Atmospheric Events energy estimation based on Seismic Data

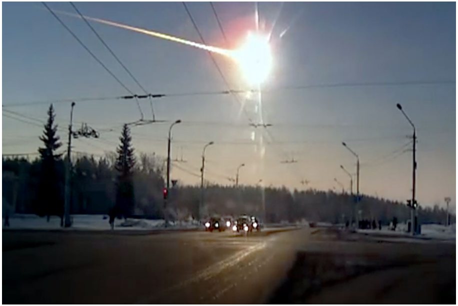
Yochai Ben Horin

Israel NDC, SNRC

June 19, 2019

Talk layout

- Background
- Challenge definition
- Method
- Examples
  - Natural
  - Man Made
- Summary



Motivation

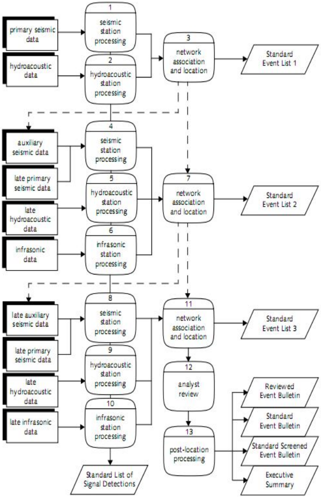
- Under the Comprehensive Nuclear-Test Ban Treaty (CTBT) the States Parties undertakes not to carry out any nuclear weapon test or any other nuclear explosion.
- The aim of the CTBT monitoring system, is to identify events in the atmosphere, underwater or underground which may be treaty violation.

Table 2-1 Contributions of key technologies to CTBT monitoring of different test environments

Monitoring Technologies	Underground	Underwater	Atmosphere	Near Space
Seismic	major	major	secondary	none
Radionuclide	major	major	major	none
Hydroacoustic	secondary	major	secondary	none
Infrasound	secondary	secondary	major	none
Electromagnetic	secondary	secondary	major	major
Satellite Imagery	major	major	secondary	secondary

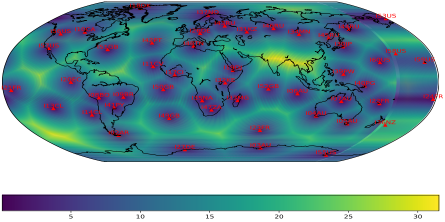
Data sources and their typical detection times:

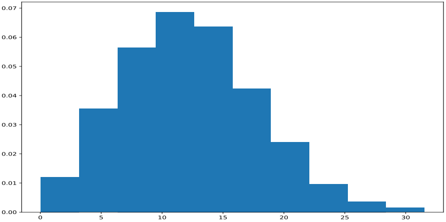
- Seismology $\Rightarrow$ seconds to minutes,
- Hydro-acoustic $\Rightarrow$ seconds to minutes,
- Infrasound $\Rightarrow$ minutes to hours,
- Radionuclide $\Rightarrow$ hours to days (weeks?).



Infrasound stations

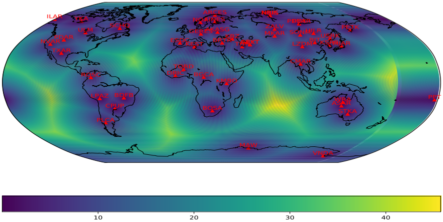
- Currently the infrasound component of the International Monitoring System includes 51 arrays:
- Distance between arrays:
  - Minimal 11°.
  - Average 91°
- Distance from possible source (grid of 1°x1°):
  - Minimal 0.04°.
  - Average 12.07°.
  - Median 12.28°.
- 330 m/sec ≈ 4096 sec

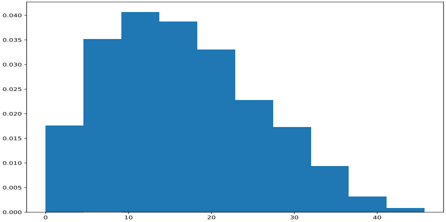




Primary Seismic Stations

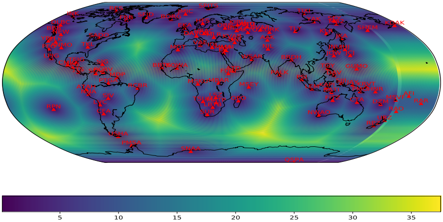
- The seismic primary station component of the International Monitoring System includes 50 stations (44 are operational):
- Distance between arrays:
  - Minimal less then 1°.
  - Average 78.17°
- Distance from possible source (grid of 1°x1°):
  - Minimal 0.0°.
  - Average 16.5°.
  - Median 15.5°.
- 3km/sec $\approx$ 610 sec

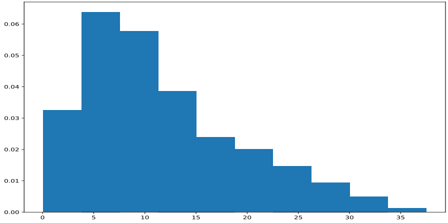




Seismic Auxiliary stations

- The seismic auxiliary station component of the International Monitoring System includes 120 stations (112 operational):
- Distance between arrays:
  - Minimal less then 1°.
  - Average 85.5°
- Distance from possible source(grid of 1°x1°):
  - Minimal 0.07°.
  - Average 11.7°.
  - Median 9.7°.
- 3km/sec $\approx$ 433 sec





Challenge definition

- The CTBT organization products includes standard events lists and a specialized event list that includes parameters which enable screening out non-relevant events.
- Event energy estimation is not part of the CTBT, However, a reliable event energy estimate can aid highlight of events which may be treaty violation.
- The accuracy of energy estimation methods of atmospheric events based on barograms is less accurate then yield estimation methods of underground and underwater explosions.
  - Sound propagation through the atmosphere is time dependent.
  - Sound propagation through the Earth is time independent.
  - The average travel time of infrasound signal (for the IMS network) is 10 times longer then the travel time of seismic signal.

Method

Journal of Geophysical Research   Vol. 69, No. 8   April 15, 1964

Excitation of Seismic Surface Waves by Atmospheric Nuclear Explosions[1]

M. Nafi Toksöz and Ari Ben-Menahem

Seismological Laboratory
California Institute of Technology, Pasadena

Bulletin of the Seismological Society of America, Vol. 104, No. 2, pp. 608–623, April 2014, doi: 10.1785/0120130130

Partitioning of Seismoacoustic Energy and Estimation of Yield and Height-of-Burst/Depth-of-Burial for Near-Surface Explosions

by Sean R. Ford, Arthur J. Rodgers, Heming Xu,* Dennise C. Templeton, Philip Harben, William Foxall,† and Robert E. Reinke

Bulletin of the Seismological Society of America. Vol. 53, No. 1, pp. 109–149. January, 1963

LONG PERIOD SEISMIC WAVES FROM LARGE, NEAR-SURFACE NUCLEAR EXPLOSIONS

By Paul W. Pomeroy

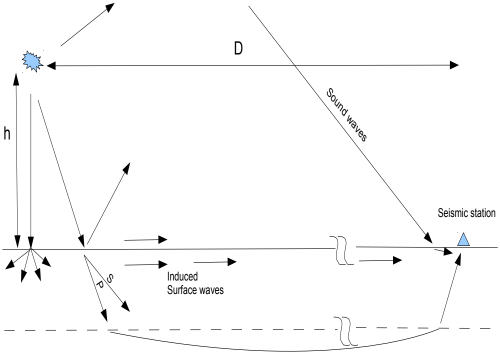
ABSTRACT

The Chelyabinsk Meteorite as a Multiple Source of Acoustic and Seismic Waves

I. O. Kitov[a], D. I. Bobrov[b], V. M. Ovchinnikov[a], and M. V. Rozhkov[b]

Presented by Academician V.V. Adushkin May 18, 2015

Received May 21, 2015


D
h
Sound waves
Seismic station
S
P
Induced
Surface waves

Assuming that:

- Event location is known (OT,lat,lon)
- Event height is unknown.
- $h \ll D$ & $h <$ few tenths of km $\rightarrow$ the atmosphere impact on the signal is limited.
- The dominant arrival are the surface-wave.

The following two steps can be used:

- Seismic Energy estimation assuming underground event:
  - following M.S. Vassiliou & H. Kanamori:
    - Energy measurement at the station .
    - Energy correction for attenuation (distance).
  - alternatives:
    - IDC Ms magnitude $\rightarrow$ energy
    - Coda magnitude (following k. Mayeda, 1993)
- Estimate the atmospheric event energy using energy height relation, theoretical or phenomenological.

The seismic efficiency $\left(\frac{E_{seismic}}{E_0}\right)$ is a function of several factors:

- event height.
- Exact place of surface wave generation.
- Local topography.

For example a phenomenological relation from Paul W. Pomeroy. "Long period seismic waves from large, near-surface nuclear explosions. BSSA, 53(1):109–149, January 1963."

Magnitude versus height for 20 kT explosion

Height [km]	mb
10	3.0
1	3.5
surface	4.0
-0.3	5.0

- Assuming UNE with the same mb magnitude as in the previous table.
- Using Sikka relation $mb = 4.04 + 0.75 log_{10}(Y)$
- We get the following Yields

mb	Y [kT]
3.0	0.05
3.5	0.2
4.0	0.9
5.0	20

↓

Height	Ratio
10	0.0025
1	0.01
0	0.045
-0.3	1

SOREQ

Ural Mountain Region, Russia 15 February 2013 IDC mb 3.0

EVENT 9492920 URAL MOUNTAINS REGION, RUSSIA

Date:	2013/02/15 03:22:06.910	Err:	3.34	RMS:	142.8	Latitude:	54.0563	Longitude:	61.8062
Smaj:	50.8	Smin:	12.7	Az:	160	Depth:	0.0	Err:	
Ndef:	19	Nsta:	15	Gap:	92	mdist:	4.31	Mdist:	92.69
Qual:	m i uk	Author:	IDC_REB	OrigID:	9535360				

Magnitude Block | Phase Block

Print Save Search:

Magnitude	Err	Nsta	Author	OrigId
mbtmp 3.0	0.2	3	IDC_REB	9535360
ML 2.2	0.1	2	IDC_REB	9535360

Show 25 entries Showing 1 to 2 of 2 entries First Previous 1 Next Last

Print Save Search:

Sta	Dist	EvAz	Phase	Time	TRes	Azim	AzRes	Slow	SRes	Def	SNR	Amp	Per	Qual
AKTO	4.31	214.2	Pn	2013/02/15 03:23:14	-0.3	45.0	13.8	10.0	-3.7	T__	1.7			___ ___
AKTO	4.31	214.2	Lg	2013/02/15 03:24:24	1.0	72.5	41.2	19.1	-12.6	T__	4.9			a__
I31KZ	4.33	213.9	I	2013/02/15 03:48:40	-38.4	29.1	-1.8	317.6	-59.4	TA_	139.5			a__
I31KZ	4.33	213.9	Ix	2013/02/15 04:03:50		347.8	-43.1	309.8		___	2.4			a__
BVAR	5.22	97.9	Pn	2013/02/15 03:23:27	0.4	316.0	31.1	6.0	-7.7	T__	3.3			___ ___
BVAR	5.22	97.9	Sn	2013/02/15 03:24:25	-1.4	302.8	18.0	21.8	-2.9	T__	5.9			a__
BVAR	5.22	97.9	Lg	2013/02/15 03:24:56	3.6	272.9	-12.0	28.7	-3.0	T__	2.8			___
KURK	10.79	101.8	Pn	2013/02/15 03:24:40	-0.1	299.1	4.0	13.5	-0.2	TA_	3.5			___
KURK	10.79	101.8	Lg	2013/02/15 03:27:51	1.6	296.0	0.9	31.8	-0.0	TA_	2.0			___
I46RU	13.53	81.1	Ix	2013/02/15 04:40:00		279.7	-0.1	261.2		___	0.9			a__
I46RU	13.53	81.1	I	2013/02/15 04:44:25	-160	269.6	-10.2	304.8	-72.1	TA_	51.2			a__

From the PTS Secure WEB Portal

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE
10.1002/2013JD021028

Key Points:
- Reconstruction of the meteoroid's trajectory
- Released energy estimation

Simulation of the airwave caused by the Chelyabinsk superbolide

Mikhail I. Avramenko[1], Igor V. Glazyrin[1], Gennady V. Ionov[1], and Artem V. Karpeev[1]

[1]Russian Federal Nuclear Center-All-Russia Scientific Research Institute of Technical Physics, Snezhinsk, Russia

Towards the azimuthal characteristics of ionospheric and seismic effects of "Chelyabinsk" meteorite fall according to the data from coherent radar, GPS and seismic networks

O.I. Berngardt, N.P. Perevalova, K.A. Kutelev, G.A. Zherebtsov[1], A.A. Dobrynina[2], N.V. Shestakov[3], R.V.Zagretdinov[4], V.F.Bakhtiyarov[5], and O.A.Kusonsky[6]

GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 1–5, doi:10.1002/grl.50683, 2013

Seismoacoustic coupling induced by the breakup of the 15 February 2013 Chelyabinsk meteor

Benoit Tauzin,[1] Eric Debayle,[1] Cathy Quantin,[1] and Nicolas Coltice[1]

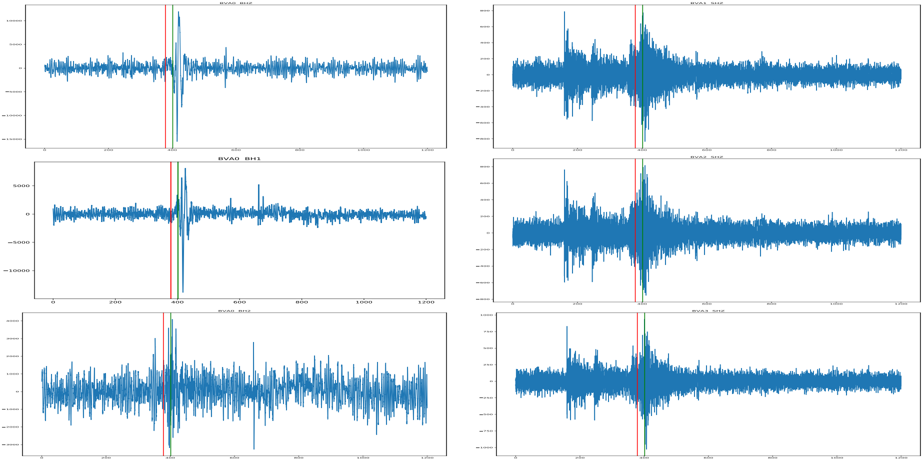
Ⓔ

Seismic Characterization of the Chelyabinsk Meteor's Terminal Explosion

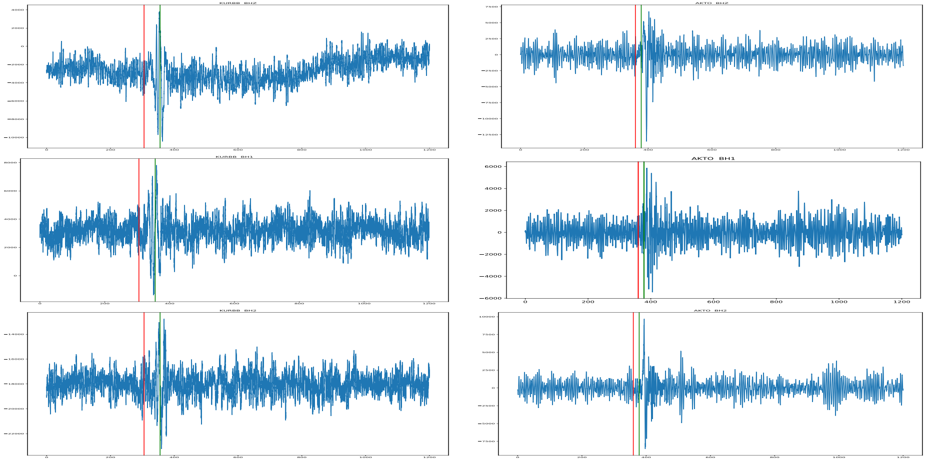
by Sebastian Heimann, Álvaro González, Rongjiang Wang, Simone Cesca, and Torsten Dahm

SRL Vol. 84, Number 6 November/December 2013

BVAR 580 km 97.9° ; BB vs SH



KURK 1196 km 101.8° - AKTO 479 km 214.2°



Southern Xinjiang 16 October 1980 IRIS mb 4.4

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DATA_TYPE BULLETIN IMS1.0:short
ISC Bulletin
Event    637150 Southern Xinjiang
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1980/10/16 04:30:29.47   1.69 3.046  41.1012   90.3414 35.24 25.04  44   0.0f          7    6 194  18.04  50.34 m i kn ISC         1413316
 (Anthropogenic event; depth fixed to 0 km)

Year Volume Page1 Page2 Journal
1993     12     1    20 AWE Report
 (#AUTHOR Douglas,A. , Marshall,P.D. , Jones,K.H.                                  )
 (#TITLE  Body wave magnitudes and locations of explosions at the Chinese Test Site,       )
 (+       1967-1989                                                                )
1995      5   205   244 Science & Global Security
 (#AUTHOR Gupta,V.                                                                 )
 (#TITLE  Locating nuclear explosions at the Chinese test site near Lop Nor        )

Sta       Dist  EvAz Phase        Time      TRes  Azim AzRes   Slow   SRes Def   SNR       Amp   Per Qual Magnitude    ArrID
KAAO     18.04 255.6 P        04:34:39.2    -3.1                           T__             30.0  1.00 _e              20140699
CHG      23.40 159.1 P        04:35:41.0     0.9                           T__                        _e              20140700
MAIO     24.49 268.8 P        04:35:48.0    -2.4                           T__                        __              20140701
MAIO     24.49 268.8 S        04:40:16.0     4.3                           T__                        _i              20140702
KJF      42.19 324.6 P        04:38:23.0    -0.6                           T__                        _e              20140703
HFS      49.13 319.9 P        04:39:20.0     1.5                           T__                        __              20140704
HFS      49.13 319.9 AMS      04:39:20.0                                   ___            400.0 20.00 __              20140705
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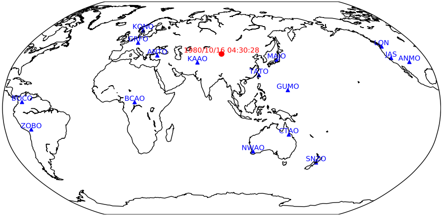
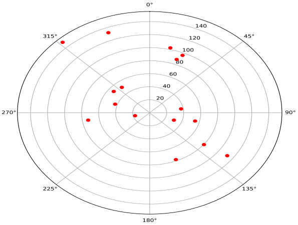
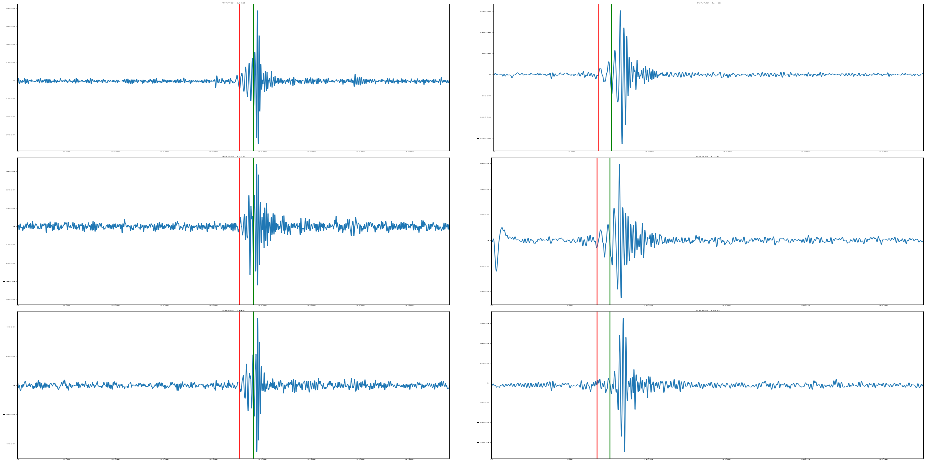
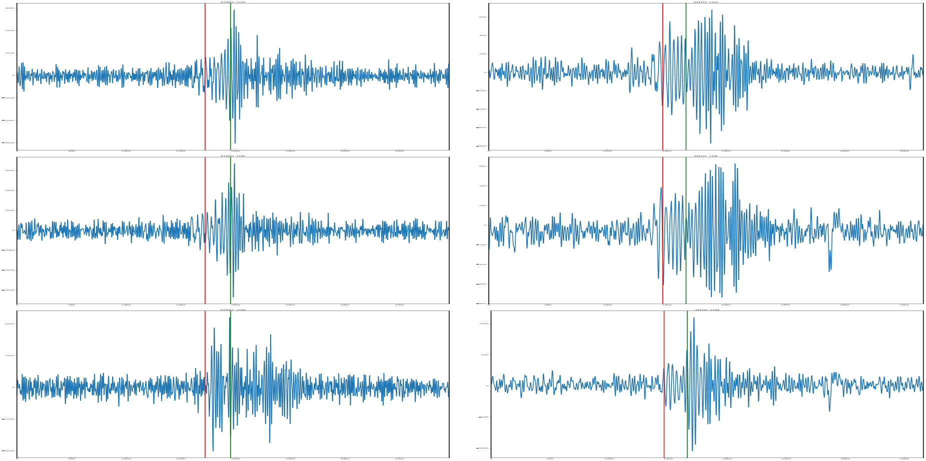




TATO 3014 km 111 - KAAO 1974 km 255°



KONO 5679 km 320° - ANTO 4763 km 288°



Naive estimation

- Using $m_b = 4.45 + 0.75 log_{10} Y$
  - mb 3.0 ≈ 0.045 kt underground ≈ 18 kt at 10 km height
  - mb 4.5 ≈ 4 kt underground ≈ 1.5 Mt at 10 km height
- At the catalog of worldwide nuclear test by V. M. Michailov the October 1980 event Yield is 150-1500 kt.
- The Chelyabinsk meteor effect was estimated to be equivalent to 400-500 kt at height approximately 30 km.

Summary

- There is a need to estimate the energy of an atmospheric event.
- The suggested path is not new.
- In the two examples the body wave magnitude was used but only for demonstration.
- The main two challenges are:
  - Estimating the seismic energy from the surface wave.
  - Calculating the height energy relation