Modern Seismology Lecture Outline

- Seismic networks and data centres
- Mathematical background for time series analysis
- Seismic processing, applications
  - Filtering
  - Correlation
  - Instrument correction, Transfer functions
- Seismic inverse problems
  - Hypocentre location
  - Tomography

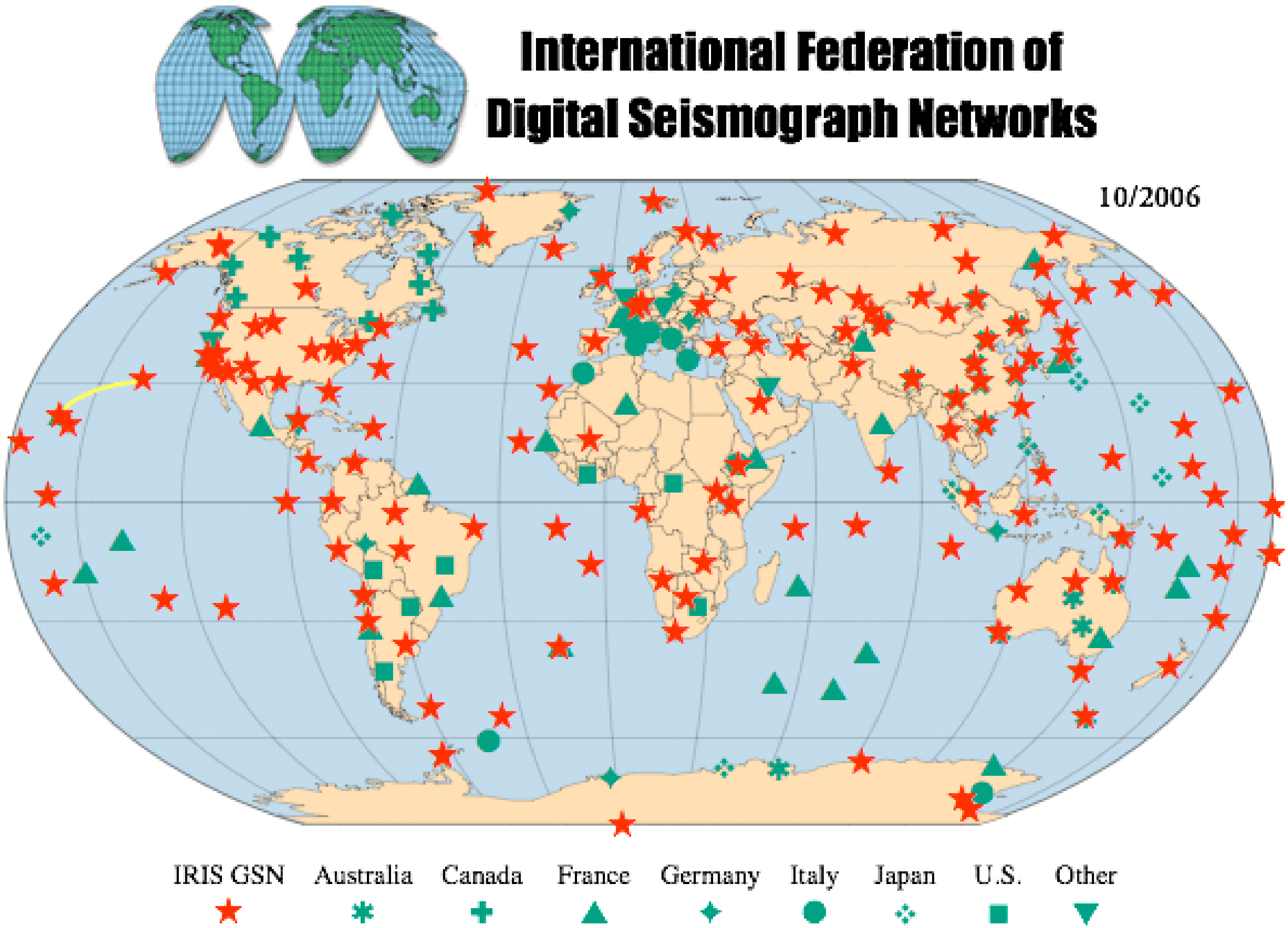
Key questions

- What data are relevant in seismology?
- Where are they acquired?
- What observables are there?
- What are acquisition parameters?
- How to process seismic observations?
- How to solve seismic inverse problems?
- What information can we gain?

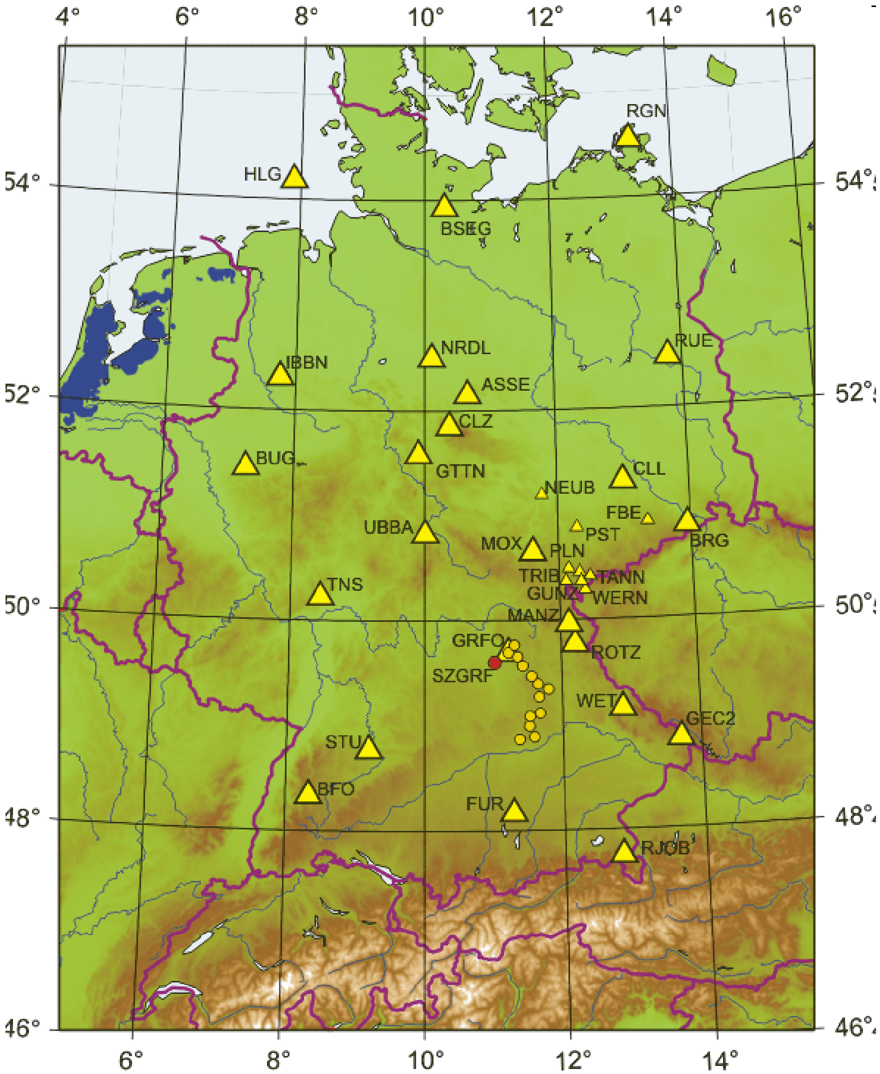
Literature

- Stein and Wysession, An introduction to seismology, earthquakes and earth structure, Blackwell Scientific (Chapts. 6, 7 and appendix) see also http://epscx.wustl.edu/seismology/book/ (several figures here taken from S+W).
- Shearer, Introduction to Seismology, Cambridge University Press, 1990, 2009 (to appear in July)
- Aki and Richards, Quantitative Seismology, Academic Press, 2002.
- Tarantola, Inverse Problem Theory and Model Parameter Estimation, SIAM, 2005.
- Gubbins, Time series analysis and inverse problems for geophysicists, Cambridge University Press
- Scherbaum, Basic concepts in digital signal processing for seismologists

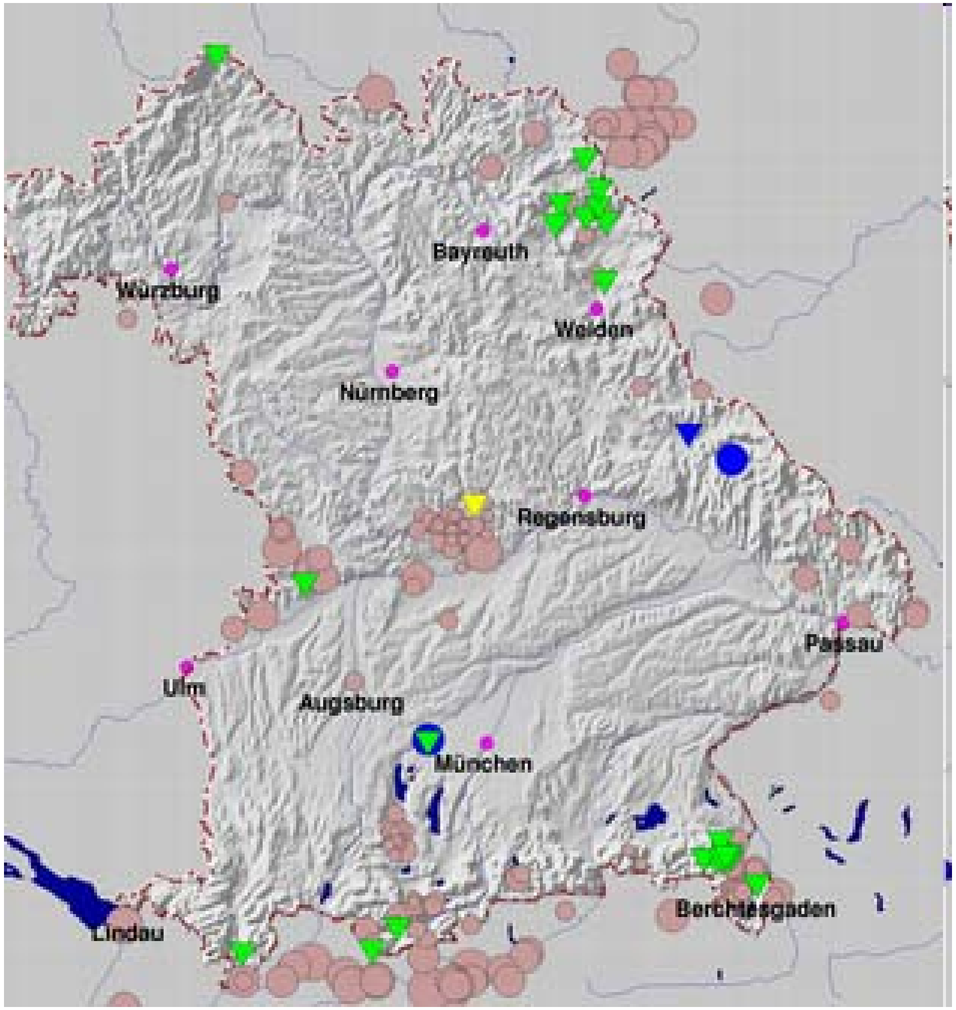
Global seismic networks



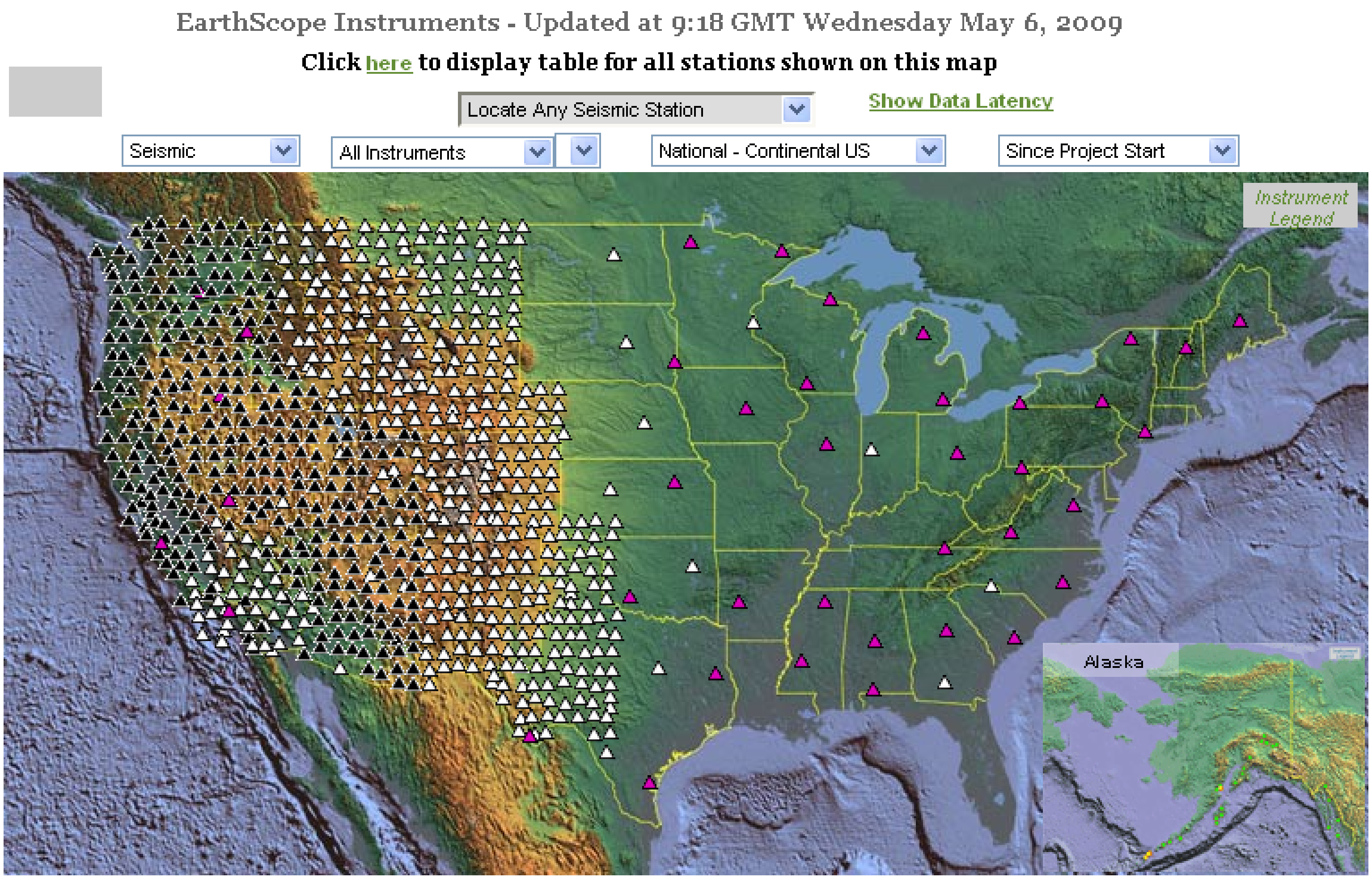
Regional seismic networks



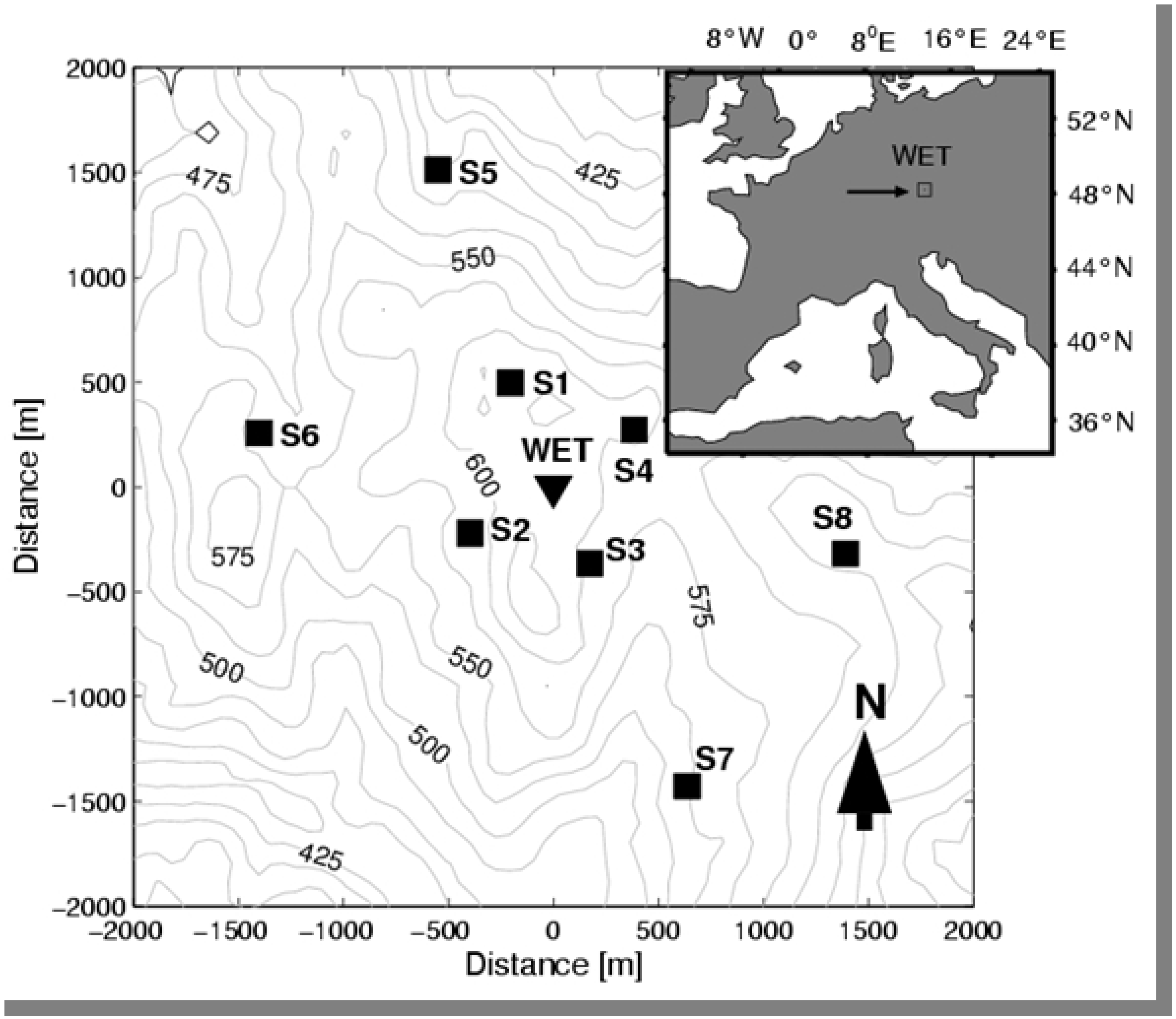
Local seismic networks



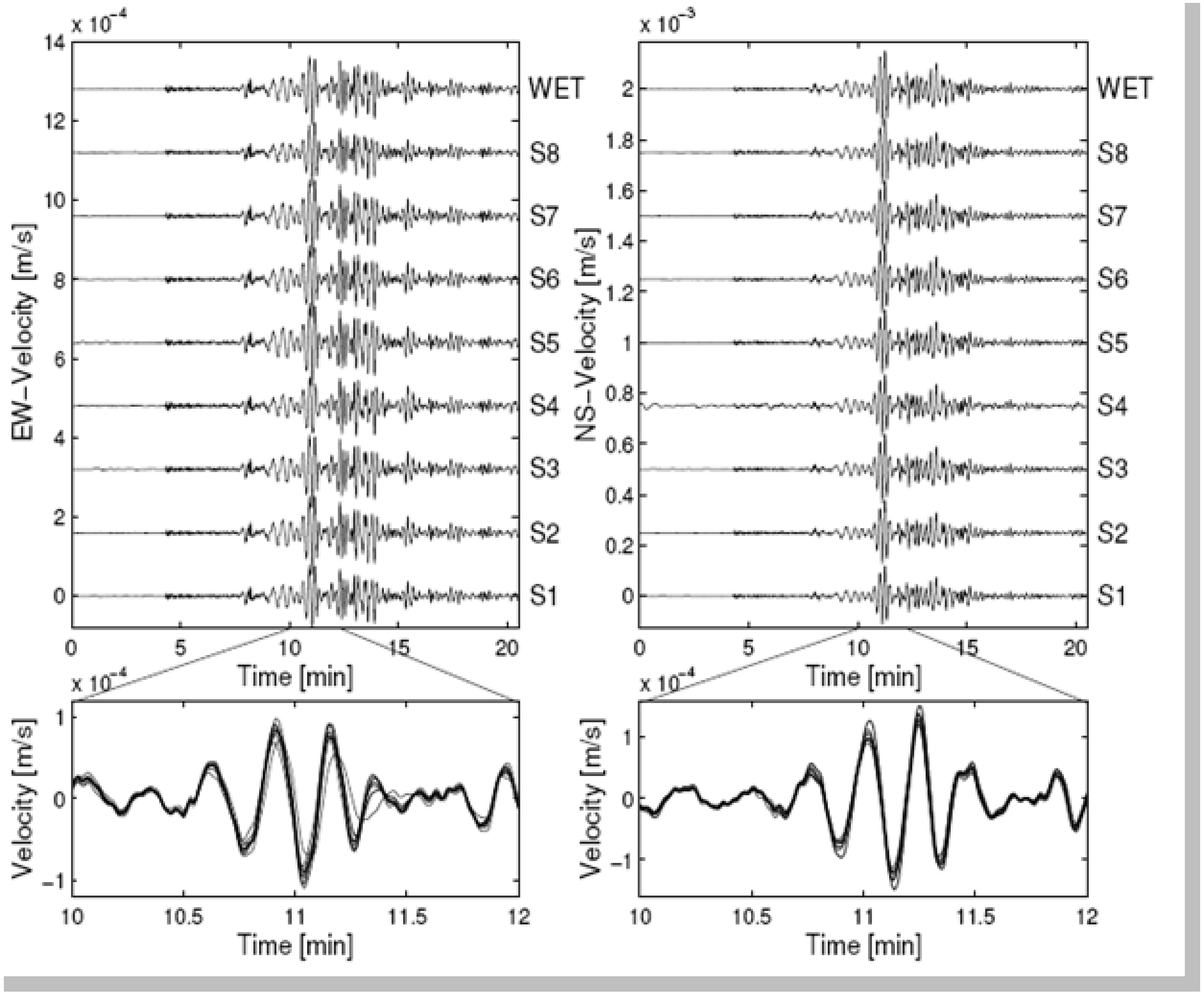
Temporary (campaign) networks



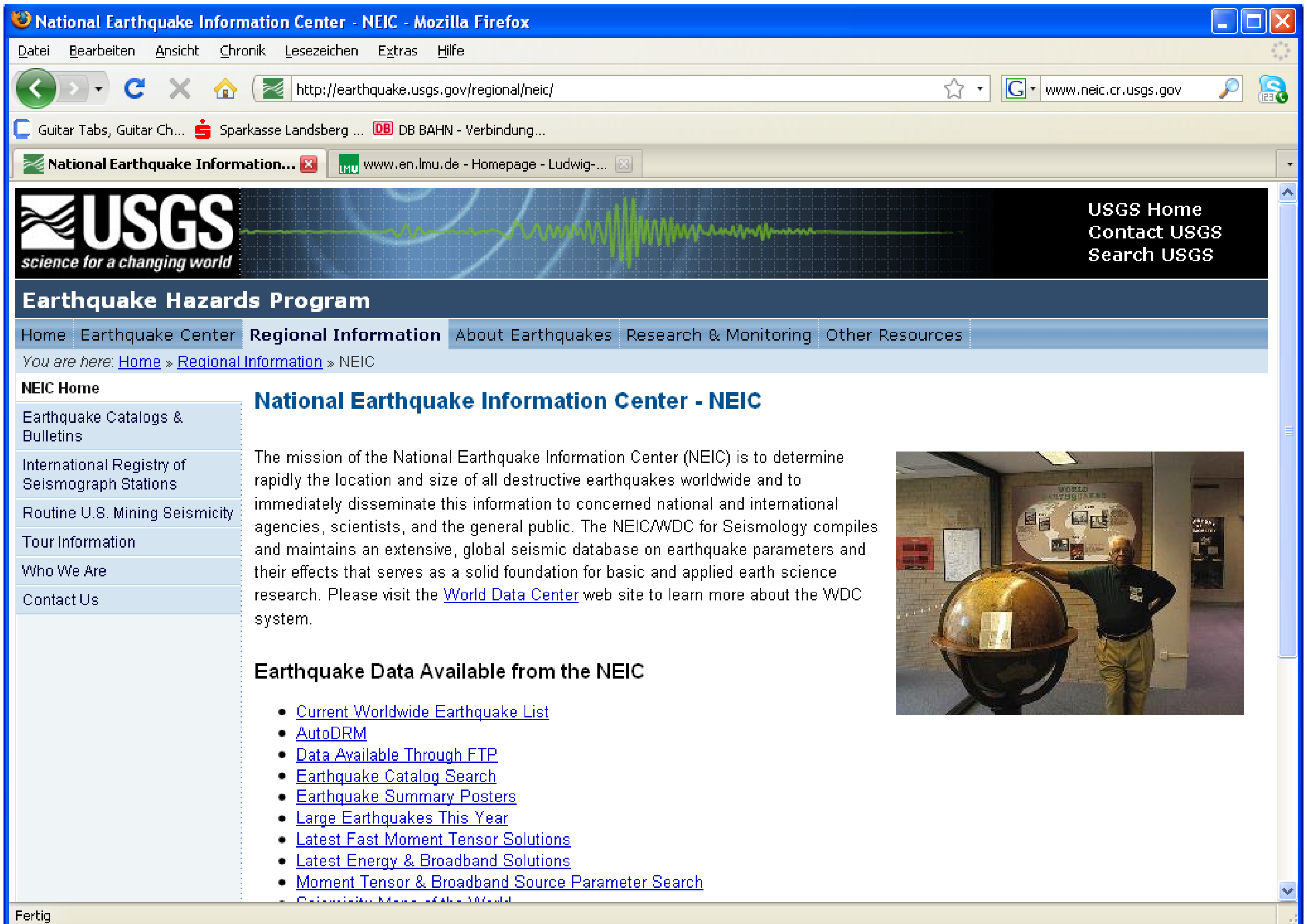
Seismic arrays



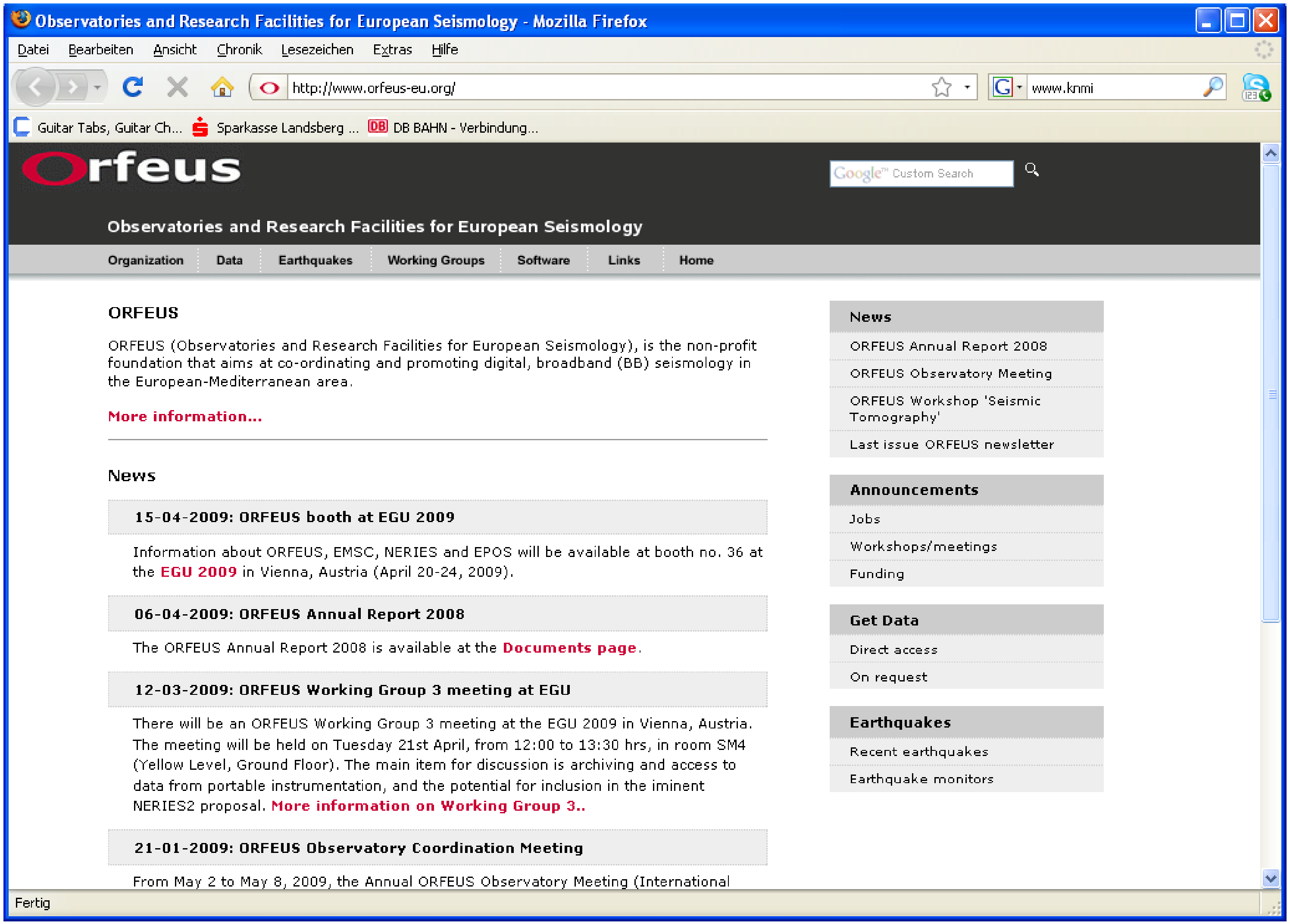
Seismic arrays



Seismic data centres: NEIC

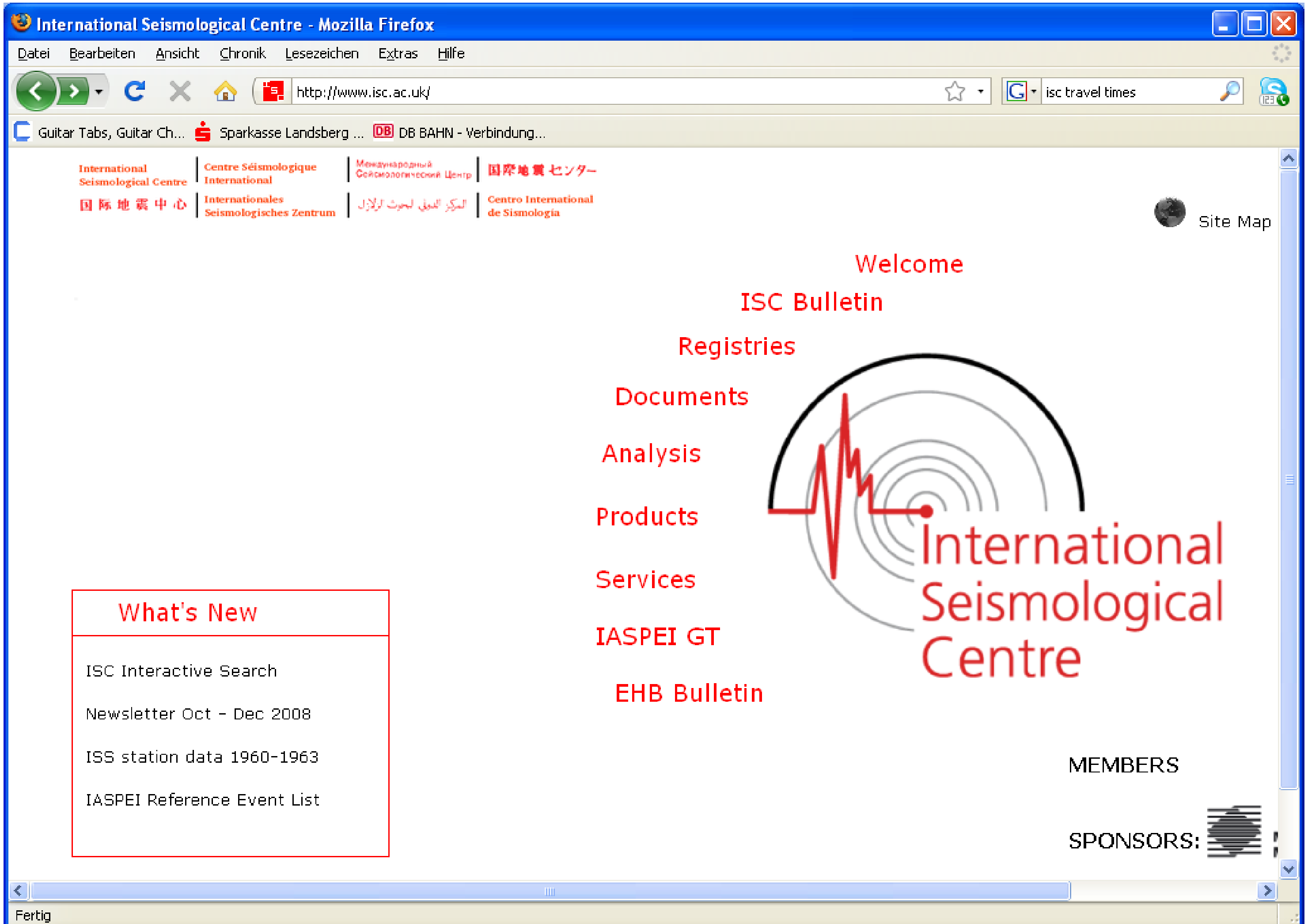


Seismic data centres: ORFEUS

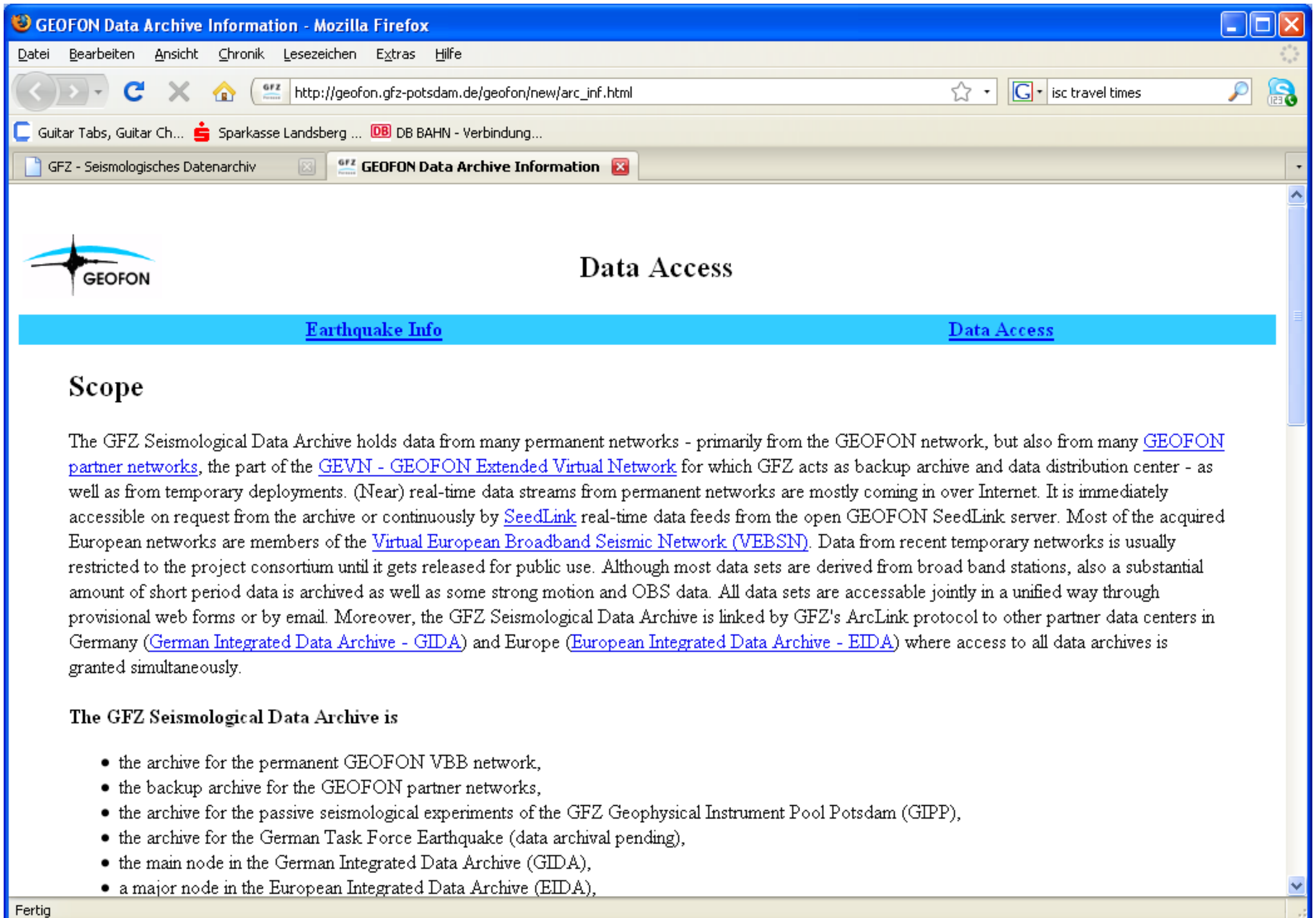


Seismic data centres: IRIS

Seismic data centres: ISC



Seismic data centres: GEOFON



Data Access

Earthquake Info Data Access

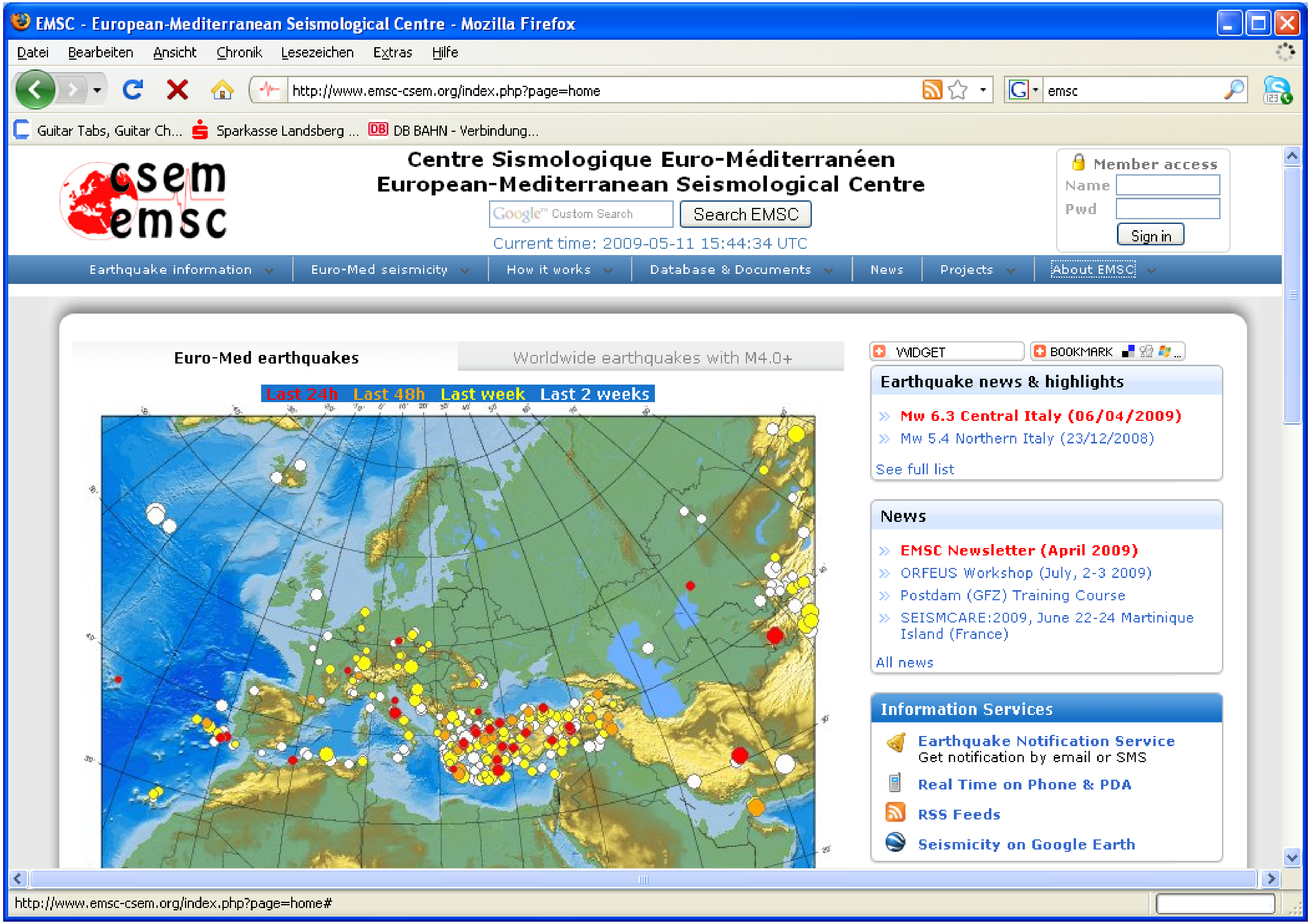
Scope

The GFZ Seismological Data Archive holds data from many permanent networks - primarily from the GEOFON network, but also from many GEOFON partner networks, the part of the GEVN - GEOFON Extended Virtual Network for which GFZ acts as backup archive and data distribution center - as well as from temporary deployments. (Near) real-time data streams from permanent networks are mostly coming in over Internet. It is immediately accessible on request from the archive or continuously by SeedLink real-time data feeds from the open GEOFON SeedLink server. Most of the acquired European networks are members of the Virtual European Broadband Seismic Network (VEBSN). Data from recent temporary networks is usually restricted to the project consortium until it gets released for public use. Although most data sets are derived from broad band stations, also a substantial amount of short period data is archived as well as some strong motion and OBS data. All data sets are accessable jointly in a unified way through provisional web forms or by email. Moreover, the GFZ Seismological Data Archive is linked by GFZ's ArcLink protocol to other partner data centers in Germany (German Integrated Data Archive - GIDA) and Europe (European Integrated Data Archive - EIDA) where access to all data archives is granted simultaneously.

The GFZ Seismological Data Archive is

- the archive for the permanent GEOFON VBB network,
- the backup archive for the GEOFON partner networks,
- the archive for the passive seismological experiments of the GFZ Geophysical Instrument Pool Potsdam (GIPP),
- the archive for the German Task Force Earthquake (data archival pending),
- the main node in the German Integrated Data Archive (GIDA),
- a major node in the European Integrated Data Archive (EIDA),

EMSC


EMSC - European-Mediterranean Seismological Centre - Mozilla Firefox
Datei Bearbeiten Ansicht Chronik Lesezeichen Extras Hilfe
http://www.emsc-csem.org/index.php?page=home
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Guitar Tabs, Guitar Ch...
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Centre Sismologique Euro-Méditerranéen
European-Mediterranean Seismological Centre
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Current time: 2009-05-11 15:44:34 UTC
Member access
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Euro-Med seismicity
How it works
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Last 24h
Last 48h
Last week
Last 2 weeks
WIDGET
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Earthquake news & highlights
Mw 6.3 Central Italy (06/04/2009)
Mw 5.4 Northern Italy (23/12/2008)
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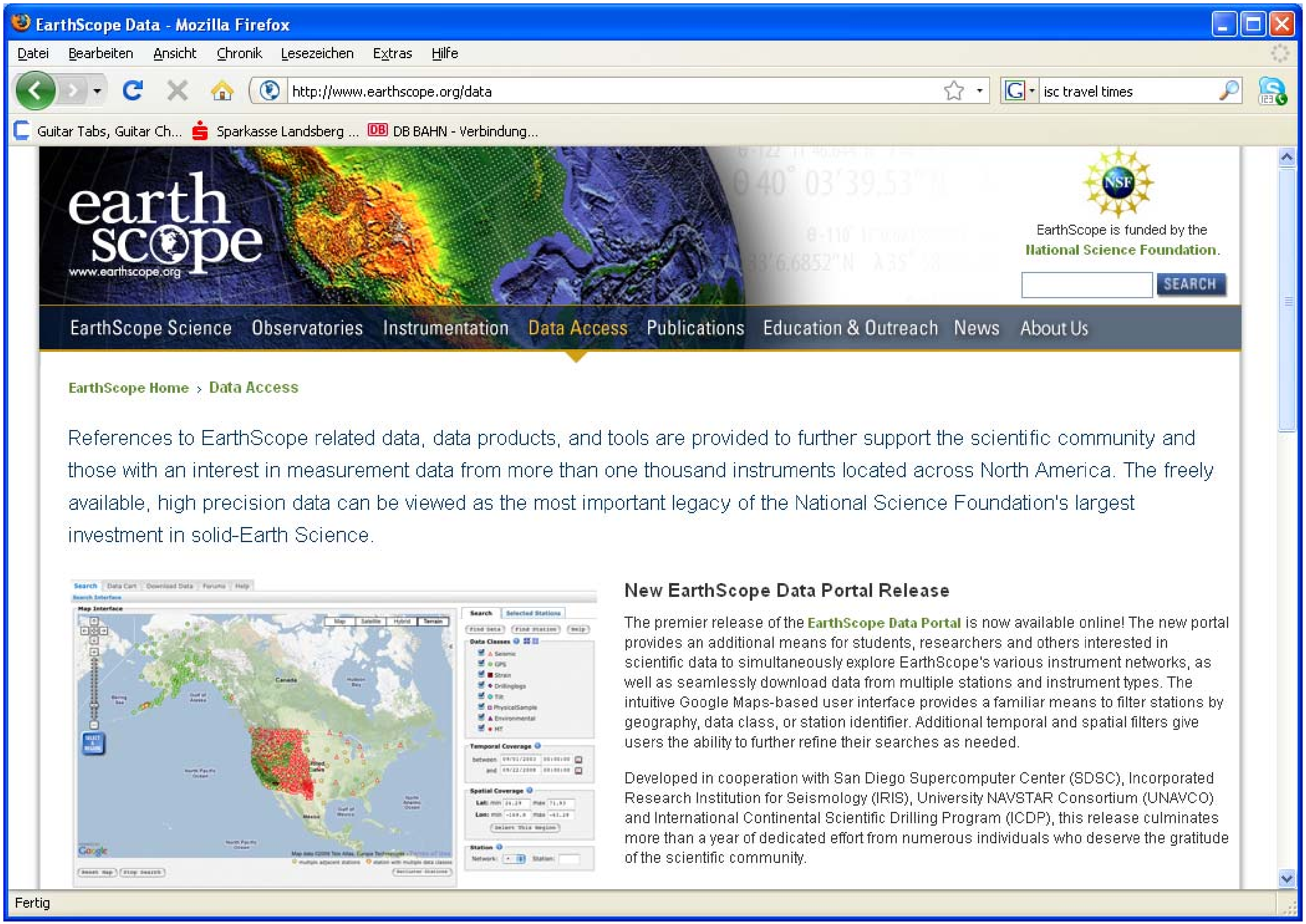
News
EMSC Newsletter (April 2009)
ORFEUS Workshop (July, 2-3 2009)
Postdam (GFZ) Training Course
SEISMCARE:2009, June 22-24 Martinique Island (France)
All news
Information Services
Earthquake Notification Service
Get notification by email or SMS
Real Time on Phone & PDA
RSS Feeds
Seismicity on Google Earth
http://www.emsc-csem.org/index.php?page=home#

Seismic data centres: EarthScope



Seismic observables
Period ranges (order of magnitudes)

- Sound 0.001 – 0.01 s
- Earthquakes 0.01 – 100 s (surface waves, body waves)
- Eigenmodes of the Earth 1000 s
- Coseismic deformation 1 s – 1000 s
- Postseismic deformation +10000s
- Seismic exploration 0.001 - 0.1 s
- Laboratory signals 0.001 s – 0.000001 s

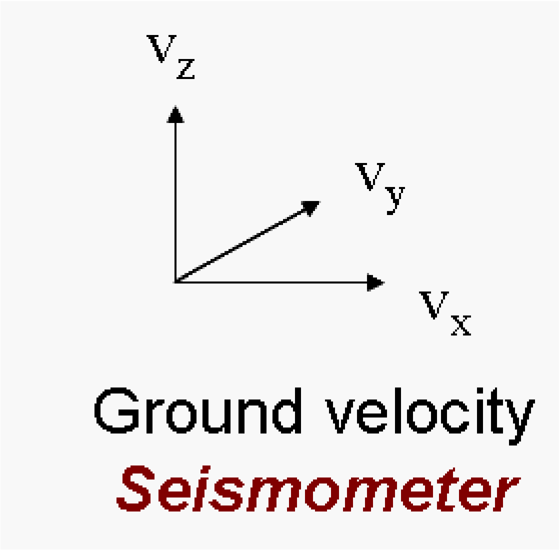
-> What are the consequences for sampling intervals, data volumes, etc.?

Seismic observables
translations

Translational motions are deformations in the direction of three orthogonal axes. Deformations are usually denoted by **u** with the appropriate connection to the strain tensor (explained below).

Each of the orthogonal motion components can be measured as displacement u, velocity v, or acceleration a.

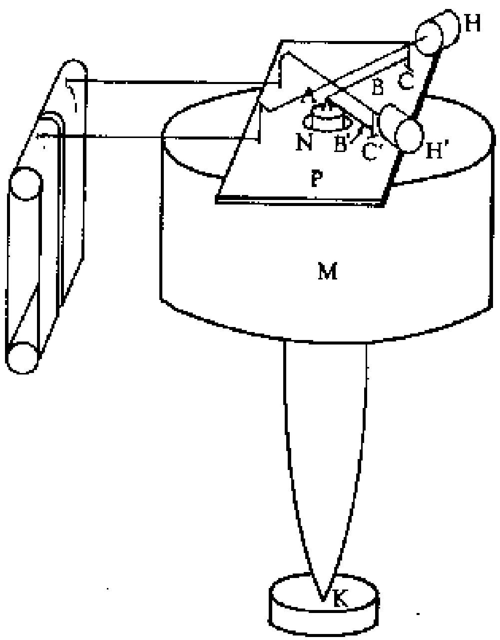
The use of these three variations of the same motion type will be explained below.



Seismic observables
translations - displacements

Displacements are measured as „differential“ motion around a reference point (e.g., a pendulum). The first seismometers were pure (mostly horizontal) displacement sensors. Measureable *co-seismic* displacements range from *microns to dozens of meters* (e.g.,Great Andaman earthquake).

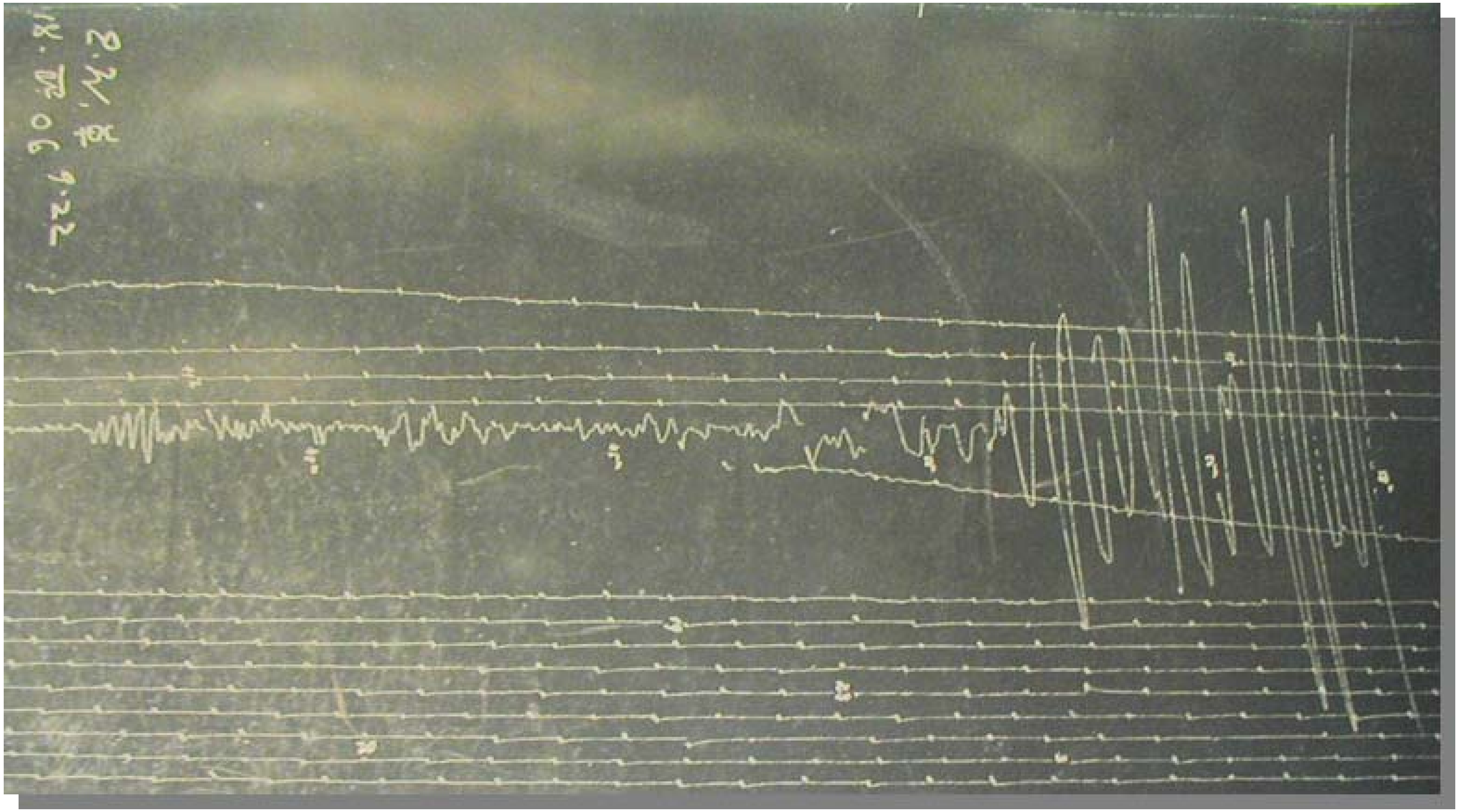
Horiztonal displacement sensor (ca. 1905). Amplitude of ground deformation is mechanically amplified by a factor of 200.



Today displacements are measured using GPS sensors.

Seismic observables
translations - displacements

Data example: the San Francisco earthquake 1906, recorded in Munich



Seismic observables
translations - velocities

Most seismometers today record *ground velocity.* The reason is that seismometers are based on an electro-mechanic principle. An electric current is generated when a coil moves in a magetic field. The electric current is proportional to ground velocity v.

Velocity is the time derivative of displacement. They are in the range of μm/s to m/s.

$$v(x,t) = \partial_t u(x,t) = \dot{u}(x,t)$$

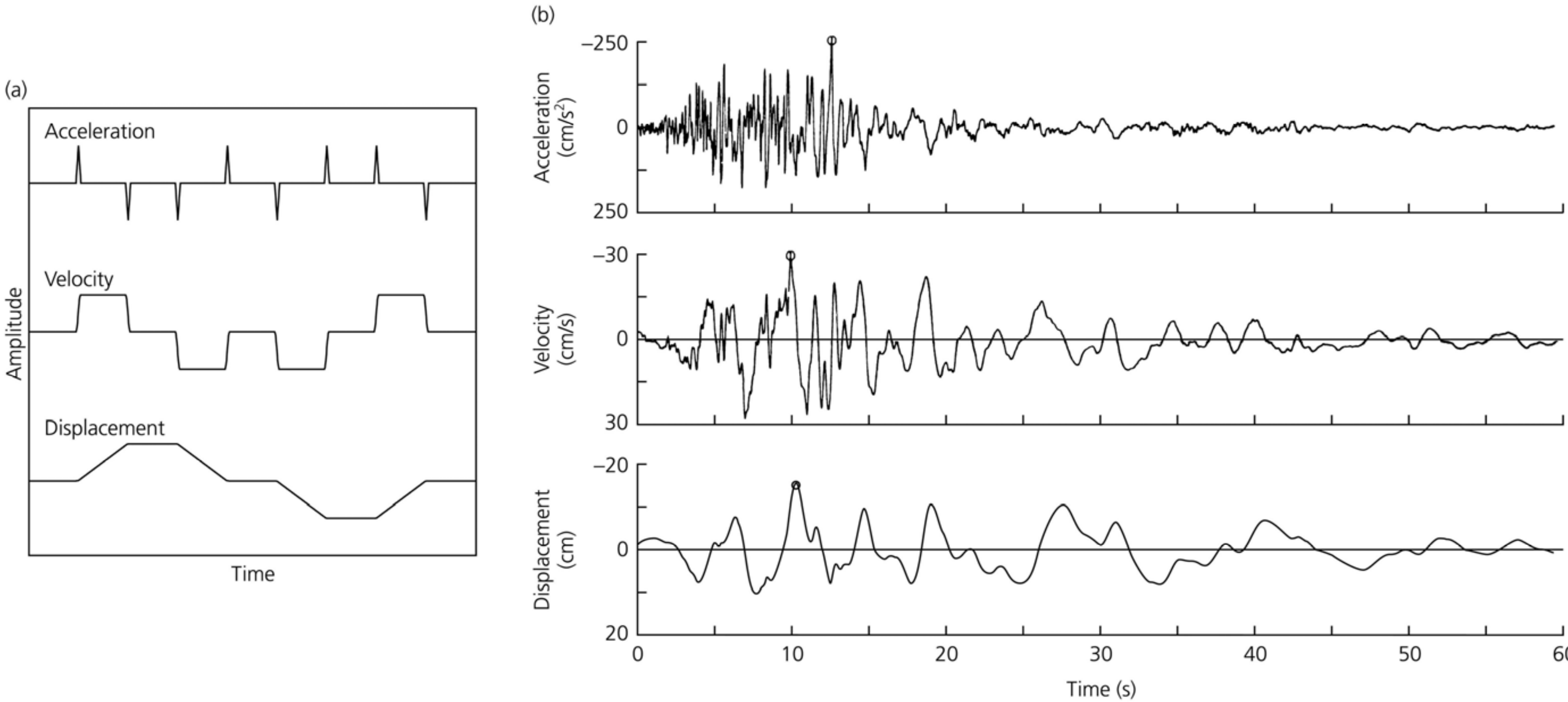
Seismic observables
translations - accelerations

Strong motions (those getting close to or exceeding Earth's gravitational acceleration) can only be measured with accelerometers. Accelerometers are used in earthquake engineering, near earthquake studies, airplanes, laptops, ipods, etc. The largest acceleration ever measured for an earthquake induced ground motion was 40 m/s^2 (four times gravity, see *Science* 31 October 2008: Vol. 322. no. 5902, pp. 727 – 730)

$$a(x,t) = \partial_t^2 u(x,t) = \ddot{u}(x,t)$$

Displacement, Velocity, Acceleration

Figure 6.6-14: Relation between displacement, velocity, and acceleration in the time domain.



Seismic observables
strain

$$\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$$

Strain is a tensor that contains 6 independent linear combinations of the spatial derivatives of the displacement field. Strain is a purely geometrical quantity and has no dimensions.

Measurement of differential deformations involves a spatial scale (the length of the measurement tube).

What is the meaning of the various elements of the strain tensor?

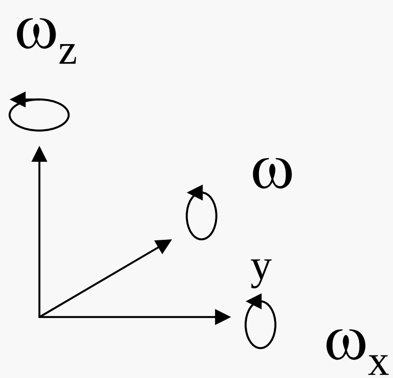
Seismic observables
strain

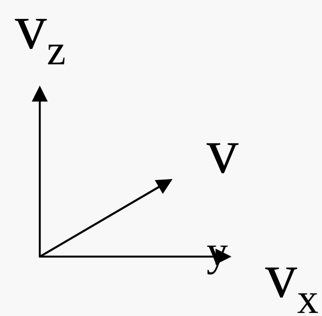
Strain components (2-D)

$$\varepsilon_{ij} = \begin{bmatrix} \dfrac{\partial u_x}{\partial x} & \dfrac{1}{2}\left(\dfrac{\partial u_x}{\partial y} + \dfrac{\partial u_y}{\partial x}\right) \\ \dfrac{1}{2}\left(\dfrac{\partial u_x}{\partial y} + \dfrac{\partial u_y}{\partial x}\right) & \dfrac{\partial u_y}{\partial y} \end{bmatrix}$$

Seismic observables
rotations

$$\begin{pmatrix} \omega_x \\ \omega_y \\ \omega_z \end{pmatrix} = \frac{1}{2}\nabla \times \underline{\mathbf{v}} = \frac{1}{2}\begin{pmatrix} \partial_y v_z - \partial_z v_y \\ \partial_z v_x - \partial_x v_z \\ \partial_x v_y - \partial_y v_x \end{pmatrix}$$





Rotation rate

Rotation sensor

Ground velocity

Seismometer

Seismic observables
rotations

- Rotation is a vectorial quantity with three independent components
- At the Earth‘s surface rotation and tilt are the same
- Rotational motion amplitudes are expected in the range of $10^{-9} – 10^{-3}$ rad/s
- Rotations are only now being recorded
- Rotations are likely to contribute to structural damage

Seismic observables
tilt

Tilt is the angle of the surface normal to the local vertical. In other words, it is rotation around two horizontal axes. Any P, SV or Rayleigh wave type in layered isotropic media leads to tilt at the Earth‘s free surface. In 3-D anisotropic media all parts of the seismic wave field may produce tilts.

$$\Theta(x,t) = \partial_x u_z$$

Other causes of tilt:

- Earth tides
- Atmospheric pressure changes
- Soil deformation (water content)
- Temperature effects
- Mass movements (lawn mower, trucks, land slides)

Summary Observables

- Translations are the most fundamental and most widely observed quantity (standard seismometers)
- Translation sensors are sensitive to rotations!
- Tilt measurements are sensitive to translations!
- Really we should be measuring all 12 quantities at each point (cool things can be done with collocated observations of translation, strains and rotations)

Questions

- How many independent motions are there descriptive of the motion of a measurement point (deformable, undeformable media)?
- Describe measurement principles for the three main observable types!
- What is the role of the time derivative of translational measurements? Domains of application?
- Compare qualitatively displacement, velocity, and acceleration of an earthquake seismogram!
- What is the advantage of having an array of closely spaced seismometers?
- What is the frequency and amplitude range of earthquake-induced seismic observations?