00 Coffee break

15:00-17:00 Breakout sessions

17:00-18:30 Poster session

18:30 Workshop Dinner

9 July 2025 - Warning dissemination and communication / Preparedness and response capabilities

Talks (20 min + 10 min questions)
Chairs: Luca Rossi & Jonathan Stone
Rapporteurs: Muhi Usamah & Sara Barsotti

8:30-09:00 Arrival and coffee

09:00-09:30 Preparedness and response capabilities: IFRC perspectives - Jonathan Stone (IFRC)

09:30-10:00 Warning dissemination & communication: needs, challenges, uncertainties and opportunities – ITU perspectives - Mira Markova (ITU)

10:00-10:30 State of pre-event risk communication: needs, challenges, uncertainties and opportunities – Carina Fearnley (University College London), Albrecht Beck (Prepared International - PPI)

10:30-11:00 Coffee break

11:00-11:30 Case Study 1 (Anticipatory actions): the example of St Vincent, West Indies - Pat Joseph (UWI Seismic Research Centre), Richard Robertson (UWI Seismic Research Centre)

11:30-12:00 Case Study 2 (Pre-event risk communication and behavioural change): the example of White Island, New Zealand - Nico Fournier (GNS)

12:00-12:30 Case Study 3 (Forecasting & warning communication): the example of Campi Flegrei, Italy - Mauro Di Vito (INGV-Naples), Luigi D'Angelo (Protezione Civile Italiana)

12:45-14:00 Lunch

14:00-14:30 Outcomes of the workshop (Organising Committee)

14:30 Workshop close

14:30-17:00 Write up of consensus summary of current state, gaps, challenges and opportunities in the integration of volcanic hazards within the EW4All initiative, with prioritised recommendations for focused actions to be taken (Organising and Scientific Committees)

3. ACRONYMS

Acronym	Expansion
AI	Artificial Intelligence
CAP	Common Alerting Protocol
CREWS	Climate Risk and Early Warning Systems
COP27	27th Conference of the Parties
EAPs	Early Action Protocols
EO	Earth Observation
EPOS	European Plate Observing System
EW4All	Early Warnings for All Initiative
EWS	Early Warning System
GDACS	Global Disaster Alert and Coordination System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IAVCEI	International Association of Volcanology and Chemistry of the Earth's Interior
ICAO	International Civil Aviation Organization
IFRC	International Federation of Red Cross and Red Crescent Societies
IO	International Organisations
IOC	Intergovernmental Oceanographic Commission
ITU	International Telecommunication Union
LDC	Least-Developed Countries
PDCs	Pyroclastic density currents
SIDS	Small Island Developing States
SMS	Short Message Service
UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction

Acronym	Expansion
UNESCO	United Nations Educational, Scientific and Cultural Organization
VO	Volcano Observatory
VONA	Volcano Observatory Notice for Aviation
WIPPS	WMO Integrated Processing and Prediction System
WIS2	WMO Information System 2.0
WMO	World Meteorological Organization
WOVO	World Organization of Volcano Observatories
WOVOdat	WOVO database