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Determination of the frequency response of seismic & infrasonic IMS station sensors using an on-site calibration approach

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HOFBURG PALACE - Vienna and Online
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EMPIR EURAMET
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Need for on-site calibration procedures

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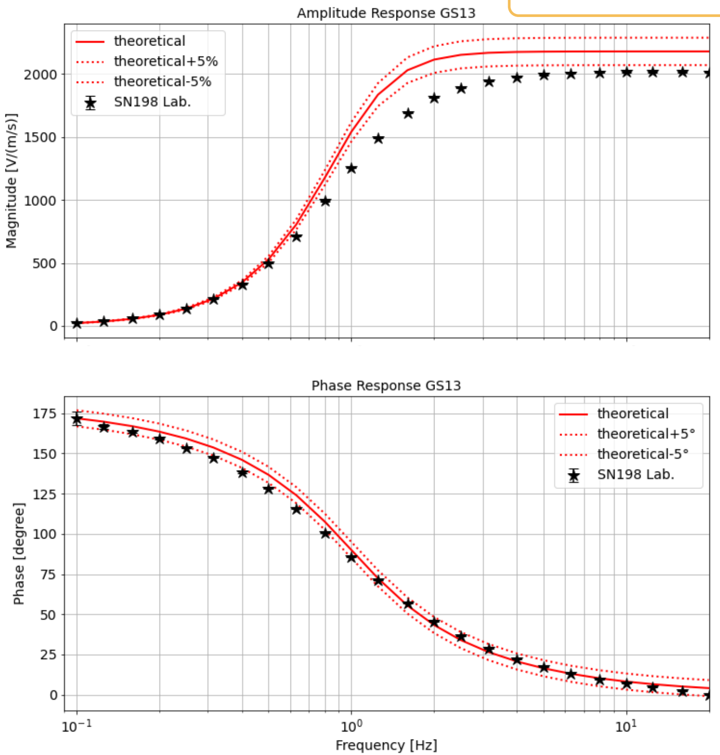
Missing standards & calibration procedures

- In the **low-frequency** range down to **0.01 Hz** reliable calibration procedures, which include **traceability to SI**, are currently **missing**
  → rely on the manufacturer's specifications

Joint Research Project ***19ENV03 Infra-AUV****

- Development of **primary** & **secondary calibration** methods
- Establish procedures, which allow permanent **on-site calibration without** any **interruptions** of the recordings
- Consideration of **traceability** & **measurement uncertainties**



* https://www.ptb.de/empir2020/infra-auv/home/

Need for on-site calibration procedures

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Interruption of measurements
Violation of technical requirements

Laboratory

multi-component calibration system of PTB

Field Sensors

Seismometer in a vault

Installation of a laboratory calibrated instruments as reference sensor

If the field sensor will not come to the laboratory, the laboratory calibration will go to the field sensor.
(freely adapted from Francis Bacon, "Of Boldness", 1625)

Development of on-site calibration methods

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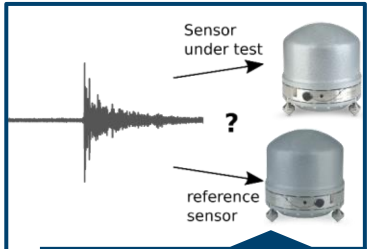
Existing calibration methods are “relative”

They rely on sensor comparison using a common excitation signal & calculate a gain ratio between the sensors to characterize "errors" in the transfer function (e.g., Pavlis & Vernon, 1994; Sleeman et al., 2006)

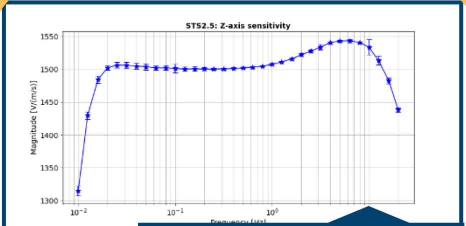
Application of a modified approach of Gabrielson (Gabrielson, 2011; Charbit et al., 2015; Green et al., 2021)

Determination of the gain ratio between a co-located reference sensor (REF) and station sensor under test (SUT) and inclusion of various similarity measures (e.g., coherence, cross-correlation)



SUT & REF measure the same coherent signal

Ensures traceability to SI



Known response of REF (Amplitude & Phase)

Algorithm behind the on-site calibration approach

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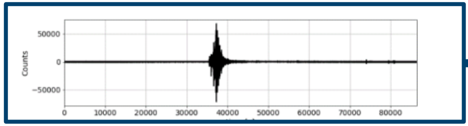
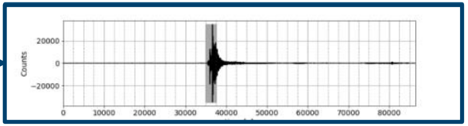


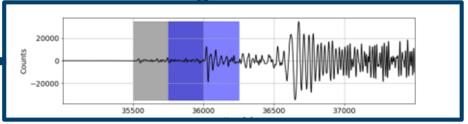
Raw data signal

Filter*[1] within Pass-bands



Division into segments

Segment *i*



9 Windows, 50% overlap

Calculations of similarity measures & cross-/auto-spectral densities

Similarity measure* ≥ Threshold?

Determination of gain ratio between REF & SUT

$$Gain\ Ratio = \frac{G_{XX}}{G_{XR}}$$

Calculation of frequency response function (amplitude & phase) of SUT using traceable response of REF

Advantages?

- The filtering & the choice of the window length allows a better determination of the response function within the individual frequency ranges
- Longer data segments with larger windows enable analysis of the low frequency range

Similarity measures:

- Magnitude-squared cohereny (MSC)
- Cross-correlation
- Cross-Array coherency*[2]

*[1] Ensure stationarity of time series (Charbit et al., 2015)

*[2] Cross-Array coherency (Green et al., 2021)

Fieldtest for the on-site calibration of seismometers

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- **Laboratory calibration** of 2 vertical station seismometers (**GS13**) and a 3-component seismometer (**STS2.5**) by PTB
- **Full frequency response is known & traceable to SI; uncertainties are given**
- Installation of the calibrated seismometers at the station in August 2022
- **260 days** of **continuous data** have been recorded
- Removal of **STS2.5** in May 2023 for a **laboratory re-calibration**

Co-located 3-component seismometer STS2.5 vs. CMG-3T (vertical component)

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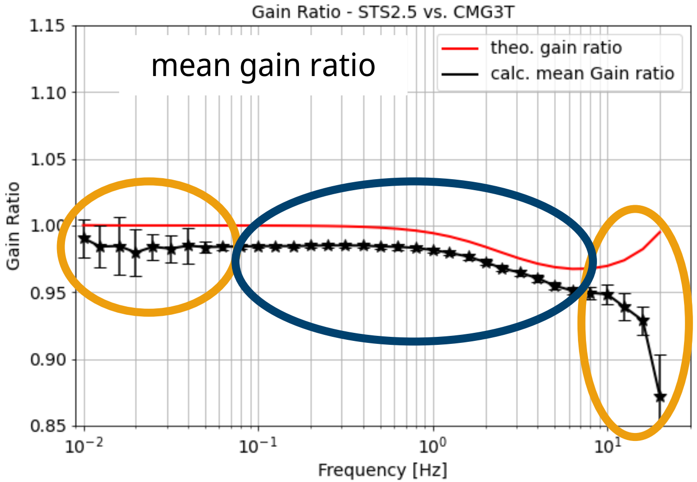
- Calculation of **complex gain ratio** on a **daily** basis
- mean over **260 days**
- **Similarity measures** taken into account:

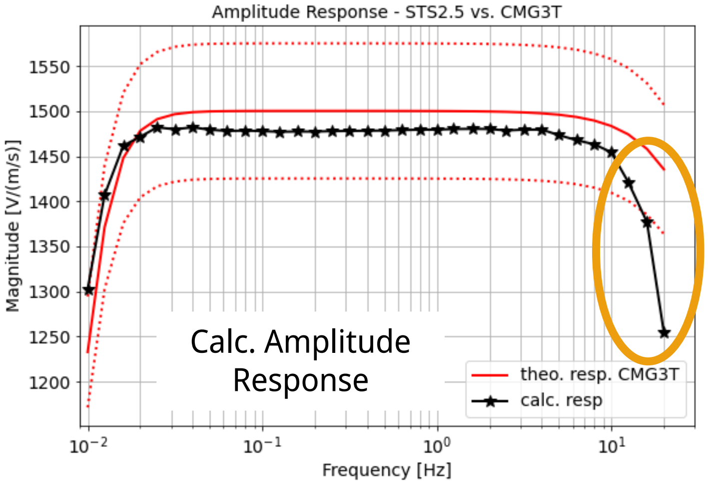
  MSC ≥ 0.98

  XC ≥ 0.8

> ➢ 0.05 - 8 Hz: low standard deviations
>
> ➢ > 8 Hz: high standard deviations, deviation from nominal value (> ±5% of nom. Value)
>
> ➢ < 0.05 Hz: high standard deviations

CMG-3T (SUT) & STS2.5 (REF)





Co-located 3-component seismometer STS2.5 vs. CMG-3T – Amplitude & Phase

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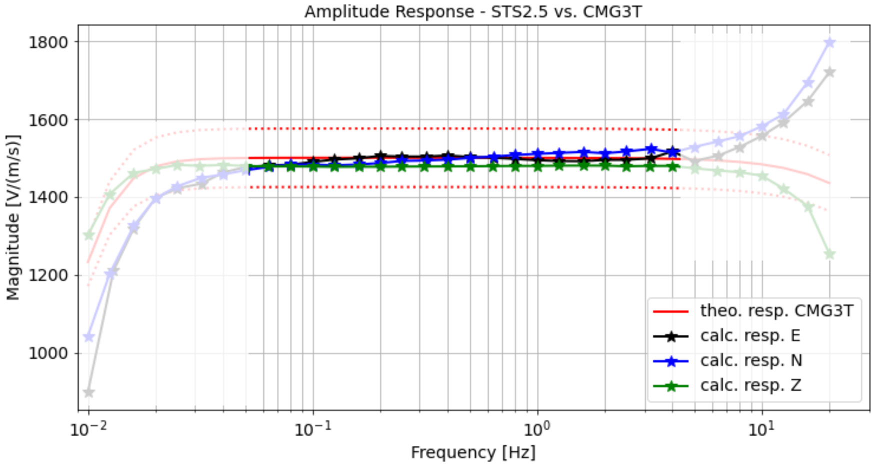

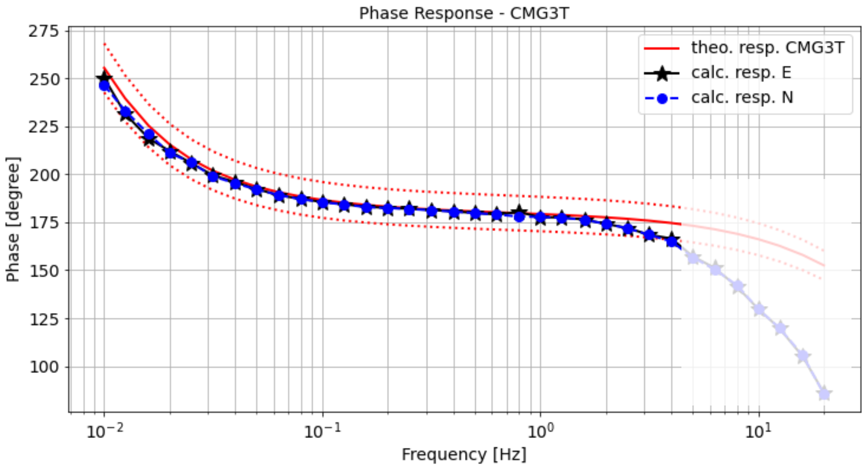

Below 0.05 Hz and above 5 Hz the transfer functions for the horizontal components could only be determined with high standard deviation in the laborator by now!
The reference is back in the laboratory for re-calibration!

Co-located broadband & short-period seismometer GS13 vs. STS2.5 (Z-component)

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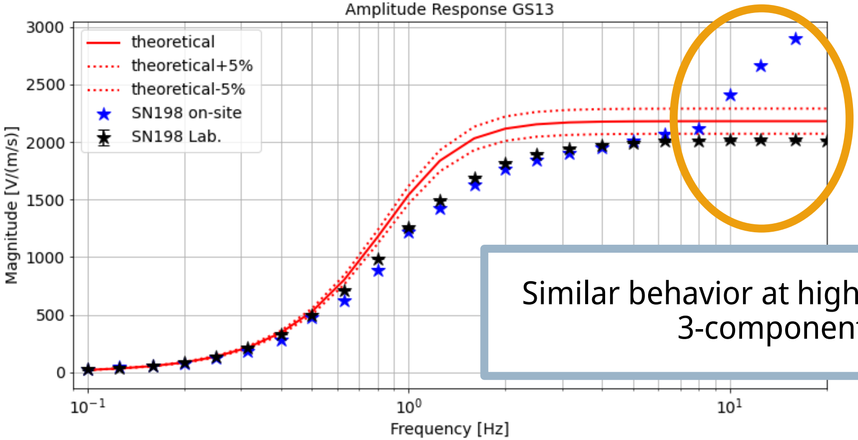
GS13 (SUT) & STS2.5 (REF)

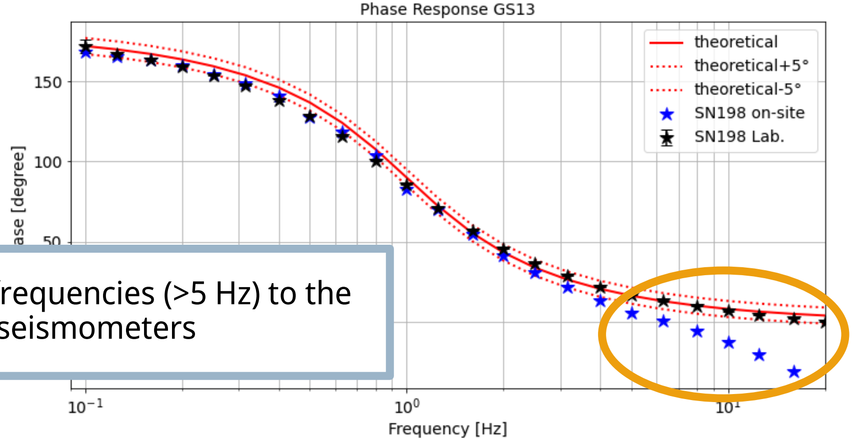
Cross-check

Both sensors are laboratory calibrated ↔ verification of the method

! Caution

different input gain *(1x vs. 8x)* & pre-amplifier *(40V/V)* ↔ effects must be taken into account





Similar behavior at high frequencies (>5 Hz) to the 3-component seismometers

Station-wide seismometer calibration?

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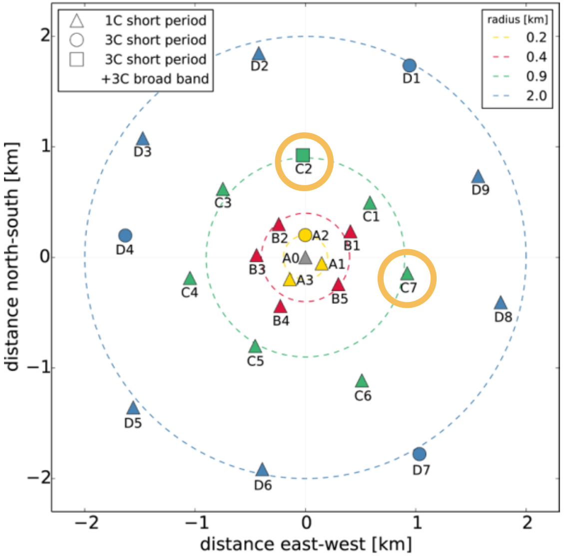
In a subsequent step, we aim at the **calibration** of **all sensors of a station** using a single temporary and stationary reference sensor.

→ **Comparison between 2 laboratory calibrated GS13 seismometer**

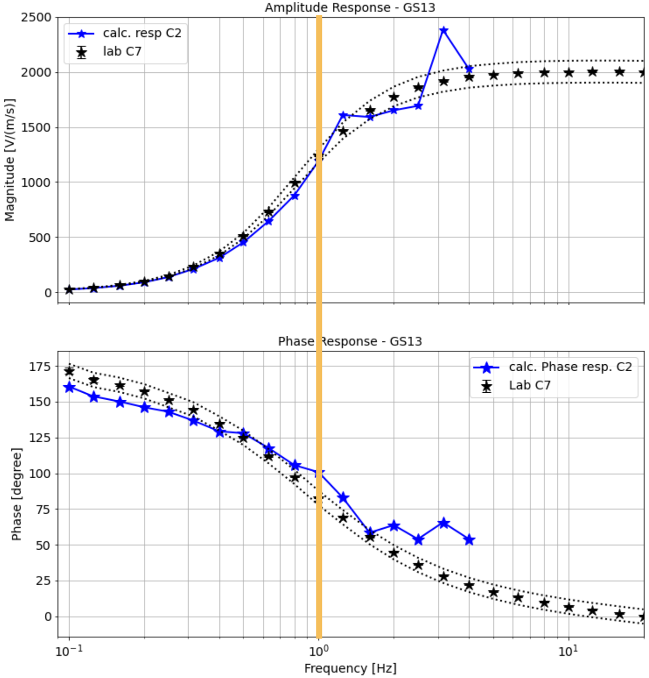


< 1 Hz	✓
> 1 Hz	× still work to do!

Distance between sensors: ≈ 1425m

SUT: C7

REF: C2



Summary

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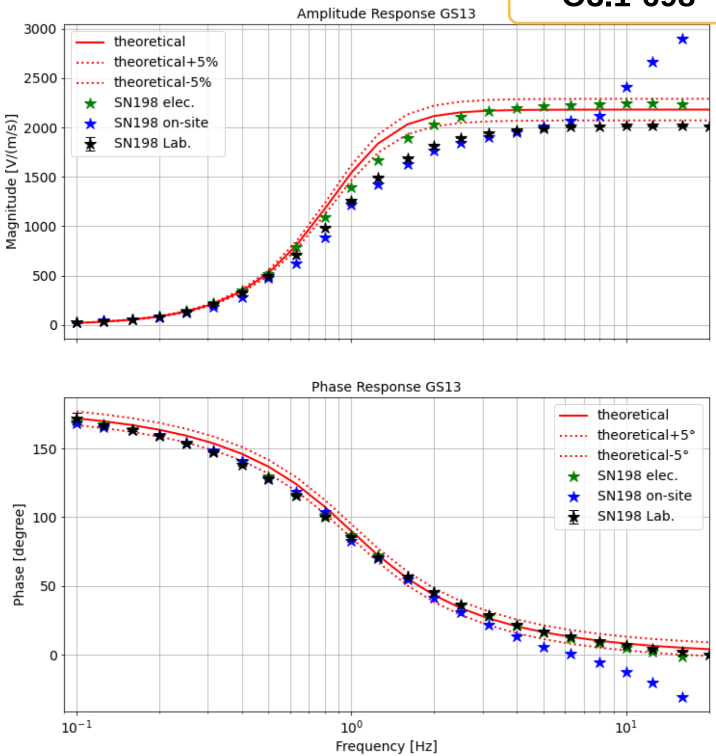
Added value

- Cross-check shows that the on-site calibration method provides values comparable to those obtained in the laboratory
- the results are closer to the true values than those of the electrical calibration (former calibration method)

On-Site calibration with traceable calibrated reference allows for a traceable calibration of station sensors without interrupting the measurements!

Open Points

- Uncertainty propagation
- Cause of deviation for frequencies > 5 Hz



THANK YOU!

BGR

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Infra AUV

* https://www.ptb.de/empir2020/infra-auv/home/

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Calibration of an Infrasound station including the wind-noise reduction system

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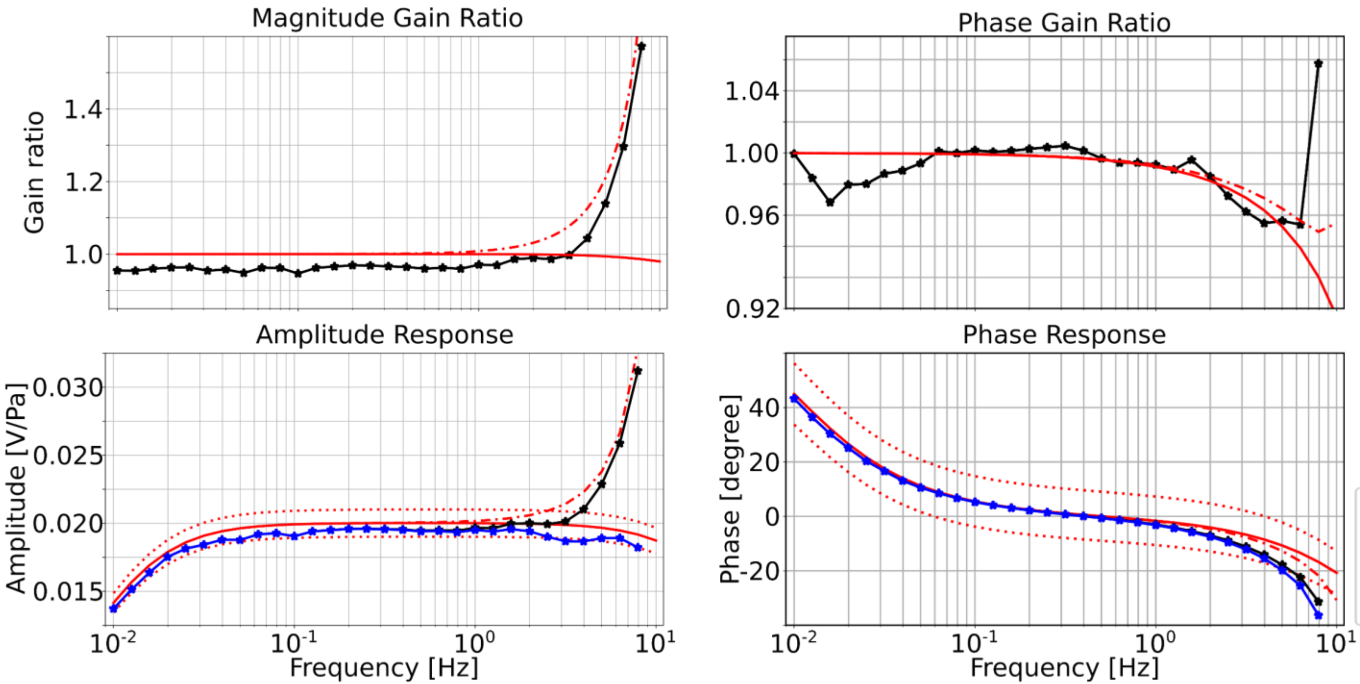

- **REF**: MB2005 (single inlet)
  SUT: MB3a (WNRS, 96 inlets)

- Calculation of gain ratio for each day (>80 days), averaging over all days
- Similarity measures:
  Coherency (MSC) >0.98
  Cross-Array Coherency >0.6
  (Green et al., 2021)

Station-wide seismometer calibration?

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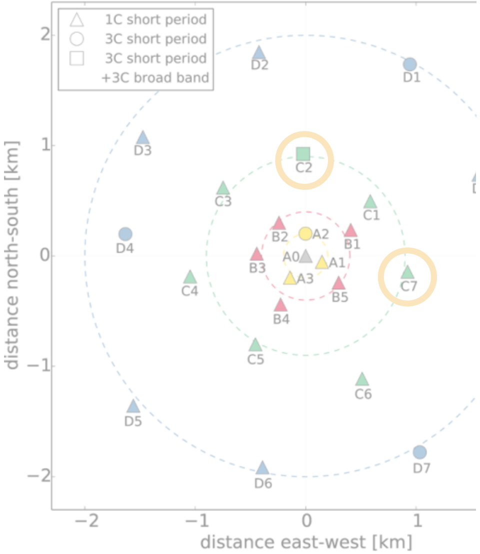
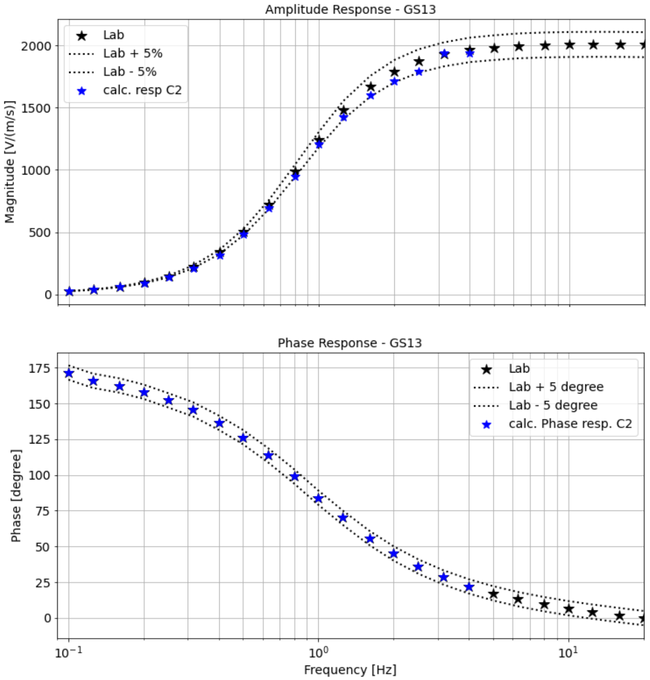
In a subsequent step, we aim at the **calibration** of **all sensors of a station** using a single temporary and stationary reference sensor.

→ **Comparison between GS13 seismometer**



After averaging:



SUT: C7

REF: C2