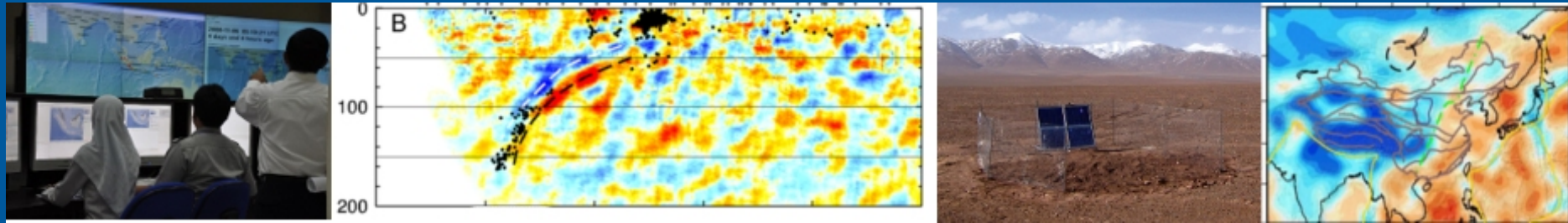


Seismology in 21st century From seismic stations to a professional Data Center



**Javier Quinteros, Angelo Strollo
and the GEOFON team**

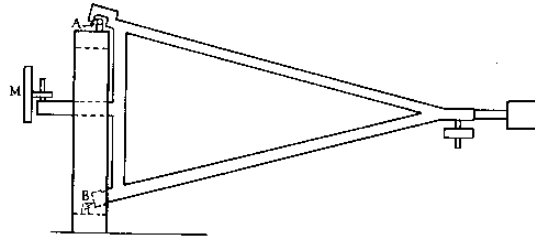
Outline

- The GEOFON Programm
- GEOFON Virtual Network
- Earthquake Monitoring
- Tsunami Early Warning System
- EIDA: A successful initiative of a virtual DC
- Latest developments: what can we expect in the future?

The first teleseismic recording



E. von Rebeur-Papst 1892



One of the first known recordings of a distant earthquake, obtained with von Rebeur's horizontal pendulum (*Nature*, **40**, 1889, p. 295). Two of these pendulums, located in Potsdam and Wilhelmshaven, recorded a large earthquake on **April 17, 1889**. The earthquake had been felt in Japan about an hour before it was recorded in Germany.

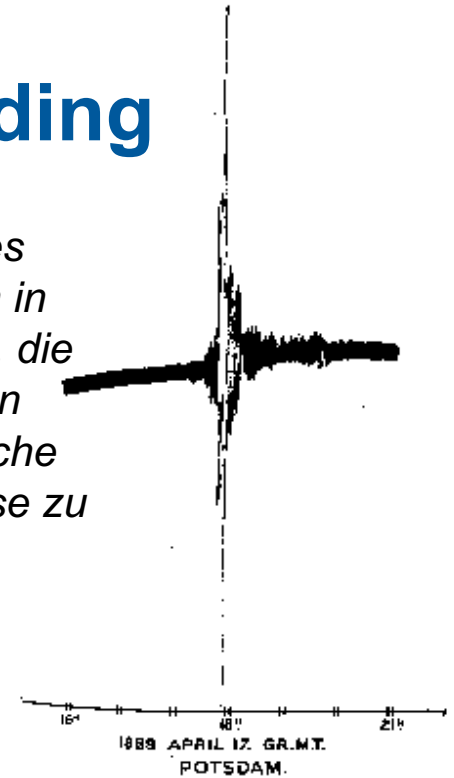
The first teleseismic recording



“Wir wollen in erster Linie die Gründung eines internationalen Netzes von Erdbebenstationen in Anregung bringen, dessen Aufgabe es sein soll, die Ausbreitung der von großen Erdbebencentren ausgehenden Bewegungen auf der Erdoberfläche und durch den Erdkörper in systematischer Weise zu beobachten.”

- Ernst von Rebeur-Paschwitz -

E. von Rebeur-Paschwitz 1897



- 1992 **GEOFON foundation. Permanent seismic Network + Data archive**
- 1999 **SeedLink real-time data exchange**
- 2004 **Start of Global Earthquake Monitoring**
- 2004-06 **ArcLink (WebDC) virtual data archive**
- 2005-10 **SeisComP3 and improved Global EQ Monitoring**

- 2010 **New GEOFON concept: Permanent and Virtual Networks, Global EQ Monitoring, Rapid Earthquake Information, European data archive, Networking and Capacity Building**

The GEOFON mandate

GEOFON aims at providing scientific infrastructure in the form of **global seismic network, data archival and monitoring facilities** to facilitate cooperation in seismological research leading to a better understanding of our complex system Earth.

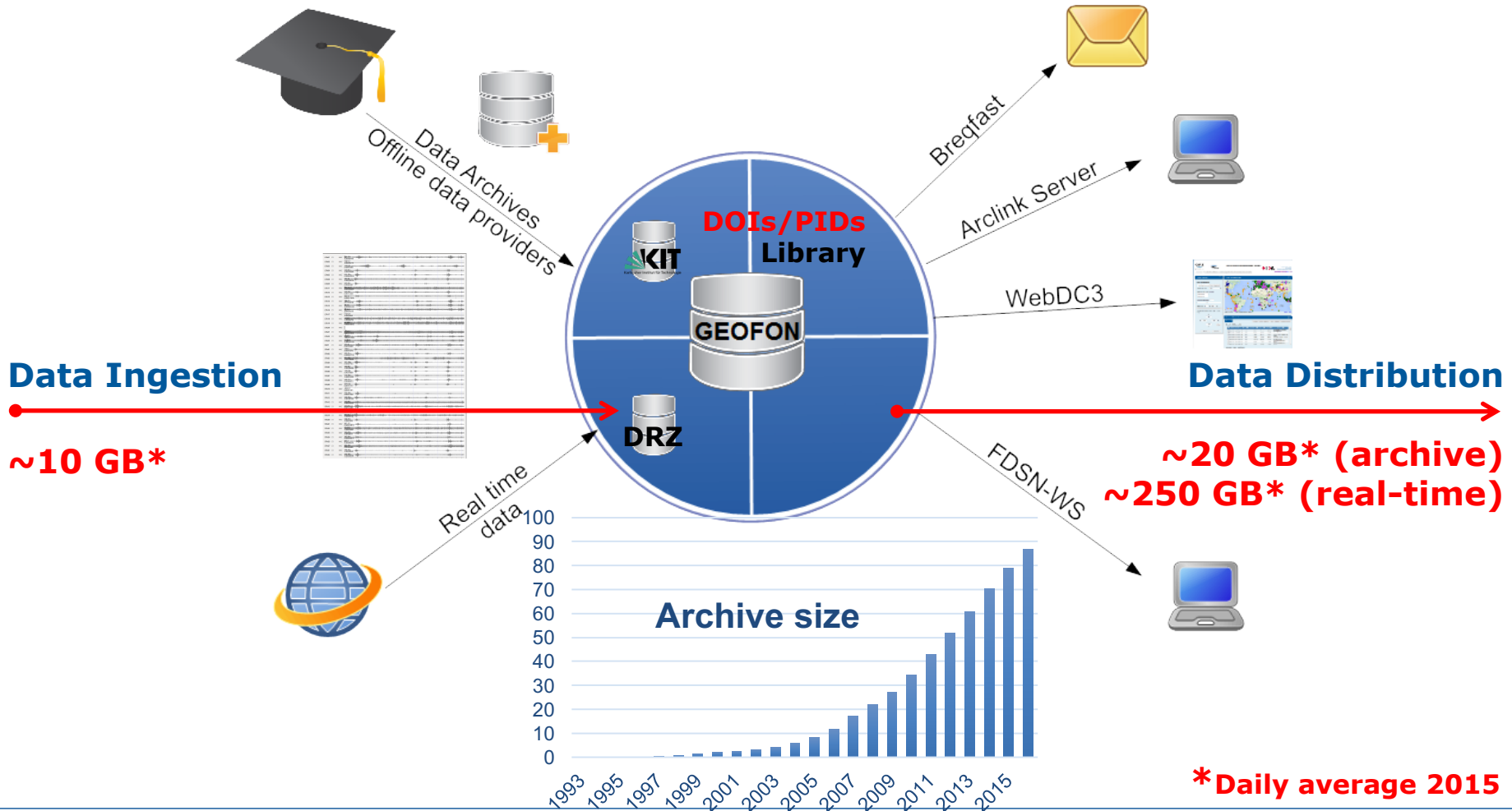
It pursues these aims by operating and maintaining a global network of permanent broadband stations in cooperation with local partners, facilitating real time access to data from this network and those of many partner networks and plate boundary observatories, providing a permanent and secure archive for seismological data.

The GEOFON mandate

Using real-time data streams, GEOFON determines rapid automatic location estimates for all globally recorded earthquakes and most regional ones, and provides manually revised solutions for the largest earthquakes with minimal delay. This service provides basic rapid earthquake information to earthquake and tsunami warning centers worldwide, governmental agencies, disaster management teams, news media and scientists at the GFZ and elsewhere.

GFZ scientific infrastructure

The GFZ seismological data archive: +75 TB, +3000 stations



Data Ingestion

~10 GB*

Data Distribution

**~20 GB* (archive)
~250 GB* (real-time)**

***Daily average 2015**

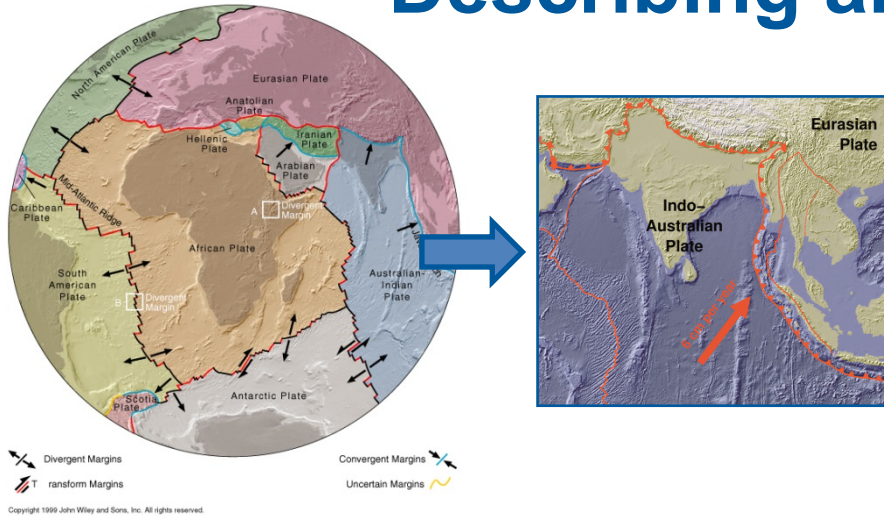
<http://geofon.gfz-potsdam.de/waveform>
<http://eida.gfz-potsdam.de>

GEOFON in numbers

- **82** GE stations + **40** cooperated stations (affiliated)
- **~900** stations acquired and processed in real-time
- **~100** TB/year real-time data distributed via seedlink
- **~3000** stations **~75** TB in archive today
- **~4.5** Million customized (successful) requests/year
- **+200.000** notifications/year via e-mail or SMS
- **~6** TB/year of data shipped from archive
- **~6500** published events in a year
- **~1500** published moment tensors in a year
- **~28000** unique visitors/day to web pages (yearly avg.)
- **~370** SeisComP3 free non-commercial licenses

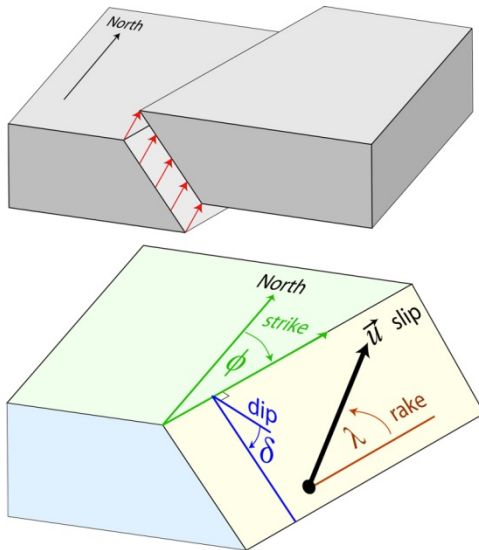
GEOFON data, products and software are open!

Describing an Earthquake



Tectonic earthquakes are caused by slippage along fractures (faults).

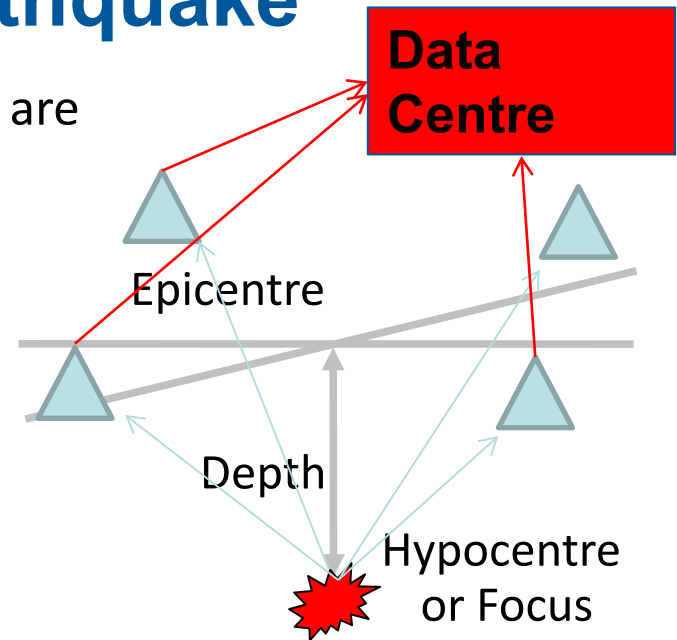
As slip along the faults occurs, energy is released which travels in the Earth interior in the form of seismic waves...



Describing an Earthquake

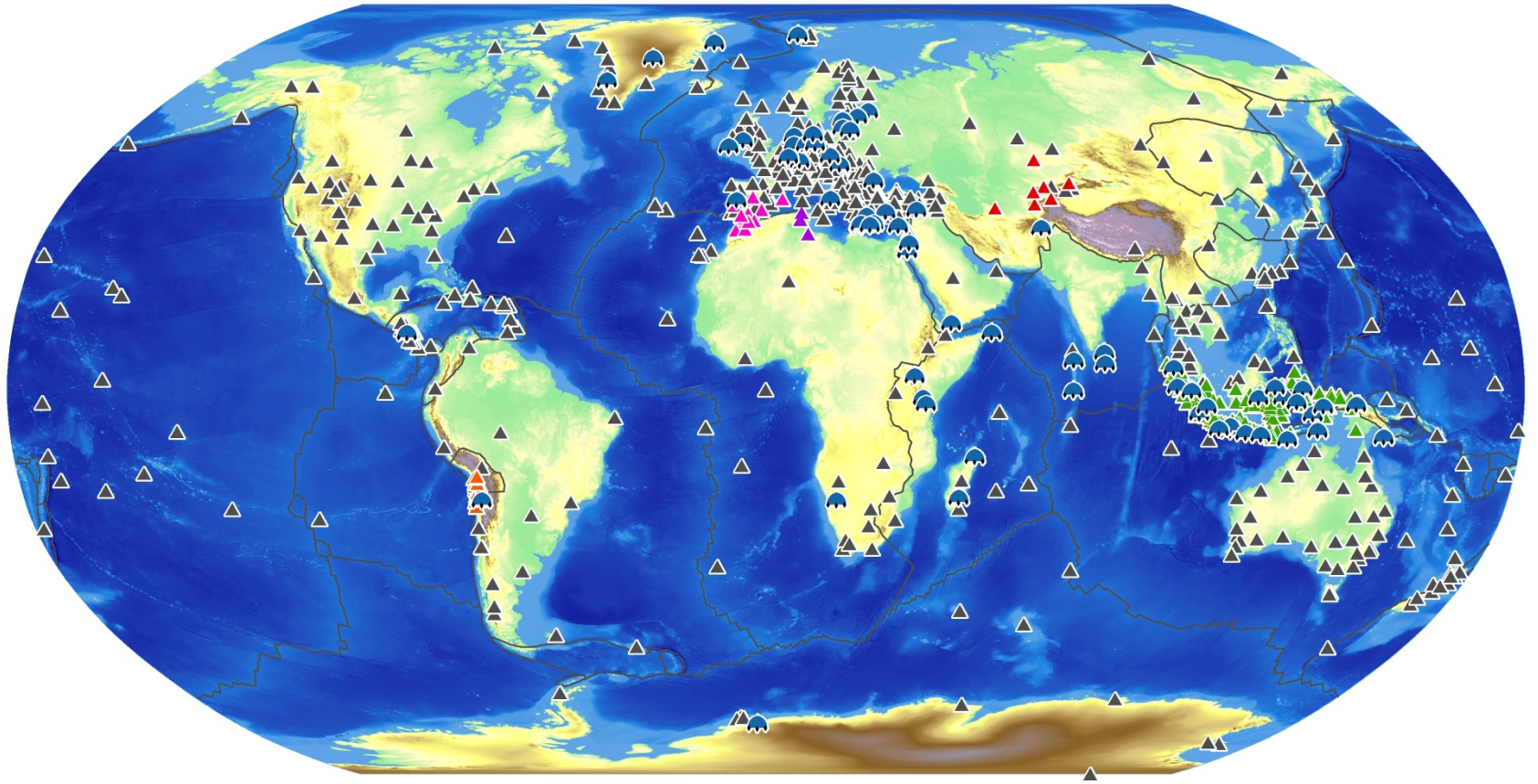
An earthquake's most fundamental characteristics are

- **Location**
 - **Hypocentre** or **focus**: Geographical location of an earthquake i.e. its epicentre and depth.
 - **Epicentre**: Point on the Earth's surface above the hypocentre.
- **Origin time**
 - Start time of the rupture.
- **Focal mechanisms**
 - **Fault geometry**: Geometric orientation of an earthquake's fault, dependent upon the local geology/tectonics.
 - **First motion**: Identifiable from the seismograms, used to identify the fault geometry
- **Size**
 - **Magnitude** or **moment**: Value describing the strength of an earthquake.



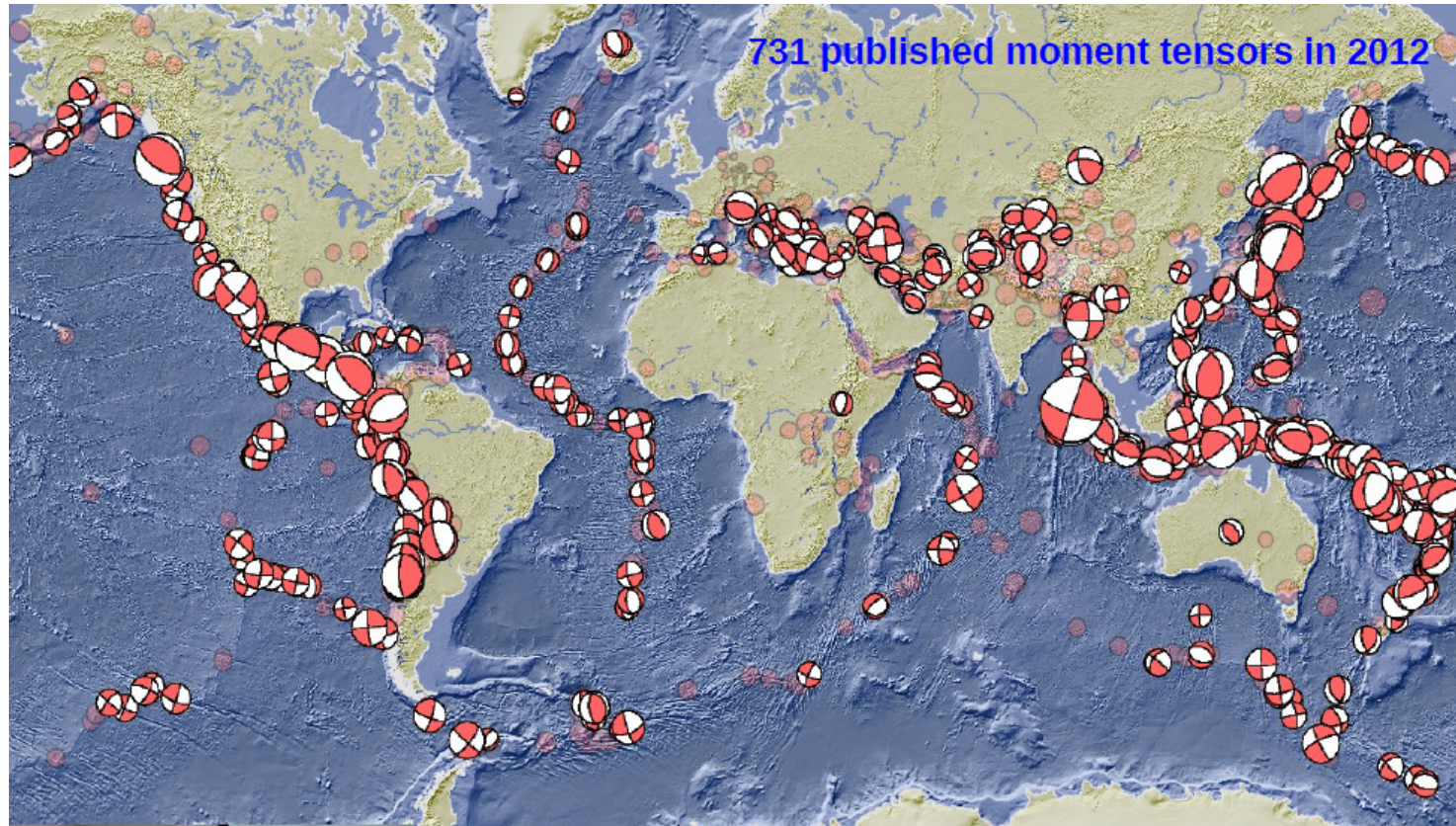
The GE global seismic network and GEVN

~82 GE stations, ~40 GFZ stations, ~900 stations for GEVN



Global earthquake monitoring

Since January 2011 also MT solutions for events larger than M 5 (depending on data quality)
~6500 events and ~1500 MT solutions published per year



Earthquake Monitoring

Rapid Earthquake Information

GFZ Helmholtz-Zentrum Potsdam

GEOFON Program

Automatic GEOFON Global Seismic Monitor

The events displayed occurred within the last 24 hours / 1.4 days / 4.14 days .

Most recent large event:
Pakistan
 Magnitude: **7.6 (Mw)**
 Origin time: **2013-09-24 11:29:53 UTC**
 Epicenter: **65.47°E 27.03°N**
 Depth: **42 km**
 Location status: **manually revised**

See also:

- The specific page for this event
- The complete list of automatic GEOFON alerts

Last updated 2013-09-24 18:02:15 UTC

GFZ Helmholtz-Zentrum Potsdam

GEOFON Program

Mission | Earthquake Info | Waveform Access | Software | Contact | Home

This real-time bulletin is a product of the GEOFON Extended Virtual Network (GEVN) and credit belongs to all involved institutions!

Disclaimer: Unless revised by a geophysicist, automatically determined earthquake locations may be erroneous!

This bulletin is customizable and also available as **RSS** news feed.

New search FAQ

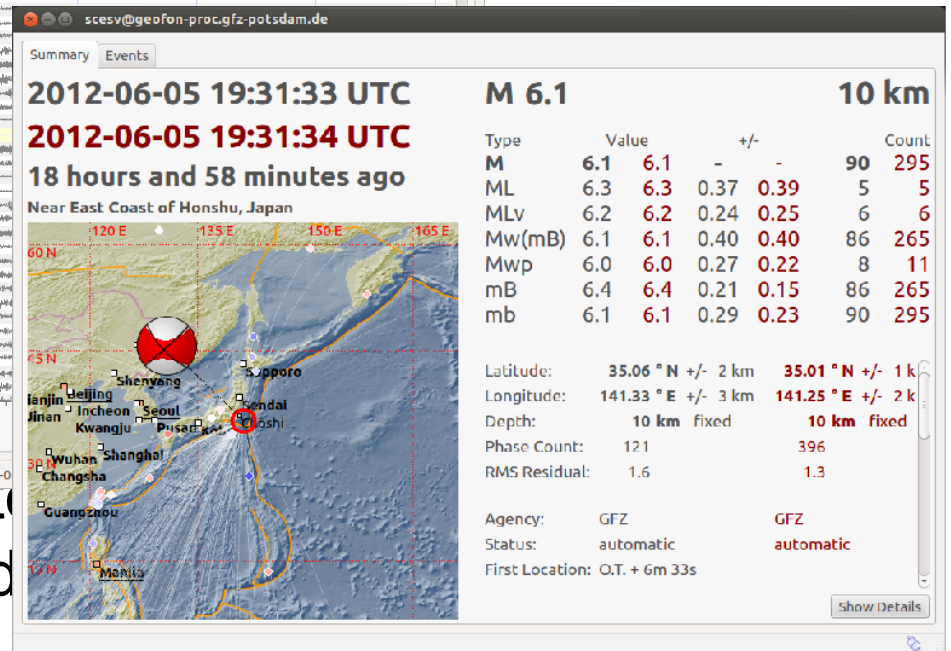
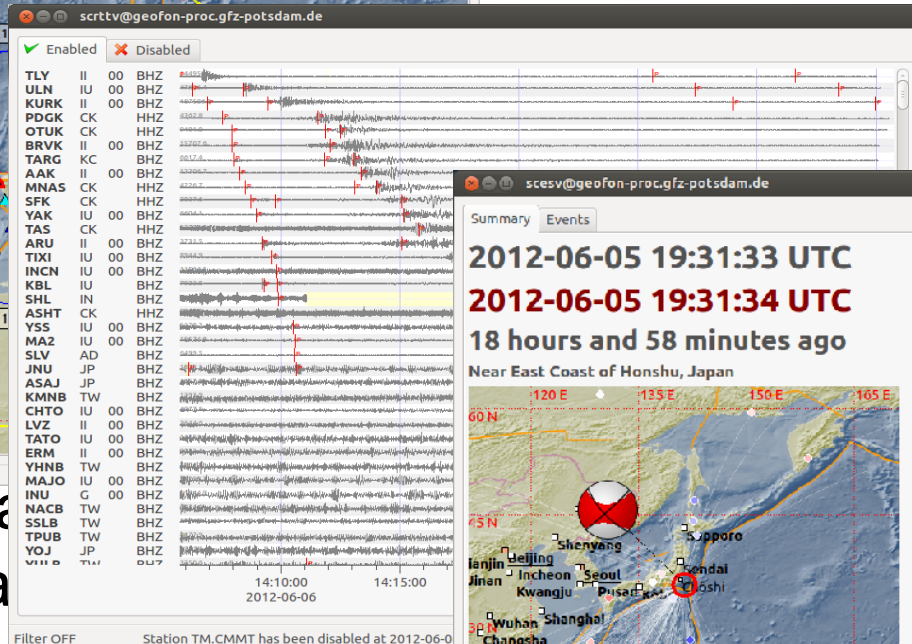
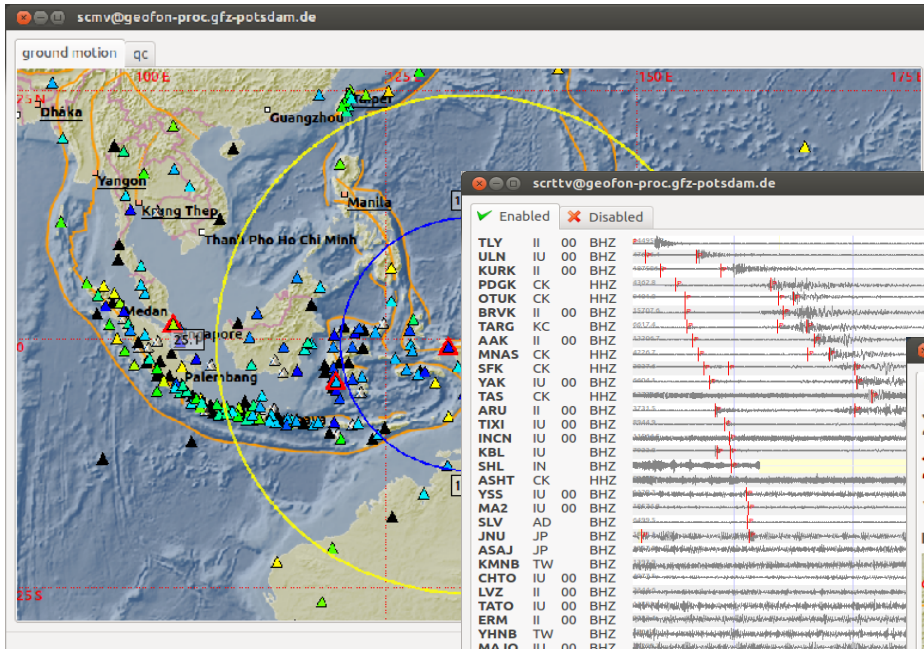
Older events	Origin Time UTC	Mag	Latitude degrees	Longitude degrees	Depth km	A	Region Name
	2013-09-24 17:20:16	5.4	27.24°N	65.53°E	10	A	Pakistan
	2013-09-24 15:39:29	4.9	67.62°N	142.88°E	10	M	Eastern Siberia, Russia
	2013-09-24 15:12:22	4.8	27.24°N	65.48°E	10	M	Pakistan
	2013-09-24 14:38:42	5.0	32.51°S	71.69°W	37	M	Near Coast of Central Chile
	2013-09-24 14:08:34	5.3	27.63°N	65.62°E	10	A	Pakistan
	2013-09-24 14:07:41	4.7	27.85°N	140.52°E	78	M	Bonin Islands, Japan Region
	2013-09-24 13:53:13	3.2	47.64°N	17.23°E	10	M	Hungary
	2013-09-24 13:44:16	4.7	32.49°N	141.21°E	32	M	Southeast of Honshu, Japan
	2013-09-24 13:01:44	5.6	27.48°N	65.72°E	37	M	Pakistan
	2013-09-24 12:42:15	5.2	27.48°N	65.73°E	41	M	Pakistan
	2013-09-24 12:07:12	5.0	27.41°N	65.75°E	51	M	Pakistan
	2013-09-24 11:36:38	5.9	27.29°N	65.68°E	15	M	Pakistan
	2013-09-24 11:29:53	7.6	27.03°N	65.47°E	42	MT	Pakistan
	2013-09-24 07:22:54	5.5	7.47°N	59.57°E	10	MT	Carlsberg Ridge
	2013-09-24 04:18:23	4.0	36.43°N	26.80°E	114	M	Dodecanese Islands, Greece
	2013-09-24 03:41:54	4.9	8.47°N	82.75°W	10	A	Panama-Costa Rica Border Region
	2013-09-24 00:21:50	4.0	40.32°N	0.76°E	10	M	Spain
	2013-09-23 20:01:17	4.9	5.66°S	150.44°E	79	M	New Britain Region, PNG
	2013-09-23 17:28:07	5.4	4.96°S	153.61°E	72	MT	New Ireland Region, PNG
	2013-09-23 16:40:29	4.8	28.35°N	138.72°E	525	M	Bonin Islands, Japan Region
	2013-09-23 15:12:57	4.8	9.96°S	115.94°E	46	C	South of Bali, Indonesia
	2013-09-23 14:12:16	4.8	5.40°S	152.43°E	20	M	New Britain Region, PNG
	2013-09-23 13:59:00	4.5	5.77°S	147.46°E	108	M	Eastern New Guinea Reg., PNG
	2013-09-23 13:41:33	4.4	7.79°S	108.08°E	89	M	Java, Indonesia
	2013-09-23 13:02:28	4.5	33.48°S	72.12°W	19	M	Off Coast of Central Chile
	2013-09-23 11:22:48	5.1	0.70°S	124.93°E	63	A	Southern Molucca Sea
	2013-09-23 07:55:53	4.6	1.57°S	77.92°W	163	M	Ecuador
	2013-09-23 02:54:13	4.3	16.25°S	73.26°W	85	M	Near Coast of Peru
	2013-09-23 01:41:36	4.5	32.91°N	48.19°E	10	M	Western Iran
	2013-09-22 23:05:37	4.6	48.57°N	154.68°E	58	M	Kuril Islands
	2013-09-22 21:06:35	4.6	13.25°S	167.16°E	208	M	Vanuatu Islands
	2013-09-22 19:30:37	5.2	12.26°N	143.77°E	27	C	South of Mariana Islands
	2013-09-22 18:10:29	4.6	6.29°S	130.02°E	173	M	Banda Sea
	2013-09-22 16:55:08	4.9	12.28°N	143.89°E	24	M	South of Mariana Islands
	2013-09-22 15:56:53	4.5	3.58°S	129.99°E	10	M	Buru, Indonesia
	2013-09-22 15:26:47	4.6	3.25°S	129.99°E	20	M	Buru, Indonesia
	2013-09-22 14:41:21	4.7	9.77°S	86.14°W	10	M	Off Coast of Costa Rica
	2013-09-22 10:36:36	4.2	0.27°S	96.18°E	5	M	Southern Sumatra, Indonesia
	2013-09-22 08:41:35	4.8	7.17°S	80.67°W	23	M	Off Coast of Northern Peru
	2013-09-22 08:32:02	4.8	5.11°N	94.09°E	15	M	Northern Sumatra, Indonesia

© Helmholtz-Zentrum Potsdam - Deutsches Geoforschungszentrum GFZ

Two of the most popular GFZ web pages!
 ~28.000 unique visitors / day (yearly average)

<http://geofon.gfz-potsdam.de/eqinfo/seismon/globmon.php>
<http://geofon.gfz-potsdam.de/eqinfo/list.php>

SeisComP3 software Architecture

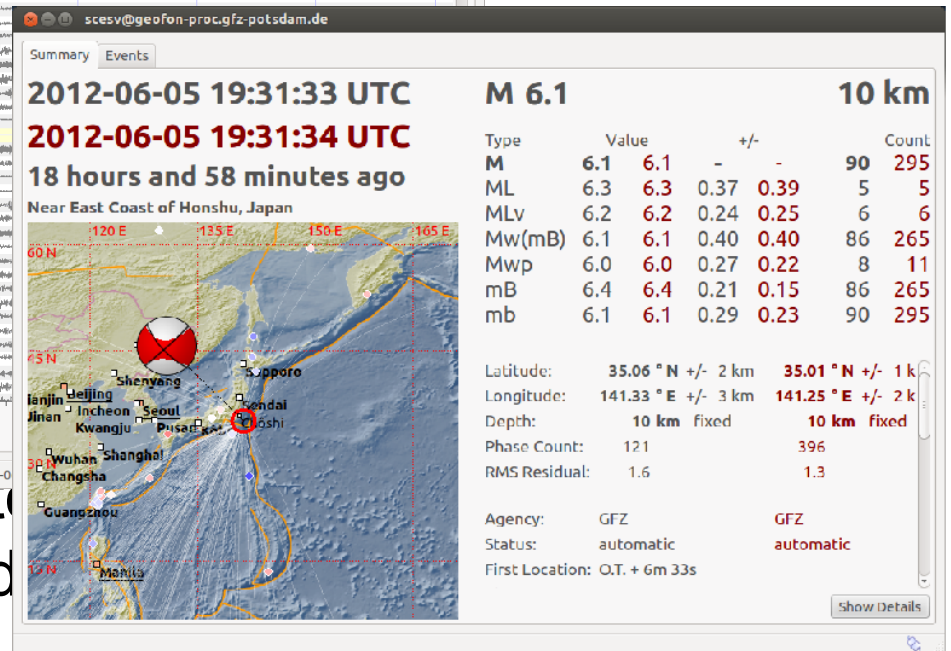
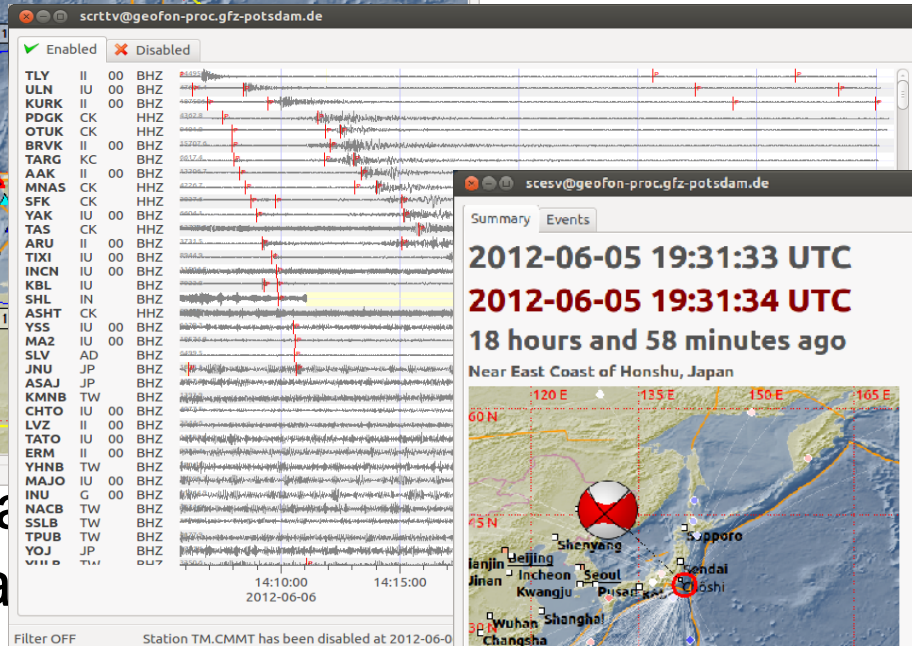
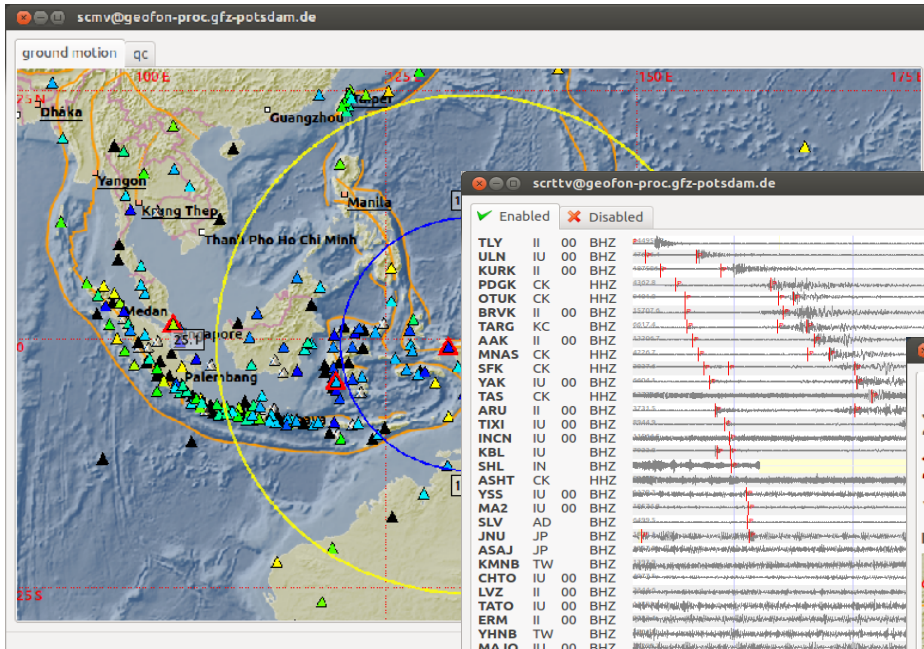


ars
enter

(national and tsunami)

- Its data transmission protocol is a world-wide standard

SeisComP3 software Architecture

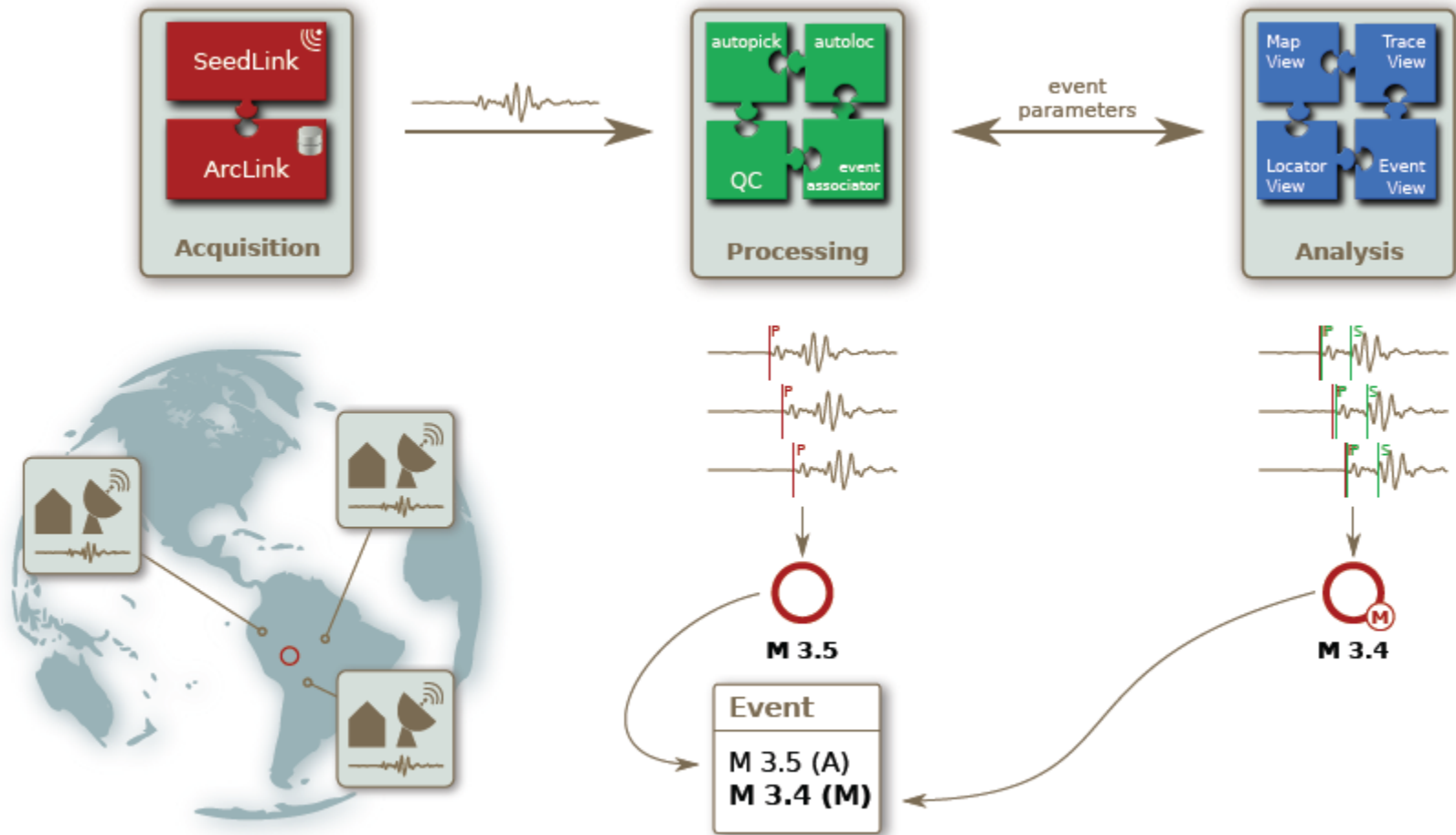


ars
center

(national and tsunami)

- Its data transmission protocol is a world-wide standard

SeisComP3 software Architecture



Courtesy of B. Weber and J. Becker

The 2014 Iquique Earthquake

From rapid event information to scientific activities through HART deployment and data curation

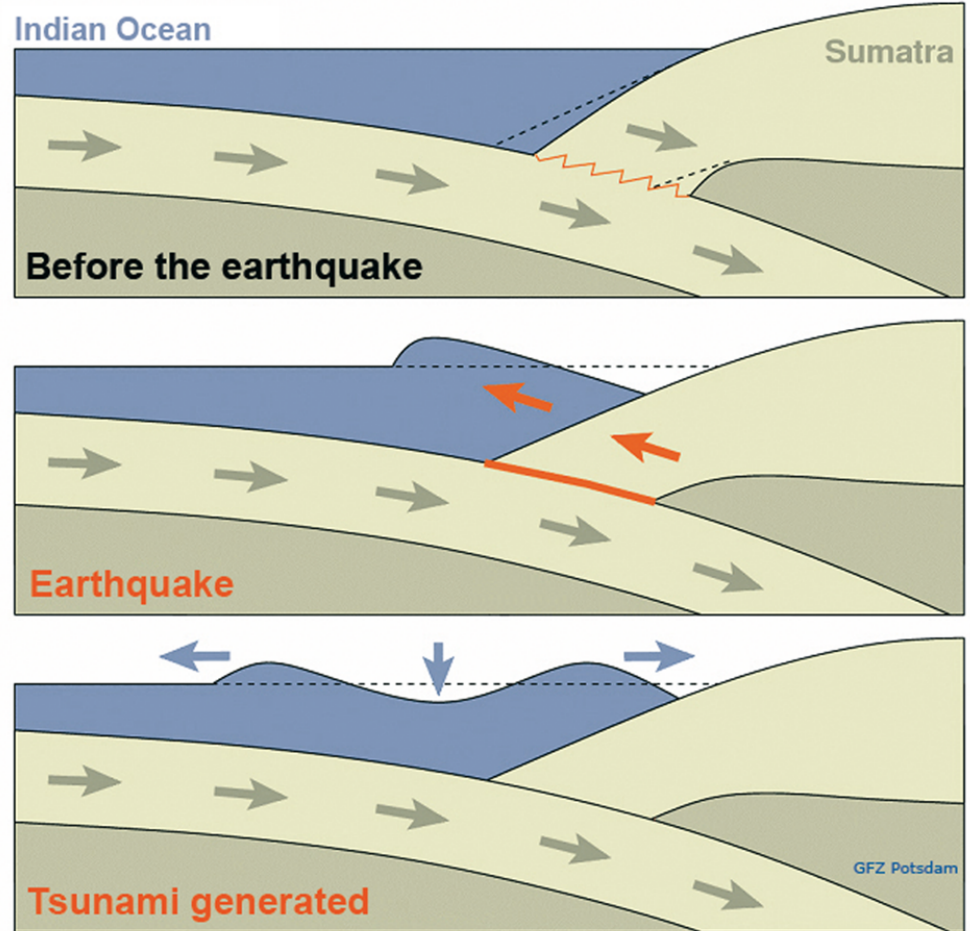
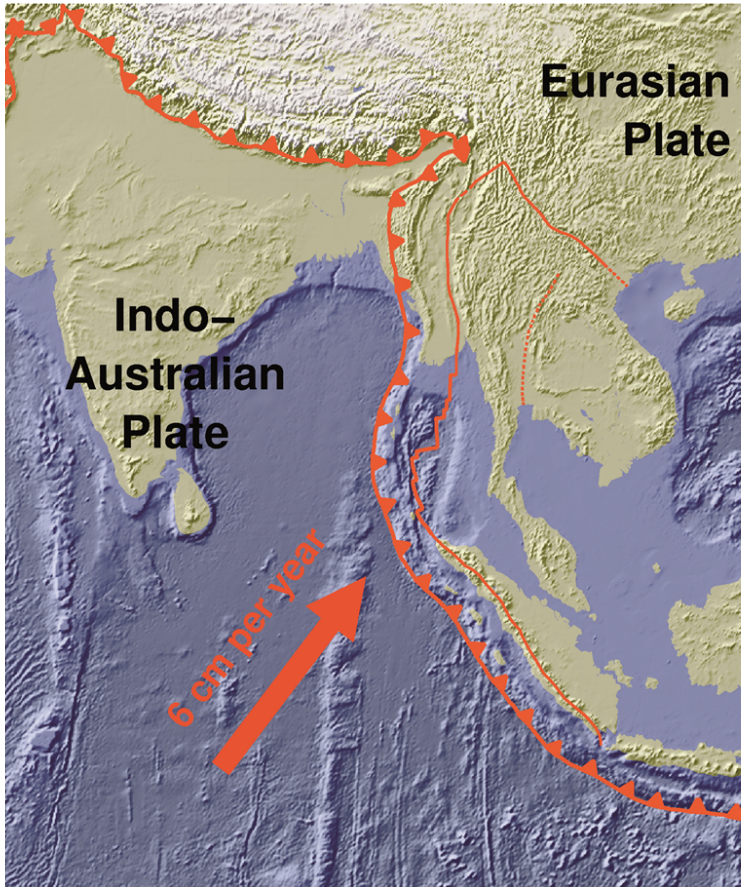
Time

- 2014.04.01 23:46:49 UTC Event OT
- + 11 minutes - 1st automatic solution M 7.9
- + 55 minutes - 1st MT manual solution Mw 8.0
- + 1 day - MT manual review Mw 8.1
- + 1 day - Event special page (DOI)
- + 1 day - HART Coordination meeting
- + 10 days - Deploying HART instruments
- + 5 months - Nature paper and more
- + 12 months - DFG proposal submission
- + 16 months - HART data collected/archived
- + 18 months - DFG proposal accepted

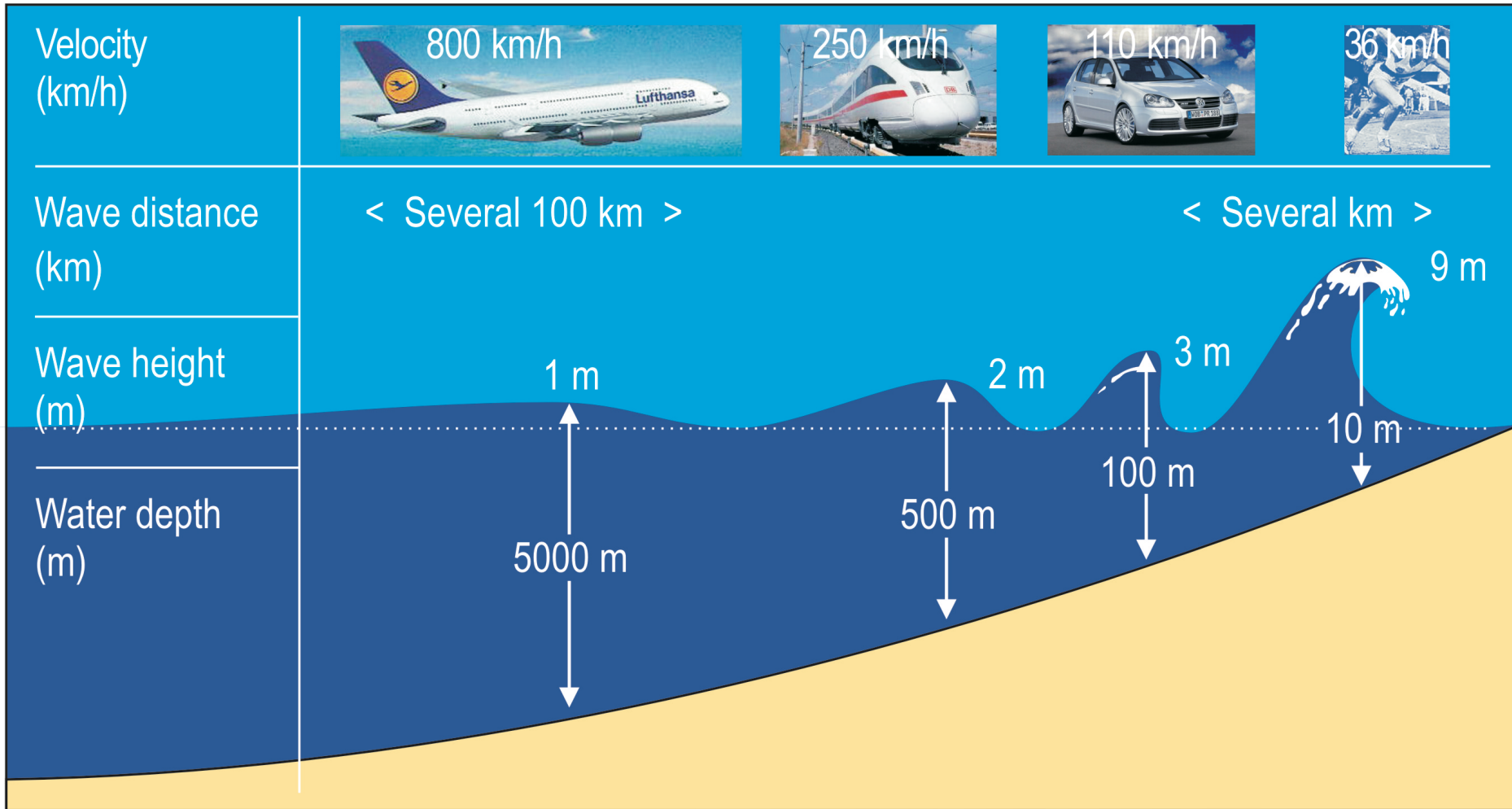


Tsunami Early Warning System

Tsunami generation



Tsunami propagation



The 26th December 2004 - Banda Aceh

Pre-Disaster-Image

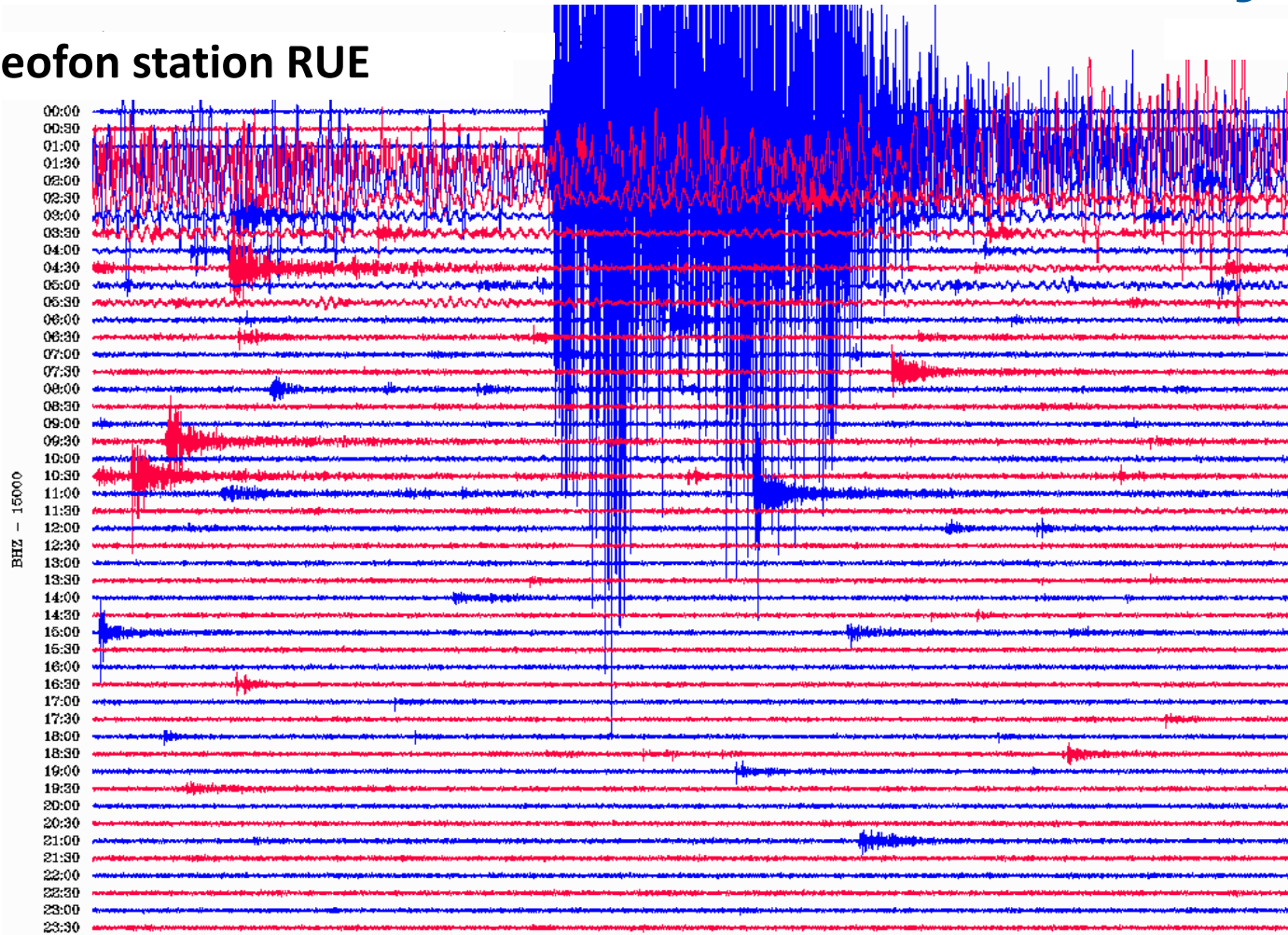


Post-Disaster-Image



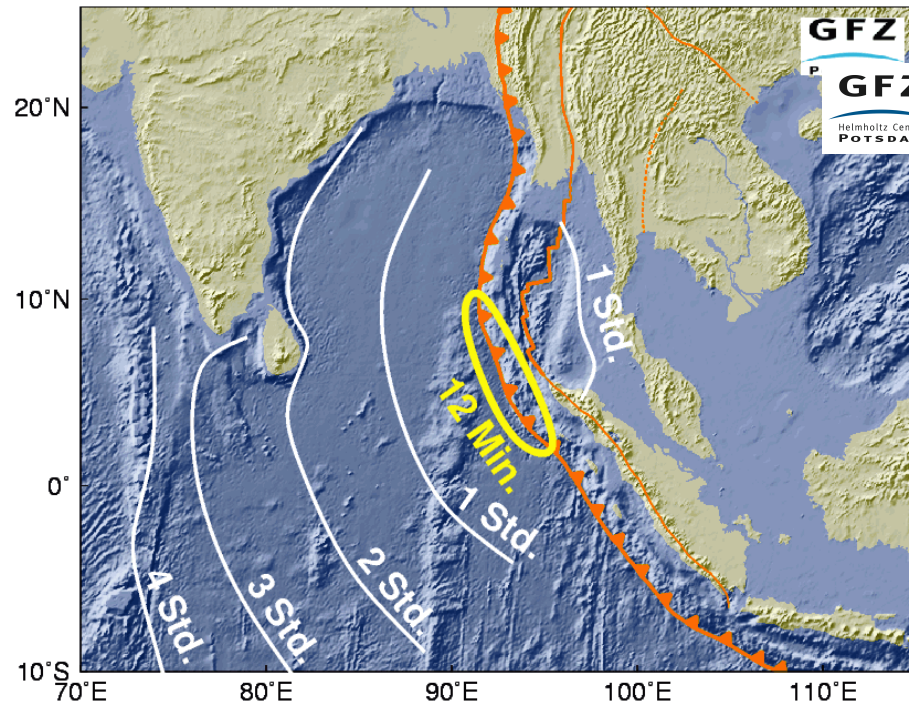
The 26th December 2004 - Germany

Geofon station RUE



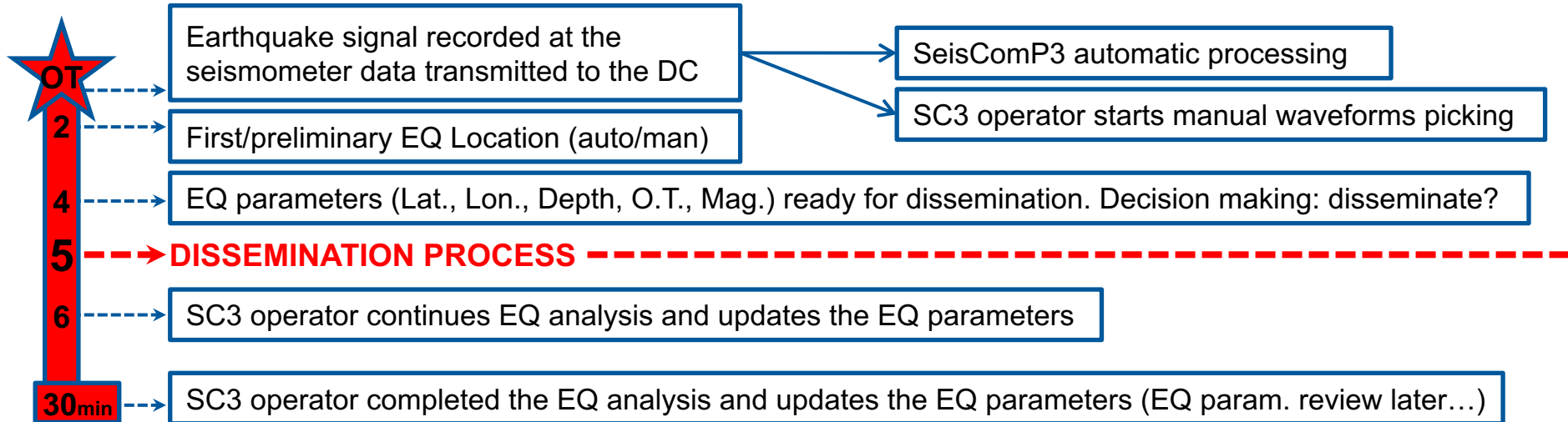
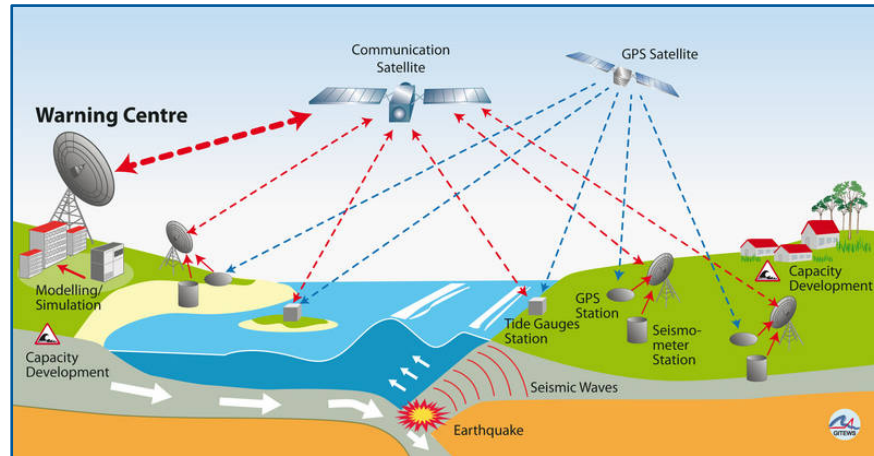
The Challenge, Tsunami Warning for Indonesia

- EQ sources very close to affected coasts
- Tsunami travel time 20 - 40 minutes



- Short tsunami travel times
require tsunami warning within ≈ 5 minutes

The Challenge, Tsunami Warning for Indonesia



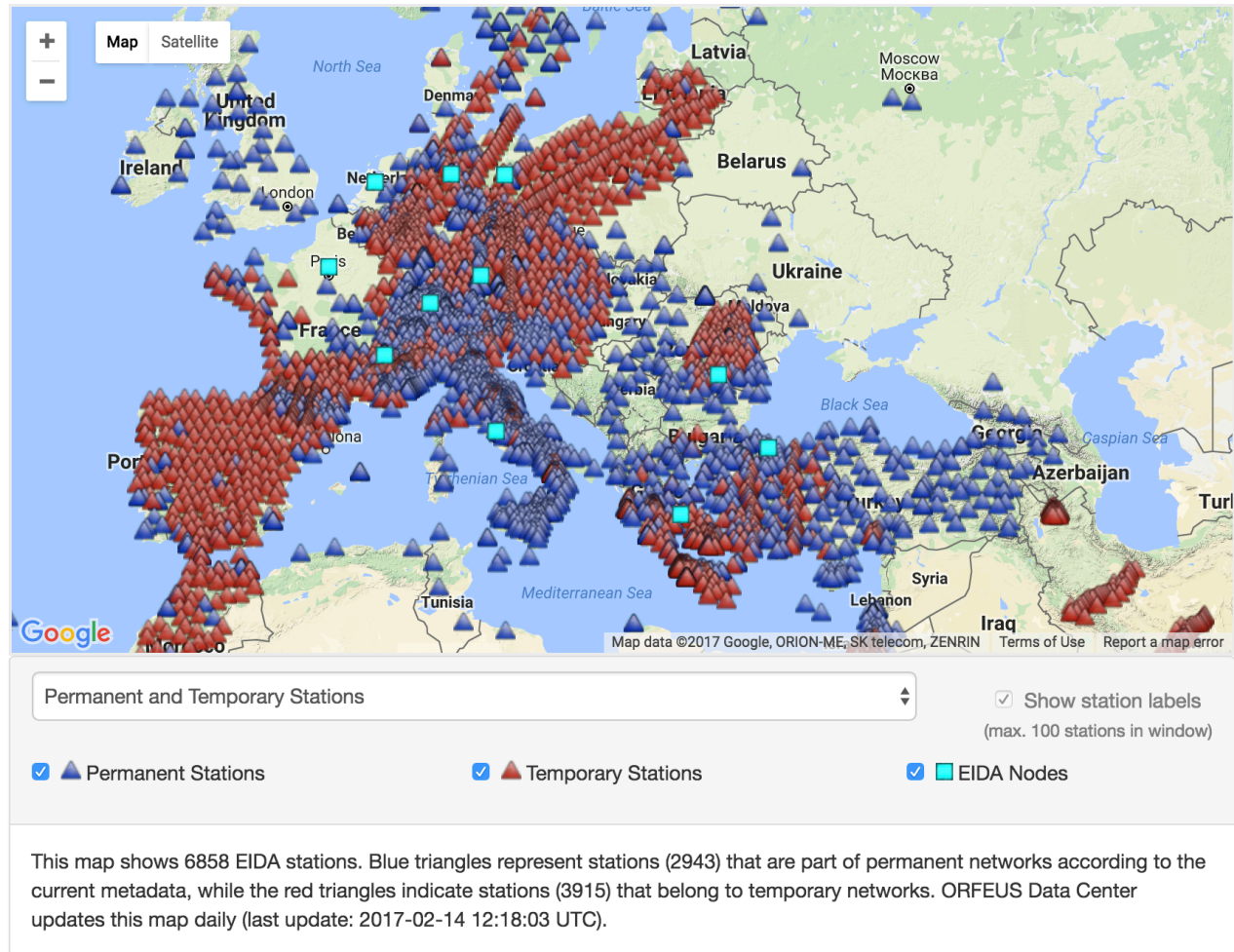
Monitoring room at Jakarta



From an isolated archive to an European Federation (EIDA/ORFEUS)

EIDA within ORFEUS

Safe, persistent archival and dissemination of seismic waveform data collected by European datacenters via distributed archives.



EIDA within ORFEUS

- Protocols to share data
 - Arclink protocol
- Synchronization of metadata
 - Daily
- Clients/tools development
 - SeisComP3
- Statistics
- Routing Table (maintenance)
- Common policies for f.i. data curation



Seismic Waveform Data

How to get waveforms and metadata: WebDC3 portal

The screenshot displays the WebDC3 portal interface, which is used for accessing seismic waveform data from the GEOFON and EIDA archives. The interface is organized into several sections:

- Header:** Features the logos for GFZ (Helmholtz-Zentrum Potsdam) and GEOFON, the text "Access to GEOFON and EIDA Data Archives", the EIDA logo, and the Helmholtz-Zentrum Potsdam Deutsches GeoForschungszentrum logo. Navigation links include "Explore events", "Explore stations", "Submit request", "Download data", and "View console". A link for "OLD webdc.eu portal PDF Help" is also present.
- Events Controls:** A sidebar panel containing:
 - Event Information:** Includes a "Catalog Services" dropdown menu set to "User Supplied" and "GFZ".
 - Date Interval:** Set to "2014-10-21 to 2014-10-28".
 - Minimum Magnitude:** Set to 3, with a slider below it.
 - Depth:** Set from 0 to 999 km, with a slider below it.
 - Coordinates:** Includes input fields for latitude (N/S) and longitude (W/E). The latitude is set to 90 N and longitude to -180 W. A "Clear" button is available.
 - Buttons:** "Reset" and "Search" buttons are located at the bottom of the sidebar.
- Event and Station Map:** A map showing the global distribution of seismic events and stations. The map includes labels for major regions and oceans (North Atlantic Ocean, South Atlantic Ocean, Indian Ocean). A legend and help link are provided.
- Event and Station List:** A section for displaying the results of the search, currently empty.

At the bottom of the interface, the text reads: "WebDC3 Interface © (2013) Helmholtz-Zentrum Potsdam - Deutsches GeoForschungszentrum GFZ".

<http://eida.gfz-potsdam.de>

FDSN Web Service Specifications

Version 1.1
2013/10/25

Purpose

To specify web service interfaces for the exchange of time series data, related metadata, event parameter and other data within the context of the International Federation of Digital Seismograph Networks (FDSN). The intention is to provide a specification that, when implemented at different FDSN data centers, can be used interchangeably by the same client software. The specification defines service names, query parameters and expected results.

List of service interfaces

- dataselect** – returns raw time series data in FDSN miniSEED format
- station** – returns metadata in FDSN StationXML and alternate formats
- event** – returns parametric data for events in QuakeML and alternate formats

Common service characteristics

Versioning

The services are versioned according the following three-digit (x.y.z) pattern:

SpecMajor.SpecMinor.Implementation

Where the fields have the following meaning:

SpecMajor: The major specification version, all implementations sharing this *SpecMajor* value will be backwards compatible with all prior releases. Values start at 1.

SpecMinor: The minor specification version, incremented when optional parameters or behavior is added to the previous specification but backwards compatibility is maintained with the previous major versions, i.e. all 1.# service versions will be compatible with version 1.0. Values start at 0.

Implementation: The implementation version, an integer identifier specific to the data center implementation. Useful to track service updates for bug fixes, etc. but with no implication on conformance to the specification.

Together the *SpecMajor* and *SpecMinor* versions imply a minimum expected behavior of a given service. This versioning scheme allows clients to expect specific behavior based on the *SpecMajor* version, while allowing the FDSN to extend the services with optional parameters while maintaining backwards compatibility. Each version number is service specific, there is no implication that *SpecMajor* version numbers across services are related.

EIDA Next Generation Software

- More than just data and federated archive
- Coordination of data holdings and software/strategic developments
- Provides quality control of data/metadata
- Help define seismological center best practices for ORFEUS community

Back to EIDA home EIDA Access to EIDA Data Archives Orfeus

Explore events Explore stations Submit request Download data View console

STATION'S CONTROLS

Station Information
Browse Inventory User Supplied

Networks
Year from 1990 to 2015

Network Type:
All nets

Network Code:
All Networks
* = temporary network; + = restricted access

Stations
By Code By Region By Events

Filter stations by station code:
All Stations

Streams
By Code By Sampling

Choose the desired set of channels:
Use SHIFT and CTRL to extend the list.

BH
LH
HH

Reset Append

EVENT AND STATION MAP

71.78 47.44

Use left SHFT + drag mouse to select regions. Legend Help

EVENT AND STATION LIST

Request: Freeze Delete Stations Save Stations Delete Events

Events (274 events)

Origin Time	Mag.	Type	Lat.	Long.	Depth	Epicen.
2015-06-28T07:18:00	3.6	ml	35.18	53.32	8.0	Northern and Central Iran
2015-06-28T06:58:06	3.1	mb	36.28	-87.51	3.0	Oklahoma
2015-06-28T06:53:07	3.0	mb	36.71	-88.29	5.0	Oklahoma
2015-06-28T04:58:00	3.1	ml	19.18	-64.35	29.0	Virgin Islands
2015-06-28T02:45:06	4.5	mb	8.28	-82.83	10.0	Panama-Costa Rica Border Region
						Near Coast of Central Chile

Stations (5016 stations)

Network	Station	Lat.	Long.	O/R Streams	
18	BUMA	0.69	30.07	0	JHE_HNS_HNZ
18	BURA	0.86	30.17	0	JHE_HNS_HNZ
18	BURA	0.03	29.77	0	JHE_HNS_HNZ

EIDA NG: Why?

Challenges:

- Growth: archive volume, data variability, new nodes, more users, downloads.
- More complex user requirements.

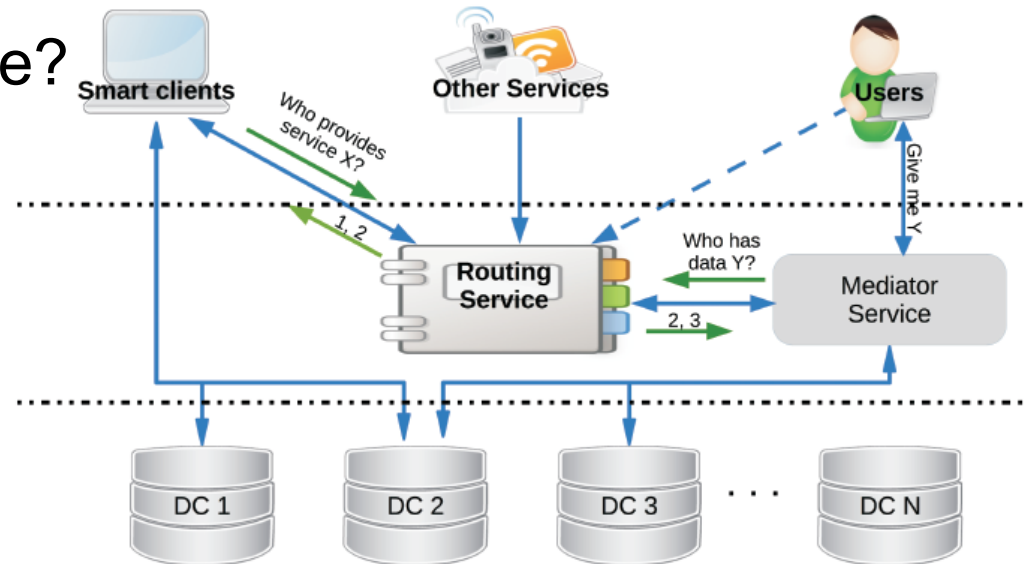
Requirements:

- Scalability: beyond traditional seismology.
- Interoperability / Compliance with standards.
- Extensibility: services can be migrated to other communities.
- Comprehensive handling of restricted datasets.
- Extended search requests.
- Combining QC / SoH information with data requests.
- Data replication and identification: Serving user only the best datasets.

The EIDA Routing Service

What does a routing service do?

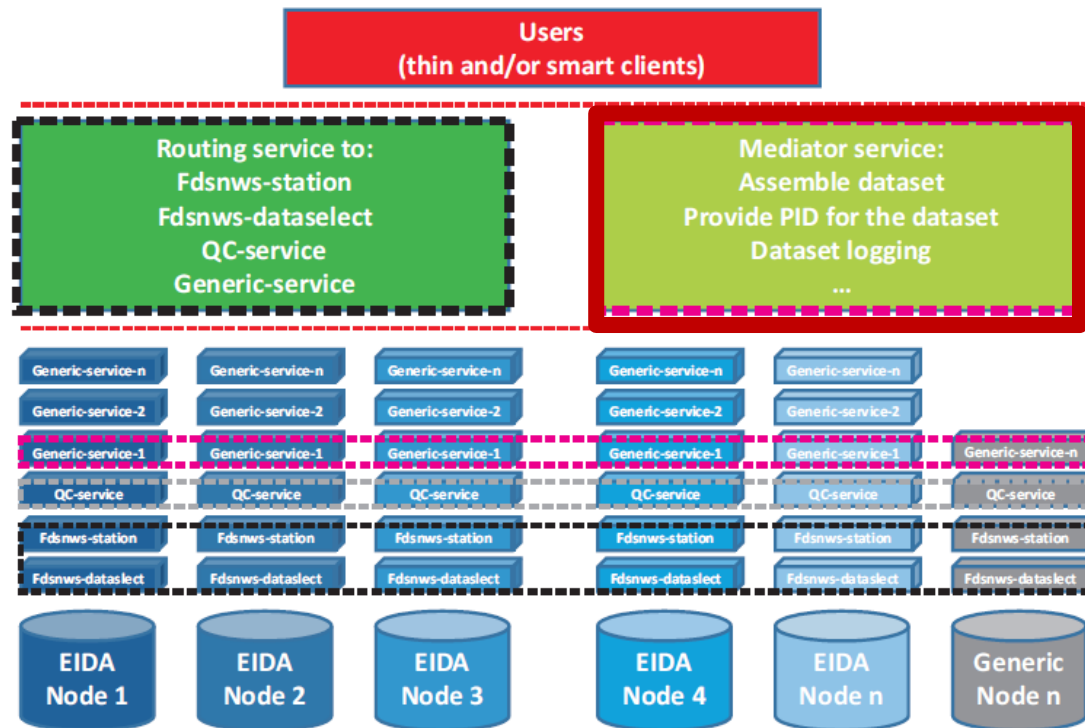
- Provides routing to data (streams)
- Routing to services
- Routing priorities
- Geolocation of data and services
- Contact information
- Can also be deployed as a standalone router to run on the client side to create virtual DCs.



First stable release 10.2014

The EIDA Mediator (implementation phase)

The Mediator will allow users to perform complex/filtered data requests based on a number of parameters available from a number of web services. Initially developed as a server/node side application, afterwards also as a client application.

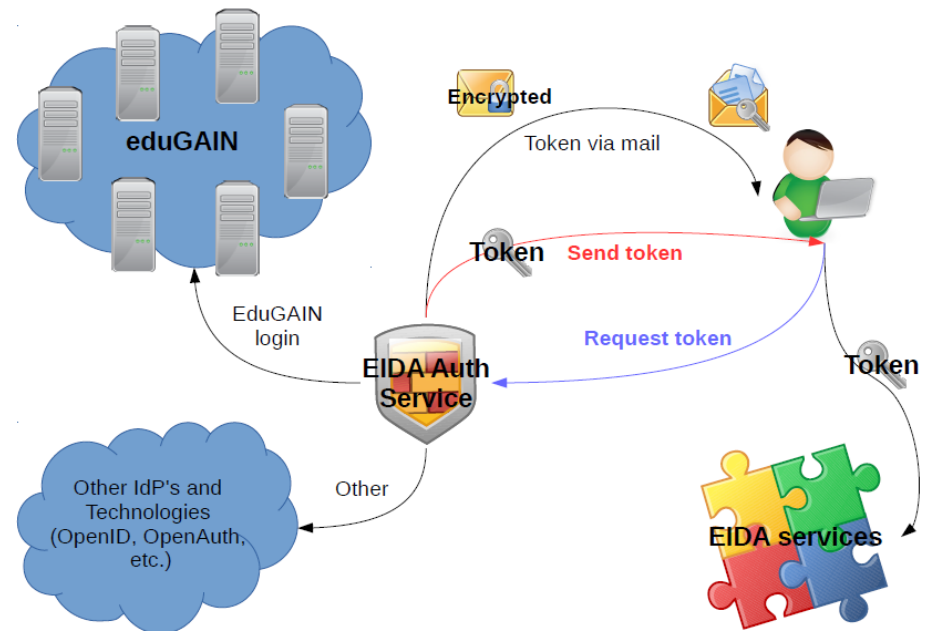
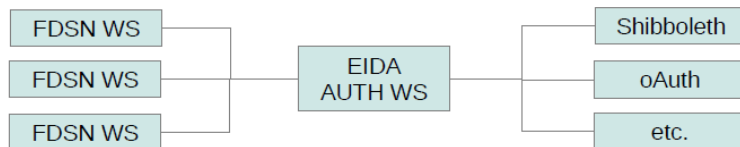


Latest developments and improvements EUDAT2020 and EPOS

The EIDA AAI System (prototype)

Separate authentication from data services (leaving just authorization to data services).

- Support multiple authentication mechanisms (Shibboleth, OAuth, E-Mail, etc.).
- Secure authentication in scripts and browser.
- Pattern-based authorization (data access rules).



How to cite a dataset or a data provider?

- Although this is recognized by the scientific community, there was no standard way to cite or acknowledge them.
- Often, distributing data centres are credited in acknowledgments with no mention of the data generators. DOI metadata allows recognition.
- Acknowledgments can be inconsistent; acknowledgement sections are not systematically indexed and therefore it is hard to quantify the scientific “impact” of a seismic network. DOI is a simple, unique string.
- Data is distinct from the scientific ideas presented in a paper. Citing a scientific paper in an attempt to acknowledge data generators, is unsatisfactory.

DOIs for Seismic Networks

The EIDA Data Centers in Europe and the IRIS DMC in the US initiated a joint effort to define the usage of DOIs for seismic networks. The FDSN through its WG III on Products, Tools, and Services has agreed upon a method to provide attribution to permanent and temporary seismic networks using FDSN Network Codes. This has been reviewed by FDSN WG III and has been agreed to by consensus.

<http://www.fdsn.org/wgIII/V1.0-21Jul2014-DOIFDSN.pdf>

Evans, et al (2015)

Do you want me to archive your data?



Data management agreement

We thank you for entrusting us with your network's data, and for your use of our services.

We offer you long term preservation of your data in the same conditions as we keep our own (see details below). However, we cannot provide any formal guarantee for its preservation.

We would like to make you aware of a few points regarding our data management policies.

1. Data surety

We will store two copies of your data in different locations at our campus.

We may hold a third copy off site if needed.

2. Your role as Principal Investigator (PI)

You are the PI for this network, and we will contact you whenever issues arise in relation to your data.

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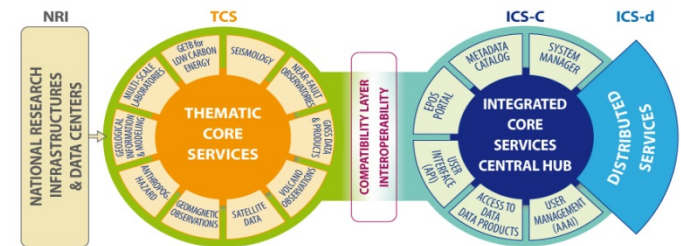
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EIDA/ORFEUS within EPOS

Long term plan to create a single, pan-European, sustainable and distributed infrastructure for solid Earth science to support a safe and sustainable society.

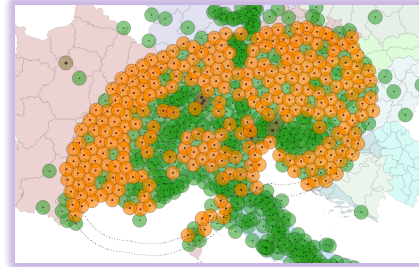
- EIDA is a core component of EPOS
Seismology;

- EIDA is the prototype service to define and demonstrate compliance with the emerging EPOS ICS (Integrated Core Services).
- EIDA and other EPOS TCS (Thematic Core Services):
 - EIDA provides a template governance and technical architecture that may be followed by other TCS.



EIDA/ORFEUS within EPOS

Long term plan to create a single, pan-European, sustainable and distributed infrastructure for solid Earth science to support a safe and sustainable society.



- Acceleration and Strong-Motion data
- Volcanology: seismic and infrasound monitoring
- **Ocean Bottom Seismometers**
- Structural monitoring
- Near-fault observatories



EUDAT2020 - Pan-European Data Infrastructure

EUDAT offers common data services, supporting multiple research communities as well as individuals, through a geographically distributed, resilient network of 35 European organizations.

GEOFON involvement (as EPOS member):

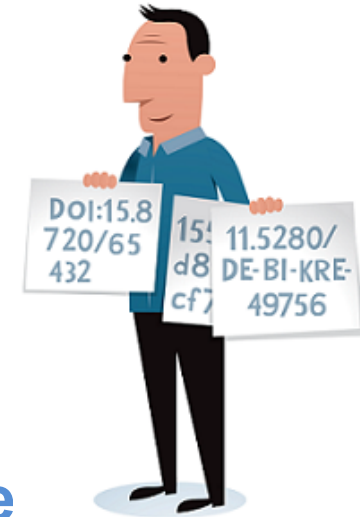
- Safe replication
- Identity Management
- Data Discovery
- Dynamic Data



Persistent Identifiers and attribution

DOI for Networks

- One of the main driving forces for the adoption of DOIs for seismic networks.
- First step to the proper attribution of data usage in scientific articles.
- Now DOIs appear in community web pages.



PID for data file

- Persistent ID for data files (~25 millions)
- Facilitate data discovery and its staging directly into the computational facility
- Include metadata related to f.i. curation, and versioning.

Data Collections

Why do we need it?

- We cannot afford to store all datasets (~5 million/year).
- Reproducibility: same request more than once can result in different datasets.
- Provide immutable network/event based datasets.
- Versions/Dynamic data.

How can we benefit from PIDs?

- Datasets defined as a collection of PIDs.
- Metadata associated with the data collection.
- Accurate statistics by monitoring of PID resolution.
- Minimize the data movement.
- Fast transmission of data collection.
- Facilitate the staging on computer facilities.

“Old” Challenges in seismology

- Standard Waveform Data Format
- Merging of different data sets
- Standard (Real-Time) Data Exchange Protocol
- Virtualization of Seismological Networks
- Standard Data Archive Access Protocol
- Virtualization of Seismological Data Archives
- Synchronization of distributed data sets
- Combining data and HPC services


Challenges in the seismological community

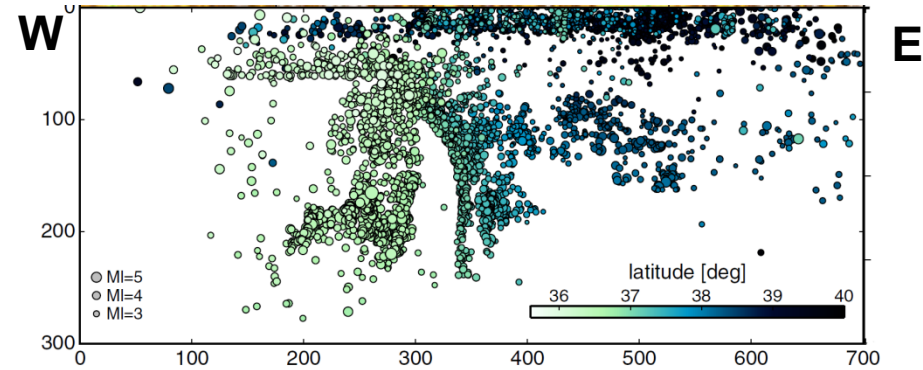
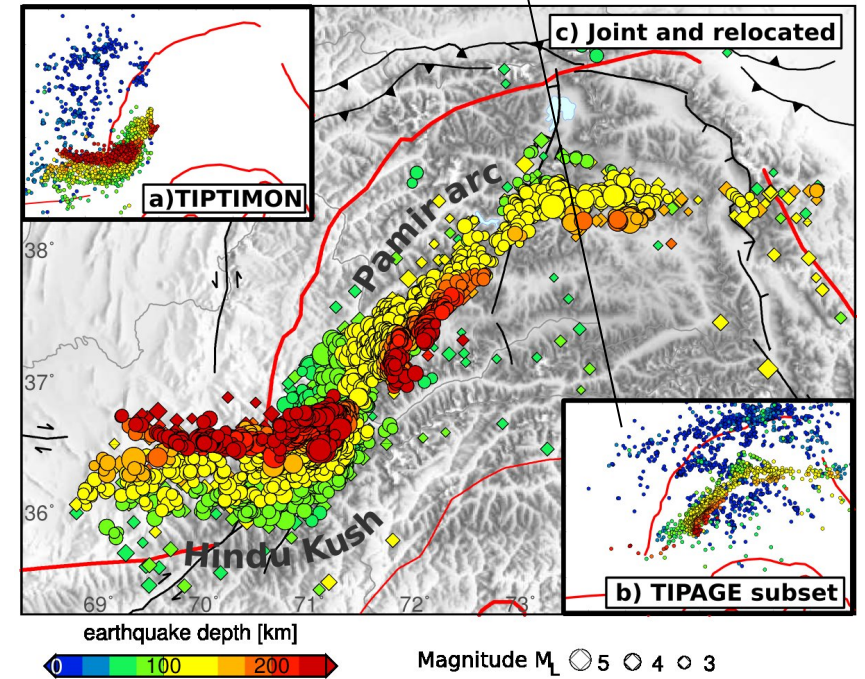
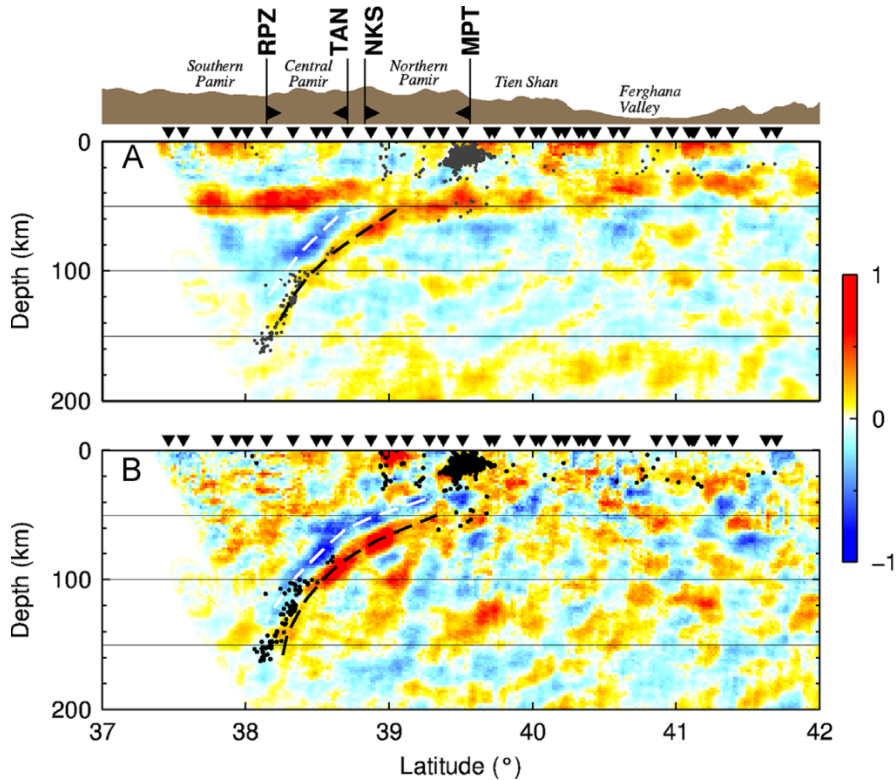
- Dynamic Data
 - ✓ Waveforms can be modified during the first days.
- Reproducibility of experiments
 - ✓ Freezing datasets in time
 - ✓ Millions of requests/year referencing thousands of records
 - ✓ Before and after curation of data/metadata
 - ✓ Real-time data seems to be much more complicated for the time being.
- Integration with other Earth sciences
 - ✓ Not enough standards in other branches of science
 - ✓ Different levels of evolution regarding infrastructure
 - ✓ Protocols and data formats
 - ✓ Semantics! What does f.i. “depth” means?

Thanks for your attention!

Imaging with earthquake data

 Moho, Lithosphere, Transition zone, Anisotropic structure

 Example: Pamir-Hindukush continental subduction (4 sections, 2 departments directly involved)



Schneider et al. (EPSL 2013), Sippl et al. (JGR, 2013), Kufner et al. (in prep)