The FDSN OBS Standards Action Group

UN

Y Ai, K Aderhold, J Carter, J Collins, C Corela, W Crawford, S Hemmlebb, T Isse, M Tsekhmistrenko

Noise reduction through rotation

US

W Crawford, G Laske, N Harmon, C Rychert

The BRUIT-FM Noise reduction challenge

W Crawford, S Ker, E Stutmann, S Rebeyrol, M-A Aminian, G Barruol, L Duval, R Dreo

FR

FDSN Action Group on OBS data and metadata standards

Kasey Aderhold, Yinshuang Ai, Jerry Carter, John Collins, Carlos Corela, Wayne Crawford, Susanne Hemmlebb, Takehi Isse, Maria Tsekhmistrenko

FDSN Action Group and You

- Goal
  - Make marine seismology accessible to and usable by the largest audience

- Process
  - Define standards
  - Document particularities of marine seismological data
  - Publicize open source, easy to use processing tools

- Mandate
  - Until September 2025 IASPEI workshop, Lisbon

Collaborative workspace

- https://github.com/FDSN/OBS-standards
- Two main files
  - standards.md: meta/data standards
  - software.md: available software
- An Issues page:
  - Please submit any questions/recommendations you may have.

obs-specific information

The StationXML format (v1.2) has no intrinsic elements for storing OBS-specific information. This information should be stored in a structured metadata file with a public-published format.

We propose to use obsinfo "subnetwork" files, which allow the storage of essential information about deployments without going into instrument-level details.

These files can be used with obsinfo instrumentation files to generate FDSN StationXML files with embedded OBS-specific information, or they can be used to fill in information in StationXML files generated using other tools.

processing steps

Processing done on data files (from data download to delivery to the data center) should be recorded in text-based, structured files. The JSON process-steps format (LINK) is an example.

Source Identifiers

The following source-subsource codes (see FDSN Source Identifiers documentation) should be used for the following types of sensor/data:

code	description
1	Unoriented seismometer, “N” channel equivalent
2	Unoriented seismometer “E” channel (+90 degrees from "1")
3	Seismometer/geophone with inverted vertical channel (positive voltage is down)
DH	Hydrophone
DG	Differential pressure gauge
DO	"Absolute" bottom pressure recorder

Station names for repeated deployments

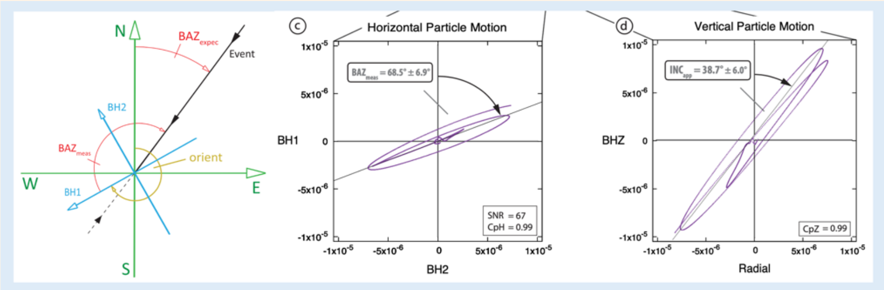
If OBSs are deployed repeatedly at one site (to make a long series), use an incrementing alphanumeric character at the end of the station name (i.e., A01A, then A01B then A01C for subsequent deployments at the same approximate location). This may be a *de facto* "standard", but I haven't seen it written down

Metadata (StationXML)

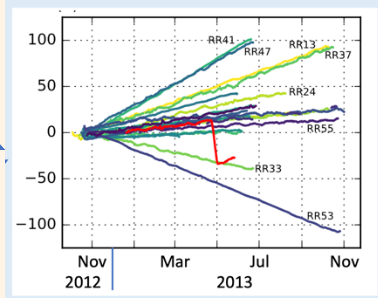
See StationXML Reference for details of StationXML elements

Software

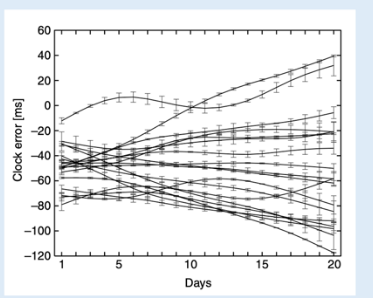
- Orientation calculation
- Clock drift calculation
- Noise removal / signal separation
- Station localization
- Metadata notation
- Clock drift correction
    - **msmod** upgrade to correct for clock drift (linear, cubic, polynomial)



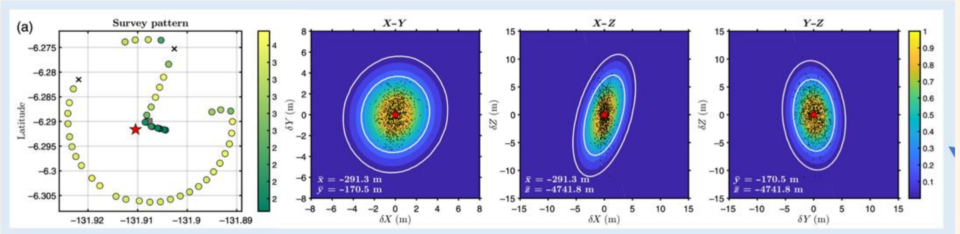
Scholz et al., 2017



Hable et al., 2018



Gouedard et al., 2014



Russell et al., 2019).

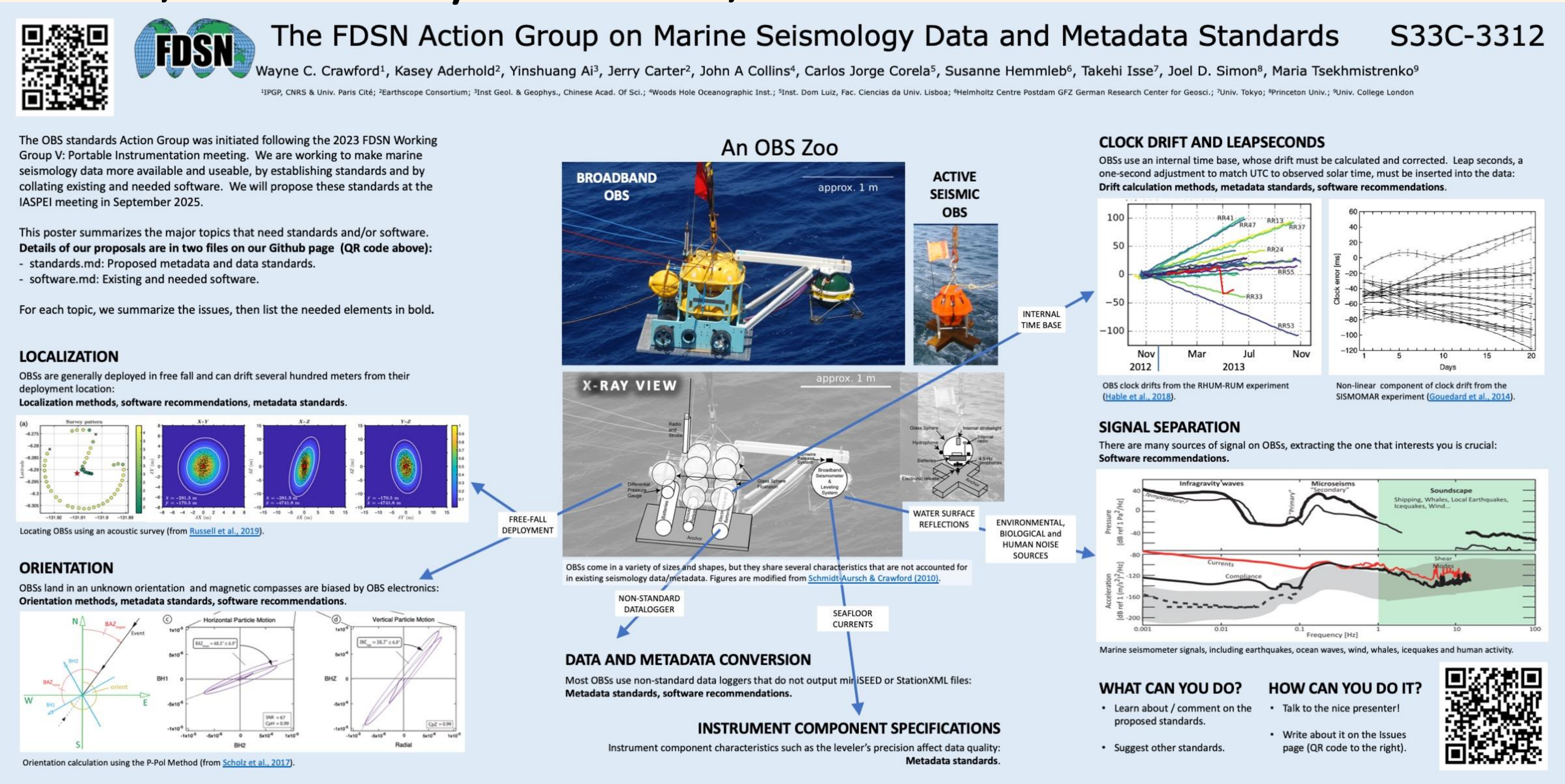
What can you do?

- Look at the standards.md and software.md files on the workspace
  - Use them if you create data/metadata
  - Make comments & suggestions on the “Issues” page

Workspace

Issues page

Poster, Wednesday afternoon, Hall B-C



The FDSN Action Group on Marine Seismology Data and Metadata Standards S33C-3312

Wayne C. Crawford[1], Kasey Aderhold[2], Yinshuang Ai[3], Jerry Carter[2], John A Collins[4], Carlos Jorge Corela[5], Susanne Hemmleb[6], Takehi Isse[7], Joel D. Simon[8], Maria Tsekhmistrenko[9]

[1]IPGP, CNRS & Univ. Paris Cité; [2]Earthscope Consortium; [3]Inst Geol. & Geophys., Chinese Acad. Of Sci.; [4]Woods Hole Oceanographic Inst.; [5]Inst. Dom Luiz, Fac. Ciencias da Univ. Lisboa; [6]Helmholtz Centre Postdam GFZ German Research Center for Geosci.; [7]Univ. Tokyo; [8]Princeton Univ.; [9]Univ. College London

The OBS standards Action Group was initiated following the 2023 FDSN Working Group V: Portable Instrumentation meeting. We are working to make marine seismology data more available and useable, by establishing standards and by collating existing and needed software. We will propose these standards at the IASPEI meeting in September 2025.

This poster summarizes the major topics that need standards and/or software.
Details of our proposals are in two files on our Github page (QR code above):
- standards.md: Proposed metadata and data standards.
- software.md: Existing and needed software.

For each topic, we summarize the issues, then list the needed elements in bold.

LOCALIZATION

OBSs are generally deployed in free fall and can drift several hundred meters from their deployment location:
Localization methods, software recommendations, metadata standards.

Locating OBSs using an acoustic survey (from Russell et al., 2019).

ORIENTATION

OBSs land in an unknown orientation and magnetic compasses are biased by OBS electronics:
Orientation methods, metadata standards, software recommendations.

Orientation calculation using the P-Pol Method (from Scholz et al., 2017).

An OBS Zoo

BROADBAND OBS

ACTIVE SEISMIC OBS

X-RAY VIEW

FREE-FALL DEPLOYMENT

INTERNAL TIME BASE

WATER SURFACE REFLECTIONS

ENVIRONMENTAL, BIOLOGICAL and HUMAN NOISE SOURCES

NON-STANDARD DATALOGGER

SEAFLOOR CURRENTS

OBSs come in a variety of sizes and shapes, but they share several characteristics that are not accounted for in existing seismology data/metadata. Figures are modified from Schmidt-Aursch & Crawford (2010).

DATA AND METADATA CONVERSION

Most OBSs use non-standard data loggers that do not output miniSEED or StationXML files:
Metadata standards, software recommendations.

INSTRUMENT COMPONENT SPECIFICATIONS

Instrument component characteristics such as the leveler's precision affect data quality:
Metadata standards.

CLOCK DRIFT AND LEAPSECONDS

OBSs use an internal time base, whose drift must be calculated and corrected. Leap seconds, a one-second adjustment to match UTC to observed solar time, must be inserted into the data:
Drift calculation methods, metadata standards, software recommendations.

OBS clock drifts from the RHUM-RUM experiment (Hable et al., 2018).

Non-linear component of clock drift from the SISMOMAR experiment (Gouedard et al., 2014).

SIGNAL SEPARATION

There are many sources of signal on OBSs, extracting the one that interests you is crucial:
Software recommendations.

Marine seismometer signals, including earthquakes, ocean waves, wind, whales, icequakes and human activity.

WHAT CAN YOU DO?

- Learn about / comment on the proposed standards.
- Suggest other standards.

HOW CAN YOU DO IT?

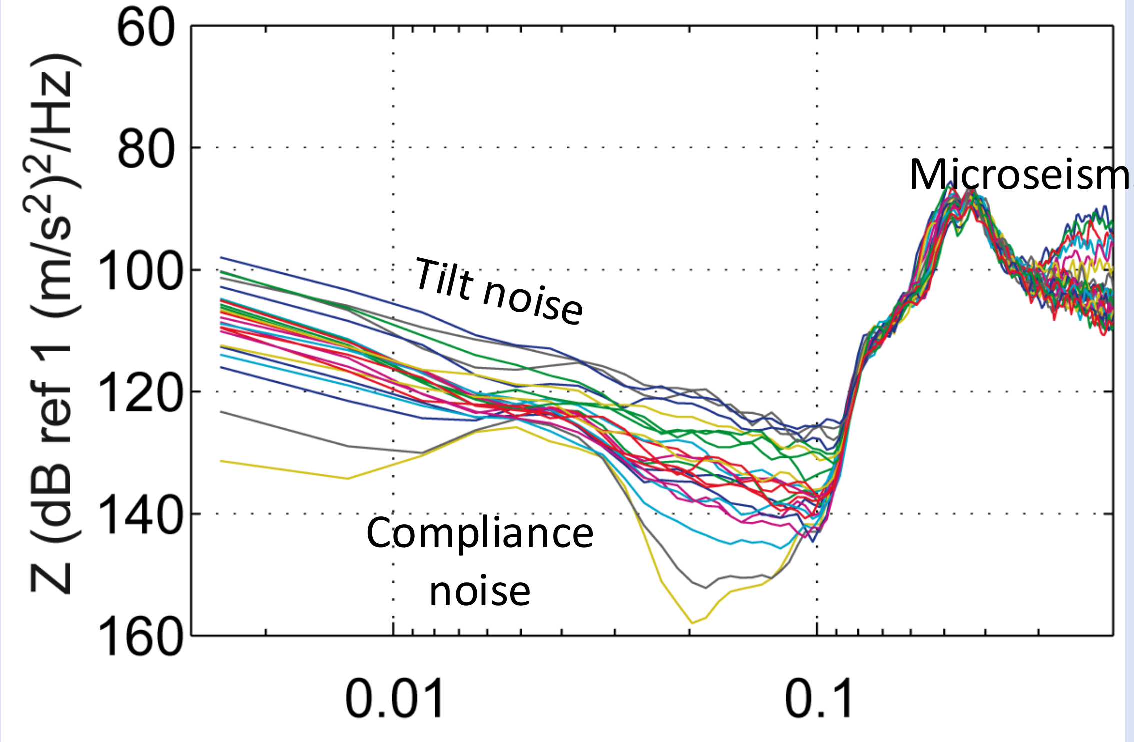
- Talk to the nice presenter!
- Write about it on the Issues page (QR code to the right).

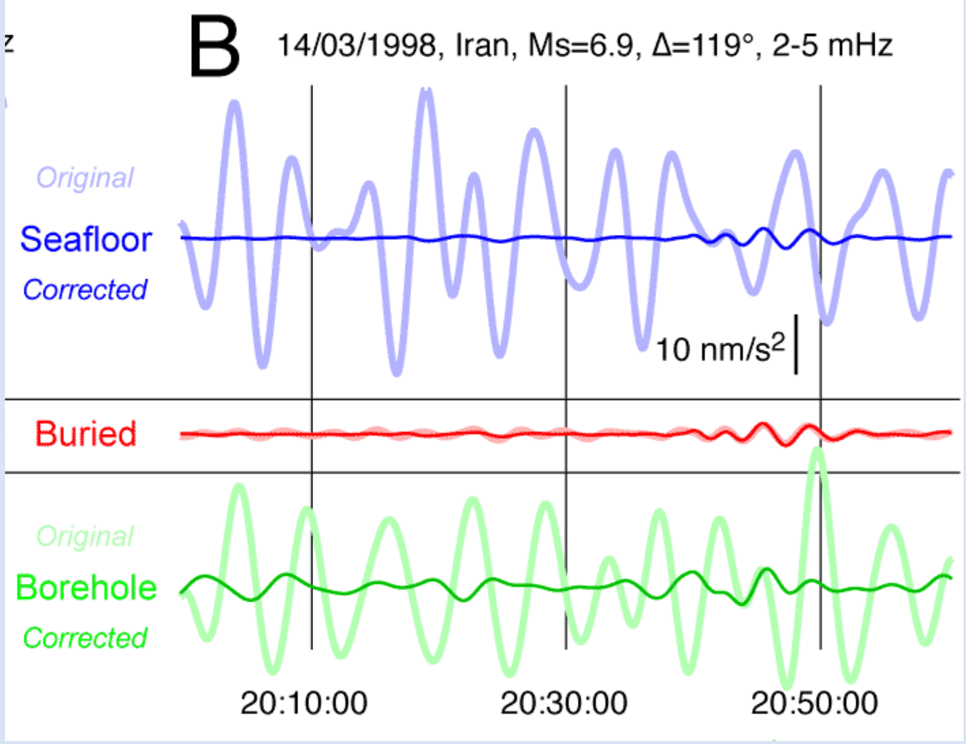
Noise reduction through rotation

Wayne Crawford, Gabi Laske, Nicholas Harmon, Catherine Rychert

Broadband seafloor seismology spectra

- Two major sources of noise below ~0.1 Hz are ocean surface gravity waves (“Compliance noise”) and seafloor currents (“Tilt noise”)

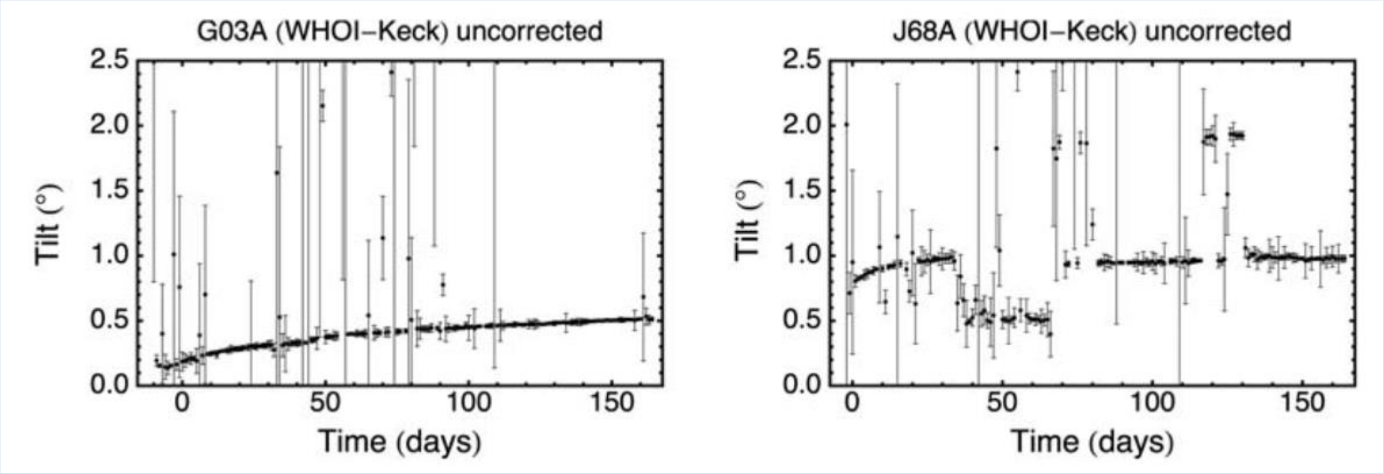




Crawford et al., 2006, BSSA

Broadband seafloor noise reduction

- Noise reduction techniques are based on frequency response “transfer” functions
  - Assumes a linear relationship between noise on the different channels
  - Most accurate when noise dominates
  - Tilt noise correction uses the horizontal seismometer channels as the source
    - Could distort earthquake signals (by a few %)
    - Transfer function interpreted as the angle of the vertical channel from true vertical



Bell et al., 2015, BSSA

Tilt noise reduction

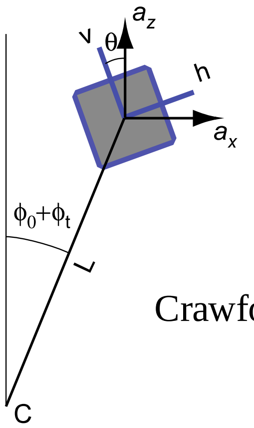
$$\mathrm{v} = \varphi_t\left[-g\left(\sin\theta + \frac{\varphi_t}{2}\cos\theta\cos\omega t\right) + L\omega^2\cos\theta\sin\varphi_0 \quad + h.o.t.\right]$$

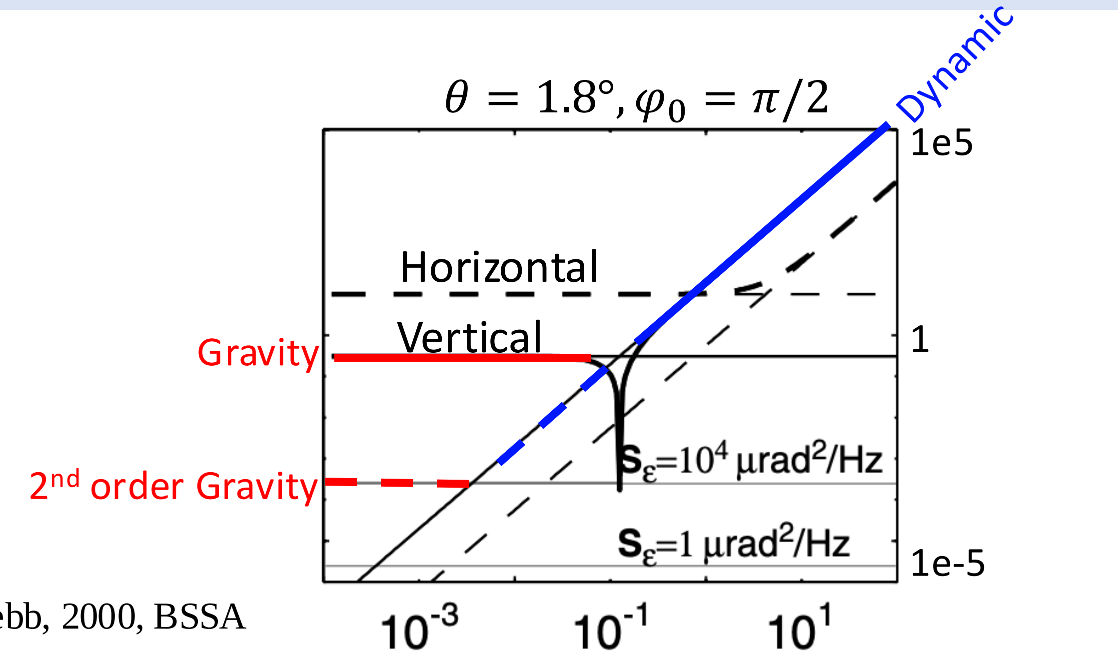
$$h = \varphi_t\left[\ g\cos\theta \qquad\qquad - L\omega^2\cos\theta\cos\varphi_0 \quad + h.o.t.\right]$$

$$\frac{\mathrm{v}}{h} \approx \left(\tan\theta + \frac{\varphi_t}{2}\cos\omega t\right) + \tan\varphi_0 \quad + h.o.t.$$

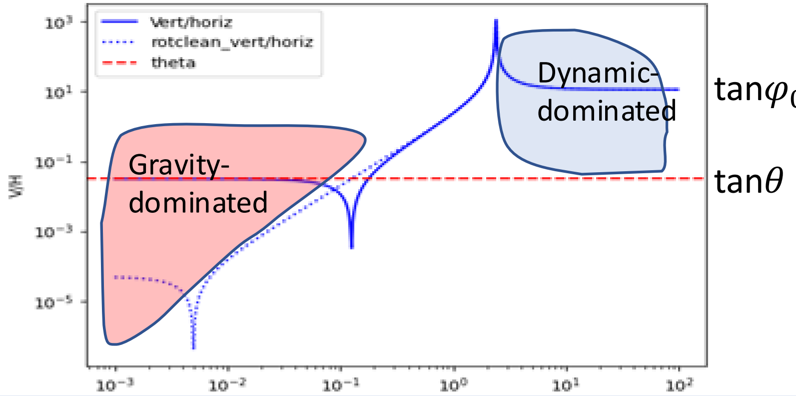
Gravity — "Dynamic"

φ_t	dynamic rotation of the seismometer about its center of mass
L	distance of the seismometer mass from the center of rotation
φ_0	angle of the seismometer mass from the center of rotation
θ	Misalignment of vertical with gravitational field
ω	Angular frequency (rad/s)





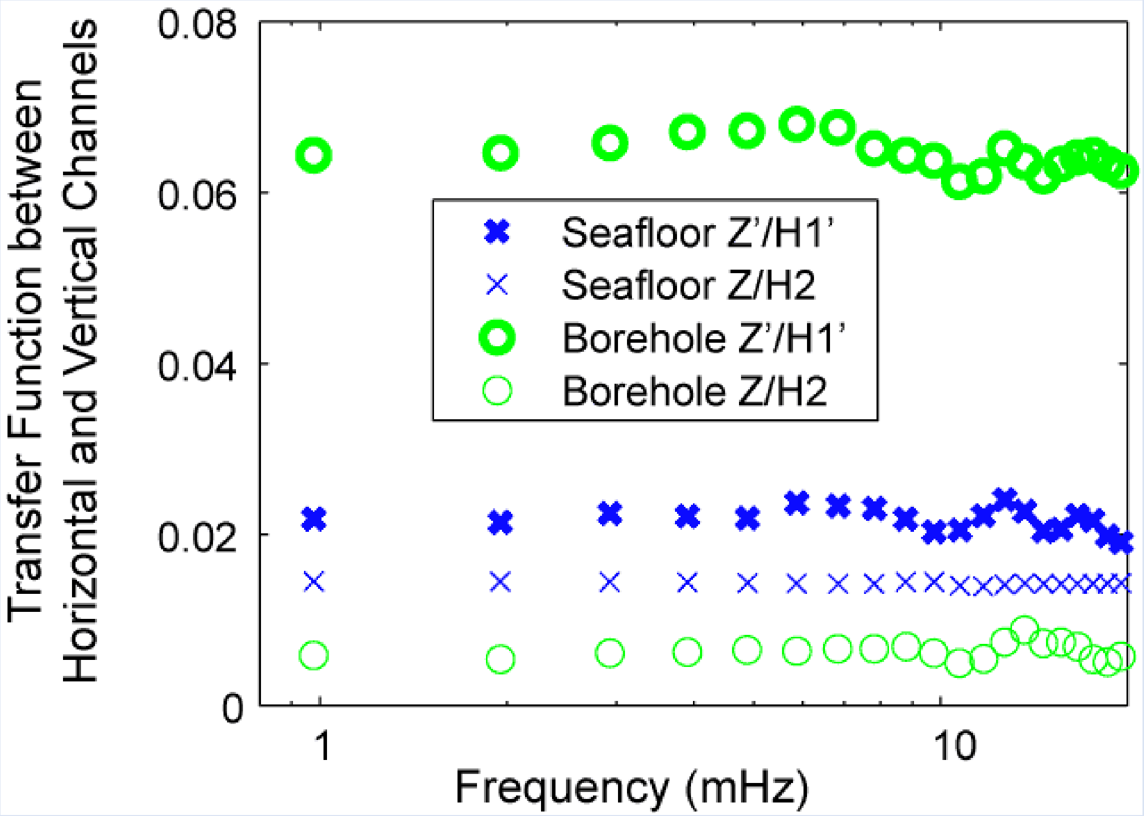
Crawford & Webb, 2000, BSSA



- The vertical/horizontal ratio approximately equals $\tan\theta$ at low frequencies, but:
  - It is not completely linear
  - It does not equal $\tan\theta$ at higher frequencies

Tilt noise reduction

- Estimated transfer functions are not completely flat
  - Could be change from the “Gravity” to the “Dynamic” regime
  - Could be non-linear effects
  - Could be measurement uncertainty



Crawford et al., 2006, BSSA

Simple rotation

- Concept
  - Before running any transfer function-based correction, ”rotate” the vertical channel to the angle at which the tilt noise is minimized
- Benefits
  - Should reduce distortion
  - Removes dilemma of whether to first remove tilt-based or compliance-based noise
  - Might reveal other noise sources
- Method
  - Define a noise metric
  - Search for the correction angle that minimizes LF noise (<0.01Hz)

```
xopt, fopt, iter, funcalls, warnflag, allvecs = sp.optimize.fmin(
    func=self._rotZ_variance,
    x0=[startAngle, startAzimuth],
    disp=False, full_output=True, retall=True)
```

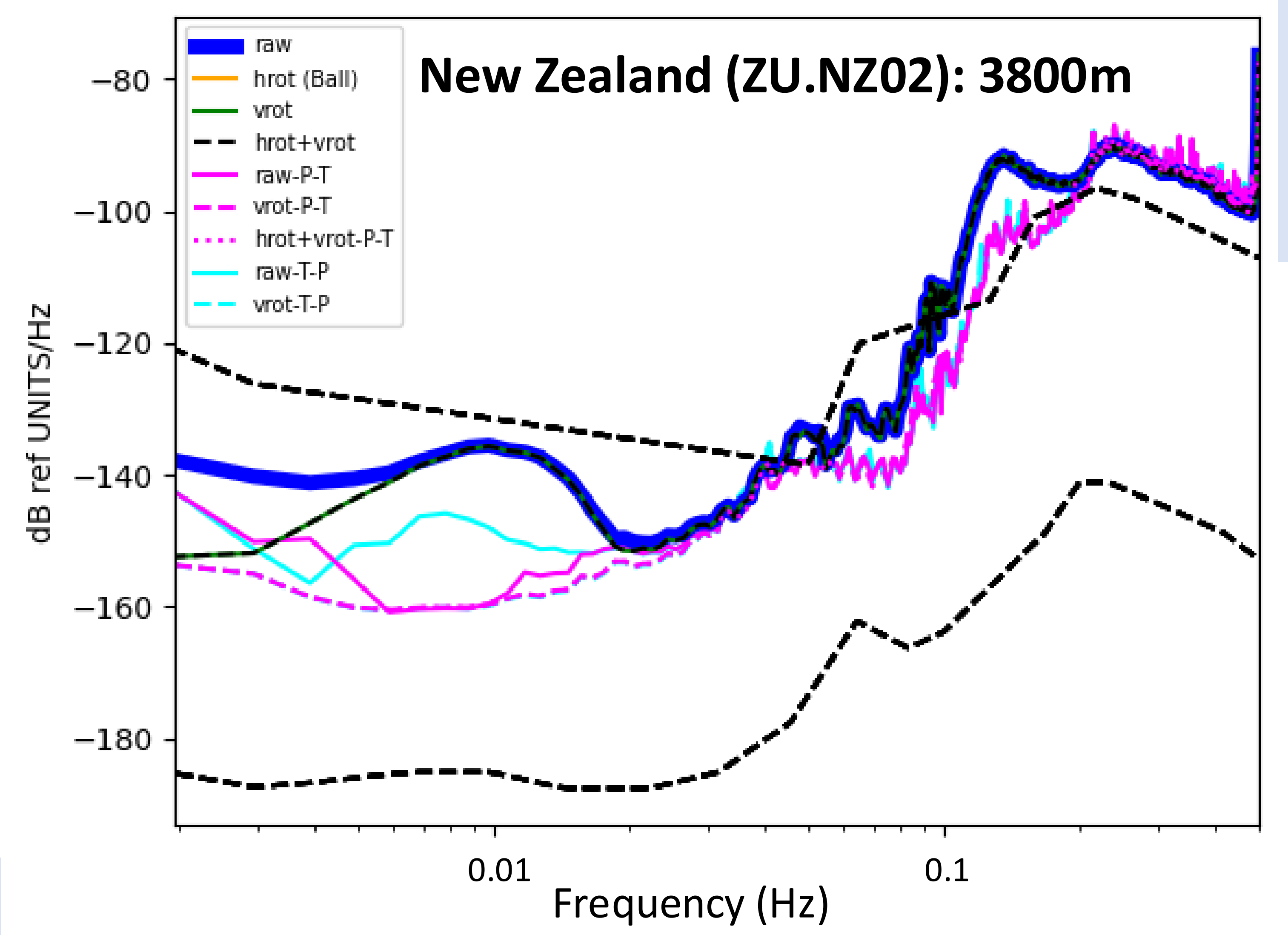
```
def _rotZ_variance(self, angles):
    """
    Calculate the variance for a given rotation

    Arguments:
        angles (list): angle, azimuth (in degrees)

    Assumes data are already filtered into relevant band
    """
    A = self.copy()
    A.zrotate(angles[0], angles[1])
    if self.uselogvar is True:
        var = np.log10(np.sum(A.Z.data**2))
    else:
        var = np.sum(A.Z.data**2)
    return var
```

Results

- Noise is lower
- After rotating, can remove pressure-correlated noise first (magenta dashed line)



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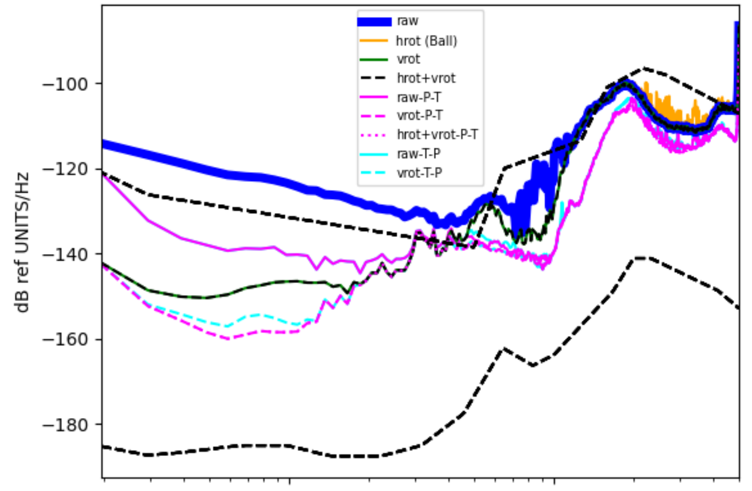
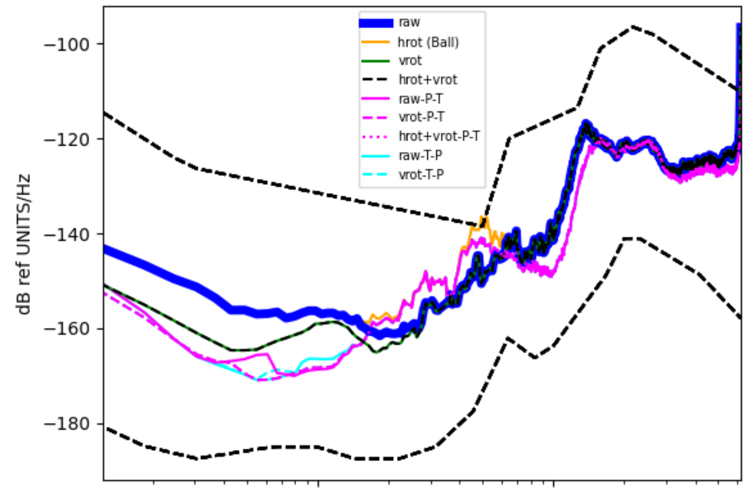
anr agence nationale de la recherche

FDSN

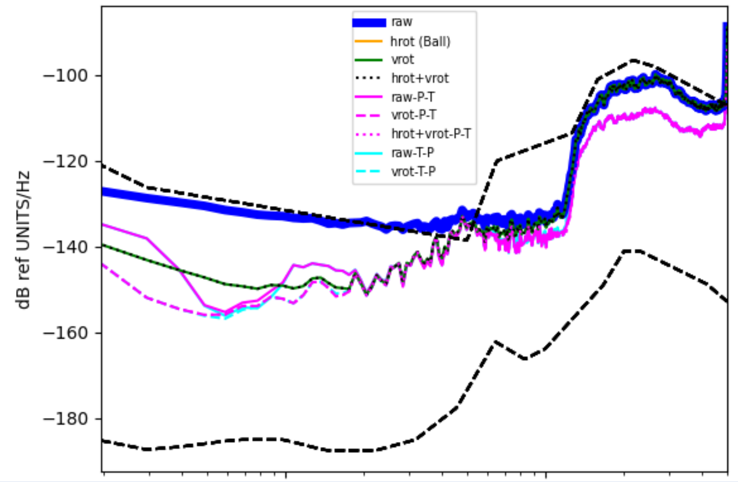
Cascadia (7D.J23B): 2650m



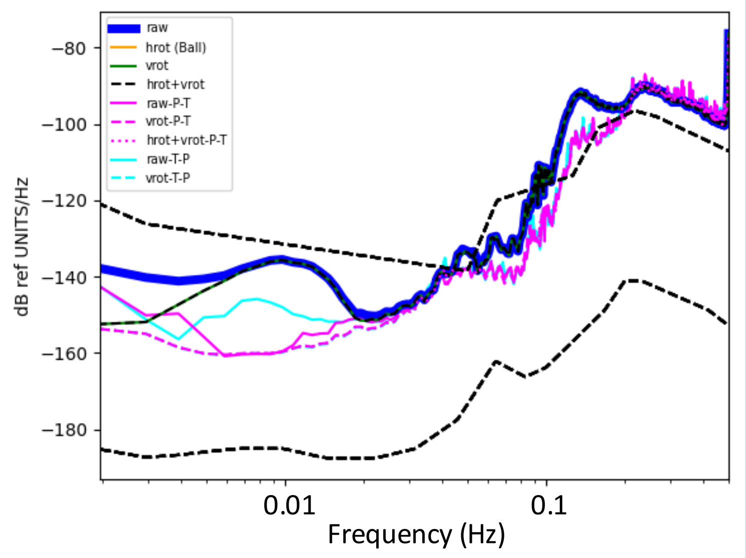
Mayotte (1T.MAUM): 3040m



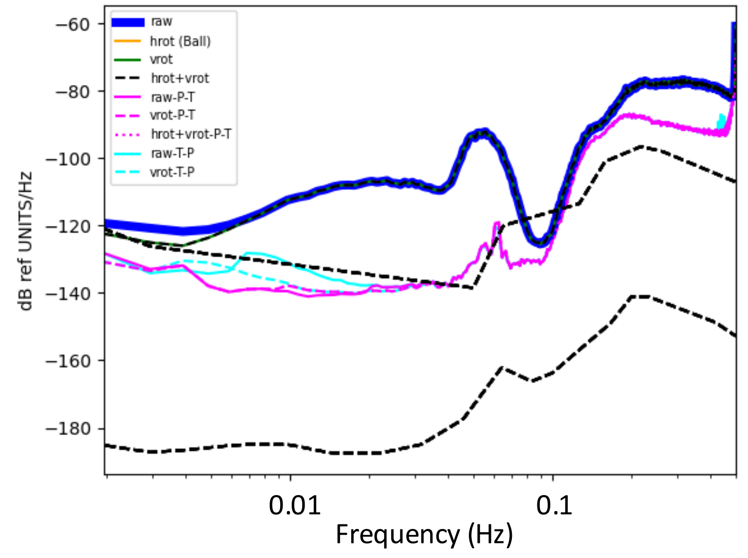
Mid-Atlantic Ridge: 2150m



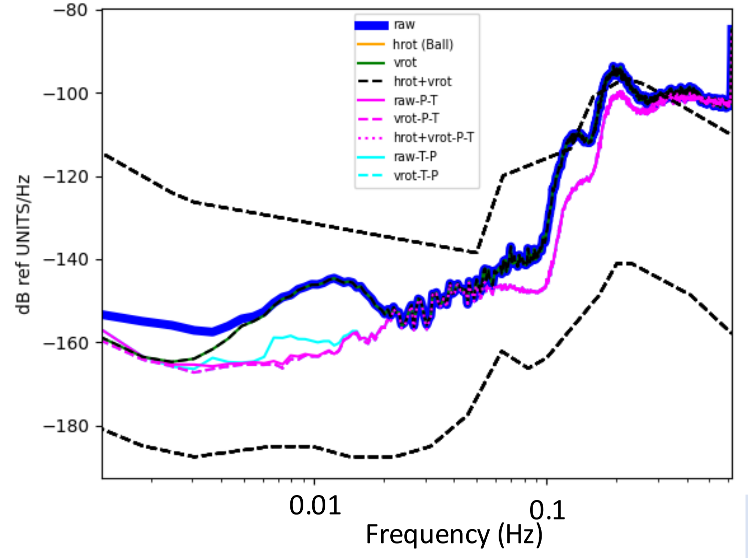
New Zealand (ZU.NZ02): 3800m



Cascadia (7D.J33A): 350m



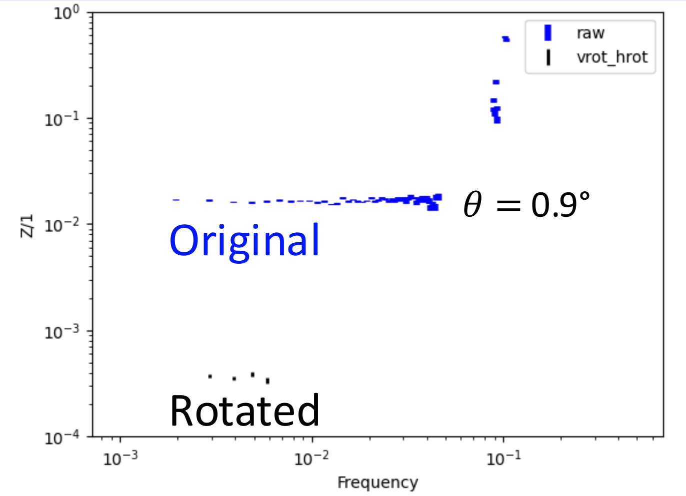
Mediterranean Sea (Z3.A422A): 2550m



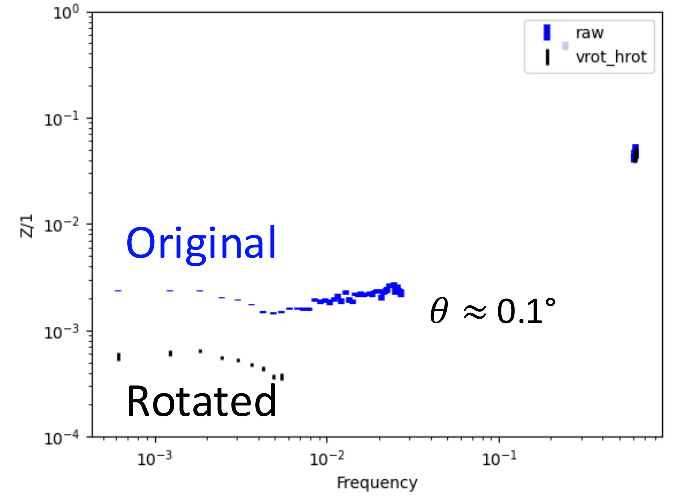
V/H transfer function after compliance noise removal

- See non-gravity effects, possibly non-linear effects

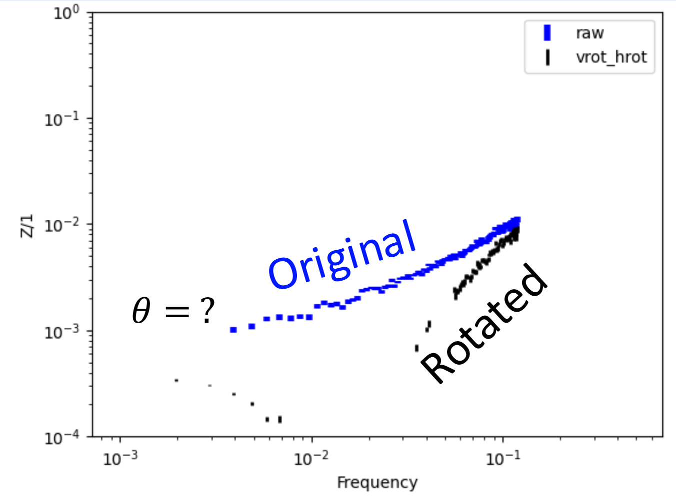
Cascadia (7D.J23B): 2650m



Mayotte (1T.MAUM): 3040m



Mid-Atlantic Ridge: 2150m



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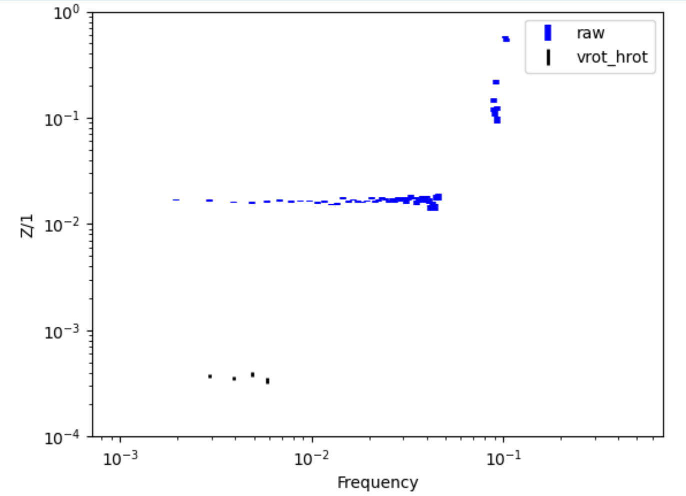

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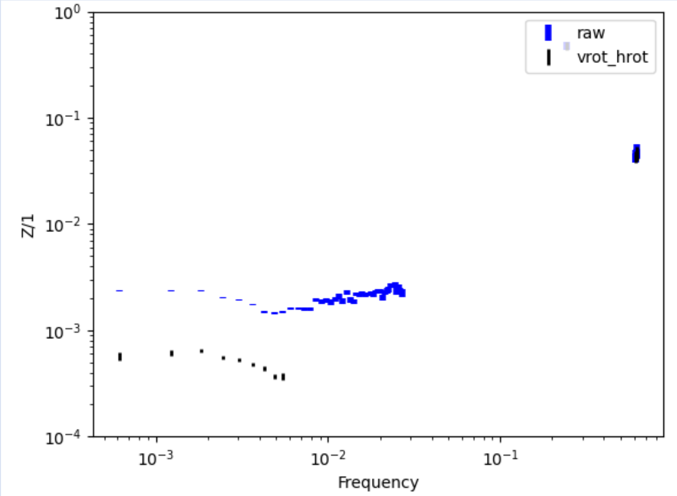
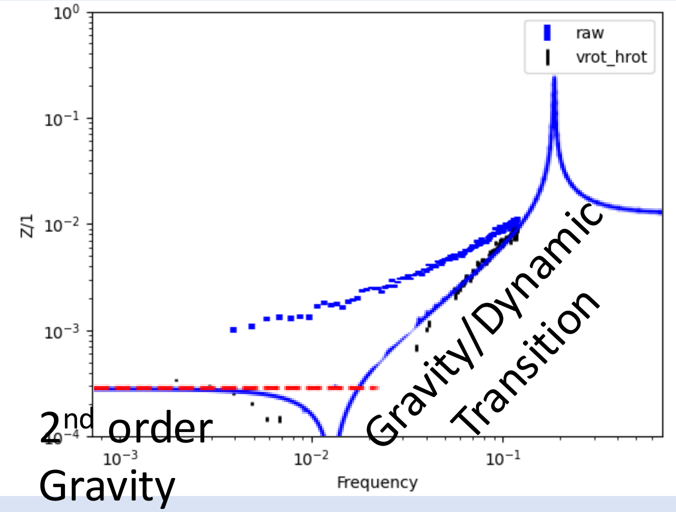


Mid-Atlantic Ridge: 2150m



Conclusions

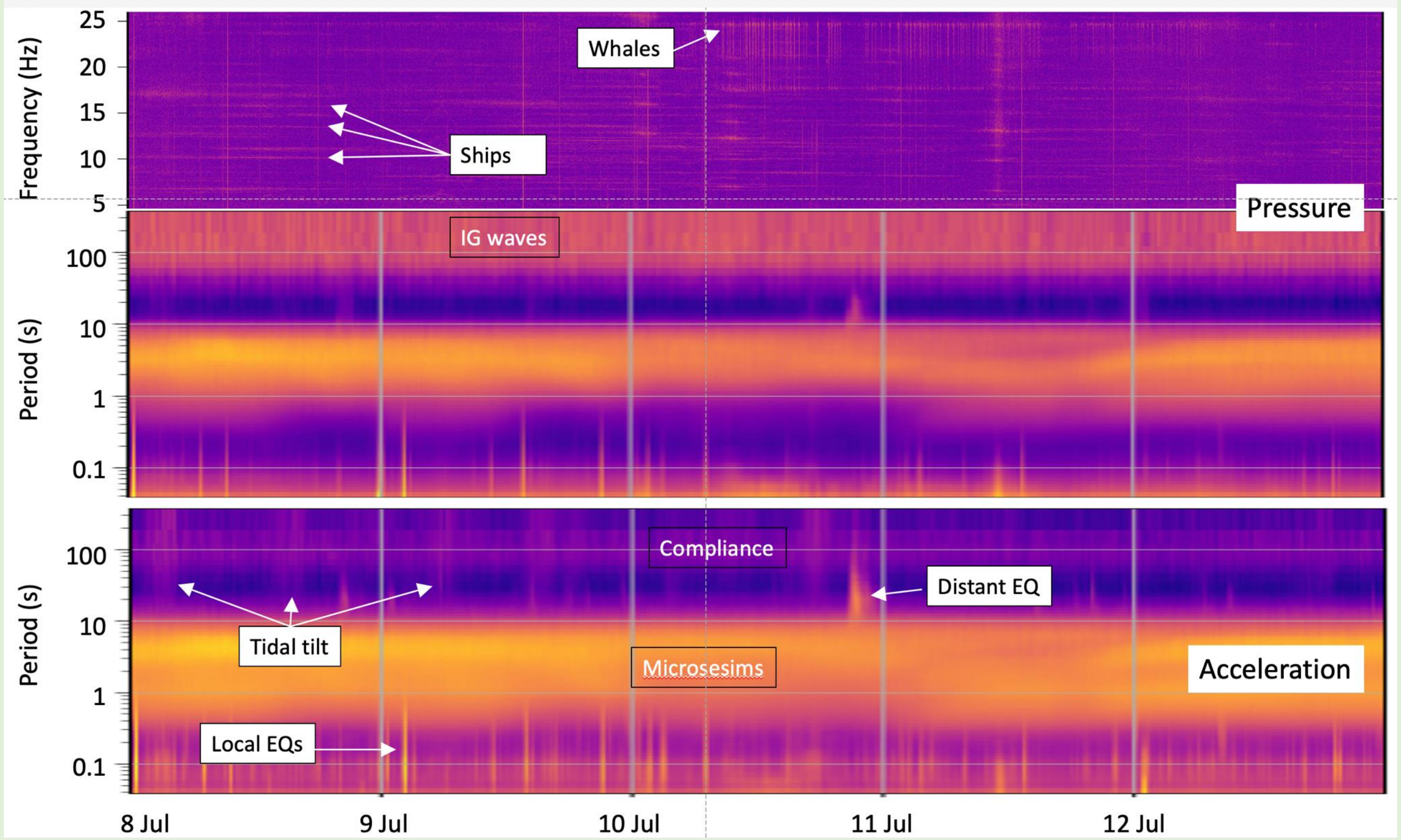
- Simple rotation of the vertical channel
  - Allows one to obtain lower noise levels
  - Simplifies the processing
  - May reduce waveform deformation
  - Can reveal other noise sources (-> more efficient noise removal)

- Available in the tiskitpy module (CleanRotator class)
  - https://pypi.org/project/tiskitpy/
  - https://github.com/WayneCrawford/tiskitpy/
  - https://tiskitpy.readthedocs.io/

The BRUIT-FM Seafloor Noise reduction challenge

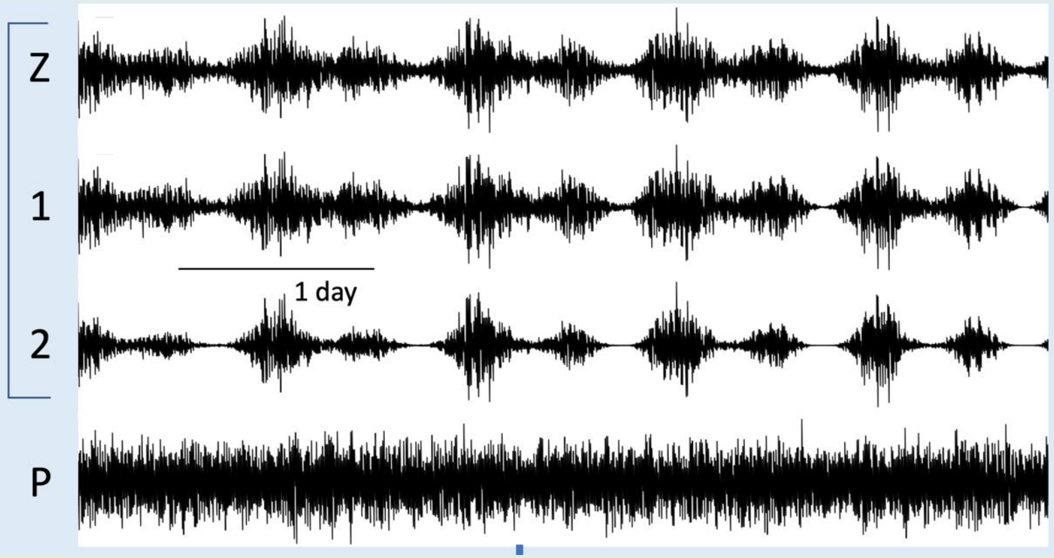
Filthy/rich seafloor data

- Full of signals
- Need to be separated
- We need better tools.



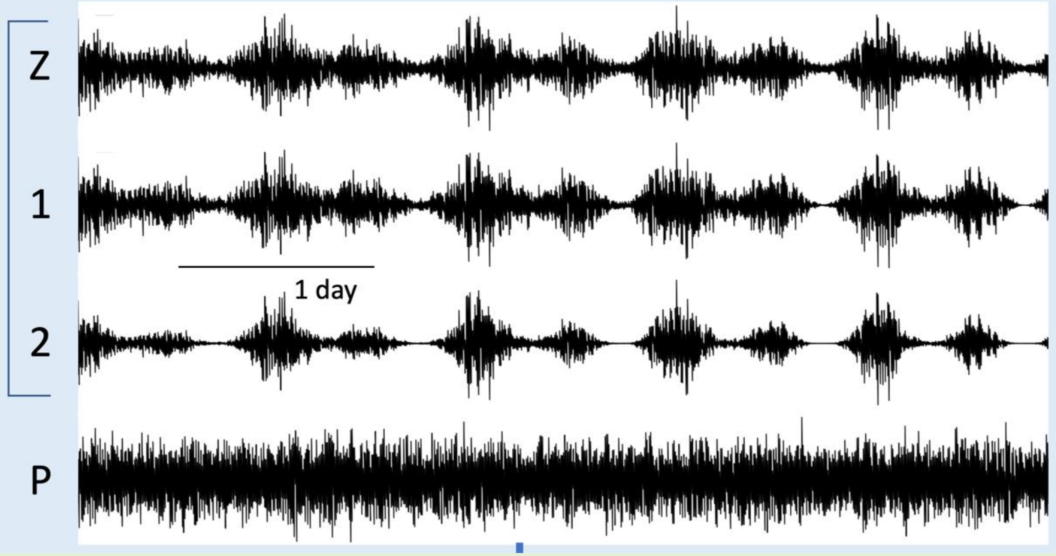
The Noise Reduction Challenge

- Go to the BRUIT-FM challenge website and download seafloor data
  - One real
  - One synthetic
- Create “clean” time series:
  - “seismologist-friendly” Z
  - “compliance-friendly” Z
  - Something else?
- Calculate useful transfer functions
  - P/Z compliance and/or admittance
  - Other?
- Send us your results (and code, if possible)



Outputs

- We will
  - Compile the results and do a first-level comparison (signal quality, PSD levels, ease of use)
  - Organize a workshop for in-depth comparison and to launch a community paper



Poster, Wednesday Afternoon, Hall B-C

The BRUIT-FM Seafloor Noise Reduction Challenge

S33B-3298

Wayne Crawford[1,4], Stephan Ker[2], Eleonore Stutzmann[1], Simon Reyberol[2], Mohammad-Amin Aminian[1], Guilhem Barruol[3], Laurent Duval[5], Richard Dréo[1]

[1]IPGP, CNRS & Univ. Paris Cité, UMR 7154; [2]Geo-Ocean, CNRS-IFREMER-UBO-UBS UMR 6538; [3]IGE, CNRS & Univ. Grenoble Alpes UMR 5001; [4]LIENSs, CNRS & La Rochelle Univ. UMR 7266; [5]Univ. Gustave-Eiffel-ESIEE Paris

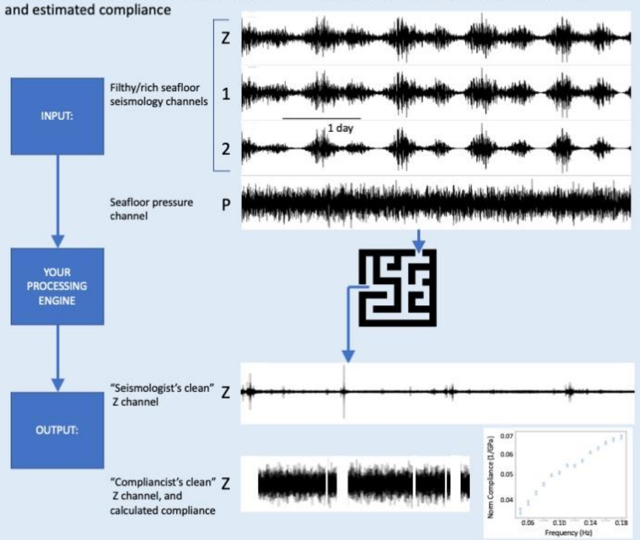
The BRUIT-FM project studies seafloor signals and noise from 0.001 to 100 Hz. Our goal is to identify, quantify and separate seismological, environmental, biological and anthropomorphic signals.

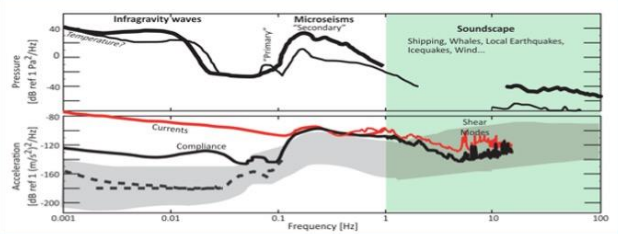
One Work Package is to reduce environmental noise between 0.001 and 0.1 Hz in order to better study seismological signals such as the earth's normal modes and ambient noise, earthquake surface waves, and seafloor compliance.

The BRUIT-FM Seafloor Noise Reduction Challenge asks you to apply your own processing tools to two sample seafloor datasets. We will write a community paper on the results, with all participants who share their codes/methods as co-authors.

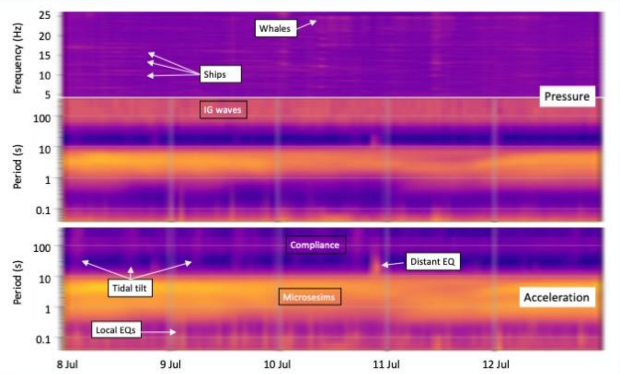
THE CHALLENGE

Take the challenge's seafloor data and extract a seismological signal, and/or a compliance signal and estimated compliance





Seafloor seismological data contains a rich variety of signals. Above: Schematic seafloor pressure and acceleration spectra. Below: Spectrograms showing microseisms, compliance, earthquakes, whales, ships and tides.



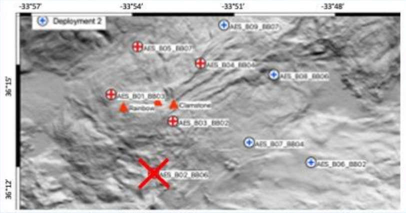
LINKS

Datasets, workflow & format descriptions
http://www.bruit-fm.org/challenge.html

Email
bruit-fm-challenge@services.cnrs.fr

DATA SET 1: RAINBOW HYDROTHERMAL FIELD

From an 8-day BBOBS deployment near the RAINBOW hydrothermal field on the Mid-Atlantic ridge. The data is full of local earthquakes, has significant seafloor currents and a small compliance signal. We have obtained 80% coherence between the pressure and acceleration data: can you do better?



Rainbow hydrothermal field, with the measurement site marked by the X.

A seafloor measurement (seismometer on the right, pressure gauge on the left).

DATA SET 2: SYNTHETIC

Built from models of infragravity waves and the different noise sources, plus earthquake measurements from a low-noise continental site.

STEP 1 (Dec 2024-July 2025): challenge responses

- Go to the Challenge Web Page (left link/QR code)
- Download the datasets and, if you want, the example codes
- Apply your codes to the data.
- Send us your results (right link/QR code).

Your tools don't have to be built for seismology data. We've set up the data and how to respond so that you can easily apply your tools and send your results.

STEP 2 (August-Dec 2025)

We will:
- Compile and compare the results
- Organize a meeting to analyze the experience and results with all participants
- Write a community paper presenting each method, their advantages and their inconveniences

Links

- Website with the data and information on processing/formats
- Email address to send your questions and results to

https://www.bruit-fm.org/challenge

mailto:bruit-fm-challenge@services.cnrs.fr