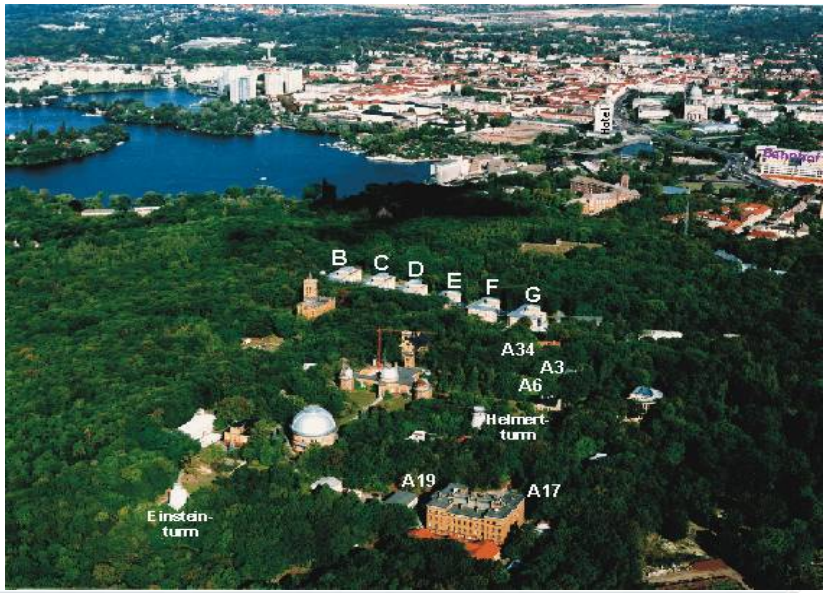
Seismological instrumentation: scientific aims and practical use - GIPP presentation and visit

Christian Haberland, GFZ

GFZ - Telegrafenberg



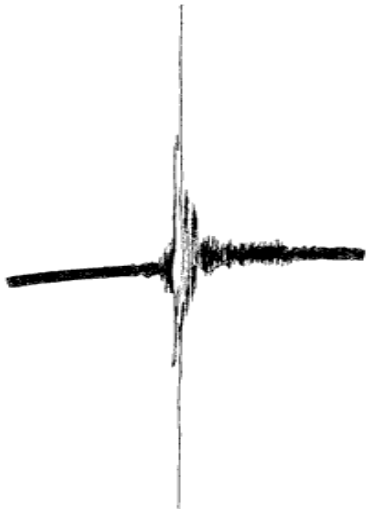
1832 Station of optical telegraf line
1870 Royal Prussian Geodetic Institute
1890 Geomagnetic observatory
…
1969 Zentralinstitut für Physik der Erde
1992 GeoForschungsZentrum Potsdam

Einstein tower(built 1919-22)

- National research center for the solid Earth Sciences
- ~1300 employes (2021)
- Yearly budget 66 Mio. € inst. funds + 30 Mio. € 3rd party (2021)
- German Federal Ministery of Education & Research and Fed. State of Brandenburg

First recording of teleseismic earthquake in Potsdam

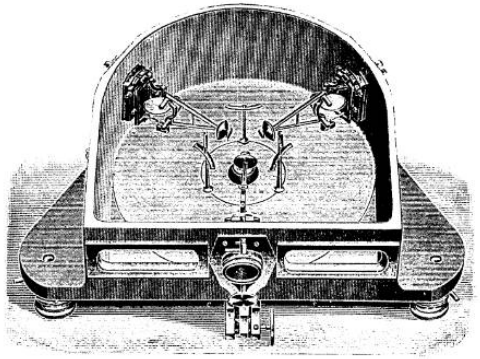
wikipedia.org

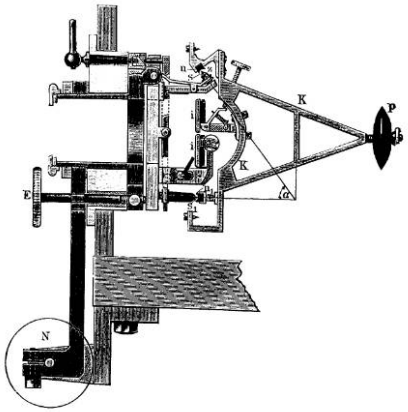


Ernst v. Rebeur-Paschwitz (1861-95)

- A focus of his work was the **improvement of a horizontal pendulum** used in gravity/geodesy
- actually designed to measure **changes in plumb direction** (gravity direction) caused by movements of the earth's crust under the influence of astronomical bodies or local mass anomalies
- 2 **instruments (Potsdam** & Wilhelmshaven)
- Seismological phenomena influencing the variation of vertical axis
- **First recording of teleseismic event 17.4.1889** (*Nature* article 1889)
- Regarded as **beginning of modern, systematic, global seismological observations**
- In 1885 proposal for homogeneous global station network

Horizontal pendulum



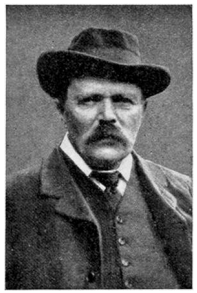


From: Eschenhagen (1985) (http://bib.gfz-potsdam.de/pub/digi/seismograms.pdf)

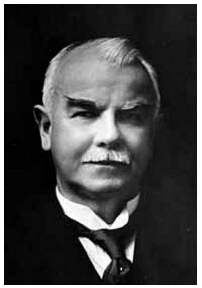
Historical seismometers

Milne horizontal pendulum seismometer

By Momotarou2012 - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=23356547



John Milne



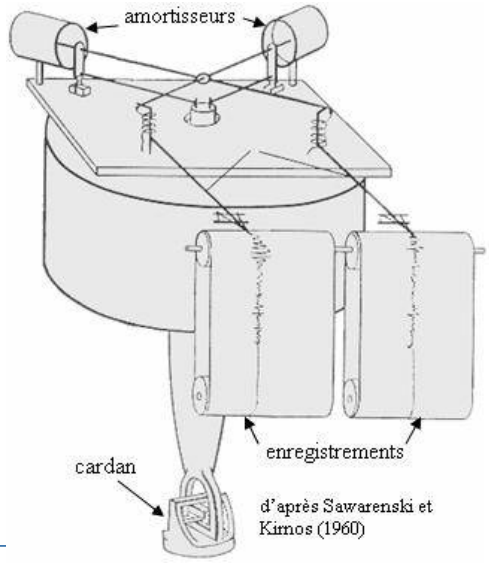
James Alfred Ewing

+ Thomas Lomar Gray

wikipedia.org

Wiechert Seismograph

Emil Wiechert

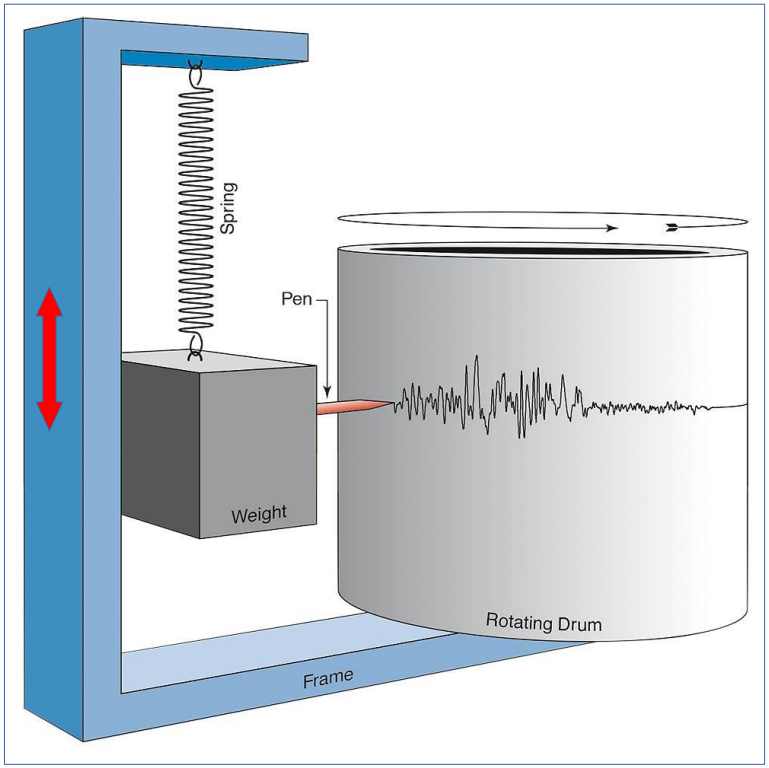


1906

Mass: 1000 kg
Period: 8 s

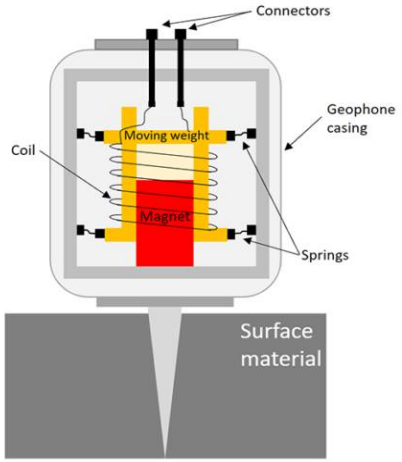
Some physics...

Seismometer principle



www.faulhaber.com

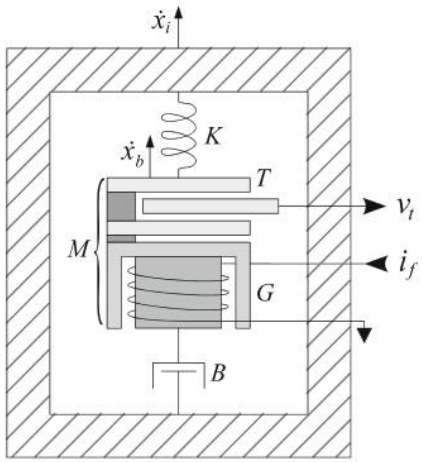
...add damping



www.guidelinegeo.com

Passive inertial sensor

Active inertial sensor (force feedback)



Ackerly (2014)

...add A/D convertor and recording system (data logger) with proper timing

Modern seismograph designs

Broadband seismometers (active, 240s - 100Hz)

Streckeisen STS-2

Nanometrics Trillium 120

Güralp CMG-3ESP

Trillium compact

… posthole

Nanometrics Horizon

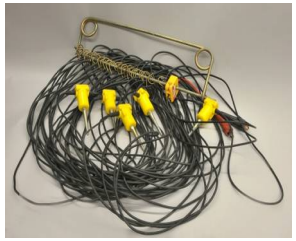
Kinemetrics MBB-2

Geophones (passive, >=1Hz)

Mark 1Hz

Geophone 4.5Hz 3-C

Geophone 4.5Hz vertical



Geophone string

Accelerometer (passive)

Kinemetrics Episensor

Modern seismograph designs

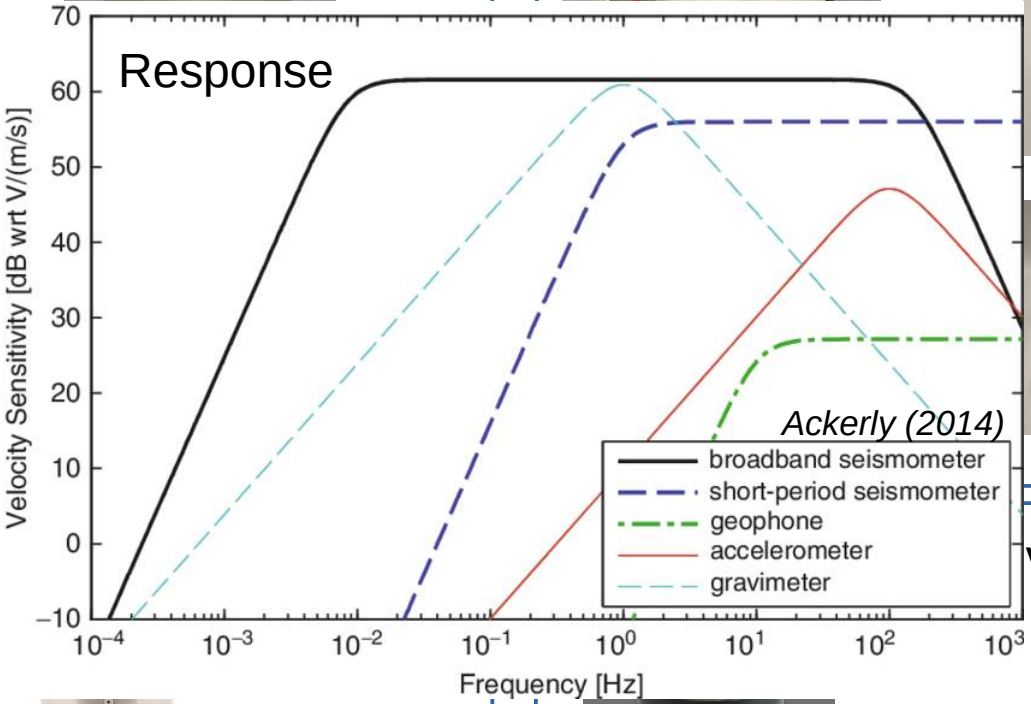
Broadband seismometers
(active, 240s - 100Hz)

Streckeisen STS-2

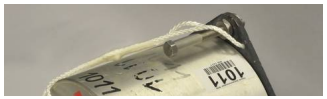
Güralp CMG-3ESP

Nanometrics Horizon

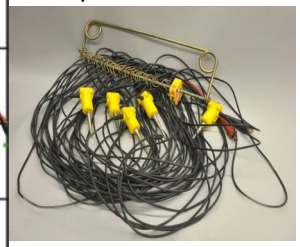
Kinemetrics MBB-2



Geophones (passive, >=1Hz)



Geophone 4.5Hz 3-C



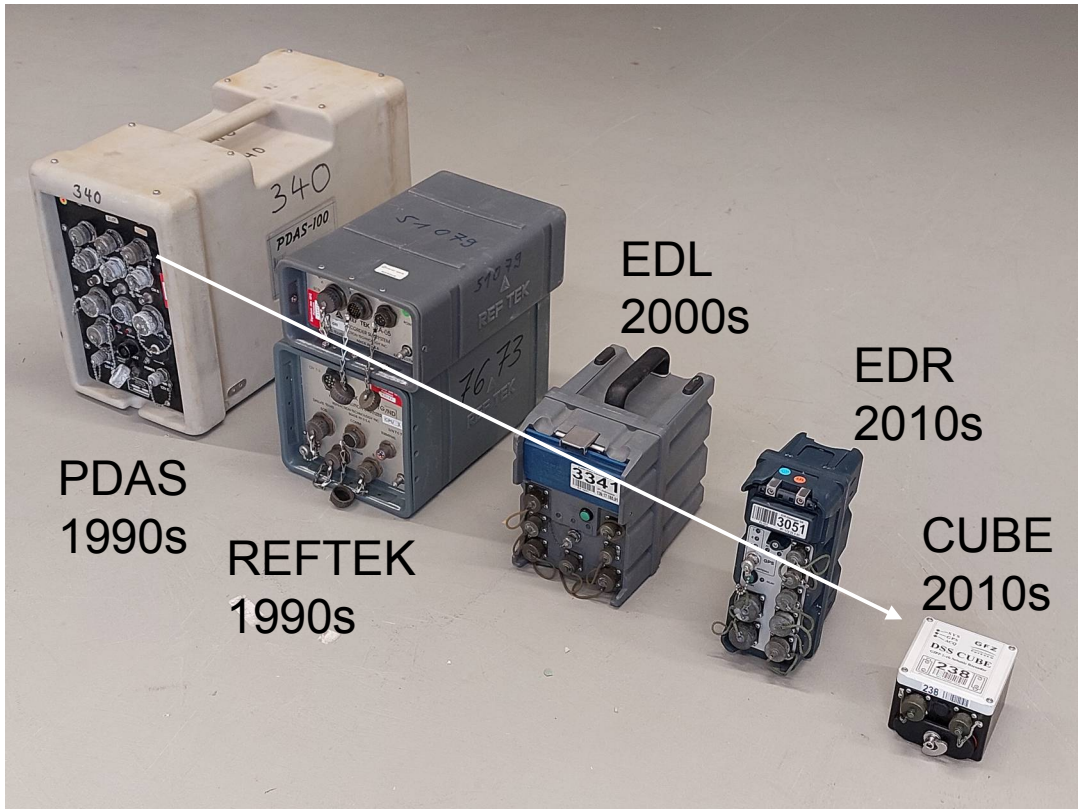
Geophone string

ve)

Kinemetrics Episensor

(Autonomous) Recorders

volume, weight, power



Kinemetrics Basalt

… Pebble

Nanometrics Centaur

… Pegasus

Güralp minimus

Geometrics Geode

… and many more

Compact autonomous recorders (nodes)

GE-ANT-3C

Geospace GS-5

NuSeis NRU

Cube

Inova Quantum

SmartSolo

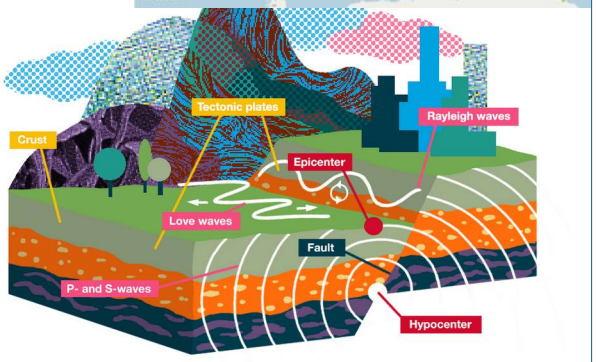
Stryde

Fairfield ZLand

SmartPoint

Sources/signals

Natural (impulsive) sources (earthquakes)



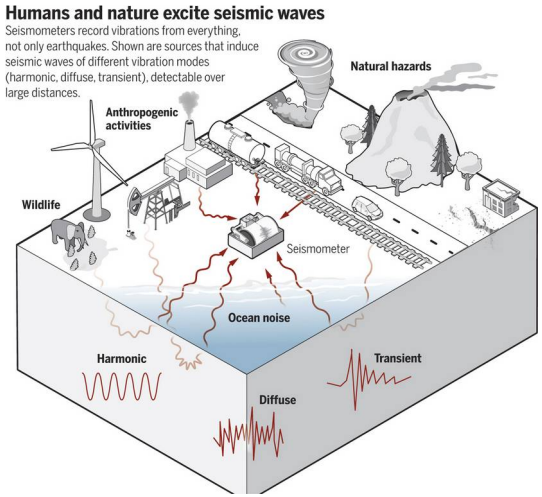
scienceexchange.caltech.edu

- EQ location/ study
- Monitoring
- Imaging

Controlled sources (hammer, vibro, blast)

- Imaging
- (monitoring)

Ambient noise



x.com/ScienceMagazine

- Imaging
- monitoring

Sources/signals

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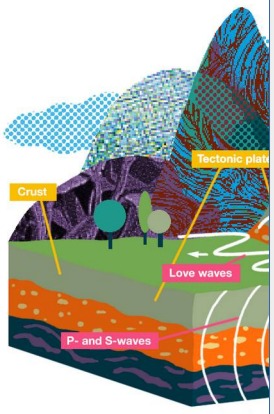

scienceexchange.ca

- EQ location/ study
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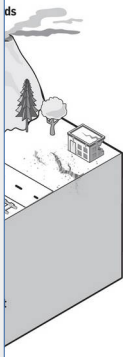


agazine

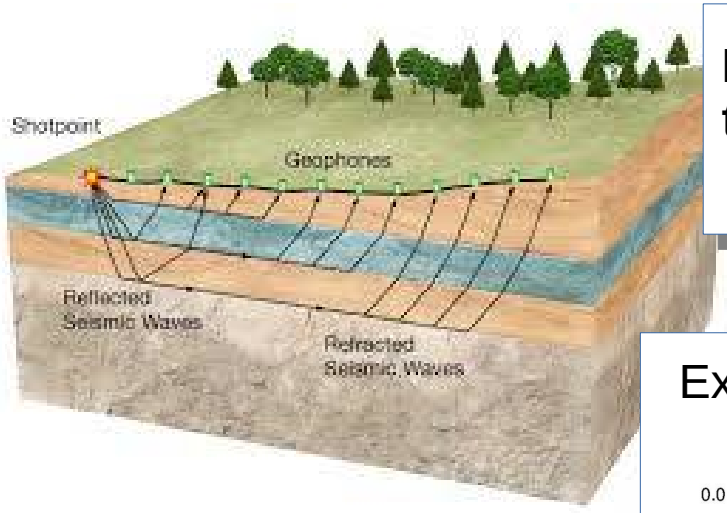
- Imaging
- monitoring

Applications (selection):

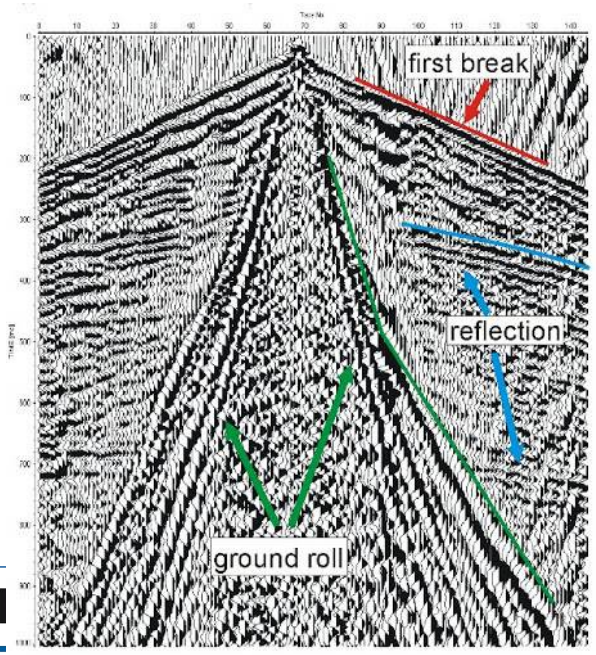
- Earth structure (meterscale to global)
- Geodynamic processes: active/passive continental margins, orogenes, shear zones, volcanoes…
- Seismicity
- Resources, exploration
- Use of subsurface (geothermal, storage)
- Hazard (EQ, volcanoes, tsunamis)
- climate (permafrost, glaciers, ice)
- Soil, engineering
- …

Controlled source seismics

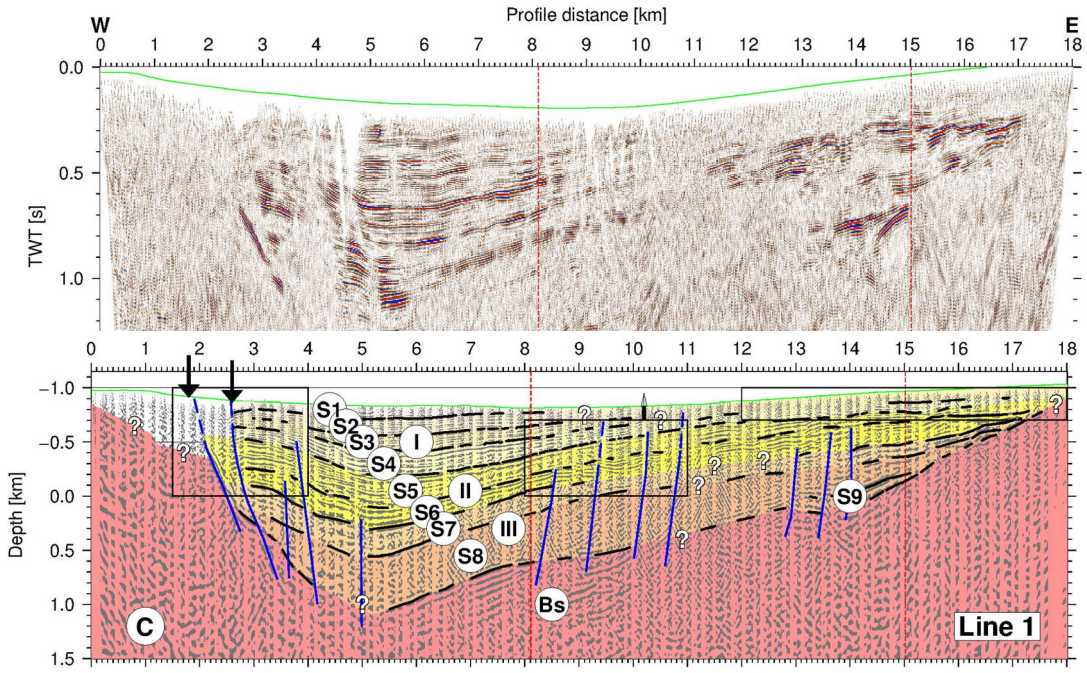
Reflection and refraction seismics, tomography



petroshine.com

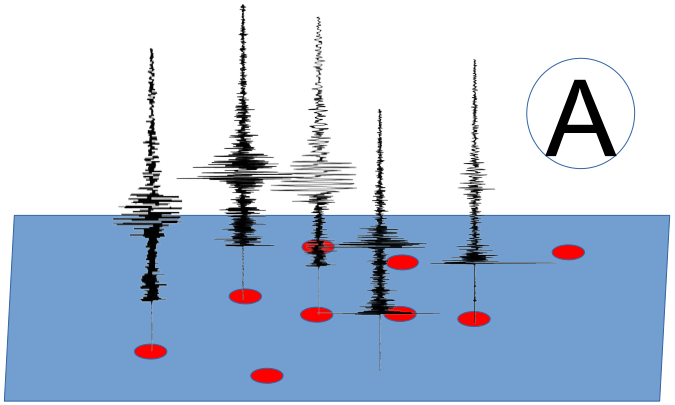


Example: Imaging of sedimentary basin structure



Haberland et al., 2017, Tectonophysics

Typical seismological observation designs

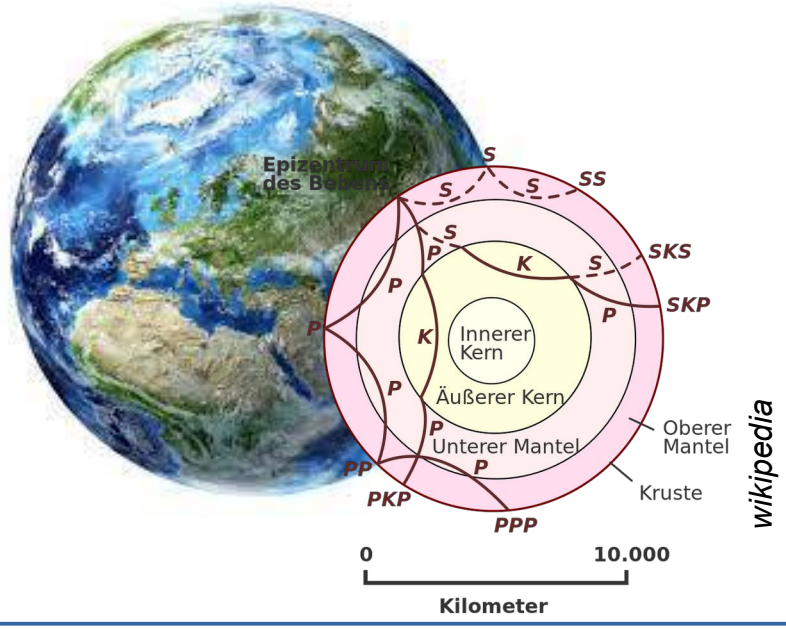


“Conventional” network

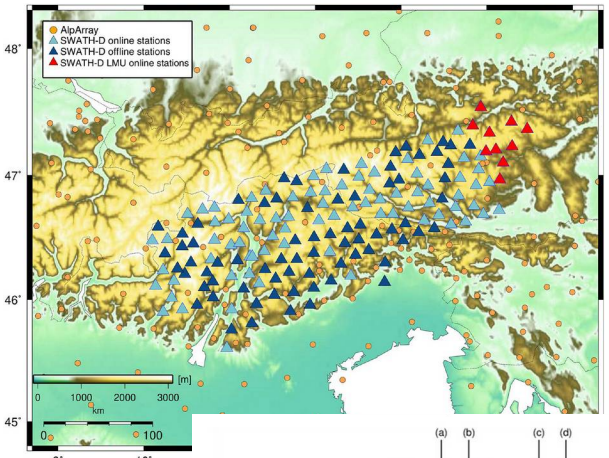
- Interstation distances “large”
- Coherent waveforms only for “low” frequencies (limiting spatial resolution)
- Use e.g. of arrival times (tomography) and/or (individual) waveforms

Typical Studies A

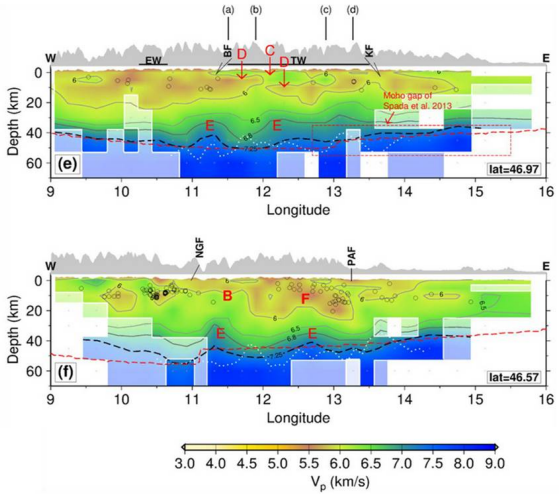
Permanent networks - Global/regional studies



Temporary seismic networks:
SPP 4D-MB: SWATH-D

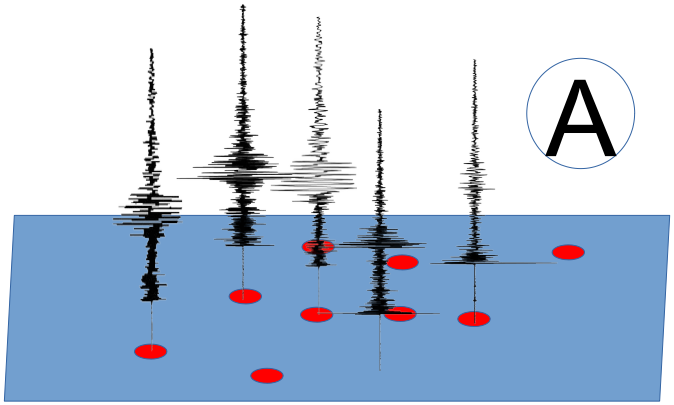


Heit et al., SRL, 2021



Jozi Najafabadi et al, JGR, 2022

Typical seismological observation designs



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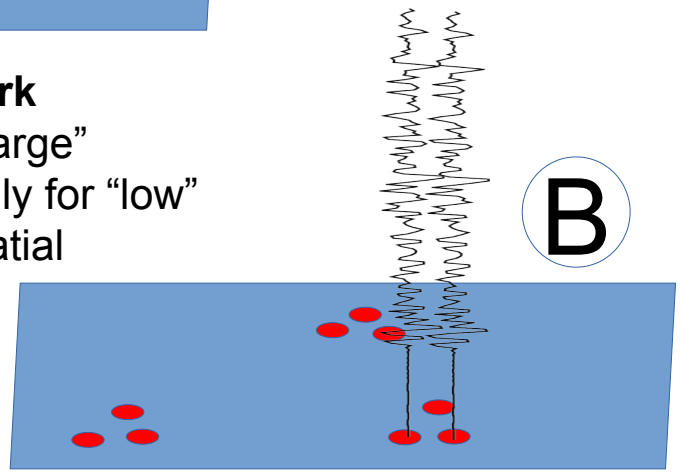
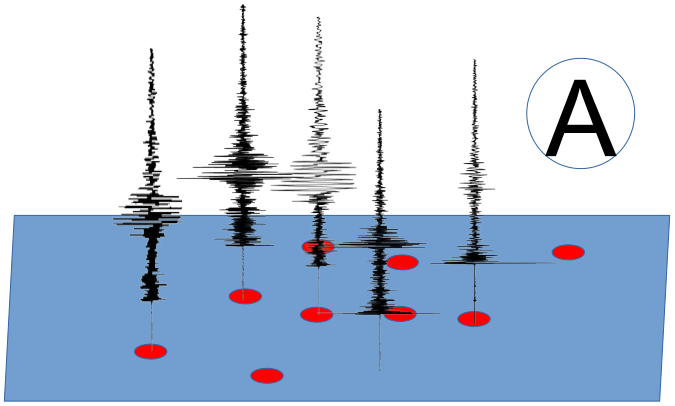


“Array” approach

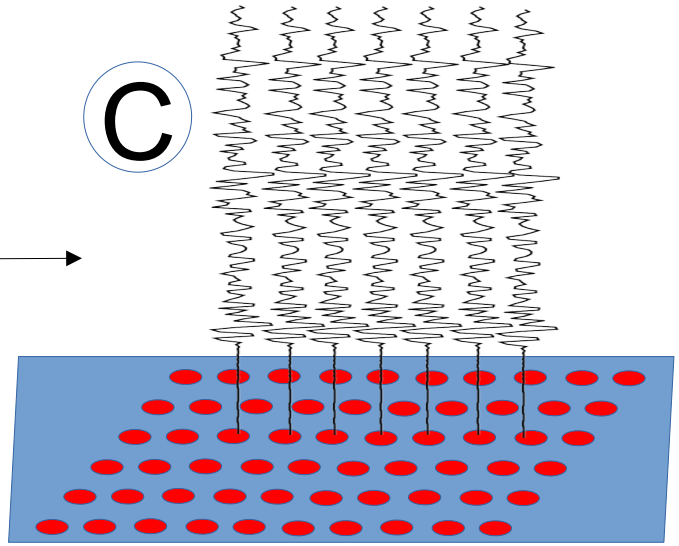
- Interstation distances within array “small”
- Coherent waveforms within array even for “high” frequencies
- Locally use of wavefield (e.g. beamforming)

Typical seismological observation designs



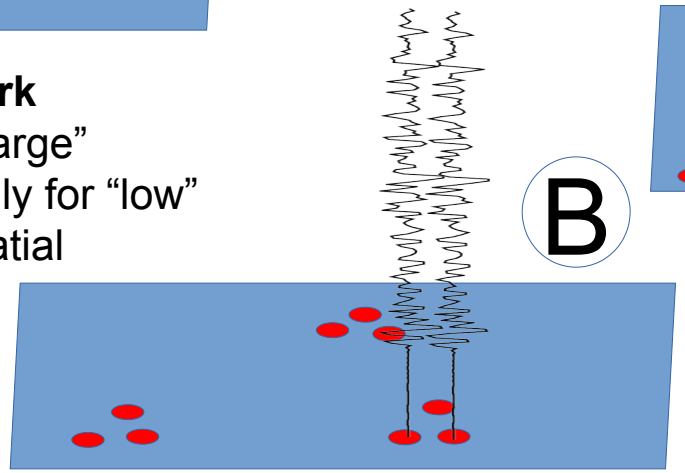
frequency/

wavelength



“Conventional” network

- Interstation distances “large”
- Coherent waveforms only for “low” frequencies (limiting spatial resolution)
- Use e.g. of arrival times (tomography) and/or (individual) waveforms



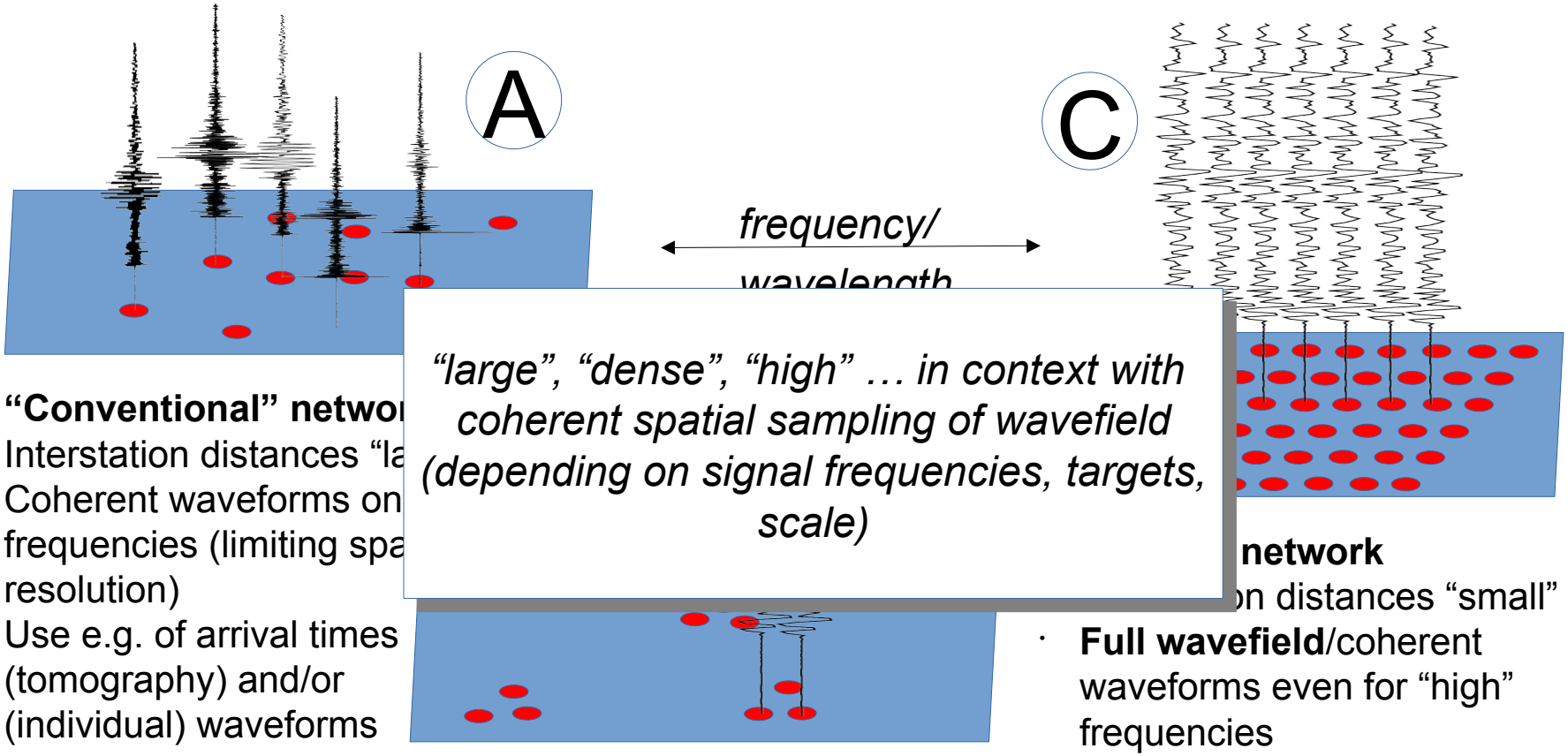
“Array” approach

- Interstation distances within array “small”
- Coherent waveforms within array even for “high” frequencies
- Locally use of wavefield (e.g. beamforming)

“Dense” network

- Interstation distances “small”
- **Full wavefield**/coherent waveforms even for “high” frequencies
- Higher spatial resolution
- Stacking, migration, imaging, time-reversel,Helmholtz-tomography, waveform/-field inversion...

Typical seismological observation designs



"large", "dense", "high" … in context with coherent spatial sampling of wavefield (depending on signal frequencies, targets, scale)

"Conventional" netwo

- Interstation distances "la
- Coherent waveforms on frequencies (limiting spa resolution)
- Use e.g. of arrival times (tomography) and/or (individual) waveforms

"Array" approach

- Interstation distances within array "small"
- Coherent waveforms within array even for "high" frequencies
- Locally use of wavefield (e.g. beamforming)

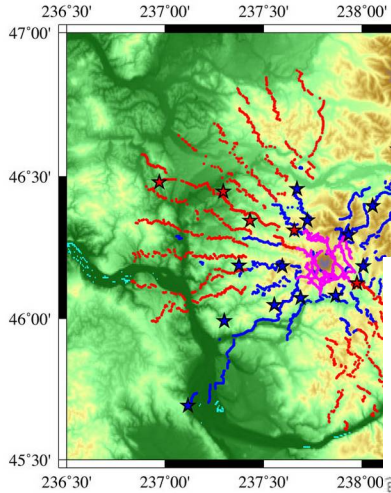
network

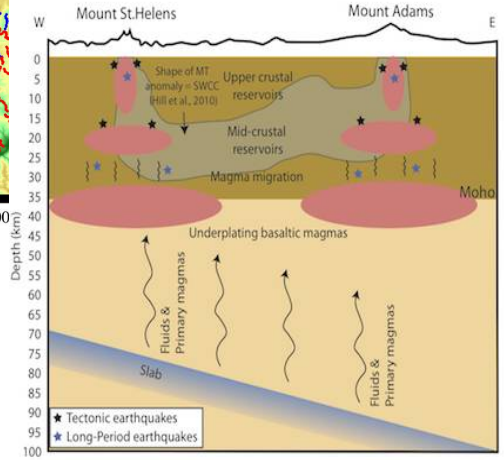
on distances "small"

- **Full wavefield**/coherent waveforms even for "high" frequencies
- Higher spatial resolution
- Stacking, migration, imaging, time-reversel,Helmholtz-tomography, waveform/-field inversion...

Typical Studies

„Large-N“

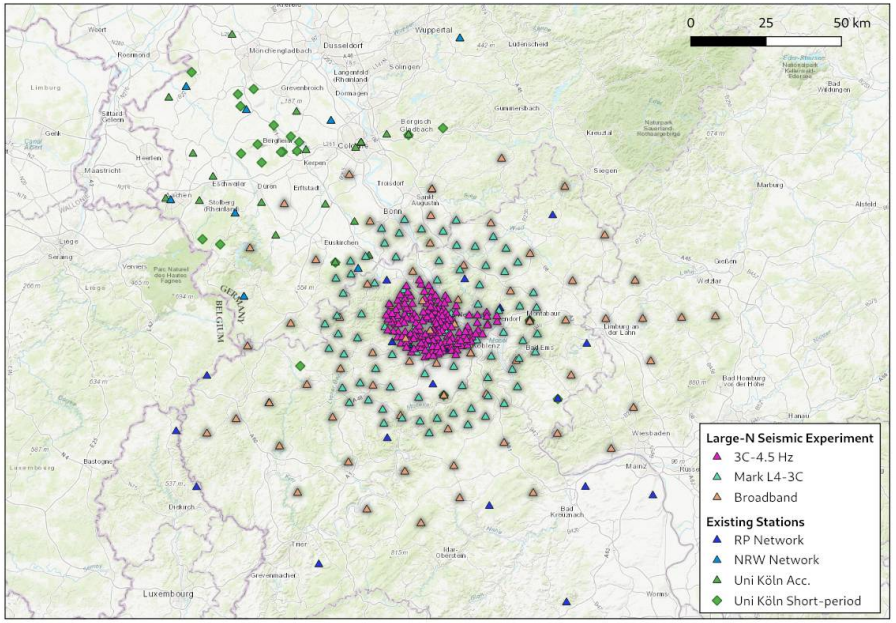




3600 nodes

http://imush.org/

EIFEL-LARGE-N (310 SP/BB stations)



Dahm et al., 2022
(www.gfz-potsdam.de)

GFZ Helmholtz-Zentrum Potsdam

RESOLUTION WAVEFIELDS NOT JUST WAVEFORMS

NO SPATIAL ALIASING

HELMHOLTZ ASSOCIATION

Geophysical Instrument Pool Potsdam (GIPP)

Christian Haberland, GFZ




Mission:

The „Geophysical Instrument Pool Potsdam" GIPP of the GFZ provides seismic and magnetotelluric instruments for temporary field experiments.

- Scientific infrastructure since 1993
- Operated by Section 2.2 „Geophysical Imaging"
- For „academic" research, GFZ + inter-/national loans
- Financed by GFZ
- 6+ staff (scientific + technical)
- Transparent procedures, terms of use, external steering board
- **Next application submission 1. October 202**

Responsibilities & duties

GIPP responsibilities/duties:

- Supply of seismological/seismic and electromagnetic field equipment
- Packing, preparation
- Maintenance of equipment
- Market/product analysis; purchases
- Guidance/training of users, assistance
- archiving of data (partly with GEOFON)
- Hard- and software-development, company spin-off

User's responsibilities/duties:

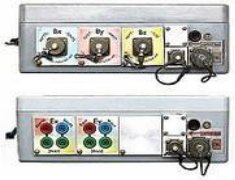
- Field operation
- Transport/shipping/customs
- Permits
- Consumables
- Fully liable (insurance!)
- Data delivery

www.gfz-potsdam.de/gipp

GIPP seismic & EM/MT instruments

Seismic recorders (>1200)

Land-MT-recorders & sensoren (magnetometers, electrodes; ~80)



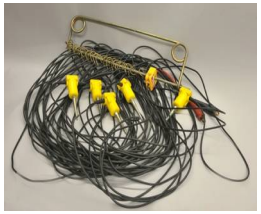




Seismic sensors/ geophones (>1300)





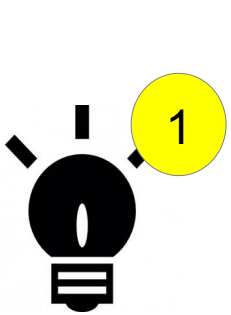




Seismic-multichannel (>288ch) & sources


managed by GFZ

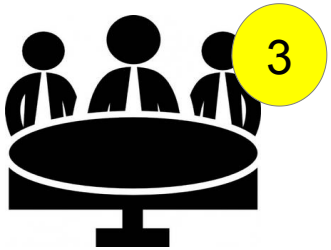
www.gfz-potsdam.de/gipp

Application & supply procedure



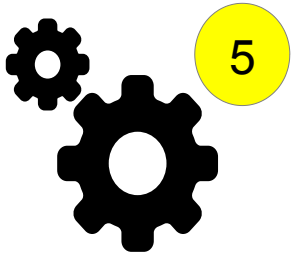
Idea

Application

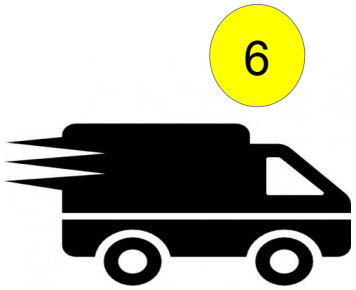


Steering board
Evaluation/
recommendation
(2 meetings / yr)

GFZ-executive board
Decision/approval

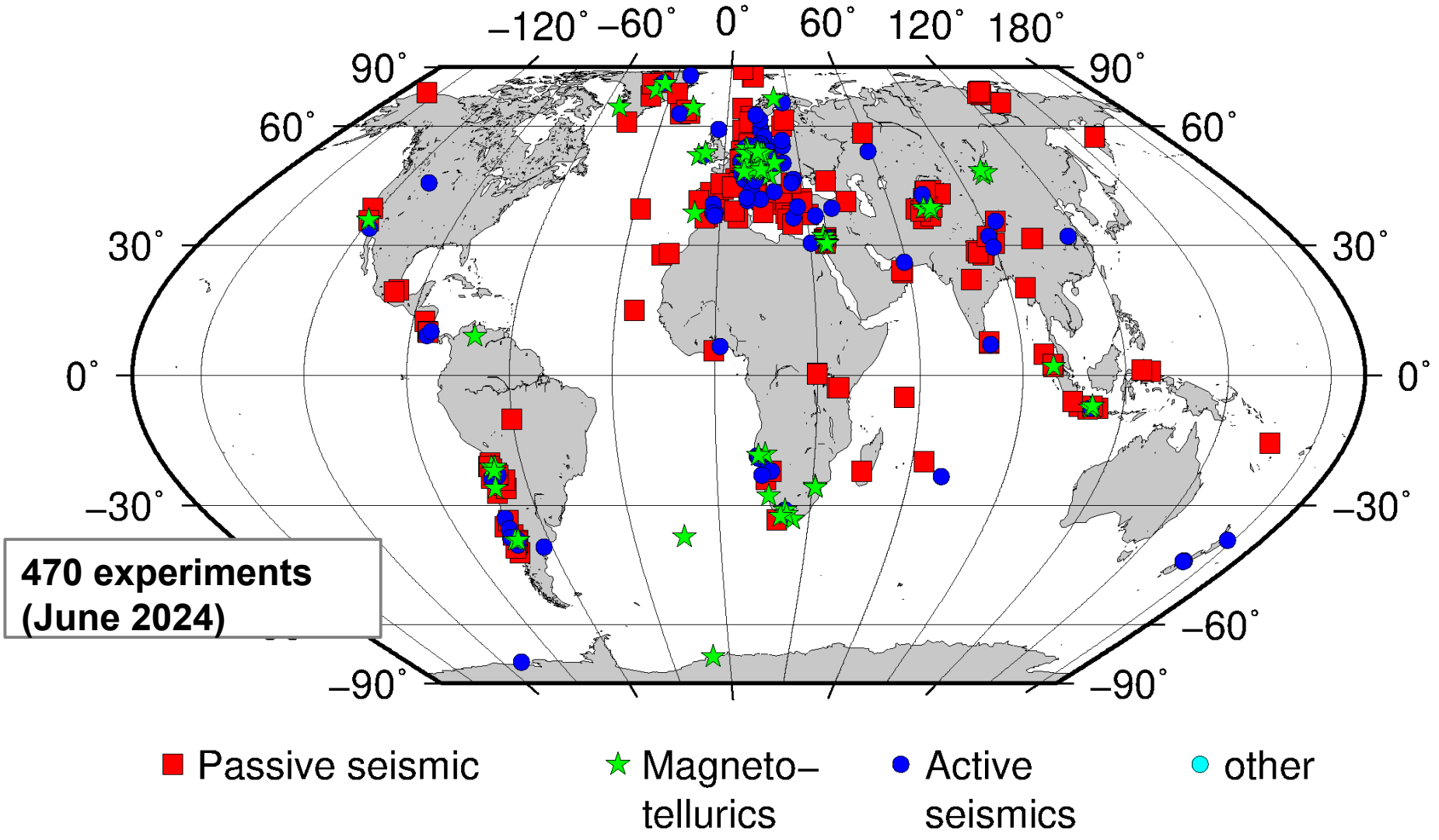


GIPP
supply, consulting,
info, training



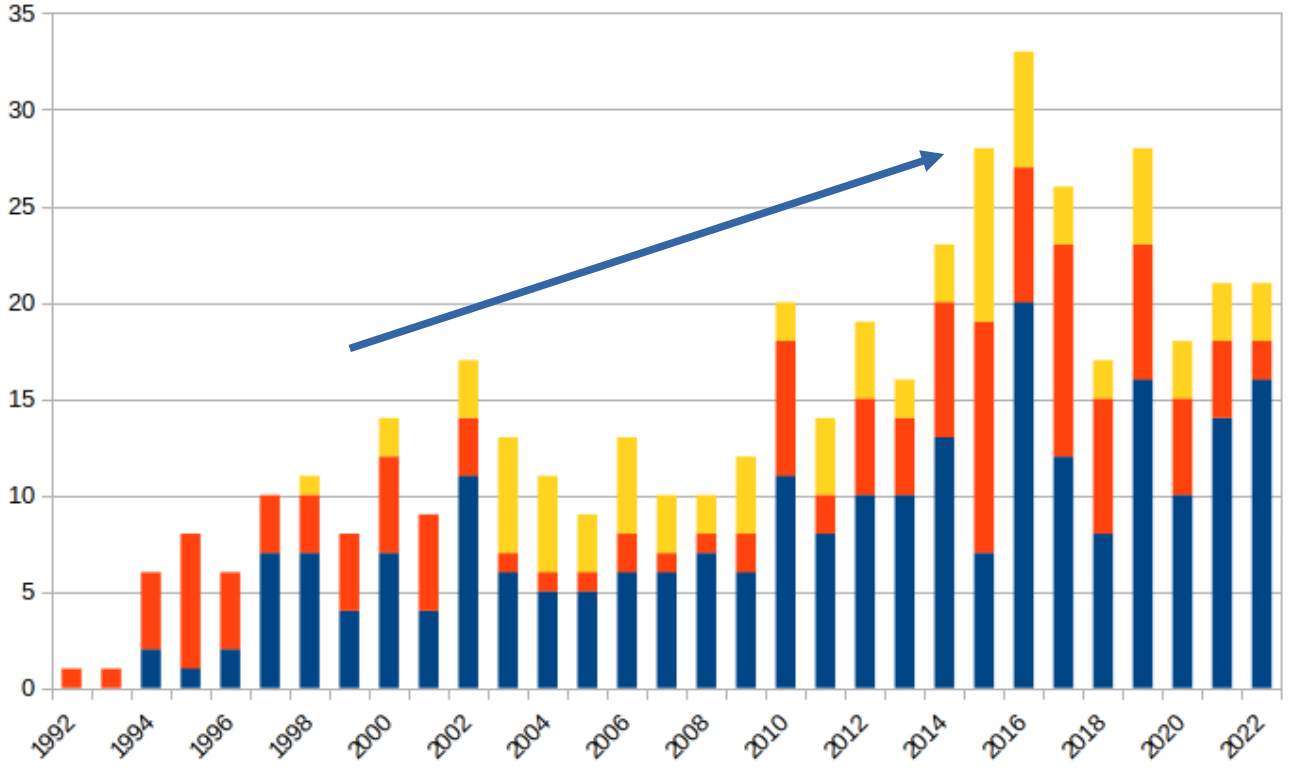
Experiment

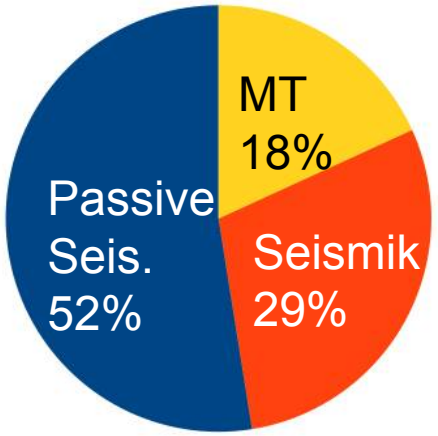
GIPP-deployments

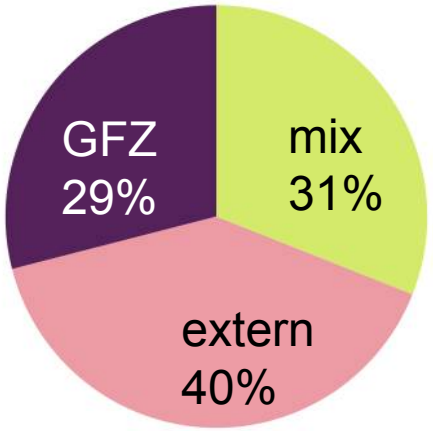


Usage

New experimente / year



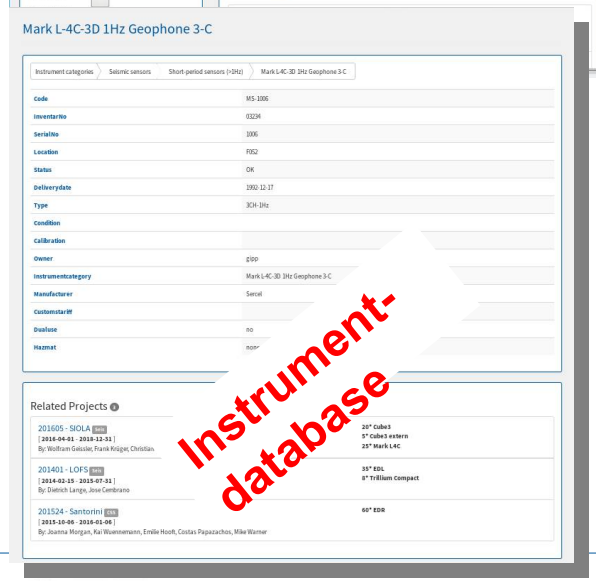


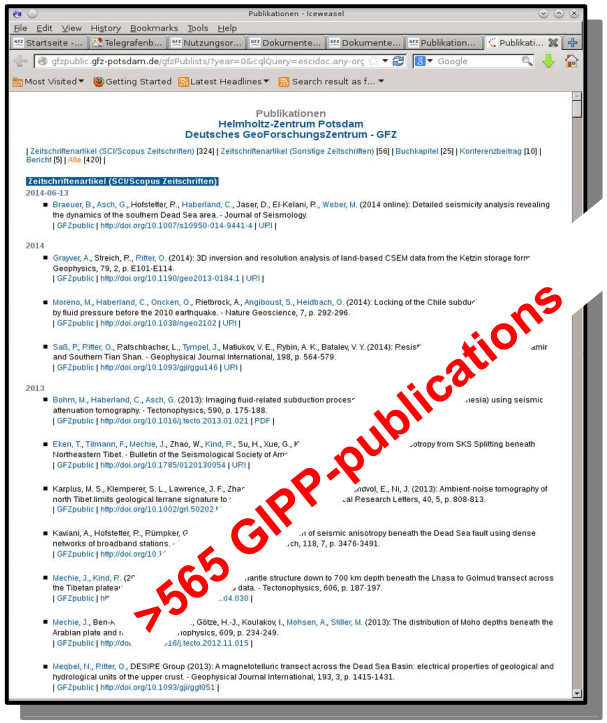


since 2010

Data & Publications

- Data policy
- Archivierung bei GEOFON oder GIPP





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Conclusions

- Seismological equipment (sensors & recorders) powerful instruments for seismological experiments
- Seismological experiments most powerful for imaging Earth‘s structure and processes
- Wide range of different instruments (from broadband to geophone) for different purposes
- Necessary for passive seismological observations (eq, ambient noise) and controlled source seismology
- Geophysical instrument pool provides instruments for temporary experiments

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