Engineering Seismology and Seismic Hazard – 2019

Lecture 15

# Earthquake Catalogues

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# Earthquake Catalogues

Earthquake catalogues are compilations of past earthquake events, usually in the form of a plain text database.

For each event, the minimum set of earthquake parameters that should be provided is:

- Origin time (t0, in different format)
- Location (latitude, longitude and depth if available)
- Size (type should be specified)

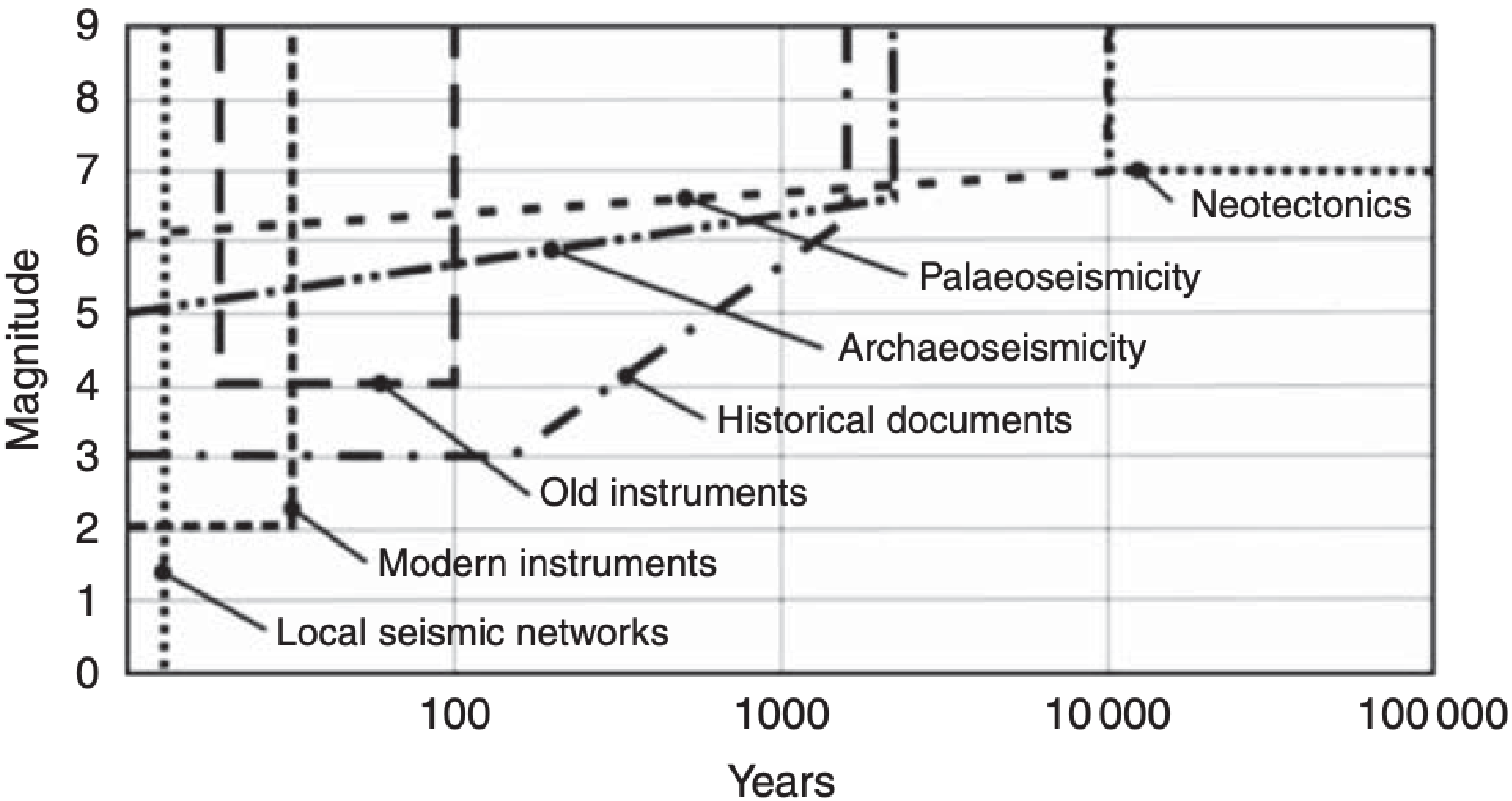
Additional useful information, whenever available, could include:

- Uncertainties (on both time, location, size…)
- Focal mechanism parameters
- Meta data (network, agency, bibliographic references…)
- Number of stations used for location solution
- …

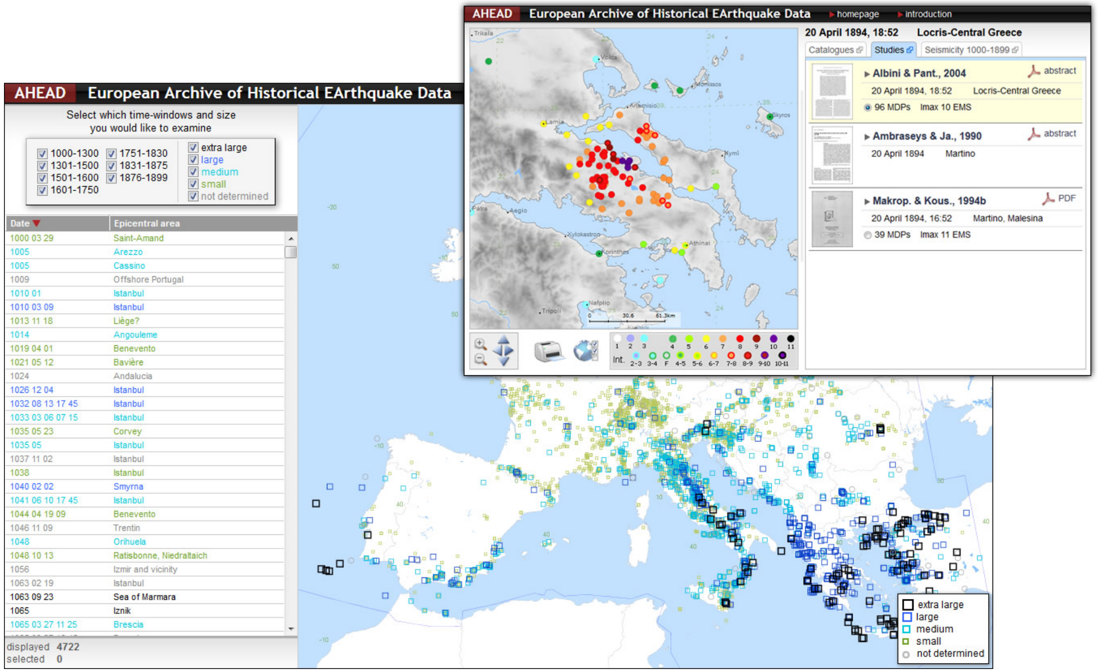
# Earthquake Catalogues

Earthquake Catalogues are generally divide in main categories:

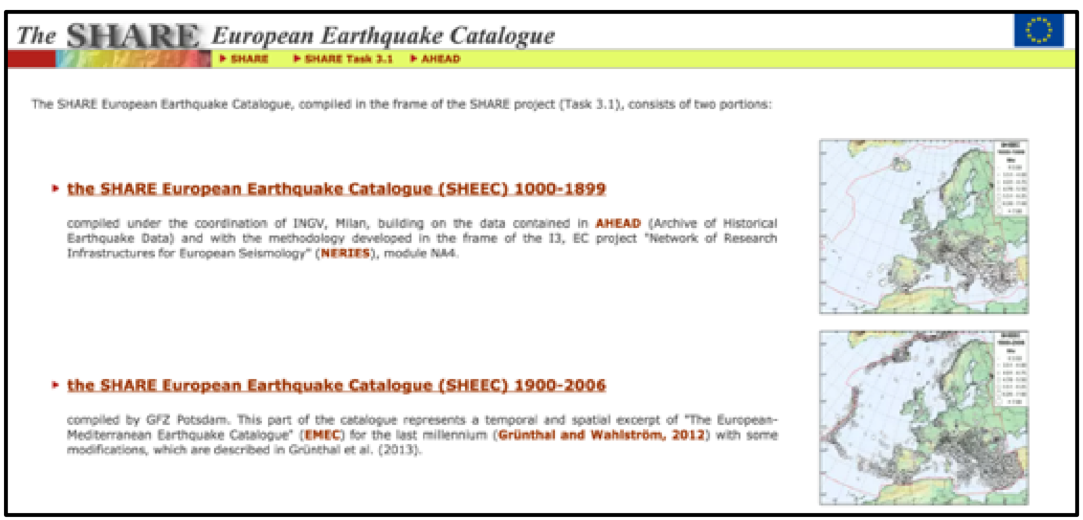
A) pre-historical and historical
B) pre-instrumental
C) instrumental catalogue



# Historical Catalogues




https://www.emidius.eu/GEH

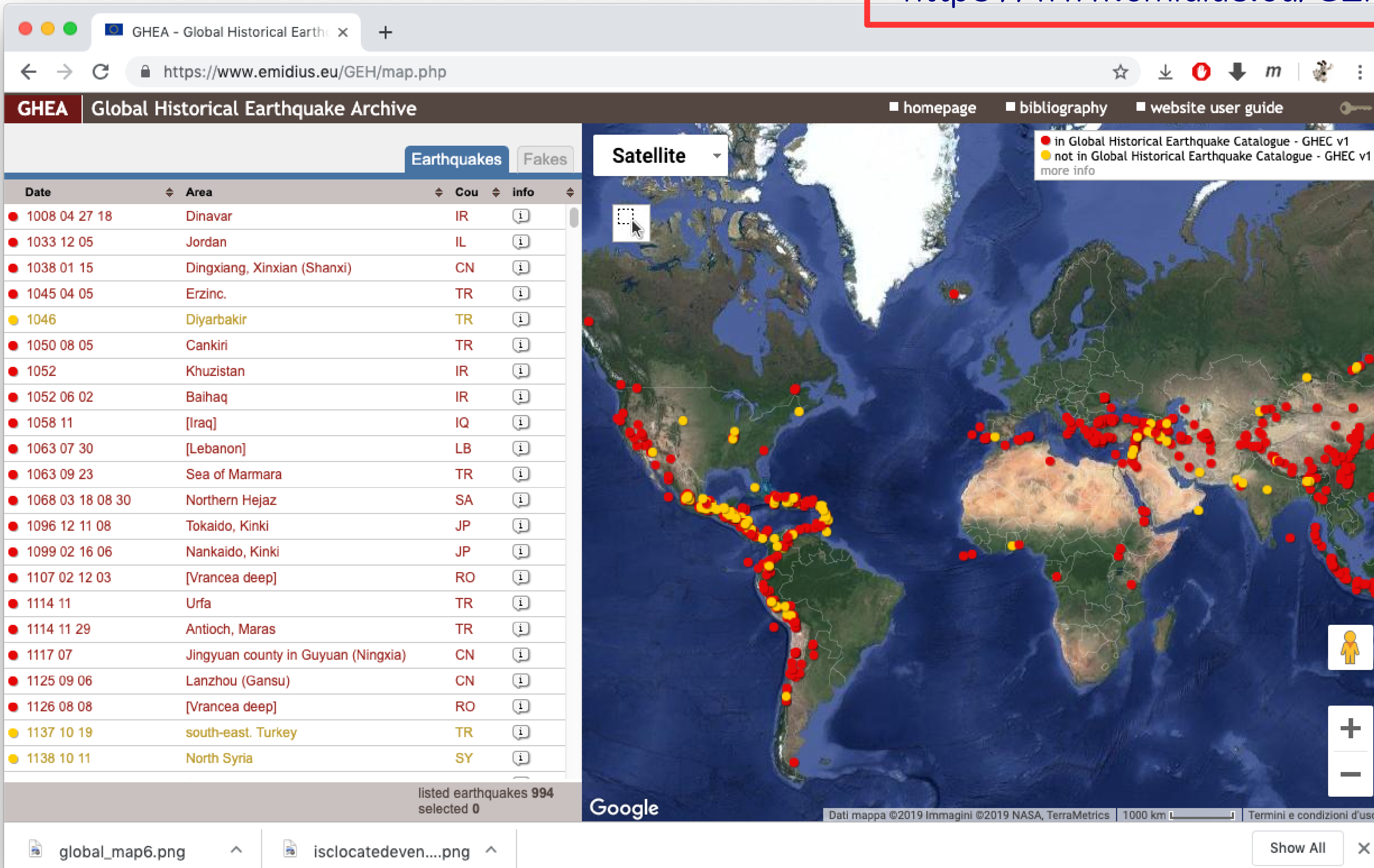




Global Historical Earthquake Archive and Catalogue (1000–1903)

# GEM Historical Archive

https://www.emidius.eu/GEH



# Historical Sources

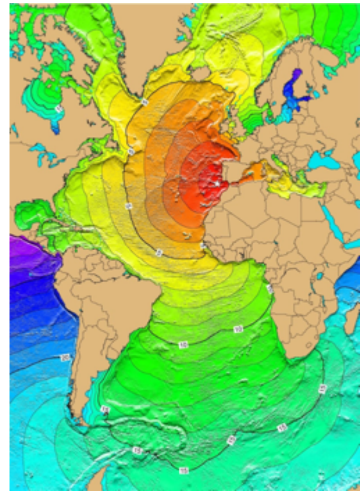
Written descriptions of historical earthquake damage provide an insight into both the impact of an event and the spatial extent of the ground shaking.

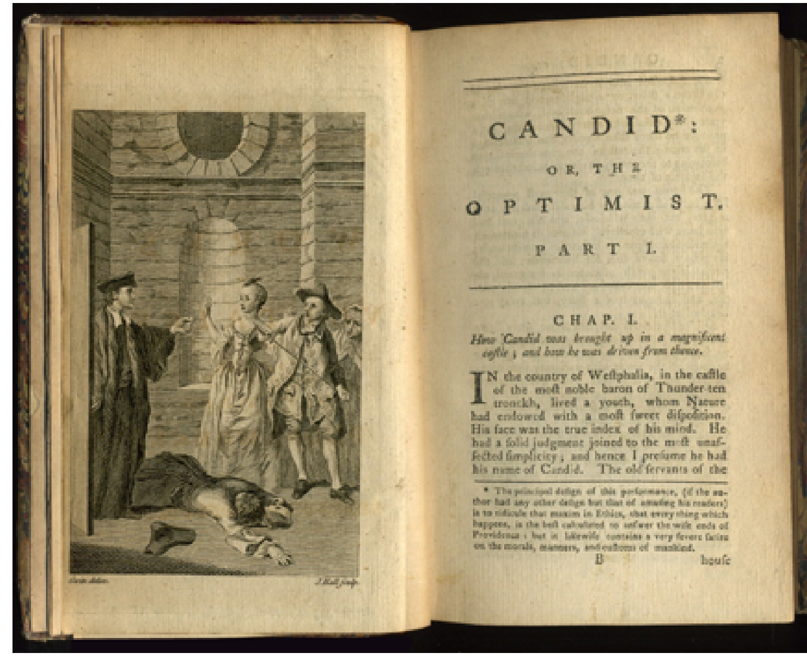
Sources come from:
- Historical chroniclers
- Monastery records
- Early newspapers/almanacs

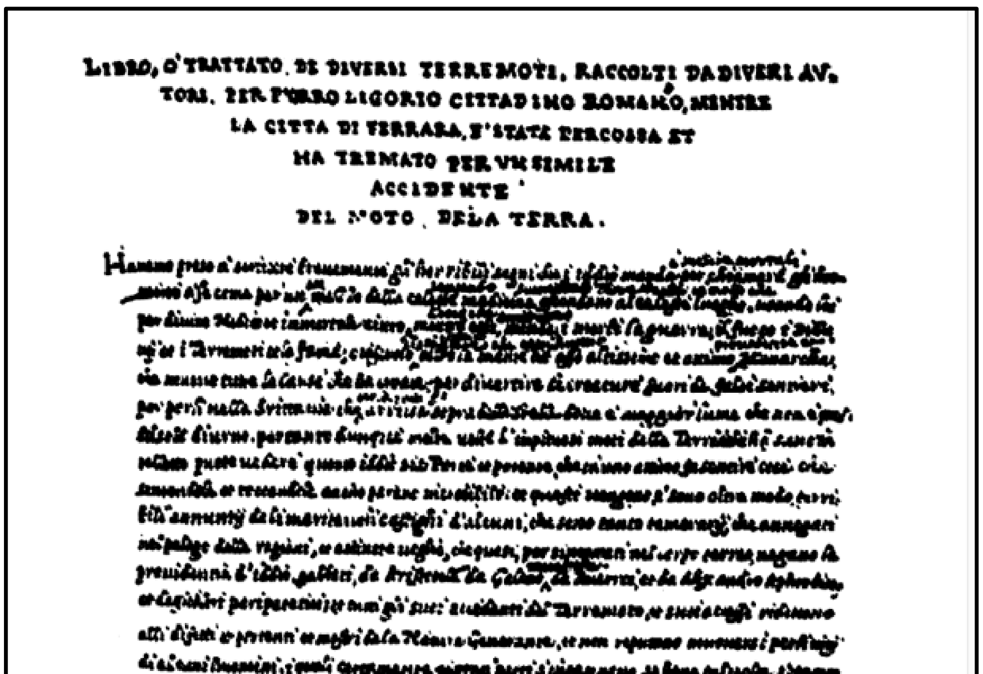
Where written accounts are abundant and relatively descriptive, estimated of the **intensity** at specific places can be made.

<u>However, estimations of intensity can be subjective!</u>

# Books and Chronicles





LIBRO, O' TRATTATO DE DIVERSI TERREMOTI, RACCOLTI DA DIVERSI AV. TORI, PER PIRRO LIGORIO CITTADINO ROMANO, MENTRE LA CITTA DI FERRARA, E' STATA PERCOSSA ET HA TREMATO PER VN SIMILE ACCIDENTE DEL MOTO DELLA TERRA.

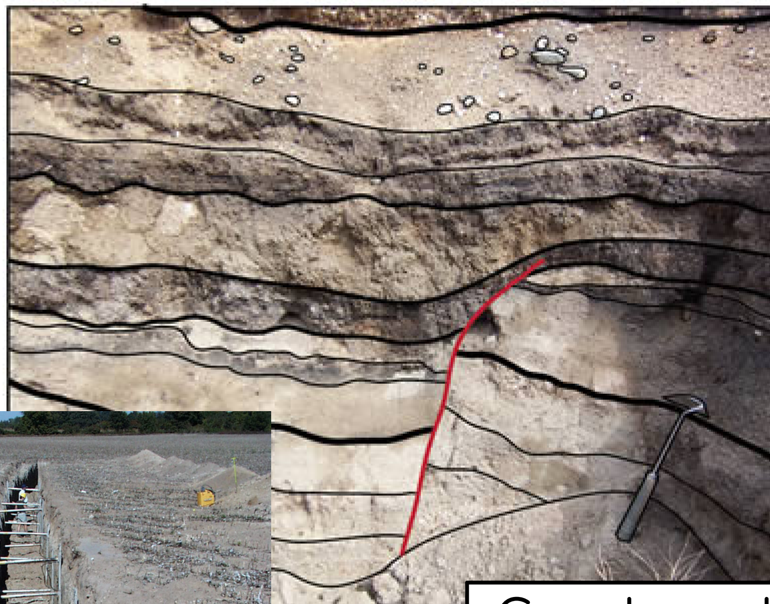
Voltaire mentions the 1755 (M~8.5–9) Lisbon earthquake in his seminal work “Candide”

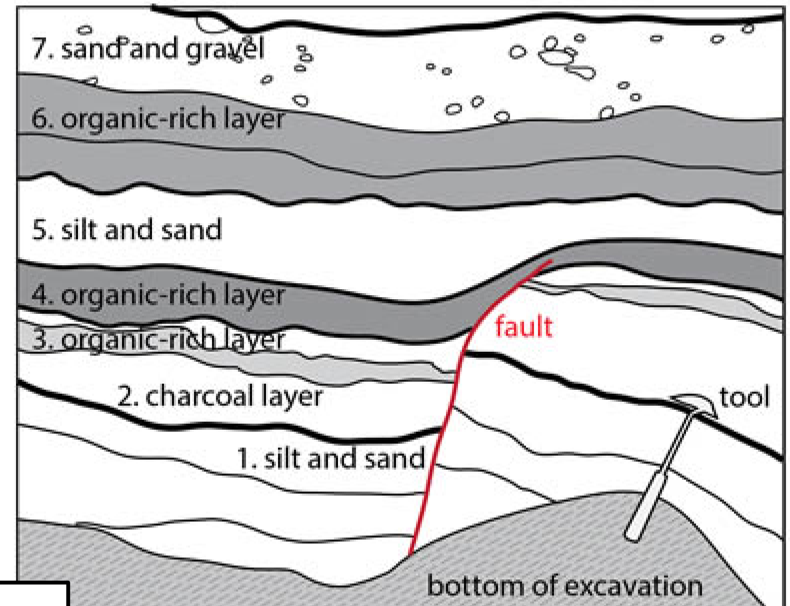
# Archaeological Evidence


Fig. 2.12 - Ruins of a tomb in Hierapolis, an ancient city in Turkey founded around 200 B.C. and abandoned after an earthquake in 1534. Many offsets can be observed between the different blocks: although gravity may be a primary driver of this tomb deformation, perhaps occasional seismic shakings contibuted (taken from Callan Bentley in AGU Blogoshere).

# Paleoseismology

Very uncertain results, mostly based on geological evidences. However, in few cases the only possibility to constraint long-return period events.






Geochronology

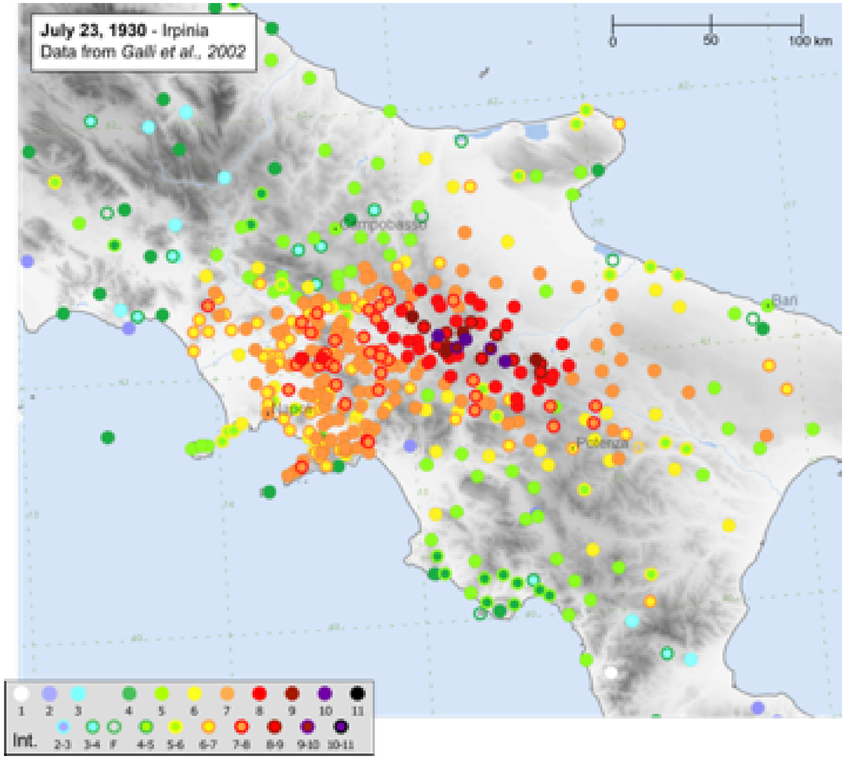
Trenches

Seismites

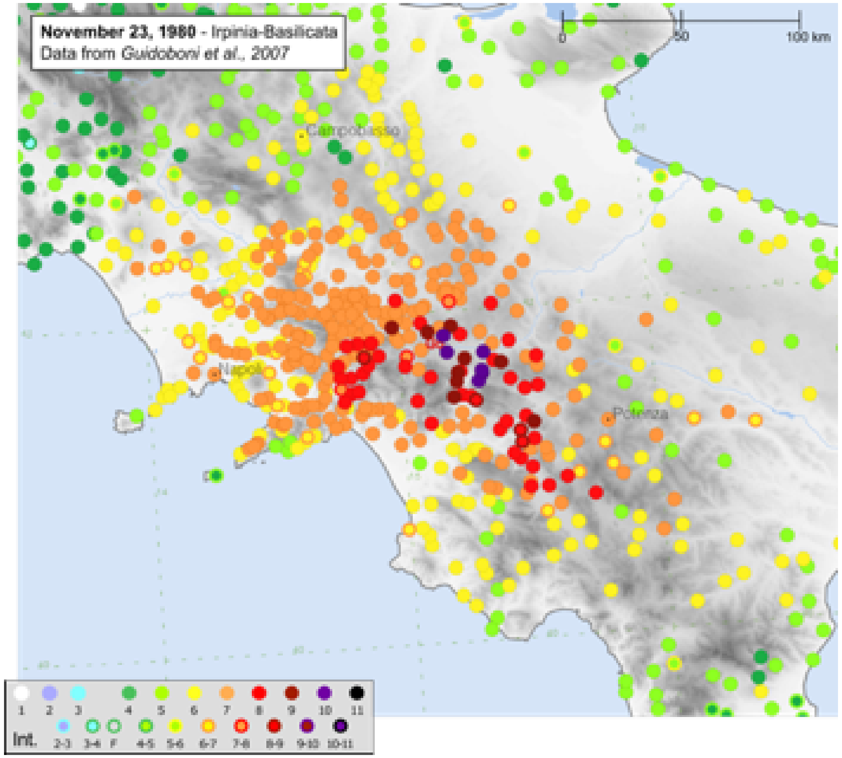
# Macroseismic Intensity

With all the known limitations, macroseismic intensity can be used to assess the size of historical events from chronicles and other indirect sources.

1930 Irpinia Earthquake M~6.6

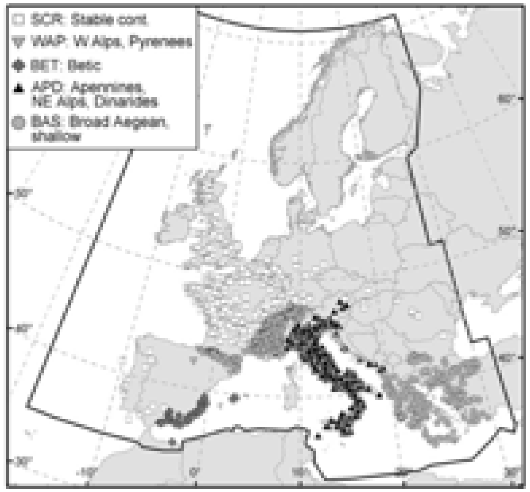


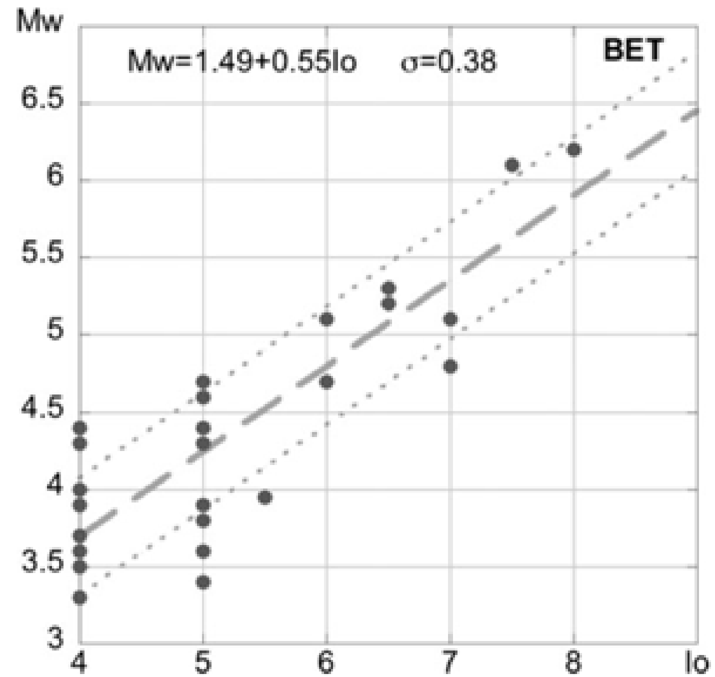

1980 Irpinia Earthquake M~6.9



# Conversion to Magnitude

From Stucchi et al. 2012

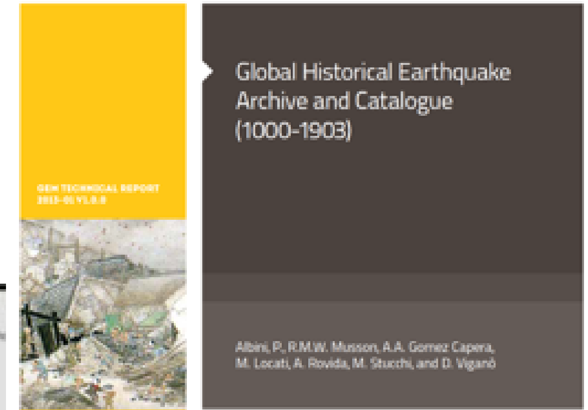



| Region | No earthquakes | Io range | Mw range | Equation | σ |
|---|---|---|---|---|---|
| BET | 32 | 4.0–8.0 | 3.3–6.2 | $Mw = 1.487 + 0.552*Io$ | 0.38 |
| SCR | 26 | 4.5–8.0 | 3.6–5.6 | $Mw = 0.528 + 0.655*Io$ | 0.25 |
| WAP | 17 | 5.0–8.5 | 3.5–5.8 | $Mw = 1.441 + 0.502*Io$ | 0.31 |
| APD | 345 | 5.5–11.0 | 4.0–7.0 | $Mw = 2.182 + 0.423*Io$ | 0.34 |
| BAS | 62 | 5.0–10.0 | 4.6–7.1 | $Mw = 3.404 + 0.355*Io$ | 0.25 |
| Central Europe | 41 | 5.0–9.5 | 3.0–6.4 | $Mw = 0.160 + 0.682*Io$ | 0.32 |

BET Betic, SCR stable continental region, WAP Western Alps and Pyrenees, APD Apennines, North-Eastern Alps and Dinarides, BAS Broad Aegean, shallow.
The relation for Central Europe by Grünthal et al. (2009b) is shown for comparison.

# Conversion to Magnitude



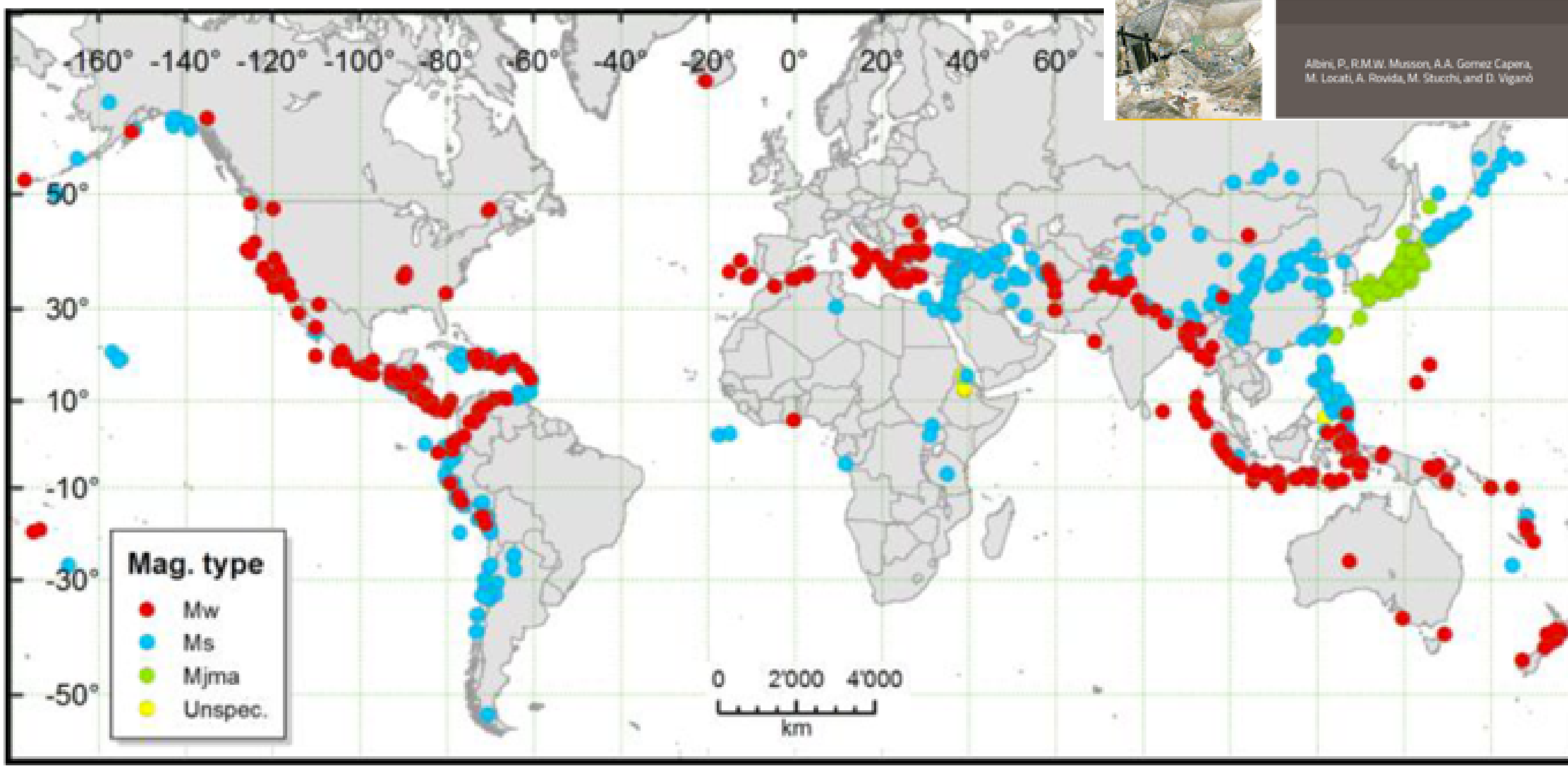




**Figure 3.3 Geographical distribution of the different magnitude types in GHEC**

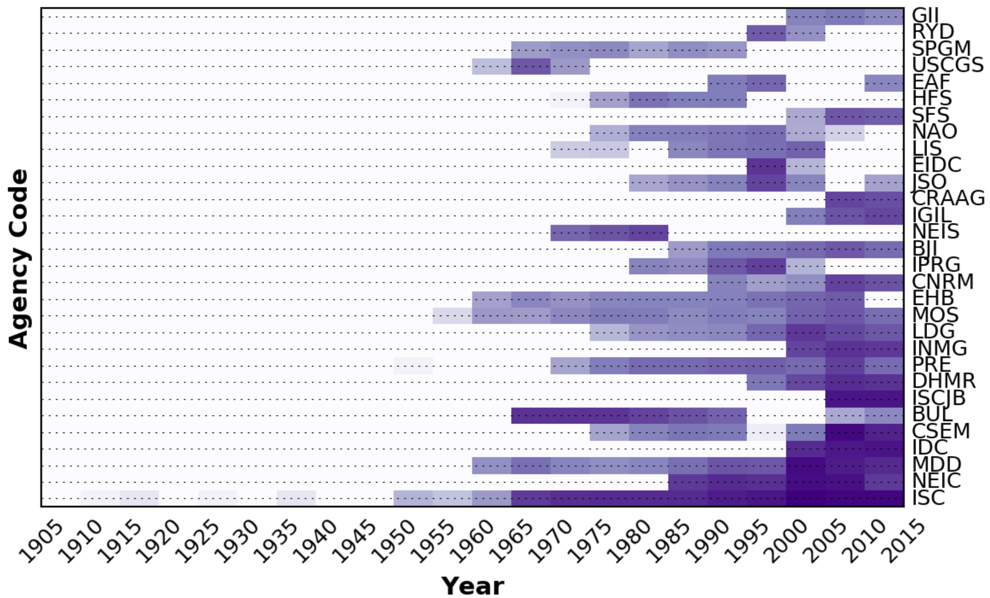
# Instrumental Catalogues

Many instrumental catalogues exist nowadays, most of them from regional or national networks.

These catalogues could be very heterogeneous in term of type and quality of the reported information and should be used carefully.

They can be compiled using different techniques with a different level of accuracy, e.g. using different Magnitude type (Ms, mb…) and location algorithms.

Homogenization and Harmonization of these catalogue is of major concern in seismic hazard analysis.



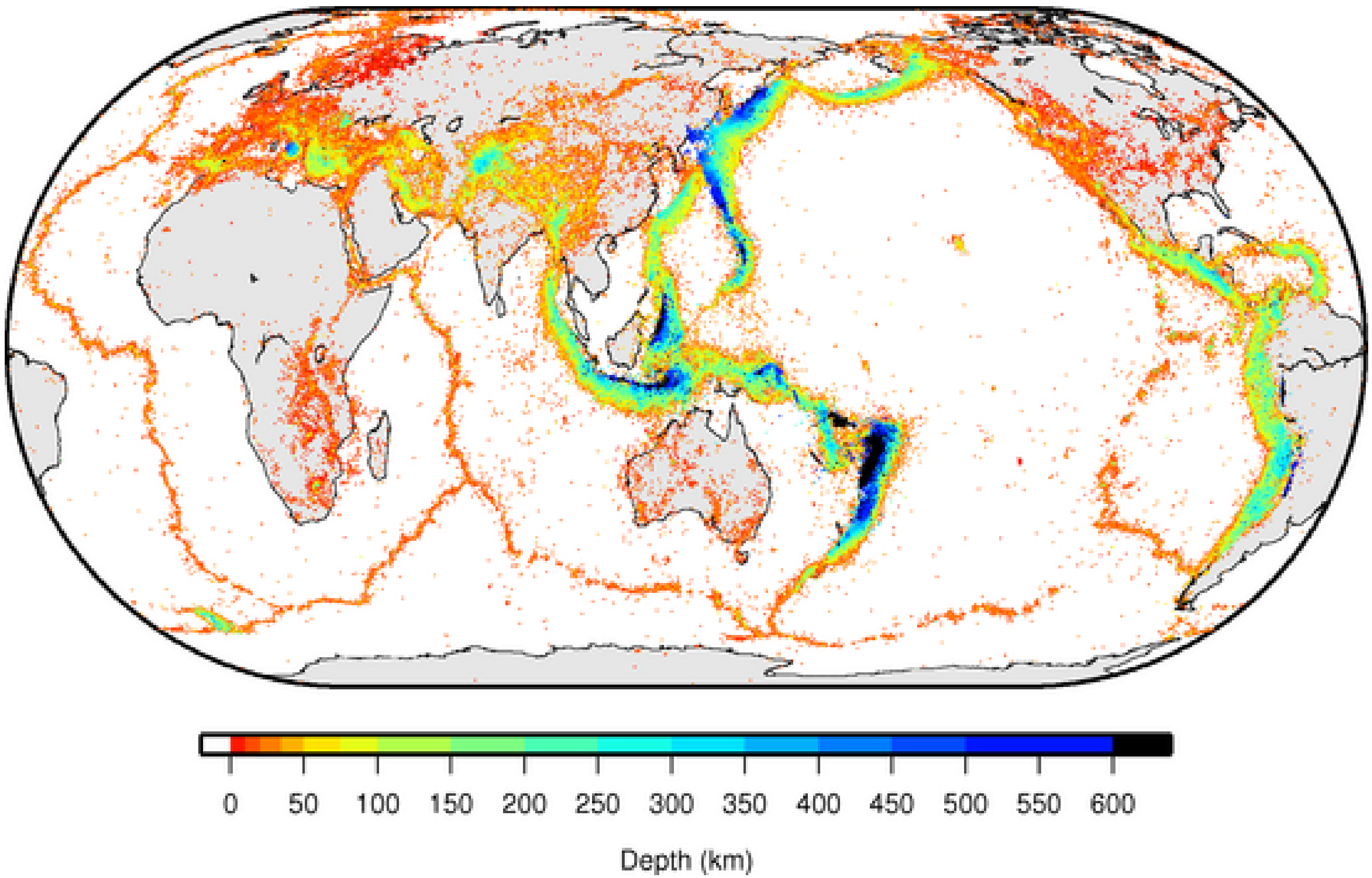
# International Seismological Centre

- International centre was founded in 1964 and gathers seismic data from from more than 130 agencies worldwide.
- Data are reviewed by seismologists and events relocated using a homogenous location algorithm.
- All data free and available online: www.isc.ac.uk
- About 2 years behind real-time

International
Seismological
Centre

# International Seismological Centre

<u>Worldwide Hypocentre Distribution</u>



# Anatomy of ISC Bulletin

Time of Event

Location of Event & Error

Metadata about location record

Event 142881 Jordan - Syria region

| Date | Time | Err | RMS | Latitude | Longitude | Smaj | Smin | Az | Depth | Err | Ndef | Nsta | Gap | mdist | Mdist | Qual | Author | OrigID |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1994/11/20 | 14:30:42.20 | | | 36.3900 | 41.0600 | | | | 5.0 | | | | | | | uk | JSO | 324899 |
| 1994/11/20 | 14:31:00.90 | | | 35.1300 | 39.5600 | | | | 33.0 | | | | | | | uk | MOS | 324900 |
| 1994/11/20 | 14:31:01.80 | | | 35.4800 | 39.5700 | | | | 28.0 | | | | | | | uk | BJI | 324901 |
| 1994/11/20 | 14:31:02.20 | | 1.220 | 35.3350 | 39.5570 | | | | 28.8 | | | 189 | | | | uk | NEIC | 324902 |
| 1994/11/20 | 14:31:03.65 | | 1.110 | 35.3660 | 39.5900 | 35.0 | 33.0 | 16 | 22.9 | 3.9 | 353 | 323 | | | | ke | EHB | 9243968 |
| 1994/11/20 | 14:31:04.40 | 0.40 | | 35.3600 | 39.0700 | 5.431 | 5.5 | 90 | 15.0 | | | | | | | uk | HRVD | 324903 |
| (#CENTROID) | | | | | | | | | | | | | | | | | | |
| 1994/11/20 | 14:31:06.00 | | | 36.0000 | 40.0000 | | | | | | | | | | | uk | NAO | 324904 |
| 1994/11/20 | 14:31:01.76 | 0.81 | 1.260 | 35.3308 | 39.6024 | 2.276 | 2.1 | 90 | 23.1 | 6.5 | 331 | 331 | 35 | 3.00 | 87.00 | m i uk | ISC | 324905 |
| (#PRIME) | | | | | | | | | | | | | | | | | | |

| Magnitude | | Err | Nsta | Author | OrigID |
|---|---|---|---|---|---|
| mL | 5.9 | | | JSO | 324899 |
| MS | 4.9 | | 21 | MOS | 324900 |
| mb | 5.3 | | 17 | MOS | 324900 |
| MS | 5.4 | | | BJI | 324901 |
| mb | 5.1 | | | BJI | 324901 |
| MSZ | 4.9 | | 6 | NEIC | 324902 |
| mb | 5.1 | | 59 | NEIC | 324902 |
| Mw | 5.4 | | | HRVD;NEIC | 324902 |
| mb | 4.6 | | | NAO | 324904 |
| MS | 5.0 | | 21 | ISC | 324905 |
| mb | 5.0 | | 65 | ISC | 324905 |

Location used for magnitude estimation

Location Recording Agency

Magnitude Scale & Value

Magnitude Recording Agency

# Merging Catalogues

Homogenization is the process of merging available catalogues in a unique database for the purpose of seismic hazard analysis.

An homogenized earthquake catalogue is characterized by:

1) Unique event (**no duplications**)
2) Uniform magnitude representation and its uncertainty
3) Best available location solution

Homogenization, however, may introduce new errors as a product of the merging process.

Most of the errors are due to issue with the input catalogues regarding notation of time or date. One catalogue may give local times, where another has corrected to UTC, and the result can be duplicate events some hours apart. Similarly, different calendars may be in use.

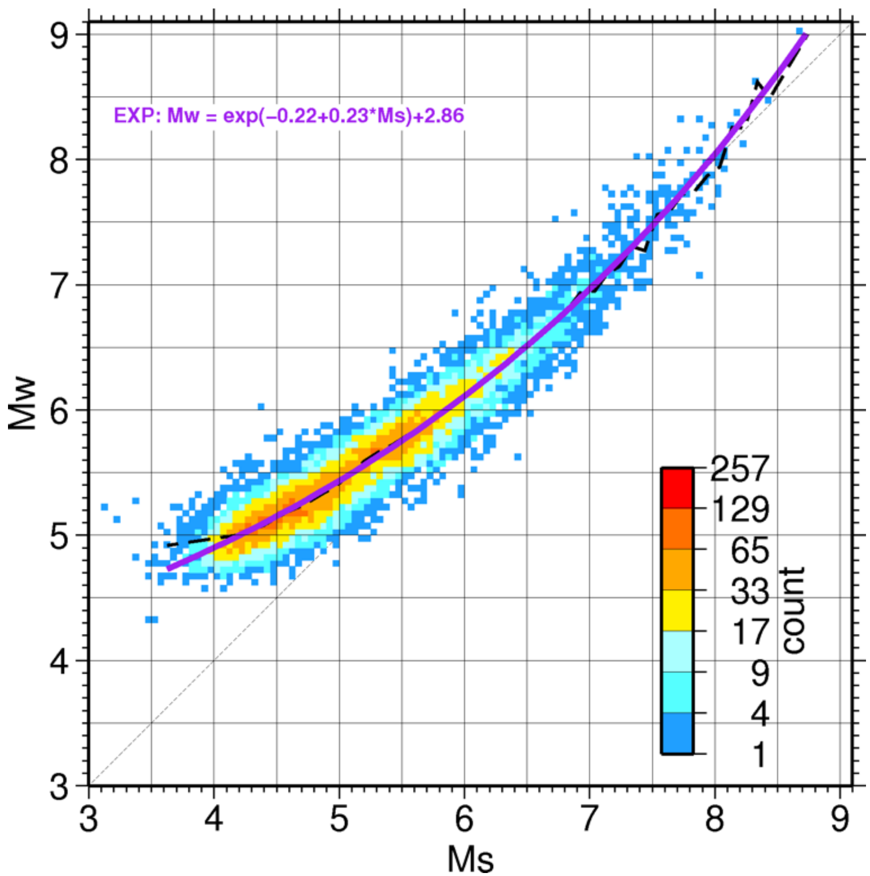
# Merging Catalogues

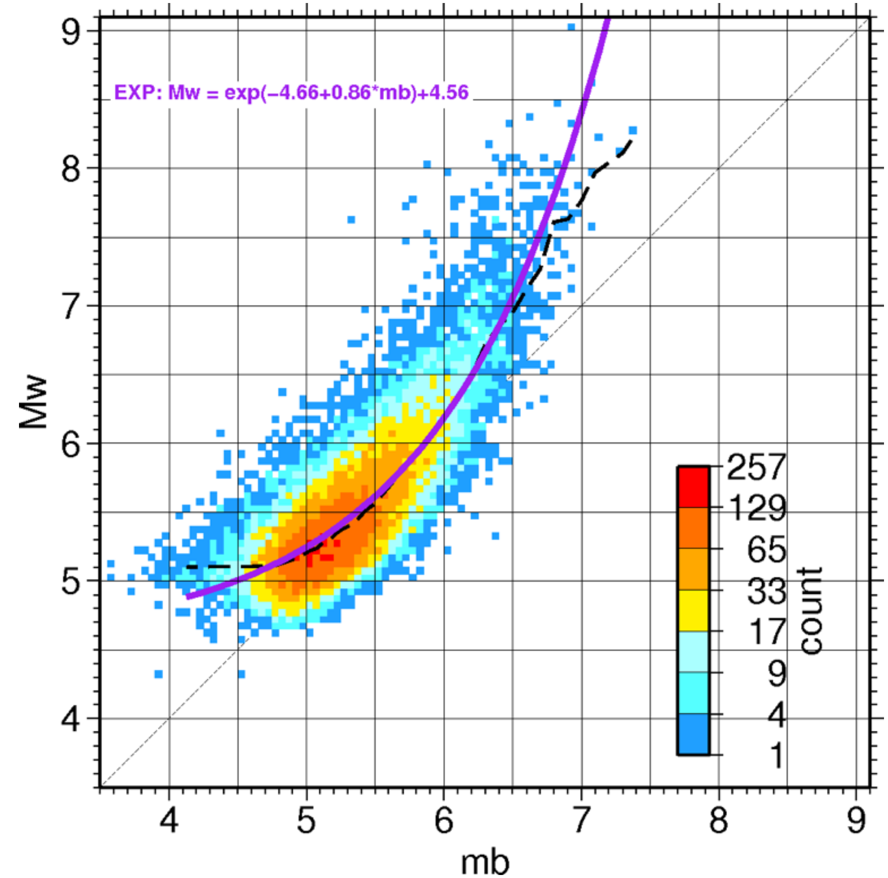
A few problems related to earthquake catalogue homogenization:

1. Local networks may offer greater precision – but operation periods may be short and variable
2. To understand the statistical properties of earthquakes we need every event rendered into a common scale – usually prefer $M_W$ for this purpose
3. How to calibrate local magnitudes against standard global magnitude scales (e.g. MS, $M_W$)?
4. Inevitable problems: missing metadata, noisy data, changes in recording procedures (or network coverage)

# Magnitude Conversion

Calibration of ad-hoc magnitude conversion relations relies on databases (e.g. ISC bulletin) that contain common events recorded in different scales by different agencies.
Carful with extrapolation: such empirical relations have strict applicability ranges!



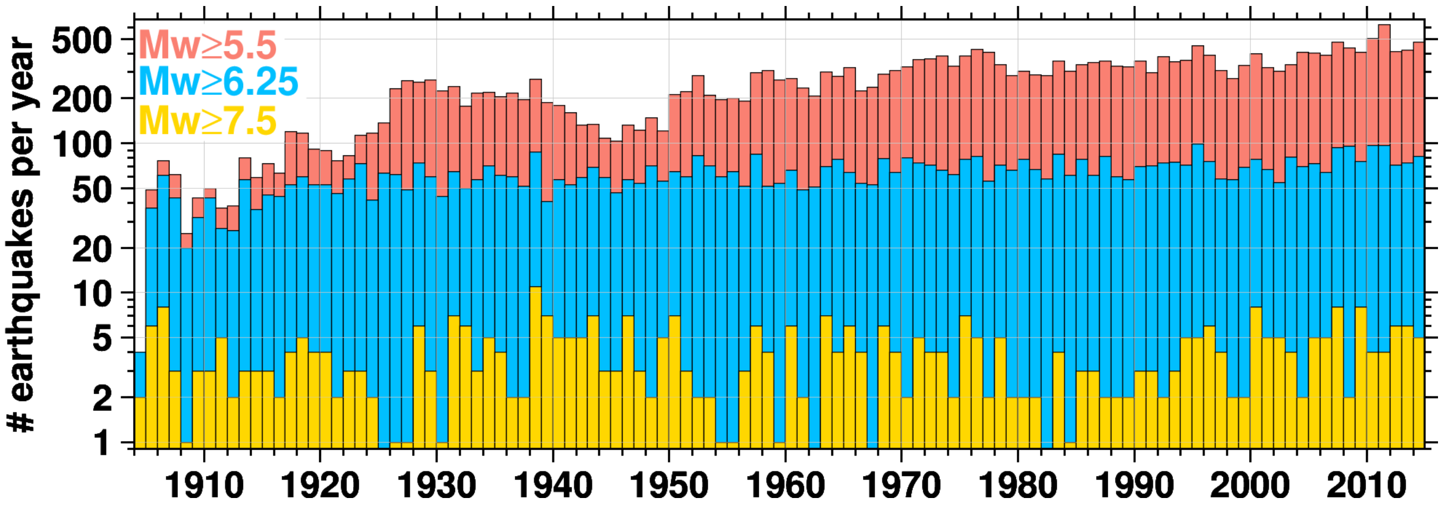



# Example: Application to EMME

| Type of magnitude | Conversion relation | Boundary | $R^2$ | n | σ | |
|---|---|---|---|---|---|---|
| mb, Mw | Mw = 0.8744 mb + 0.8277 | 3.5≤mb≤6.0 | 0.8803 | 16752 | | This study |
| | Mw = 0.85(±0.04) mb + 1.03(±0.23) | 3.5≤mb≤6.2 | 0.53 | 39784 | 0.29 | Scordilis |
| Ms, Mw | Mw = 0.6633 Ms + 2.1117 | 2.8≤Ms≤6.1 | 0.9425 | 4123 | | This study |
| | Mw = 0.9307 Ms + 0.4491 | 6.2≤Ms≤8.2 | 0.88 | 129 | | |
| | Mw = 0.67 (±0.005) Ms + 2.07(±0.03) | 3.0≤Ms≤6.1 | 0.77 | 23921 | 0.17 | Scordilis |
| | Mw = 0.99 (±0.02) Ms + 0.08(±0.13) | 6.2≤Ms≤8.2 | 0.81 | 2382 | 0.2 | |
| Ml, Mw | Mw = 1.0136 Ml – 0.0502 | 4.0≤Ml≤8.3 | 0.9805 | 2271 | | This study |

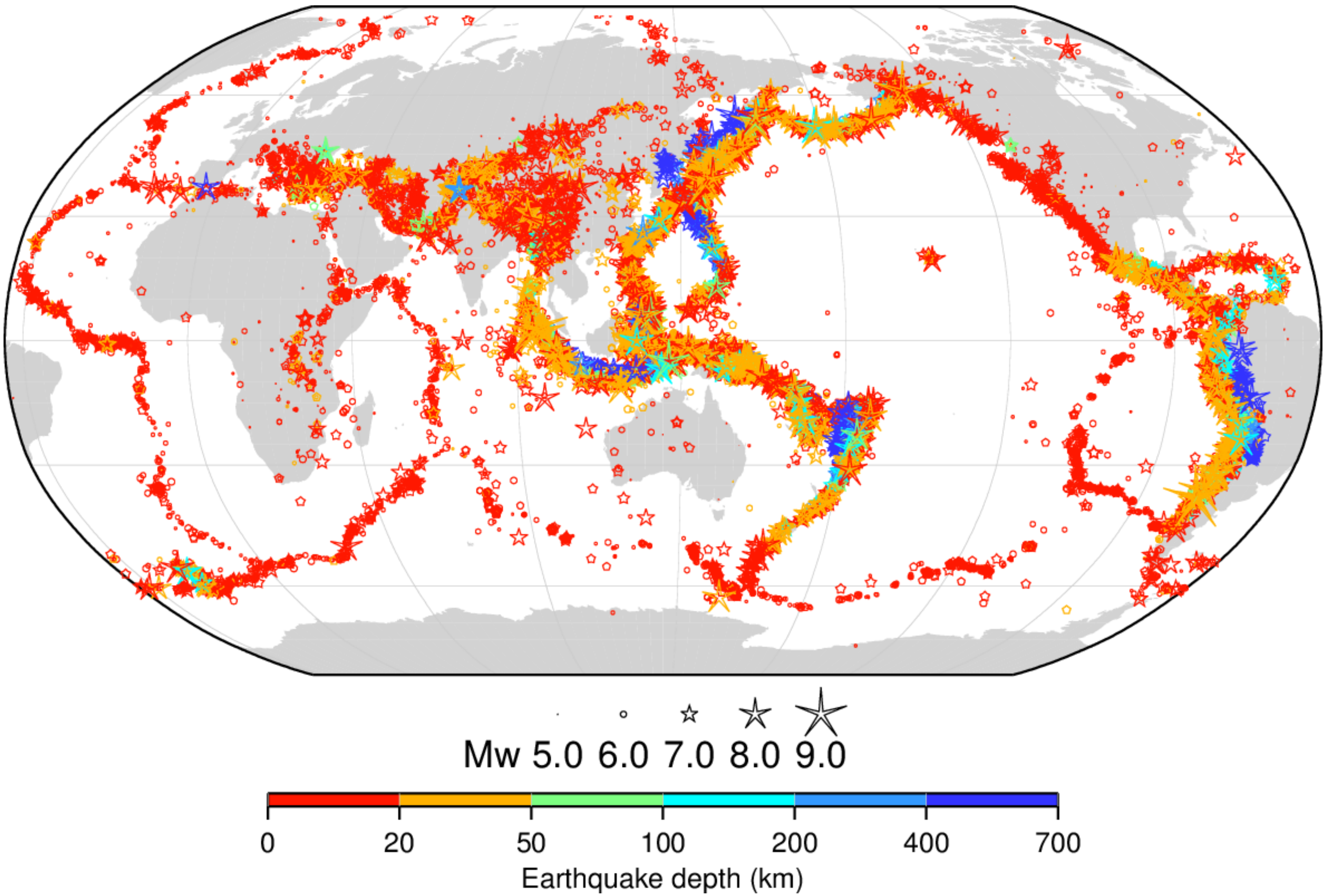
# ISC-GEM Catalogue

- Collecting, digitizing and processing data from a multitude of historical sources for earthquakes occurred up to 1970;
- 110 years of relocated earthquake hypocenters;
- recomputed MS and mb values for relocated events using uniform procedures;
- MW values (with uncertainty) based on:
  1. seismic moment from GCMT (mainly 1976-2009);
  2. seismic moments from the literature search for earthquakes up to 1979;
  3. proxy values based on recomputed MS and mb in other cases using appropriate empirical relationships.



# ISC-GEM Catalogue

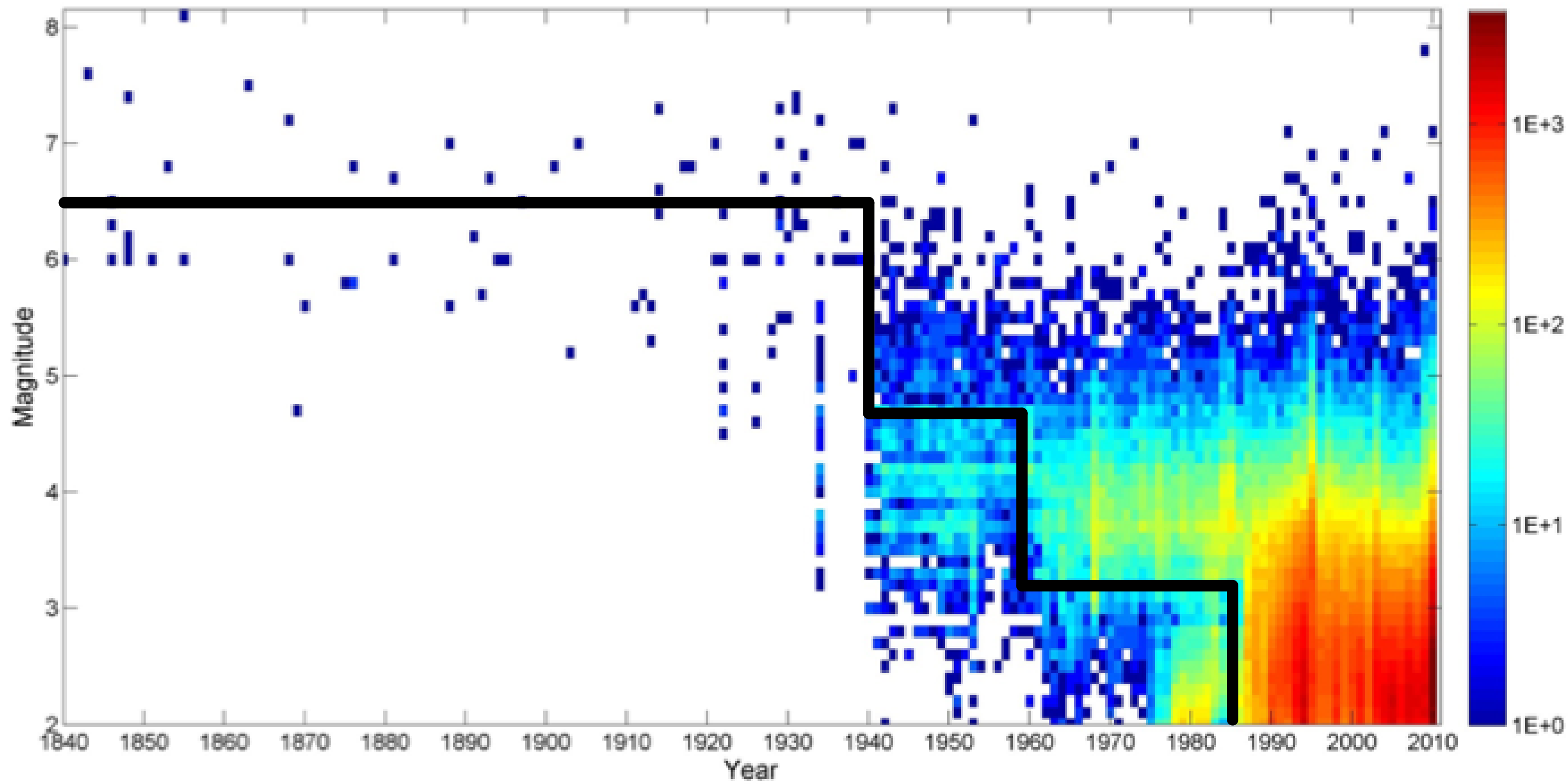
## Worldwide Hypocentre / Magnitude Distribution



# Magnitude of Completeness

Magnitude of Completeness (Mc): the minimum magnitude above which it is thought that all earthquakes are reliably recorded

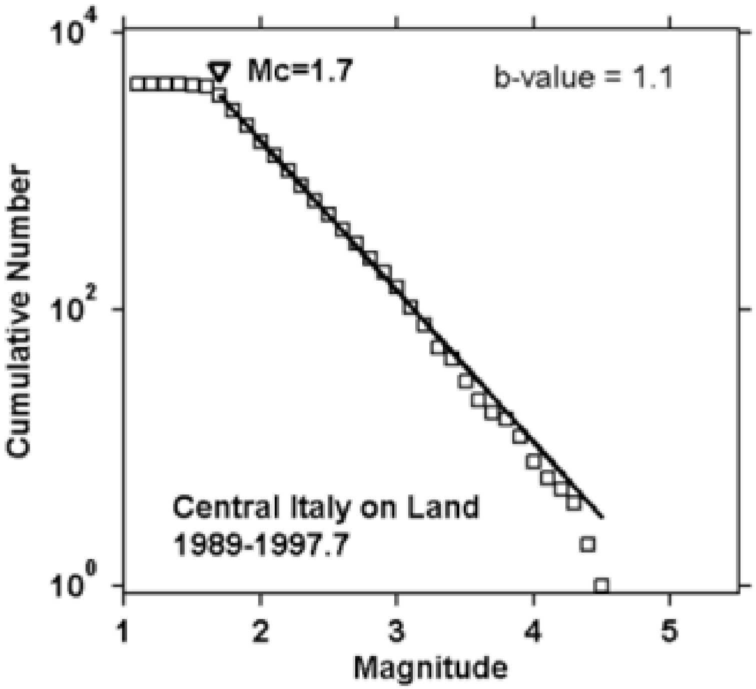
Mc is time and magnitude dependent, therefore a catalogue is characterized by different **completeness intervals**.

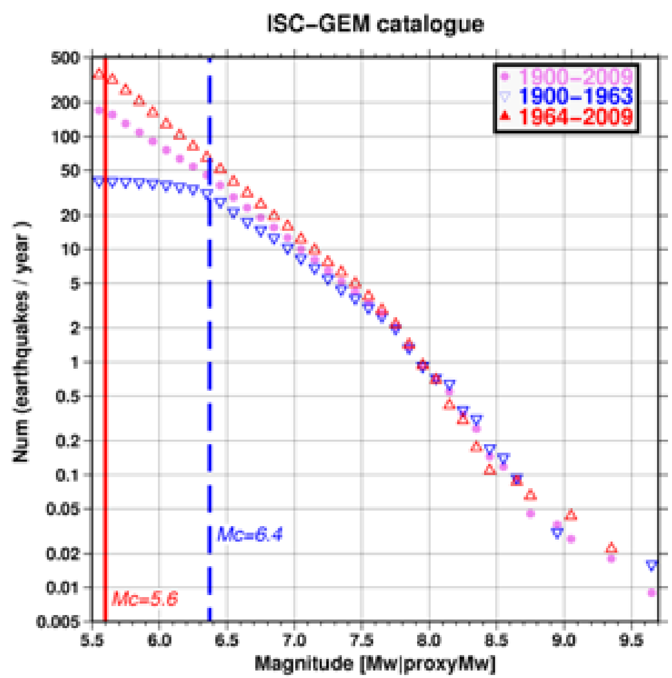


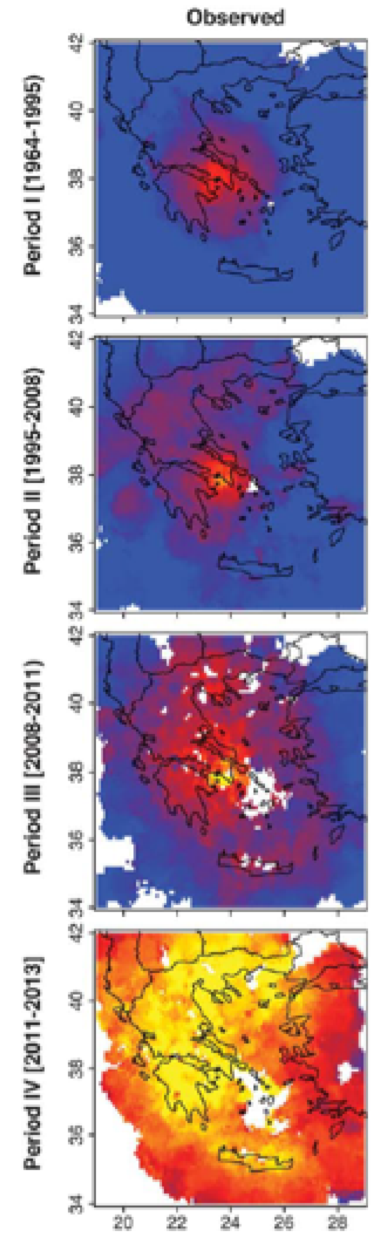
# Magnitude of Completeness

Mc describes the magnitude of the smallest events completely detected by the network.

Mc itself is defined as the deviation point from the “Gutenberg-Richter” magnitude distribution of an earthquake sample.



# Magnitude of Completeness

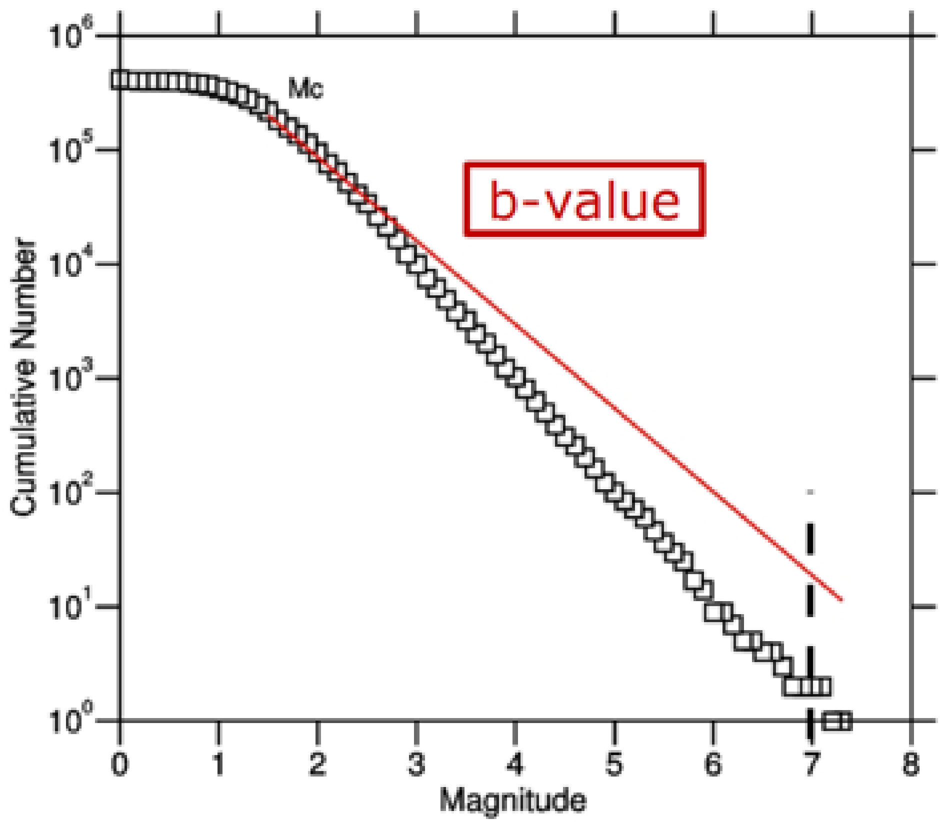
Why are not all earthquake detected?

(1) the event is too small and its signal undistinguishable from the background noise on the seismograph,
(2) the event is too small to be recorded on a sufficiently large number of stations – a minimum number of stations must be triggered to initiate the location procedure and thus the report of the event,
(3) network operators decided that events below a certain threshold are not of interest,
(4) in case of an aftershock sequence, some events are too small to be detected within the coda of larger events (i.e. increased noise).

# Why Mc Matters?

Wrong completeness estimates propagates to:

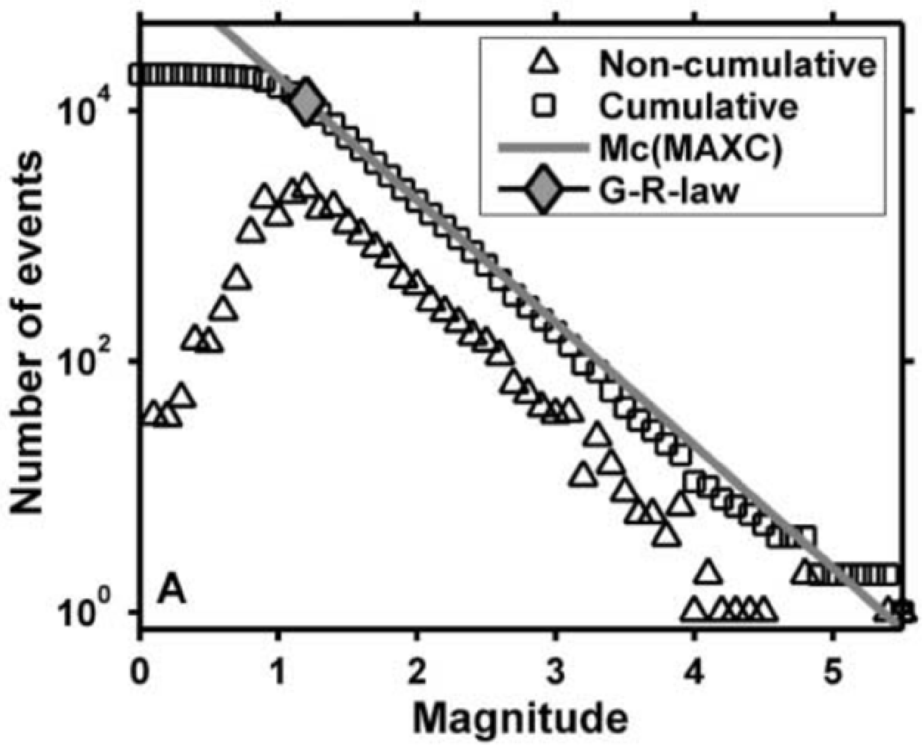
- b–value
- activity rates
- seismic hazard estimates



# Main Techniques for Mc

## 1) Catalogue based methods

Magnitude of completeness is defined as the threshold where the cumulative (or the incremental) occurrence distributions do not follow anymore a typical G-R relation.



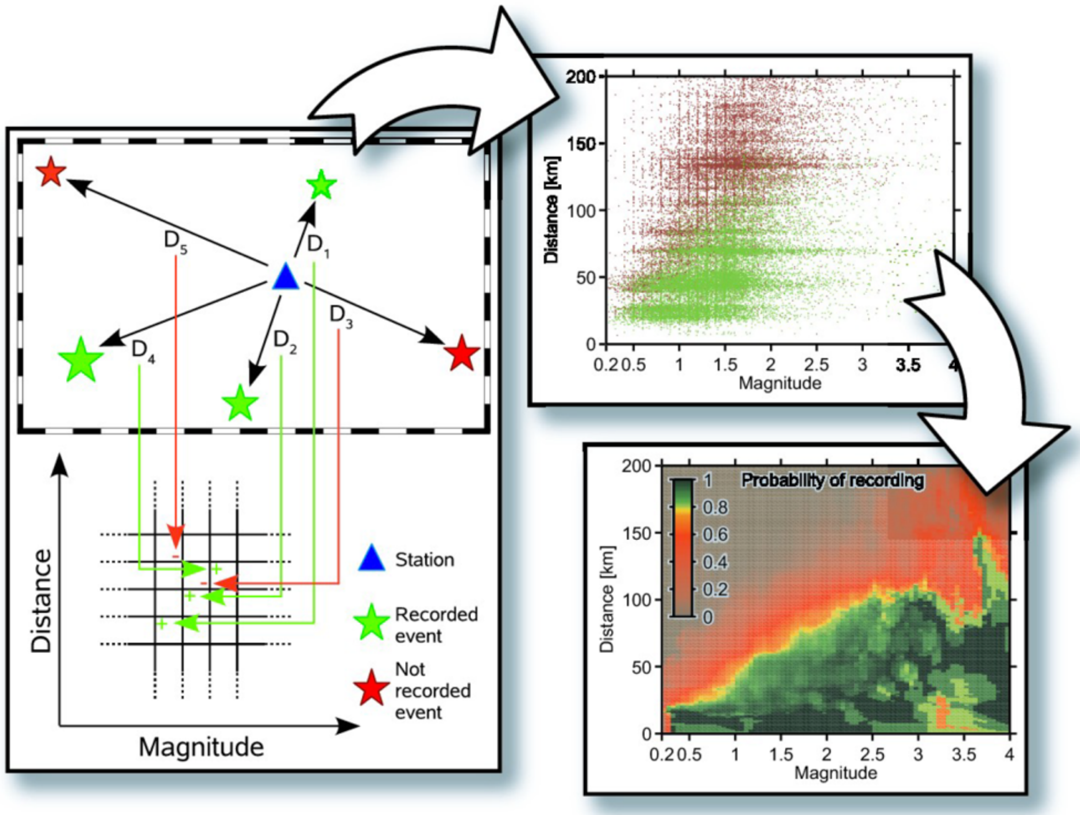

<u>Performs poorly if power-law not well defined (e.g. low seismicity, historical)</u>

Maximum Curvature (MAXC)
Wiemer and Wyss 2000

# Main Techniques for Mc

## 2) Network methods

Used to define the the probability level with which an earthquake can be detected given the station (sensor) sensitivity and station distribution. Often used to design networks and to assess hypocenter location accuracy.

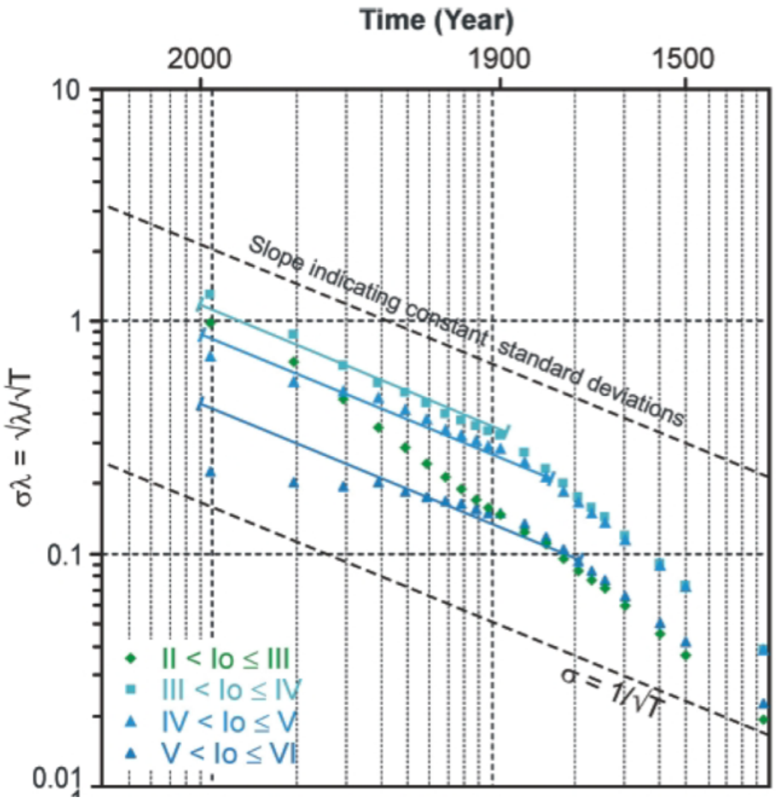



Cannot be applied to composite catalogues!

PMC
Schorlemmer & Woessner, 2008

# Stepp Method

Evaluates the stability of the mean rate of occurrences (λ) of events which fall in a predefined intensity range in a series of time windows (T).




1) If λ is constant, then the standard deviation (σ) varies as $1/\sqrt{T}$.
2) if λ is not stable, σ deviates from the straight line of the $1/\sqrt{T}$ slope.

The length of the time interval at which no deviation from that straight line occurs defines the completeness time interval for the given intensity range

<u>Require Poisson assumption</u>

# Poisson Assumption

Time-independent PSHA assumes that seismic activity within a source is represented by a "Poisson" model – for long term activity rates

A Poisson process requires three assumptions:

**Stationarity:** The rate of occurrence ($\lambda$) is constant (also results in proportionality)

**Independence:** The number of occurrences in a given interval does not dependent on the number of occurrences in preceeding intervals

**Non-simultaneity:** The probability of simultaneous occurrences is zero

# Title

Text