Towards a Standardised Model of Volcano-Seismic Unrest & NRFi Project Overview

Benoit Taisne[1,2], Andika Bayu Aji [3], Christina Widiwijayanti[1], Nang Thin Zar Win[1], Tania Espinosa-Ortega[1], Julie De Groote[1,2], Susanna Jenkins[1,2]

WOVOdat

– in collaboration with WOVO observatories –

[1]Earth Observatory of Singapore, Nanyang Technological University, Singapore
[2]Asian School of the Environment, Nanyang Technological University, Singapore
[3]Merapi Volcano Observatory, BPPTKG, CVGHM, Yogyakarta

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Developing a new platform for assessing volcano hazard through analysis of globally acquired monitoring data

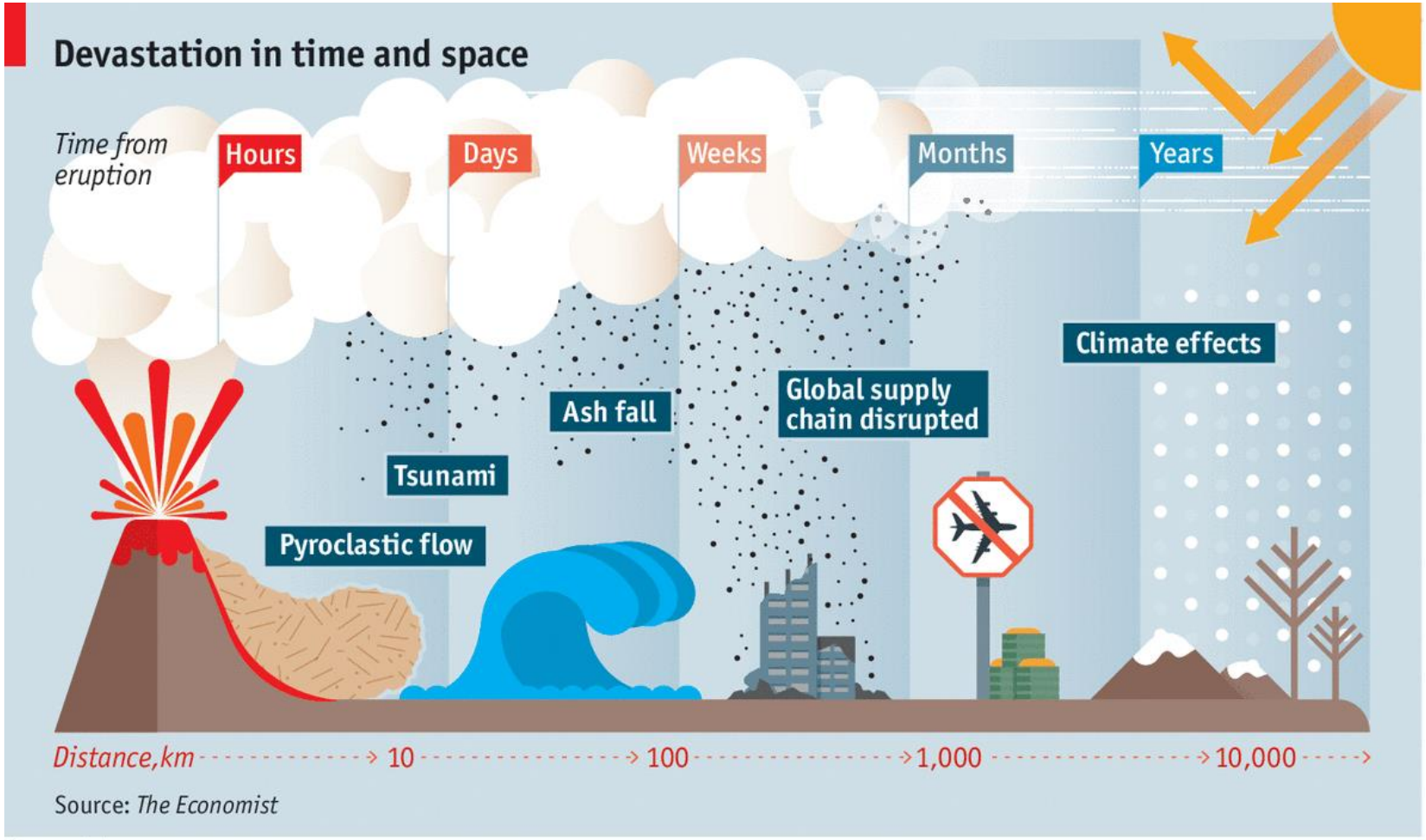
Benoît Taisne
Associate Professor
Asian School of the Environment

Principal Investigator
Earth Observatory of Singapore

***19th* November 2025**

Volcanic Impacts: a threat to be addressed

The earlier the alert the better the mitigation



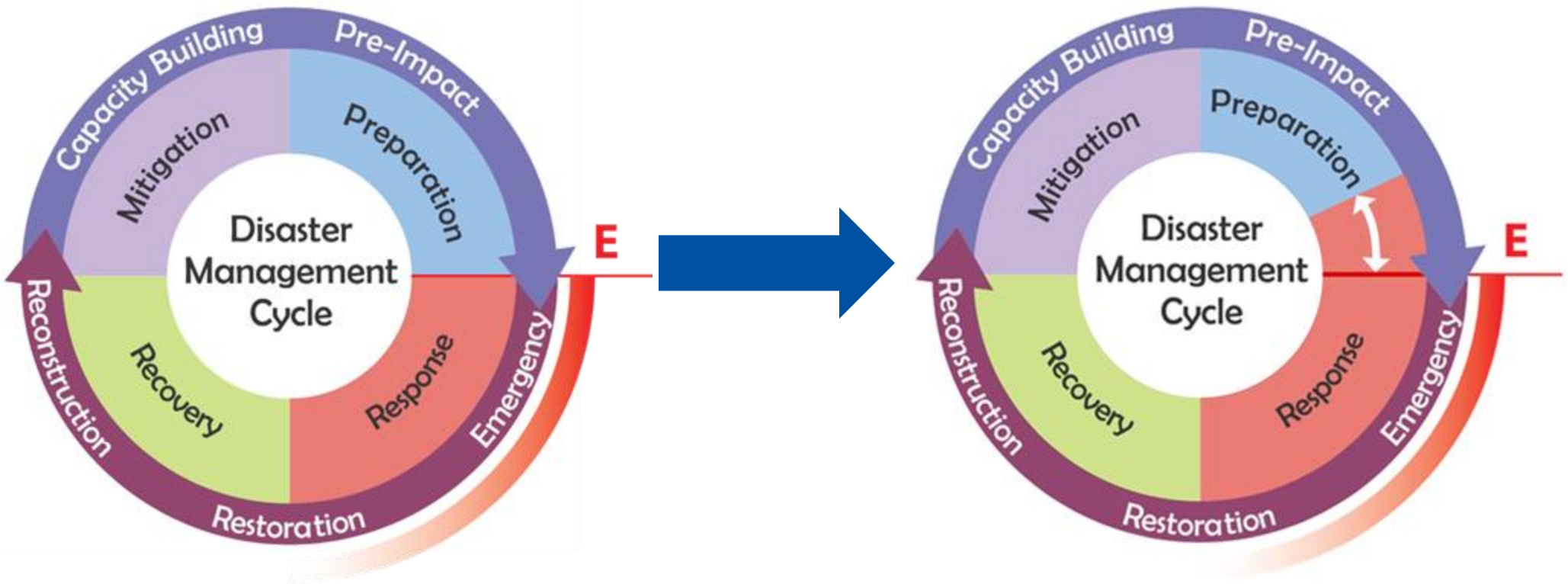
Economist.com

Source: Alphonso Chan Straits Times, 19 June 1991

Source: Dini Nurfiani/Earth Observatory of Singapore

Towards reducing disaster risk

Support decision makers and reduce impacts by increasing response time



Risk reduction approach

Risk reduction through proactive measures:

- More accurate forecasts
- Capacity building between agencies

Challenges in real-time situation

Failed management of a crisis:

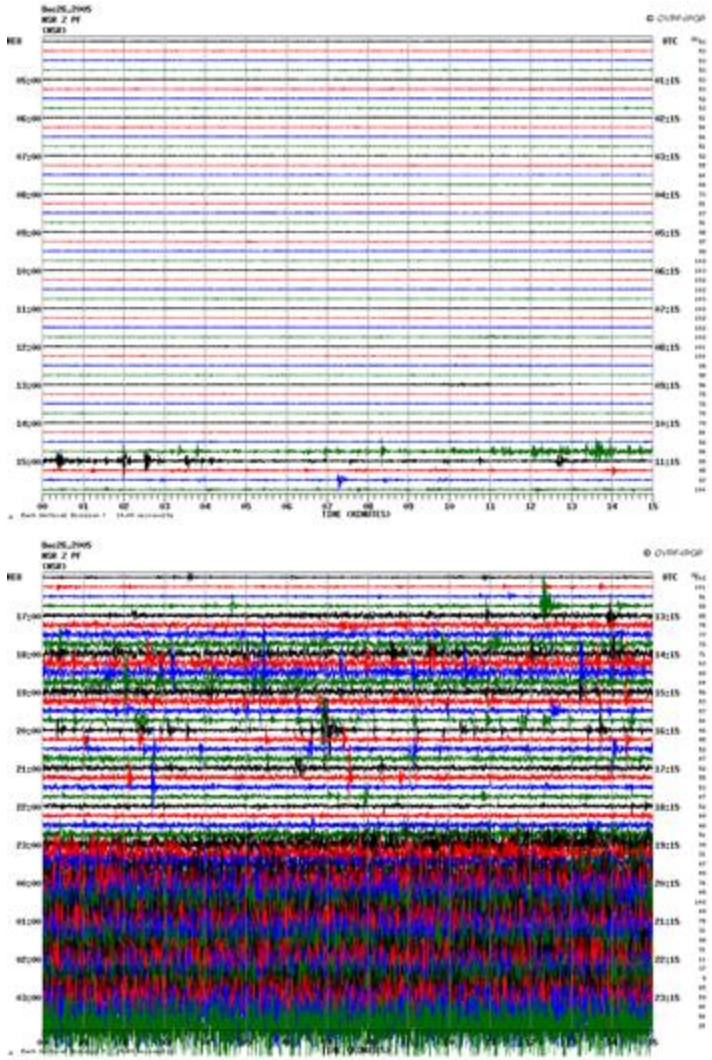
- Inability to identify changes in seismic data
- Inability to compare with similar volcanoes due to different naming convention
- Too many events to identify in real time

Proposed approach from lessons learned

- To standardise naming convention of volcano seismic events
- To improve forecasts by creating a dynamic framework for data processing and assimilation

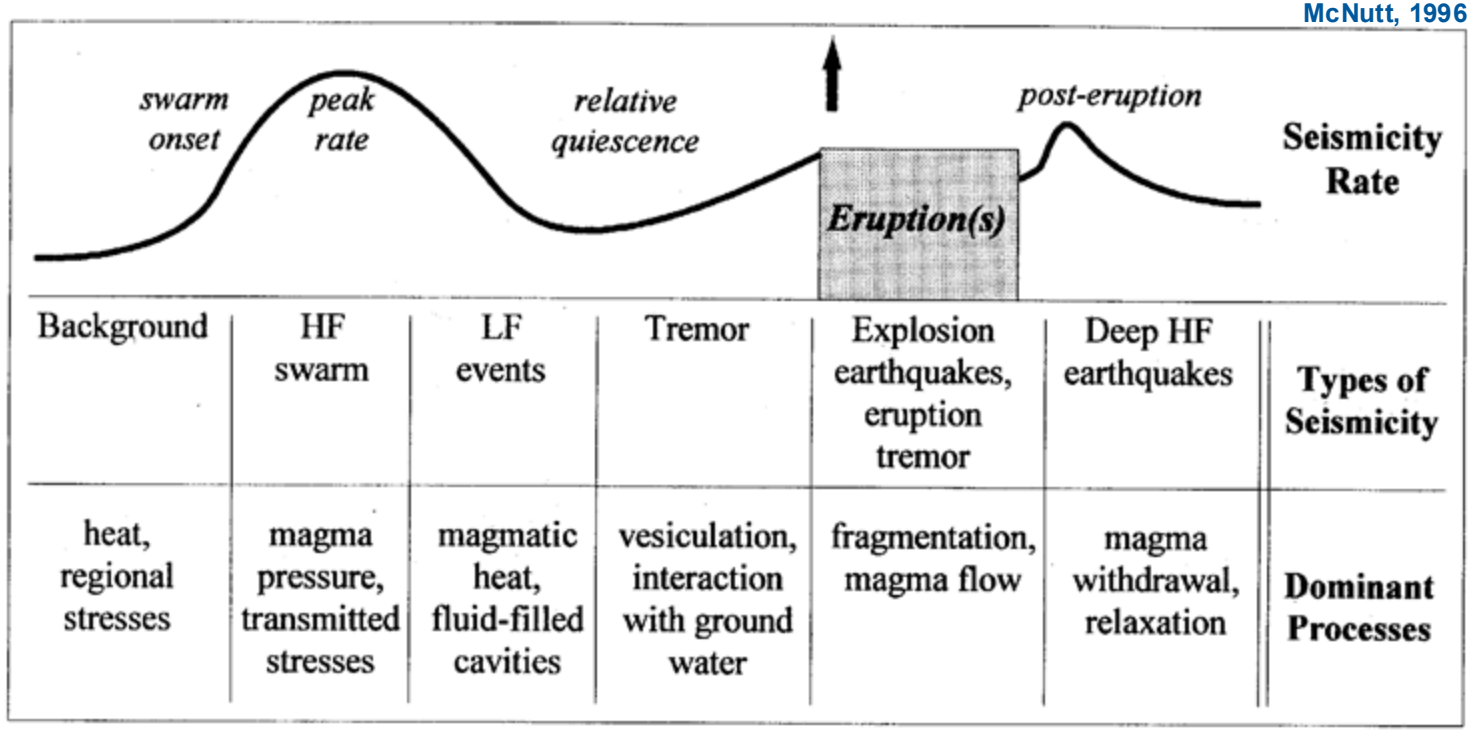
Identify and label changes in seismic monitoring

A standardized approach



Build-up seismicity before eruption (24 hours)

McNutt, 1996

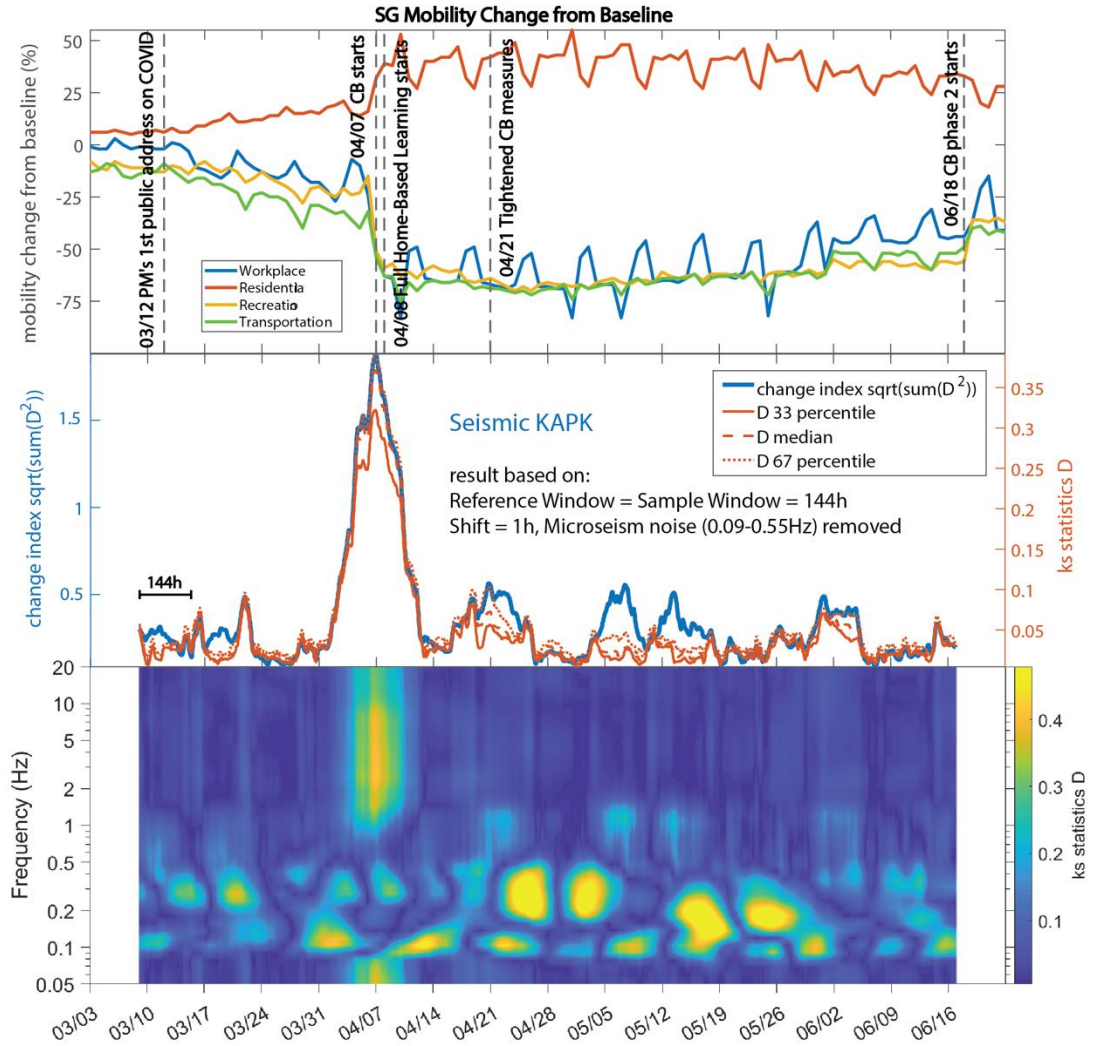


Problem: Identifying temporal evolution and changes of earthquake's type is **challenging in real-time** and not universal across volcanoes

Solution: **Standardized analysis** allowing inter-volcano comparison and refined assessment.

Going beyond what we have now

Developing new ways to look at continuous monitoring data



Example of data processing during pandemic in Singapore

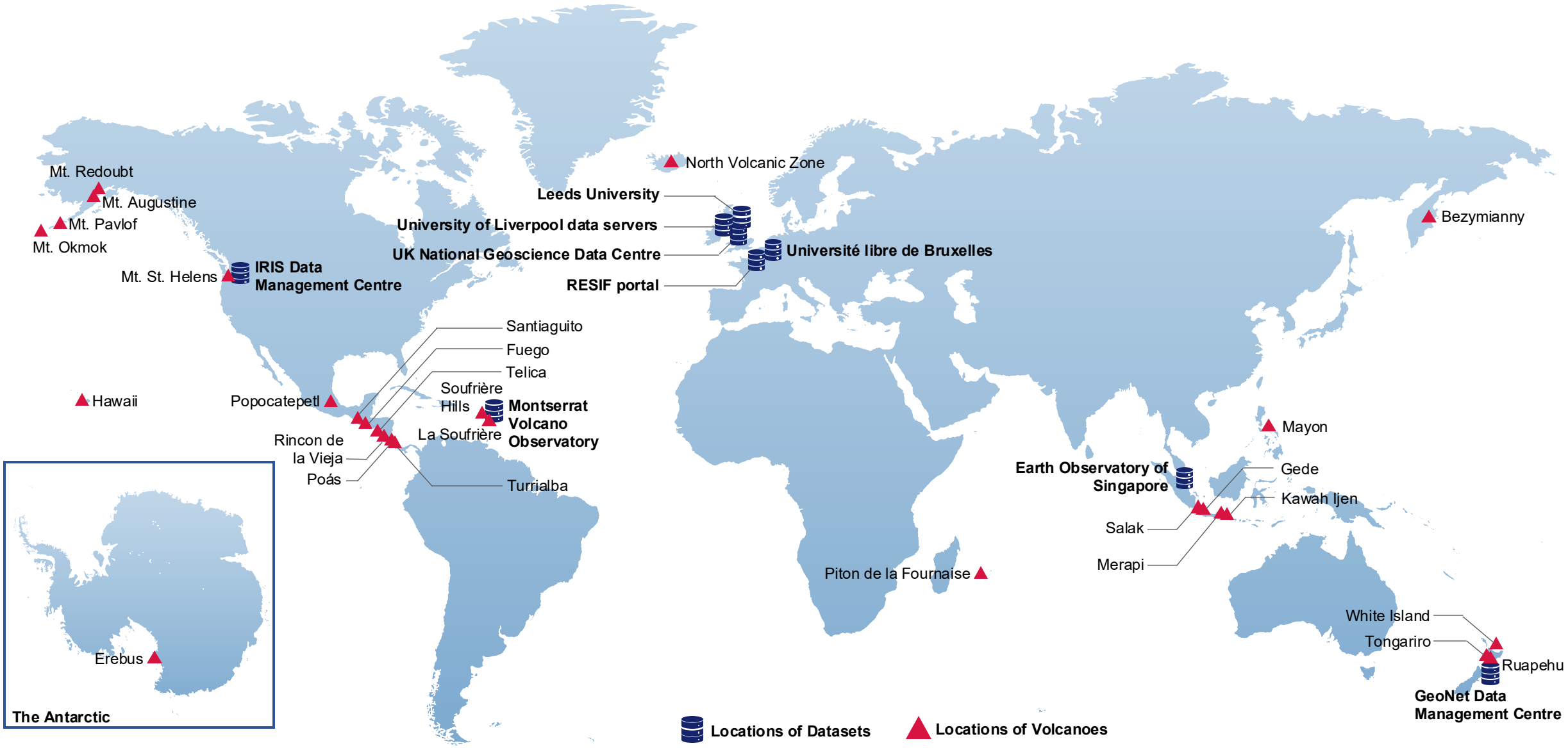
Problems:

- Long list of research papers on event classification
- Scientists generally only explore a single, isolated dataset
- Lack of centralised and freely available data catalogues

Solutions:

- **Linking changes in the seismic data to physical volcanic processes**
- **Universal probabilistic classification to take into account ambiguity between events**

Datasets available



Feasibility of the project

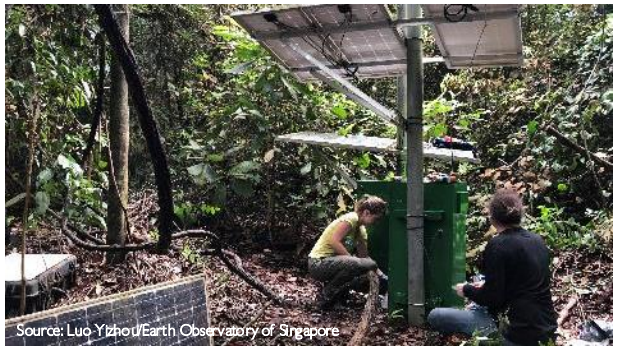
Right time, right place, right grant to create a step change in volcano monitoring

Large amount of continuous seismic data made publicly available (>100 Tb)

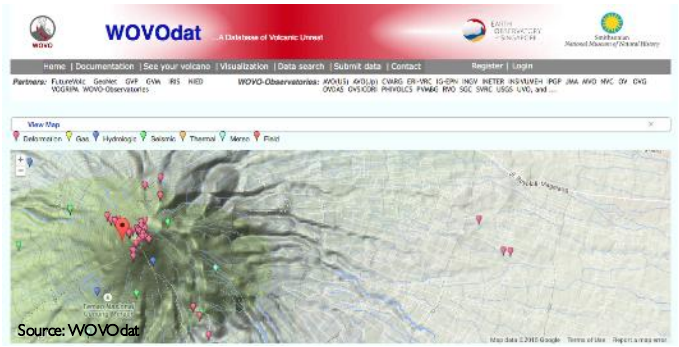
Already hosting internationally recognized database of volcanic unrest

Infrastructure in place at NTU/EOS to host such ambitious project

Possibility to maintain a team for 5 years to ensure success and impact

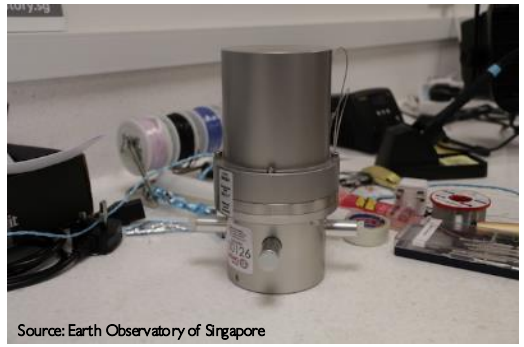


Source: Luo Yizhou/Earth Observatory of Singapore



Source: WOVOdat

Source: Earth Observatory of Singapore



Source: Earth Observatory of Singapore

Impact of the project

Create new knowledge in processing volcano monitoring data to improve forecasting

Benchmark, standardize and identify key features for classification

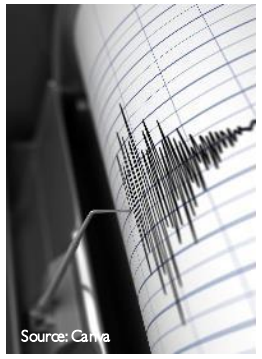
Produce the first global probabilistic volcanic earthquake classification

Identify common unrest patterns across different tectonic environments

Improve confidence in forecasting volcanic unrest and triggering mitigation plans


Source: Dini Nurfani/Earth Observatory of Singapore


Source: Benoit Taisne/Earth Observatory of Singapore


Source: Canva


Source: Canva

Source:

Impact and feasibility of the project

Dissemination of the results

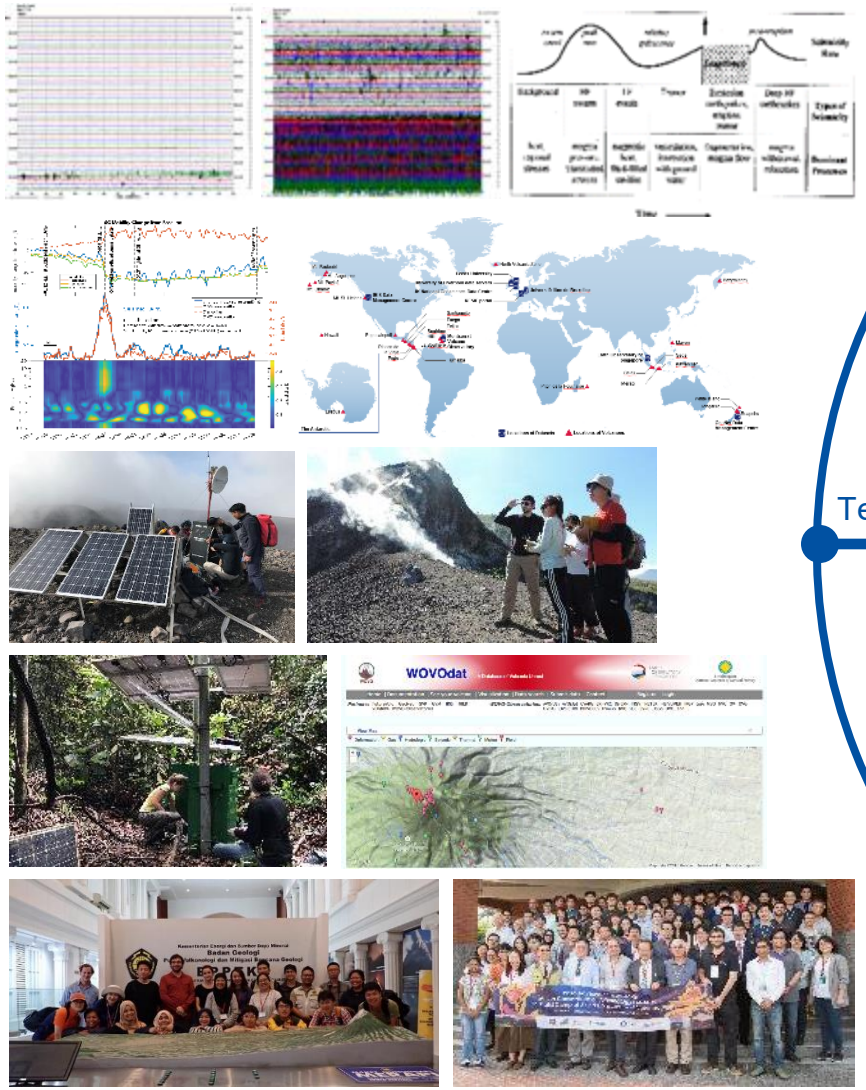
- New earthquake catalogue to be shared and made available through the existing WOVOdat platform
- Publications in peer-reviewed journals
- Experience in leading workshop and training volcano observatory staffs. Collaborators with similar experience will be involved throughout the project.

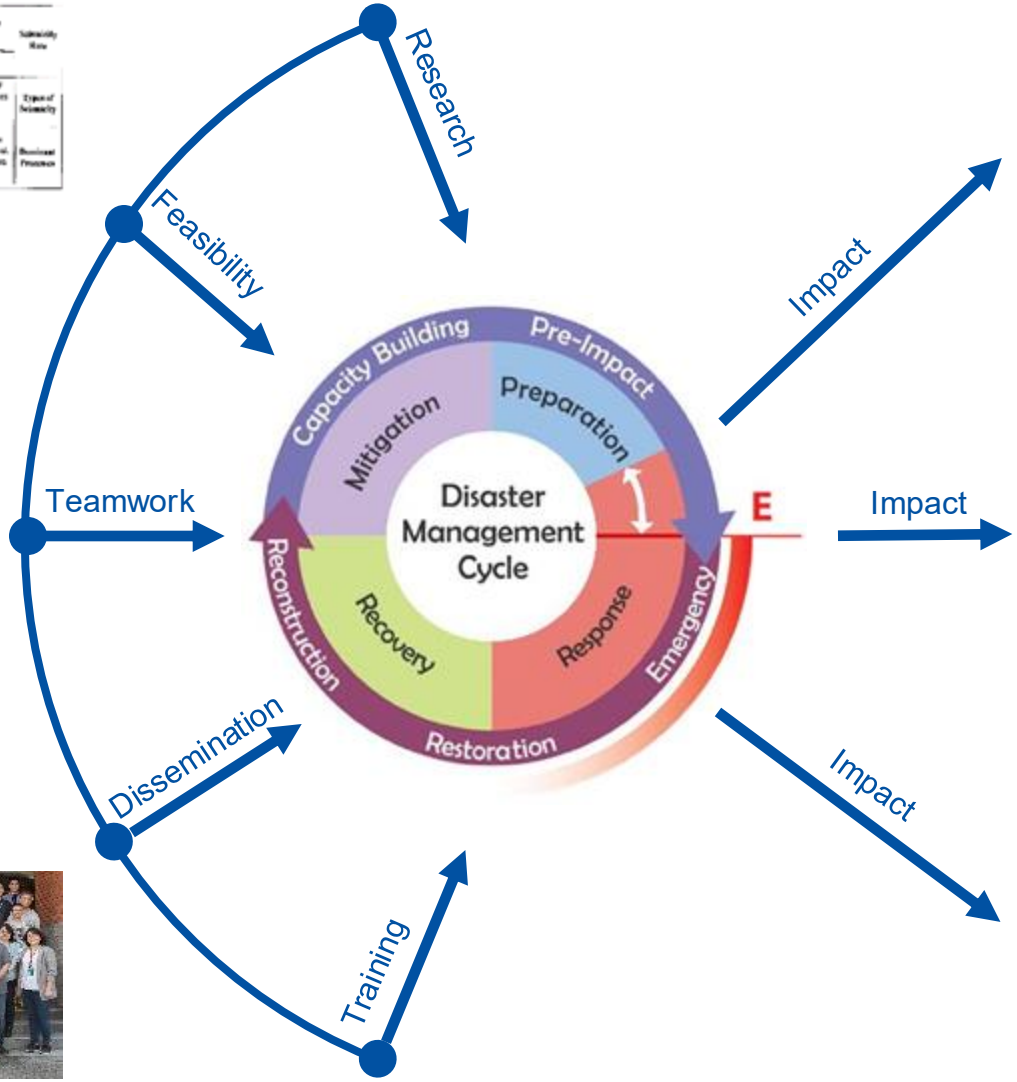
Taiwan, 2019

Indonesia, 2018

Impact and feasibility of the project

The right place at the right time





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Q&A

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What since then…

Q&A

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Advancing Homogenization and Integration of Historical Global Volcano Monitoring Data

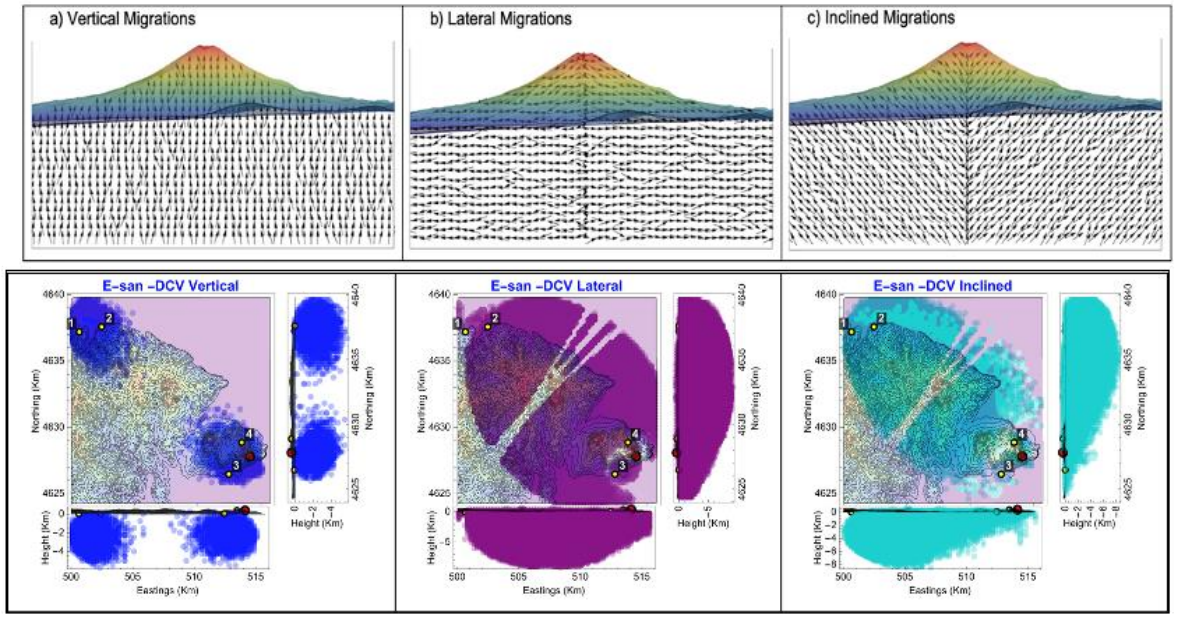
Why they are useful?

- **WOVOdat** providing a ready access into the most comprehensive and authoritative global volcano monitoring database, serve as a global resource for comparative analysis and pattern recognition, essential for understanding volcanic processes and improving eruption forecasts through robust statistical analysis.
- **GVMID** is useful in optimising network design to better anticipate volcanic eruptions, to improve the detection capability, enabling global analyses of monitoring capabilities and identifying gaps.

About GVMID
Widiwijayanti et al. (2024)

Assess seismic network potential

- **Detection Capability Volumne (DCV)** Volume under the volcano where the seismic network is capable to detect migrations, based on the seismic network location.



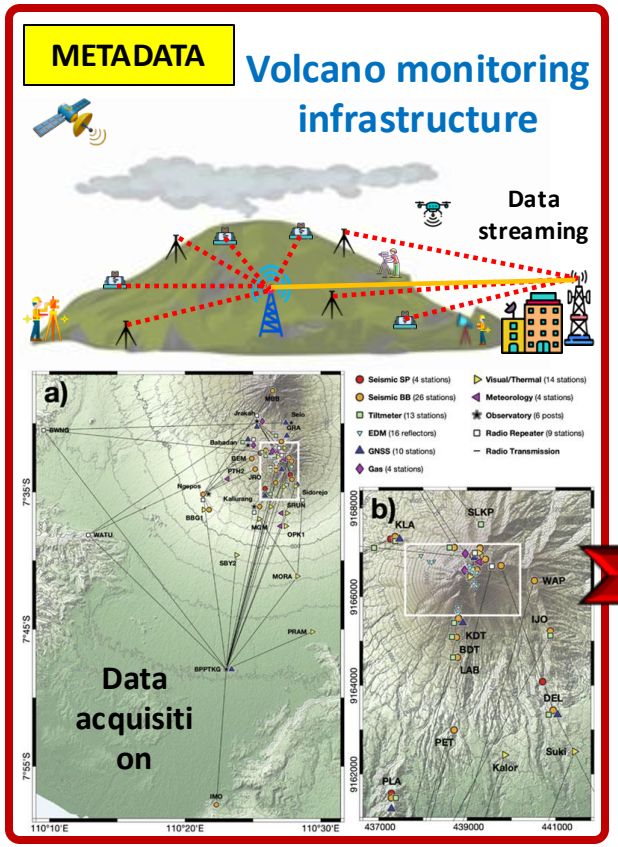
Espinosa-Ortega, T. & Taisne (2024).

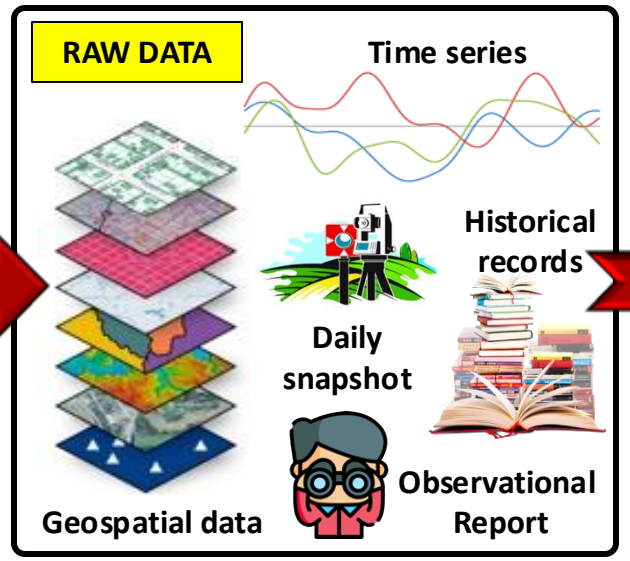
From data to decision-making:

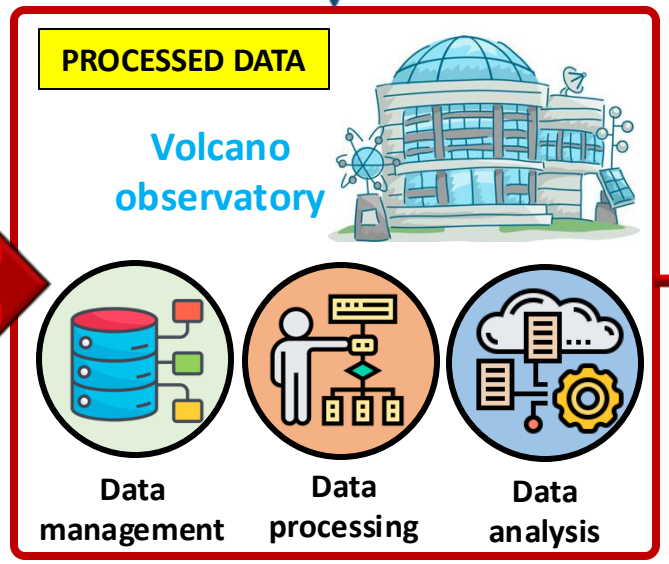
Volcano monitoring workflows and information systems

Volcano monitoring is an integrated system of hardware, software, networks, databases, personnel, and procedures.

Technological advances have increased the resource demands needed to handle growing data volume and the complexity of multi-parameter datasets from diverse sources and formats.







This requires efficient, real-time analysis for timely decision-making during crises, supported by automated processing and standardized data to ensure long-term continuity, improve statistical analysis, and enhance probabilistic forecasting.

SEISMIC DATA ANALYSIS WORKFLOW

OBJECTIVES:

⇒ to develop **automated techniques** for optimizing warning times before volcanic impacts

⇒ to create a **standardized** model of volcano-seismic unrest, using global volcano seismic waveform data

⇒ to develop **open-source tools** and training programs

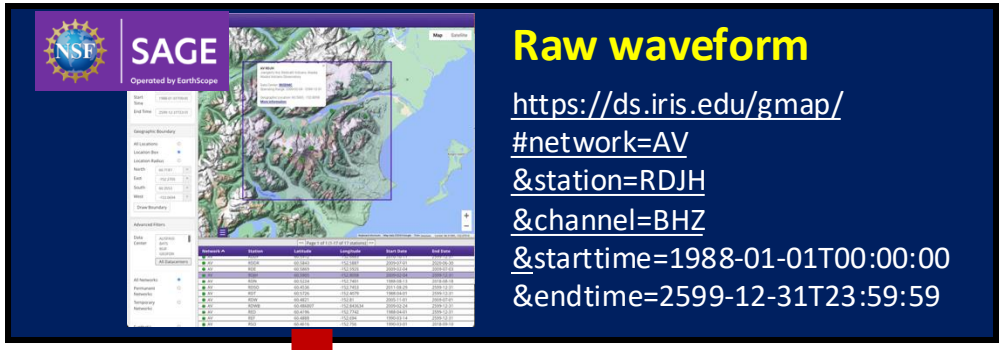
⇒ to contribute the outcomes to open repository **WOVOdat**.

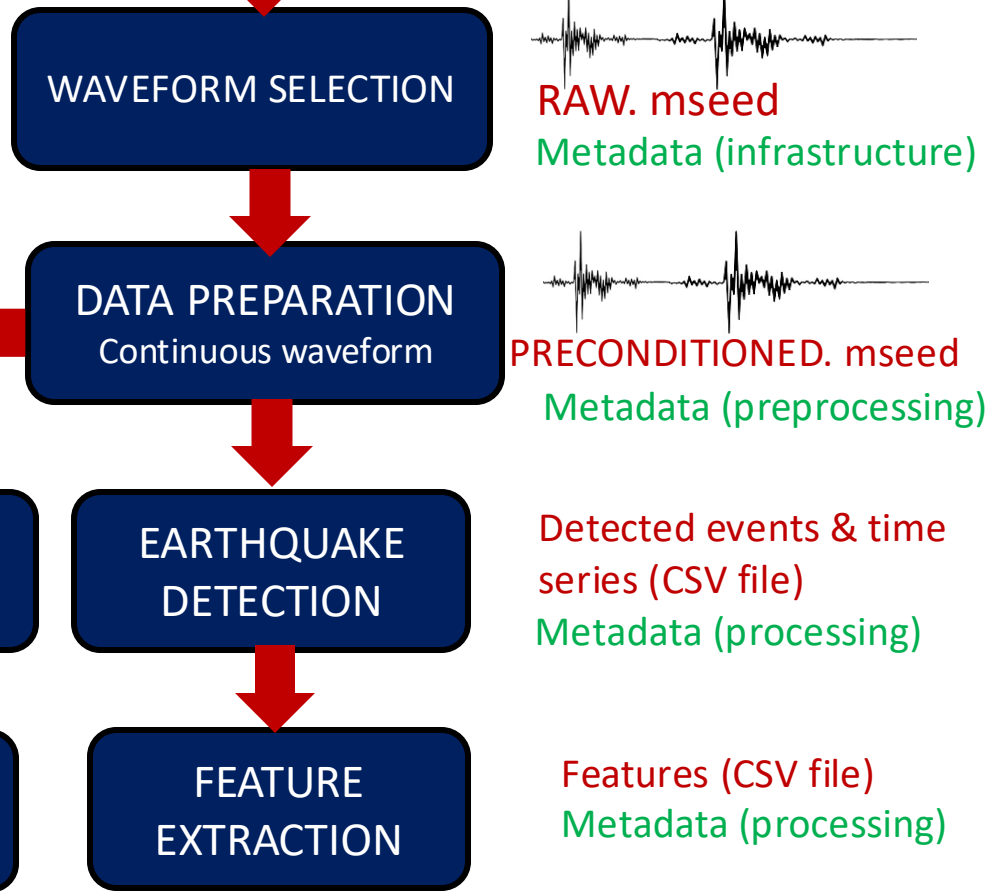
Obtaining Continuous Waveform Data requiring preconditioning:

- ❑ Gaps => fixed number, interpolation, average, folding.
- ❑ Pre-filled gaps
- ❑ Sampling rate
- ❑ Overlaps
- ❑ Spikes/big numbers/calibration pulses
- ❑ Start-time and End-time not match the metadata

Archiving & managing the datasets:

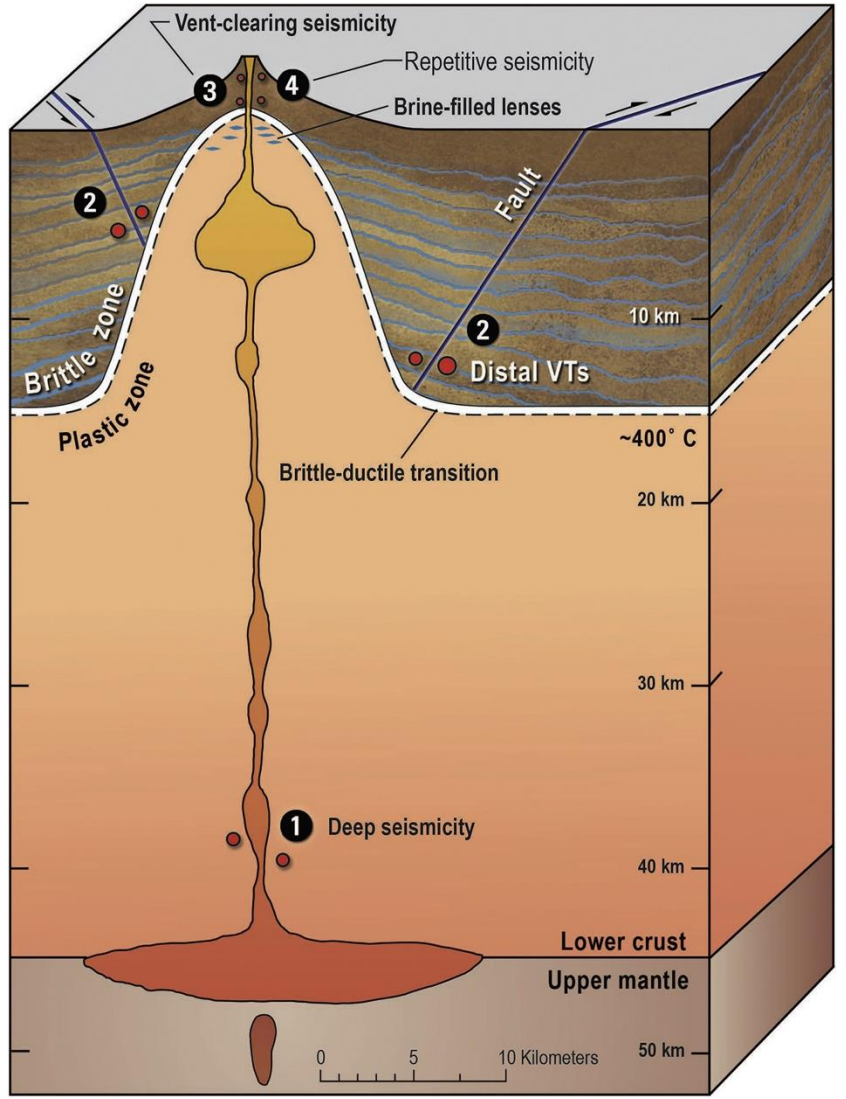
- Preconditioned (waveform) data
- Metadata
- Processed data: detected events & features, SSxM, RSxM, SARA, DSAR, SOM, Spectrogram, etc.
- Eruption/unrest phases





OBJECTIVES

- Develop **automated, standardized** volcano monitoring workflows for reliable, efficient data processing, especially during **crises to support** early warning and timely decisions.
- **Produce time-series outputs**, including event classifications, amplitude analyses (RSAM, SSAM), and **machine learning-based features**.
- **Identify** and **classify** seismic characteristics across all volcanic activity stages to improve pattern recognition and **eruption forecasting**.
- **Standardized data** to enable consistent, cross-volcano and temporal comparisons with past unrest, **strengthening probabilistic forecasting**.
- Leverage **public datasets**, international partnerships, and **open-source tools** to foster global collaboration and community capacity building.
- Contribute outcomes to **WOVOdat**, advancing **shared knowledge and open science**.



Process-based *geological model of pre-eruptive seismicity at dormant volcanoes showing four general stages and types of* ***seismicity observed prior to eruptions***

White and McCausland, 2019

EARTHQUAKE DETECTION

MOTIVATION:

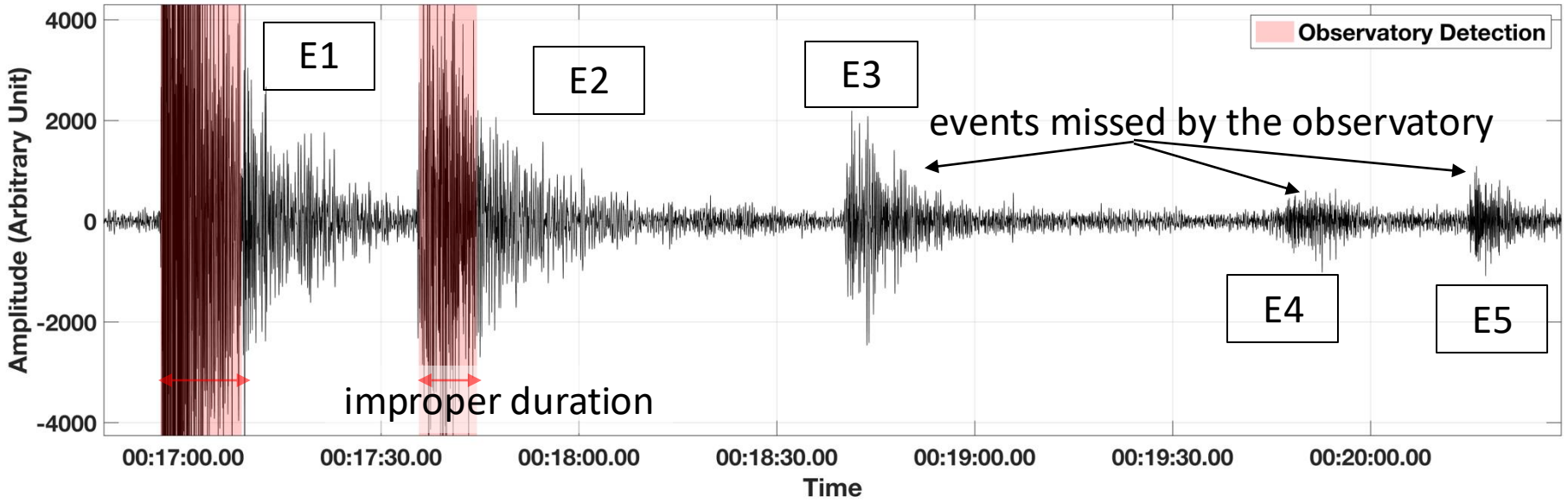
- Some **volcanic earthquakes** were **not identified** by volcano observers, and the coda waves of detected earthquakes were often **not fully captured**.
- As a result, the recorded earthquake **durations are shorter** than their true lengths.

OBJECTIVE:

- Identifying **more earthquakes**
- Obtaining **more proper durations** for the detected earthquakes:

a) **Not too short** so that we get almost all the earthquake's phases (P, S, and Coda waves)

b) **Not too long** so that the noise does not overshadow the signals of interest



Several visible earthquakes (E3, E4, and E5) were not identified by the observatory. Additionally, the coda waves of E1 and E2 were not fully captured.

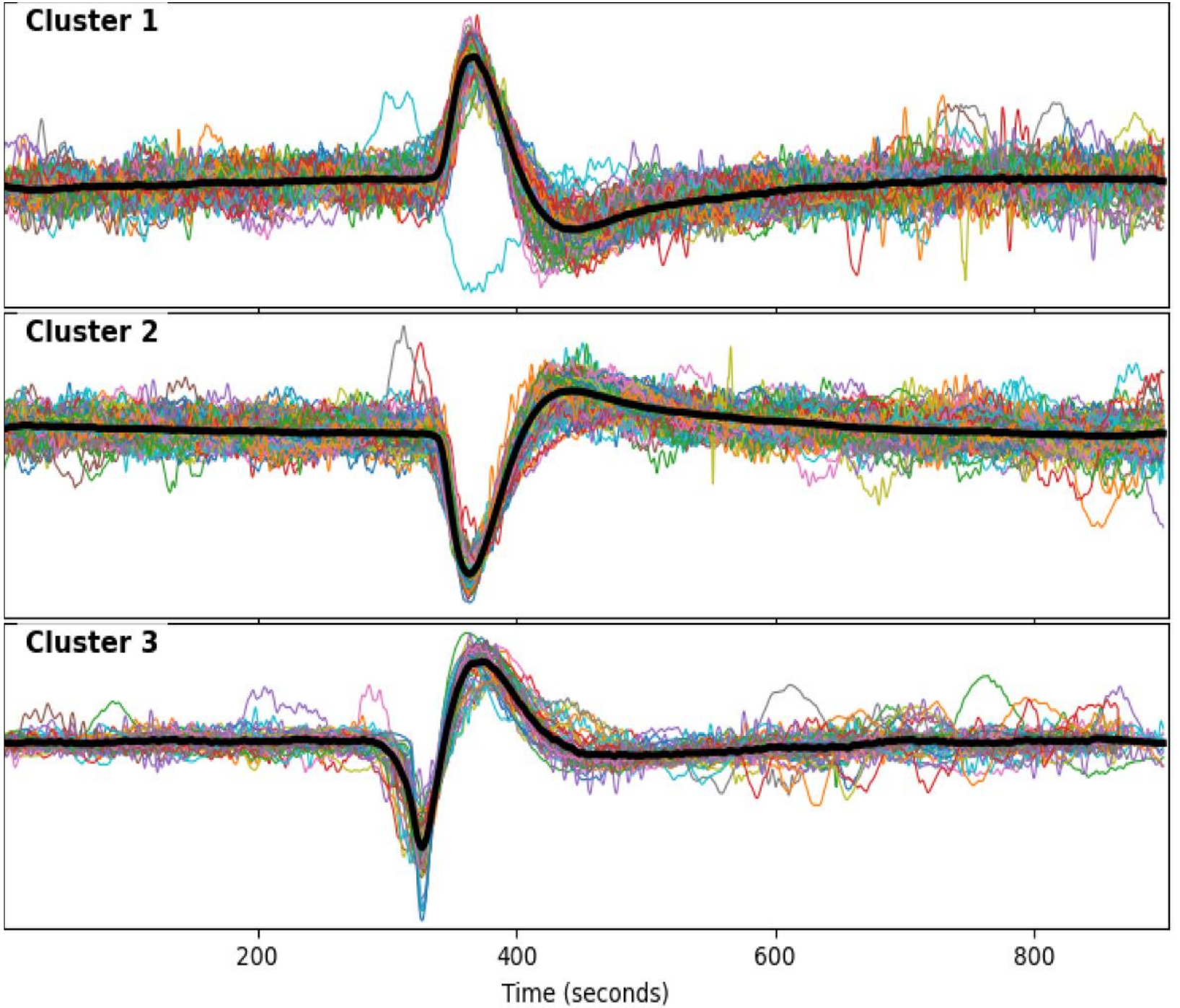
Very-Long-Period Seismic Signals at Mount Marapi

We detected ~400 VLP at PCAK station in four months preceding the phreatic eruption in April 2018.

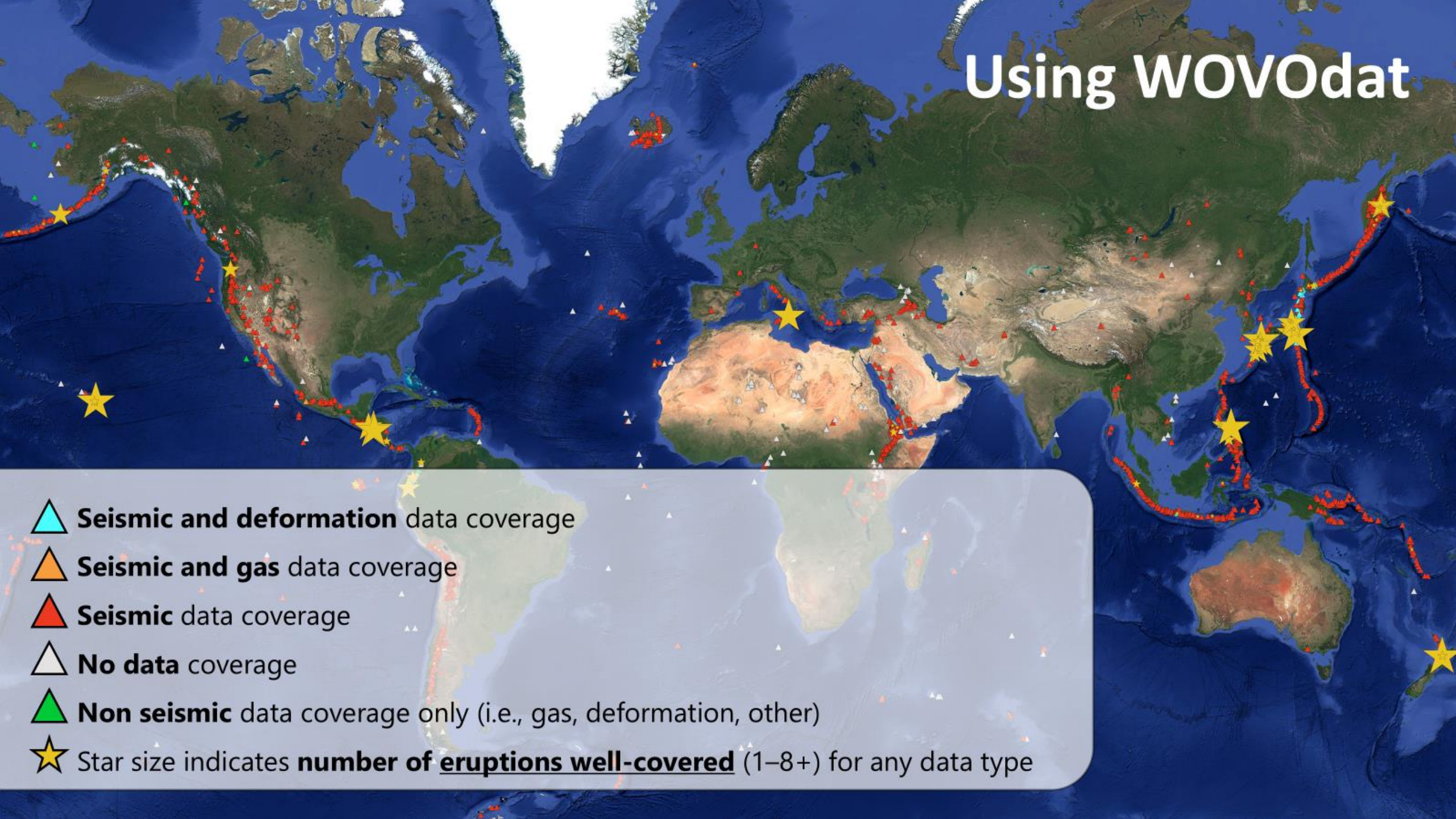
- **Unsupervised Classification**
- **Systematic Restitution to ground deformation**
- **Allow us to track source and physical process**

(In progress)

T.Espinosa-Ortega, B. Taisne (NTU), J. Neuberg (University of Leeds) and Y.Superman (CVGHM)



Using WOVOdat



Optimising timescales for machine learning-based eruption forecasting: insights from Miyakejima volcano (Japan)

>>> Use of WOVOdat to explore timescale selection in eruption forecasting

>>> WOVOdat allows for direct application of this study to other volcanoes and data types

1. Which data do you consider to make a forecast ?

How far do you go back in time ?

2. How far ahead do you want to forecast ?

How far do you look ahead in time ?

Short + Short

Short + Long

Long + Short

Long + Long

(And everything in between)

Machine learning

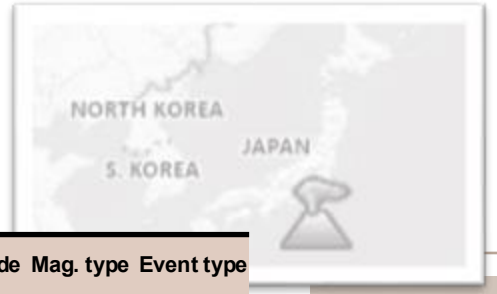
train

test

NOW

Miyakejima volcano: 2002-2010

Seismic Network Event data

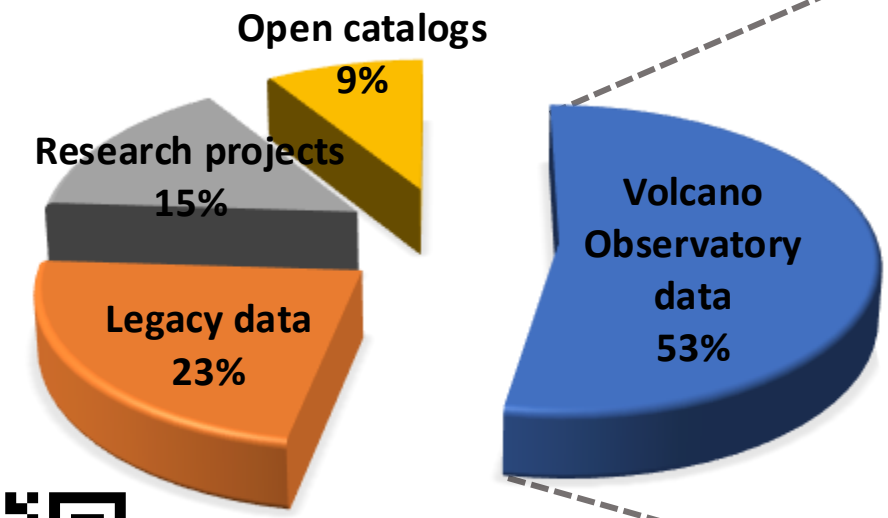


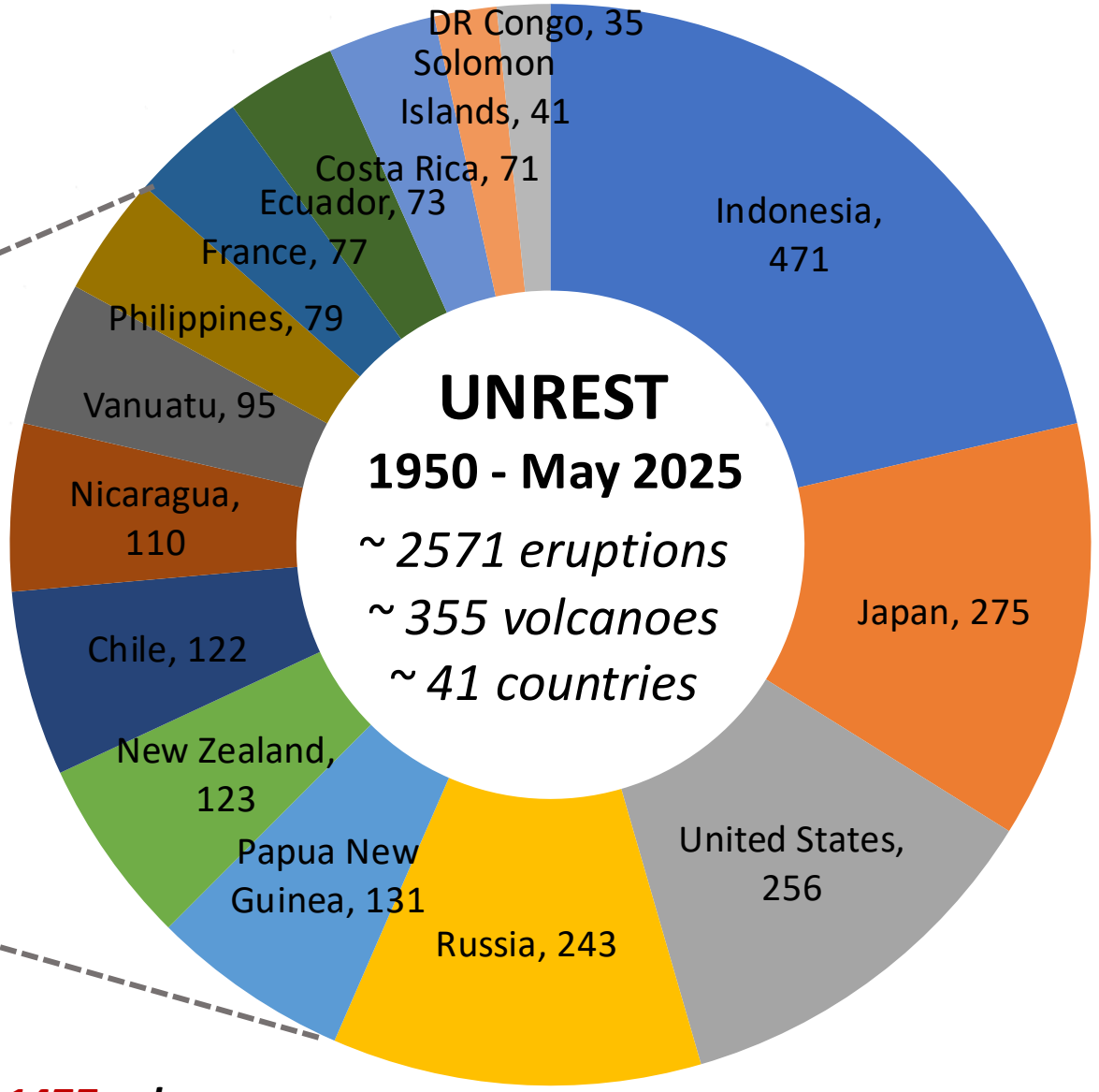
Event time	Latitude	Longitude	Depth	Magnitude	Mag. type	Event type
1/1/2002 15:47	34.08849	139.5225	-0.36	-0.2	Mb	VT
2/1/2002 18:04	34.08098	139.5255	0.207	0.1	Mb	VT
2/1/2002 19:37	34.08697	139.5259	1.295	2.4	Mb	VT
2/1/2002 19:57	34.08299	139.532	2.062	0.4	Mb	VT
2/1/2002 20:09	34.07367	139.5297	1.751	1	Mb	LF
2/1/2002 20:14	34.07464	139.5269	-0.61	0.8	Mb	LF
2/1/2002 20:18	34.05968	139.5288	3.32	1.1	Mb	LF

De Groote, Taisne, Jenkins (in prep)

Data resources

Main data contributor for WOVOdat will be volcano observatories, but we also explore data from open database and references (legacy data), as well as liaise with the ongoing research projects related to volcano unrest.





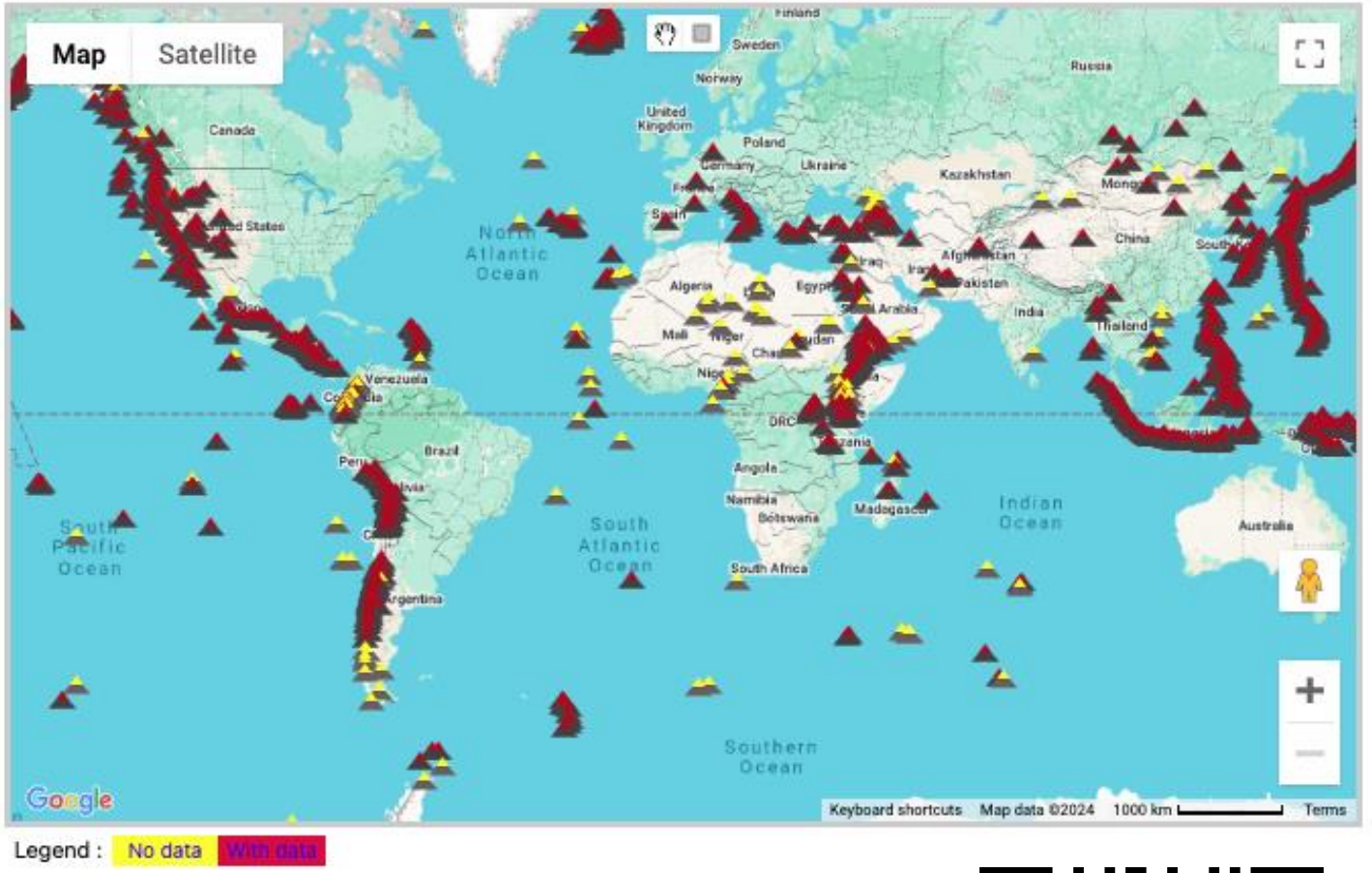
WOVOdat statistics

As of May 2025:

- ***WOVOdat*** *includes monitoring data from* ***1477*** ***volcanoes****, with unrest records for* ***282*** ***volcanoes*** *and* ***1678*** ***eruptions****.*
- ***GVMID*** *documents over* ***13,000 monitoring stations*** *and* ***16,000 instruments*** *across* ***550+ volcanoes*** *worldwide.*

Key Points

Towards standardizing and integration of the global historical volcano monitoring data for research and crisis response.



Legend : No data With data

- **Challenges in inconsistent data formats** and database structures have **hindered comparative** research on volcanic unrest and analog identification.
- **WOVOdat** addresses this by **standardizing** and consolidating diverse processed data into **accessible web formats**.
- It serves as a **reference during crises**, supporting comparative studies, fundamental research on eruptive processes, and **improving eruption forecasting**.

We created WOVOdat Web Service data retrieval system

- WOVOdat provides scientists with **historical unrest** data for studying eruption precursors and **helps forecast outcomes** by finding analogs to current crises.
- **The more comprehensive the database, the more valuable it becomes.**

Nang et al., 2025

Bulletin of Volcanology – Data Report

Data Reports are short (2-3 journal pages) reports presenting and describing data related to eruptive activity, unrest and other observations.

Managers of monitoring networks can quickly publish sensitive data through this platform.

- These data will then receive a DOI and copyright protection and be citable.
- Data reports are intended for presenting only data, and not extended interpretation or debate.

- We encourage monitoring data sets attached to the reports to be archived in **WOVOdat** (wovodat.org) as being part of a global initiative to build the comprehensive global database on volcanic unrest and promoting FAIR data principles.
- Spreadsheet templates in the **WOVOdat** format will be provided.
- These will be included as SI, provided a DOI and linked to wovodat.org.

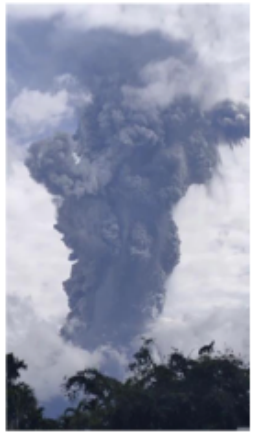
Call for Papers:

Data related to Volcanic Unrest in Asia – A collection of data reports

As part of "The Ring of Fire", Asia is home of active volcanoes with frequent unrest and eruptions. Agencies and universities in the region put significant effort into monitoring these volcanoes to better understand their behavior and provide timely warnings to local communities. This special issue will collate various monitoring reports that present the data related to the volcanic unrest in Asia, highlighting the characteristics of the onset of unrest and how it evolved leading to eruption. Though unrest without eruption also considered. The monitoring parameters may include Seismic, deformation, hydrology, fumarole and soil temperature, Soil degassing (CO_2), Gas flux (SO_2) and gas chemistry, remote sensing, volcanic ash analyses, among others.

Data reports submitted to Bulletin of Volcanology are short (2-3 journal pages) reports presenting and describing data related to eruptive activity, unrest and other observations. Managers of monitoring networks can quickly publish sensitive data through this platform. These data will then receive a DOI and copyright protection and be citable. Data reports are intended for presenting only data and not extended interpretation or debate. Reports should include (as well as title, authors, affiliations and abstract):

i. A short introduction to the eruptive setting and/or the context of the observations.
ii. A brief description of the network, equipment and/or methodological approach, supported by maps and schematics.
iii. A presentation of the data (as graphs and tables) with a description of changes in levels of activity, data trends, variations, data usage etc.
iv. Conclusions



Large datasets can be included as supplementary information. We encourage research data to be archived in WOVOdat (wovodat.org) as data repository, being part of a global initiative to build the comprehensive global database on volcanic unrest and promoting FAIR data principles. Spreadsheet templates following WOVOdat standardized format will be provided.

For those interested to participate in this Special Issue, please contact the guest editor with tentative title, authors, and brief description about the paper by **30th September 2025**.

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https://link.springer.com/journal/00445/submission-guidelines?IFA

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