GOES-17 satellite, NOAA

The 2022 Hunga Volcano Eruption from the Multi-Technological Perspective of CTBT Monitoring

S. Donner[*], A. Steinberg[*], J. Lehr[*], C. Pilger[*], P. Hupe[*], P. Gaebler[*], O. Ross[*], E.P.S. Eibl[#], S. Heimann[#], T. Plenefisch[*], D. Rebscher[*], L. Ceranna[*]

[*]Federal Institute für Geosciences and Natural Resources (BGR)
[#]Institute for Geosciences, University of Potsdam

B4.3 – Federal Seismological Survey, CTBT (German NDC)

21.06.2023

SnT 2023
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE
HOFBURG PALACE - Vienna and Online
19 TO 23 JUNE

O1.4-085

Monitoring compliance with the CTBT

BGR: National Data Center for the Comprehensive Nuclear-Test-Ban Treaty (CTBT)

- Access to all data of the International Monitoring System (IMS)
- CTBT-IMS: detect any explosion of 1 kt TNT equivalent

⚠ HT-HH eruption: natural event with global imprints

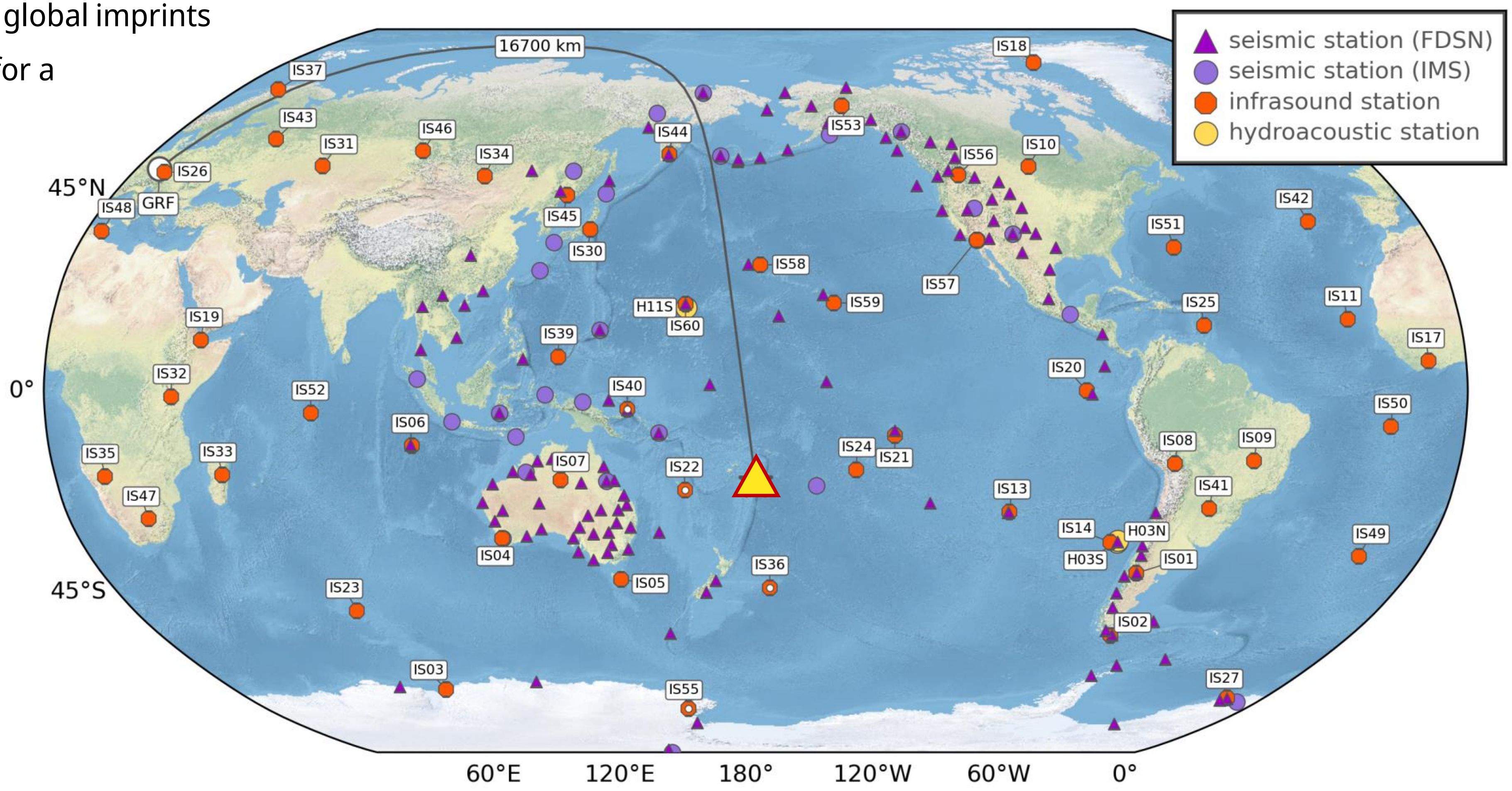
- Use the capability of the CTBT-IMS for a **multi-technology event analysis**

Seismology

Infrasound

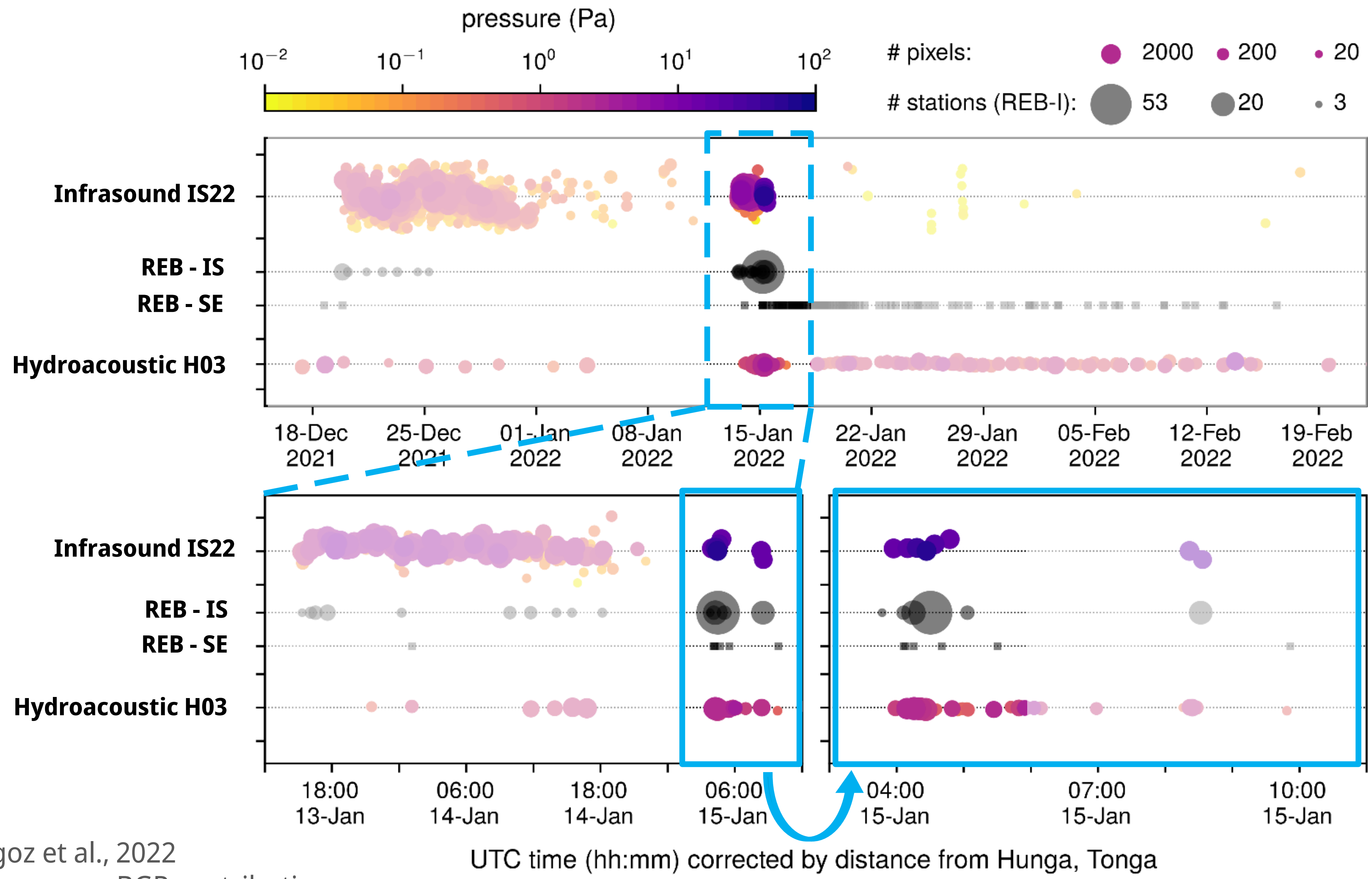
Hydroacoustic

Atmospheric Transport Modelling



Pressure waves in atmosphere, ocean and solid Earth

IMS only



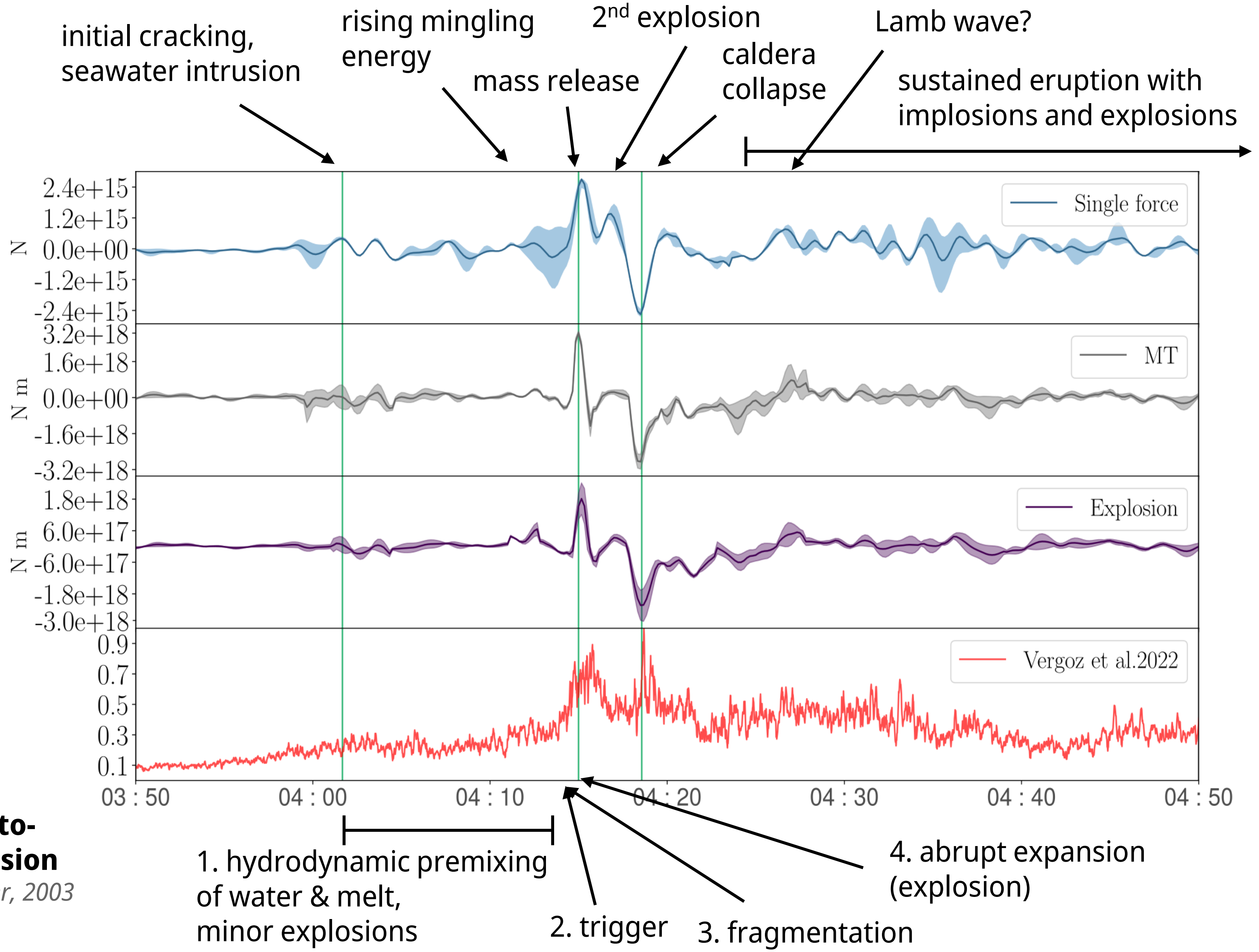
Perfect **benchmark data set** for evaluating IMS data and routines!

Vergoz et al., 2022
EPSL paper + BGR contribution

What happened between 4 and 6 am UTC on January 15th?

IMS +

interpretation

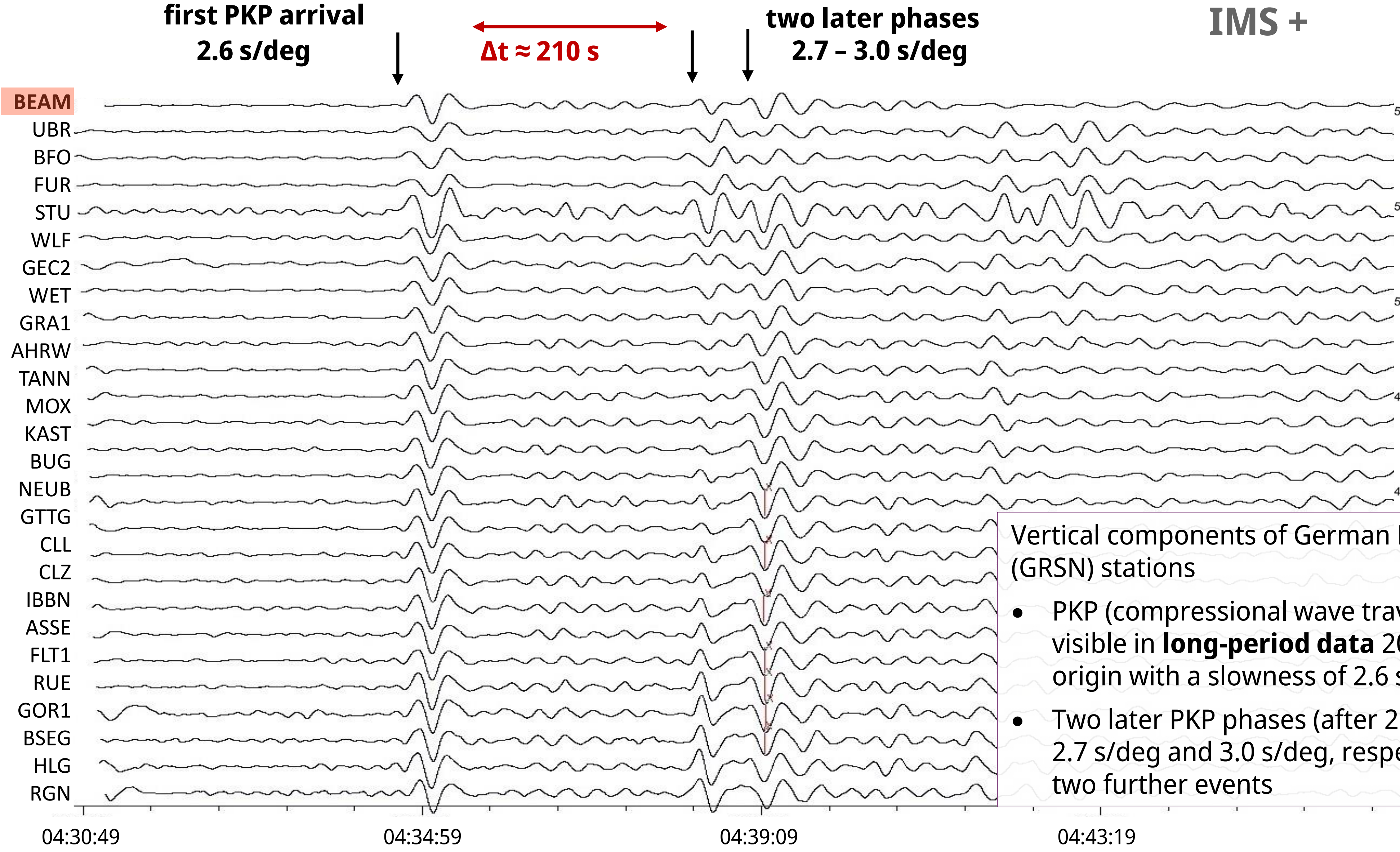


Seismic source time functions assuming different source types

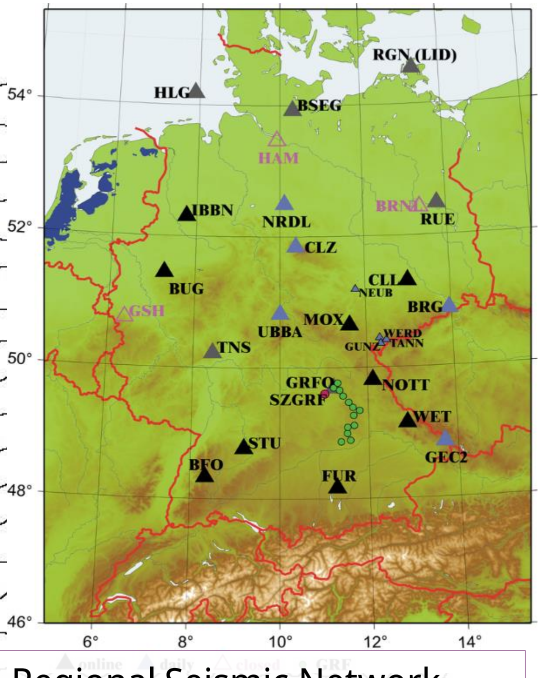
distinct events with transient seismic signals at 04:01, 04:15, 04:18 UTC

phases of phreato-magmatic explosion
Zimanowski & Büttner, 2003

First arrivals of the Hunga event at GRSN stations in Germany



IMS +



Vertical components of German Regional Seismic Network (GRSN) stations

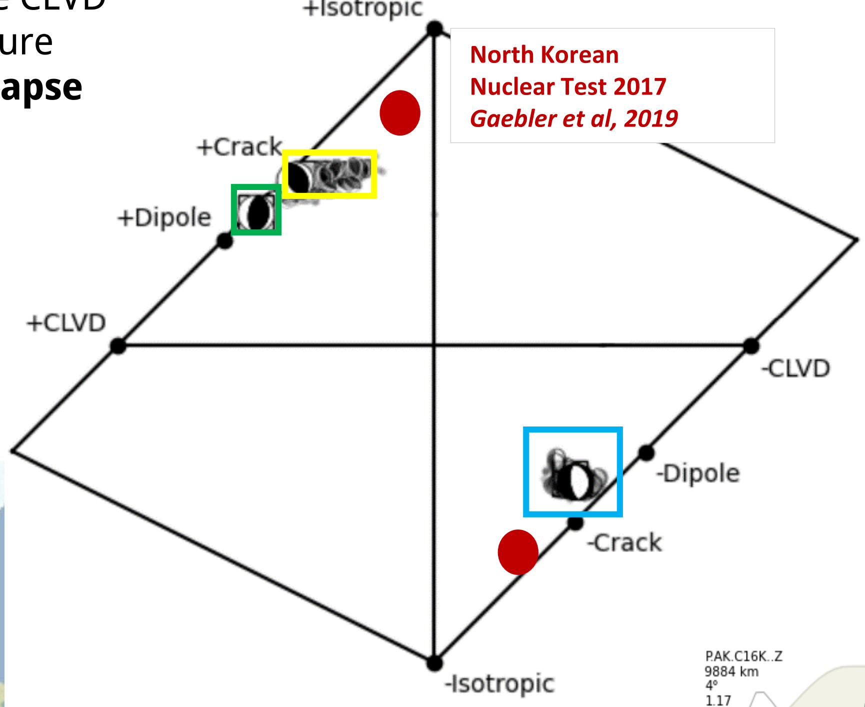
- PKP (compressional wave travelling through the core) visible in **long-period data** 20 minutes after main event origin with a slowness of 2.6 s/deg
- Two later PKP phases (after 210 s and 245 s) with slowness 2.7 s/deg and 3.0 s/deg, respectively, indicating at least two further events

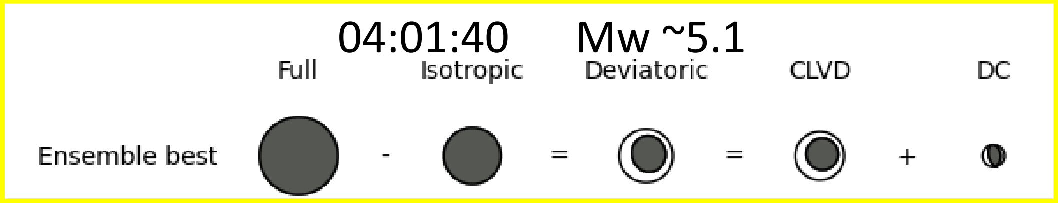
Seismological moment tensor analysis

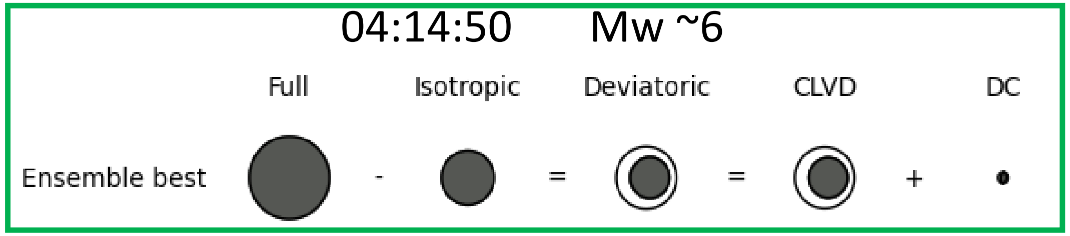
IMS +

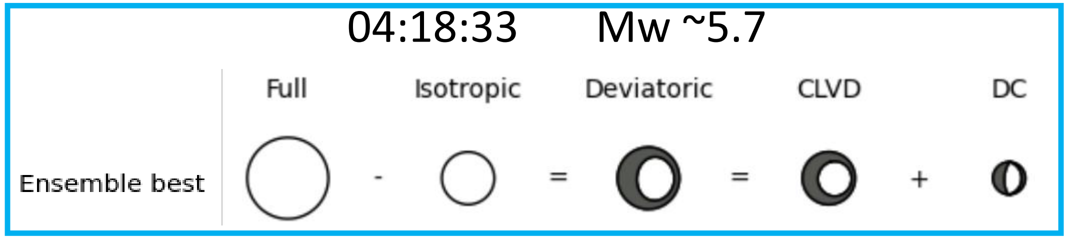
- Inversion between **1° and 93°** with Pyrocko-Grond + 1D AK135
- Inversion for **time, depth, duration** and **MT components**
- **Pre-event** and **first event** are mostly **explosive** with tensile **crack opening**
- **Second event** with negative CLVD components with crack closure indicates an **implosion/collapse**

Hudson plot

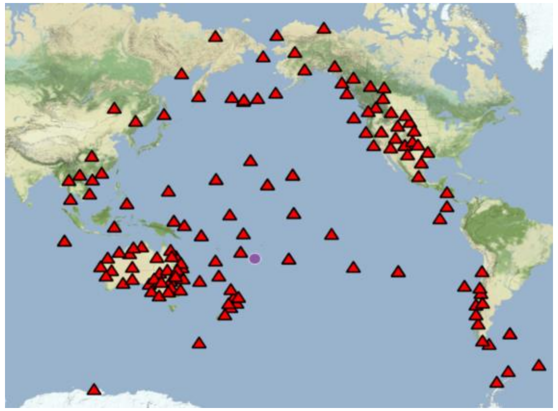




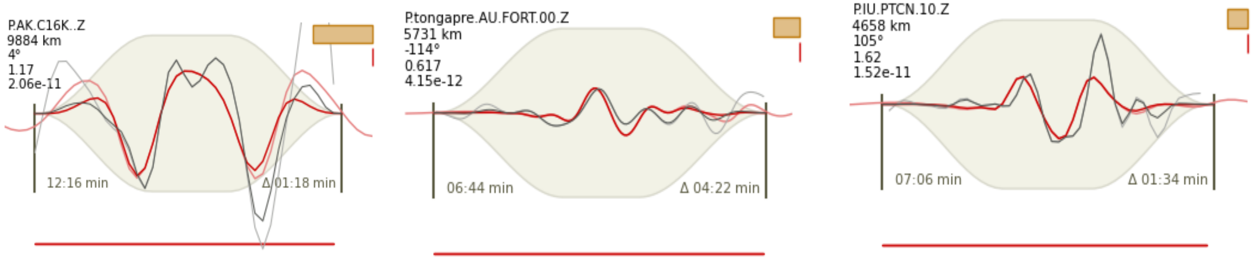




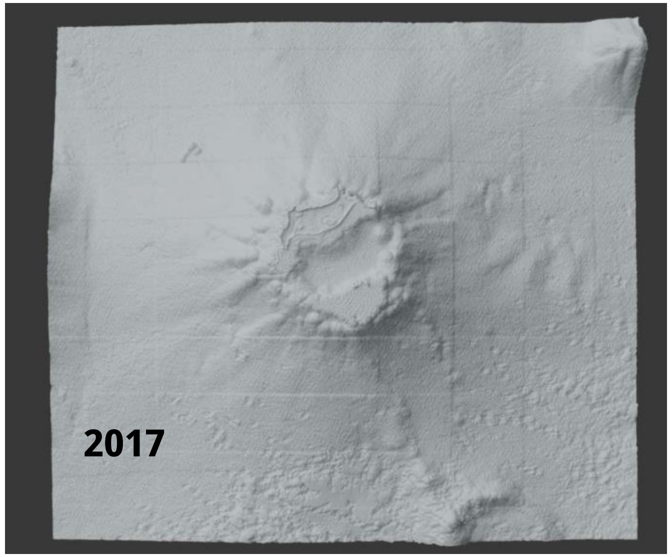
Stations used

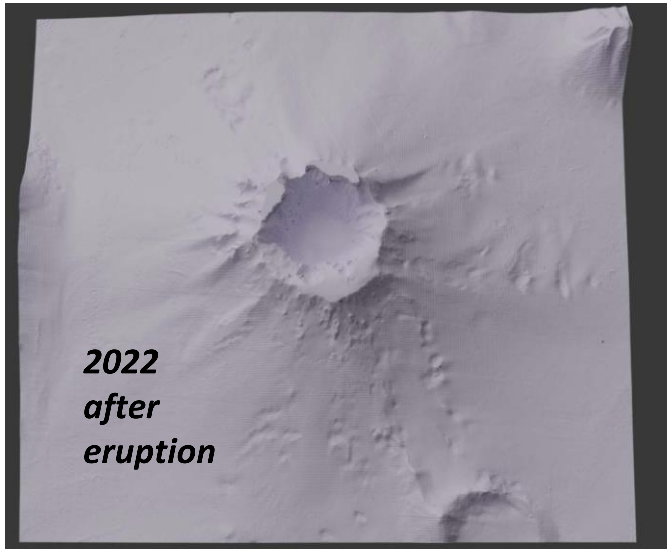


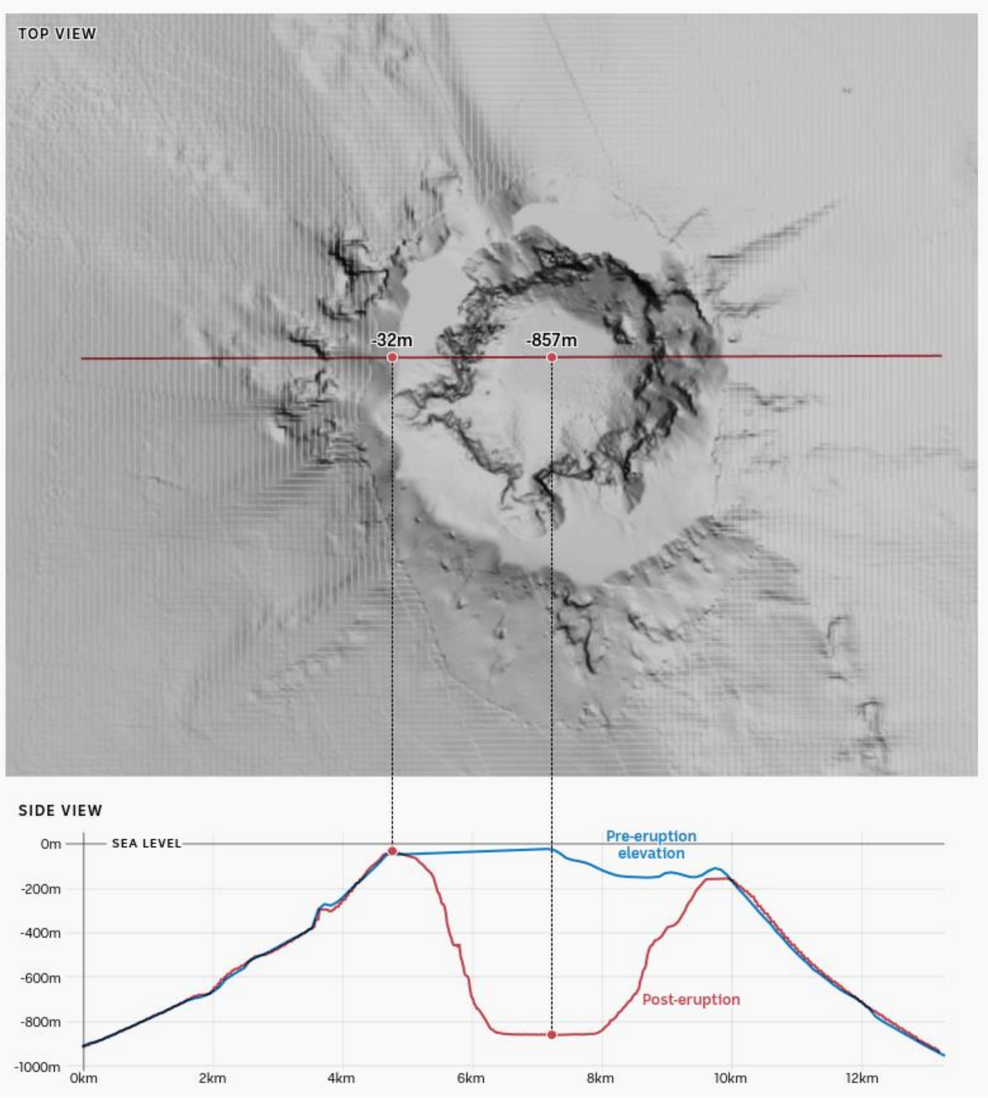
Examplary data fit



Bathymetry







Apparently no significant damage to crater walls indicates purely vertical acting forces!

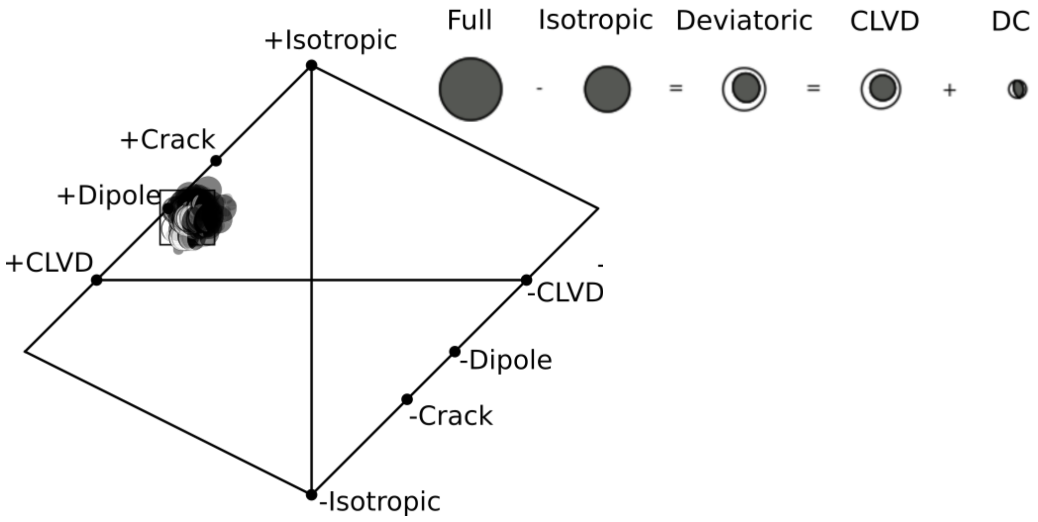
Source:
ABC News Online;
Seabrook et al.

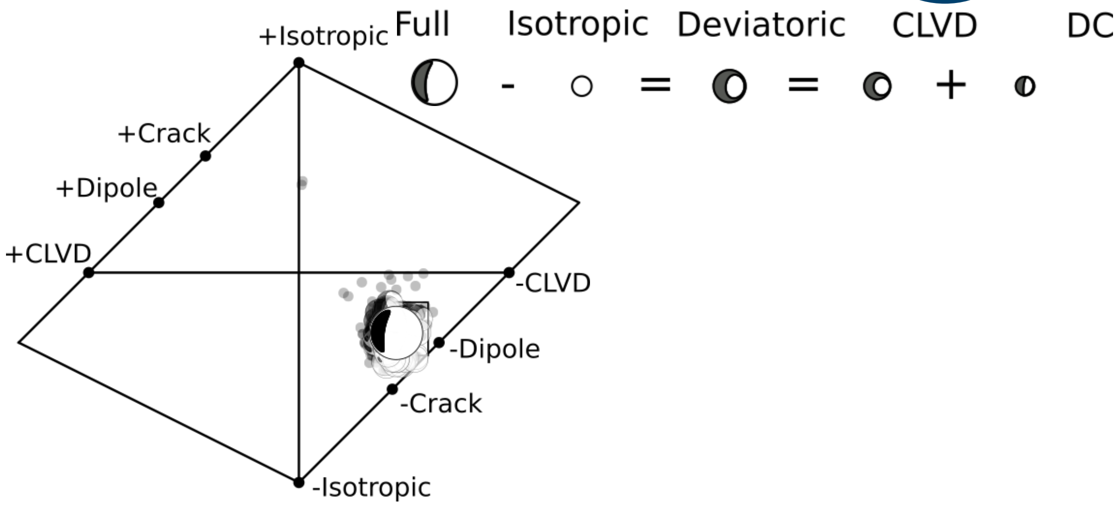
Seismological moment tensor analysis – IMS versus FDSN

04:15 UTC

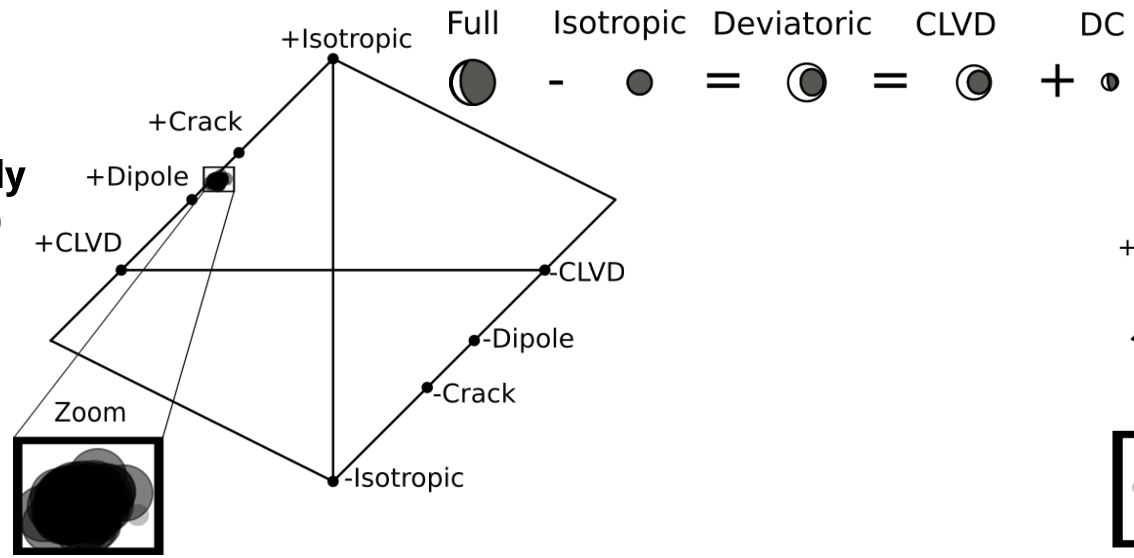
04:18 UTC

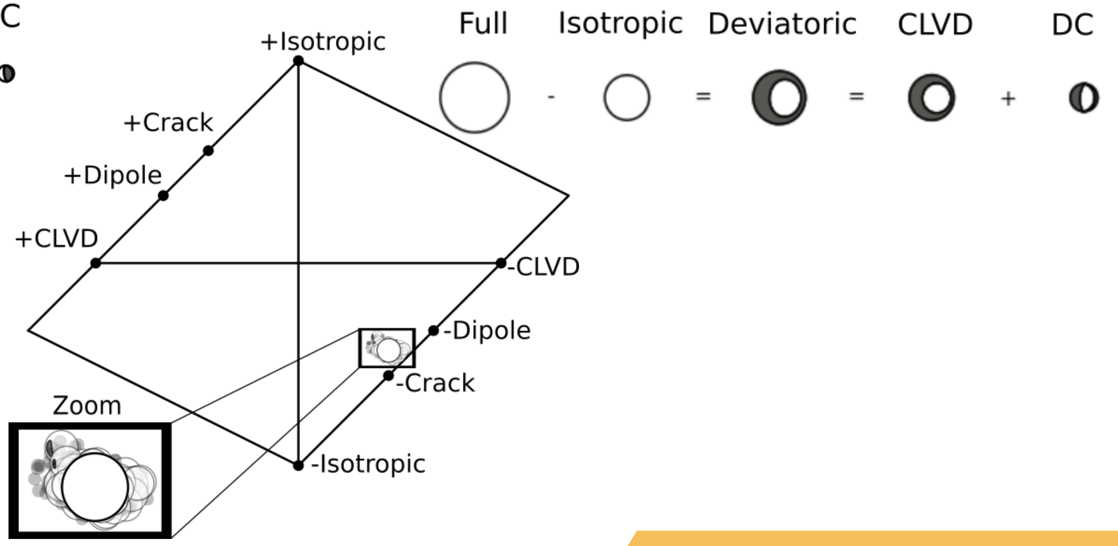
IMS data only
(29 stations)



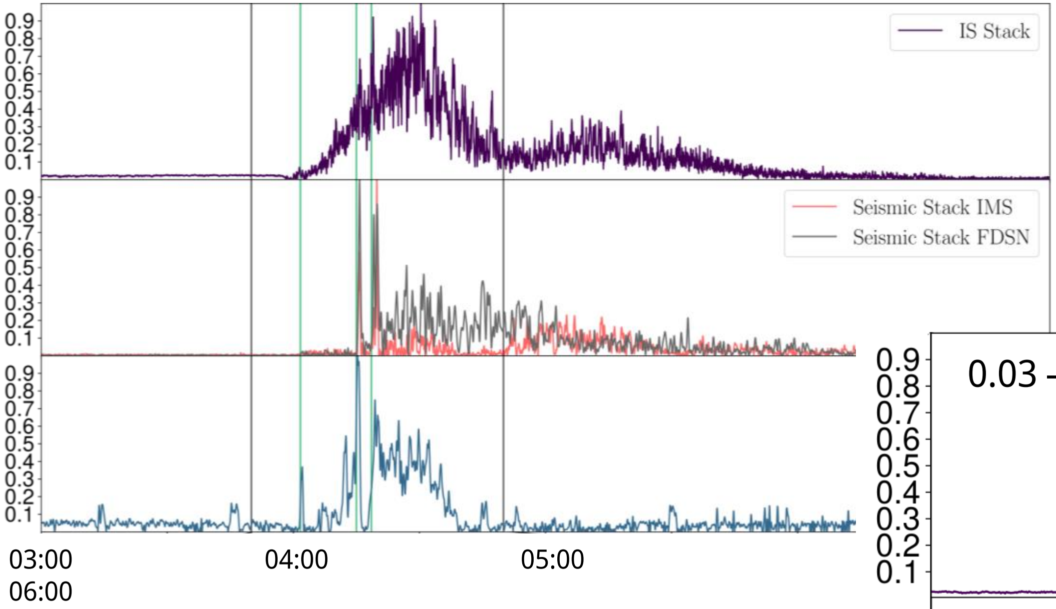


FDSN data only
(119 stations)

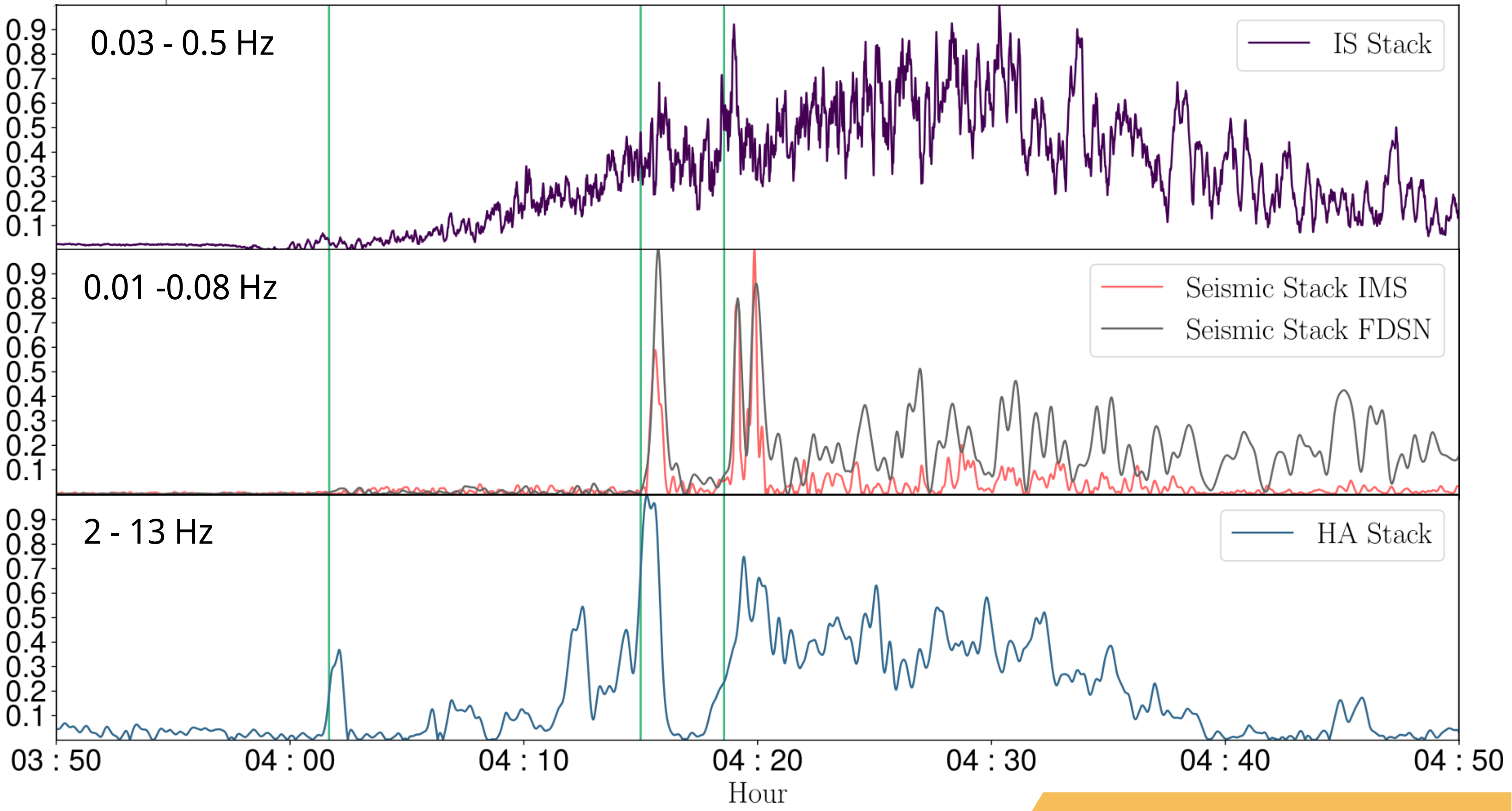




Stacking of all three waveform technologies



- stacking of normalised waveforms aligned according to expected theoretical arrival time
- averages out path and site effects
- kind of **source time function** remains



- consistent increase of coherently radiated energy at 04:00 UTC
- decrease to energy background level at ~5:50 UTC
- peaks of 04:15 and 04:18 UTC subevents in all three technologies
- peak in infrasound around 04:30 UTC
- gap between 04:15 and 04:18 UTC in hydroacoustic data

What happened between 4 and 6 am UTC on January 15th?

IMS +

interpretation

initial cracking, seawater intrusion

rising mingling energy

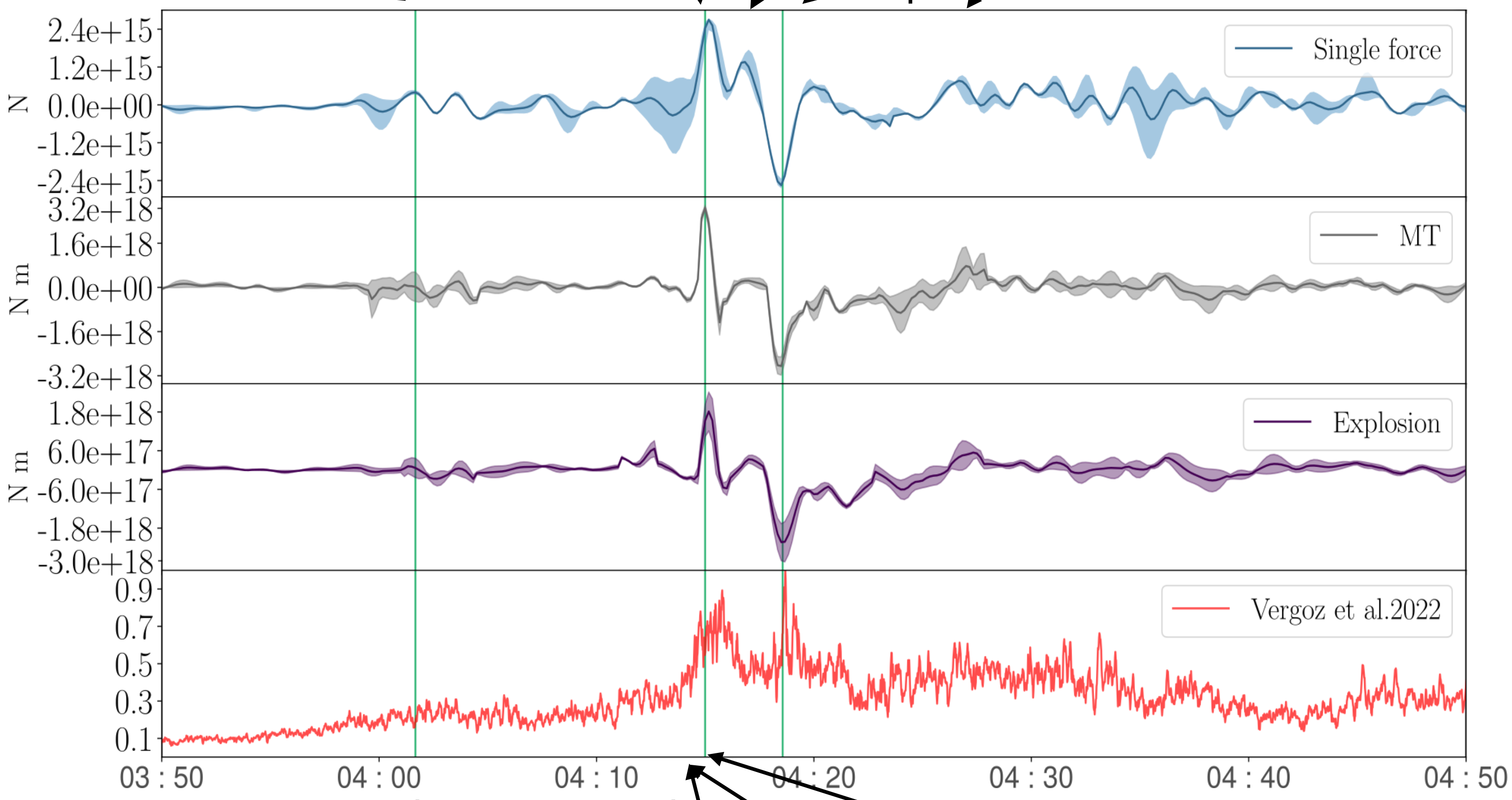
mass release

2nd explosion

caldera collapse

Lamb wave?

sustained eruption with implosions and explosions



Seismic source time functions assuming different source types

distinct events with transient seismic signals at 04:01, 04:15, 04:18 UTC

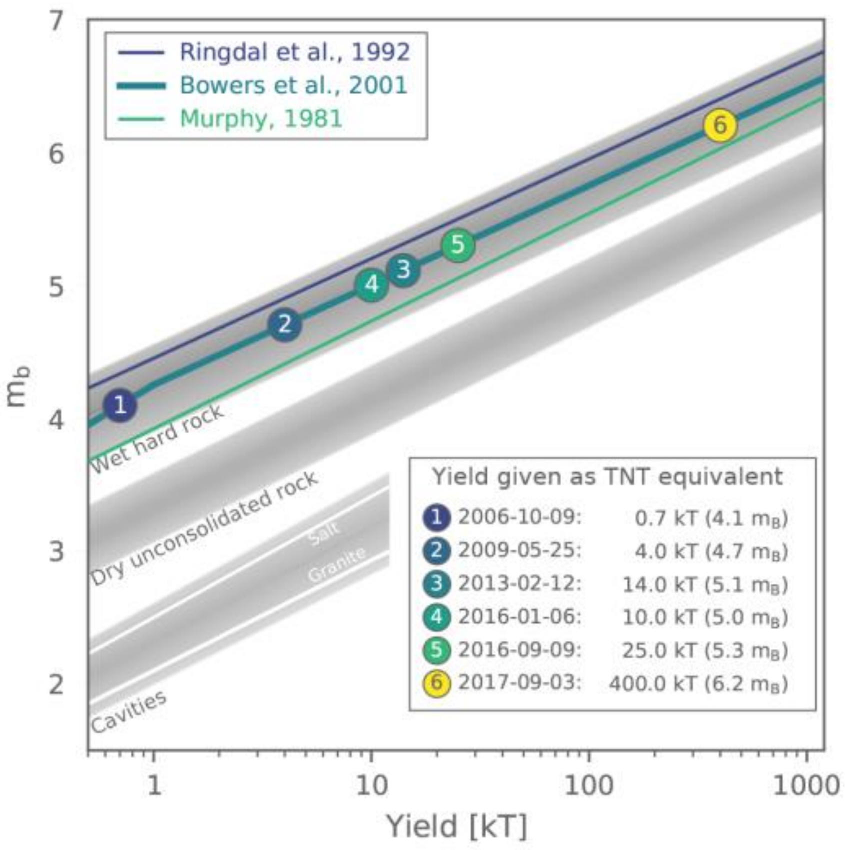
phases of phreato-magmatic explosion

Zimanowski & Büttner, 2003

1. hydrodynamic premixing of water & melt, minor explosions
2. trigger
3. fragmentation
4. abrupt expansion (explosion)

Yield estimation from seismic body waves

classic CTBT approach: determine body-wave magnitude m_b → m_b – yield relations



Gaebler et al., 2019

General problem:

- magnitude scales developed for tectonic earthquakes (shear source instead of explosion)
- derived from hard-rock onland data
- magnitude-yield relation depends on several factors

Solution (partly): yield estimation based on IS and HA data

Tonga specific problem:

- almost no P-wave energy → no body wave magnitude
- neither a tectonic earthquake, nor a classic explosion
- neither onshore, nor offshore

→ energy leaking into different medium

We need models of interaction and coupling of energy in all three media: Earth, water, atmosphere.

We need more specific magnitude-yield relations for all three media.

Yield estimation – IS Lamb wave amplitude comparison

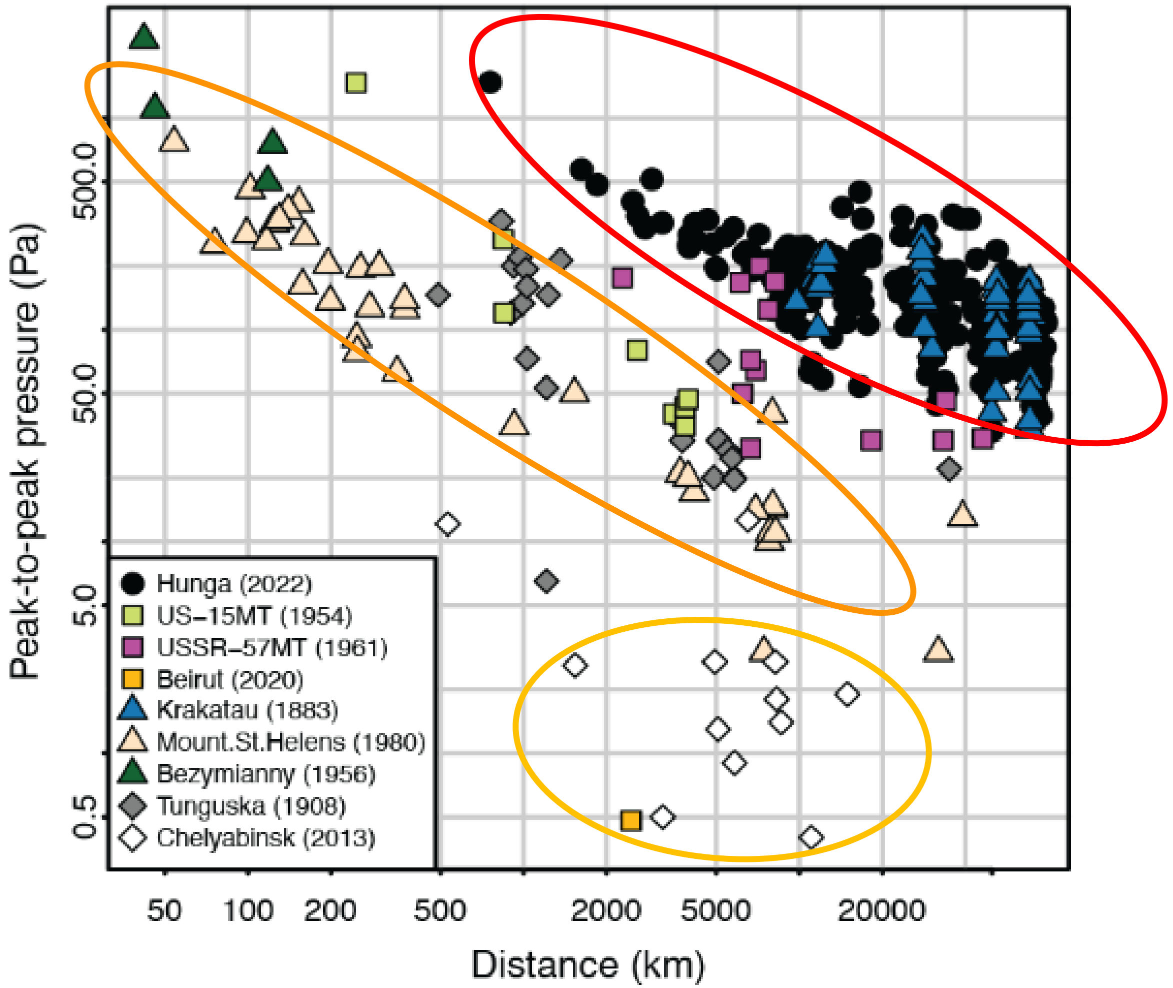
Estimation of Lamb wave

- **Global detectability** (Krakatau: 4+ global circumnavigations)
- **Amplitude** (only Krakatau is comparable since instrumental records)
- **Yield** (using Lamb-wave amplitudes, *Pierce and Posey, 1971*)
  - Mt. St Helens 35 MT
  - Tsar-bomb 57 MT
  - Krakatau 100-150 MT
  - Hunga (estimate from *Vergoz et al., 2022*): **100-200 MT**

Hundred(s) of Megatons - Krakatau (1883) & Hunga (2022)

Megatons - Tunguska (1908) & St Helens (1980)

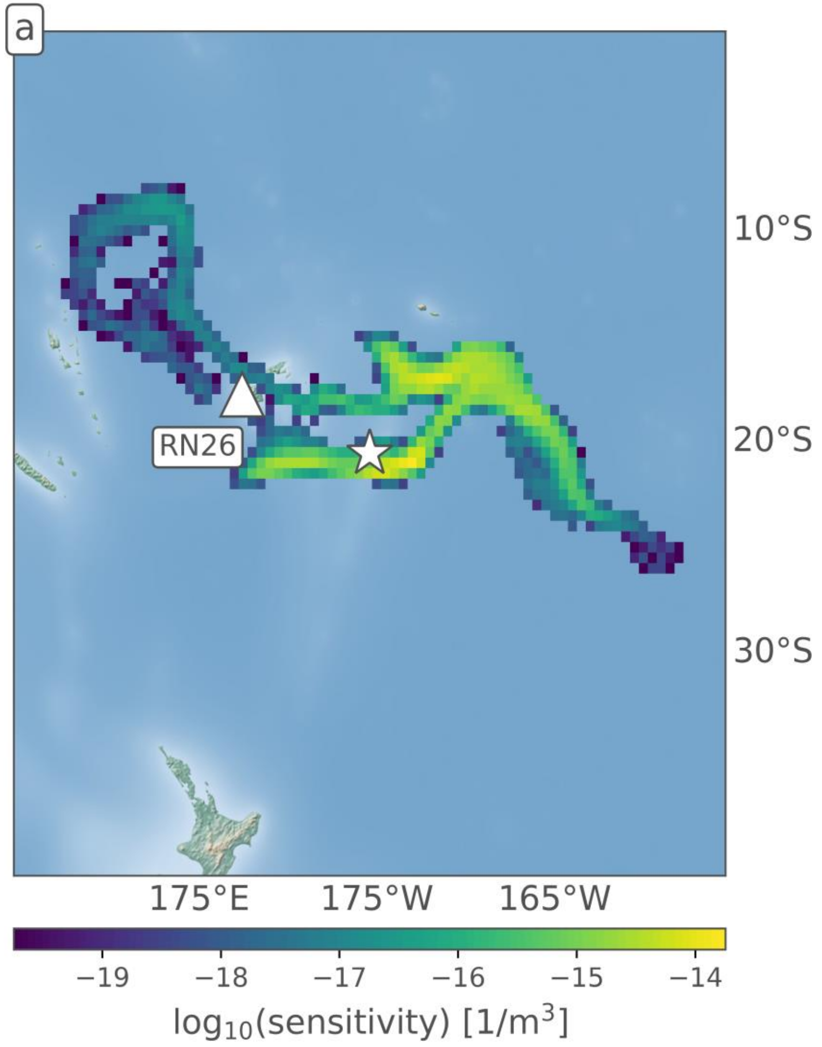
Kilotons - Chelyabinsk (2013) & Beirut (2020)



Matoza et al., 2022
Science paper + BGR contribution

Atmospheric sensitivity to the HT-HH region

RN26, Fidji
Sample: 18 Jan 2022, 01:00 UTC + 24h
source time: 15 Jan 2022, 06:00-09:00 UTC



Atmospheric transport models simulate dispersion to assess potentially affected stations or source regions.

- **no CTBT-relevant isotope** was measured at RN26
- **no** significant **elevation of natural radioactive isotopes** detected at RN26
- **activity release** of $>10^{9}$ Bq would have been detectable, **well above detection threshold**

Typical: 1 kt TNT $\rightarrow$ 10^{14} Bq

HYSPLIT (NOAA-ARL), 0.5° sensitivity grid

Meteorology: NCEP-GDAS 1°, 3-hourly

Publications

BGR

Geophysical Journal International

Geophys. J. Int. (2023) **235**, 48–73
https://doi.org/10.1093/gji/ggad204
Advance Access publication 2023 May 18
GJI Heat Flow and Volcanology

The January 2022 Hunga Volcano explosive eruption from the multitechnological perspective of CTBT monitoring

S. Donner,[1] A. Steinberg,[1] J. Lehr,[1] C. Pilger,[1] P. Hupe,[1] P. Gaebler,[1] J.O. Ross,[1] E.P.S. Eibl,[2] S. Heimann,[2] D. Rebscher,[1] T. Plenefisch[1] and L. Ceranna[1]

[1]*Federal Institute for Geosciences and Natural Resources (BGR), Stilleweg 2, 30655 Hannover, Germany. E-mail: stefanie.donner@bgr.de*
[2]*Institute for Geosciences, University of Potsdam, 14469 Potsdam, Germany*

Science
AAAS

RESEARCH

REPORT

VOLCANOLOGY

Atmospheric waves and global seismoacoustic observations of the January 2022 Hunga eruption, Tonga

Robin S. Matoza[1]*, David Fee[2], Jelle D. Assink[3], Alexandra M. Iezzi[1], David N. Green[4], Keehoon Kim[5], Liam Toney[2], Thomas Lecocq[6], Siddharth Krishnamoorthy[7], Jean-Marie Lalande[8], Kiwamu Nishida[9], Kent L. Gee[10], Matthew M. Haney[11], Hugo D. Ortiz[1], Quentin Brissaud[12], Léo Martire[7], Lucie Rolland[13], Panagiotis Vergados[7], Alexandra Nippress[4], Junghyun Park[14], Shahar Shani-Kadmiel[3], Alex Witsil[2], Stephen Arrowsmith[14], Corentin Caudron[15], Shingo Watada[9], Anna B. Perttu[16,17], Benoit Taisne[16,18], Pierrick Mialle[19], Alexis Le Pichon[20], Julien Vergoz[20], Patrick Hupe[21], Philip S. Blom[22], Roger Waxler[23], Silvio De Angelis[24], Jonathan B. Snively[25], Adam T. Ringler[26], Robert E. Anthony[26], Arthur D. Jolly[27], Geoff Kilgour[28], Gil Averbuch[14], Maurizio Ripepe[29], Mie Ichihara[9], Alejandra Arciniega-Ceballos[30], Elvira Astafyeva[31], Lars Ceranna[21], Sandrine Cevuard[32], Il-Young Che[33], Rodrigo De Negri[1], Carl W. Ebeling[34], Läslo G. Evers[3], Luis E. Franco-Marin[35], Thomas B. Gabrielson[36], Katrin Hafner[37], R. Giles Harrison[38], Attila Komjathy[7], Giorgio Lacanna[29], John Lyons[11], Kenneth A. Macpherson[2], Emanuele Marchetti[29], Kathleen F. McKee[39], Robert J. Mellors[34], Gerardo Mendo-Pérez[40], T. Dylan Mikesell[41], Edhah Munaibari[13], Mayra Oyola-Merced[7], Iseul Park[33], Christoph Pilger[21], Cristina Ramos[42], Mario C. Ruiz[42], Roberto Sabatini[25], Hans F. Schwaiger[11], Dorianne Tailpied[16], Carrick Talmadge[23], Jérôme Vidot[8], Jeremy Webster[22], David C. Wilson[26]

Earth and Planetary Science Letters 591 (2022) 117639

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

ELSEVIER

Frontiers paper

IMS observations of infrasound and acoustic-gravity waves produced by the January 2022 volcanic eruption of Hunga, Tonga: A global analysis

Check for updates

J. Vergoz[a,*], P. Hupe[b], C. Listowski[a], A. Le Pichon[a], M.A. Garcés[c], E. Marchetti[d], P. Labazuy[e], L. Ceranna[b], C. Pilger[b], P. Gaebler[b], S.P. Näsholm[f,g], Q. Brissaud[f], P. Poli[h], N. Shapiro[h], R. De Negri[i], P. Mialle[j]