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25 Years of Seismic, Hydroacoustic, and Infrasound Data Analysis at the CTBTO – Achievements, Changes, and Challenges

CTBTO PREPARATORY COMMISSION

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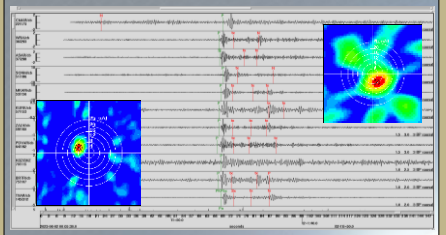
INTRODUCTION

CTBTO has been delivering processed event bulletins on a daily basis since 1999. we show here statistics of the automatic processed bulletins (SEL3), and the two output event bulletins (LEB and REB) for the past 25 years.

METHODS/DATA

1. Automatic Processing
2. Interactive Analysis

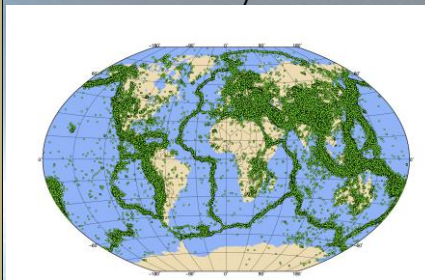


3. Releasing Reviewed Event Bulletins

START

RESULTS

945,000 LEB events
760,000 REB events
over 25 years



CONCLUSION

Improvement of the IMS station coverage, and data analysis tools remarkably increases the number of detected and analysed events.

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Overview of Bulletin Production

Automatic Processing

SEL1 / SEL2 / **SEL3**	SEL1: Standard Event List 1 is produced one 1 hour behind real time. This report lists preliminary waveform events recorded by the primary seismic and hydroacoustic stations. SEL2: Standard Event List 2 is produced four 4 hours behind real time. This report uses additional data requested from the auxiliary seismic stations along with data from the infrasound stations and any other waveform data that arrive late. SEL3: Standard Event List 3 is produced six 6 hours behind real time. Improved automated event list, which incorporates any additional late arriving waveform data.

Interactive Analysis

1. First pass 2. Scanner 3. Manual scanning 4. Review 5. Quality checking	• First pass: Analysing SEL3 events to be saved as Late Event Bulletin (LEB) by retiming, renaming, recalculating parameters, FK, adding missed phases, etc. • Scanner: To build missed events by NET-VISA and Global Association scanner. • Manual scanning: Building missed events by reviewing waveforms and un-associated arrivals. • Review: Checking accuracy of the location, associated arrivals, and the parameters of the LEB events • BullQC: Checking quality and consistence of LEB events.

Reviewed Bulletin

LEB / **REB**	LEB: Consists of 3 seismic stations, and/or 2 infrasound stations, and/or 2 hydroacoustic stations, or a combination of these. REB (Reviewed Event Bulletin): Consist of 3 primary stations or more and a event weight > 4.6. During the current provisional operating mode of the IDC, the REB is targeted to be issued within 10 days. After the Treaty enters into force, the REB will be released within two 2 days.

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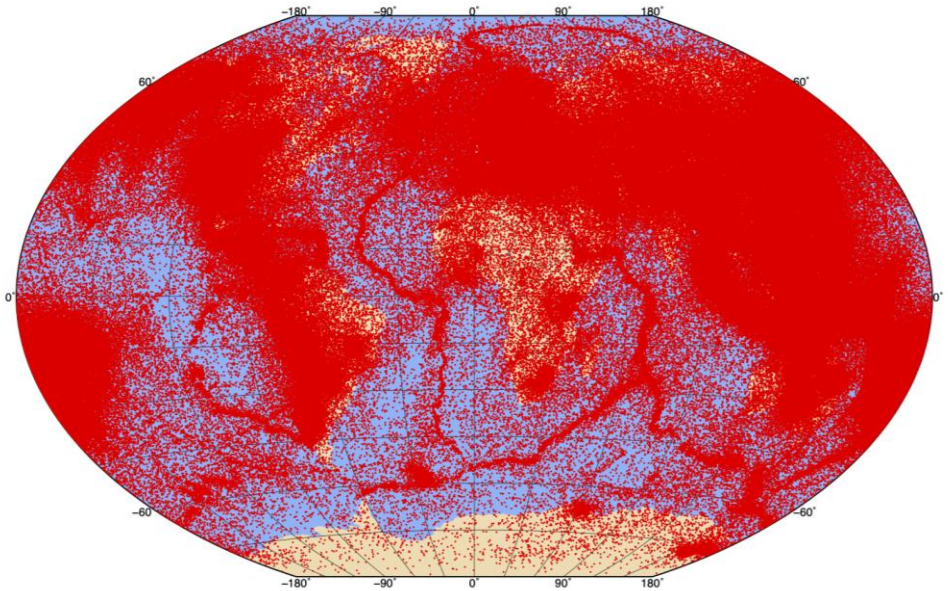
Automatic Processed vs Reviewed Bulletins

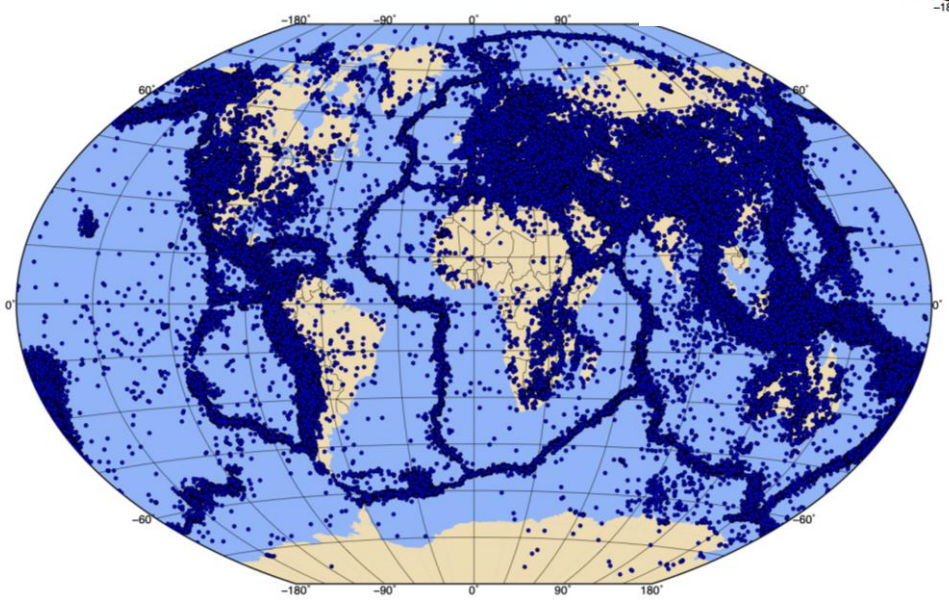
Geographical distribution of
- Automatic Processed (SEL3)
- Late Event Bulletins (LEB)
- Reviewed Event bulletin (REB)



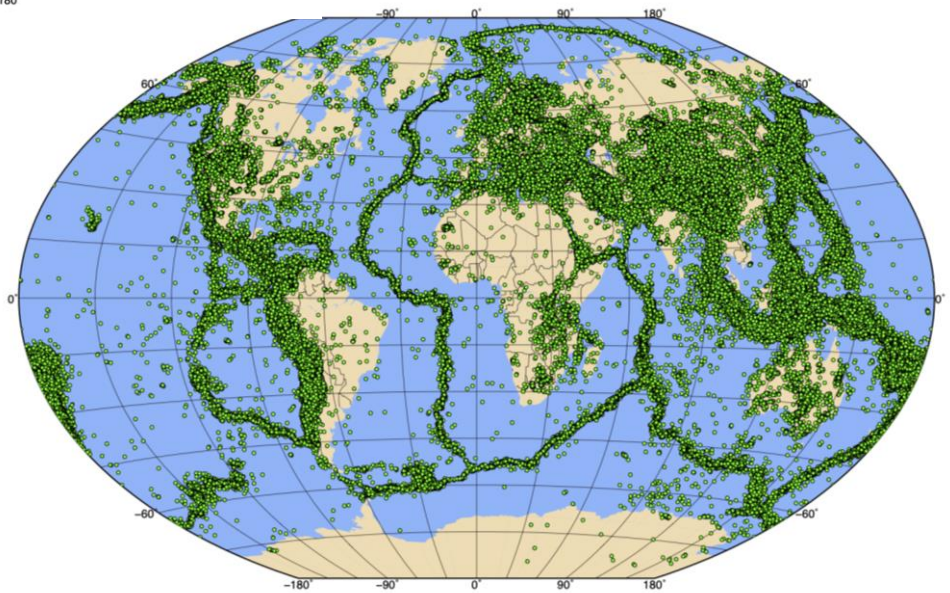
SEL3

Between Jun 1999 – May 2023
1,270,000 SEL3 events
945,000 LEB events
760,000 REB events
have been analyzed, reviewed, and released

LEB



REB



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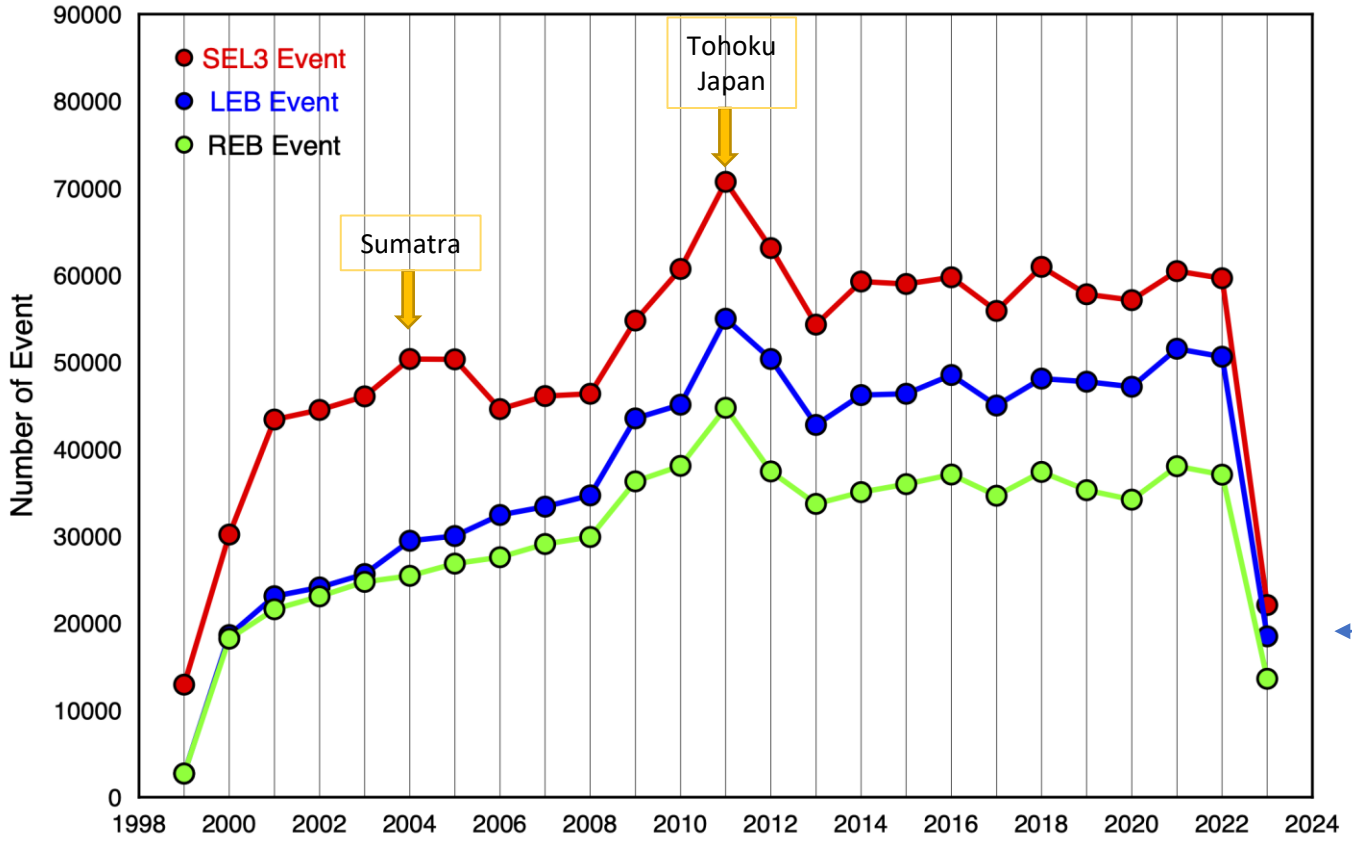
SEL3, LEB, and REB Events over 25 years

Number of SEL3, LEB and REB events received and analyzed each year for the time period between 1999 to 2023 is presented in the figure. The large number of event in 2004-2005 and in 2011 are related to the 2004 Indian Ocean earthquake, and 2011 Tohoku Japan earthquake, respectively.



The decrease in 2023 is due to availability of data up to May-2023

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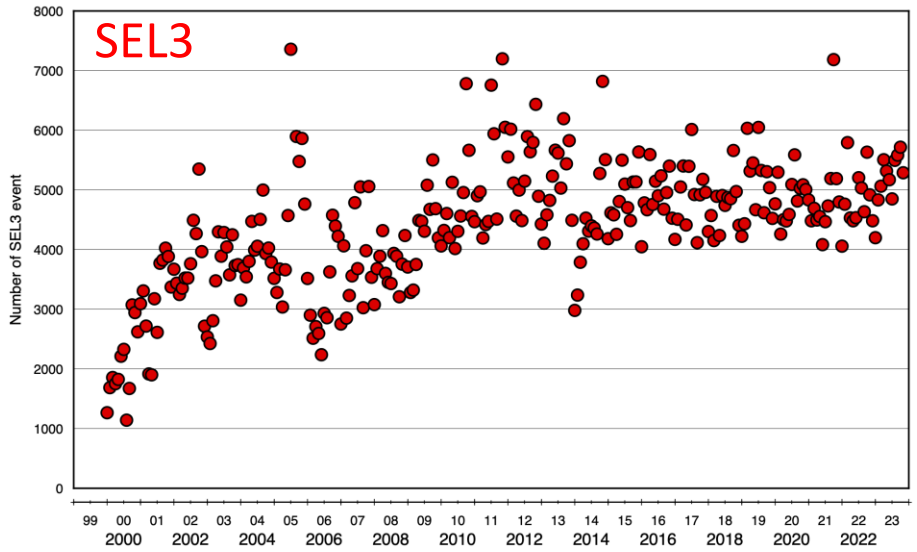
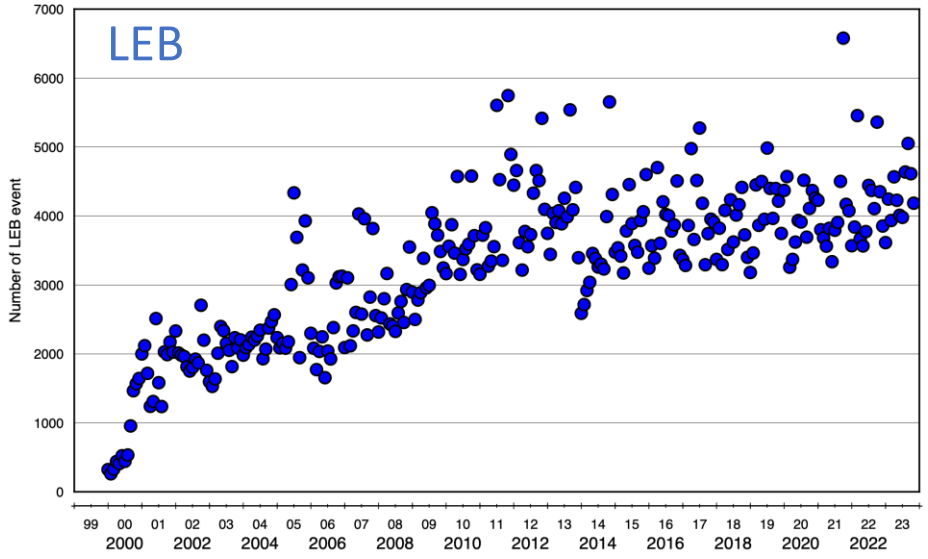
Statistics on Number of Monthly Events

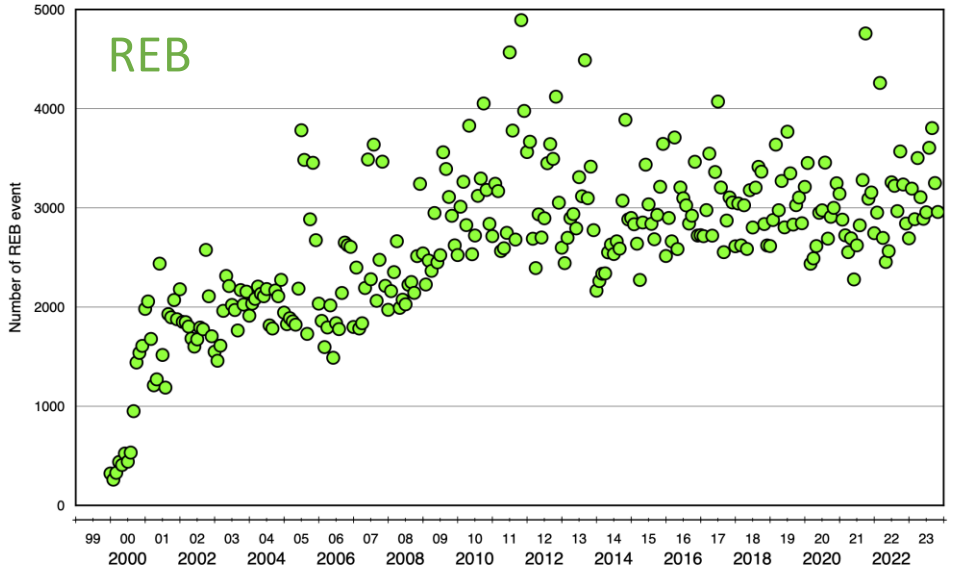
Number of SEL3, LEB, and REB events in monthly interval.

LEB bulletin includes small size of event. A notable increase of the number of events over the last 25 years can be seen especially in the LEB. As the IMS station coverage has been improved over time, more smaller size event are received and being processed.

Note that the very high number of monthly events from 2011 (March) Tohoku earthquake are not shown in the plots to have better visibility.







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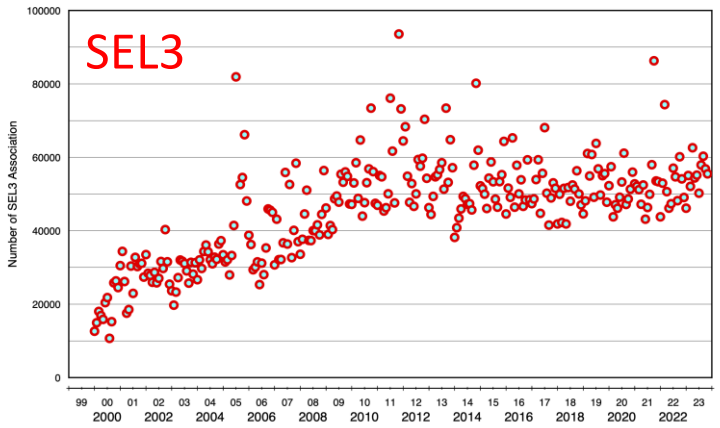
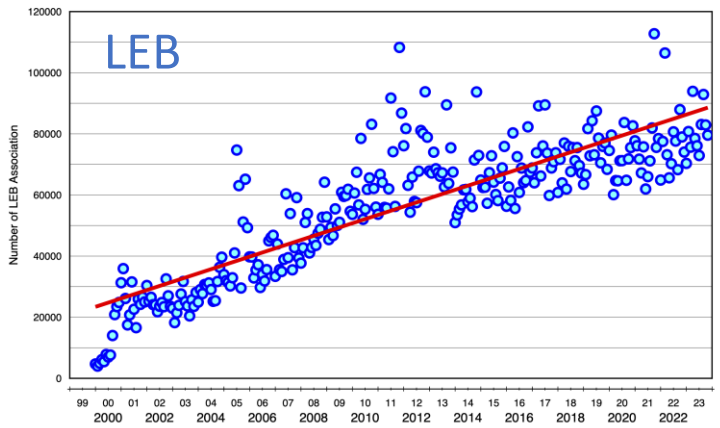
Statistics on Number of SHI Phase and Station

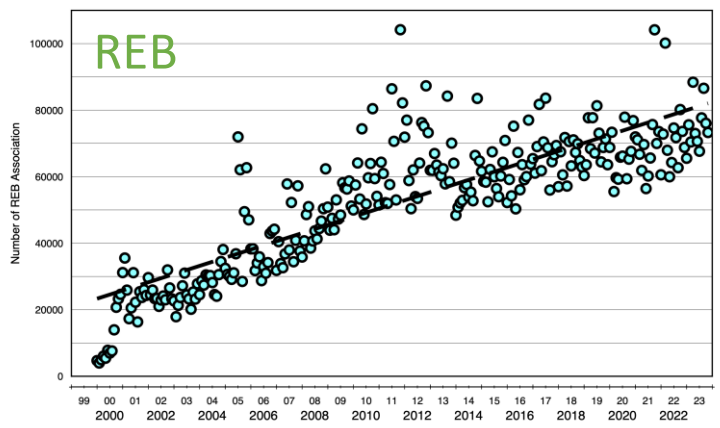
Plots show variation of the number of associated Seismic (S), Hydroacoustic (H), and Infrasound (I) arrivals (top panels) and the number of SHI stations (bottom panels) contributed to the event location between 1999 to 2023, for SEL3, LEB and REB.

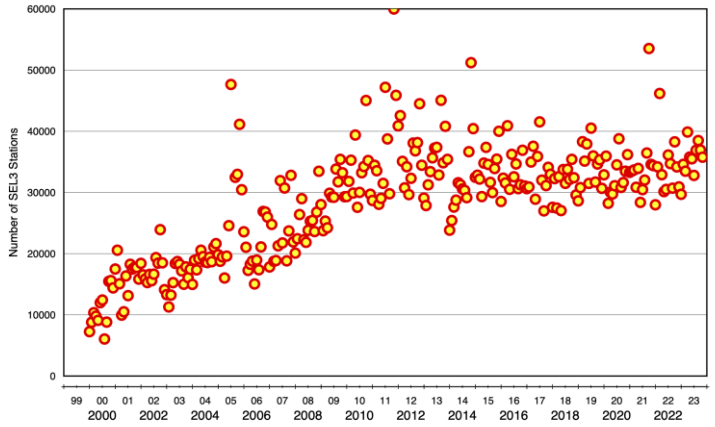
Both the number of associations and stations is increasing over the last 25 years.

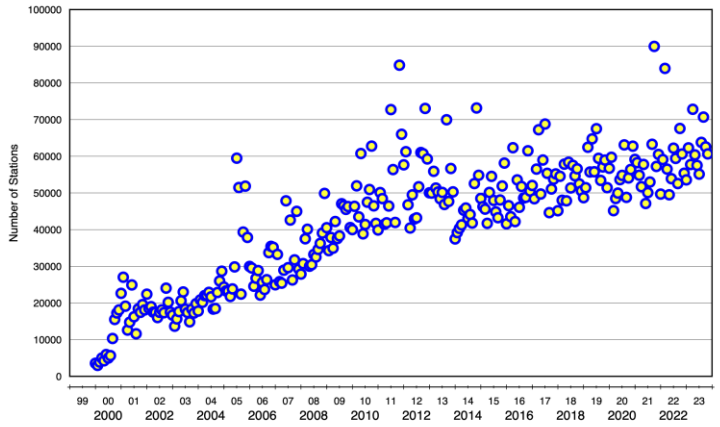
This is due to growth of the CTBTO International Monitoring System (IMS) stations and also due to the updates and improvements of the technologies.

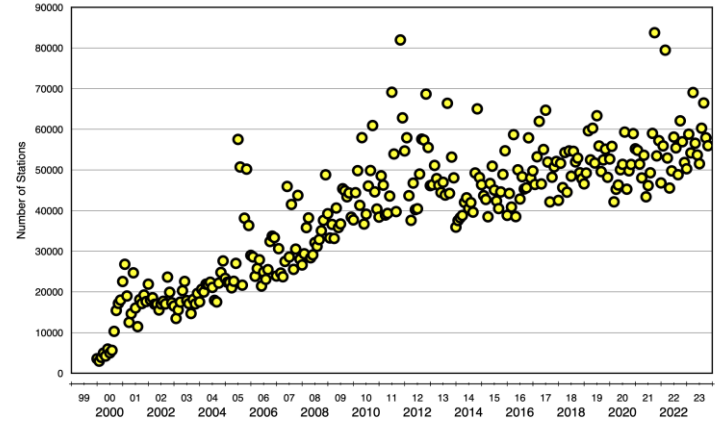












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Contribution of Hydroacoustic and Infrasound technologies

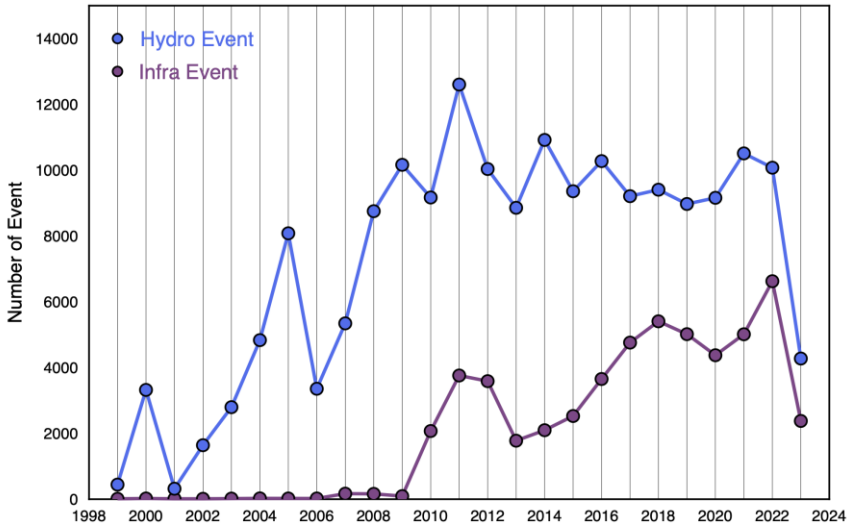
Hydroacoustic technology has been in operation since 1999. Hydroacoustic signals from 11 hydroacoustic and T-Phase stations are used and contributed to the event location.

Infrasound technology was introduced to the routine event bulletin production in 2010. Since then, Infra arrivals from 53 out of 60 world-wide Infrasound stations, are received and analyzed to detect event from volcanoes, explosion, meteorites, and etc.

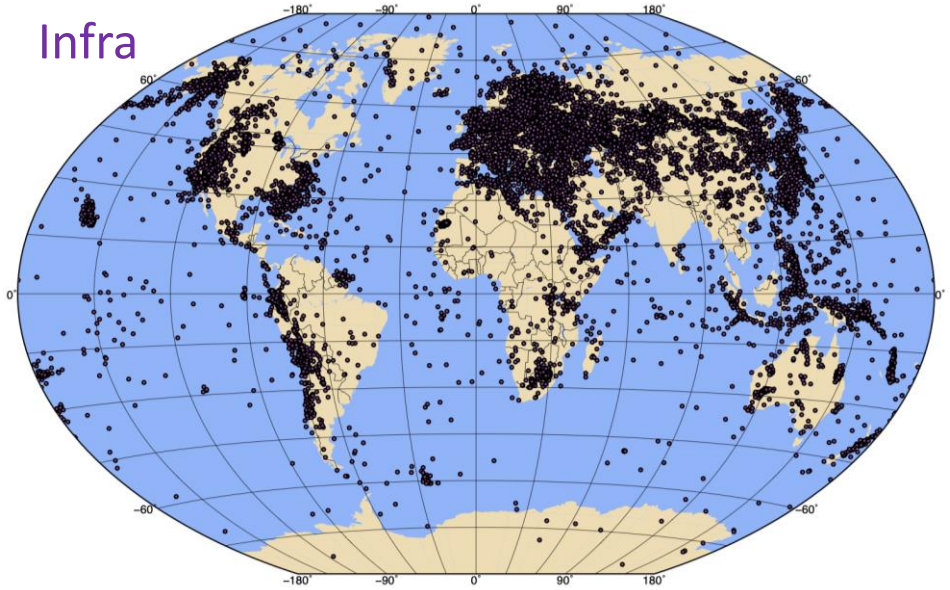
Plot shows the number of LEB events that include Hydro and Infra arrivals. Maps show geographical distribution of the Infra and Hydro LEB events.

LEB Events includes Infrasound arrivals: **53,500**

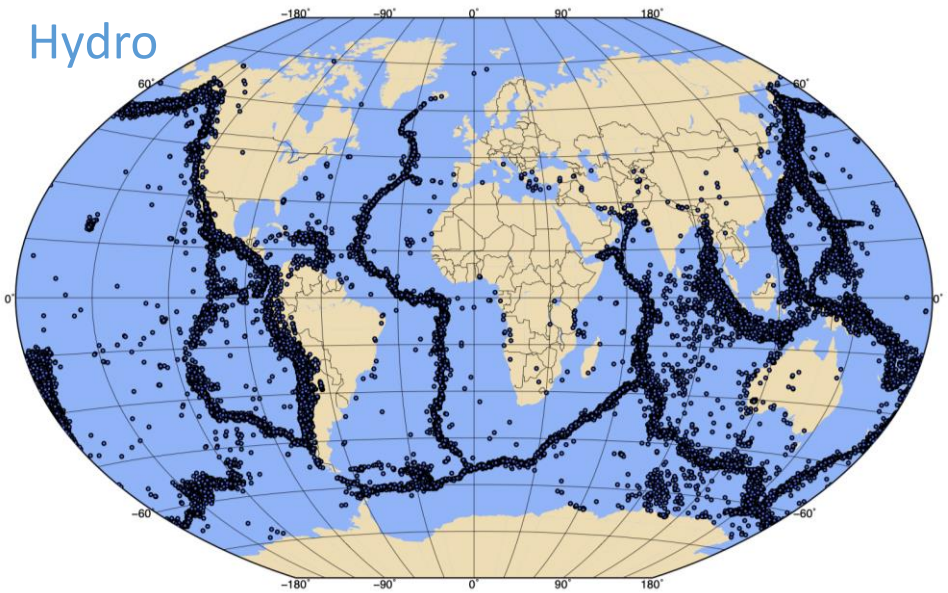
LEB Events includes Hydroacousic (H or T) arrivals: **182,000**



Infra



Hydro

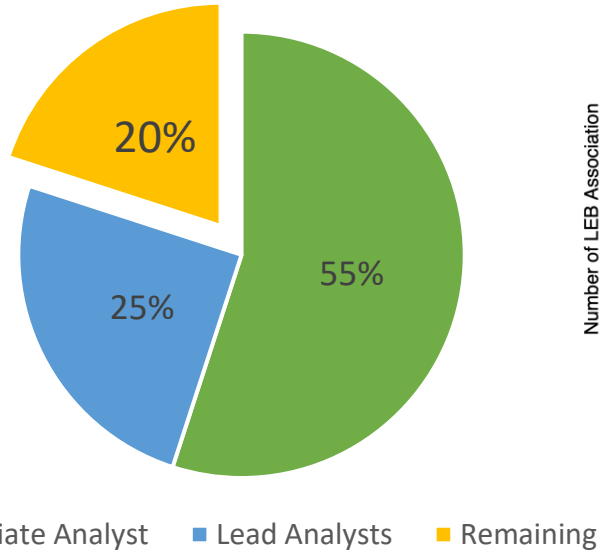


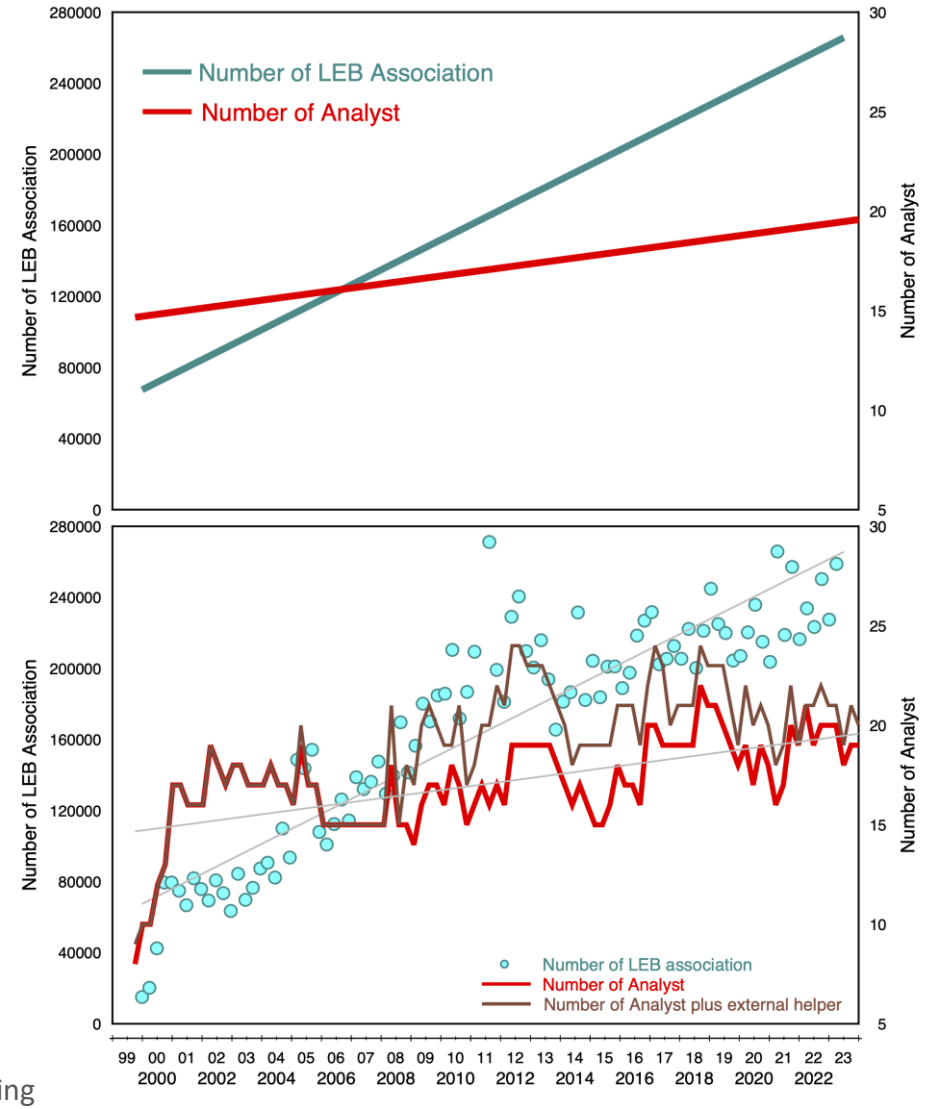
Work Capacity vs Workload of Monitoring and Data Analysis

Over years of data analysis, the number of analyzed events is increasing significantly. However, the number of expert resources to perform the interactive analysis has only slightly increased. Hence, external helpers are quite often required in order to timely deliver the bulletins.

Plot (bottom panel) compares the growth of the associated arrivals to the LEB events with the number of analysts without (in red) and with (in brown) external helpers. Top panel shows the significant difference between the growth rates of the workload and number of analysts.

The chart represents more details of the work capacity of the monitoring and data analysis. A minimum of **20%** of the workload is out of the work capacity of the unit, which often requires 2 external helpers.





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Conclusion

- Since June 1999 data from the CTBTO International Monitoring System (IMS) are received in near real time at the International Data Center (IDC) in Vienna.
- The data from seismic, hydroacoustic and Infrasound stations are being processed automatically and then analyzed and reviewed manually at the Monitoring and Data Analysis (MDA).
- Between 1999 to 2023, MDA has successfully delivered **945,000** LEB and **760,000** REB events out of **1,270,000** automatic processed SEL3 events on daily basis.
- Hydroacoustic and Infrasound signals are used to event detection and location. Infrasound has great contribution to the bulletin production but at the same time it increases the number of detected events and more importantly demands notable resources and analysis time.
- Improvement of the IMS station coverage, detection and processing (e.g. NET-VISA) and analysis tools remarkably increases the number of detected and analysed events.
- The increase in the number of analyzed events is not proportional to the number of analysts, which is one the main challenges of the data analysis at the MDA.

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Additional Information

The authors acknowledge the CTBTO IMS and the IDC sections who liaise with the MDA in bulletin production.

Standard Event List (SEL3), Late Event Bulletin (LEB) and Reviewed Event Bulletin (REB) used in this study are available for authorized users of the CTBTO State Signatories.

Seismic, Hydroacoustic, and Infrasound data are available to the scientific community by request to the CTBTO vDEC platform.
(https://www.ctbto.org/resources/for-researchers-experts/vdec)

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