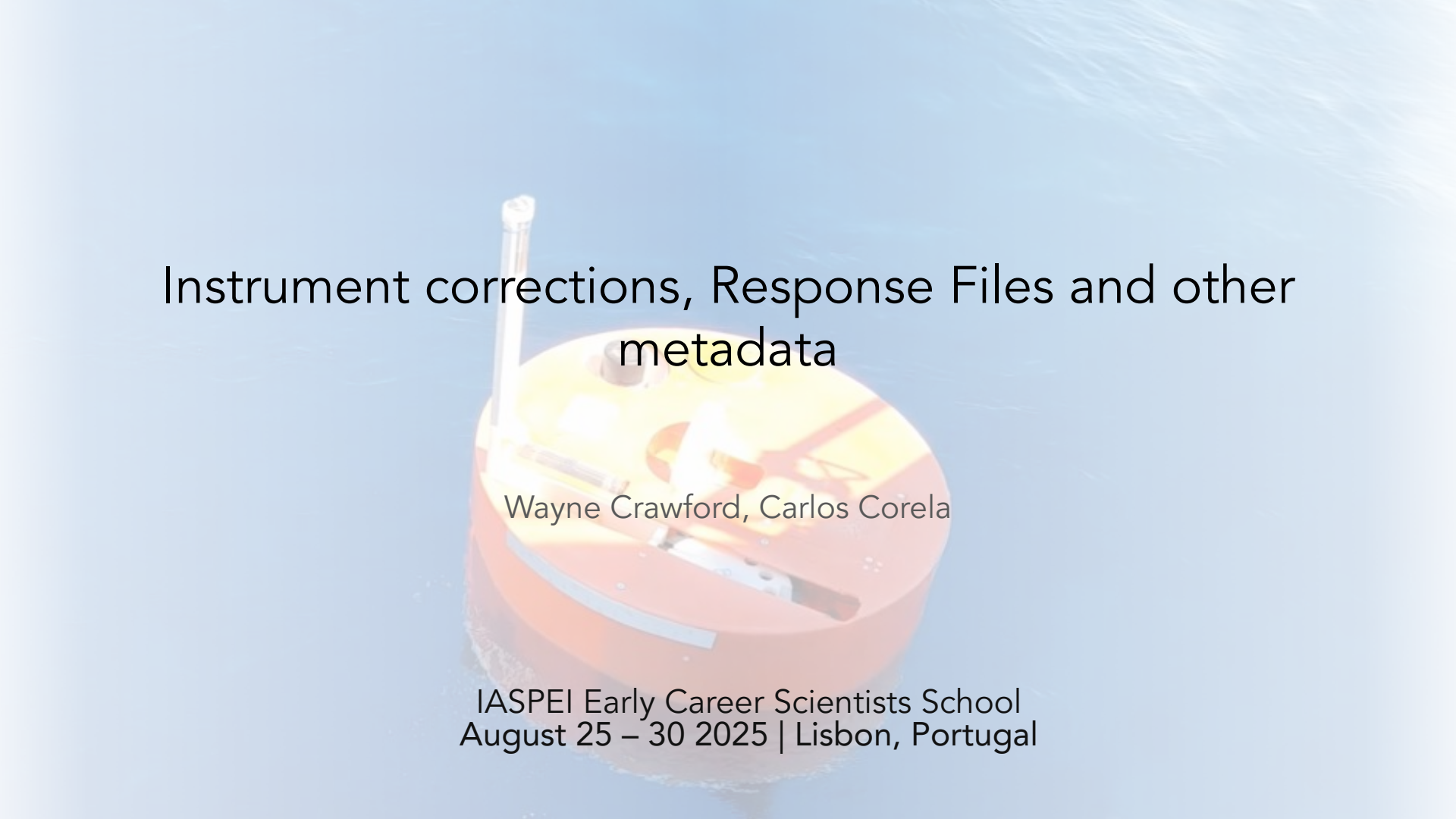
Instrument corrections, Response Files and other metadata



Wayne Crawford, Carlos Corela

IASPEI Early Career Scientists School
August 25 – 30 2025 | Lisbon, Portugal

Metadata

Data that provides information about other data (first known use: 1983).

In seismology, for a given station:

- Position
- Instruments used (sensors, amplifiers, dataloggers)
- Sensor orientations (if relevant)
- Instrument responses
- Epoch(s) of validity (position, response, …)

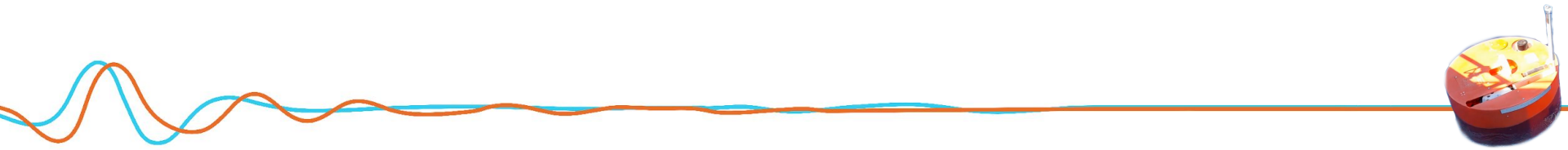
Instrument responses (and corrections)

Overview

Recorded data are transformed from physical units (m/s, Pa, …) to digital counts in a series of stages. Below is a typical example

- Sensor: physical units -> volts
- Preamplifier: volts -> volts
- A/D converter: volts -> counts
- Digital filtering and decimation: counts-> counts

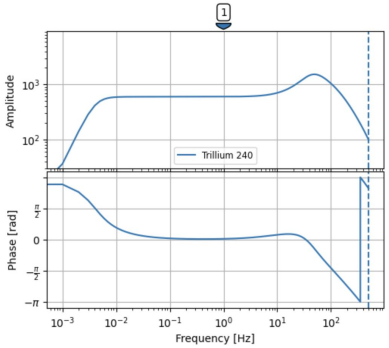
For much of our work, we need to convert back to physical units or some kind of reference instrument (e.g. Wood-Anderson seismometer)



Response stages

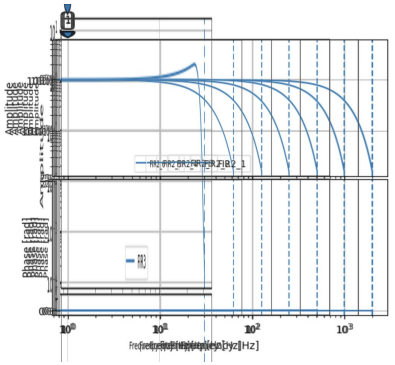
A stage can apply filtering (frequency dependent) and/or gain (frequency independent)

Seismometer (V/m/s) x Preamplifier (V/V) x A/D (counts/V) x Digital filters (counts/count) = YV.RR29.BHZ (counts/m/s)



x1

x1165080



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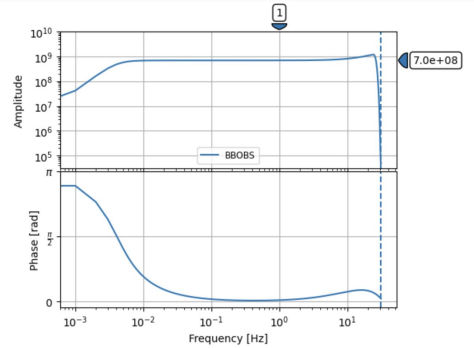
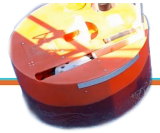
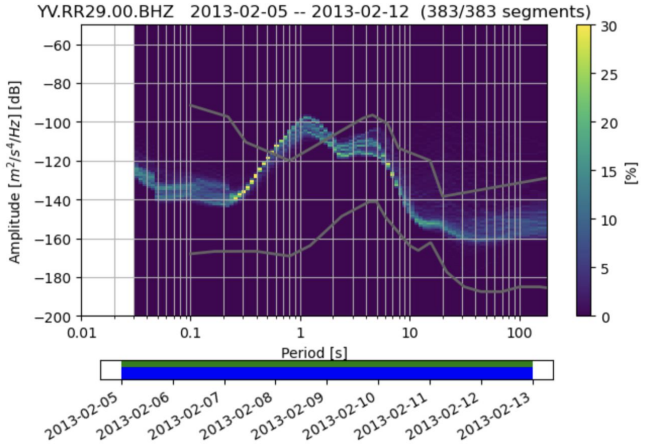


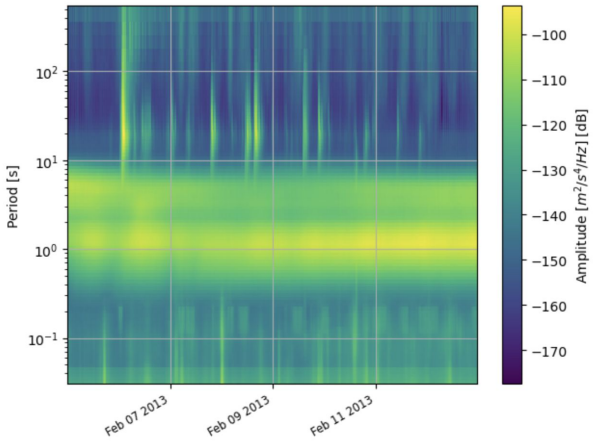


Probabilistic Power Spectral Densities (PPSDs)

Show the probability of a signal or noise level throughout the measurement period

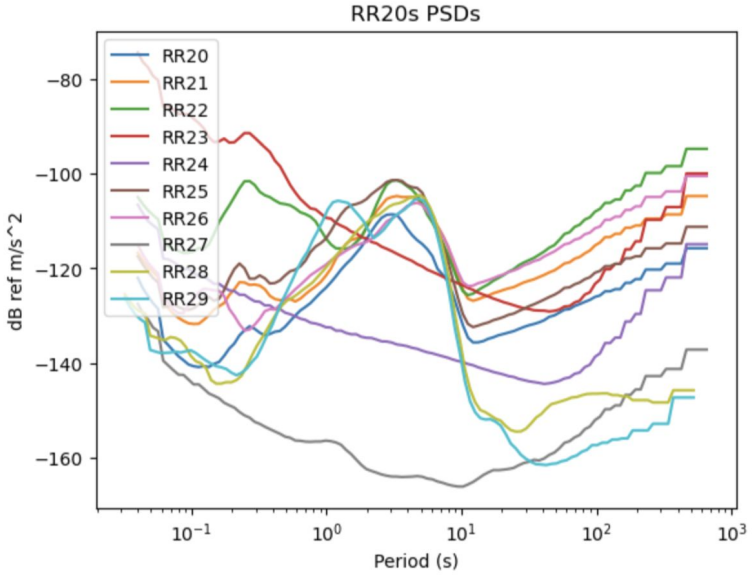
Can be used to evaluate the data quality (combination of sensor and site quality)

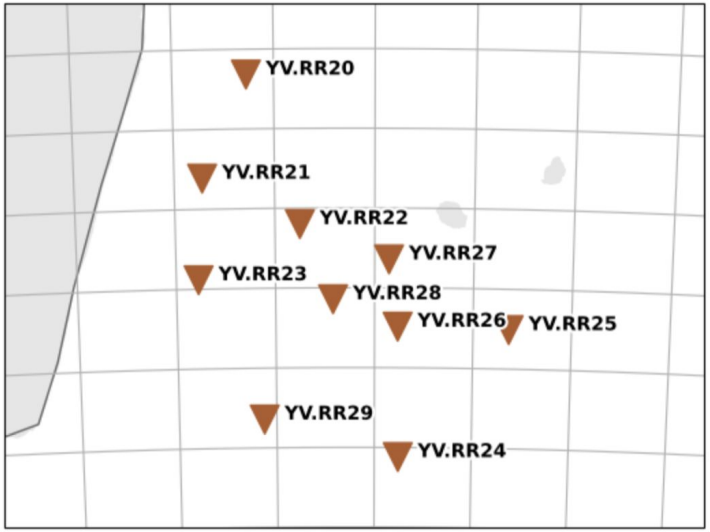




Mean and Median Power Spectral Densities

Help you to compare stations



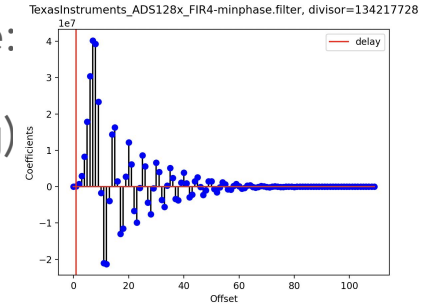


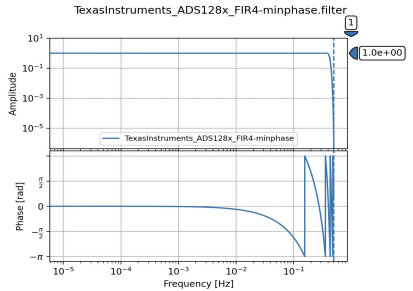
The Digital Filter response (sometimes) matters!

Ignored by most people, but can be important for signals near the Nyquist

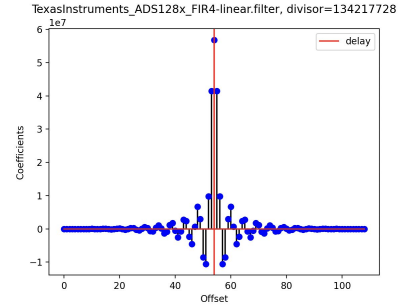
Mostly FIR filters, two main types at last stage:

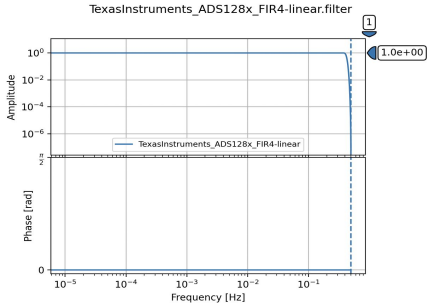
- Minimum phase (better for arrival picking)





- Zero phase (better for waveform fitting)



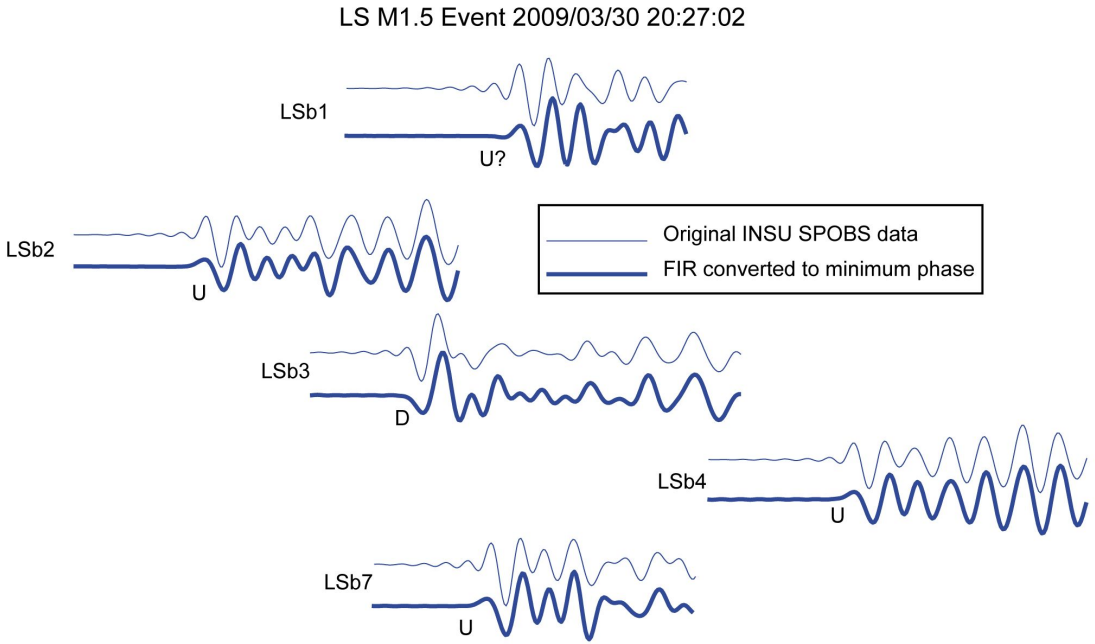


The Digital Filter response (sometimes) matters!

Lucky Strike volcano network

- Nearby earthquakes (3-4 km)
- Slow sampling rate (62.5 sps)
- Zero-phase FIR

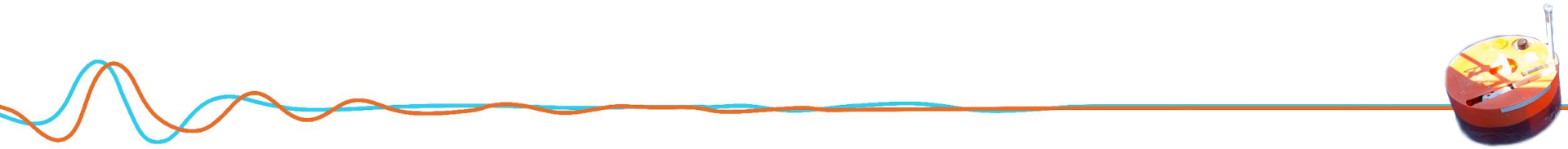
But can be post-converted to minimum phase! (Scherbaum & Bouin, 1997, GJI)



Metadata

Inventory, station and response files

Type	Inventory	Station	Response
Contains	Networks Stations Channels Responses	One station Channels Responses	One response
Examples	StationXML	Dataless SEED	RESP SACPZ SEISAN GSE2



Common response file types

SAC pole-zero: simple pole-zero representation of response

Dataless SEED: stage-based representation of response, plus station metadata

RESP: textual representation of the response part of Dataless SEED

StationXML: Replaces Dataless SEED, RECOMMENDED

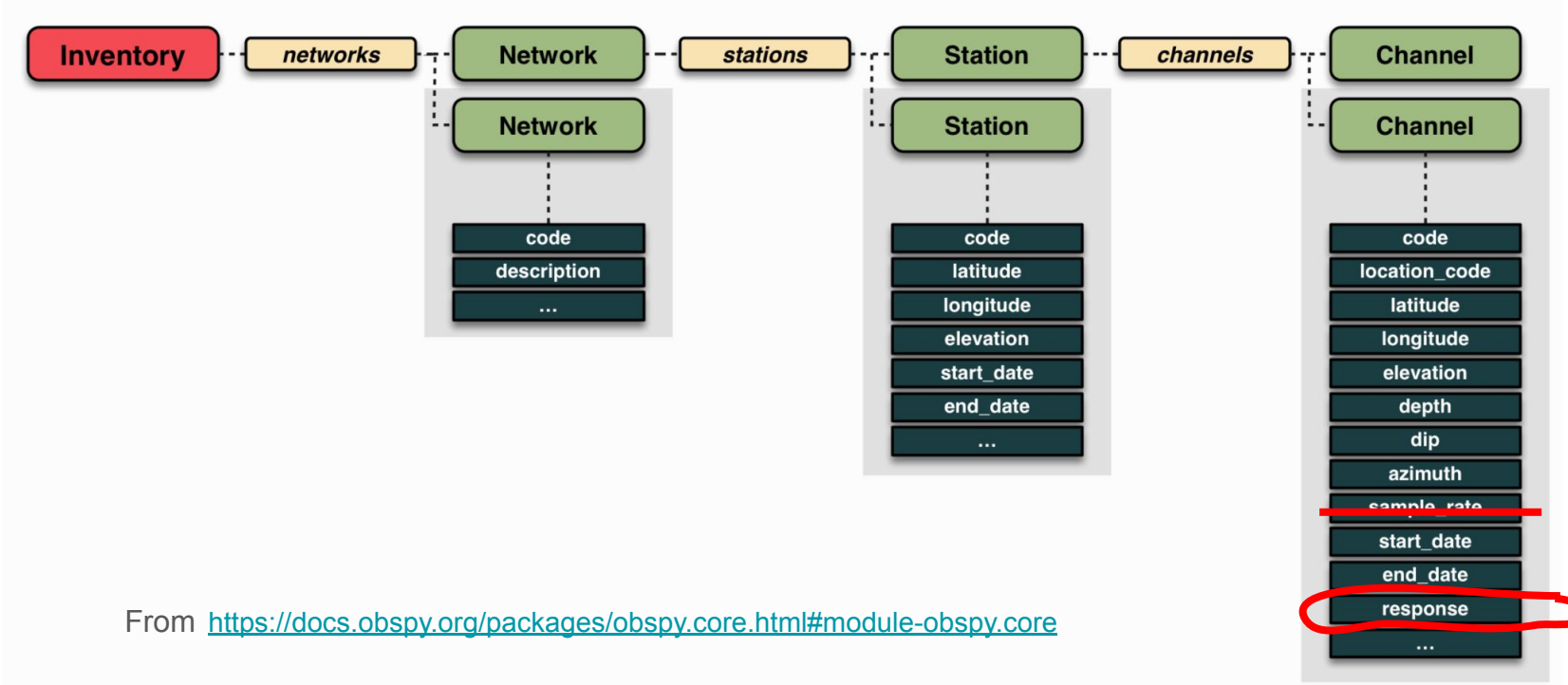
Some softwares only read certain formats (for example, SEISAN13 only reads SACPZ, GSE, SEISAN and RESP response files)

Obspy handles

Format
CSS
KML
SACPZ
SHAPEFILE
STATIONTXT
STATIONXML

+Dataless SEED & RESP

Inventory file structure

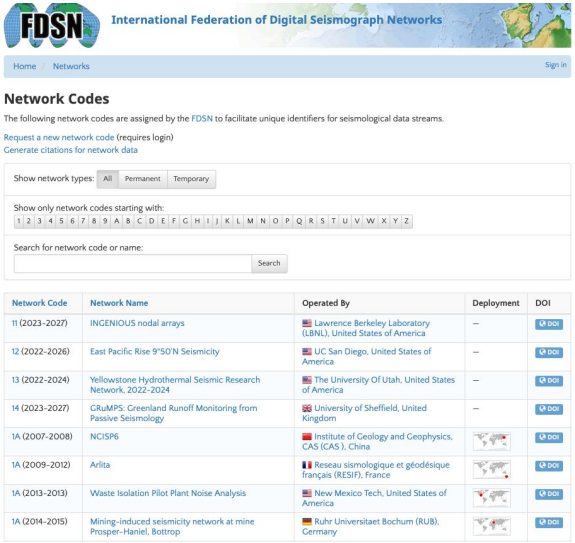


From https://docs.obspy.org/packages/obspy.core.html#module-obspy.core

Where to find network information

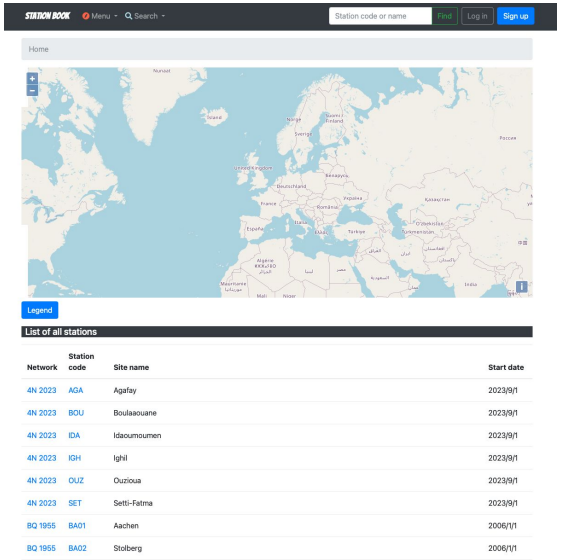
FDSN Networks list

https://www.fdsn.org/networks/

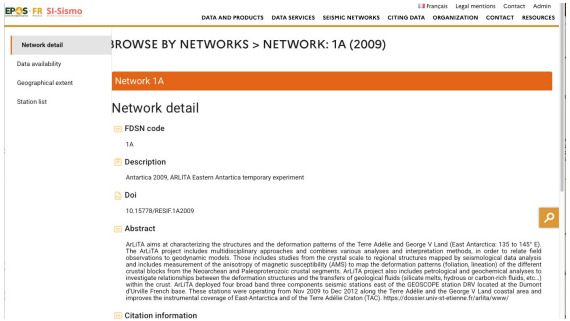


ORFEUS Station Book

https://orfeus-eu.org/stationbook/



Individual data centers



FDSN references

Online Documents

- StationXML: https://docs.fdsn.org/projects/stationxml/en/latest/index.html#
- Source Identifiers: https://docs.fdsn.org/projects/source-identifiers/en/v1.0/index.html
- MiniSEED3: https://docs.fdsn.org/projects/miniseed3/en/latest/

Marine Seismology (temporary site)

- Standards: https://github.com/FDSN/OBS-standards/blob/main/standards.pdf
- Software: https://github.com/FDSN/OBS-standards/blob/main/software.pdf

Legacy

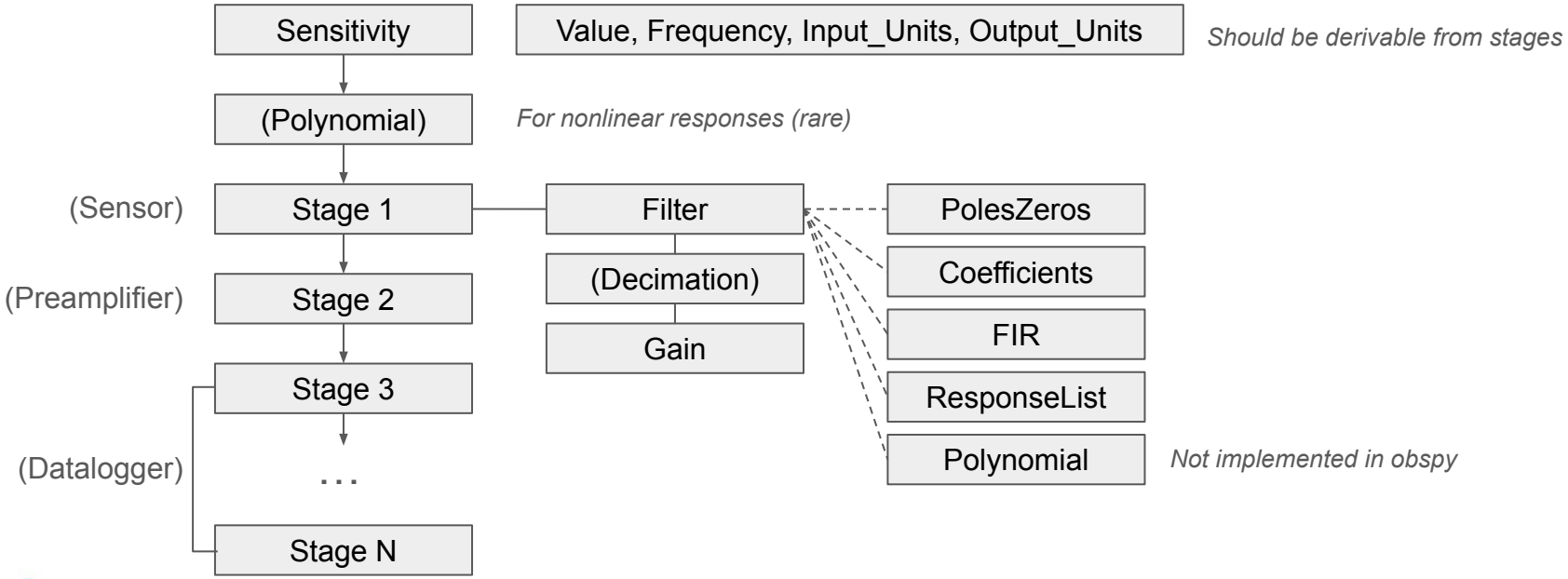
- MiniSEED2 and Dataless SEED: https://www.fdsn.org/pdf/SEEDManual_V2.4.pdf

Response Files

Response structure

https://docs.fdsn.org/projects/stationxml/en/latest/overview.html

Depends on file format, SEED/RESP/StationXML structure is:



Getting stage responses

From the [Nominal Response Library](#) (NRL), if you're lucky

If not, from the documentation

Table 9-1 - Ground motion response nominal parameters

Symbol	Parameter	Nominal Values	Units
z_n	Zeros	0 0 -392 -1960 -1490 ±1740i	rad/s
p_n	Poles	-0.03691 ±0.03702i -343 -370 ±467i -836 ±1522i -4900 ±4700i -6900 -15000	rad/s
k	Normalization factor	4.34493 ×10^{17}	(rad/s)^5
f_0	Normalization frequency	1	Hz
s	Ground motion sensitivity at f_0	754.3	V•s/m

The seismometer module sensitivity (s), poles (p_n), and zeros (z_n) define the transfer function according to this equation:

$$F(s) = S \cdot k \cdot \frac{\prod_n (s - z_n)}{\prod_n (s - p_n)} \quad \text{(EQ1)}$$

Where the normalization factor (k) is defined by

$$k = \left| \frac{\prod_n (i2\pi f_0 - p_n)}{\prod_n (i2\pi f_0 - z_n)} \right| \quad \text{(EQ2)}$$

and is given for informational purposes only.

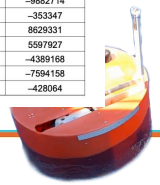
The first two subsections are half-band filters with fixed decimation ratios of two. The third subsection of the FIR filter decimates by four (fixed), and the fourth subsection decimates by two (fixed). The overall decimation ratio of the entire FIR section is 32. Two coefficient sets are used for the third and fourth subsections, sets for linear phase mode and minimum phase mode (programmable). Table 10 lists the data rate programming and overall decimation ratio of the FIR stage. See Table 11 for the FIR filter coefficients.

Table 10. FIR Filter Data Rates

DR[2:0] REGISTER	OVERALL DECIMATION RATIO (COMBINED SINC + FIR)		FIR DATA RATE (SPS)
	HIGH-RESOLUTION MODE	LOW-POWER MODE	
000	4096	2048	250
001	2048	1024	500
010	1024	512	1000
011	512	256	2000
100	256	128	4000

Table 11. FIR Stage Coefficients

COEFFICIENT	SECTION 1	SECTION 2	SECTION 3		SECTION 4	
	LINEAR PHASE SCALING = 1 / 512	LINEAR PHASE SCALING = 1 / 8388608	SCALING = 1 / 134217728		SCALING = 1 / 134217728	
			LINEAR PHASE	MINIMUM PHASE	LINEAR PHASE	MINIMUM PHASE
b_0	3	–10944	0	819	–132	11767
b_1	0	0	0	8211	–432	133882
b_2	–25	103807	–73	44880	–75	769961
b_3	0	0	–874	174712	2481	2940447
b_4	150	–507903	–4648	536821	6692	8262605
b_5	256	0	–16147	1372637	7419	17902757
b_6	150	2512192	–41280	3012996	–266	30428735
b_7	0	4194304	–80934	5788605	–10663	40215494
b_8	–25	2512192	–120064	9852286	–8280	39260213
b_9	0	0	–118690	14957445	10620	23325925
b_{10}	3	–507903	–18203	20301435	22008	–1757787
b_{11}		0	224751	24569234	348	–21028126
b_{12}		103807	580196	26260385	–34123	–21293602
b_{13}		0	893263	24247577	–25549	–3886901
b_{14}		–10944	891396	18356231	33460	14396783
b_{15}			293598	9668991	61387	16314388
b_{16}			–987253	327749	–7546	1518875
b_{17}			–2635779	–7171917	–94192	–12979500
b_{18}			–3860322	–10926627	–50629	–11506007
b_{19}			–3572512	–10379094	101135	2769794
b_{20}			–822573	–6505618	134826	12195551
b_{21}			4669054	–1333678	–56626	6103823
b_{22}			12153698	2972773	–220104	–6709466
b_{23}			19911100	5006366	–56082	–9882714
b_{24}			25779390	4566808	263758	–353347
b_{25}			27966862	2505652	231231	8629331
b_{26}			25779390	126331	–215231	5597927
b_{27}			19911100	–1496514	–430178	–4389168
b_{28}			12153698	–1933830	34715	–7594158
b_{29}			4669054	–1410695	580424	–428064



Creating a response file

The Normalized Reference Library contains response files for commercial/common sensors and dataloggers

Academic tools

- PDCC: GUI that can read the NRL
- Yasmine: GUI editor/creator, replaces PPSD
- Yasmine-CLI: modify an existing StationXML file from the command line
- obsinfo: Specific for marine seismology data, simplifies creating your own responses
- obspy: has what it takes to create Inventory files, but not immediately clear how
- stationxml-validator: Validate your created file