

Workshop on

Advancing Volcanic Hazards in

Early Warnings for All

(Geneva, Switzerland, 7-9 July 2025)

Annex 1

Summary report on breakout discussions

Introduction

For the breakout sessions, the workshop was divided into eight groups, with each group given a theme and a list of guide topics, and a total of three hours to explore the topics and come back with recommendations. The list of themes was based on insights from a half-day workshop following the IAVCEI 2023 Scientific Assembly in Rotorua, New Zealand, with some adjustment for context. Each group had an appointed facilitator and rapporteur, who collaborated to prepare summary notes. Those notes have been edited to prepare this summary.

Group One: Relationships

The Relationships group were asked to focus on:

- Understanding the main actors (in-country and cross-border)
- Inter-agency relationships (in-country and cross-border)
- Inter-disciplinary relationships
- Examples of good structural approaches

State of play:

- Across the world there is a great variety of approaches, contexts and levels of formality in EWS and different levels of local agency within organisations.
- Trust and personal connections are a common theme that underlies the successful implementation of early warnings.
- Prescriptive approaches are unlikely to be successful as every context is different.

Recommendations:

- Avoid prescriptive mandates and protocols and allow for local ownership, empowerment and implementation (high priority).
- Clear procedures and protocols with well-defined roles across agencies and with communities will support successful implementation of EW4A and crisis response in general (high priority).
- Appreciate the importance of trust and the time it takes to build and maintain across people, agencies and communities. Trust underpins successful implementation of EW4A (high priority).
- A perfect message will fail if it's not understandable. Awareness building, education and focus on last mile linkages are critical for warning turning into action.

Implementation:

- Respect the time it takes to develop effective systems and include testing before a crisis to ensure clarity of message and clear delineation of roles and responsibilities. This is likely to be an iterative process.
- We support the exchange and review of ideas through interagency peer review processes and secondments to strengthen partnership and increase empathy of the

role's counterparts play during an event. An outside solicited perspective, respectively provided, can be used to improve the effectiveness of developed protocols. We encourage inclusion of views from fellow VOs, Civil Protection entities and other relevant agencies in an invited peer review process.

- We acknowledge the considerable work the WMO has facilitated on other natural hazards and encourage the volcanology community to draw on these as appropriate when developing or improving their own systems.
- Any successful endeavour requires funding to support personnel and resources.

Group Two: Governance (in-country)

The Governance group were asked to focus on:

- Roles & responsibilities
- Funding
- Legislation
- Accountability
- Data sharing and decision making
- Mutually beneficial relationships
- Dealing with 'rogue' actors

State of Play:

- **Roles and responsibilities** are variable across place, administration level, clarity and level of documentation.
- **Funding and expertise vary** in terms of quality and quantity across different places and central vs. local locations.
- **Difference in language and interpretation** across governance documentation (or a lack of legislation and documentation) are amplified during times of crisis.
- There is multi-decadal disagreement on the **role of observatories**: role of volcano observatories being confined to the determination of condition/status based on scientific observation vs. this plus provision of scientifically sound recommendations or guidance for response?
- **Structured governance** of all aspects of the warning system across agencies is critical. However, these are often disconnected, and one agency may not adequately connect with other parts of leadership (ministries, departments), or an umbrella structure for coordination may be lacking
- There is an ongoing **challenge with ethics of support of lower income places** incorporating accountability, data sharing, mutual benefit and rogue actors. Overseas project-based support is common and may be endorsed at a governance level but can be detrimental, with visitors providing short-term instrumentation or funds then disappearing, or undermining the role and voice of the locals, who carry the responsibility and liability (while the visitors do not).

- The **WMO model of coordination focuses on setting indicators and evaluating, but in terms of consistent governance local observatories and volcanoes need substantially different solutions from one another.** This is critical and links to Recommendation #3.
- **Impacts are widespread** and affect different geographies and governance contexts. Volcanoes may not pose a local threat, but can still be a threat to aviation across governance jurisdictions.
- **When we look at other hazards and EWS, they are specific and well defined.** Volcanologists have monitoring and data. Expert interpretation and forecasting, however, are crucial for warnings. Some places have structured communication – bulletins, structured data communication, while others less so.
- **Protocols and thresholds are often lacking** – for decision-making, and handling of uncertainty. Fixing thresholds is variable, and variably present or applicable. Sometimes related decision-making is rigid and automatic, sometimes a guideline. Unlike other EWS that have clear thresholds (e.g. tsunami, cyclones) it is difficult to define thresholds for volcano EWS. The behaviour of the volcanoes can change significantly from unrest to eruptive activity, and be reflected by many different parameters in a non-proportional way.
- **A volcano with a dearth of historical knowledge or data is challenging** to set a decision-making governance threshold for. Setting a threshold for each parameter deemed significant may be difficult, and challenging to prescribe.
- **WOVO (and IAVCEI) are bottom-up organizations** (not high-level law making or influencing), because each country has different observatories that have different roles. Outside of ICAO there are rarely documents defining legal duties of volcano observatories, compromising the ability to force governments to have proportional funding for the observatories in tandem with the roles and responsibilities.
- **Lack of funding hinders our ability to do our duties.** What consequences are there when funding is not provided? We have aviation VONA obligations usually without funding. Sources and levels of funding vary very widely. **Volcano observatories need to have regular and adequate funding compatible to the role and responsibilities they were given.**
- **Some cross-governmental structures** such as the AHA Centre facilitate access to donor funding, but this can lead to some competition, and limit data sharing, especially problematic when there are cascading hazards.
- **The location of monitoring and civil protection legislation varies widely** across the world and is often within policy domains of other priorities – e.g. mining, civil protection, science – this leads to issues of funding prioritisation. There is also a growing legislative prioritization of climate change adaptation, which is de-emphasising volcanic hazards.
- **There are many volcanos that are quiescent and have a lack of historical data,** hampering the ability to manage their risk or inform monitoring and mitigation strategies.

Recommendations:

1. **HIGH - We highlight a substantial ethical problem related to support of lower income countries from abroad in terms of accountability, data sharing, benefit and rogue actors. We recommend a stronger, targeted protocol and process additional to the existing IAVCEI crisis protocol.** We recommend clear direction that international and local governance mechanisms both champion the primary role of the observatory at all times (including non-crisis) as the official voice. All data should be provided to them, not past them. The observatory is the authority in terms of directing any scientific activities of any visiting actor. This should note that the domestic responsible observatory is liable, and as such is the lead agency and not sidelined or superseded by the visitor (by nature having no liability). The new protocol should also highlight that long-term stable funding through the local observatory is more effective and sustainable – preferred – than project-based funding or equipment that comes and goes.
2. **IMPLEMENTATION: Enforcement needs to be at international and especially domestic governance level. Currently because of the provision of donor funds decision-makers may approve an international actor's involvement but without checks and balances and potentially to the detriment of the observatory.** Good practice could and should include a written MoU that follows the protocol, however compliance and commitment remain a challenge, thoughts include: An education campaign led by IAVCEI, and an IAVCEI bylaw. IAVCEI should provide templates for good practice agreements.
3. **HIGH - There should be an internationally mandated and domestically legislated obligation for all countries to monitor and fund active volcano monitoring, based on the potential impact, and need for expert advice. Including across national boundaries.** We need a mechanism to highlight the need for and deliver funding for volcano monitoring, especially also including those volcanoes that could generate low-probability but high-impact events and may not have historically erupted.
4. **IMPLEMENTATION We need to provide specifics around legislation, levels of funding, international borders and protocols & criteria. We should reach out to inter-governmental structures, recognising a need to mitigate poor outcomes like competition. It is important to share impact information for neighbouring countries, but a contribution may be needed. Recognising that levels and sources of funding vary, sufficient regular ongoing stable funding is required for monitoring to provide the basis for civil protection. Governments must provide appropriate funding and sustainability of that funding to do critical work. There needs to be an analysis completed by our community to define this and available pathways for global advocacy. Funding and legislation for geo-hazards should be separate and in its**

own high-profile legislative space, raising the level of importance to the same status as other climate-related impacts. SVOs should be supported to recover costs as defined under ICAO by WMO/IAVCEI and ICAO.

5. Multi-parametric decision-making criteria: **Ranges and thresholds for triggering decisions should be discussed and documented as guidance**, rather than hard rules or criteria. Thresholds should be defined based on the needs of the target population, stakeholders, and geographical scale (local, regional, community etc.).
6. **HIGH - Roles and responsibilities need to be underpinned by a clear broadly-endorsed international framework. Roles and responsibilities will vary, but we recommend that they are clear, documented and championed by all levels of governance - and exercised across observatories and civil protection especially.** This documentation must clarify the roles of national, regional/provincial, and local actors. This will help with clarity around ethics when civil protection agencies are approached by national and international actors. **The approach should promote impact-based warnings, risk communication and decision-making in the receiving environment in terms of proactive risk tolerance/acceptance.** The international framework for roles and responsibilities needs to be flexible and able to be tailored to location.
7. **IMPLEMENTATION - Two-way communication, planning and exercising should be promoted and supported with international guidance and resources. This should include a component of 'peacetime' working with civil authorities, so that they understand information as it comes in, to prepare for real-time crises.** An additional important goal is to build trust and relationships. Rapid judgements are made during eruptions, so a clear two-way communication mechanism should be introduced and regularly exercised. The exact nature of planning and communication is dependent on activity as it evolves over a temporal scale and is very situational – resources can't be too prescriptive, but rather need to be flexible. **IAVCEI/WOVO or another emergent associated community-UN entity is needed, akin to WMO, to provide guidance, standards, community of practice and training, informed also by any other UNDRR approaches to non-weather hazards.**
8. **MEDIUM- Climate change adaptation and volcanoes:** Our community needs to be adaptable to current issues, highlighting the multi-hazard need for adaptation in both legislation and funding. **Volcano monitoring and science needs to be funded and included in a multi-hazard way so that adaptation decisions are not perverse.** We need to emphasise within climate change advocacy and decision-making structures that volcanoes are far reaching and not just local in scale. Critical infrastructure decisions come with risk reduction and adaptation requirements, and need to include volcano science and observatory expertise even for potentially active volcanoes with no recent eruption history documented.

9. LOWER (relative to the others) - Decision-making at the level of civil protection: **People who are mandated to make decisions should be closer to where the decision needs to be made.** Local impacts should be discussed, and evacuations should be informed at the local scale. **Decisions should be made possible in a timely manner at the appropriate level**, if this is at a national level, national leaders should utilize delegation to proxies rather than allowing lengthy delays.

Group Three: User Needs

The User Needs group were asked to focus on:

- Sectors (e.g., marine, aviation, health)
- Emergency Management
- Direct community engagement
- Assessing global ability to meet needs
- Setting up feedback loops (continuous improvement of services)

Current State of Play

- While there has been significant scientific progress in hazard detection, modelling, and monitoring, most volcanic early warnings remain reactive (based on real-time observations) rather than predictive
- Systems often lack integration into broader multi-hazard EWS frameworks.
- Alerts across countries differ in format and governance (e.g., Indonesia has a 4-level system, Philippines has 5 levels) but still face similar user challenges worldwide.
- Mixed effectiveness in warning dissemination and user response due to variable infrastructure, understanding of and trust in the alerts/alert levels.
- Institutional confusion sometimes arises from multiple sources issuing conflicting messages.

Challenges

- Trust gaps between scientists and communities, fuelled by past false alarms or misunderstood uncertainty.
- Insufficient local capacity both technical (e.g., instrumentation, trained staff) and social (e.g., resources to evacuate).
- Disparities in coverage - many volcanoes remain unmonitored or insufficiently monitored.
- Cultural and economic factors hinder evacuation despite warnings (e.g., reluctance to leave homes/livelihoods).
- Lack of tailored messaging for diverse sectors and users (e.g., tourism, agriculture, marine, public).

Opportunities

- Integrate volcanic warnings into trusted communication chains and multi-hazard systems.

- Enhance participatory processes to co-design warnings with communities.
- Use multiple channels of dissemination - mobile technology, social media, and local mechanisms like sirens for broader dissemination.
- Establish clear governance protocols for consistent, unified messaging.

Recommendations:

1. Improve capacities of observatories, ensuring they can provide user-centric early warning [MEDIUM PRIORITY]

Develop clear metrics and indicators to assess the capacities, effectiveness, reliability and reach of volcanic hazard EWS. To do so requires identification of current data availability and institutional roles through comprehensive assessments of existing data sources, human resources, technical capacities, and legal frameworks governing early warning responsibilities.

The following can help in this: 1) clarify roles and responsibilities across agencies to ensure coordinated and accountable early warning delivery; 2) enhance communications through training of scientists and observatory staff to translate complex scientific information into clear, actionable messages tailored for diverse audiences.

IMPLEMENTATION:

- Create platforms for sustained institutional collaboration, focusing on long-term North-South partnerships and investment in scientific and technical capacity in developing countries. In parallel, facilitate South-South collaboration by empowering strengthened regional centres to support peers through mutual learning, resource sharing, and locally grounded innovation.
- Establish a development fund contributing to job creation in observatories and investment in instrumentation.

2. Establish warning mechanisms that are appropriate culturally, technologically and financially for the community to promote risk-informed decision making [HIGH PRIORITY]

It is important to understand who the members of the communities using early warnings are, what they know about the risks, and what their trusted networks and means of communication are. This can help identify cultural, linguistic, and cognitive obstacles to understanding. Communication methods must be culturally and technologically suited to local realities, literacy levels, technological access, and economic constraints and should be co-developed with the communities.

IMPLEMENTATION:

- Launch targeted awareness and communication campaigns that explain the nature of volcanic risk and the scientific limitations of prediction.
- Engage schools and media for bringing the discussion within each family.

3. Make volcanic hazard EWS more actionable for all users and by all users [HIGH PRIORITY]

Promote the integration of volcanic early warning systems into national and sub-national legal and institutional frameworks. These frameworks should explicitly include representation from diverse stakeholder groups—such as local communities, scientific institutions, civil society, private sector, and indigenous organizations—to ensure their needs, knowledge, and capacities are formally recognized. Their inclusion in governance structures will support the co-design, implementation, and continuous improvement of user-tailored systems that are contextually relevant and widely trusted.

IMPLEMENTATION:

- Promote continuous learning through feedback mechanisms and conduct post-event evaluations to understand what made warnings effective (or not) across different groups so that it is possible to adapt warnings based on user feedback and lessons learned. This can help strengthen a preparedness culture. Regularly conduct education and awareness sessions to ensure communities know how and when to respond when alerts are issued.

Group Four: Best Operations Practices

The Best Operations Practices group were asked to focus on:

- Training, competencies
- Quality management
- Verification
- Monitoring requirements
- Continuous Improvement
- Emergency simulations

Current State of Play

VOs have a great variety of maturity levels across countries (and within countries) regarding capacities for monitoring and hazard assessment. From an international perspective, different countries have different rules for who is responsible for what. For example, volcano observatories are not appointed everywhere as official SVO (e.g., Goma). Some countries (e.g. Vanuatu) have VOs and Response Organization (Civil Protection) under the same ministry, others (e.g. Tonga) do not.

This disparity has complicated the development of standards for communication and data sharing across VOs. One overarching recommendation is to develop standards that promote data, information and knowledge sharing across entities responsible for issuing and utilising warnings and associated hazard forecasts. Overarching requirements to achieve this recommendation include:

- Perennial funding
- Role of WOVO in supporting link between VOs and academia
- Role of WMO to consolidate procedures to align with international standards (includes warnings, quality management, data standards)

Recommendations:

Pillar I

Recommendation: Encourage co-creation of hazard output products

Implementation: Engage the end-users to contribute / provide feedback / optimise hazard maps

Recommendation: Provide basic hazard assessment at all volcanoes

Implementation: Collaboration with academia to explore solutions at data-poor volcanoes (e.g., use of analogues, generic eruption scenarios)

Recommendation: Explore the use of impact-based approaches in providing different perspectives to warnings/monitoring

Implementation: Collaboration between VOs and academia (e.g., loss models)

Pillar II

Recommendation: Achieve minimum requirement needed for volcanic hazard management (e.g. operational monitoring, resources, competencies, information dissemination)

Implementation:

- Find balance between in situ and remote sensing techniques according to both volcano threat index and accessibility
- Regular staff training
- Can academia/WOVO temporarily help with missing resources?

Recommendation: Develop skills and standards for communication with stakeholders/public

Implementation: Role of IAVCEI/WOVO/WMO to support workshops to foster and standardise communication/standards, namely:

- Training on what already exists to reinforce these procedures (e.g., VONA, WOVOdat)
- Learn from other hazard communities for global coordination and mechanism (e.g. WMO framework, IOC tsunami – International Oceanographic Commission)
- Identify open minimum sets of key information about an ongoing activity, to the volcano community. (e.g., alert levels & associated recommendations)

Pillar III

Recommendation: Observatories should have a structured alert level system co-developed with partner agencies;

Implementation: Needs expert input

Recommendation: Standardised information across VOs

Implementation: Guidance from WOVO and WMO

Pillar IV

Recommendation: Develop collaborative relationships (either domestic or international) with i) other VOs/academia to make new techniques or methodologies available to ensure adequate monitoring and analysis of volcanic signals and ii) stakeholders (e.g., decision makers, emergency managers)

Implementation: Guidance from WOVO and WMO

Recommendation: Maintain a continuous engagement ☐ even for volcanoes with low eruption rates (e.g., Caribbean Wave)

Recommendation: Build a structured evidence-base of lessons learned during/after crises (successes as well as failures) to serve as a “white book” for other VOs

Implementation: Guidelines of best practices to record daily challenges during the crisis and redact it soon after the crisis. Could this be published? BV special paper?

Recommendation: Prepare for the unexpected ‘black swan’ events

Implementation: Plan training and simulations

Group Five: Multi-hazard Capacity Building (Spanish)

In this discussion, the Guatemala and Ecuador National Roadmap for the Early Warnings For All initiative were presented and unpacked, and key questions were discussed by the group:

Key questions:

Assessment / Quick View of Current Roadmaps

1. Do the national EW4All roadmaps explicitly include volcanic hazards in their scope and objectives?
2. Are volcano-specific early warning systems (EWS) clearly mapped within the multi-hazard framework?
3. Is there recognition of distinct early warning needs for volcanic risks (e.g., long onset, complex forecasting, diverse impacts)?
4. Are existing national volcanic risk management plans or institutions (e.g., INSIVUMEH in Guatemala, Instituto Geofísico in Ecuador) referenced and integrated?

Stakeholder Engagement and Governance

1. Have volcanological institutions, local governments in volcanic zones, civil protection, scientists, and affected communities been adequately consulted and engaged in the development of the implementation plans?
2. Are local populations living near volcanoes actively included in co-designing warning messages, evacuation protocols, and risk communication?
3. Is the role of indigenous knowledge systems and traditional risk reduction practices considered?
4. Are cross-sectoral coordination mechanisms (science, civil protection, infrastructure, communications, health, etc.) well established?

Recommendations for Improvement

1. How can volcanic hazards be more explicitly integrated into national multi-hazard early warning frameworks under EW4All?
2. How can countries develop volcano-specific annexes or operational plans that align with the broader EW4All roadmap?
3. How can national volcanic early warning task forces or technical working groups be established or strengthened within EW4All governance structures?
4. How can structured consultations be ensured with key volcanic stakeholders (e.g., observatories, scientists, civil protection, and at-risk communities) during the roadmap development and implementation?
5. How can regional collaboration on volcanic early warning systems be fostered, including peer learning, technical exchanges, and joint simulation exercises across Latin America?

Key Observations and recommendations:

1. Both roadmaps recognize volcanic hazards, but the operational integration remains partial and overly narrow. There are high-risk volcanoes (e.g., Sangay, Reventador (Ecuador), and Chiles-Cerro Negro) that are not fully considered in the roadmaps.
2. Volcanic hazards are described in general terms, without comprehensive differentiation of hazards such as lahars, pyroclastic flows, ashfall, or gas emissions and the temporal dynamics (precursor, eruptive, post-eruptive phases) of volcanic activity. This limits the capacity to tailor EWS protocols to different volcanic behaviours and timelines.
3. Both roadmaps do not specify whether local volcano observatories or municipalities in high-risk volcanic zones were consulted in the development process of the documents. Special attention should be given to high-volume tourism activities, particularly in places like Volcán de Fuego in Guatemala, including specific EWS protocols for visitors and guides.
4. Transboundary stakeholders to include a cross-border coordination component, especially for volcanoes like Chiles-Cerro Negro (Ecuador and Colombia) and Tacaná (Guatemala and Mexico).

Group Six: Multi-hazard Capacity Building (English)

This group was asked to focus on:

- Inter-pillar support (EW4All context)
- Equitable approach
- LDC and SIDS inclusion
- Cultural appropriateness
- Alert levels, hazard maps, uncertainties
- Risk-based decision making
- Social science engagement

1. What are the challenges and opportunities in building multi-hazard early warning systems (MHEWS)?

- Challenge: Governance
- Challenge: How to facilitate MHEWS
- Challenge: Marketing of volcanology to non-volcanologists
- Challenge: Funding
- Opportunities: EW4ALL, collaborations and synergies for MHEWS

In building MHEWS, our team has identified four primary challenges. First, the governance of an MHEWS will be complex, particularly if being facilitated across multiple institutions or agencies. Our team suggested there could be benefits to a single facilitator, including that there will be more likelihood of streamlined, consistent messaging to end users (as opposed to potential conflicting messages coming from various sources).

Second, we must decide how to facilitate the MHEWS. Will it be a single system addressing all desired hazards? Or multiple systems that each account for distinct hazards, with the added challenge of then determining how to manage these systems in one place or amongst multiple teams.

Third, our team strongly believes that volcanology has a marketing problem. We would like to see a change in how our field is marketed to stakeholders, as the world will be safer if there is more money to spend on reducing volcanic risk in line with Pillars 1-4, but our current arguments for funding support of volcanic work aren't working. In contrast, the risk from a large-scale meteor impact gathers much wider attention, funding, and designated mitigatory programs, despite having a significantly lower probability of impacting Earth and the global climate than do large volcanic eruptions.

Naturally, this leads to our last challenge: funding. Volcano observatories need financial resources to monitor, detect, and respond to unrest, eruptions, and related hazards, as well as to secure the personnel and equipment required to perform such efforts. These

challenges are vast, globally varied, and will be difficult to overcome, but we believe that opportunities exist within EW4ALL to address them. The potential for collaborations and synergies in developing MHEWS are addressed below in our key recommendations and implementation plans.

2. What key recommendations would the group like to make? What relative priorities should these have (low, medium, or high)?

- Do a gap/cost analysis to assess the current gap in volcano and volcanic hazard monitoring capabilities and the cost required to close this gap
- Improve marketing of volcanic hazards
- Get representation for volcanoes within EW4ALL/UN
- Secure financing for VOs, monitoring equipment, personnel
- ALL ARE HIGH PRIORITY

To address the challenges listed above, we have four key recommendations to improve the volcanology community's capacity to reduce risk and provide vital information to the WMO/UNDRR on a global scale.

First, a gap/cost analysis is needed to quantify the current shortcomings in monitoring capabilities at observatories around the world. We can look at Monday's US Case Study by Jake Lowenstern [VDAP] as an example that a given volcano needs a certain amount of some type of equipment to be considered sufficiently monitored but only has some lesser amount at present. For maximum reach and efficiency, we should convey this gap/cost in a one-line message to relevant stakeholders. For example: "If you spend this amount of money, you can get that result in return."

Our second recommendation is to improve the marketing of volcanic hazards. By reframing how we discuss the threat that volcanoes pose on a local to global scale, we may reach a broader audience and not only improve the goals outlined in Pillars 1 and 4, but also obtain more funding to address Pillars 2 and 3.

To achieve these, our third recommendation is to establish permanent representation for volcanoes within EW4ALL and/or the UN. In adding our collective voice to the policy table, both communities may benefit from shared knowledge, established partnerships ranging from the local to international level, and a broader capacity to create meaningful impact in reducing volcanic and climate risk.

Our final recommendation is to secure financing for volcano observatories, allowing them to hire trained personnel and purchase necessary equipment. Expertise and equipment are crucial in the detection of volcanic activity and subsequently the analysis of climate impacts from eruptions and their hazards. Our team believes that

these recommendations are interconnected and that if one is not done, the rest may fail.

3. **How could each recommendation be implemented?**

- **Gap/cost analysis:** WMO can get a collaborative researcher that could be based at WMO to learn how WMO do similar analyses and how can we translate this into volcanology. The researcher should build on the 2015 Global Assessment Report on disaster risk reduction (GAR15). They should identify and update gaps and determine the cost of addressing gaps. Funding sources could then look at addressing specific regions, or perhaps highly funding the top 10 need areas, or funding to a lesser extent the top 20.
- **Marketing:** When working outside of academia, we need to become less rigorous about volcanological terminology and focus instead on hazard impacts and the benefits of monitoring multi-hazards. For example, when we improve monitoring capabilities for flash floods, this is also useful in monitoring for lahars. We also need to consider the entry point for volcanoes in MHEWS in terms of EW4ALL pillars. For example, there are many SIDS in volcanic environments facing risk from both flash floods and landslides. If we market the need for these regions in broader hazard terminology that is accessible to policy makers and funding sources, we are more likely to create synergies between different hazard monitoring and generate capability for MHEWS. This ties into the previous implementation as well; we can pick a nation as a case study, do a small economic cost-benefit analysis and return on investment to present to EW4ALL and UNDRR. The takeaway is that if you invest this much money in this country, it could save this much in the long run. The messaging becomes straightforward and in terms that are accessible to relevant stakeholders.
- **Financing:** Work with different stakeholders to secure state funding. Engage with the UN to access previously untapped funding resources and improve regional awareness with the UN and other agencies. As a community, we should also work more on interactions with climate change to access money from climate funds. We can tap into philanthropic sources (e.g., Global Volcanic Risk Alliance) for needs within LEDCs and SIDs. We can also reach out to the insurance sector and request support for monitoring hazards and impacts, with benefits being returned through lower insurance payouts. We should work within the WMO system at a national level to support investment into volcano hazard management (as per national meteorological organizations).
- **Representation:** IAVCEI could take the lead on coordinating all above activities and to establish a representative within the WMO/UNDRR to work alongside IAVCEI and focus on volcanic hazards/risk and their contribution to multi-hazards within EW4ALL. This representative should work within the WMO/UNDRR because we believe it is crucial to understand the policy space for this representation to be most productive.

Group Seven: Innovations

This group was asked to discuss issues such as:

- Testing new approaches for joint projects
- Meeting marine requirements (pumice, ash, tsunami)
- Quantitative volcanic ash (incl. ashfall)
- Common Alerting Protocol
- Improved rainfall prediction for lahars
- Gas dispersion
- Radar projects
- Working with big tech
- Observations exchange
- WMO operations systems (e.g., WMO Integrated Processing and Prediction System (WIPPS))

The group was encouraged to have a wide-ranging discussion of the ‘bright ideas’ that can help improve warnings for volcanic hazards, including new technologies and adaptation of existing initiatives and approaches from across the sciences, including in operational meteorology and volcanology.

Day 1 – Ice breaker summary on the following question: what is the most important innovation - technical or experimental - that could help us close gaps in volcanic early warning systems?

The group identified several key innovations—both technical and organizational—that could significantly improve volcanic early warning systems. A recurring theme was the need to address the **onshore–offshore observational gap**, particularly through the use of pressure sensors and possible **small, inexpensive systems** tailored to specific volcanic hazards. There was a discussion on small-satellite missions with high temporal and spatial resolution sensors, which could improve detection of volcanic events. **Advances in telecommunications**, including satellite internet (e.g., Starlink), were highlighted as critical for ensuring reliable data transmission from remote volcanoes. Another major point was the **development of decision-making protocols** that clearly define what science can and cannot provide, especially under uncertainty. Such frameworks would facilitate trust and alignment between scientists and decision-makers, and clarify the timescales and consequences of different actions. Participants also emphasized the importance of **cross-border data sharing**, drawing comparisons with the meteorological community’s effective information exchange. This includes more structured collaborations between volcano observatories (VOs) and meteorological offices (MOs), supported by shared case studies. **Cost-effective, innovative sensors** (e.g., borehole pressure sensors from geothermal plants, distributed acoustic sensing) were discussed as valuable tools for early detection. Finally, concerns were raised over the **fragmentation in modelling efforts**, calling for streamlined, **community-supported approaches** to simulate ash dispersion and magma migration—areas currently reliant on a few individuals. Across all points, the need for better **communication and coordination protocols**

was emphasized as a cornerstone for both technological and organizational innovation in early warning.

Four main points from Group 7 discussion:

1. **Exploiting opportunistic data, methods and instruments** (e.g., fiber optic geodesy, pressure sensors, code, publications). Finding, or creating a venue, for observatories to show how non-traditional data were used successfully. Those stories could be the motivation leading to innovation in the type of instrumentation deployed on volcanoes.
2. **White-box AI solutions**, explainable with existing or new physical science. Consideration of AI use and application, needed or trendy? Example of innovation, out of the box thinking, training AI on non-events and identifying deviation from background. Moving toward interpretable and operationally useful, a.k.a. actionable, applications of machine learning for early warning.
3. **Transparent, calibrated language for hazard, risk management and communication**, improving consistency amongst the public, scientists, civil servants and any other stakeholders.
4. **Co-developed operational protocols for decision making and crisis coordination**. There was a strong agreement that agreed-upon protocols, jointly developed with all actors (observatories, meteorological agencies, civil protection, aviation, and local authorities), are essential to clarify responsibilities, improve timely action, and build trust.

Group Eight: International Strategies

The group was asked to consider issues such as:

- Working with IAVCEI Commissions
- World Organization of Volcano Observatories
- Enabling / promoting Volcano Observatory best practices
- UN relations (WMO, UNESCO, UENSCO-IOC UNDRR etc)
- UN level coordination
- Respecting country-level plans
- Considering regional needs and arrangements

The group was encouraged to have a wide-ranging discussion of the international strategies for improving volcanic warnings, including coordination at UN and IUGG/IAVCEI level.

Comments:

1. **Current situation:** WOVO is heavily dependent on volunteer time. We need to progress the issue of how we sustain international volcanology in a way that has not been done yet. How do we bring UN agencies together with IAVCEI's expertise and raise resources over the long-term to sustain operational volcanology? We need **advocacy for volcanology and VOs at a high level**.

The other point is **how we support the grassroots VOs to operate**. A risk is that we take an exclusively global approach when the reality is first and foremost a local problem. There are global consequences of volcanism but the bulk of the consequences are local. How do we practically support VOs to do their job? A problem is the **HUGE inequality in resourcing of VOs and therefore their capacity to engage**. The opportunity with EW4ALL is that it's a badge we can use with governments to say it's a UN-level programme. Perhaps the consolidation at the international level can help VOs be the authoritative voice for volcanoes as Met Offices already are for meteorology. **We still don't know which observatories are recognised as doing the ICAO job**. Three kinds: SVO – mandated by ICAO (possibly getting refunded); VOs with a clear state mandate and part of the CP response chain; volcano institutions that have monitoring activities but not a mandate (and then academia, which might help occasionally). A challenge is the need for information – the projects need resourcing.

Minimum requirements are still hugely varied worldwide. It's not just something top-down. What should be the minimum capability for VOs so that we can define it authoritatively, and governments have to provide it? If you can adopt the local volcano systems and then connect them at regional level, this will improve resources and sustainability.

2. Recommendations:

- **Partner with UNESCO**, which has [a strong DRR unit](#) and the interest, and then bring together key actors from other agencies. Partnering with UNESCO will enable us to reach out to the member states.
- Get an overview of who does what in each country so that we are ready when the process is done (**mapping exercise**). Provide the evidence to advocate for national-level funding in the meantime. We need assessment tool/process to monitor operational maturity of observatories and how it improves over time. GVM did an assessment in 2015 and IAVCEI could run a similar exercise and compare, to feed into the post-2030 agenda. Explore funding mechanisms for this work.
- Establish **good practices for monitoring organisations** at the minimum. WOVO has no mandate to encourage countries to do monitoring – we need the UN to mandate it. But the WMO has a mandate and still struggles to get governments to comply and has to do a lot of capacity building.
- Work with [the UNDRR national focal points](#) to bring forward the post-2030 agenda and advocate for more resources for volcano observatories.
- Try to get processes to access climate finance for volcanic hazards
- Develop a road map for improved volcano warnings

3. Implementation:

Partnership with UNESCO: IAVCEI executive committee and advisory board to discuss a strategy and then have a meeting with UNESCO, within the [DRR unit](#) to discuss the next steps and how to go about setting up the commission. IAVCEI takes the lead in taking this into UNESCO, but WMO can provide support (not least because of its responsibility for

aviation/ash). Develop a proposal in collaboration with the DRR unit and the other geological hazards. Eventually have an agreement with member states to mandate volcano monitoring agencies. Set up a multi-agency committee – ICAO, UNDRR, WMO and others and IAVCEI as IUGG member, with ToR to be discussed but including actions to systematically improve global monitoring for DRR and aviation. Should also include the International Maritime Organisation. Perhaps also WHO, UNEP, UNDP.

Discuss also with CREWS about how they might be able to support **the mapping exercise**. WOVO should be able to take needs to CREWS from the observatories. This will need to be a sound proposal and competitive. Make the point that we can use volcanoes as a pilot with the intention of bringing in the other geological hazards, if needed.

Encourage observatories to talk to their [national focal points for Sendai](#).

On issues of **data sharing**: [CODATA is a UNESCO/ISC programme](#) that is looking at open data policies in times of crisis and VM is on the exec committee.

Need also to **collaborate within the volcanological community to think about strategy** and work together more effectively. The volcano community is very bottom up.