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The Synergy between the Comprehensive Nuclear Test-Ban Treaty Organization and the Kenya National Data Centre: Insights from Analysis of Chyulu Earthquake using Seismic and Infrasound Technologies

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ABSTRACT

Chyulu hills is located on an off-rift volcano in the southwestern Kenya and has been seismically active. On 24th March 2019, Chyulu hills experienced one of the strongest earthquake in Kenya in recent times. The body wave seismic phases, surface wave seismic phase as well as the focal depth was used to analyse the seismic events. The propagation velocity of the seismic wave signal detection through infrasound station I32KE was also used. The seismic and infrasound data were processed using Geotool and DTK-GPMCC softwares provided to member states. The results showed that the seismic event was a natural earthquake by virtue of its focal depth of about 9.1 km and seismic wave velocity of 6.2 km/s. The infrasound station to source azimuth of 139.63° further complemented the epicentre of the seismic event as being in the southwestern Kenya near Chyulu hills.

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1. Introduction

The Comprehensive Nuclear Test-Ban Treaty (CTBT) is an international and multilateral treaty that bans all nuclear explosions, for both civilian and military purposes, in all environments [1]. The CTBT was adopted by the United Nations General Assembly on 10th September 1996 in New York, and opened for signature on 24th September 1996. On the 19th November 1996, during the first meeting of the States Signatories to the CTBT, the Preparatory Commission for the Comprehensive Nuclear-Test Ban Treaty Organization (CTBTO) was established. The objective of the CTBTO is to prepare for the entry into force (EIF) of the Treaty and its role is to achieve the object and purpose of the treaty, to ensure the implementation of its provisions, including those for international verification of compliance with it, and to provide a forum for consultations and cooperation among States Parties [1].

The CTBTO stipulates the creation of a National Data Centre (NDC) within the member states. The sole responsibility of the NDC is to advise the government of any cases of Treaty violations, in addition to using the data for training, research, civil and scientific applications. The NDC is expected to have the capacity to receive, process, analyse and interpret data from any of the CTBTO's 337-facility International Monitoring System (IMS), as well as receiving additional raw and processed data (i.e. IDC Products) from the CTBTO's International Data Centre (IDC) in Vienna, Austria [2]. The IMS comprises of four technologies; seismic, hydroacoustic, infrasound, and radionuclide monitoring each with its specific objective in the verification regime of the CTBT [1,2].

Kenya being a member state of the CTBTO signed and ratified the treaty on November 14, 1996 and November 30, 2000 respectively. Kenya therefore hosts a National Data Centre (KE-NDC) domiciled in the Department of Geology, University of Nairobi.

At the Kenyan NDC waveform data from the CTBTO's 337-facility International Monitoring System (IMS) is received, processed, analyzed and interpreted so as to determine the nature and characteristics of the events (whether natural or man-made) generating such waveform data. The sole responsibilities of the Kenyan NDC include: - (i) receiving, processing, analyzing and interpreting IMS data and IDC products and verifying the nature of the events; (ii) advising the government, through the National Authority, i.e. National Commission for Science Technology and Innovation (NACOSTI), of any cases of treaty violations; and (iii) using IMS data and IDC products for training, research, civil and scientific applications. The civil and scientific applications of IMS data and IDC products include among others:- monitoring and characterization of earthquakes, tsunamis, landslides, terrestrial and underwater volcanic eruptions, studies on the earth's internal structure, monitoring of sea/ocean temperature and signs of global warming, ocean swell research, whale populations, atmospheric and meteorological studies, detection of meteor impacts in the atmosphere, radiation monitoring on possible radioactive releases and studies on natural radioactivity [2].

IMS data and IDC products are accessed at the Kenyan NDC from CTBTO through any of four data access methods [2]. These methods include: - (i) IDC Secure Web Portal (an interactive graphical web-based server interface that allows the user to browse, view, download and retrieve IMS data and IDC products online using the CTBTO's secure web portal, (ii) Requests (on demand one-time requests of IMS data and IDC products of special interest submitted either via email or through a command line client software). Data and products access using this method requires a preformatted text message in IMS2.0 format [2]. Email requests are also known as automated data request manager (AutoDRM) requests, (iii) Subscription (standing requests of IMS data and IDC products forwarded continuously once available at IDC until cancelled by the subscriber). Subscriptions also require a preformatted text message in IMS2.0 format [2], (iv) IDC External Database Service or Virtual Data Messaging System (VDMS) (a timely and direct data access method to replicas of the CTBTO/IDC operational and archival databases and parameters. This method requires the use of structured querry language (SQL) statements. Access right(s) is/are required for all the four data and products access methods. Such rights are given by the CTBTO on recommendation by the CTBTO's Point of Contact (PoC) at the National Authority (NACOSTI).

This paper presents the methods of data access of International Monitoring System (IMS) facilities data sources at the Kenya National Data Centre from the CTBTO's International Data Centre (IDC), as well as results of seismic and infrasound waveform data analysis, source location and characterization at KE-NDC.

2. Materials and Methods

In order to demonstrate the contribution of the Kenyan NDC in fulfilling the mandate and objectives of the CTBTO, we considered an event which occurred on March 24, 2019 in the southwestern part of Kenya in the vicinity of Chyulu hills. We requested two sets of IMS waveform data (i.e. infrasound and seismic) using the IDC Secure Web Portal data request method, from the International Data Centre (IDC) recorded by the Infrasound station I32KE in Kenya and seismic stations KMBO (Kenya), MBAR (Uganda), ATD (Djibouti), LSZ (Zambia), OPO (Madagascar), LBTB (Botswana), TSUM (Namibia), BOSA and SUR (South Africa), TORD (Niger), BRTR (Turkey), GNI (Armenia), PALK (Sri Lanka), KBZ, ARTI and OBN (Russia), KEST (Tunisia), NIL (Pakistan), AKASG (Ukraine), DAVOX (Switzerland), AAK (Kyrgyzstan), GERES (Germany), ESDC (Spain), and BVAR and MKAR (Kazakhstan). Table 1 below gives details of the IMS stations used in the analysis of the 24 March 2019 Chyulu earthquake.

Table 1. Infrasound and seismic stations used in the analysis of the 24 March 2019 Chyulu earthquake (Station information obtained from https://swp.ctbto.org/web/swp/ims-map)

Station Code	Station Name	Location		Host Country
		Latitude (Degrees)	Longitude (Degrees)	
I32KE	Nairobi	-1.3000	36.8000	Kenya
KMBO	Kilimambogo	-1.1268	37.2523	Kenya
MBAR	Mbarara	-0.6019	30.7382	Uganda
ATD	Arta Tunnel	11.5300	42.8470	Djibouti
LSZ	Lusaka	-15.2766	28.1882	Zambia
OPO	Ambohidratompo	-18.5706	47.1879	Madagascar
LBTB	Lobatse	-25.0151	25.5966	Botswana
TSUM	Tsumeb	-19.2022	17.5838	Namibia
BOSA	Boshof	-28.6140	25.2554	South Africa
SUR	Sutherland	-32.3797	20.8117	South Africa
TORD	Torodi	13.5044	2.0842	Niger
BRTR	Keskin	39.7250	33.6390	Turkey
GNI	Garni	40.1495	44.7414	Armenia
PALK	Pallekele	7.2728	80.7022	Sri Lanka
KBZ	Khabaz	43.7269	42.8996	Russia
KEST	Kesra	35.7317	9.3460	Tunisia
NIL	Nilore	33.6506	73.2686	Pakistan
AKASG	Malin	50.7010	29.2242	Ukraine
DAVOX	Davos	46.7806	9.8798	Switzerland
AAK	Ala-Archa	42.6390	74.4940	Kyrgyzstan
GERES	Freyung	48.8451	13.7016	Germany
ESDC	Sonseca	39.6744	-3.9630	Spain
OBN	Obninsk	55.1200	36.5700	Russia
ARTI	Arti	56.4293	58.5615	Russia
BVAR	Borovoye	53.0300	70.3900	Kazakhstan
MKAR	Makanchi	46.7937	82.2905	Kazakhstan

Whereas seismic technology monitors propagation of seismic waves in the earth's subsurface, infrasound technology monitors low frequency infrasonic and acoustic waves either through the atmosphere or in the subsurface. The waveform data were processed, analyzed and interpreted in order to characterize and locate this event. Analysis of the infrasound waveform data was used to supplement our characterization of the March 24, 2019 event and to provide additional information in regard to the epicentral location on the basis of the station to source azimuth.

Seismic waveform data were first filtered using a Butterworth filter of 0.6 – 12 Hz in order to enhance the onset times of the seismic phases [6]. P-wave seismic phase was then picked on a number of seismic stations and a preliminary epicentral location of the source zone determined. The seismic waveforms were then sorted according to epicentral distances in degrees and aligned on time minus predicted first P. This criterion aligns the waveforms vertically based on the onset times of the P-wave seismic phase. Once a preliminary source location was determined, the P-wave seismic phases were then refined for each seismic station according to the respective epicentral distances of the station to source location [4, 5]. Subsequently, other seismic phases i.e. S- and Lg were picked on other seismograms and a final source location was then determined. The guiding criterion for the Lg seismic phase is dependent on the station to source distance and the focal depth [4-6].

The Infrasound station I32KE is an array station consisting of four elements (sensors) in rectangular configuration and three elements (sensors) in triangular configuration. Infrasound waveform data was processed using Dase Tool Kit Progressive Multi-Channel Correlation (DTK-PMCC) software. The first step of infrasound data processing and analysis involved definition of subnets for each of the respective configurations [7]. Once the subnets were defined, the next step was to set the pixel parameters i.e. minimum (0.1 Hz) and maximum (4.0 Hz) frequencies of the infrasonic signals as well as the Threshold Consistency criteria (0.1). Higher decimal value of the Threshold Consistency criteria allows fewer event detections at the Infrasound stations, some which are likely to be false events. The next step of the processing involved setting the family parameters e.g. transition speed (3.00 km/s) and Threshold Family minimum (30) and maximum (300) parameters. The higher the values of the Threshold Family, the more the detections. As with the Threshold Consistency criteria, some of the detections are likely to be false events. Once the Subnets were defined and Pixel and Family parameters set, the DTK-PMCC was executed and the results displayed in three pixels (windows) of Azimuth, Speed and waveforms with detections in red vertical lines.

3. Results and Interpretation

Figure 1 shows a snapshot of seismic phases on waveforms (seismograms) for four seismic stations i.e. KMBO (Kenya), MBAR (Uganda), ATD (Djibouti), LSZ (Zambia) and OPO (Madagascar) closest to this event at epicentral distances of 2.3^{o}, 8.0^{o}, 15.2^{o}, 15.7^{o}, and 17.6^{o} respectively. The waveforms are characterized by the compressional (Pn) and shear (Sn) phases refracted at the crust-upper mantle boundary [3,4,5] in addition to Lg surface wave seismic phase. Whereas the Pn and Sn seismic phases are dependent on station to source distance, the Lg surface wave seismic phase is an indication of a shallow event. As such, the shallow event is likely to be generated by man-made (anthropogenic) or natural sources. Further characterization of the March 24, 2019 event is based on the focal depth (km). The focal depth (km) was determined to be 9.1 km. Table 2 shows a summary of the results of final analysis of this event based on seismic waveform data.

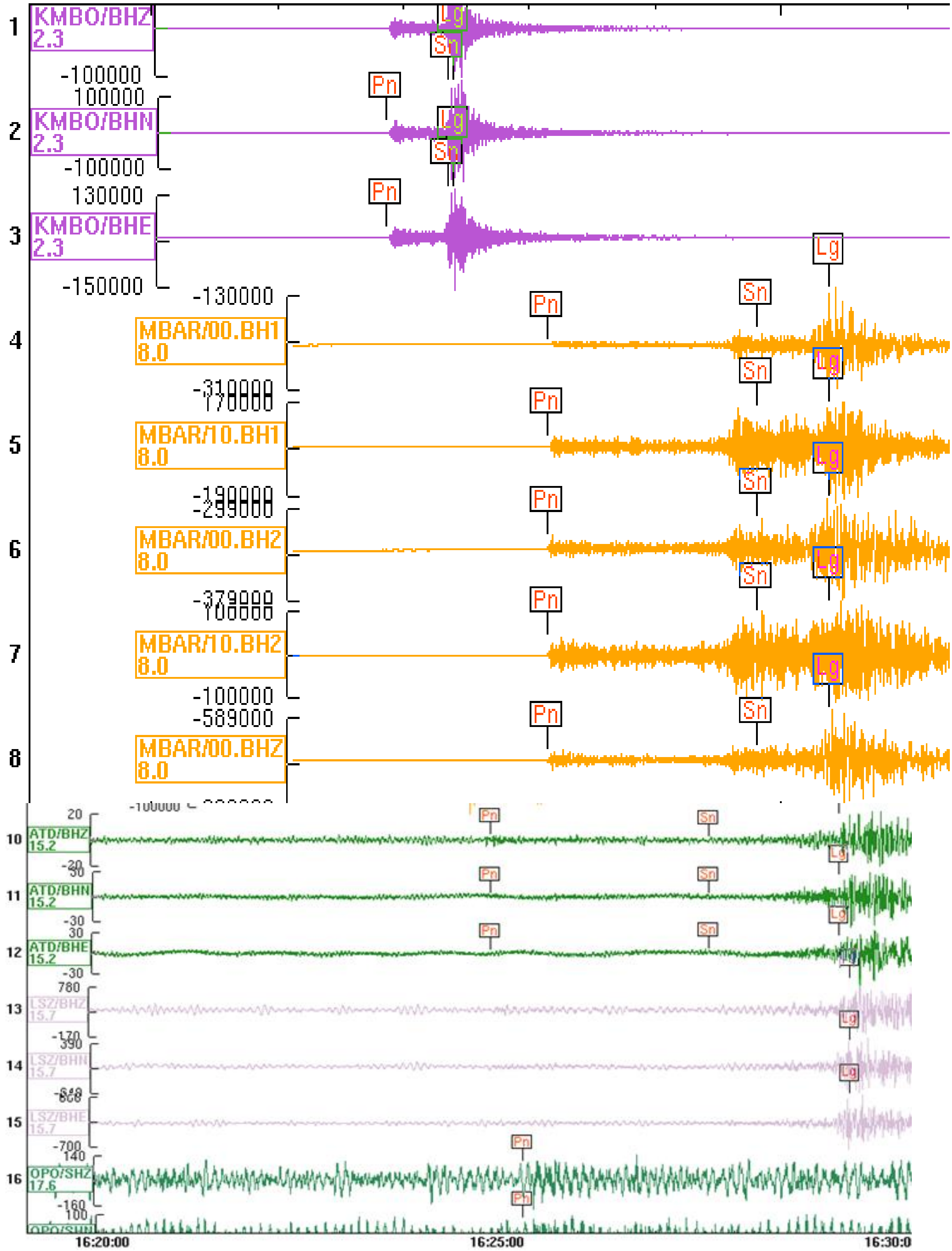

Figure 1. Seismic phases picked on seismograms for KMBO, MBAR, ATD, LSZ and OPO seismic stations for the 20190324 event.

Table 2. Coordinates, date, origin time (UTC), focal depth, magnitude, number seismic stations used in analysis and location area of the Chyulu hills seismic event.

Latitude	Longitude	Date and Origin time (UTC)	Depth (km)	Magnitude		Number of seismic stations	Epicentral location
				ml	mb		
-3.0807°	38.3428°	20190324 16:21:13	9.1	4.9	4.2	25	Chyulu hills in SW Kenya

Figure 2 shows events and their associated azimuths and speeds detected at the Infrasound station I32KE for a duration of one and half hours on the 20190324. Based on the azimuth and wave speed, the sixth detection in the lower (waveform) panel corresponds to the Chyulu hills earthquake. Figure 3 shows a spectrogram of the detection associated with the Chyulu hills earthquake at one of the sites (array element I32H1) at Infrasound station I32KE. The frequency content of the signal due to the Chyulu hills earthquake ranges between 0-9 Hz suggesting an infrasonic signal

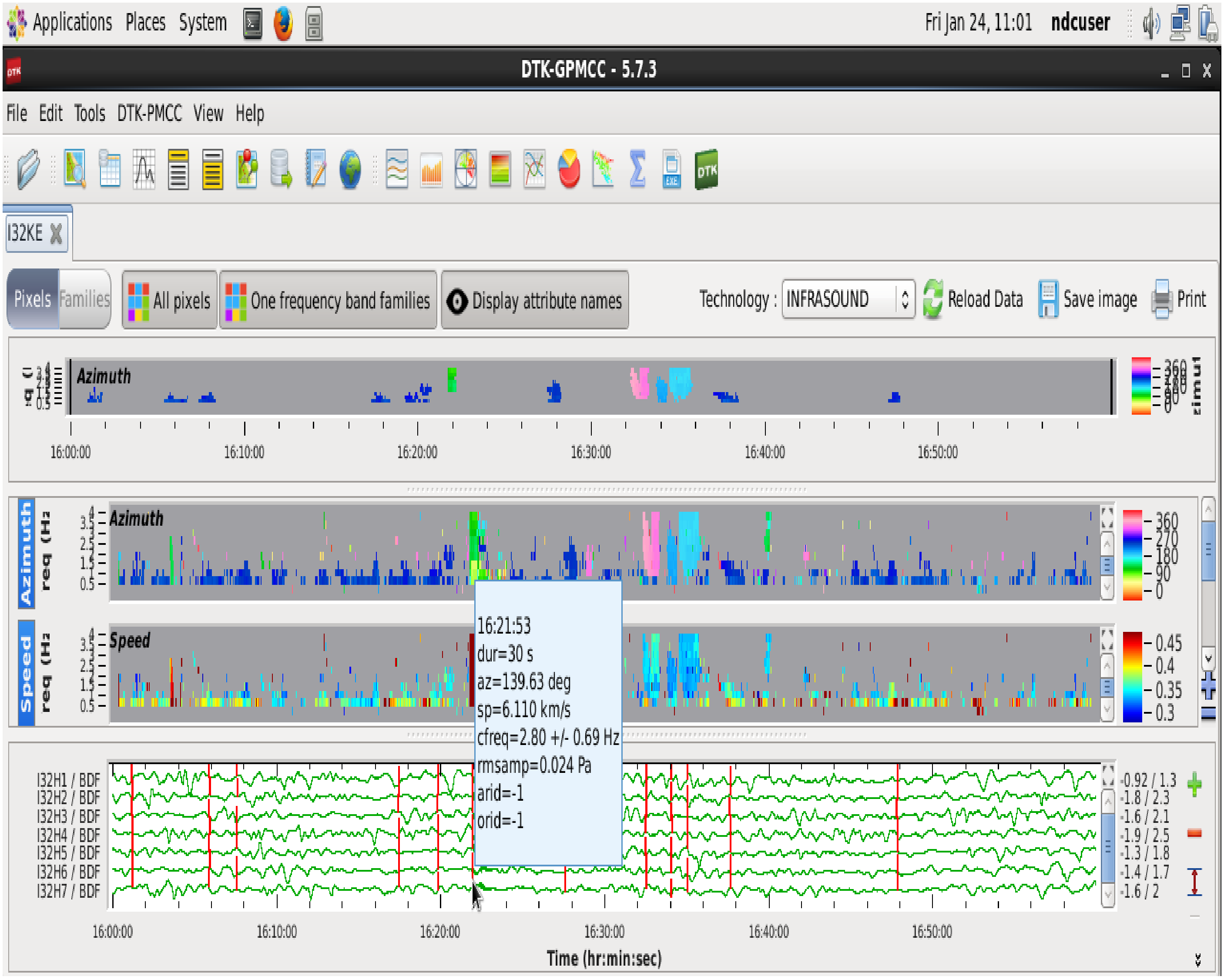

Figure 2. Pixels of events (red lines) and their associated azimuths, speeds and waveforms detected at I32KE infrasound station.

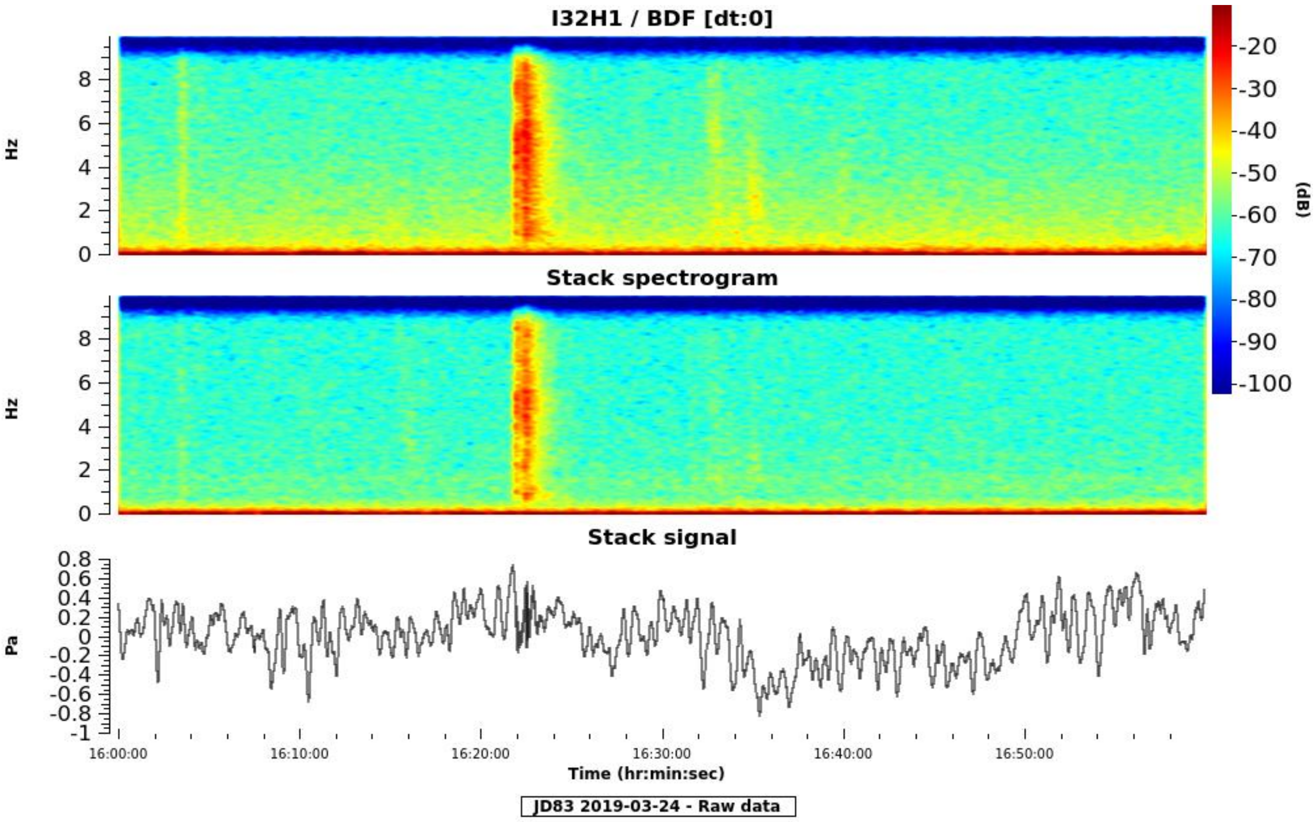

Figure 3: Spectrogram of the seismic event detection for array site I32H1 at the Infrasound station I32KE.

4. Discussion

Analysis of waveform data from twenty-five seismic and one-infrasound stations was undertaken in order to characterize the March 24, 2019 event. Based on the results presented in figure 2 and the summary of the results from seismic waveform analysis in table 2, the March 24, 2019 Chyulu hills event corresponds to the sixth detection in figure 2. The arrival time of this event at the infrasound station (16:21:53 UTC) closely corresponds to the arrival time of the Pn seismic phase (16:21:52 UTC) at KMBO seismic station which is the closest seismic station (D=2.2^o or ≅ 244 km) to Chyulu hills event in Kenya. The velocity of propagation (V=6.110 km/s) of the infrasonic signal is consistent with a P-wave propagation path through the earth's interior as opposed to atmospheric propagation (V≅344 m/s). The difference in arrival times of the infrasonic and seismic waves is attributed to the slight difference in distances from the source to the respective seismic and infrasound stations and hence the delay of about one (1) secs in arrival time of the infrasonic signal to the infrasound station. If the infrasonic wave had purely propagated through the atmosphere, and assuming a propagation distance of ~244 km from the source to the infrasound station, the total time taken would have been ~709 seconds (i.e. 11 min 49 secs). Based on the origin time (16:21:13) of this event obtained using seismic data as presented in table 2 above, the arrival time of the infrasonic wave propagated through the atmosphere to the infrasound station would have been 16:33:02 due to the low propagation velocity through the atmosphere. This arrival time does not, however, include the upward trajectory from the source and downward trajectory at the infrasound station, hence would be the minimum time for atmospheric propagation of the infrasonic wave to the infrasound station. The infrasound station to source azimuth of 139.63^o (from figure 2) coincides with the direction of the epicentral location of the Chyulu hills event determined using seismic waveform data. Figure 4 shows the locations of the epicenter of the March 24, 2019 event as well as the infrasound (I32KE) and seismic (KMBO) stations in Kenya.

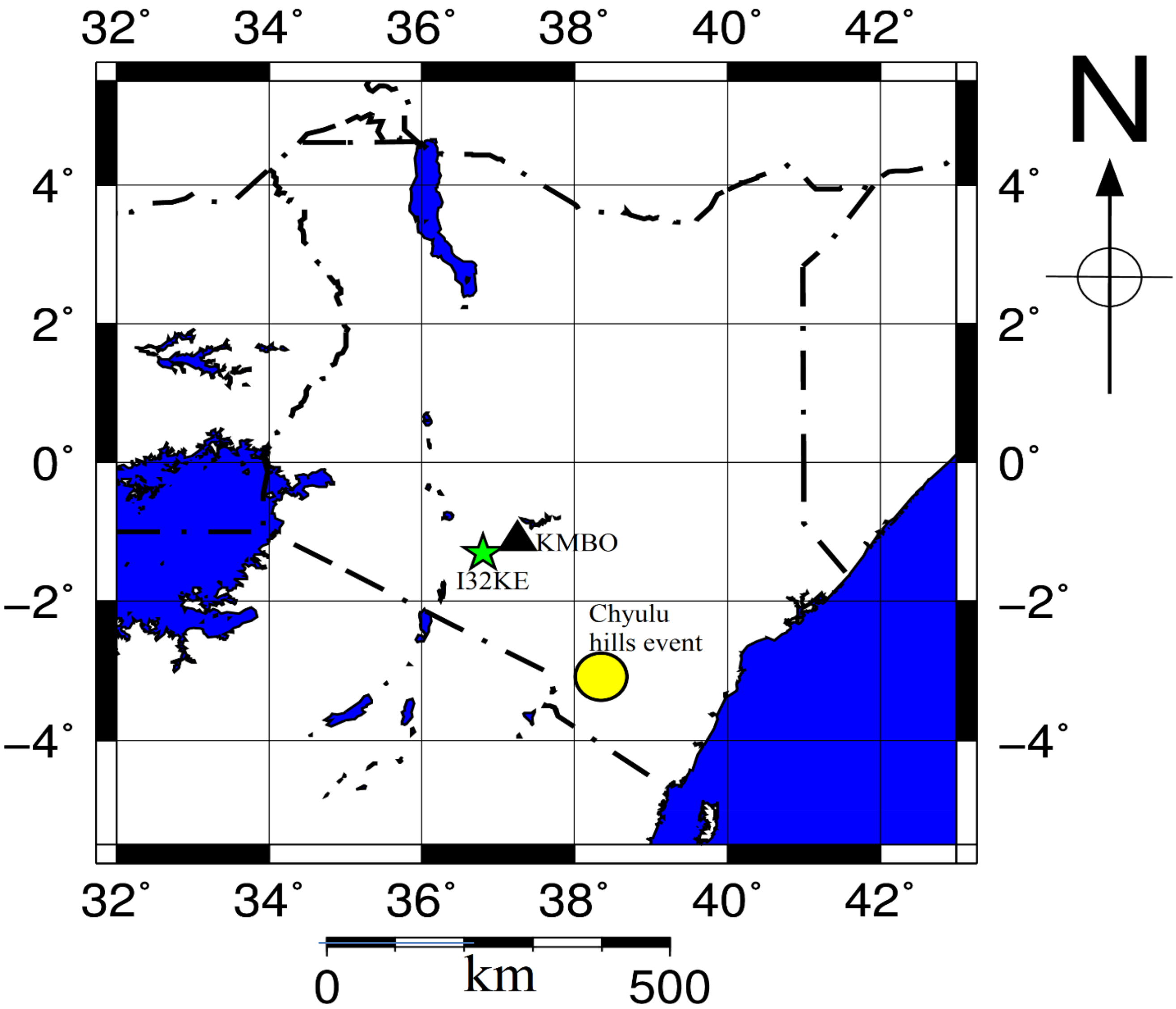

Figure 4. Locations of Infrasound (I32KE) and Seismic (KMBO) stations and the epicenter of the March 24, 2019 Chyulu hills event.

5. Conclusion

The Chyullu Hills event of March 24, 2019 Seismic waveforms from its closest stations are characterized by the Lg surface wave phase indicative of a shallow event, which is likely to be anthropogenic or natural. The focal depth, however, indicates that it is a natural event of a depth of 9.1 km. The epicentral location of the event at 3.0807^{o}S and 38.3428^{o}E in the southwestern Kenya around Chyulu hills area coincides with the direction of the infrasound station to source azimuth of 139.63^{o}. Infrasound and seismic technologies are therefore complementary in the location and characterization in order to fulfil the objective and mandate of the Comprehensive Nuclear Test-Ban Treaty and ensuring nuclear testing and non-proliferation free world, hence promoting peace.

Acknowledgments

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