Preparing for Rare, Great Earthquakes

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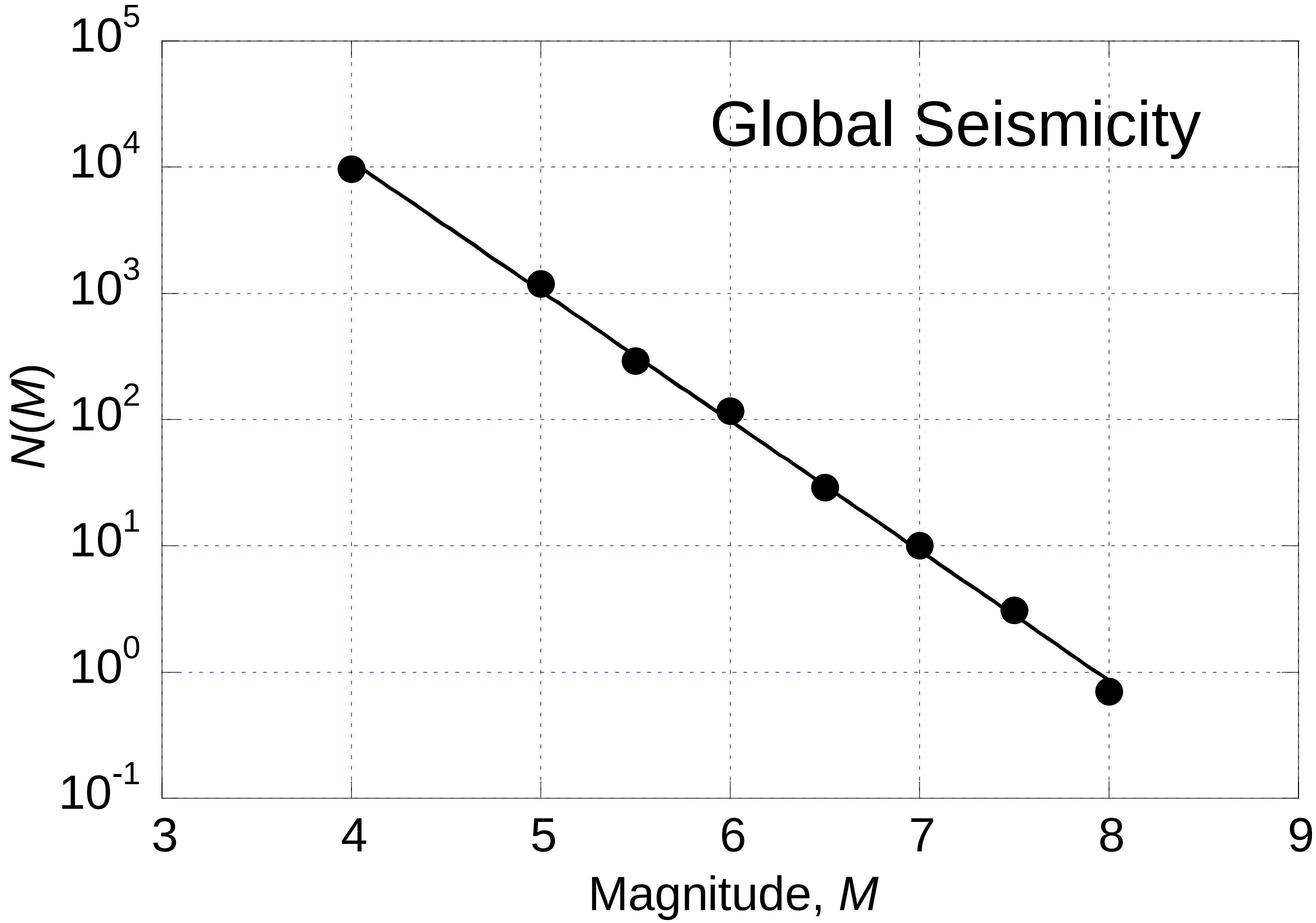
How rare are great earthquakes?

Only 4 events with $M_w \geq 9$ in the past century



M≥9 earthquakes during the last 100 years

1952 Kamchatka (9.0), 1960 Chile (9.5), 1964 Alaska (9.2), 2004 Sumatra (9.2)

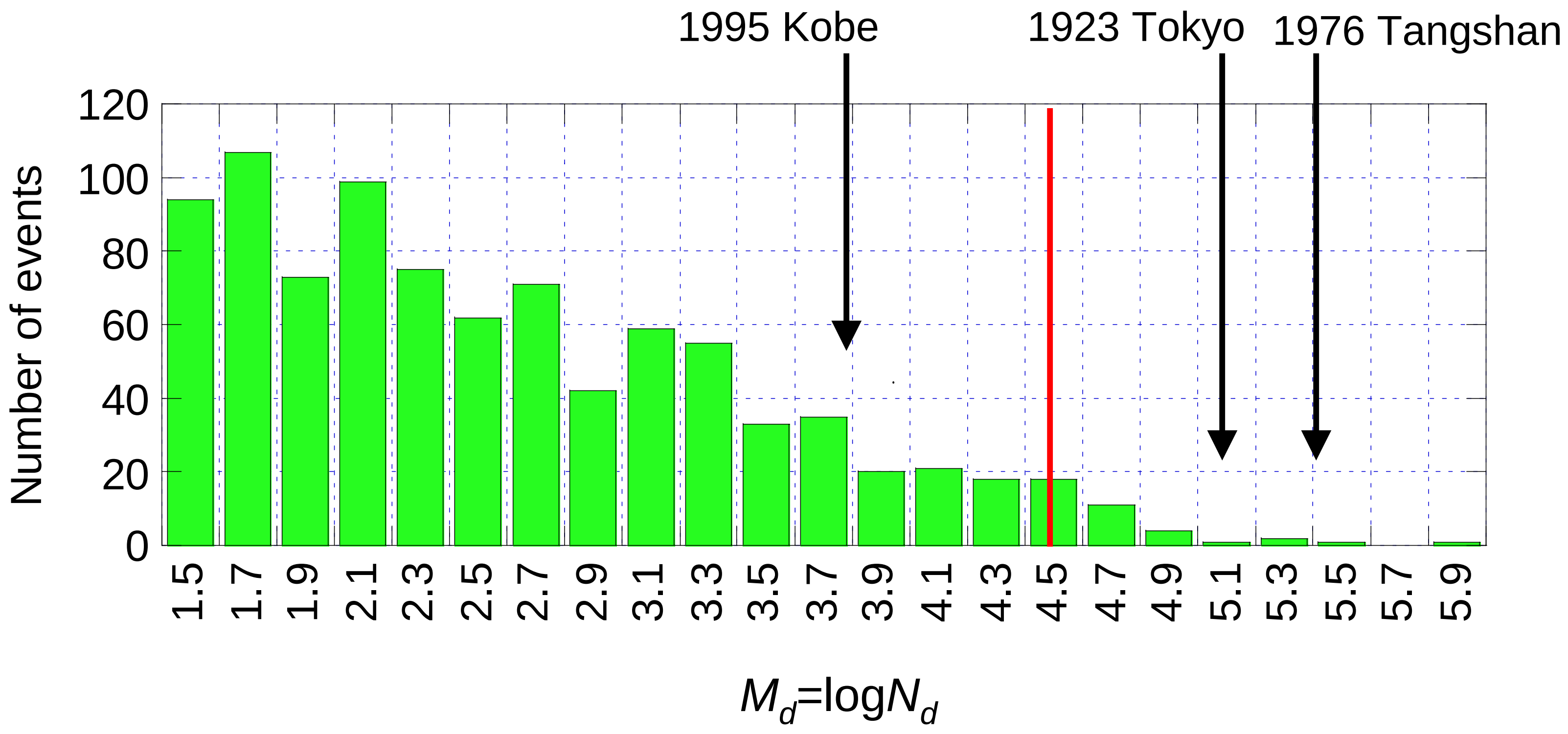
Great earthquakes are not necessarily most damaging, but some can be extremely damaging.

Impact of Rare, Damaging Earthquakes on Society (1400-2000)
900 events with death toll > 30

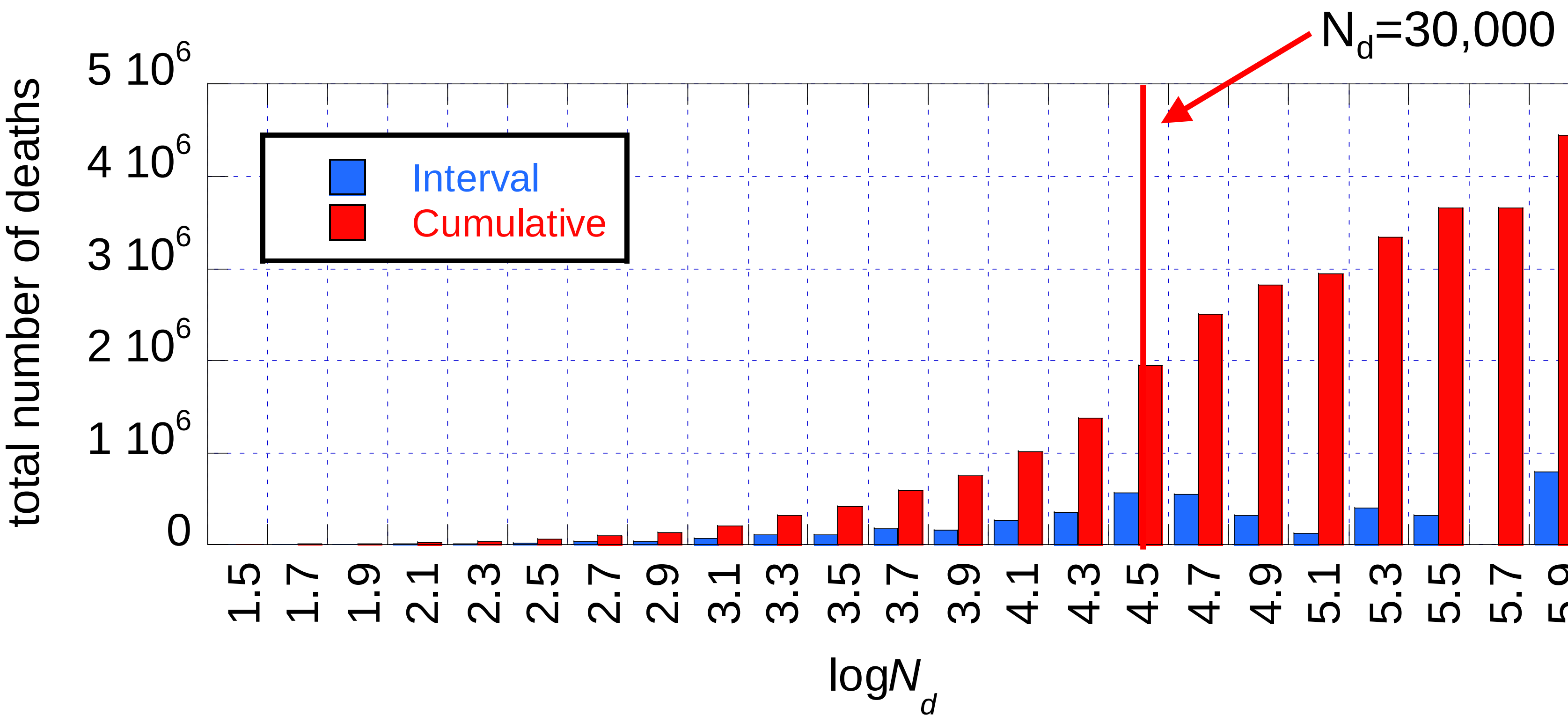
Only 36 out of the 900 events have death toll > 30,000

Utsu (2003)

$M_d = \log N_d$ N_d=Death toll, M_d=“damage” Magnitude



Yet, 2 million out of 4 million died in these 36 events with death toll > 30,000



Example:

2004 Sumatra-Andaman Earthquake (M_w=9.2)

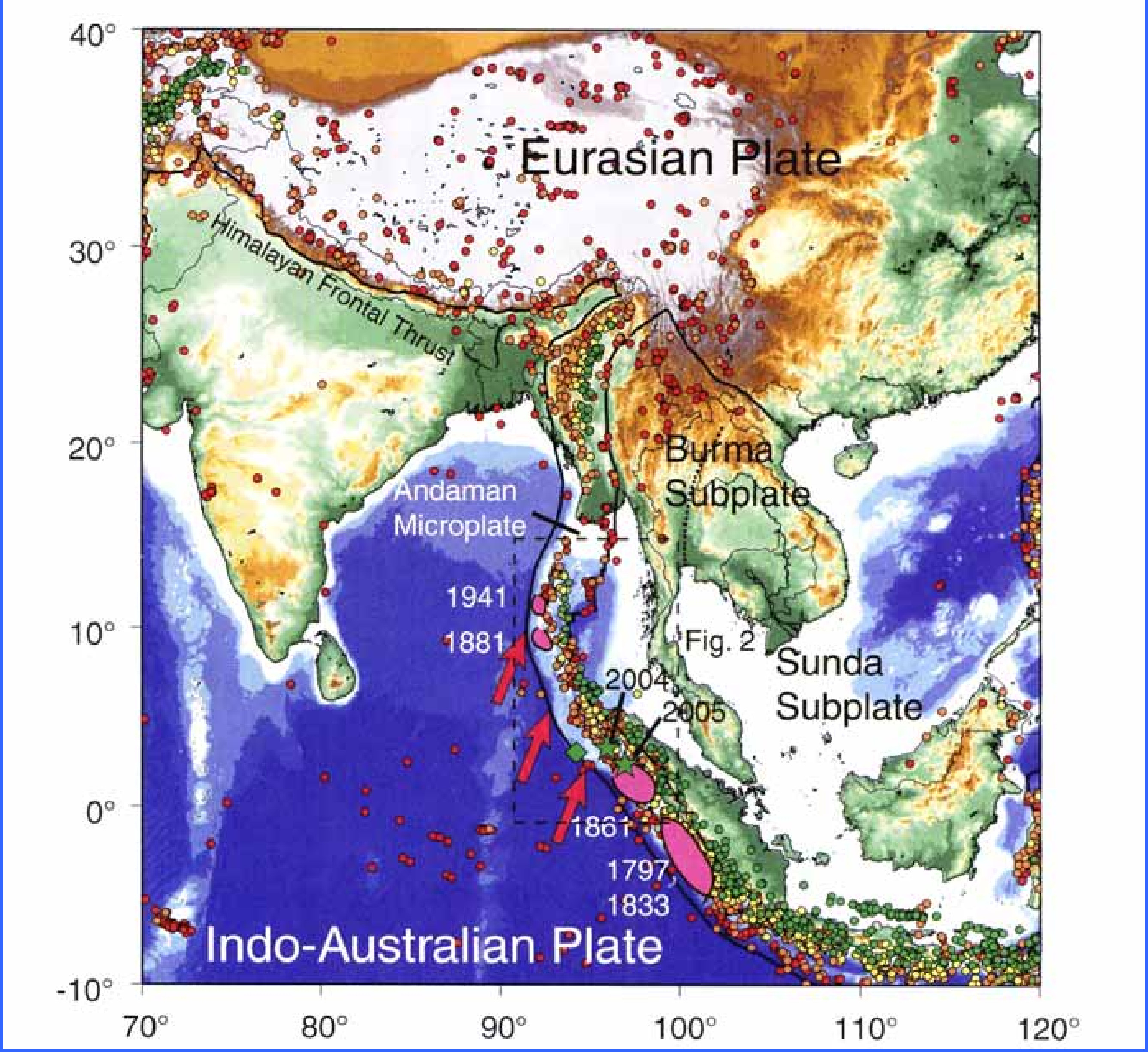
Physically, one of the largest.

One of the most damaging (death toll > 280,000).

Global Seismic Network worked well

Technical difficulty, Lack of knowledge

The 2004 Sumatra-Andaman Earthquake

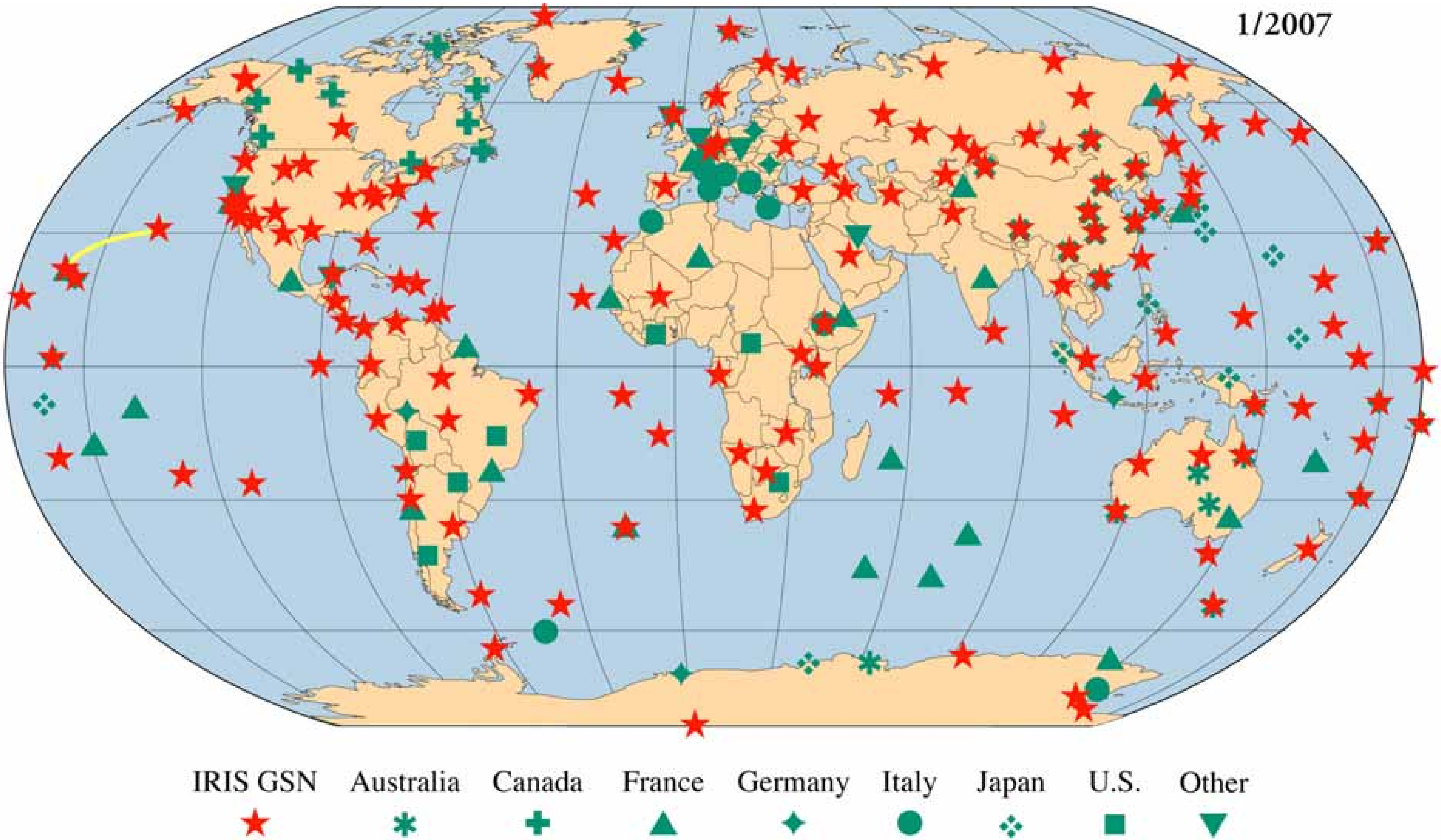


Backbone Global Seismic Network and FDSN Stations (211 stations)

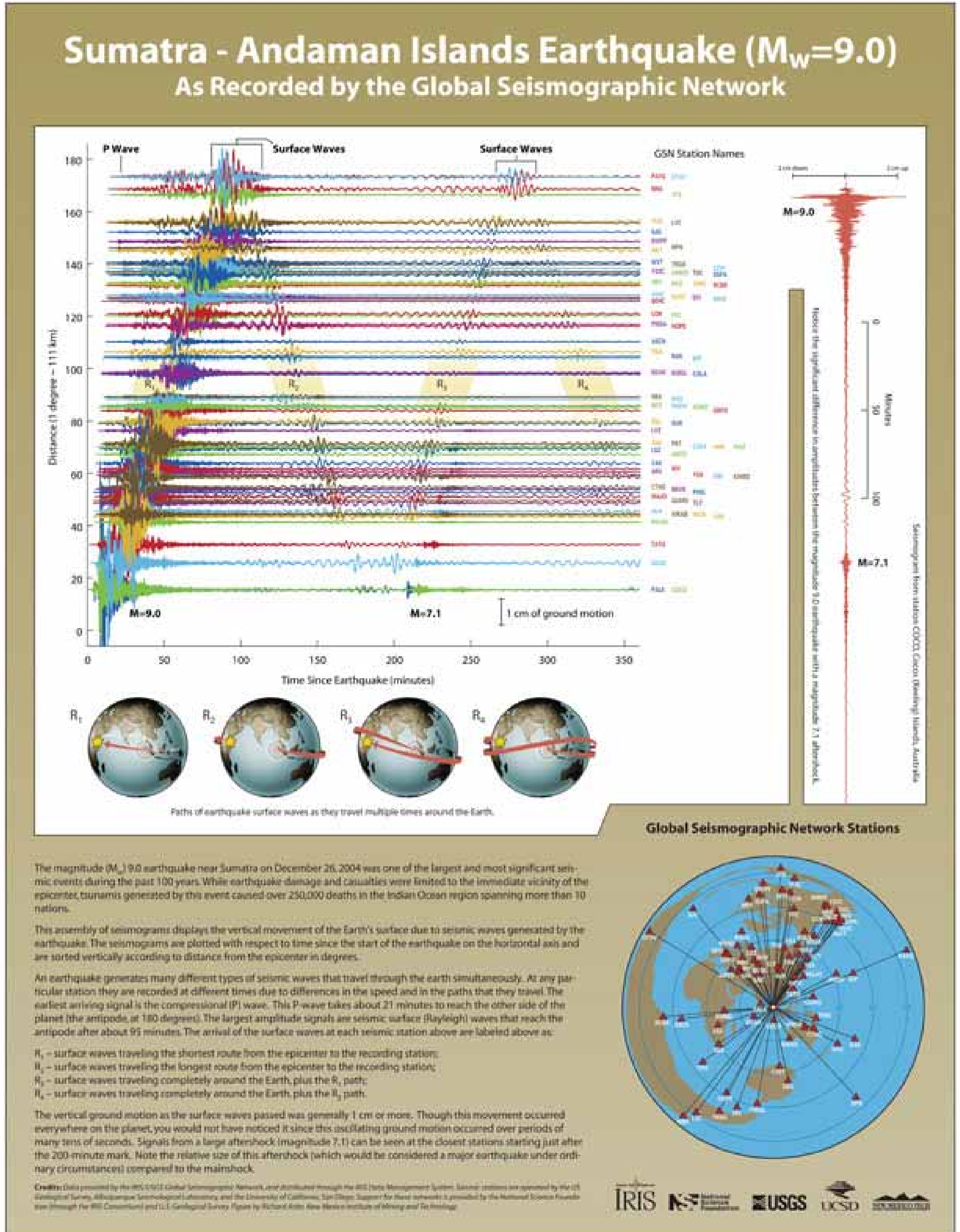
More than 500 stations, available online to seismologists

More than 100 stations, not easily available (requires special arrangement)

(FDSN: Federation of Digital Seismic Network)



Global record section of the 2004 Sumatra-Andaman earthquake

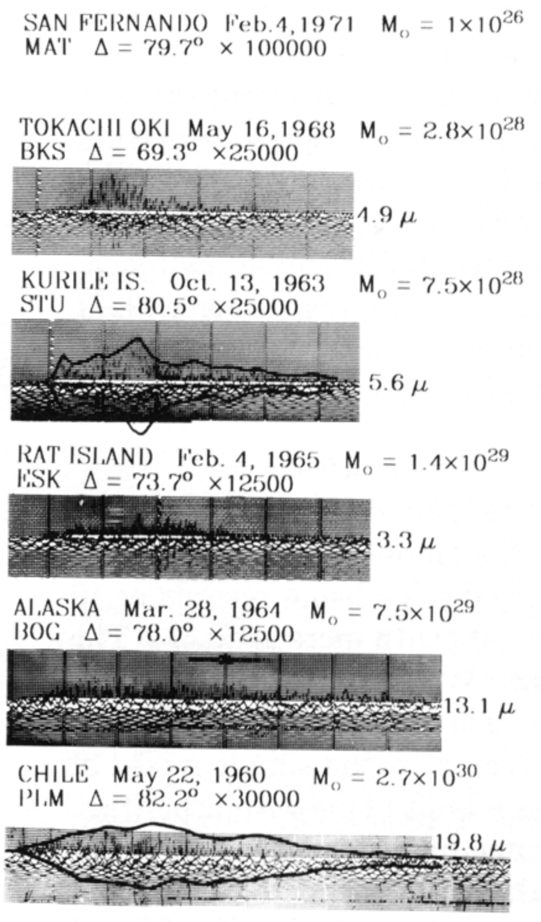


How large?

Source duration, about 500 sec

cf.   1960 Chile Earthquake (Mw=9.5),   344 sec

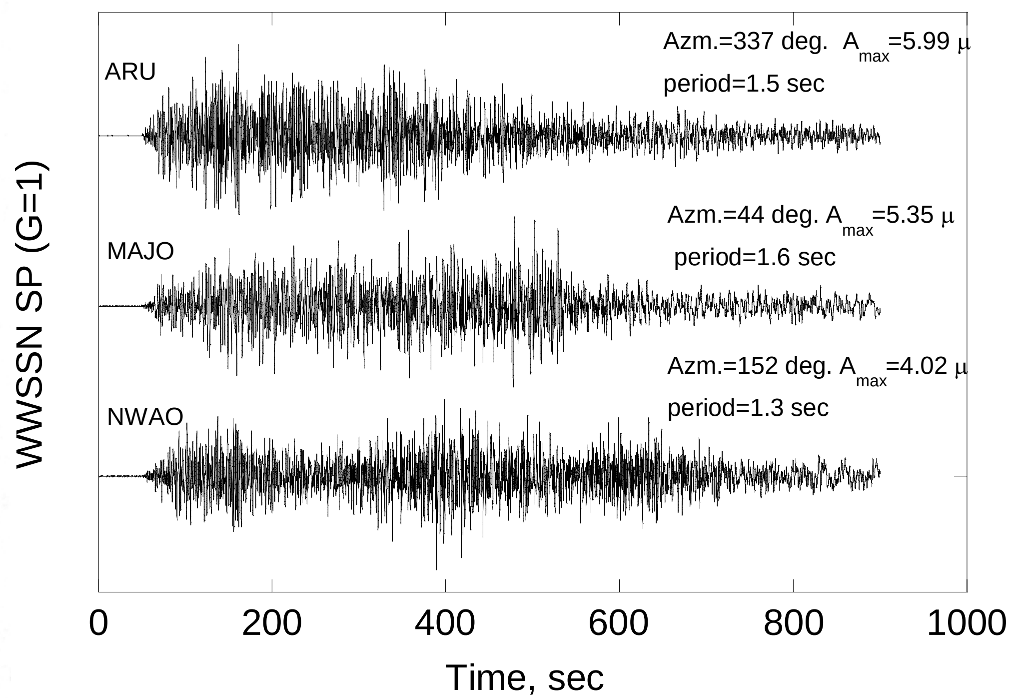
1964 Alaska Earthquake (Mw=9.2),   338 sec



1964 Alaska

1960 Chile

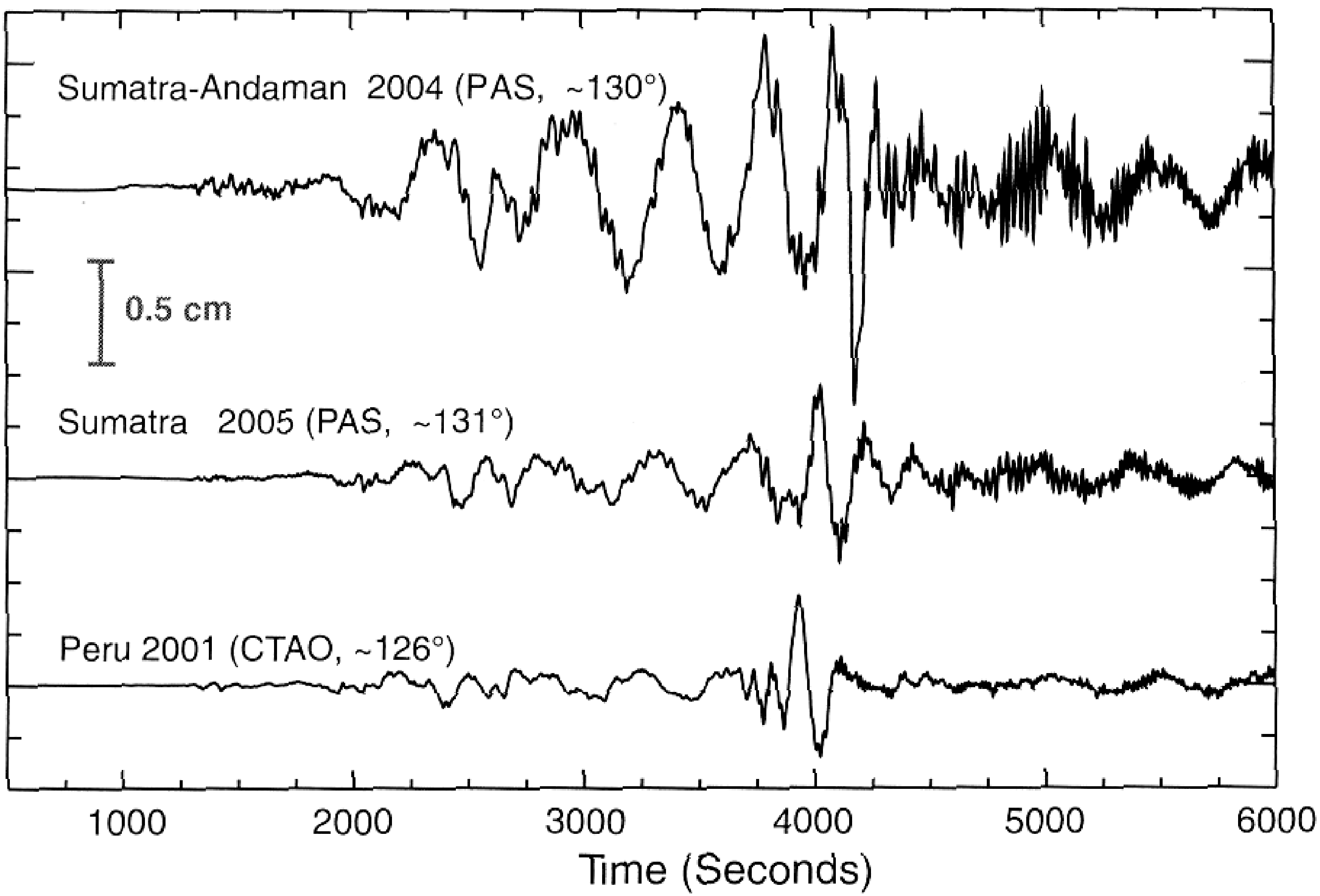
2004 Sumatra Earthquake



Houston and Kanamori, 1986

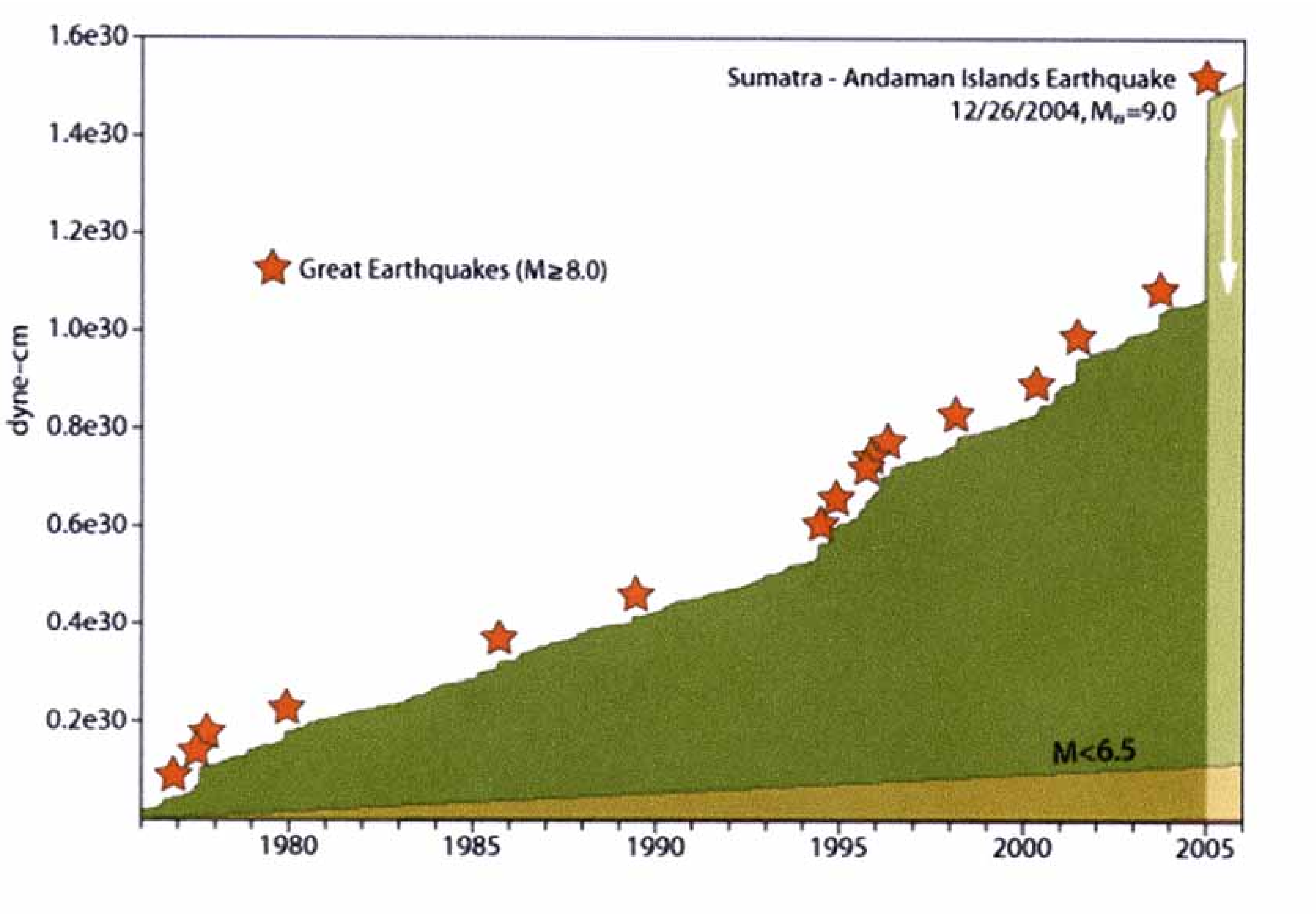
How large? Ground motion ≥ 1 cm anywhere on the planet.

Comparison with the 2nd and 3rd largest events



How large?

"Energy" release (about 1/3 of the total for the last 30 years.)



2004 Sumatra-Andaman Earthquake

Source duration in time, about 500 sec

(Ni et al., 2005; Ishii et al., 2005)

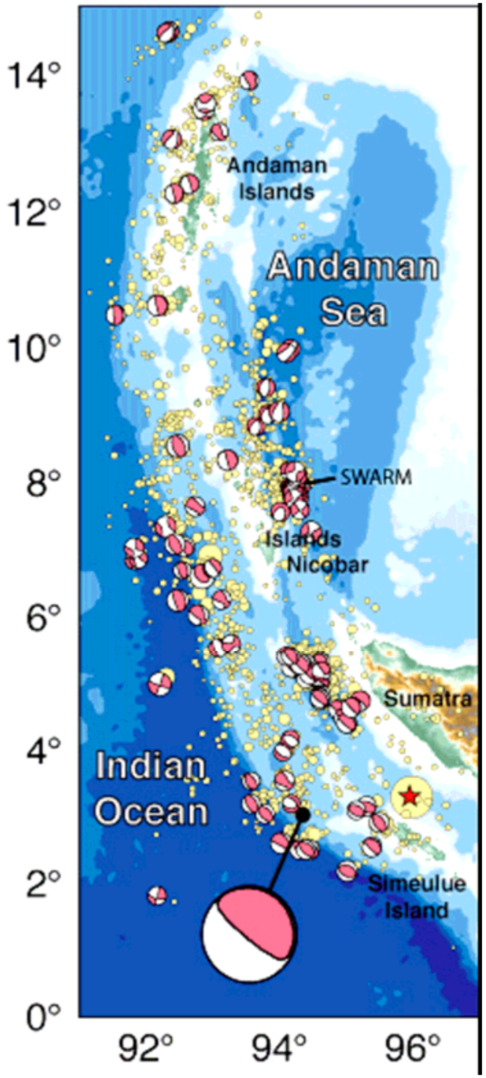
cf. 1960 Chile (Mw=9.5), 344 sec
1964 Alaska (Mw=9.2), 338 sec

(Houston and Kanamori, 1986)

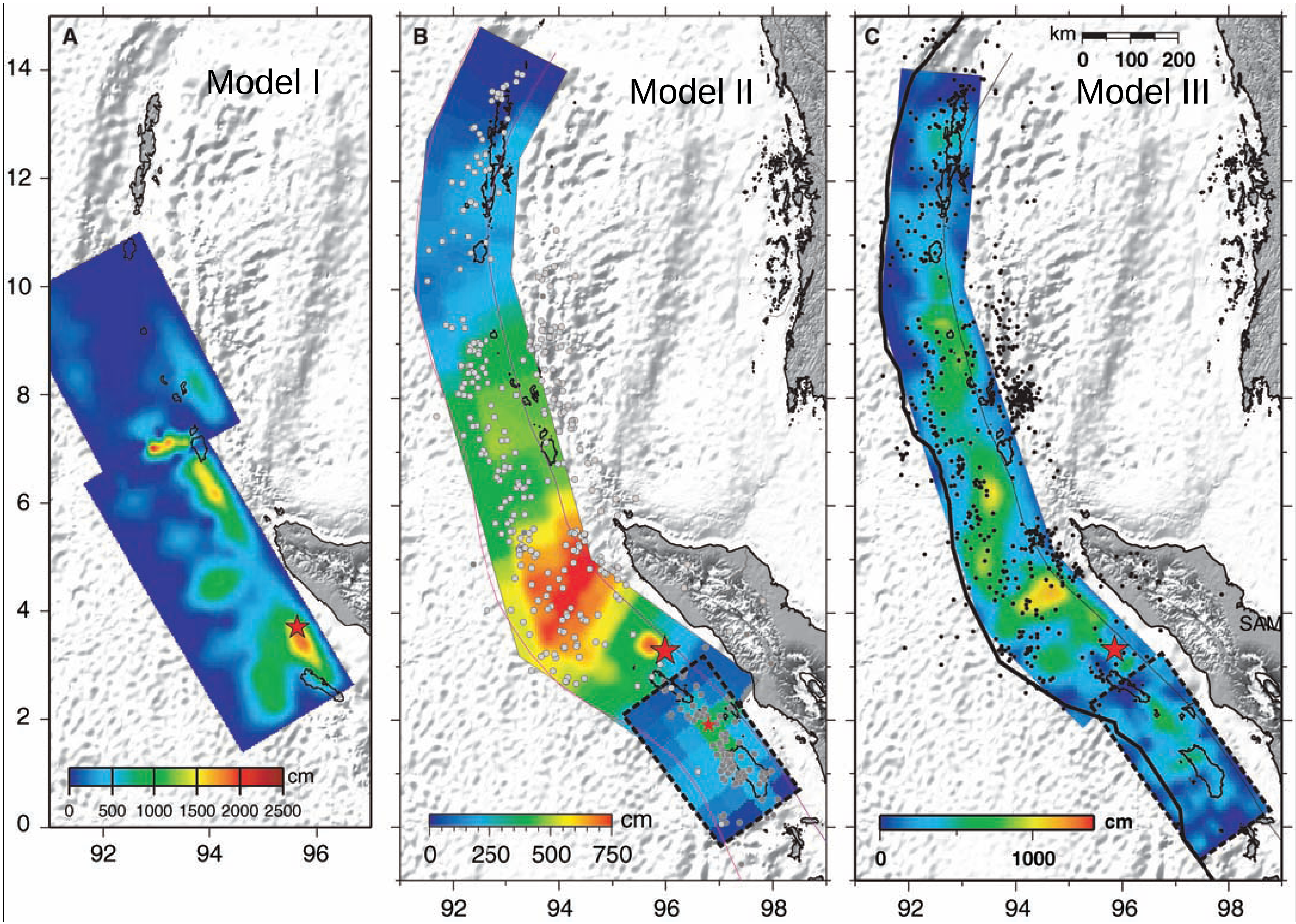
Rupture length, 1200 to 1300 km

cf. 1960 Chile (Mw=9.5), about 1000 km
1964 Alaska (Mw=9.2), about 700 km

M_w 9.0 to 9.3
M_t 9.1

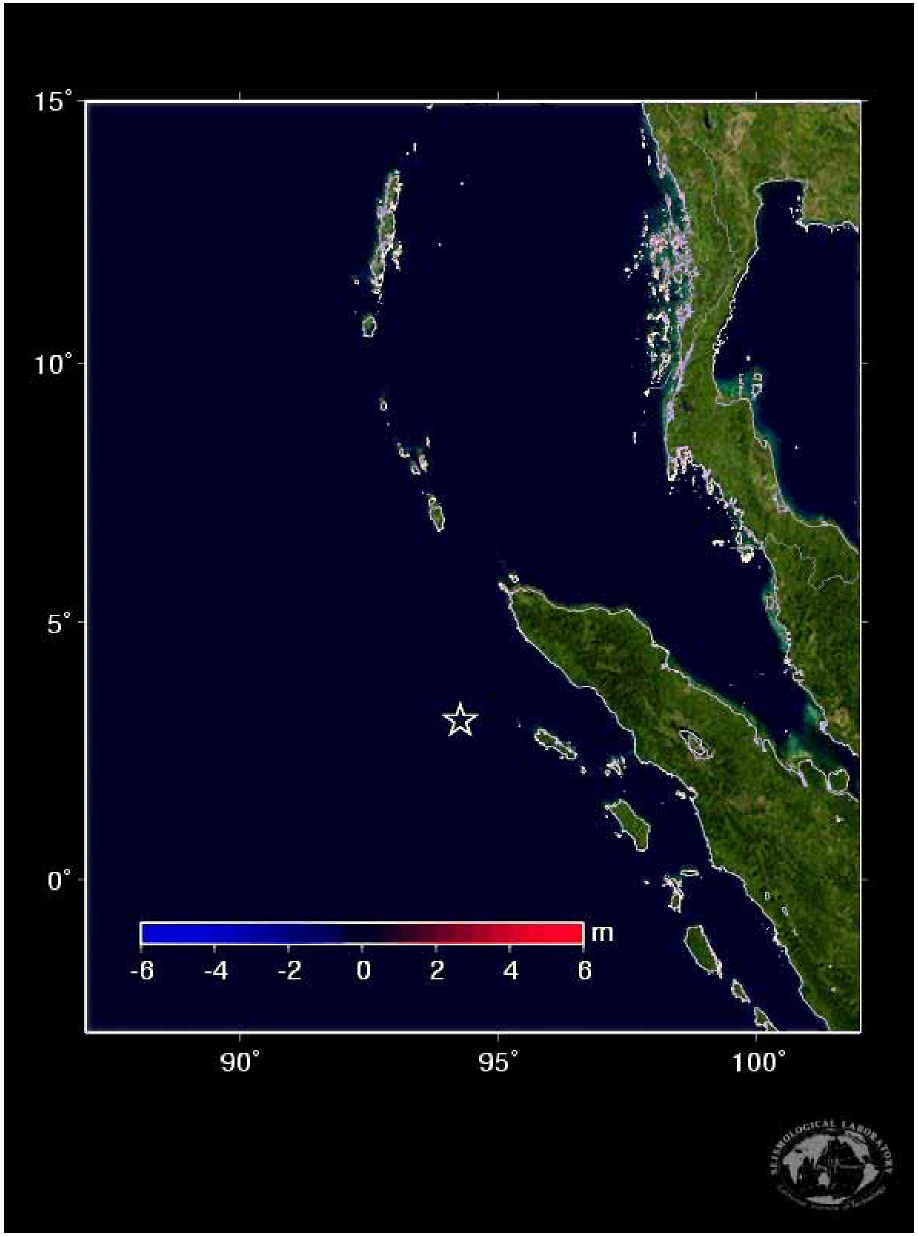


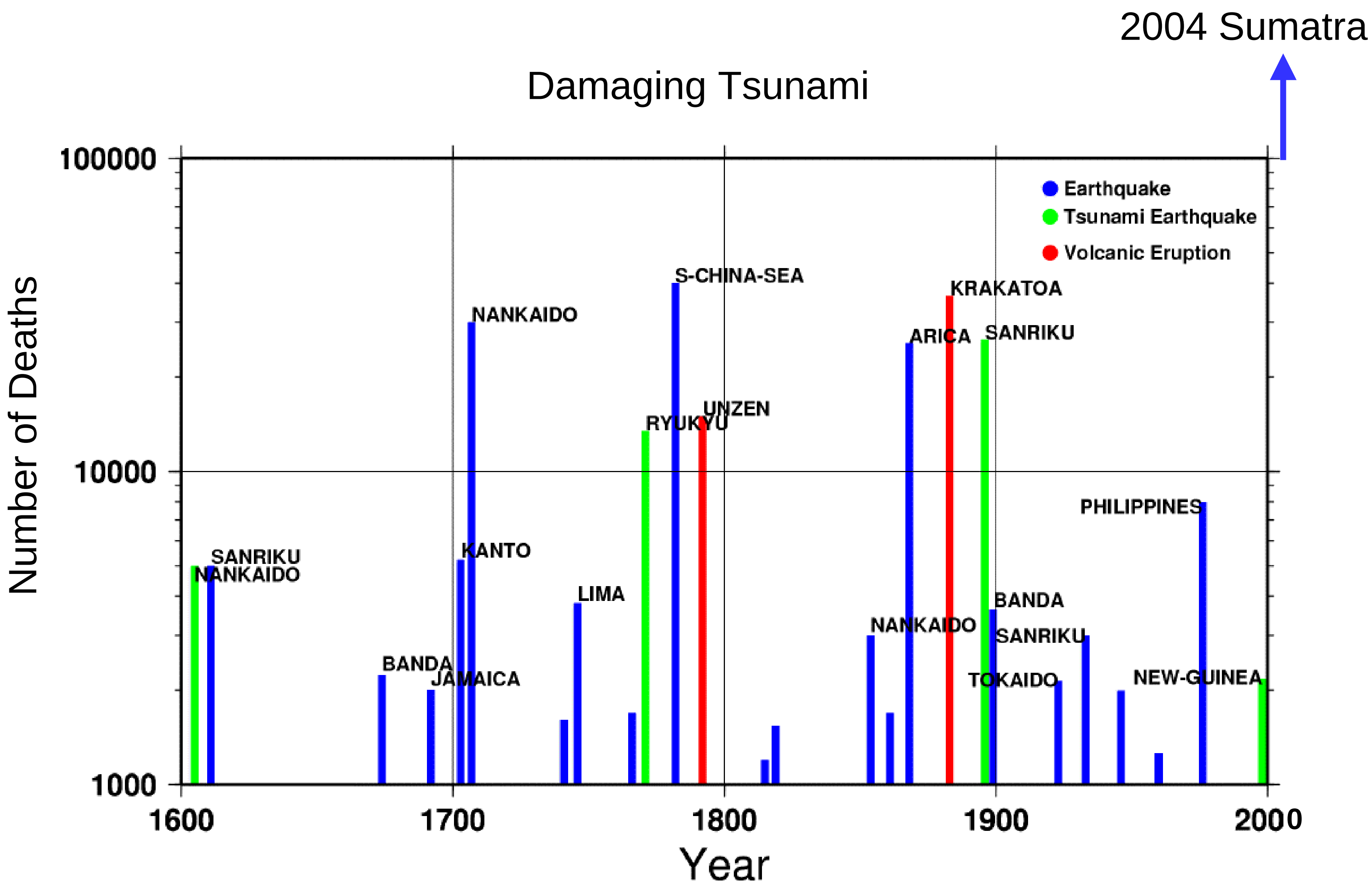
Slip Distribution from Waveform Inversion



Ground displacement

during the initial 10 min





2004 Sumatra
Damaging Tsunami
Earthquake
Tsunami Earthquake
Volcanic Eruption
S-CHINA-SEA
KRAKATOA
NANKAIDO
ARICA
SANRIKU
UNZEN
RYUKYU
PHILIPPINES
SANRIKU
NANKAIDO
KANTO
LIMA
BANDA
NANKAIDO
SANRIKU
BANDA
JAMAICA
TOKAIDO
NEW-GUINEA
100000
10000
1000
Number of Deaths
1600
1700
1800
1900
2000
Year

Technical problems

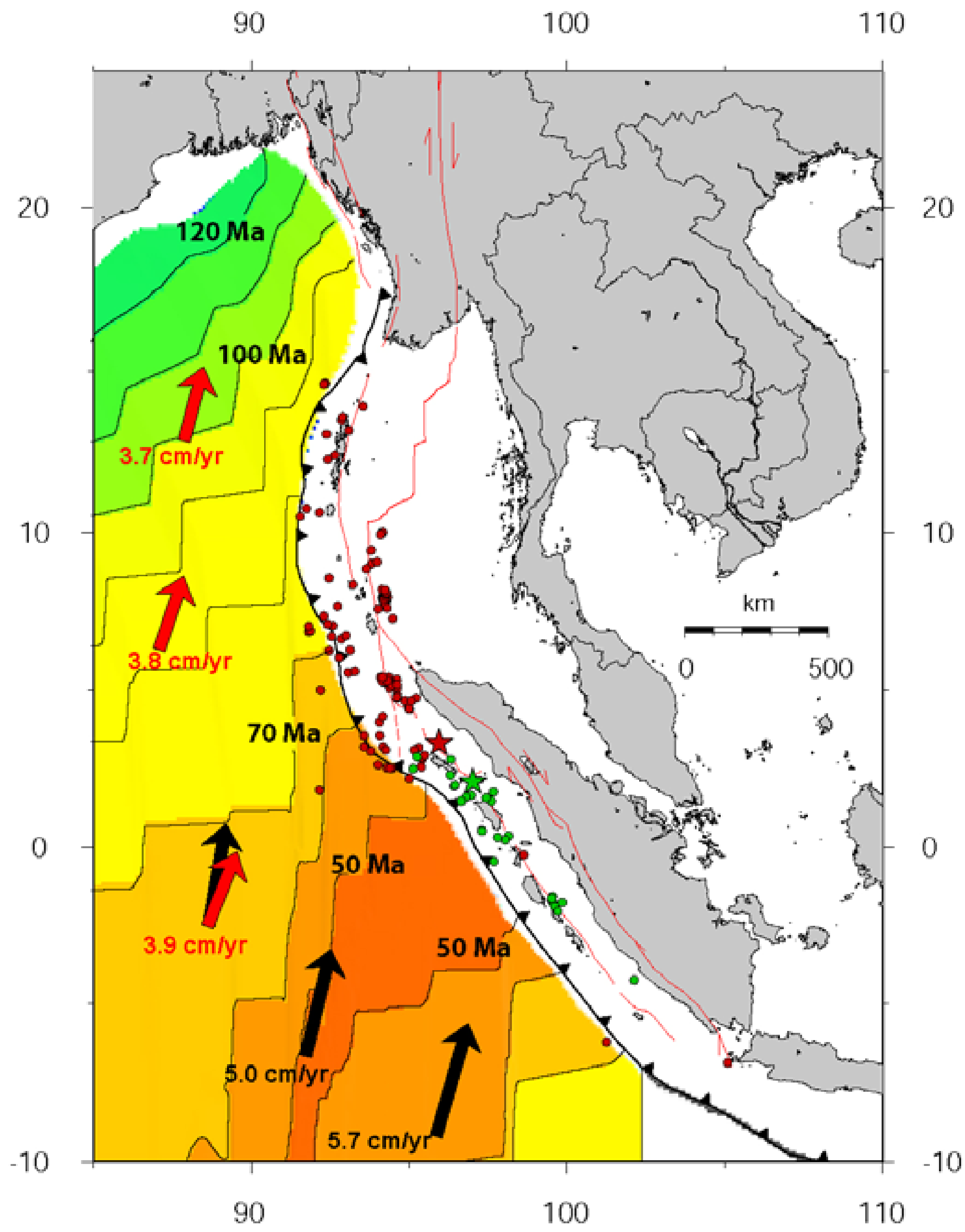
No real-time methods could handle the long duration and the long-period waves properly.

Lack of Knowledge

Great earthquakes in the Andaman Is. not expected by most seismologists.

Expected?

Zone	Age (My)	V (cm/y)	Mw
Chile	20	11	9.5
Alaska	40	6	9.2
Kamchatka	80	9	9.0
Sumatra	60	3	9.2



Practical Difficulty

Long-term monitoring for such events is difficult.

The monitoring system needs to be maintained for very rare events.

Needs long-term financial support as well as sustained interest.

Solution?

Deployment; Maintenance; Data Archive-Distribution-Exchange; Research should be budgeted together.

Data should be constantly used by researchers.

An outstanding problem: Tsunami Warning

1. Seismic, Technically Feasible, 10 to 30 min, False Alarm
2. Water wave, Verification, Technically feasible, Expensive (Buoy, OB Cable)
3. Local infrastructure, Some exist (Hawaii, Alaska, Japan, ...)
4. Education and Training, Difficult for rare events

Seismic Methods

Merits:

- Seismic networks and infrastructures exist
- Long-range
- Versatile

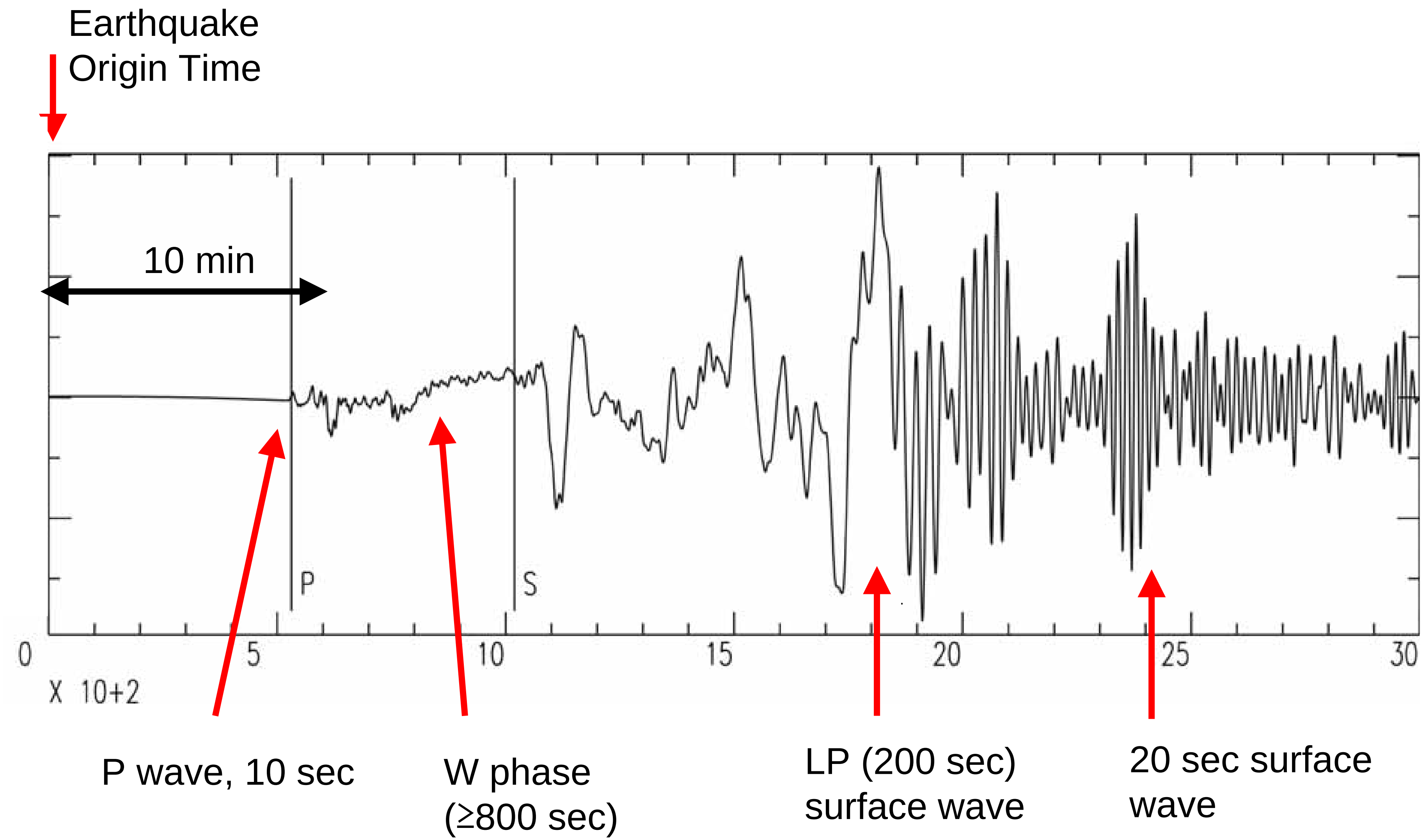
Demerits:

- Indirect (i.e., does not measure water waves) → false alarms
- Too slow for near-field tsunami (finite wave propagation time)

Future direction:

- For $M_w \geq 9$ (almost certainly tsunamigenic)
- Use of very long-period waves (≥ 800 sec)

Illustration of Seismic Phases on a Seismogram at ~7000km

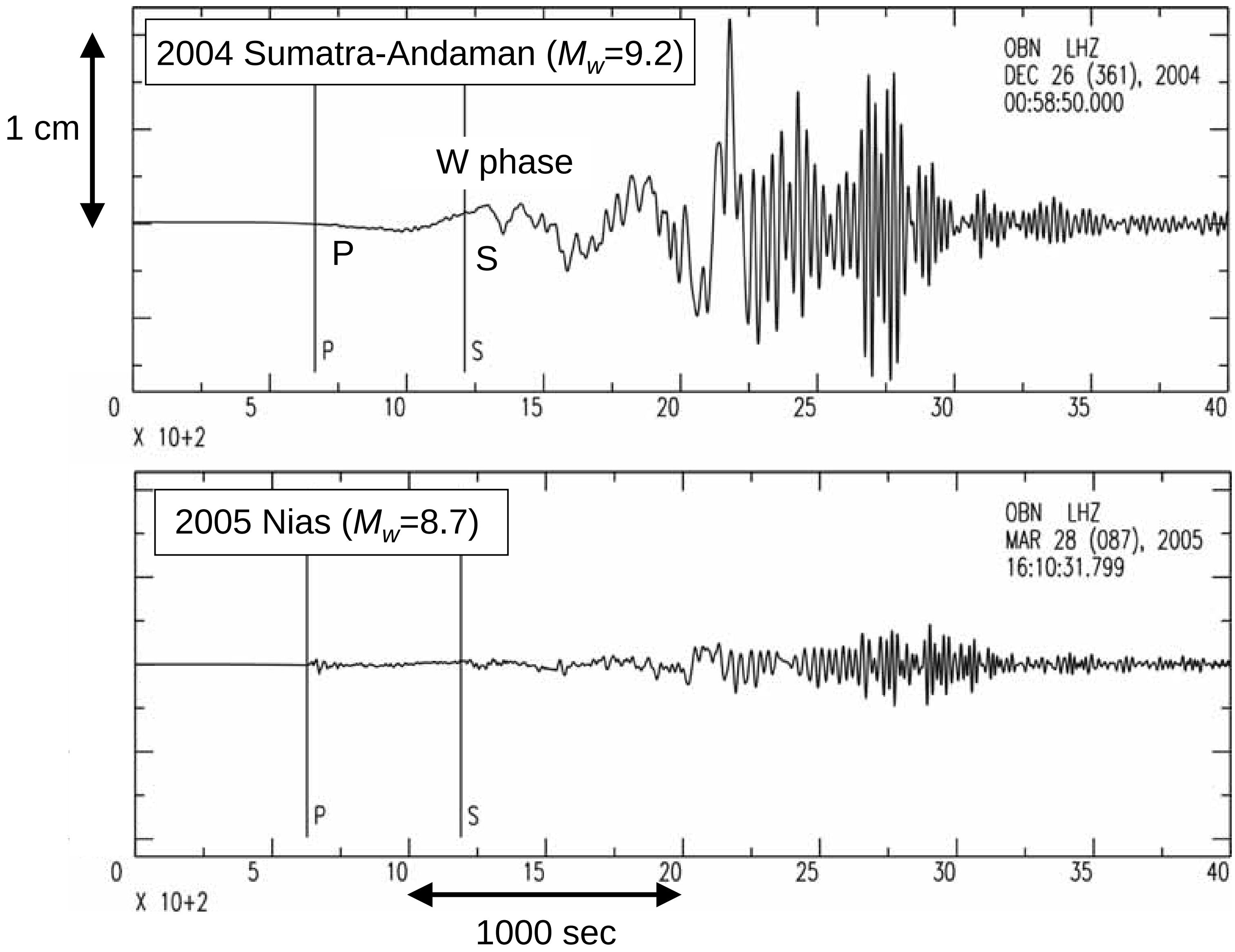


Problem with using short-period waves for tsunami warning of great earthquakes

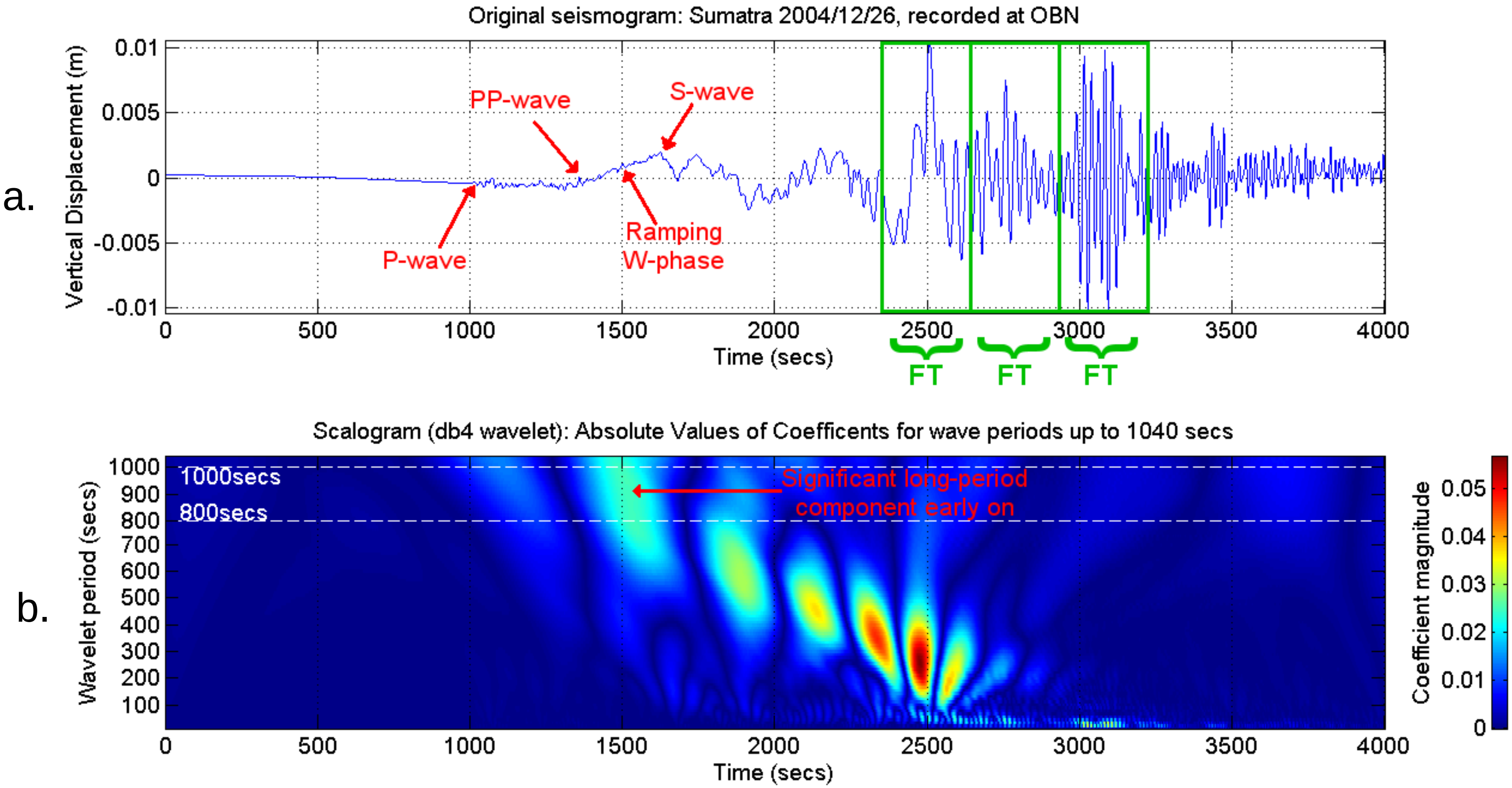
Short period ($T \leq 200$ sec) magnitude saturates.

i.e., cannot assess the true tsunamigenic potential of great earthquakes

Diagnostics of Tsunami Potential



Wavelet Scalogram of the Sumatra-Andaman Earthquake



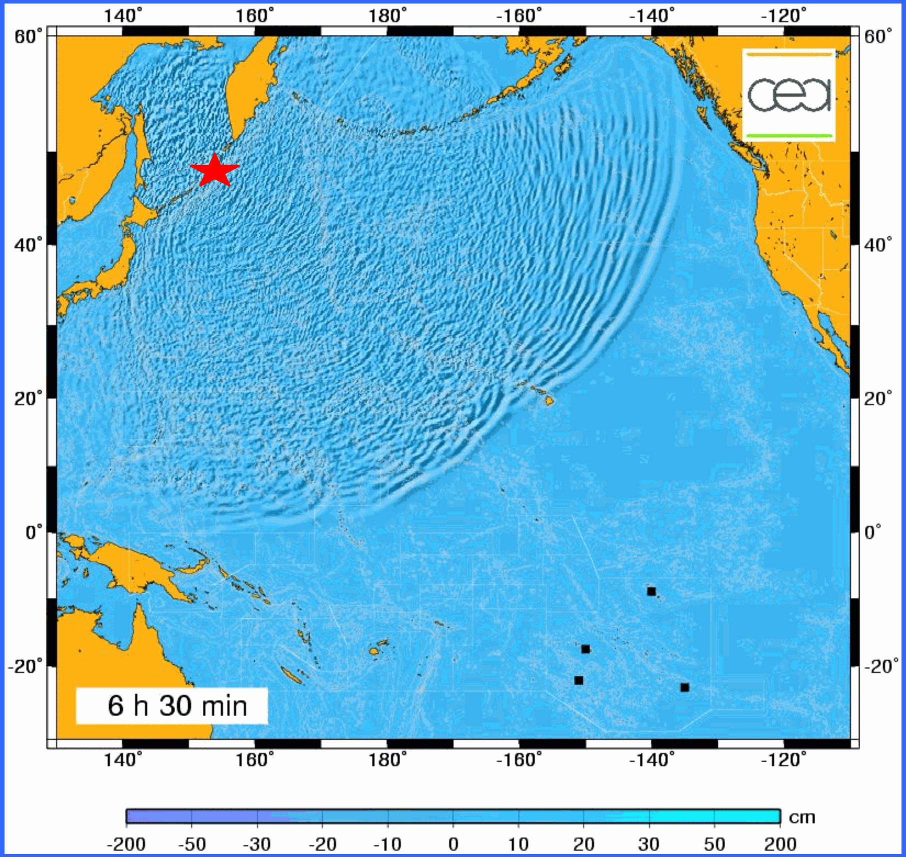
Lockwood and Kanamori (2006)

Recent Accomplishments:

- Tsunami Warning of Nov. 15, 2006 Kuril Is. Earthquake (M_w=8.3)
- NIED/JMA Seismic Early Warning
- Tsunami Warning of July 17, 2006 Java Tsunami Earthquake

Nov. 15, 2006 Kuril Is. Earthquake, M_w=8.3

JMA Tsunami Warning



8:15 PM Origin time

8:29 PM Warning issued

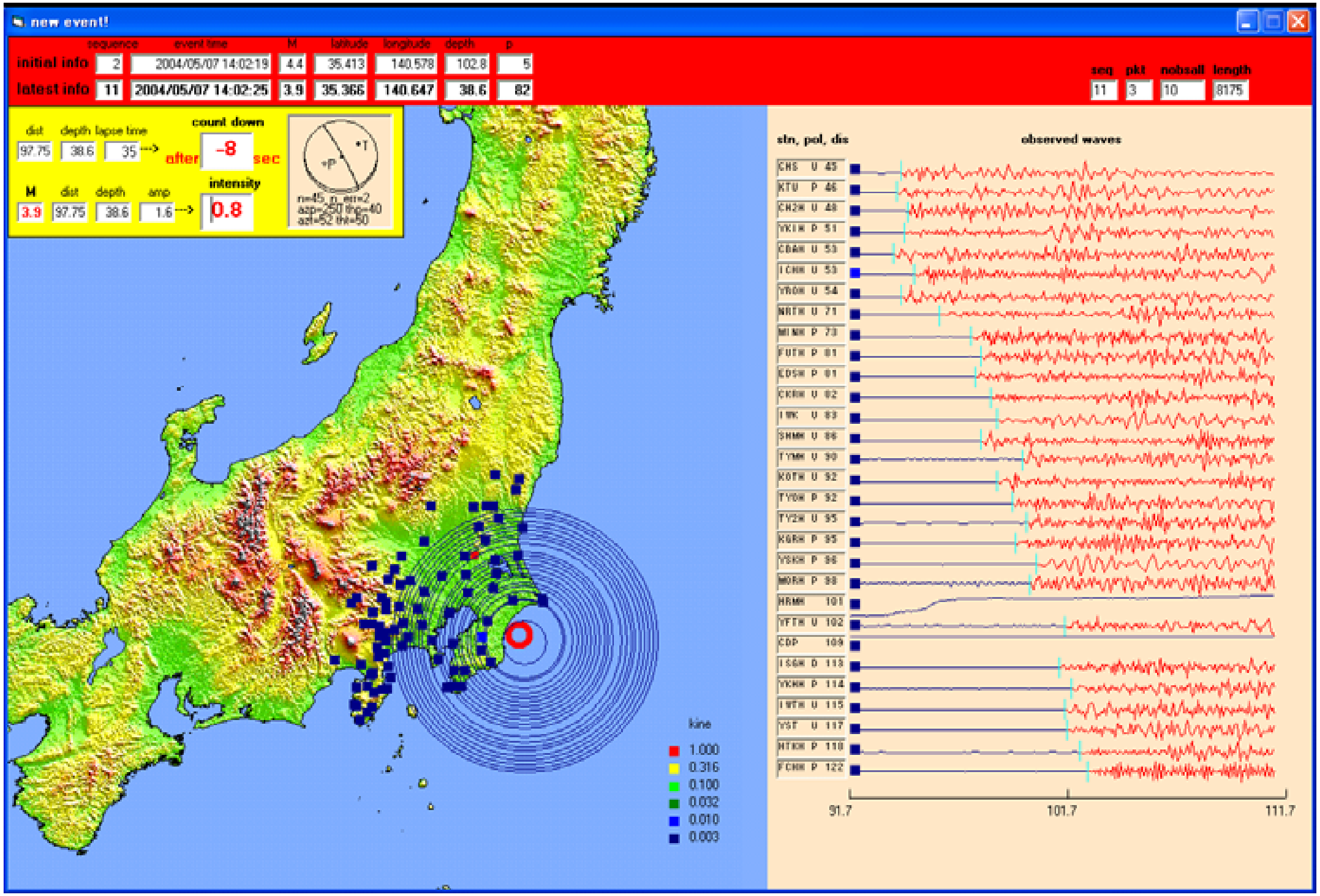
Wave height estimated

From this time on: NHK continuously broadcasted update of warning.

Entire Japanese population was given minute by minute update.

Real-time Earthquake Information System (NIED)

Warning for ground shaking before it starts



July 17, 2006, Java

15:19 Earthquake

~15:30 BMG announces that there is no danger of a tsunami (M6.8)

15: 36 Pacific Tsunami Warning Center issues local watch for Indonesia and Australia (M7.2)

15:46 JMA issued tsunami watch for Indian Ocean (same as PTWC message)

~16:15 Tsunami hit Pangandaran

From Jim Mori

Conclusion

- Great earthquakes are rare but can be extremely damaging
- Long-term monitoring for such events is difficult

  Because of rarity,

    Network for only monitoring purposes is impractical.

    Insufficient knowledge, Inadequate methodology

    More research and development are necessary.

- Instrument Network

    Data should be open to researchers and should be constantly used. Prerequisite for reliable operation.

    Deployment-operation-maintenance-research should be supported as a whole.

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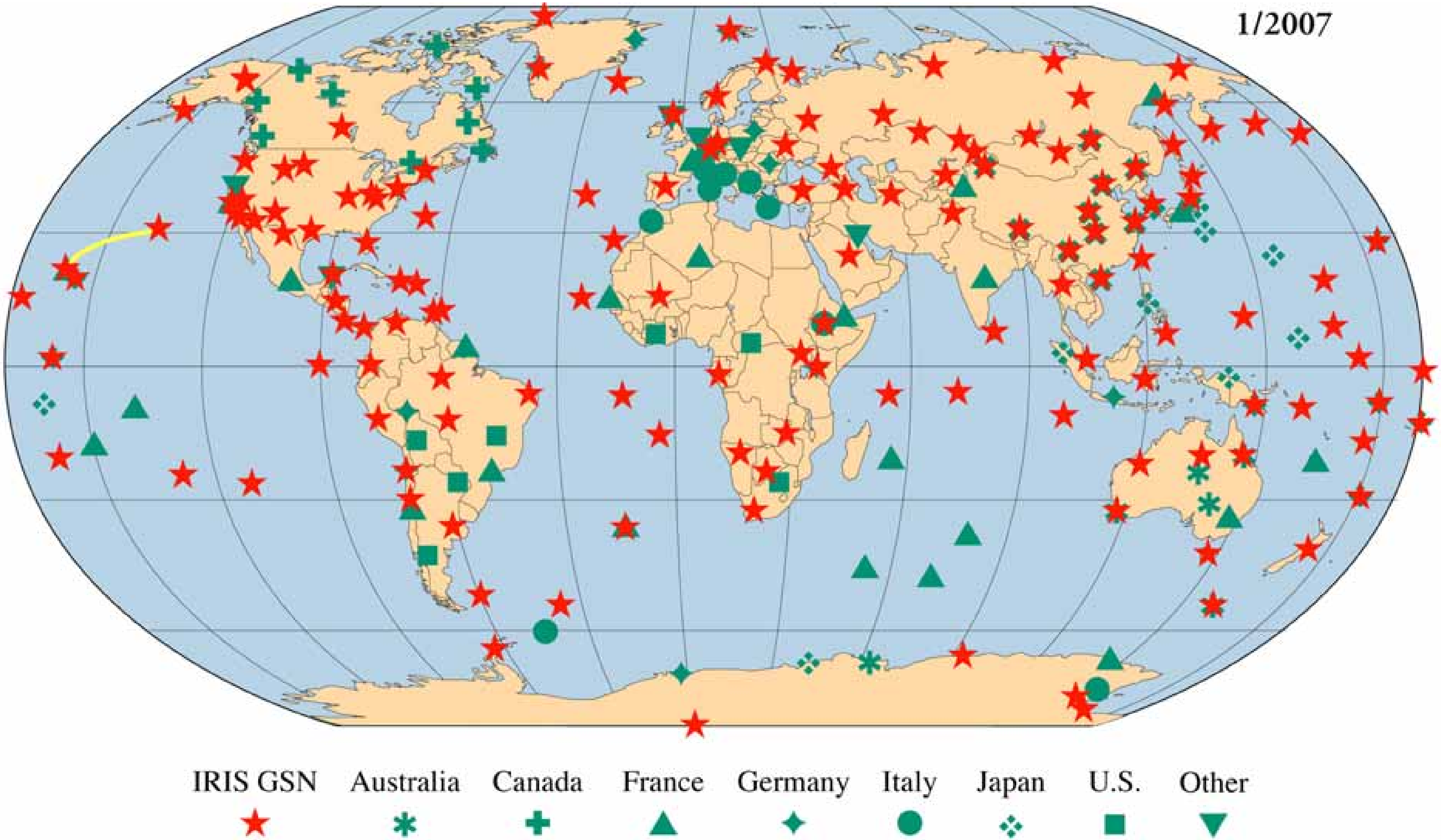
More than 100 stations, not easily available (requires special arrangement)

(FDSN: Federation of Digital Seismic Network)



End

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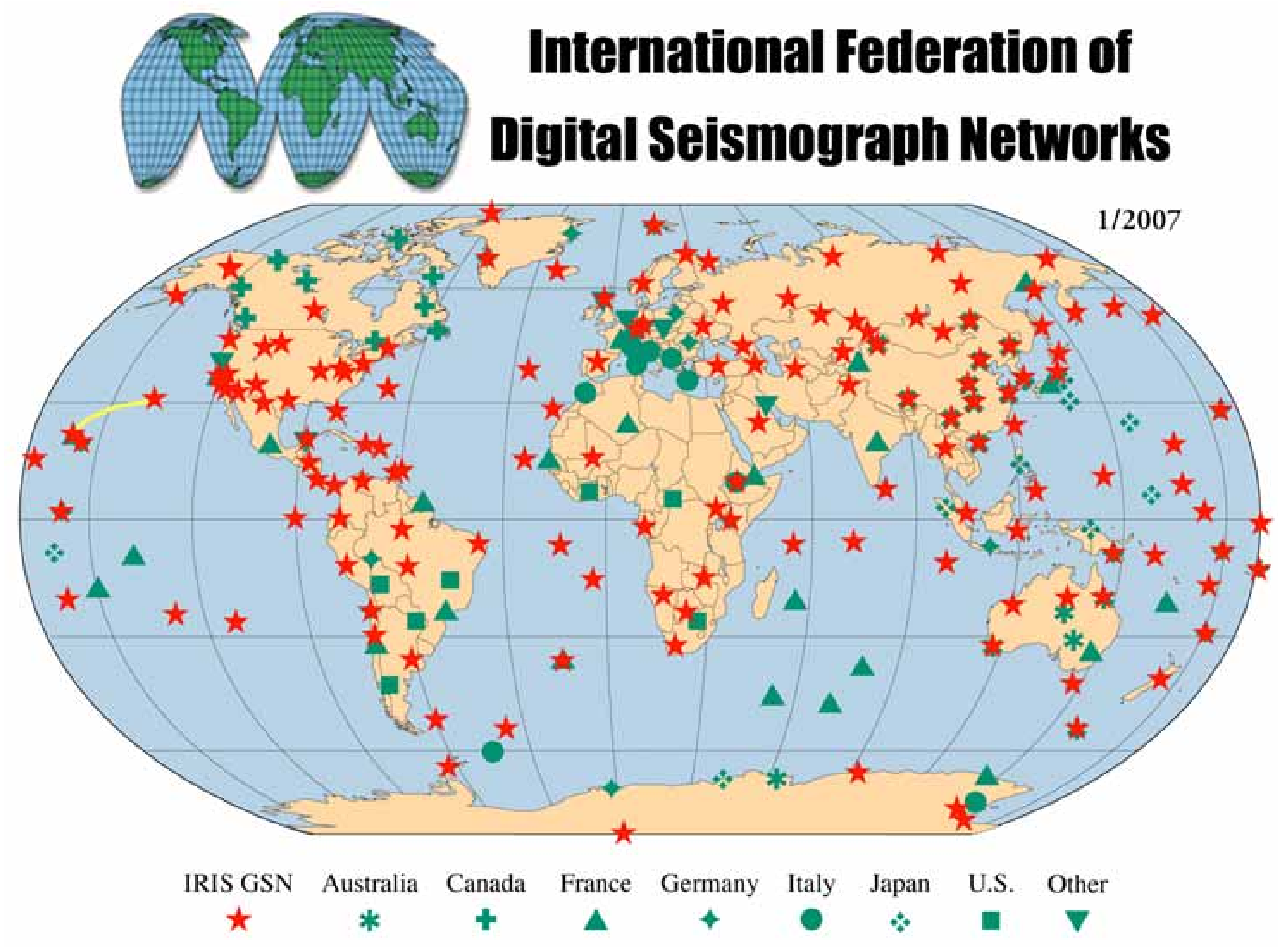
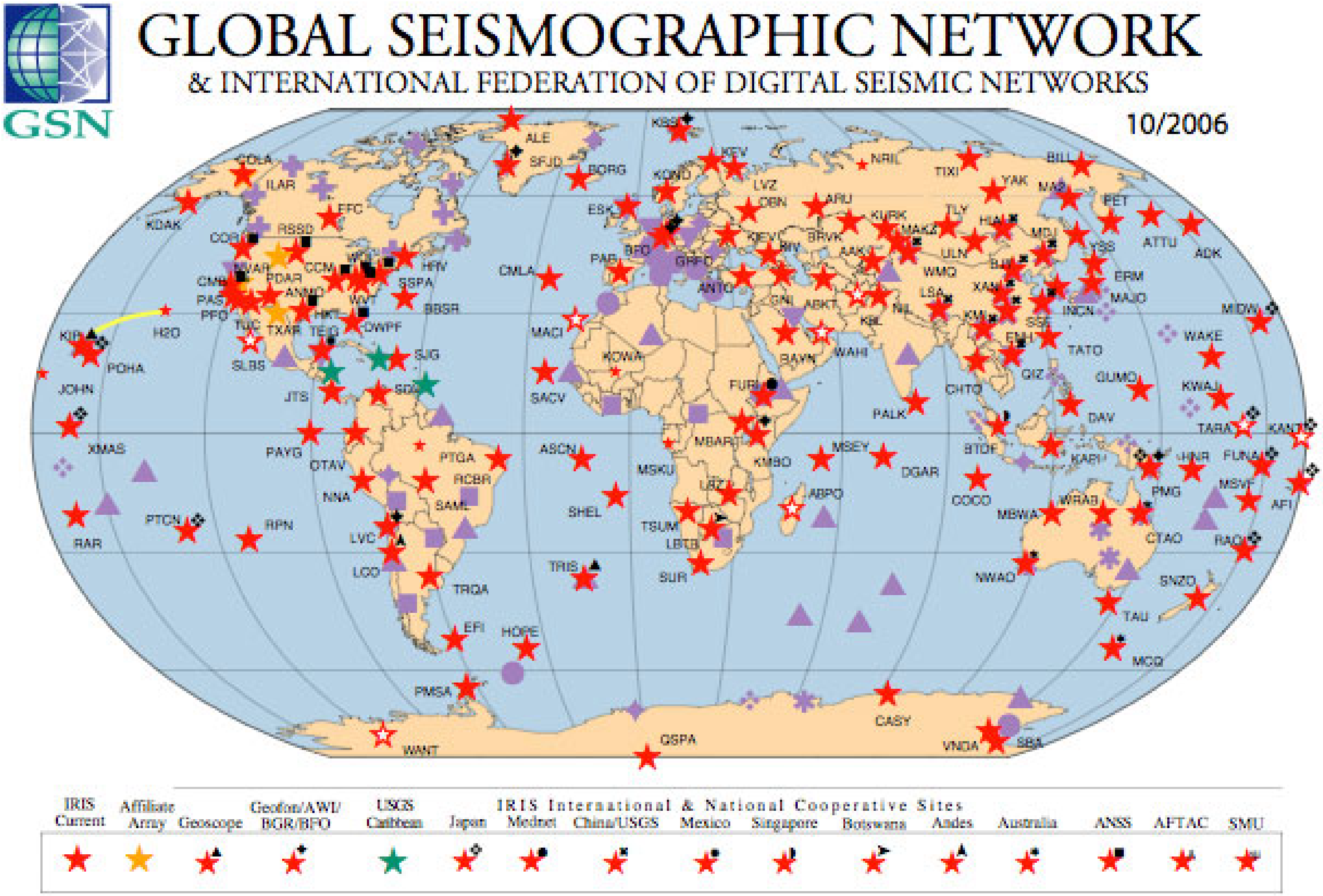


More than 400 stations, available online to seismologists



Summary

- Great earthquakes are rare but can be extremely damaging
- Example: 2004 Sumatra-Andaman Earthquake (M_w=9.2)

  Global Network worked well

  Technical difficulty, Lack of knowledge
- Long-term monitoring for such events is difficult
- Instrument Network

  Deployment; Maintenance; Data Archive, Distribution, Exchange; Research should be budgeted together

  Data should be constantly used by researchers