PREDICTION OF THE VIBRATION MOMENT OF MOUNT ETNA BASED ON ELECTROMAGNETIC SIGNAL MONITORING

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The forecast of the start date of the Etna volcano eruption is considered. For the first time in the history of volcanology, the forecast was made by two independent methods. The first method analyzed the nature of changes in electromagnetic emission in the environment surrounding the volcano, while the second method predicted the date of Etna's eruption based on a trend composed of regularly measured electromagnetic emission parameters.

KEYWORDS

Eruption, volcanology, forecasting, trend, electromagnetic emission, Mount Etna.

1 INTRODUCTION

Forecasting an eruption and earthquake remains very relevant for humanity, but the problem has not yet been resolved [Kanamori 2004]. The forecasting methods adopted in seismology, based on a comparison of the monitored parameters current values with their standard, do not lead to the desired result [Geller 1997, Giovambattista 2000, Console 2003, Faenza 2003, Fedorov 2005, Gerstenberger 2005].

The solution this problem is to increase the information content of eruption precursors that have proven themselves in practice [Dobrovolskiy 2005, Nagornyi 2018a, Panda 2021].

For example, the relationship between the deformation of crystalline structure and the genesis of electrical and electromagnetic signals is known and studied since several decades. The experimentation of the Radio Direction Finding (RDF) method, conducted independently and, at the moment, self-financed, by the Radio Emissions Project of Rome (Italy), has allowed to associate in the preparation phases of the event, electromagnetic signals to geophysical phenomena. The studies, to date, have focused mainly on earthquakes and analysis of crustal stress in the pre-seismic phases. The experimentation has been extended to the monitoring of electromagnetic signals potentially coming from Italian volcanoes and, in particular, Mount Etna, in eruptive phase for over a year, starting from December 2020. Research on the potential relationship associating volcanic activity with electromagnetic signals has been encouraged by the outcomes of previous research conducted on Japanese, Russian and American volcanoes [Johnston 1989, Hata 1994 and 2001, Malkin 2021]. In some cases, as described by [Zlotnicki 2009], electromagnetic signals occurred several days before eruption. This is a significant finding that, in perspective, may direct research not only in the scientific field, but also in the public interest for the safety of communities and anthropogenic activities. The particular frequency band used for RDF monitoring allows to select anthropogenic signals from natural ones, such as those generated by endogenous phenomena. The study that is presented and discussed shows the "non-randomness" of the detections that anticipated the eruptions of Mount Etna and at the same time, the modelling of the data, offers a future perspective for the monitoring of volcanic activity both at the national level, given the proximity of the RDF stations, and at the global level. Future studies, already started by the RDF network, will allow discriminating the type of eruptions, between effusive and explosive ones, using the electromagnetic frequency detection system.

This information should be regularly collected in the period leading up to a volcanic eruption or earthquake. In this case, it can be used as input for trend forecasting.

So, in [Nagornyi 2017, 2018a,b,c and 2020a,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. 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 [Bozek 2021, Panda 2013, 2014, 2016 and 2019]. Externally, this process manifests itself as trajectory (trend) of a change in time of a controlled parameter [Macala 2009, Murcinkova 2013, Valicek 2016 and 2017, Pandova 2018]. This trend contains information necessary for decision-making, both about the current state criticality degree of seismic situation, but also about the moment of the earthquake. This forecasting method is called trend forecasting [Lonzich 2012, Krenicky 2021].

The success of forecasting largely depends on the sensitivity of the precursor to changes in the seismic situation.

The detection system used in this study to detect natural electromagnetic signals consists of a series of radio receivers capable of receiving, recording and processing (by means of a PC) the electromagnetic emissions of radio-nature, emitted at the level of the lithosphere. terrestrial [Straser 2017].

This article discusses the results of forecasting the eruption of Mount Etna, obtained on the basis of these data [Straser 2021] and trend forecastin [Nagornyi 2018a].

2 METHODOLOGY

2.1 Forecasting based on electromagnetic emission

Monitoring system has been in operation since 2017 [Straser 2017] and is composed as shown in Fig. 1.

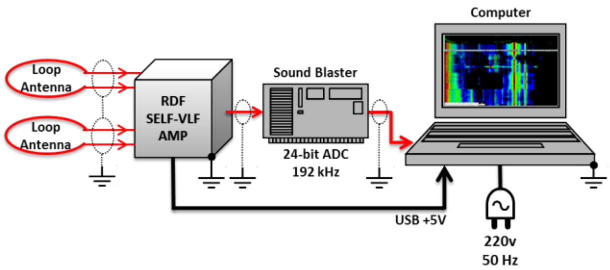

Figure 1. Graphic diagram showing the operation of an RDF station

In Fig. 1 shows the schematization of an RDF station, equipped with Radio Direction Finding technology, a technology that is able to understand the arrival angle of the natural electromagnetic signals (azimuth), and highlights, through coloring, the azimuth characteristics, as well as the 'intensity. The use of multiple RDF stations is able to identify the exact geographical area within which the signals are generated at the level of the lithosphere, thanks to the radio triangulation technique [Straser 2017].

The RDF station mainly consists of two loop antennas, oriented in an orthogonal pattern and with respect to the cardinal points (north, south, east and west). The signal coming from the antennas is then processed by a radio receiver (prototype) made by the Radio Emissions Project which amplifies and filters the radio signals and sends them to the sound card of a PC, which analyzes the spectrum.

The analysis thus identifies the signals, and shows them in Fourier transform, through the creation of an archive consisting of dynamic spectrograms in which the signals are displayed in steps of their intensity, frequency and UTC time.

To understand if the electromagnetic detection system (RDF network) was able to detect electromagnetic phenomena correlated with volcanic events produced by Etna, the researchers of the Radio Emissions Project monitored the electromagnetic signals in the SELF-ELF (Super Extremely Low Frequency-Extremely Low Frequency bands) band (0-30 Hz) and verified whether there were increases or variations in electromagnetic emissions with the azimuth of the Etna Volcano as the direction of arrival.

In this case the data are derived from two RDF stations, both located in Lariano, Rome, Italy, as shown in Fig. 2.

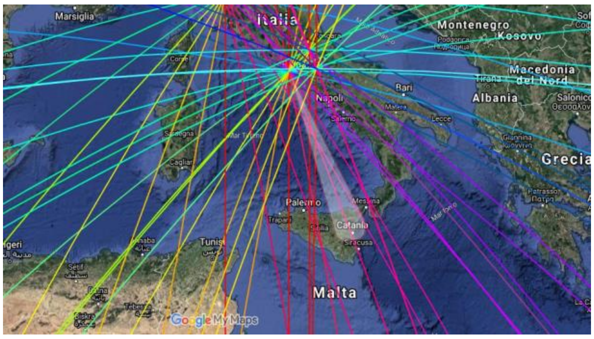

Figure 2. World mapping of the RDF

World mapping of the RDF network, with particular reference to the geographical position of the RDF stations of Lariano, Rome, Italy and that of the Etna Volcano. The RDF system highlights the electromagnetic signals with purple color and provides indications of the direction of arrival of the recorded signals, indicating the azimuth in degrees. In this case, those coming from the azimuth between 152° and 160°. The signals to be traced were those with the arrival azimuth between 152° and 160°, or from S-S-E with respect to the geographical position of Lariano, Rome, Italy. In addition to this, in order to verify whether the RDF network was able to detect pre-eruption signals from the Etna Volcano, these electromagnetic emissions should have been recorded within a short time span of the volcanic event. Emissions therefore that must have been emitted by the Volcano, before the eruption occurred.

The survey station interprets the radio signals coming from the antennas, processing them in the Fourier transform and then generates a series of dynamic spectrograms, where these processing are represented graphically. The graphic representation of these signals allows us to understand some important characteristics of the perceived electromagnetic signals, which possess characteristics that can be measured and evaluated by researchers.

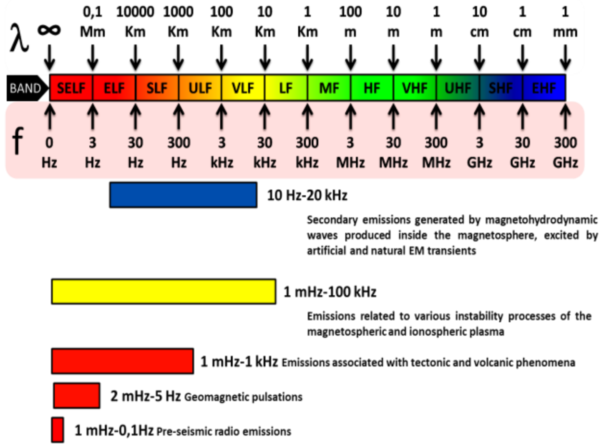

Figure 3. Schematic diagram of the electromagnetic frequencies

2.2 Forecasting based on the frequency spectrum of an electromagnetic signal

Frequency spectra highlighting the frequency bands within which certain natural phenomena are perceptible. In this case it is understandable to observe how the majority of pre-seismic and volcanic radio emissions are emitted in the SELF-ULF (Ultra Low Frequency) band, i.e. from 0.00 Hz to 1 kHz.

Precisely for this reason, the frequencies monitored by the RDF network are mainly those included between the SELF and ELF bands (0.0 Hz - 30 Hz). In this case we considered the signals that appeared temporally close to the seismic and volcanic phenomena indicate a precise direction of arrival (azimuth in degrees).

Thus, discarding but the majority of the electromagnetic signals received by the RDF network, it was possible to analyze only a small portion of the radio-nature to understand whether the electromagnetic signals highlighted by the detection network had or not recorded precursor signals of eruptive phenomena.

2.3 Forecasting based on trend forecast

Electromagnetic emission constituted a series of numbers "time - electromagnetic emission signal" and were the source material for predicting eruption. Graphically, this series is depicted in the form of a time graph (trend) [Lonzich 2012], the mathematical analysis of which allows predicting the eruption time T_{for}.

The eruption time (T_{for}), was determined in the process of minimizing the functional U (1)

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

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 is as follows:

$$H_{\text{mod}} = H(t_0)\cdot\left[1 + A\cdot\left(\frac{t-t_0}{T_{for}-t}\right)^{\alpha} - B\cdot\left(\frac{t-t_0}{T_{for}-t}\right)^{\beta}\right], \qquad (2)$$

where T_{for} – eruption time forecast; t_0, t - registration time of the controlled parameter, respectively, at the time of the initial and current measurements; $H(t_0)$ - the value of the controlled parameter, recorded during the first measurement; A, B, α, β - 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).

3 RESULTS

3.1 Results based on electromagnetic emission

Emissions therefore that must have been emitted by the Volcano, before the eruption occurred. In this case the volcanic phenomena occurred on the following dates (Table 1).

Table 1. The table shows the date on which the eruptive phenomena of the Etna Volcano occurred

Volcanic event date	Considered period
8.2.2022	from 20.1.2022 to 1.3.2022
11.2.2022	from 22.1.2022 to 24.2.2022
12.2.2022	from 1.2.2022 to 24.2.2022

The table shows the period considered by the researchers for the analysis of the electromagnetic signals received by the Italian RDF rate. As can be seen, the survey considered the period before and after each eruption.

As can be seen in the Table 1, three eruptive events on Etna were considered, in this case the monitoring data are those from a few days before to a few days after the eruptive event itself, and precisely between 8 and 12 February 2022.

3.2 Results based on the frequency spectrum of an electromagnetic signal

One of the RDF stations of Lariano, Rome, Italy, recorded between 10 and 11 February 2022, a very short time distance from the eruption of the Etna Volcano on 12 February 2022 (Fig. 4).

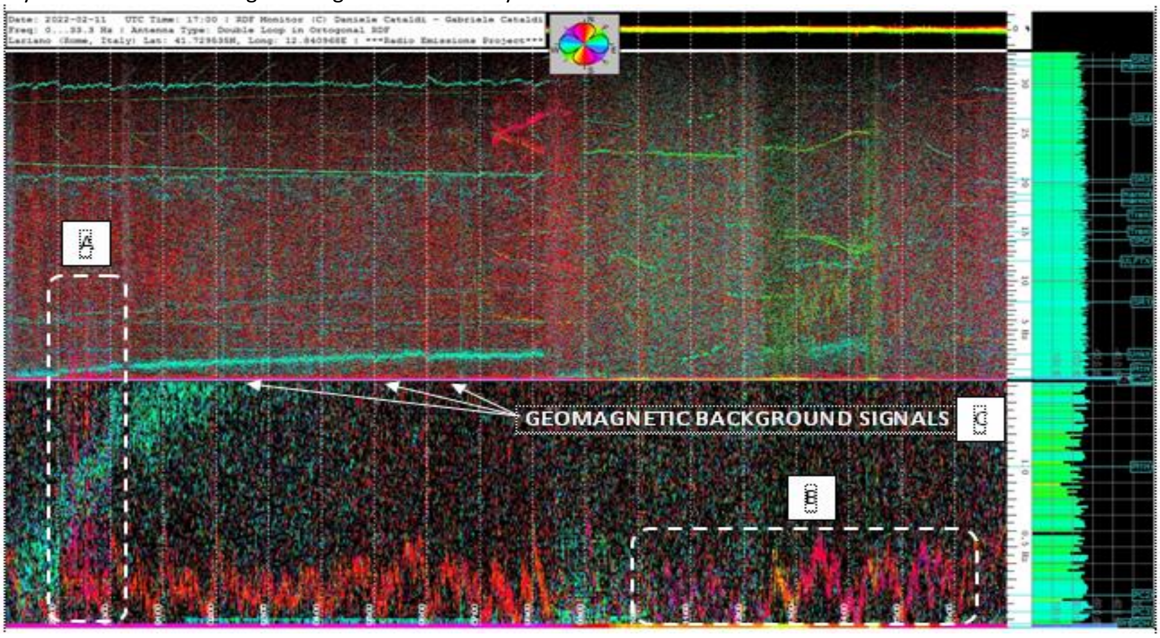

Figure 4. Dynamic spectrogram of one of the RDF stations of Lariano, Rome, Italy, recorded between 10 and 11 February 2022

A very short time distance from the eruption of the Etna Volcano on February 12, 2022. It highlights the electromagnetic signals with purple color and provides indications of the arrival direction of the recorded signals indicating their azimuth in degrees. On the horizontal axis of the abscissas, we find the UTC time, while on the vertical axis of the ordinates, we find the electromagnetic frequency of the electromagnetic signals received. In this case, those coming from the azimuth between 152° and 160°.

As can be seen in the Fig.4, the purple color suddenly appears, a symptom of an electromagnetic emission that suddenly changes its arrival azimuth, at the electromagnetic detection station (RDF station). In this case, the impulsive signals with variable frequency (0-5 Hz) recorded between 23:00 UTC and 00:00 UTC on February 10, 2022 (A), and those that appeared between 09:00 UTC and 16:00 UTC of 11 February 2022 (B), with electromagnetic frequency between 0 Hz and 0.5 Hz.

In this spectrogram we also note the appearance of azimuthal variation on the geomagnetic background (0.00 Hz) which turns purple (C). Here, signals of this type are recorded before earthquakes or eruptions occur at the volcanoes. Electromagnetic emissions which substantially indicate that there are piezoelectric phenomena [Dahiya 2013] capable of generating electromagnetic emissions detectable in the Earth-Ionosphere cavity.

Piezoelectricity is the property of some crystalline materials to polarize, generating an electric potential difference when subjected to mechanical deformation (direct piezoelectric effect) [Straser 2017] therefore the structural modifications of the volcanic cone or of portions of it seem to emit radiofrequency, which is then localized by the RDF network [Straser 2021].

These signals are precursors of precursor phenomena of seismic activity or volcanic activity providing precise geographical indications on their location, especially if at a relatively short distance from the detection station.

3.3 Results based on trend forecast

The trend forecasting results are shown in Fig. 5, 6 and in the «Protocol eruption forecast».

Fig. 5 shows a graph of changes in electromagnetic emission from September 30, 2021 to February 16, 2021. In Fig. 5 arrows also marked the actual date of the eruption and its forecast.

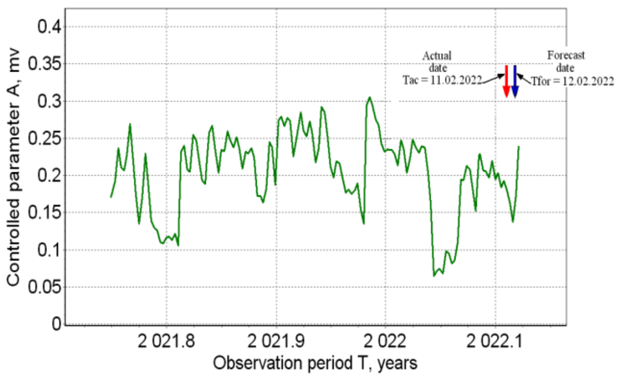

Figure 5. Change in the electromagnetic emission during the observation period

The change in the forecast over the observation period is shown in Fig. 6.

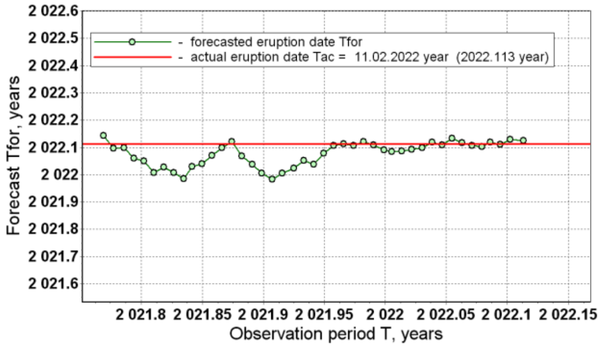

Figure 6. Variation in the forecasting of the start date of the eruption of Mount Etna

PROTOCOL

eruption forecast

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|| Forecast date: ||

|| **7.1.2022** ||

=============================

FORECAST:

forecast quality: - good

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

11.2.2022

and changes with a confidence probability P=0.95

within the following limits:

from 5.2.2022 to 18.2.2022

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|| Forecast date: ||

|| **18.1.2022** ||

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FORECAST:

forecast quality: - good

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

8.2.2022

and changes with a confidence probability P=0.95

within the following limits:

from 30.1.2022 to 15.2.2022

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|| Forecast date: ||

|| **29.1.2022** ||

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FORECAST:

forecast quality: - good

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

12.2.2022

and changes with a confidence probability P=0.95

within the following limits:

from 7.2.2022 to 14.2.2022

4 DISCUSSION

As follows from the "Protocol ...", from January 7 to January 29, 2022, the eruption forecast was the following set of dates 11.02.22, 08.02.22 and 12.02.22, coinciding with the forecasts obtained based on the analysis of electromagnetic emission and its frequency spectrum.

The results obtained by the detection system are essentially based on the analysis of the radio signals detected by the RDF system and the time context in which these signals appear.

4.1 The RDF System

The electromagnetic detection system created by Gabriele Cataldi and Daniele Cataldi (founders of the Radio Emissions Project), called "RDF System", is a "continuous" electromagnetic monitoring system based on Radio Direction Finding (RDF) technology; from which the system takes the name). It is a project that the Radio Emissions Project has expressly conceived for the study of pre-seismic radiofrequency [Straser 2017].

The heart of the RDF System is represented by a prototype of a double-channel "single ended" radio receiver whose amplification stages work with a gain of 46 dB: it is a prototype of a radio receiver that filters and amplifies the incoming signal (transduced by two loop antennas aligned orthogonally to each other) and sends it to a computer which subsequently converts it into digital data with a resolution of 24 bits and a sampling of 196 kHz [Straser 2017].

This solution allows the RDF System to analyze a bandwidth of 30 kHz (SELF-VLF bands; Super Extremely Low Frequency-Very Low Frequency bands; 0 Hz < f ≤ 30 kHz) with a resolution of a few tens of mHz (1 mHz = 0.001 Hz) [Straser 2017].

The analog-digital conversion is carried out in real-time allowing to perform various types of measurements on the radio signals received: intensity, frequency, spectral and azimuth imprint; in relation to time [Straser 2017].

4.2 Comparative methodology

The RDF System is used to search for a match between a low-frequency radio signal, coming from a precise geographical area, affected by seismic and volcanic phenomena [Straser 2017 and 2019b,c].

The radio signal correlation technique is based on the analysis of the electromagnetic signals detected by the RDF network, data that are able to provide the following information:

1. Time (UTC) and date of appearance of the signals themselves.
2. Intensity of recorded electromagnetic signals.
3. Morphology of electromagnetic signals, such as duration, electromagnetic frequency, frequency variation, bandwidth, appearance and disappearance. Azimuth of electromagnetic signals and its variation.

To analyze this information, continuous monitoring of the 24H7 natural electromagnetic background is required [Straser 2017].

In summary, the correlation of signals follows a pragmatic and precise practice, which essentially begins with the identification of a radio signal that appears suddenly and that the RDF network detects immediately. This signal often appears without warning, it can have a certain intensity with respect to the normal natural electromagnetic background (also in relation to the distance from which this signal is emitted or to its emission depth in the lithosphere), the more distant signals will obviously be weaker, while those closest to the survey station will be more intense. Therefore, the intensity of these signals almost always provides an indication of the distance within which they are general, this indication is provided by the azimuth that these signals possess, compared to the RDF stations located on the globe [Straser 2017].

In this case, the second important correlation data is precisely the azimuth indication, or the angle of arrival in degrees of these signals that precisely provide the position of the

geographical emission point within which these signals are generated.
The arrival angle is analyzed on each RDF station located on a specific point on the Earth's surface and thanks to the triangulation technique of the radio signal, these stations indicate, all together, the point of genesis at a geographical level.

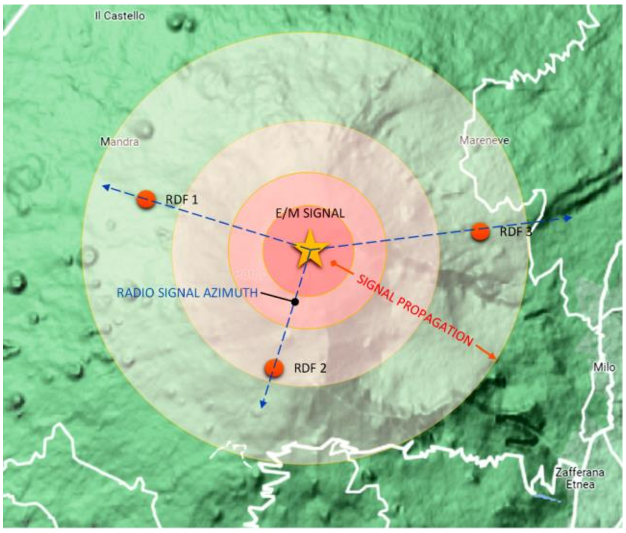

Figure 7. Schematic functioning of the triangulation of radio signals with the RDF network, developed by the Radio Emissions Project

The RDF network, developed by the Radio Emissions Project. It is characterized by the presence of several radio detection stations, positioned at a distance, each of which on a precise geographical point, by means of the knowledge of the arrival azimuth of the electromagnetic signal on each RDF station, it is possible to detect the exact geographical position of emission. Credits: Radio Emissions Project, Google Maps.
Once the position where this signal is emitted is understood, the studies have shown that the earthquake can occur in that particular geographical point within an average of 20 hours, but it also depends on the duration of the emission, i.e. a longer duration of the signal indicates times of much longer pre-warning, while a short duration signal (a few hours) indicates that the earthquake will occur soon.
There is not yet the ability to precisely understand the temporal context within which this signal will warn us of an earthquake or a volcanic eruption, but we know that these phenomena may occur within 20 hours (on average), or to a lesser extent within a few days [Straser 2017, 2019b,c and 2021].
For the prediction of volcanic phenomena, we already know where the volcano is positioned, so we already know the direction in azimuth (degrees) of the signals emitted by it, so it will be enough to keep under control that particular azimuth within which the electromagnetic signals will arrive. We will therefore wait for the appearance of these signals, by measuring their previously listed characteristics; this will provide unambiguous indications within which we can expect an eruption or a paroxysmal phenomenon [Straser 2021].

5 CONCLUSIONS

To date the data [Straser 2017 and 2019a,b,c] of the experimentation of the RDF network, indicated how the RDF network was able to detect the exact position of earthquakes that occurred even at a distance of 20,000 km, with high azimuth precision, as well as identifying electromagnetic signals from Italian volcanoes [Straser 2021] before these we produced earthquakes.
Last but not least are the results of this study focused on the electromagnetic monitoring of the Etna volcano, which provided information on the detection times of the electromagnetic waves generated by the volcano before the occurrence of the paroxysmal phenomena.
In the case in question, i.e. the experimentation of the forecasting methodology based on RDF technology, on the Etna volcano, the data presented encouraging results on the ability of the RDF system to predict paroxysmal phenomena of the volcano itself in time.
The research results clearly show that the combination of a trend forecast using electromagnetic emission and frequency spectrum as initial data is an effective tool for predicting the time of the Etna volcano eruption.

REFERENCES

[Bozek 2021] Bozek, P., Nikitin, Y., Krenicky, T. The Basics Characteristics of Elements Reliability. In: Diagnostics of Mechatronic Systems. Series: Studies in Systems, Decision and Control, 2021, Vol. 345, pp. 1-15. ISBN 978-3-030-67055-9.

[Console 2003] Console, R., et al. Re-fining earthquake clustering models. Geophys. Res., 2003, Vol. 108, No. 10., pp. 2468-2477. ISSN 2169-9356.

[Dahiya 2013] Dahiya R.S. and Valle, M. Appendix A - Fundamentals of Piezoelectricity. In: Robotic Tactile Sensing. Springer: Dordrecht, Germany, 2013.

[Dobrovolskiy 2005] Dobrovolskiy, I.L. Gravitational precursors of tectonic earthquake. Physics of the Earth, 2005, No. 4, pp. 23-28. ISSN 0022-3743. (in Russian)

[Faenza 2003] Faenza, L., et al. A non-parametric hazard model to characterize the spatio-temporal occurrence of large earthquakes: An application to the Italian catalogue. Geophys. J. Int., 2003, Vol. 155, No. 2, pp. 521-531. ISSN 0956-540X.

[Fedorov 2005] Fedorov, V.M. Chronological structure and possibility of volcanic activity in connection with tidal deformation of lithosphere. Volcanology and seismology, 2005, No. 1, pp. 44-50. (in Russian)

[Geller 1997] Geller, R.J., et al. Earthquakes cannot be predicted. 1997, Vol. 275, No. 5306., pp. 1616-1617.

[Gerstenberger 2005] Gerstenberger, M.C., et al. Real-time forecasts of tomorrow's earthquakes in California. Nature, 2005, No. 435, pp. 328-331. ISSN 1476-4687.

[Giovambattista 2000] Giovambattista, R. and Tyupkin Y. Spatial and temporal distribution of seismicity before the Umbria-Marche September 26, 1997 earthquakes. J. Seismol., 2000, No. 4, pp. 589-598. ISSN 1383-4649.

[Hata 1994] Hata, M., Yabashi, S. Observation of ELF radiation related to volcanic and earthquake activities. In: Electromagnetic phenomena related to earthquake prediction, Hayakawa, M. and Fujinawa, Y. (Eds.). Terra Scientific (TERAPUB), Tokyo, pp. 159-174, 1994.

[Hata 2001] Hata, M., Takumi, I., Yasukawa, H. Electromagnetic-wave radiation due to diastrophism of magma dike growth in Izu-Miyake volcanic eruptions in Japan in 2000. Natural Haz. & Earth System Sciences, 2001, Vol. 1, pp. 43-51.

[Johnston 1989] Johnston, M.J.S. Review of magnetic and electric field effects near active faults and volcanoes in the U.S.A. Physics of the Earth and Planetary Interiors, 1989, Vol. 57, Issues 1-2, pp. 47-63.

[Kanamori 2004] Kanamori, H. and Brodsky, E.E. The physics of earthquakes. Rep. Prog. Phys., 2004, Vol. 67, No. 8, pp. 1429-1496. ISSN 0034-4885.

[Krenicky 2021] Krenicky, T. and Nahornyi, V. Trend Forecast for Short-term of Shock-Vibration Prediction. MM Science Journal, 2021, Volume Oct., pp. 4786-4790.

[Lonzich 2012] Lonzich, P.A. and Eliseev, S.V. Trend prognosis and control of system of quality. Sistemy. Metody. Tekhnologii. 2012, No. 4, pp. 29-35. (in Russian)

[Macala 2009] Macala, J., Pandova, I., Panda, A. Clinoptilolite as a mineral usable for cleaning of exhaust gases. Mineral Resources Management, 2009, Vol. 25, No. 4, pp. 23-32.

[Malkin 2021] Malkin E.I., et al. Dirty thunderstorms caused by volcano explosive eruptions in Kamchatka by the data of electromagnetic radiation. Conf. Ser., Earth Environ. Sci. 946012015, 2021.

[Murcinkova 2013] Murcinkova, Z., Krenicky, T. Implementation of virtual instrumentation for multiparametric technical system monitoring. In: SGEM 2013: 13th Int. Multidisciplinary Sci. Geoconf., Vol. 1; 16-22 June, 2013, Albena, Bulgaria. Sofia: STEF92 Technology, 2013, pp. 139-144.

[Nagornyi 2017] Method of long-term forecasting of the coordinates of the epicenter of the next earthquake. Application registration No.: u 2017 11548, Date of submission: 27.11.2017. (in Ukrainian)

[Nagornyi 2018a] Nagornyi, V. Earthquake forecasting by the results of the seismic signal trend analysis. Geofizicheskiy Zhurnal, 2018, Vol. 40, No. 6., pp. 159-176. (in Russian)

[Nagornyi 2018b] Method of forecasting the time of the next earthquake. Application registration No.: u 2018 00119, Date of submission: 30.01.2018. (in Ukrainian)

[Nagornyi 2018c] Method for predicting the strength of the expected earthquake. Application registration No.: u 2018 01307, Date of submission: 12.02.2018. (in Ukrainian)

[Nagornyi 2020a] Nahornyi V., Pigulevskiy P., et al. To the question of verification of forecasting methods of earthquakes. In: XIV Int. Sci. Conf. "Monitoring of Geological Processes and Ecological Condition of the Environment", 10-13 November 2020, Kyiv, Ukraine. (in Russian)

[Nagornyi 2020b] Nagornyi V., Pigulevsky P., et al. On the development of a method for short-term forecasting of earthquakes based on fluctuations in the water level in wells / Structure, material composition, properties, modern geodynamics and seismicity of platform territories and adjacent regions. In: XXII All-Russian Sci. and Practical Conf. Shchukin Voronezh with International Partic., Sept. 22-25, 2020. Voronezh State Univ. Publ. House, pp. 247-252. (in Russian)

[Panda 2013] Panda, A., Duplak, J., Jurko, J., Pandova, I. Roller Bearings and Analytical Expression of Selected Cutting Tools Durability in Machining Process of Steel 80MoCrV4016. Applied Mechanics and Materials, 2013, Vol. 415, pp. 610-613.

[Panda 2014] Panda, A. and Duplak, J. Comparison of Theory and Practice in Analytical Expression of Cutting Tools Durability for Potential Use at Manufacturing of Bearings. Applied Mechanics and Materials, 2014, Vol. 616, pp. 300-307.

[Panda 2016] Panda, A., Jurko, J., Pandova, I. Monitoring and Evaluation of Production Processes. An Analysis of the Automotive Industry. Springer, Switzerland, 2016, 117 p.

[Panda 2019] Panda, A., et al. Development of the method for predicting the resource of mechanical systems. Int. J. of Adv. Manuf. Technology, 2019, Vol. 105, No. 1-4, pp. 1563-1571.

[Panda 2021] Panda, A. and Nahornyi, V. Forecasting Catastrophic Events in Technology, Nature and Medicine. Springer Briefs in Applied Sciences and Technology. Computational Intelligence. Springer Nature Switzerland AG, Cham, 2021, 110 p.

[Pandova 2018] Pandova, I., et al. Use of Sorption of Copper Cations by Clinoptilolite for Wastewater Treatment. Int. J. of Environmental Research and Public Health, 2018, Vol. 15, No. 7, pp. 1364-1376.

[Straser 2017] Straser, V. Cataldi, D., Cataldi, G. Radio Direction Finding System, a new perspective for global crust diagnosis. New Concepts in Global Tectonics Journal, 2017, Vol. 6, No. 2.

[Straser 2019a] Straser, V. Cataldi, D., Cataldi, G. Radio Direction Finding (RDF) - Geomagnetic Monitoring Study of the Himalaya Area in Search of Pre-Seismic Electromagnetic Signals. Asian Rev. Envir. and Earth Sci., 2019, Vol. 6, No. 1, pp. 16-27.

[Straser 2019b] Straser, V. Cataldi, D., Cataldi, G. Registration of Pre-Seismic Signals Related to the Mediterranean Area with the RDF System Developed by the Radio Emissions Project. Int. J. of Eng. Sci. Invention, 2019, Vol. 8, Issue 3, pp. 26-35.

[Straser 2019c] Straser, V. Cataldi, D., Cataldi, G. Electromagnetic monitoring of the New Madrid Fault us area with the RDF system - Radio Direction Finding of the radio emissions Project. New Concepts in Global Tectonics Journal, 2019, Vol. 7, No. 1, pp. 43-62.

[Straser 2021] Straser, V. et al. Electromagnetic Monitoring of Italian Volcanoes with the RDF Network, Developed by the Radio Emissions Project. Int. J. of Social Relevance & Concern (IJSRC), 2021, Vol. 9, Issue 7.

[Valicek 2016] Valicek, J., et al. A new approach for the determination of technological parameters for hydroabrasive cutting of materials. Materialwissenschaft und Werkstofftechnik, 2016, Vol. 47, No. 5-6, pp. 462-471.

[Valicek 2017] Valicek, J., et al. Identification of Upper and Lower Level Yield strength in Materials. Materials, 2017, Vol. 10, No. 9, 982.

[Zlotnicki 2009] Zlotnicki, J., et al. Electromagnetic and geochemical methods applied to investigations of hydrothermal/volcanic unrests: Examples of Taal (Philippines) and Miyake-jima (Japan) volcanoes. Physics and Chemistry of the Earth, 2009, Vol. 34, Issue 6, pp. 394-408.

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