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Effect of Hunga Tonga - Hunga Ha'apai Volcanic Eruptions on Atmospheric Pressure

Hunga Tonga - Hunga Ha'apai Volkan Patlamalarının Atmosfer Basıncına Etkisi

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Öz

Bu çalışmanın amacı, Hunga Tonga - Hunga Ha'apai yanardağının 15 Ocak 2022'de 04:14 UTC'de volkanik patlamasının neden olduğu atmosfer basıncındaki dalgalanmanın incelenmesidir. Patlamanın yarattığı dalganın ses hızında sabit hareket edeceği öngörülerek, 16.000 km uzaklıktaki Türkiye'ye 13 saat 22 dakika sonra 17:36 UTC'de varacağı hesaplanmıştır. İkinci aşamada, Türkiye'deki 12 Meteoroloji İstasyonunun (Otomatik Hava Gözlem Sistemi, AWOS) 1 dakikalık basınç verileri analiz edilmiştir. Yapılan analiz ve değerlendirmelerde, ilk olarak en doğudaki istasyon olan Van Meteoroloji İstasyonunun 15 Ocak 2022, 18:38'deki basıncında keskin bir yukarı yönlü hareket gözlemlenmiştir. Şok dalgasının bu istasyona ortalama 304.8 m/s hızla 14.4 saatte geldiği hesaplanmıştır. Lamb Dalgalarının hesaplanan varış zamanları uydu görüntüleri ile teyit edilmektedir. Meteosat-8 görüntülerine göre (IR6.2), Lamb Dalgası Türkiye'nin doğusundan 18:30 UTC'de girmiş ve 20:00 UTC'de Türkiye'den ayrılmıştır.

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Abstract

The aim of this study is to examine the atmospheric pressure fluctuation caused by the volcanic eruption of Hunga Tonga - Hunga Ha'apai volcano on January 15, 2022 at 04:14 UTC. It was estimated that the wave created by the explosion would move at a constant speed of sound and it was calculated that it would arrive in Turkey in 13 hours and 22 minutes at 17:36 UTC. In the second stage, 1-minute pressure data of 12 Meteorology Stations (Automatic Weather Observation System, AWOS) in Turkey were analyzed. In the analyses and evaluations made, a sharp upward movement was observed in the pressure of Van Meteorology Station, which is the easternmost station, at 18:38 on January 15, 2022. It has been calculated that the shock wave arrived at this station in 14.4 hours at an average speed of 304.8 m/s. The calculated arrival time of Lamb waves are confirmed by satellite images. According to Meteosat-8 images (IR6.2), lamb wave appeared to enter from the east of Türkiye at 18:30 UTC and left Türkiye at 20:00 UTC.

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1. Introduction

As a result of volcanic eruptions, sulfur and phosphate aerosols are emitted into the atmosphere abundantly. While aerosol emissions affect air quality negatively, they cause short-term cooling on the climate as it reduces the amount of solar energy reaching the earth. In a study conducted in Scotland, it has been reported that in the decades after the explosion, decreases in temperatures up to 2.6 °C were observed as a result of Icelandic volcanic eruptions occurred between 1783-1784 (Cole-Dai, 2010; Dawson et al., 2021; Di Martino et al., 2021).

Acoustic waves named as Lamb waves are formed in the atmosphere as a result of major volcanic eruptions. Lamb waves have purely horizontal motion, occupying the full depth of the troposphere with a maximum pressure signal at the surface. These waves are only slightly affected by the Earth's rotation and travel at the speed of sound (Gossard and Hooke, 1975). Volcanic eruptions often cause the pressure fluctuation. In a study conducted in England, it is stated that the series of rapid rises and falls in pressure takes over about 30 minutes. It has been observed by the Global Seismic Network (GSN) that the atmospheric pressure has risen by approximately 2 hPa on global scale (Burt, 2022; Kubota et al., 2022; Le Pichon, 2005).

The effect of the Hunga Tonga explosion on pressure has been observed worldwide. This effect is the first example in this respect. The explosion caused perturbation in pressure. Lamb waves have been observed in different parts of the world in the same period of time. Lamb waves formed as a result of a volcanic eruption move at approximately the speed of sound (Amores et al., 2022; Sepic et al., 2022).

Lamb waves caused by major volcanic eruptions affect atmospheric pressure. In this study, the effect of the extreme eruption that occurred on the Hunga Tonga - Hunga Ha'apai volcano in the Pacific Ocean on January 15, 2022 at 04:14 UTC on the pressure values measured in Türkiye was investigated.

2. Data and methods

2.1. Study Area

Hunga Tonga - Hunga Ha'apai submarine volcano is located approximately 65 kilometers north of Nuku'alofa, the capital of Tonga, in the eastern Australia (Figure 1) and approximately 16,000 km away from Türkiye (Figure 2).

An extreme volcanic eruption occurred at the Hunga Tonga - Hunga Ha'apai volcano in the South Pacific on January 15, 2022, at 04:14 UTC. According to the U.S. Geological Service, the explosion caused seismic waves with a magnitude of 5.8 and a tsunami. The volcanic eruption produced tsunami waves that affected the entire Ocean, including the tropical Pacific region, 18,000 km far from the source (*M 5.8 Volcanic Eruption - 68 Km NNW of Nuku'alofa, Tonga*; *The January 15, 2022 Hunga Tonga-Hunga Ha'apai Eruption and Tsunami, Tonga*, Sepic et al., 2022).

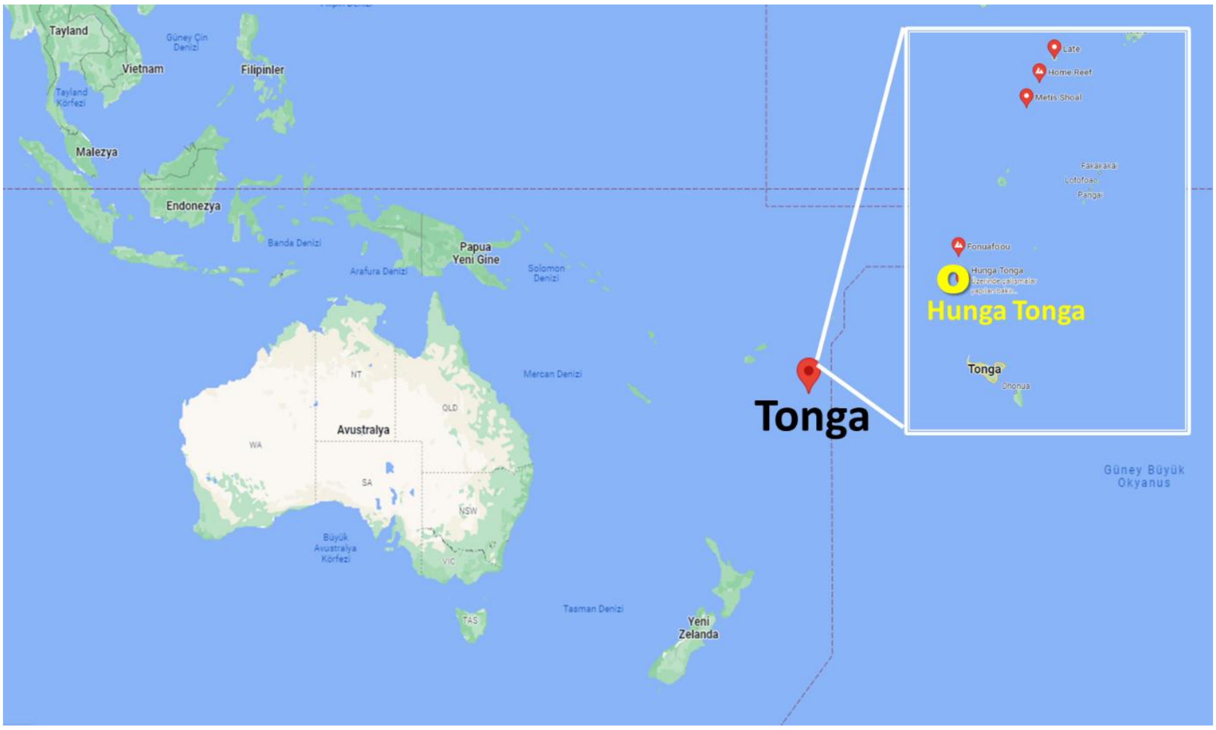

Figure 1. Hunga Tonga - Hunga Ha’apai Volcano location map (175.40°W - 20.5°S)

Figure 2. Distance of Hunga-Tonga Volcano to Türkiye

Satellite observations revealed, in the next few hours, unprecedented large-scale Lamb waves from the explosion that spread throughout the entire Pacific Ocean in the middle stratosphere (at an altitude of about 40 km). These wave observations are unprecedented in stratospheric satellite observations has been over the past 20 years (Figure 3). This explosion could potentially have produced the first observations of an acoustic wave in the middle stratosphere that can be measured from space (Hindley et al., 2022).

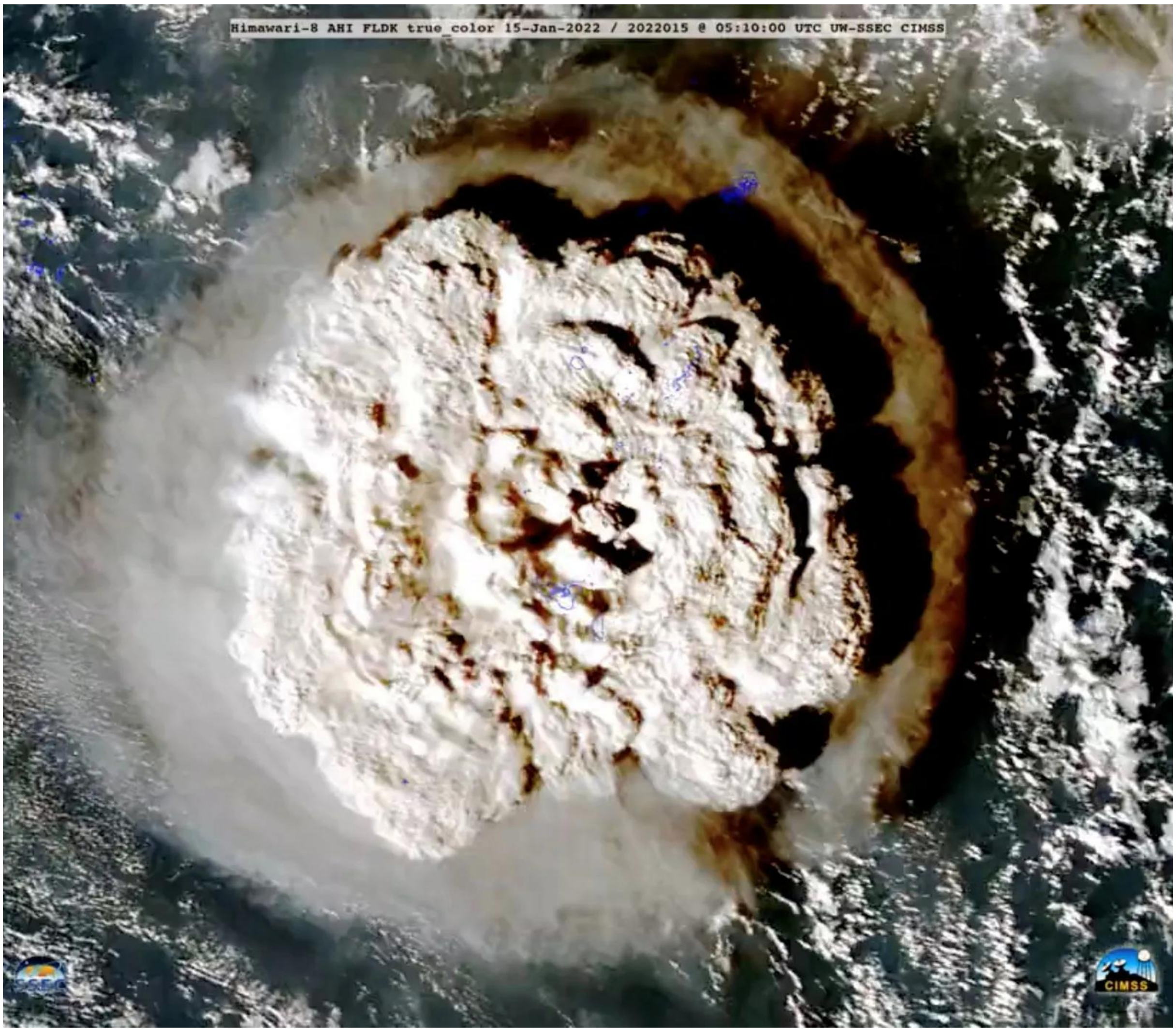

Figure 3. JMA Himawari-8 True Color RGB images,
Source: https://cimss.ssec.wisc.edu/satellite-blog/archives/44252

2.2. Data

In order to monitor the impact of the explosion over Türkiye, 1 minute air pressure measurement of selected automated weather observing systems (AWOS) were examined from 15 January 2022 00:01 UTC to 16 January 2022 06:00 UTC (Table 1, Figure 4).

Table 1. Selected automated weather observation systems (AWOS)

Province	WMO Code	Latitude	Longitude	Elevation	Distance (km)
Samsun	17030	41,344	36,256	4	16519
Trabzon	17037	40,999	39,765	25	15992
Istanbul	17064	40,911	29,156	18	16766
Erzurum	17095	39,906	41,254	1860	15921
Ankara	17130	39,973	32,864	891	16563
Van	17172	38,469	43,346	1675	15802
Afyonkarahisar	17190	38,738	30,560	1034	16803
Kayseri	17196	38,687	35,500	1094	16429
Izmir	17220	38,395	27,082	29	17075
Konya	17245	37,869	32,471	1029	16706
Diyarbakır	17281	37,909	40,213	680	16082
Adana	17351	37,004	35,344	23	16519

Figure 4. Meteorological stations selected for the study

2.3. Wave Velocity Calculation Method

In order to estimate the arrival time of the Lamb wave created by the explosion in Türkiye, it is assumed that the Lamb wave moves at the speed of sound (343 m/sec) and the distance between the volcano and Türkiye is approximately 16500 km (Equation 1).

$$Lamb\ Wave\ Arrival\ Time = \frac{Distance}{Speed\ of\ Sound} \qquad (1)$$

In the equation 1, Distance=16500 km, Speed of sound=343 m/s.

With the equation 1, date on which Lamb wave started to be observed was predicted. In the second stage, sea level pressure values measured at the regional directorates were examined and Lamb wave arrival time for the station was determined. The moment when the pressure starts to move rapidly upwards is determined as the arrival time of Lamb wave. With equation 2, it was calculated how long it took for the Lamb wave to arrive.

$$Lamb\ Wave\ Velocity = Distance/\Delta t \qquad (2)$$

In Equation 2, Distance= distance between the regional directorate and the volcano, Δt = the difference between the time when sea level pressure at the regional directorate jumps upwards and the time of the volcanic eruption occurred.

3. Results and discussion

Mean sea level pressure charts for January 15 and January 16, 2022 are given as Figure 5 with cold and warm frontal systems. According to the pressure maps, low pressure center and the frontal system were located on Russia. In addition cold front was passing through northern Black Sea during the period. There was also a high pressure center in eastern Türkiye so the pressure tended to rise. It is seen that the isobar value of 1016 hPa found over the western parts on January 15 reached the inner parts of Türkiye with its horizontal movement within a 24-hour period. As a result, there is an increasing trend in pressure measured at the stations.

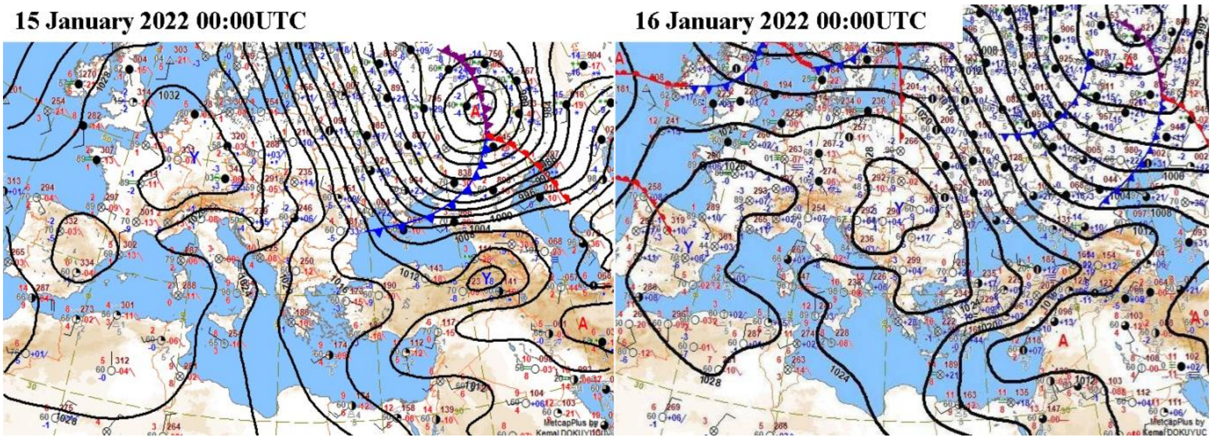

Figure 5. Sea level pressure (SLP) charts for January 15 and January 16, 2022

It is predicted that (from equation 1) the first Lamb wave will arrive in Türkiye from the northeast direction, starting from January 15, 2022 17:36 UTC, 13 hours and 22 minutes later.

Pressure measurement values obtained from 1 minute data recordings are given in Figure 6, Figure 7 and Figure 8. When the pressure changes are examined, it is understood that the Lamb wave started to reflect on the pressure curve of the stations in the northeast of Türkiye from 18:38 and then it was seen at the stations in the southwest direction. It is understood that the Lamb waves formed as a result of volcanic eruptions affect the pressure at least twice during the period from 18:38 on 15 January 2022 to 23:59 on 17 January 2022. The jumps (I, II) observed at the stations were consistent with each other and took place at close hours.

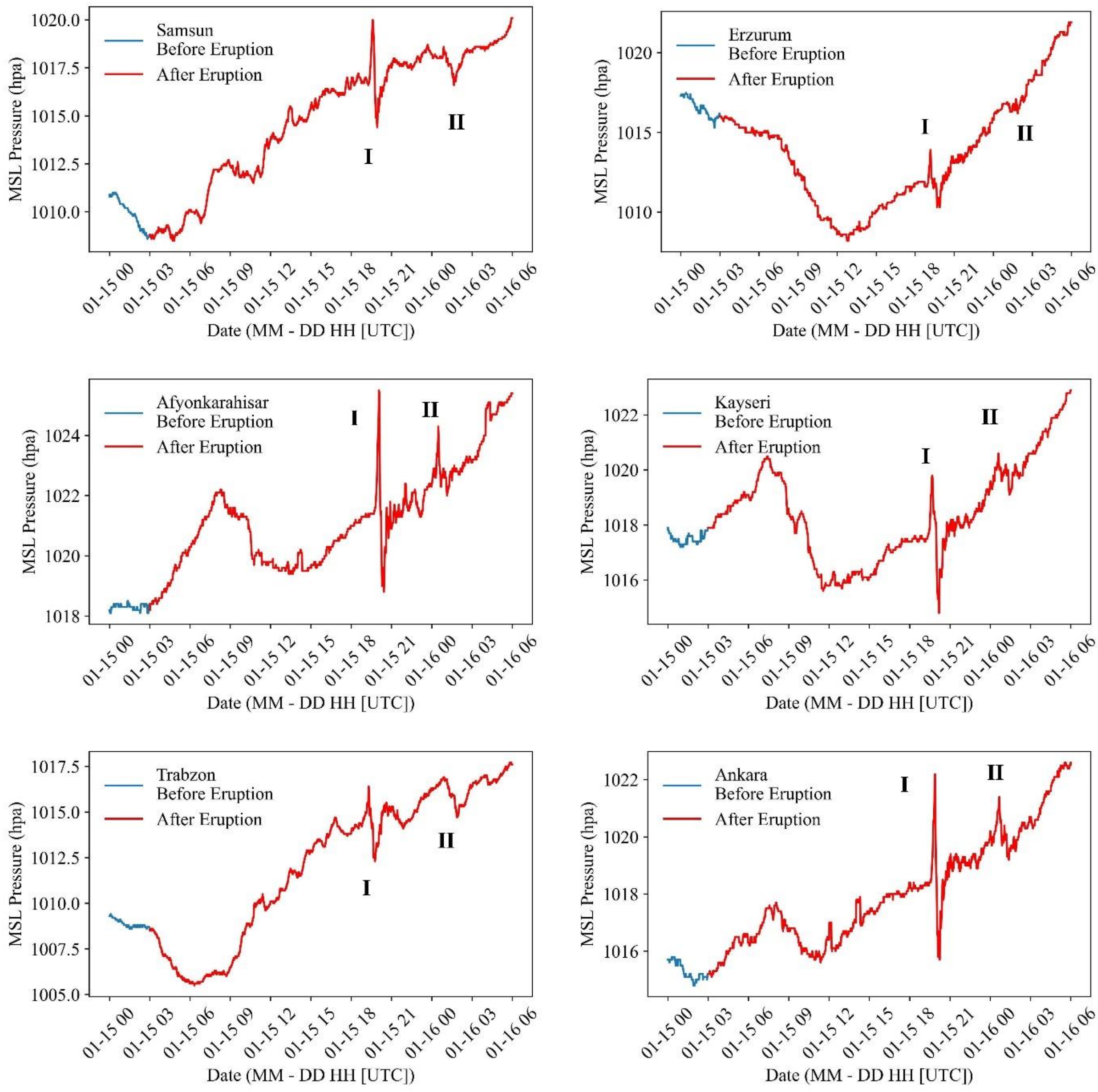

Figure 6. Station pressure changes (Samsun, Erzurum, Afyonkarahisar, Kayseri, Trabzon and Ankara)

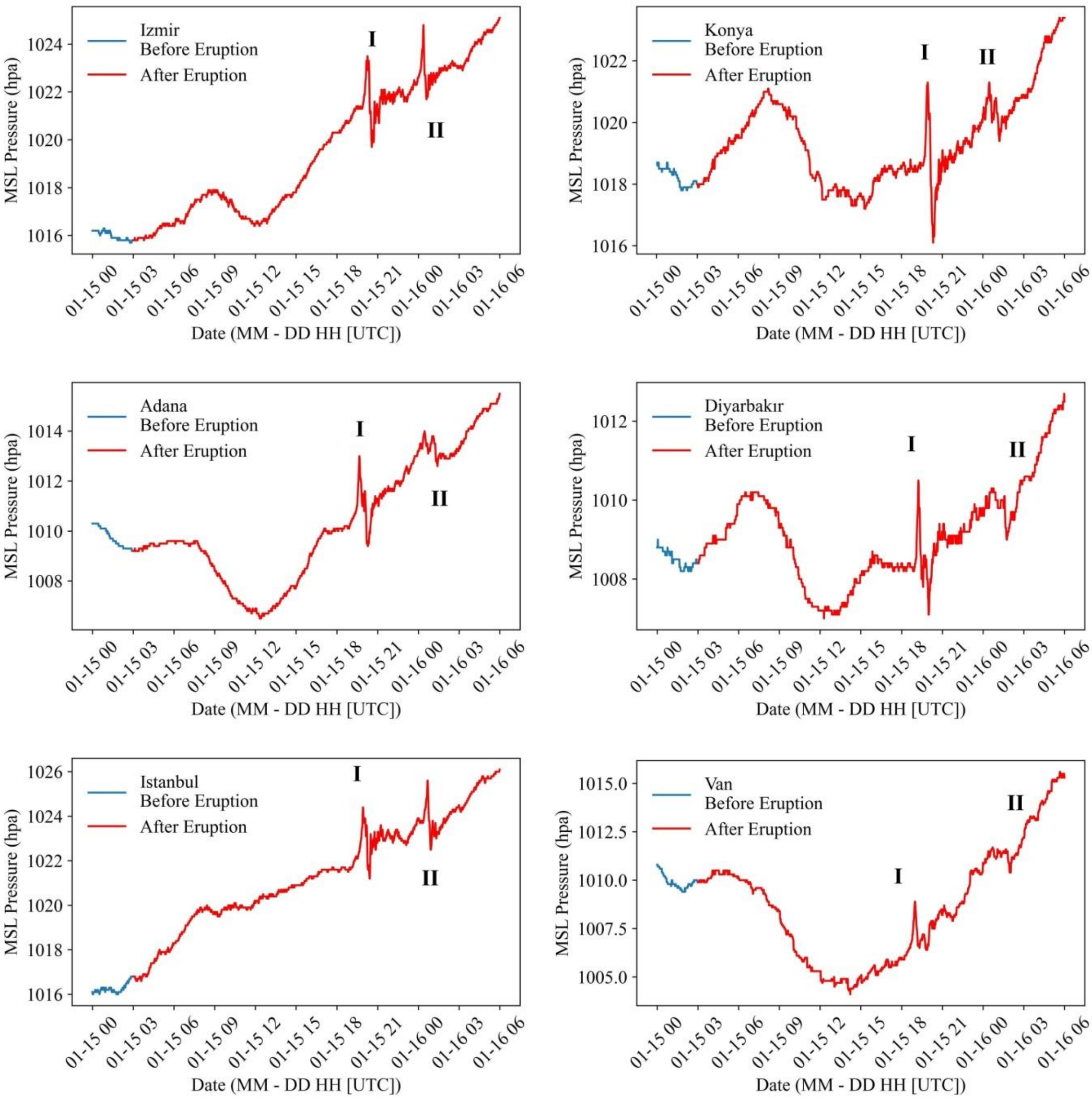

Figure 7. Station pressure changes (İzmir, Konya, Adana, Diyarbakır, İstanbul and Van)

When the sea level pressures of 673 AWOS are examined, it is seen that the Lamb wave started to affect from the east-northeast of Türkiye and left from the south-west (Figure 8). Total exposure time of Türkiye was approximately 1.5 hours.

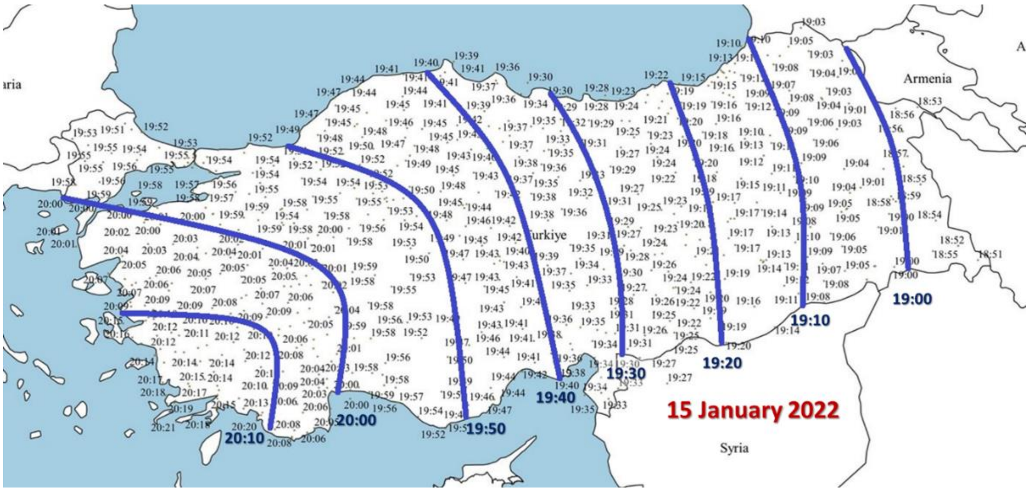

Figure 8. Peak time of the atmospheric pressure fluctuation caused by the Lamb wave (GMT)

Pressure moving upwards with the first Lamb wave; start, peak and fall hours are shown in Table 2.

Table 2. Sea level pressure analysis of the AWOS

	Start		Peak		Fall					
	Time (utc) a	Pressure (hpa) b	Time (utc) c	Pressure (hPa) d	Time (utc) e	Pressure (hPa) f	c-a (mins)	d-b (hPa)	e-c (mins)	f-d (hPa)
Van	18:38	1007,0	18:59	1008,9	19:11	1006,6	12	1,9	12	-2,3
Erzurum	18:44	1011,8	19:10	1013,9	19:25	1011,5	10	2,1	15	-2,4
Diyarbakır	18:56	1008,5	19:14	1010,5	19:35	1007,8	10	2,0	21	-2,7
Trabzon	18:49	1014,9	19:18	1016,4	19:46	1012,3	11	1,5	28	-4,1
Samsun	19:20	1016,7	19:36	1020,0	19:56	1014,4	16	3,3	20	-5,6
Adana	19:24	1011,0	19:39	1013,0	20:12	1009,5	10	2,0	33	-3,5
Kayseri	19:20	1017,9	19:40	1019,8	20:11	1014,8	10	1,9	31	-5,0
İstanbul	19:32	1022,1	19:55	1024,4	20:25	1021,2	23	2,3	30	-3,2
Ankara	19:33	1018,4	19:53	1022,2	20:08	1015,8	18	3,8	15	-6,4
Konya	19:37	1018,9	19:56	1021,3	20:20	1016,1	12	2,4	24	-5,2
Afyonkarahisar	19:43	1021,6	20:04	1025,5	20:19	1019,0	16	3,9	15	-6,5
İzmir	19:52	1021,3	20:15	1023,5	20:34	1019,7	23	2,2	19	-3,8
Mean		1015,8		1018,3		1014,1	14,3	2,4	21,9	-4,2

According to the table, the first Lamb wave in the pressure parameter was seen on January 15, 2022 at 18:38 in Van, which is located in the easternmost of the stations examined. The pressure jump was last detected at 19:52 in İzmir. When the locations of the stations are considered, it is understood that the direction of the wave is from the northeast to the southwest. The pressure increased by 2.4 hPa at an average of 14.3 minutes at 12 stations and decreased by 4.2 hPa after 21.9 minutes. The highest increase was seen in Afyonkarahisar with 3.9 hPa in 16 minutes. After the pressure peaked, the highest decrease was observed in Afyonkarahisar as 6.5 hPa in 15 minutes.

According to the pressure analysis, it has been calculated that the Lamb wave moves at an average speed of 303,2 m/sec, slightly below the speed of sound. The arrival time of the Lamb wave to the observation station and the calculated average velocity according to the moment when the pressure movement started are given in Table 3.

Table 3. First Lamb wave arrival time and average velocity (from equation2)

	Elapsed Time (Hour)	Wave Velocity (m/s)
Van	14,4	304,8
Erzurum	14,5	305,0
Diyarbakır	14,7	303,9
Trabzon	14,6	304,6
Samsun	15,1	303,9
Adana	15,2	302,5
Kayseri	15,1	302,2
İstanbul	15,3	304,4
Ankara	15,3	300,4
Konya	15,4	301,7
Afyonkarahisar	15,5	301,5
İzmir	15,6	303,4
Mean	15,1	303,2

As expected, the Lamb wave traveled at approximately the speed of sound. This result is consistent with other studies (Amores et al., 2022; Burt, 2022; Hindley et al., 2022; Kubota et al., 2022; Sepic et al., 2022). According to another study, theoretical predicted speed of a Lamb wave is 312 m/s (Bretherton, 1969). With the eruption of Tonga Hunga, the atmospheric pressure change propagated as a Lamb wave at the speed of sound, approximately 310 m/s (Imamura et al., 2022). In the tsunami simulation made by Kubota et al. (2022), the velocity of the pressure wave is given as 300 m/s. In a study conducted for Britain and Ireland, the average velocity of Lamb wave was calculated as 311 to 321 m/s for 21 stations (Burt, 2022).

The volcanic eruption also triggered waves in the atmosphere that reverberated around the planet reached close to their theoretical maximum speeds at 320 m/sec. A broad spectrum of waves was triggered by the initial explosion, including Lamb waves propagating at 318.2±6 m/s at surface level and between 308±5 to 319±4 m/s in the stratosphere, and fast gravity waves propagating at 238±3 to 269±3 m/s in the stratosphere (Wright et al., 2022).

The calculated arrival times are confirmed by Meteosat-8 satellite images (Figure 8). According to the satellite images of Meteosat-8 (IR6.2 brightness temperature differences), Lamb wave appeared to enter from the east of Türkiye at 18:30 UTC. It was determined that Lamb wave, which affected the Eastern Mediterranean at 19:30 UTC, left Türkiye at 20:00 UTC.

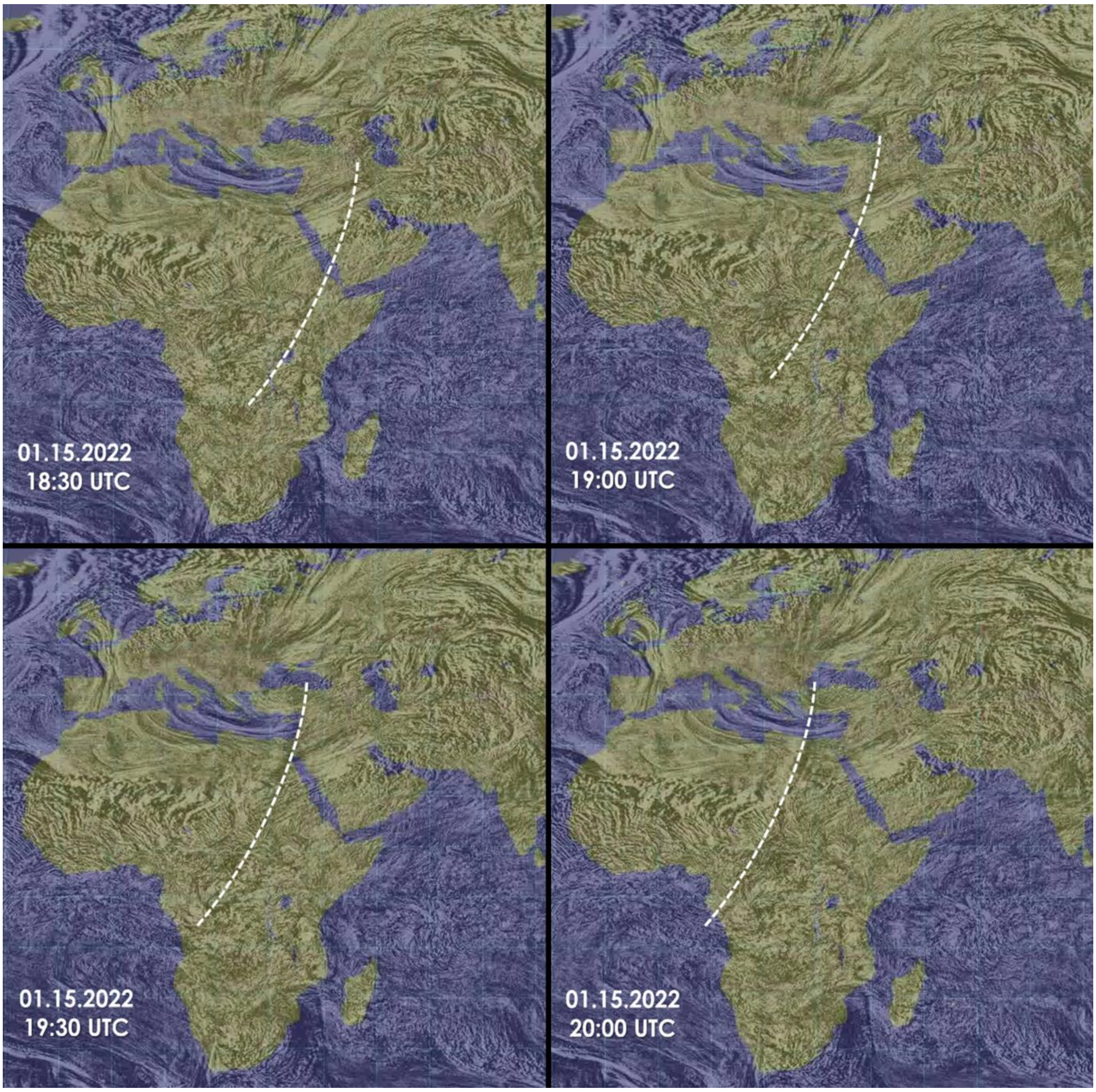

Figure 8. Arrival Times of Lamb waves (dashed lines), Meteosat-8, IR6.2 brightness temperature differences
Source: https://www.eumetsat.int/hunga-tonga-hunga-haapai_2022

4. Conclusion

The Lamb wave resulting from the Hunga Tonga - Hunga Ha'apai volcanic eruptions caused fluctuations in atmospheric pressure globally. The Lamb wave, which is theoretically expected to move at the speed of sound, reached Türkiye where is approximately 16,000 km away from the Hunga Tonga - Hunga Ha'apai Volcano, in 15.1 hours at an average speed of 303.2 m/sec. The pressure first showed an increasing trend in our country as well as all over the world and then decreased again after reaching the peak value. As the average of the 12 selected stations; the pressure increased by 2.4 hPa at 14.3 minutes and decreased by 4.2 hPa at the next 21.9 minutes. The highest increase was calculated in Afyonkarahisar with 3.9 hPa in 16 minutes, and the highest decrease again in Afyonkarahisar was calculated as 6.5 hPa in 15 minutes.

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