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The shockwave from Tonga volcano on 15 January 2022 was detected by weather stations of NIMH

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Abstract: A rare geological event occurred on 15 January 2022 – a powerful eruption of an active volcano in the archipelago of Tonga in the Pacific triggered an atmospheric shock wave that traveled the globe. It was visible in infrared satellite images and was detected in pressure records from weather stations around the world. The National Institute of Meteorology and Hydrology has been installing during the last years in weather stations around the country automated instruments for measuring atmospheric pressure. The Tonga shock wave was detected by those in due time in line with similar detection in neighboring countries. The detection of multiple passings of the wave allowed for the calculation of the time of occurrence of the blast in Tonga. Examples of pressure records and explanations are given.

Keywords: Tonga volcano, atmospheric shock wave, atmospheric pressure

1. INTRODUCTION

A rare geological event occurred on 15 January 2022 – a powerful underwater eruption of the active volcano Hunga Tonga–Hunga Ha'apai in the archipelago of Tonga in the Pacific (NASA Earth Observatory Undersea Eruption Near Tonga) – Figure 1. Different sources put the time of the blast between 4:00 and 7:00 UTC. The pressure wave timing in Bulgaria allows to give our own estimate of the time of occurrence of the initial blast in Tonga. The eruption triggered a tsunami in the Pacific that traveled to shores as far as South America and Japan. It also triggered an atmospheric shock wave that traveled the globe with the speed of sound – Figure 2.

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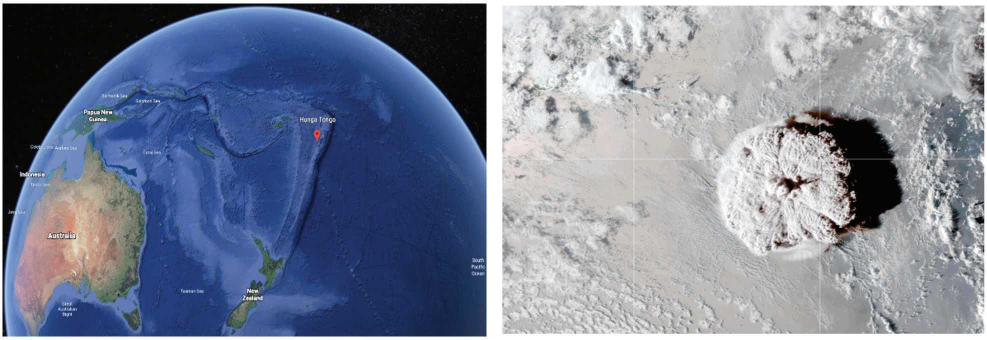

Fig. 1. The location of the Hunga Tonga volcano (left) – source https://earth.google.com/ – and the mushroom cloud of its eruption on 15 January 2022 (right) – source https://earthobservatory.nasa.gov/images/event/85016/undersea-eruption-near-tonga.

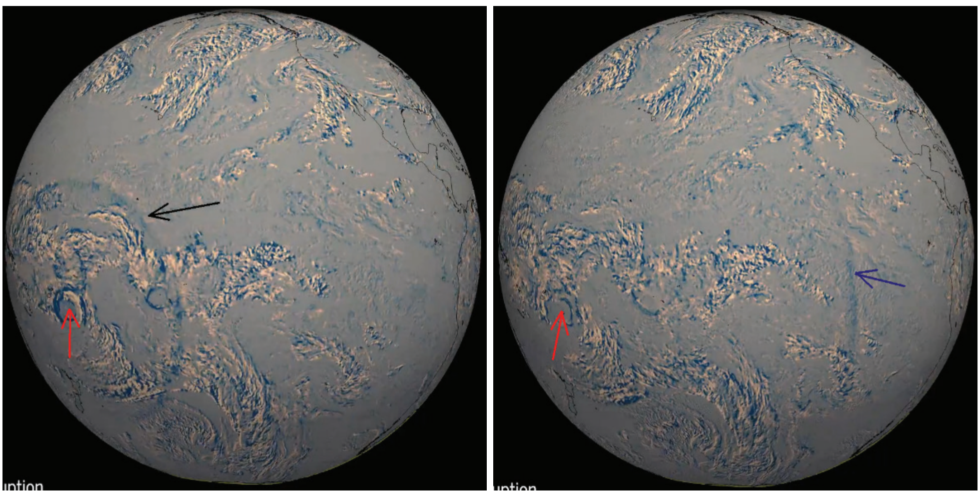

Fig. 2. Shock wave seen in infrared satellite images – NOAA's GOES-17. Source - https://www.science.org/content/article/tonga-shock-wave-created-tsunamis-two-different-oceans. Red arrrow points to the location of the volcano. Black arrow on left image points to the circle of front of the shock wave at an earlier stage and blue arrow on the right image – at a later stage.

The early hypotheses are that the relatively shallow underwater eruption lead to very rapid evaporation of a large amount of sea water which instantly expanded into the atmosphere and worked similarly to a nuclear explosion. The sudden compression of the air in situ provoked a shock wave. There was audible sound wave heard as far as Alaska but the pressure wave that traveled the world was a single low frequency acoustic wavelet. It was visible in infrared satellite images (Figure 2) and was detected in pressure records from weather stations around the world.

The National Institute of Meteorology and Hydrology (NIMH) has been installing during the last 3 years automated instruments - psychrometers Unisyst Meteo100 and Meteo200 for measuring air temperature and calculating the humidity characteristics. For that, also an atmospheric pressure measurement is realized for the automated process of calculations upon formulae of the World Meteorological Organization (WMO). Although the atmospheric pressure sensor is not in the strict WMO limits for error (its own maximum absolute error is +/– 2hPa), it is precise enough for the calculations of humidity characteristics in the WMO standard limits and to catch the trend of atmospheric pressure. The measurement resolution is fixed to 1 and 10 minutes. The Tonga shock wave was detected in the pressure records taken by those instruments throughout the whole country. The time of the detected perturbations corresponds roughly to the theoretical expectations for an acoustic wave and are in line with similar detection in neighboring countries. They allow an independent estimate of the time of the initial blast to be given. This short paper also shows examples of pressure records where the perturbations are visible and gives explanations.

2. SHOCK WAVE IN PRESSURE RECORDS

The news about the Tonga volcano on 15 January 2022 found their way through the media very rapidly. Satellite images and animations were posted showing the mushroom of the explosion in the Pacific – Figure 1.

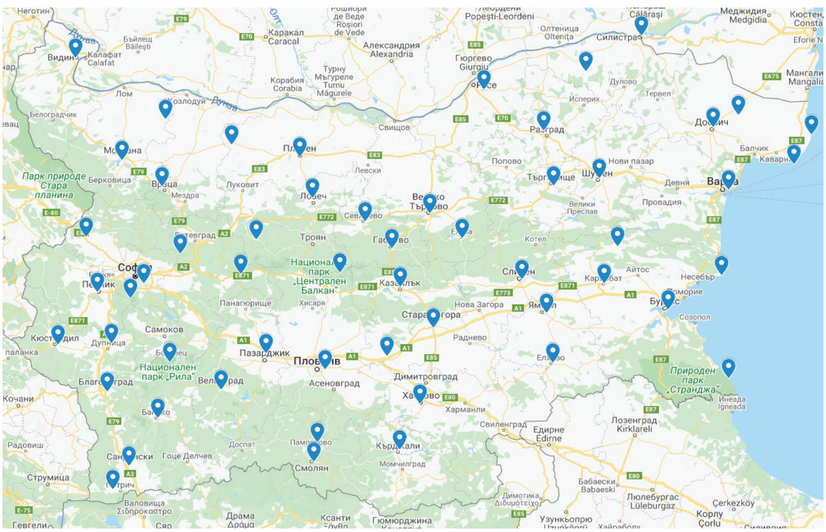

Fig. 3. Location of the weather stations of NIMH with automated psychrometer. The map has been produced by https://mymaps.google.com .

The shock wave was also very easily distinguishable in the infrared satellite images – Figure 2. It was almost perfectly circling the globe for its first tour. Meteorologists and other experts around the world started to report anomalies in pressure records soon after the explosion. Some offered model simulations of such shock wave traveling the sphere – Figure 4. The new automated instruments of NIMH, installed in operational weather stations, take atmospheric pressure and temperature to estimate air humidity parameters. Figure 3 shows the locations where the new automated instruments of NIMH have been installed. Data from those are instantly available and the perturbations in pressure could have been followed in real time.

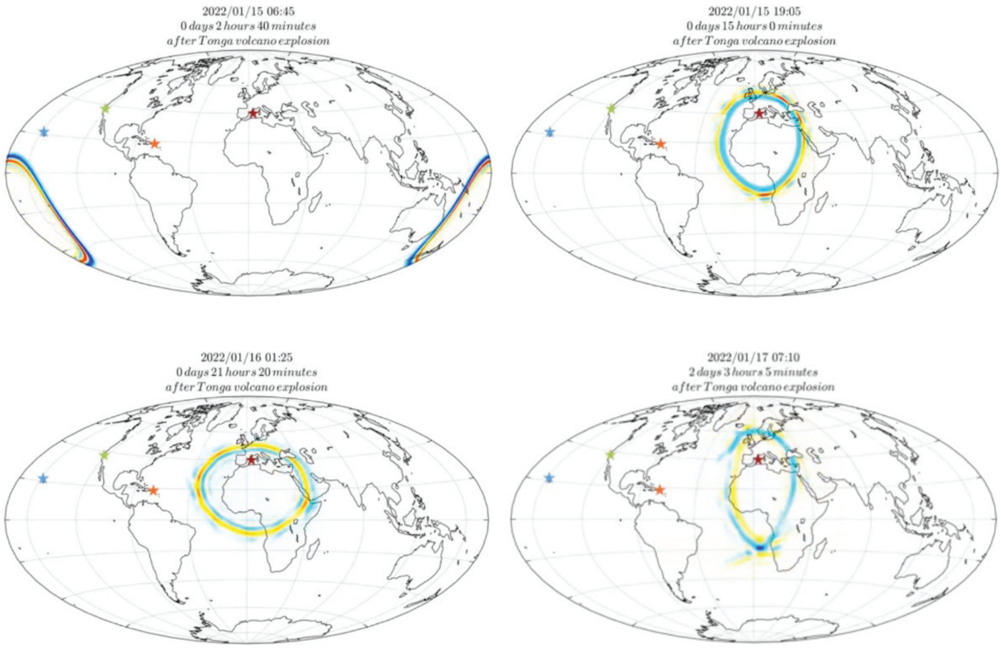

Fig. 4. Model simulations of the pressure wave: upper left – 2 h 40 min after the eruption; upper right – first passage over Bulgaria – 15 h later; lower left – second passage over Bulgaria – around 21 h 20 min after the shock; lower right – third passage over Bulgaria – about 2 days and 3 h after the shock. Source – Angel Amores, Physical Oceanographer. Postdoctoral researcher at @IMEDEA_UIB_CSIC . https://twitter.com/an_amores/status/1484516695087759363 . The time of initial eruption may not match the one used in this paper.

This is perhaps the first time in the history of meteorological observations at NIMH when such a rare atmospheric event can be followed in real time. Pressure records from the stations in Shabla – one of the most northeastern weather stations in Bulgaria, and in Sandanski – one of the most southwestern – are given in Figure 8 to illustrate the timing of the shock wave. Data are recorded in a minute interval, which allows the detection and the follow up of rapid atmospheric processes or processes with short lifetime. The passage of the Tonga shock wave is one such rapid event.

The NIMH also operates one Vaisala AWS310 weather station with BARO-1Q atmospheric pressure sensor, measuring air pressure in the Central meteorological observatory in Sofia – the capital. The pressure records from this station are given in Figures 5 and 6. Figure 5 shows the actual sequence of pressure records by the minute (in dark blue) together with the 1-hour running average (in red).

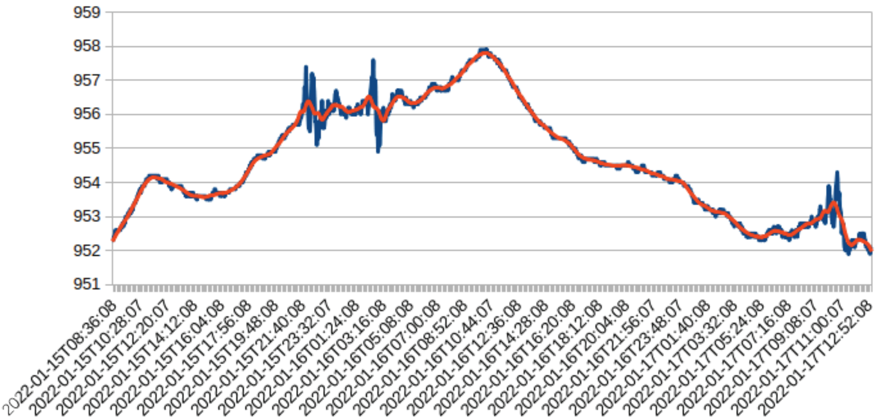

Fig. 5. Atmospheric pressure record (hPa) from the Central meteorological station of NIMH in Sofia from 8:30 on 15 January to 13:00 on 17 January 2022 (local time). Dark blue line - air pressure by minute; red line - 1-hour running average. Left axis – pressure in hPa; bottom axis – date and time in format YYYY-MM-DD T HH:MM:SS where "T" is a separator between date and time.

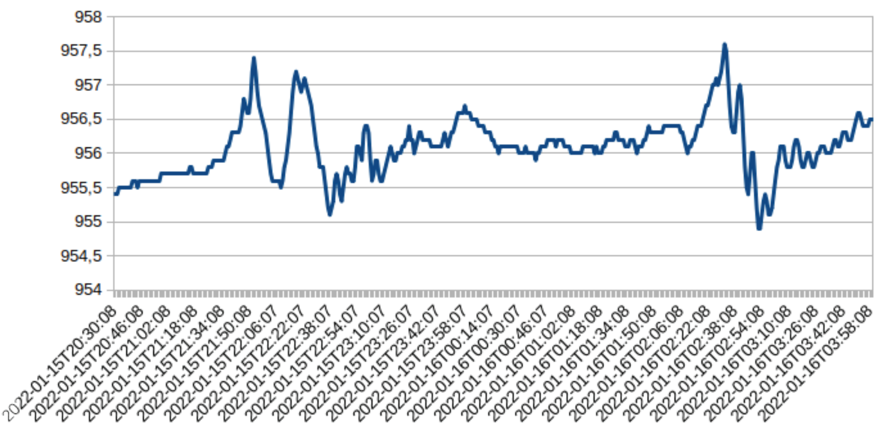

Fig. 6. Zoom of the pressure record (hPa) from Fig. 5 for the time zone between 8:30 p.m. (20:30) on 15 January to 4.00 a.m. on 16 January. Left axis – pressure in hPa; bottom axis – date and time in format as in Fig. 5.

This allows the perturbations caused by the shock wave to be easily recognized. The pressure shows a jump for the first time at around 9:40 p.m. (21:40) local time on 15 January. It is followed by a second jump at around 2:15 a.m. on 16 January. The pressure line pattern between the two also looks perturbed but to a smaller degree. The pressure line restores its normal trend after the second shock. It is illustrated by the fact that the more frequent record line matches almost perfectly the 1-hour running average. A third shock can be seen in the morning of 17 January at around 9:20 a.m.

Figure 6 zooms the pressure record from Figure 5 for the time zone between 8:30 p.m. (20:30) on 15 January and 4:00 a.m. on 16 January. It allows to analyze the pressure spikes more thoroughly.

The amplitude of the first spike is around 2 hPa. It consists of two similar peaks following each other within 1 hour and 20 minutes from around 9:20 p.m. (21:20) to 10:40 p.m. (22:40). The two pressure shocks seem to be both at the positive side of the average trend. They do not show a significant compensating negative phase of the wave. The pressure pattern after the second positive shock remains perturbed for about 1 and a half hour before returning to its background trend. The second wave begins at around 2:15 a.m. on 16 January. It has a positive phase and a negative phase with an amplitude of about 1.5 hPa. It lasts for about an hour. The first front of the shock wave produced a pressure anomaly of about 2 hPa, as said above. Figure 5 shows that a similar increase takes around 12 hour to materialize by the background trend of the day resulting from synoptic scale atmospheric processes .

3. THEORETICAL EXPLANATIONS

It was reported in media that the eruption took place around 6:30 a.m. Bulgarian local time. Originally we thought acoustic wave could have been the nature of the phenomenon. Acoustic waves spread in the air theoretically at the speed of sound and travel from one point to another on the shortest way.

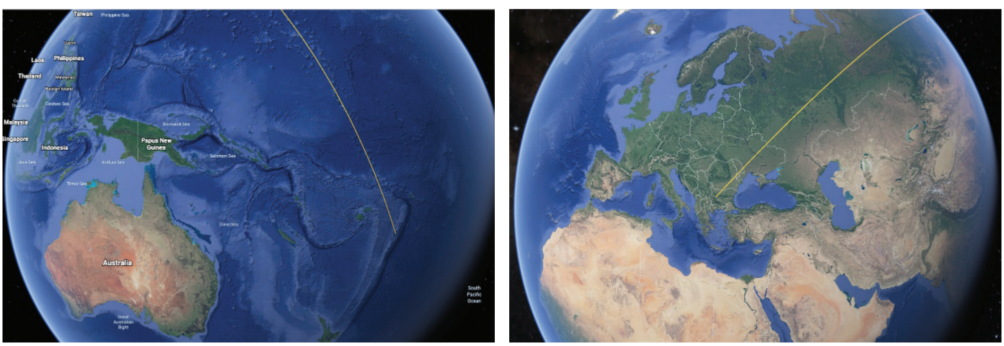

Fig. 7. Beginning in Tonga (a) and end in Bulgaria (b) of the shortest line between the two. Source - https://earth.google.com/.

The shortest distance between Tonga and Bulgaria is about 17 000 km. The line connecting the two comes to Bulgaria from the northeast and can be followed on Figure 7.

The timing of the pressure wave crossing Bulgaria could actually help to determine its mean speed. The first pressure shock was detected in Sofia at 9:40 p.m. (21:40) local time on 15 January after having traveled around 17000 km from Tonga. It arrived from northeast – the shortest distance from the Pacific archipelago. The second one arrived at 2:15 a.m. on 16 January or about 4 h 35 min later. The second shock wave front traveled to Bulgaria from the opposite direction – southwest. It should have traveled about 23 000 km – the entire circumference of the globe being around 40 000 km (Earth radius – 6 371 km). In other words, the second wave has traveled around 6000 km longer and arrived 4 h 35 min later than its opposite twink wave. This fact gives an opportunity to estimate the mean speed of the shock wave for its first round of the Earth: $V_{Tongawave} = \frac{6000km}{4h35min} \approx 364m/s$. Having this in mind we can now give an estimate of the time of occurrence of the blast: $t_1 = 21:40 - \frac{17000km}{364m/s} \approx 8:40$ Bulgarian local time (6:40 UTC). Identical computation gives practically the same result if estimated by the time of arrival of the second wave.

What could be the explanation for the third pressure peak at around 9:20 a.m. on 17 January – about 35 h 40 min after the first wave front hit Sofia? The Tonga shock wave was so strong that it traveled the world and back more than once. Model simulations (Figure 4) as well as stations pressure records reported detectable shock wave up to 5 days after the event. The third shock on 17 January in Sofia is the first from the second round of the wave after having made the full turn around the Earth. This allows us to give another estimate of the mean speed of the Tonga shock wave for its second round of the Earth: $V_{tongawave} = \frac{40000km}{35h40min} \approx 312m/s$. The Tonga wave to arrive to Sofia by this speed, however, requires the blast to have occurred between 3:50 and 4:35 UTC. This timing of occurrence of the blast in Tonga corresponds better to other reports from the web: https://michilehr.de/the-eruption-of-hunga-tonga-volcano-and-its-blast-wave-around-the-globe .

The average speed of the shock wave for its first two rounds of the Earth is ≈ 338 m/s. The speed of sound in air at 20 °C is about 343 m/s. It depends strongly on temperature and, for example, it is about 331 m/s at 0 °C. This has been theoretically derived for ideal gas where it depends only on temperature and the air composition. A formula for sound speed can be found at: https://www.weather.gov/media/epz/wxcalc/windConversion.pdf

$$V_{sound} = 331x\left(\frac{T}{273.15}\right)^{0.5} ,$$

where the speed V comes in m/s and T is the absolute temperature in degrees Kelvin. The estimated average speed of the Tonga shock wave for its first two rounds of the Earth fits the theoretical range of the speed of sound for normal air temperatures.

It has to be kept in mind that these calculations are approximate. The error of taking the distance from the exact site of the volcano in Tonga and Sofia can be as much as a 1000 km – a distance, the sound travels in about an hour. Another factor that could influence the wave travel is that the Earth is not an exact sphere.

In bigger countries the shock waves could have been followed going through the country by the hour and thus illustrate the direction in which they have passed. Bulgaria, however, is relatively small. The longest distance between its northeastern and southwestern corner is about 450 km. It takes about 22 min of a sound wave to travel the distance.

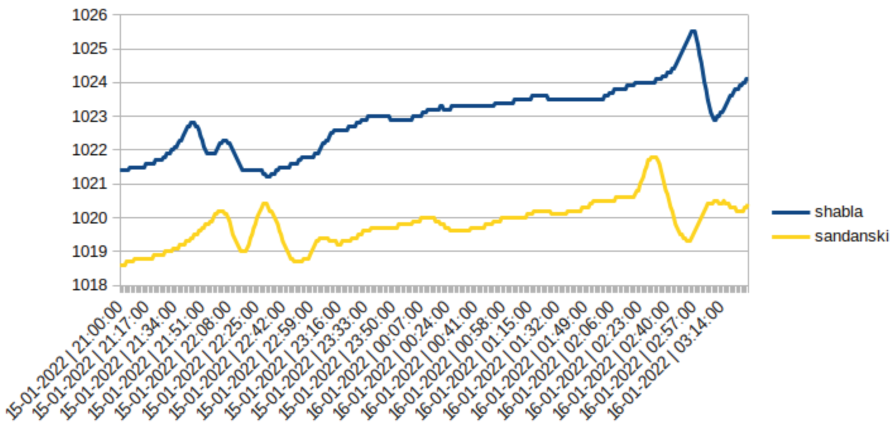

Fig. 8. Pressure (hPa) trend in Shabla (upper deep blue line) and Sandanski (+18 hPa) (lower yellow line) between 21:00 on 15 January and 3:30 a.m. on 16 January 2022. Left axis – pressure in hPa; bottom axis – date and time in format DD-MM-YYYY I HH:MM:SS where "I" is a separator between date and time.

We have chosen to illustrate the effect how the first and the second front arrived in Bulgaria by showing in Figure 8 the pressure records from instruments in Shabla, one of the most northeastern stations in Bulgaria, and Sandanski, one of the most southwestern. Sandanski is at higher altitude and the pressure there is typically about 20 hPa lower than in Shabla. In Figure 8 its pressure has to be increased by 18 hPa in order to fit the diagram and be easily compared to the pressure in Shabla. As seen in Figure 8, the pressure wave arrives in Sandanski about 20 min later than in Shabla, which is the time a sound wave would travel the distance between the two. The second wave, however, arrived in Sandanski earlier than in Shabla and the reason for that is that the second front came from the opposite side – from southwest.

3. CONCLUSIONS

This short paper illustrates the recently built capacity of NIMH to detect short lived atmospheric phenomena by a network of automated instruments. The case of a rare geological phenomenon – an atmospheric shock wave triggered by a violent eruption of a volcano at the other side of the globe – gave an opportunity to demonstrate this newly built capacity of NIMH. The shock wave itself is a once-in-a-life-time event that merits its documentation in our national scientific literature.

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