NEW EFFECTIVE DISASTER FORECASTING METHODOLOGY

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The article discusses a new effective methodology for forecasting natural disasters. The technique is a combination of two methods of observing natural phenomena. The first method involves continuous monitoring of the electromagnetic signal observed at the epicenter of a future natural disaster. The second method, based on the signal trend analysis, predicts the moment of the expected natural event. The effectiveness of the methodology is demonstrated by the example of a retro predict of the Hunga-Tong volcano eruption, which confirmed the actual eruption date. Additionally, a prediction was made for the date of the future volcanic eruption.

KEYWORDS

eruption, volcanology, forecasting, trend, electromagnetic emission, Mount Etna

1 INTRODUCTION

The problem of the possibility or impossibility of predicting future events and phenomena, in particular, natural disasters, has long worried all thinking people. Natural disasters very often occur "unexpectedly", when any even minor disturbances can throw the system out of balance. Synergetics or non-linear science for the first time made it possible in principle to study such processes [Kurdyumov 2000].

The unexpectedness of catastrophes is a purely external manifestation of them. In fact, disaster is being prepared in advance. You need to learn how to track its preparatory stage. One of the ways to solve this problem is the "trend forecasting" considered in this article [Balara 2018, Duplakova 2018, Flegner 2019 and 2020, Monkova 2013, Murcinkova 2019, Baron 2016, Mrkvica 2012, Zaborowski 2007, Chaus 2018, Vagaska 2017 and 2021, Straka 2018a,b, Modrak 2019, Michalik 2014, Olejarova 2017]. The essence of trend forecasting is continuous monitoring of a sign (harbinger) of a developing natural disaster, followed by determining, based on the analysis of the trajectory of the change in the controlled value, the moment of the disaster [Rimar 2016, Panda 2011a,b, and 2013a,b, Jurko 2011, 2012 and 2013, Valicek 2016, Sedlackova 2019, Kurdel 2014 and 2022, Labun 2017 and 2019, Pollak 2019 and 2020, Svetlik 2014, Zaloga 2020].

In the period preceding the catastrophe, the sign changes dramatically in magnitude. Such changes in the controlled value are called exacerbation modes [Podlazov 2009]. Such regimes include natural disasters.

The solution this problem is to increase the information content of eruption precursors that have proven themselves in practice [Nagornyi 2018–A]. So, in [Nagornyi 2017, 2018-B,C, 2020–A,B], based on long-term experience of forecasting, showed that as a prognostic sign it is necessary to consider not only the current value of the control parameter, but also take into account its change dynamics during the controlled object observation period [Saga 2019, Krenicky 2021]. In other words, the observed phenomenon should not be regarded as a statically frozen picture but should be presented as a process whose characteristics continuously change throughout the observation period.

Externally, this process manifests itself as trajectory (trend) of a change in time of a controlled parameter. This trend contains information necessary for decision-making, both about the current state criticality degree of approaching disaster, but also about the moment of the disaster [Krenicky 2022]. The success of forecasting largely depends on the sensitivity of the precursor to changes in the seismic situation.

In recent decades, there have been many destructive natural phenomena that have raised concern for our future and for the very protection of the entire ecosystem that keeps us alive. A phenomenon driven primarily by volcanic events that cannot be corrected and are increasingly becoming an obstacle to, for example, air travel or, more worryingly, is changing the environment in which we live. This is an alarming scenario, which worries many countries with a high seismic and volcanic risk, such as those in the Pacific Area.

This study aims to highlight the results of a new instrumental monitoring system with respect to natural phenomena that can cause disasters to the environment and therefore be a great risk to human life.

The researchers involved in this study present here a new forecasting technique which appears to be effective for this purpose and which finally solves this problem. The essence of the technique lies in the combination of monitoring the electromagnetic signals emitted by volcanoes and the prediction of associated trends, therefore the analysis of electromagnetic data and the mathematical processing of the data provided by the monitoring system itself.

The effectiveness of the methodology is demonstrated by the example of forecasting the catastrophic eruption of the Hunga Tonga Volcano which took place on January 15, 2022, which it was possible to verify thanks to the data provided by the new monitoring and processing system.

2 RESEARCH METHODOLOGY

2.1 Forecasting based on the theory of blow-up regimes

Electromagnetic emission constituted a series of numbers «time -electromagnetic emission signal» and was the source material for predicting eruption. Graphically, this series is depicted in the form of a time graph (trend).

The trend is an object of the blow-up regimes theory [Samarsky, 1987] and is described by the following equation

$$\frac{dx}{dt} = x^{1+1/\alpha} \tag{1}$$

The solution of this equation increases without limit as we approach the peaking moment (eruption time T_{for})

$$x(t) \sim \left(T_{for} - t\right)^{-\alpha}. \tag{2}$$

The eruption time (T_{for}), was determined in the process of minimizing the functional U (3)

$$U = \sum_{i=1}^{n} \left(H - H_{\text{mod}}\right)^2, \tag{3}$$

where H_{mod} - the value of the controlled parameter, calculated by the predictive model; n - the number of time series values.

The analytical expression for the predictive model, taking into account (2), is as follows:

$$H_{\mathrm{mod}} = A \cdot \left(T_{for} - t\right)^{-\alpha}, \tag{4}$$

where t - registration current time of the controlled parameter; A, α - experimental parameters, determined together with time T_{for} in the process of approximation of the graph of the parameter H by the predictive model (2).

The research methodology is based on the use of a series of stations located on Italian soil that are equipped with a series of radio receivers capable of detecting the weak electromagnetic variations emitted at the crustal level. Since 2007 [Straser 2017], studies have shown that both seismic faults and volcanoes can be defined as radio frequency emitters [Straser 2021], generated by piezoelectric phenomena that determine an emission of flowing electrical charges which generate an electromagnetic field. Depending on the density of these particles accumulating in the lithosphere, these electromagnetic signals may also have strong power, such as to be then propagated in the earth-ionosphere cavity [Cataldi 2022].

The receiving system is therefore able not only to detect the frequency, the intensity, the movement in the band of these signals, but also the arrival azimuth, with respect to the geographical position of the station itself. knowing therefore the gps (global positioning system) position of the station and knowing the azimuth of arrival of the radio signals, it is possible to know where these are generated thanks to triangulation [Cataldi 2022].

In general, each RDF station is able to detect the azimuth of origin of these signals. In this study, the researchers wanted to understand if the recordings of the RDF station of Lariano, Rome, Italy, had detected radio emissions in the direction of the Hunga Tonga Volcano, before its eruption (which took place on January 14, 2022 - 4:14:45 UTC) and if after such emissions the volcano in question was providing the same data useful for a medium-term forecast.

2.2 Volcano data

The eruption of the Hunga Tonga volcano took place on January 14, 2022, in the archipelago of Tonga, in the Pacific Ocean. Hunga Tonga is an underwater volcano located 65 km north of Tongatapu, the main island [Moodie 2022].

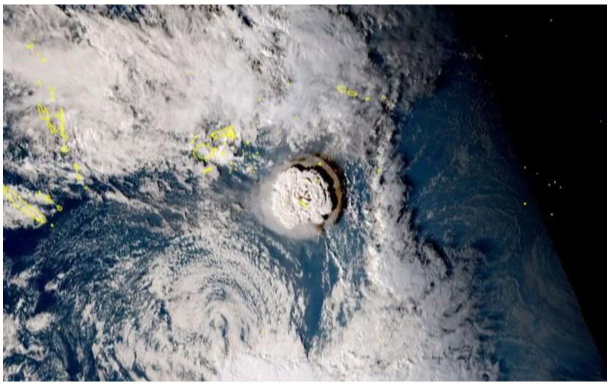

Figure 1. Tunga Tonga Explosion

Footage (Fig. 1) taken by Japan's Himawari-8 satellite and released by the National Institute of Information and Communications (Japan) on 15 January shows the volcanic eruption. Credits: AFP / National Institute of Information and Communications.

The eruption also caused tsunamis that hit Tonga, Fiji, Vanuatu and the American Samoa Islands, also causing concern for the coasts of New Zealand, Australia, Japan, Russia, North America (Canada, United States and Mexico) and South America (Ecuador, Peru and Chile). Two women drowned in Peru after being washed over by two-meter-high waves, while two fishermen were reported injured in California in the United States. Since tsunamis are statistically caused in greater numbers by earthquakes that do not give volcanic eruptions.

These tsunamis of 2022 are therefore a rarity considering that similar episodes have been recorded less than a hundred times in the last two hundred years. At the moment this eruption is the largest of the 21st century. Rescue operations are still active on the island of Atata, near the volcano and almost submerged by the tsunami. New Zealand Prime Minister Jacinda Ardern specified that her Foreign Ministry employees are discussing how to subsidize aid for Tonga. Ardern expressed concern about the event. On January 16 announced that New Zealand would donate around NZ $ 500,000 (around € 300,000) as first aid. The Australian government has also moved to help the island. The massive ash emissions from Pinatubo on Luzon Island in the Philippines (September 2, 1991) had global consequences. “The studies of this extraordinary eruption have yet to begin” - explains the volcanologist Boris Behncke of the Italian National Institute of Geophysics and Volcanology - “but they will certainly give a treasure of knowledge (...) in the fields of meteorological and atmospheric sciences”. Consequently, the effects and aspects of this eruption are currently unknown. Given the high index of volcanic explosiveness it would be classified, according to the New York Times, as one of the most notable events in the last thirty years. Eruptions of this magnitude occur very rarely. Behncke believes that there may have been important changes in the morphology of the underwater part of the volcano. Therefore, the exact mechanism of formation of volcanic tsunamis in those areas will have to be studied. It will be necessary to monitor the continuation of the volcano's activity: it must be said that after the great eruption of January 15, there were only a few small explosive episodes. It will be evaluated, explains Behncke, whether the cataclysm of January 15 was the culmination of the current period of activity. Currently, the possible effects on the regional and global climate are not known. Predictably it seems that the impact on the climate will be negligible, the volcanologist is convinced. The first informative estimates obtained by the Sentinel 5P satellite on the production of sulfur dioxide, regarding this eruption, reveal the emission of a modest quantity of about 0.4 Tg (tons of gas), i.e. four hundred thousand tons (different sources speak of only 112,000 tons or a little more), 50 times lower than that of the Pinatubo volcano in 1991.

2.3 RDF Data

The RDF data considered in this study are those analyzed before and after the date of the explosive eruption of the Hunga Tonga Volcano, this served to understand if the volcano had begun to provide indications of its imminent awakening.

It is located at a considerable distance, or more than 17,500 km from the RDF station of Lariano, Rome, Italy (Fig. 2).

The recordings of the detection station, located in central Italy, therefore had to identify the signals emitted by the Volcano with respect to the rest of the radio emissions from the entire globe. The data therefore had to consider variables that cannot be underestimated, as well as the depth of the volcano, largely

The attenuation of the electromagnetic signals emitted by the Hunga Tonga was therefore due to the following factors:

-Distance of the emission source, with respect to the RDF detection.

-Depth of emission of the electromagnetic signals emitted by the Volcano with respect to the earth's surface.

-Propagation phenomena and propagation interruption determined at the ionosphere's layers.

-Fading phenomena, due for example to the presence of humidity, clouds, thunderstorms and obstacles (mountains) present along the path of the propagation of radio emissions generated by the Volcano.

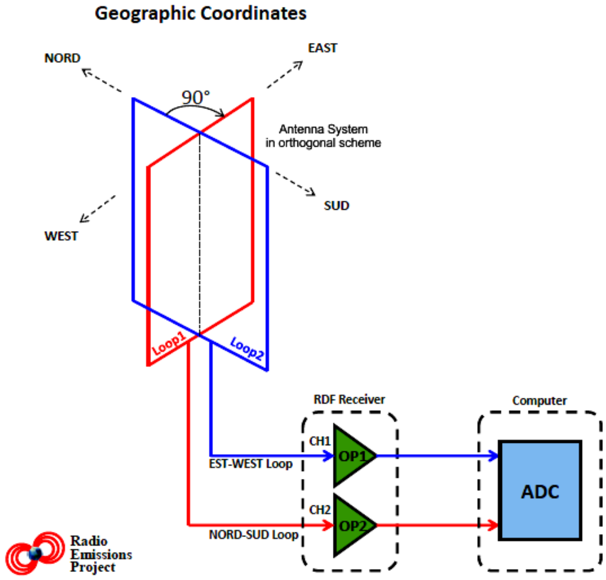

Figure 2. Summary diagram of the components relating to the RDF station of Lariano, Rome, Italy. Credits: Radio Emissions Project, Lariano, Rome, Italy

The RDF detection station monitors electromagnetic signals with a frequency ranging from 0 to 30 Hz, in the SELF-ELF band. Electromagnetic band in which pre-seismic electromagnetic emissions and in general those related to magmatism and crystal phenomena propagate (Fig. 3). The electromagnetic monitoring of the station is continuous 24H7.

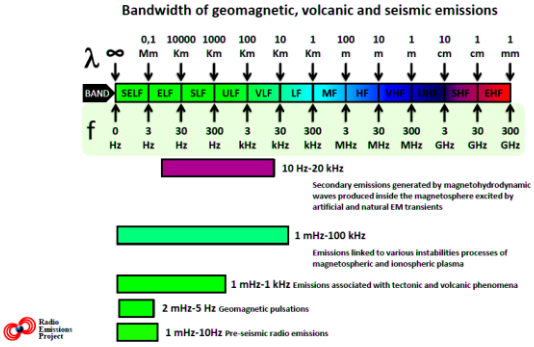

Figure 3. Schematic of the electromagnetic frequency spectra with the relative emission sources. Credits: Radio Emissions Project, Lariano, Rome, Italy

The attenuation of the signals has certainly caused difficulties for the detection system in discriminating these signals. Nevertheless, the signals recorded at this distance (over 17,500 km) show how efficient the RDF system (Italian network) is in identifying signals generated from very distant sources.

3 RESEARCH RESULTS

The trend forecasting results are shown in Fig. 4 and in the «Protocols eruption forecast».

Fig. 4 presents:

– a graph of changes in electromagnetic emission from September 30, 2021, to May 13, 2022;

– the retro forecast period from September 30, 2021, to January 15, 2022, and the current forecast period from January 15, 2022, to May 13, 2022;

– arrows marked the actual date of the eruption and its forecast obtained from the retro forecast (January 15,2022 and January 17, 2022, respectively);

– with red arrow is marked the expected eruption in the future (August 4, 2026).

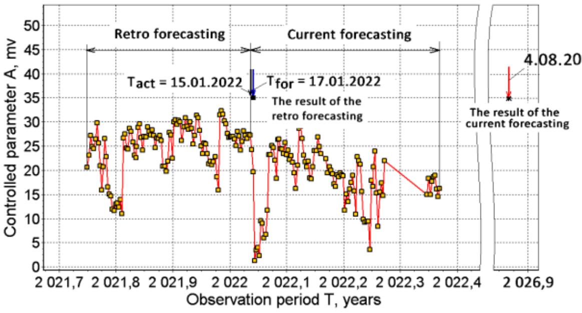

Figure 4. Change in the electromagnetic emission during the observation period and results of eruption dates forecasting

3.2 Results of retro forecast

The results of retro forecast are presented in Fig. 5, in Table 1 and in the "Protocol eruption retro forecast".

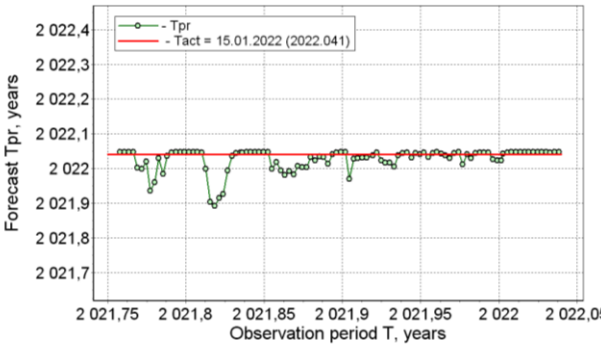

Figure 5. Variation in the retro forecasting of the Hunga Tonga volcano eruption

Table 1. Eruption retro forecast (actual date of the eruption 15.1.2022)

The date forecasting	12.1.2022	13.1.2022	14.1.2022	15.1.2022
Forecast dates eruptions	17.1.2022	17.1.2022	17.1.2022	17.1.2022
Deviation forecast from actual date, %	-0.2	-0.2	-0.2	-0.2
Deviation forecast from actual dates in days	1.92	2.05	2.27	2.01

PROTOCOL

eruption retro forecast

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| Forecast date: |

| **3.10. 2021** |

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FORECAST:

forecast quality: - **good**

The forecast of the most probable date of the eruption is:

16.01.2022

and changes with a confidence probability P=0.95 within the following limits:

from **16.01.2022** to **16.01.2022**

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| Forecast date: |

| **14.01.2022** |

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FORECAST:

forecast quality: - **good**

The forecast of the most probable date of the eruption is:

16.01.2022

and changes with a confidence probability P=0.95 within the following limits:

from **16.01.2022** to **16.01.2022**

3.2 Results of current forecast

The results of the current forecast are presented in Figure 6, in Table 2 and in the "Protocol eruption current forecast".

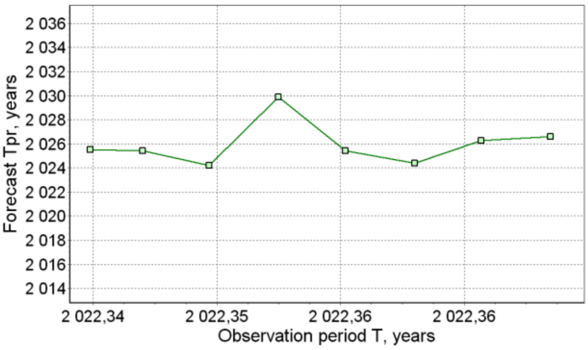

Figure 6. Variation in the current forecasting of the Hunga Tonga volcano possible eruption

Table 2. Eruption current forecast

The date forecasting	8.5.2022	9.5.2022	10.5.2022	11.5.2022
Eruption date forecast	2.6.2025	21.5.2024	2.4.2026	4.8.2026

PROTOCOL

eruption current forecast

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| Forecast date: |

| **20.1.2022** |

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FORECAST:

forecast quality: - **good**

The forecast of the most probable date of the eruption is:

1.7.2026

and changes with a confidence probability P=0.95 within the following limits:

from **15.04.2026** to **14.10.2026**

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| Forecast date: |

| **10.05.2022** |

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FORECAST:

forecast quality: - **good**

The forecast of the most probable date of the eruption is:

4.08.2026

and changes with a confidence probability P=0.95 within the following limits:

from **3.08.2026 to 5.08.2026**

4 CONCLUSIONS

The natural event considered in this study is certainly definable: very destructive, if this had happened in a populated area, it would probably have been the most destructive natural event in human history. In this regard, the group of researchers decided to use data from the Italian RDF network to understand if the Volcano had recorded in advance the radio emissions from Hunga Tonga, which could have indicated a possible eruption. In a forecasting context, it would therefore be important to verify whether a certain monitoring technique can be used in the future to predict such catastrophic events in advance.

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