Schweizerischer Erdbebendienst
Swiss Seismological Service

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

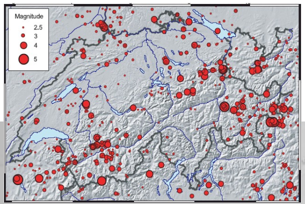
State-of-the-art in earthquake early warning and implications of real-time OBS deployments

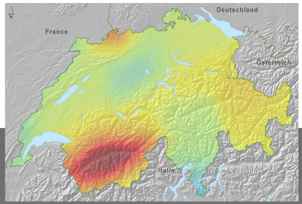
Georgia Cua

Swiss Seismological Service, ETH Zürich

contributions from

Richard Allen, *UC Berekely*
Masumi Yamada, Jim Mori *DPRI, Kyoto University*
Hiroo Kanamori, *Caltech*
Andreas Krause, *ETH Zürich/Caltech*
California Integrated Seismic Network EEW Team





26 May 2011

Outline

- What is Earthquake Early Warning (EEW)
- JMA system & performance during

  M9.0 Tokohu earthquake
- EEW efforts in California
- EEW in Europe
- Conclusions and Outlook

"Kinkyu Jishin Sokohu"

Namazu = in Japanese mythology, a giant catfish who causes earthquakes

EEW is not a new idea…

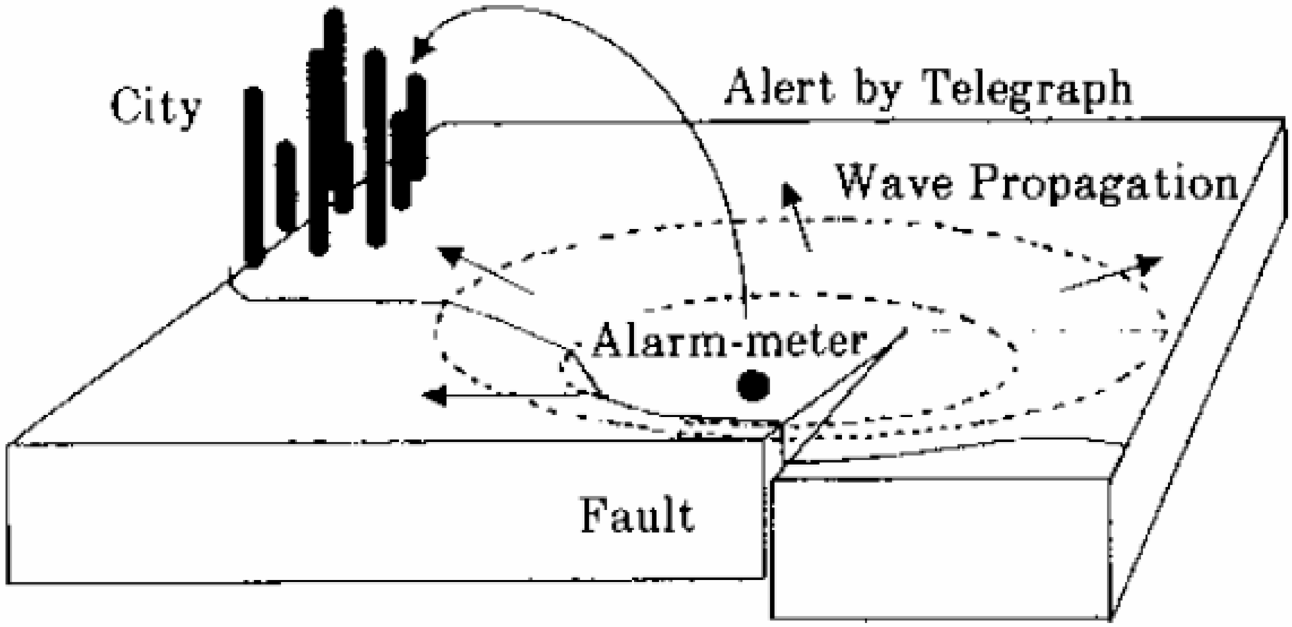
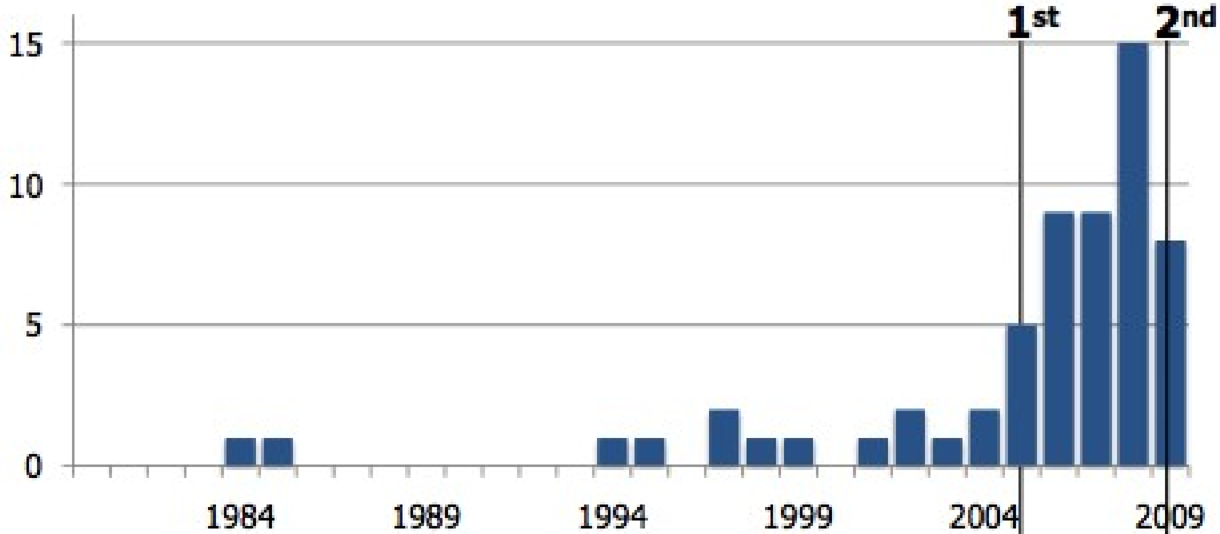


Fig. 1 Concept of the Front Alarm by Dr. J. D. Cooper.

from J. D. Cooper, 1868
courtesy of H. Negishi, NIED

Accelerating early warning development

Number of early warning publications per year

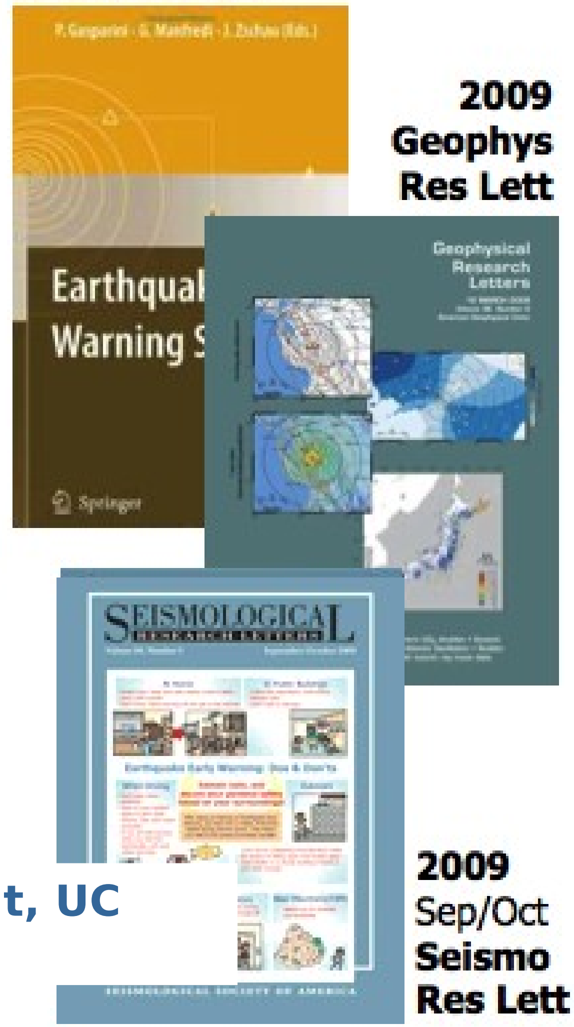


2005: 1st International EEW conference, Caltech

2009: 2nd International EEW conference, Kyoto

2007 Springer

2009 Geophys Res Lett



2009 Sep/Oct Seismo Res Lett

2011 Soil Dyn Earthquake Eng

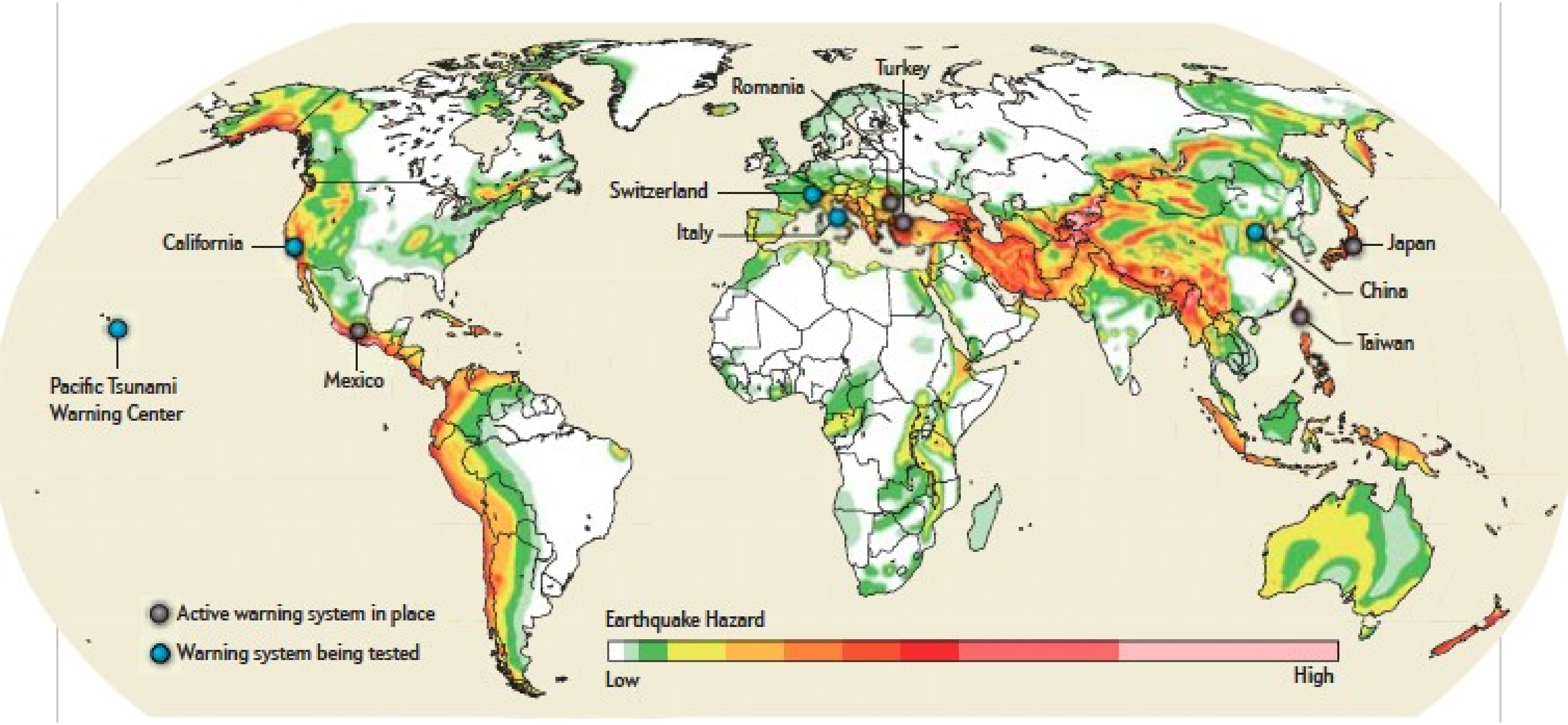
2011: EEW Summit, UC Berkeley

Development projects

California: CISN ShakeAlert
Europe: SAFER / REAKT
Japan: Implementation of public warning

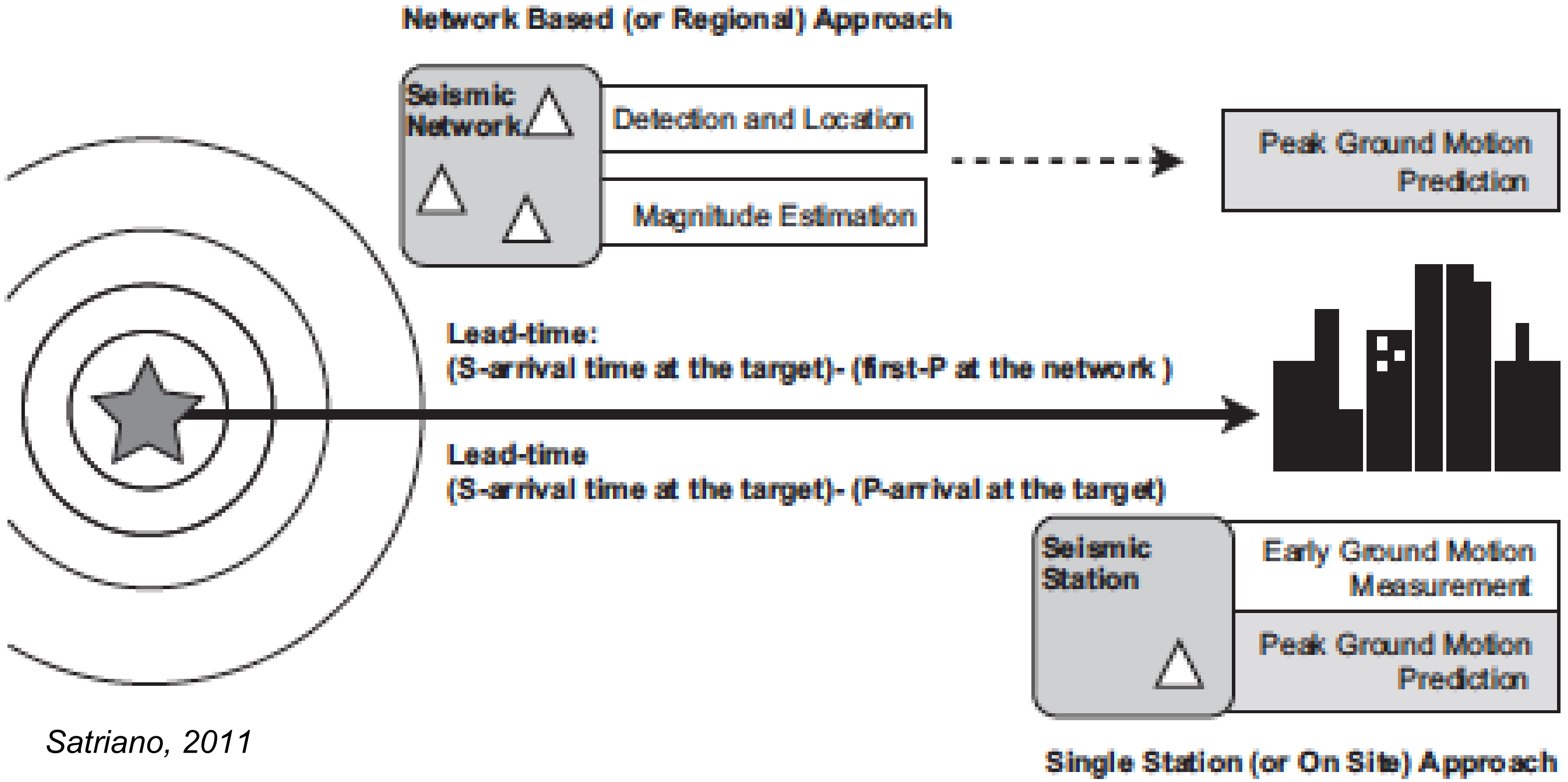
from Richard Allen

EEW around the world



Allen, 2011

Regional and single-station EEW



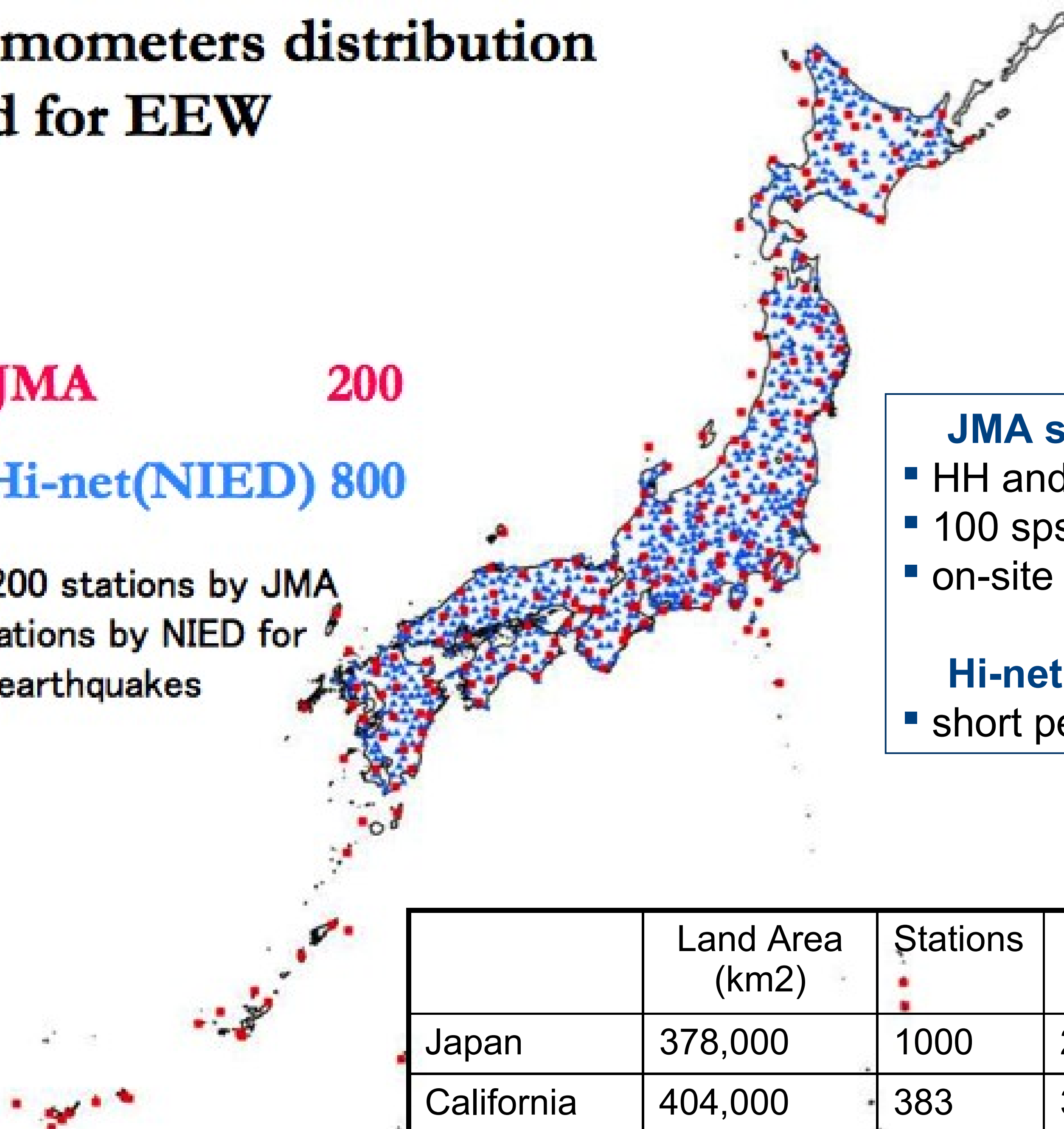
Satriano, 2011

Advanced users and general public

EEW in Japan

- Japan Meteorological Agency (JMA)
- Meteorological Service Law (2007.12.1) states that only JMA can release EEW information to public
- Combination of single station and regional approaches
- HomeSeismometer

Seismometers distribution used for EEW



Data from 200 stations by JMA with 800 stations by NIED for location of earthquakes

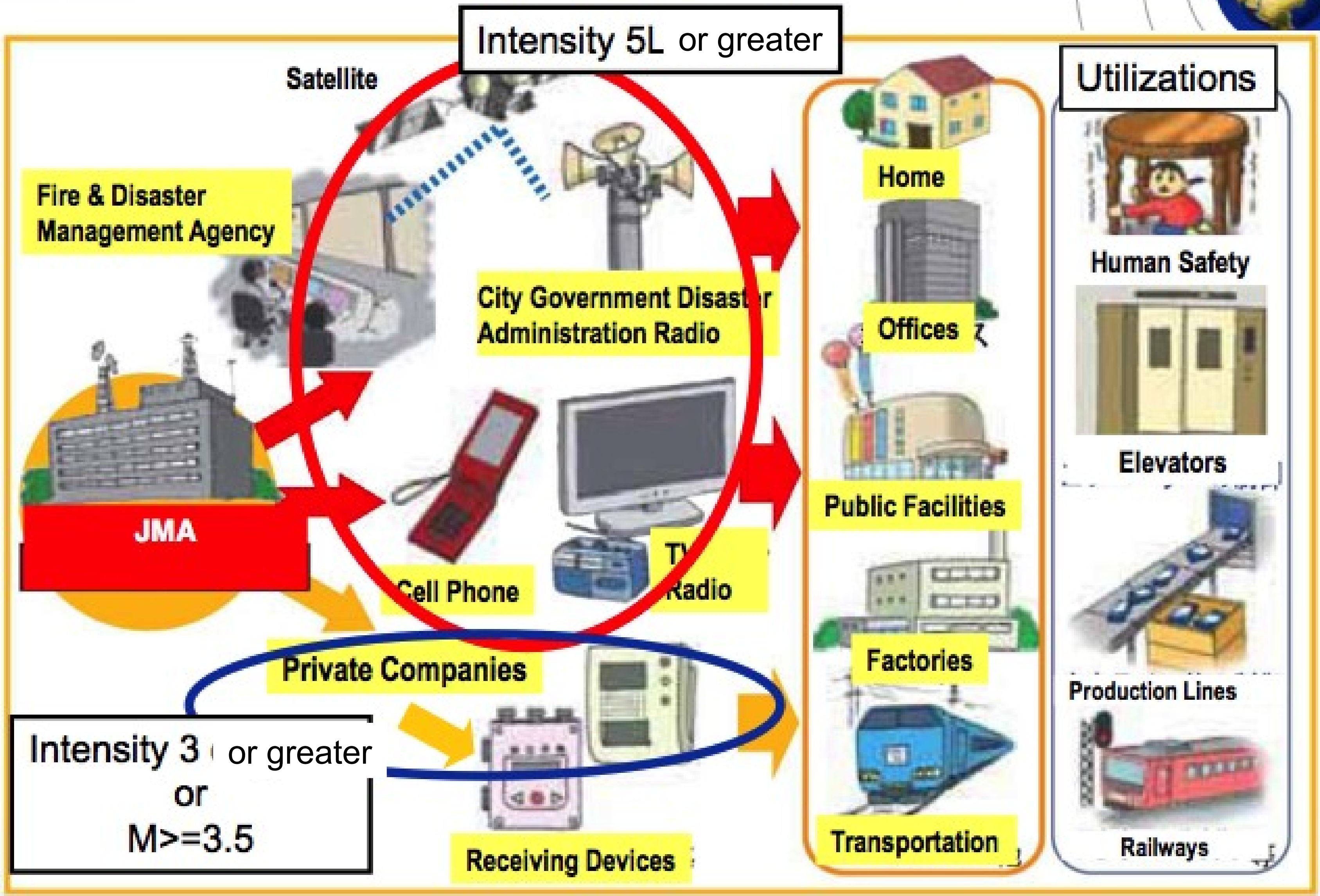
JMA stations
- HH and HG channels
- 100 sps, 24 bit
- on-site processing

Hi-net stations
- short period stations

from Keiji Doi, JMA

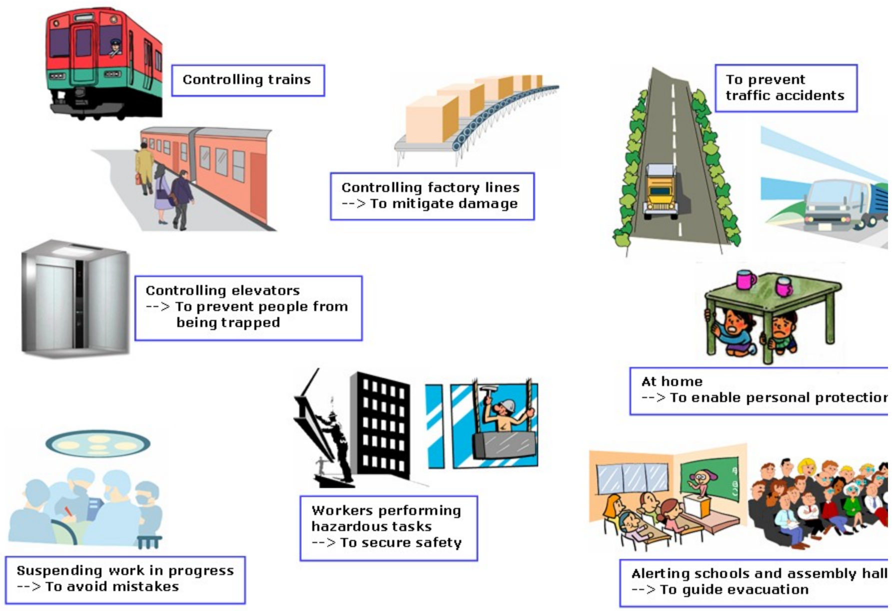
	Land Area (km2)	Stations	Ave. interstation spacing (km)
Japan	378,000	1000	20
California	404,000	383	33 (non-unif)
Switzerland	39,769	46	33 (non-unif)

Dissemination of EEW



from Keiji Doi, JMA

Possible EEW applications …



Extensive public education campaign

Earthquake Early Warning: Dos & Don'ts

At Home
- Protect your head and shelter under a table
- Don't rush outside
- Don't worry about turning off the gas in the kitchen

In Public Buildings
- Follow the attendant's instructions
- Remain calm
- Don't rush to the exit

When Driving
- Don't slow down suddenly
- Turn on your hazard lights to alert other drivers, then slow down smoothly
- If you are still moving when you feel the earthquake, pull safely over to the left and stop

Remain calm, and secure your personal safety based on your surroundings!

After seeing or hearing an Earthquake Early Warning, you have only a matter of seconds before strong tremors arrive. This means you need to act quickly to protect yourself.

Outdoors
- Look out for collapsing concrete-block walls
- Be careful of falling signs and broken glass
- Take shelter in a sturdy building if there is one close enough

On Buses or Trains

Hold on tight to a strap or a handrail

In Elevators

Stop the elevator at the nearest floor and get off immediately

Near Mountains/Cliffs

Watch out for rockfalls and landslides

For more information about the Earthquake Early Warning system, please contact the following department or visit the agency's website.
Administration Division, Seismological and Volcanological Department
Japan Meteorological Agency
Address: 1-3-4 Otemachi, Chiyoda-ku, Tokyo 100-8122
Phone: 03-3212-8341
Website: http://www.jma.go.jp/jma/indexe.html

The Earthquake Early Warning system has been made possible through joint technological development by the Japan Meteorological Agency and the Railway Technical Research Institute, as well as through achievements in technological development by the National Research Institute for Earth Science and Disaster Prevention.

JMA detection rate

First 3 years: 2007-2010
•21 warnings
•9 warnings for M>6.0 earthquakes

	M	Predicted Intensity	Observed Intensity	P-to-warning time (sec)
May 8, 2008	7.0	5-	5-	58.3
Jun 14, 2008	7.2	6+	6+	4.5
July 8, 2008	6.1	5-	5-	13.9
July 24, 2008	6.8	5-	6-	20.8
Sep 11, 2008	7.1	5+	5-	9.7
Aug 11, 2009	6.5	5+	6-	3.8
Oct 30, 2009	6.8	5-	4	26.8
Feb 27, 2010	7.2	6-	5-	4.1
Mar 14, 2010	6.7	5-	5-	3.6

← **"false"**

➔ one false, zero missed

Warning threshold: JMA intensity 5- (equivalent to MMI 8-9)

Kamigaichi et al 2009, Doi et al 2011 and Jim Mori

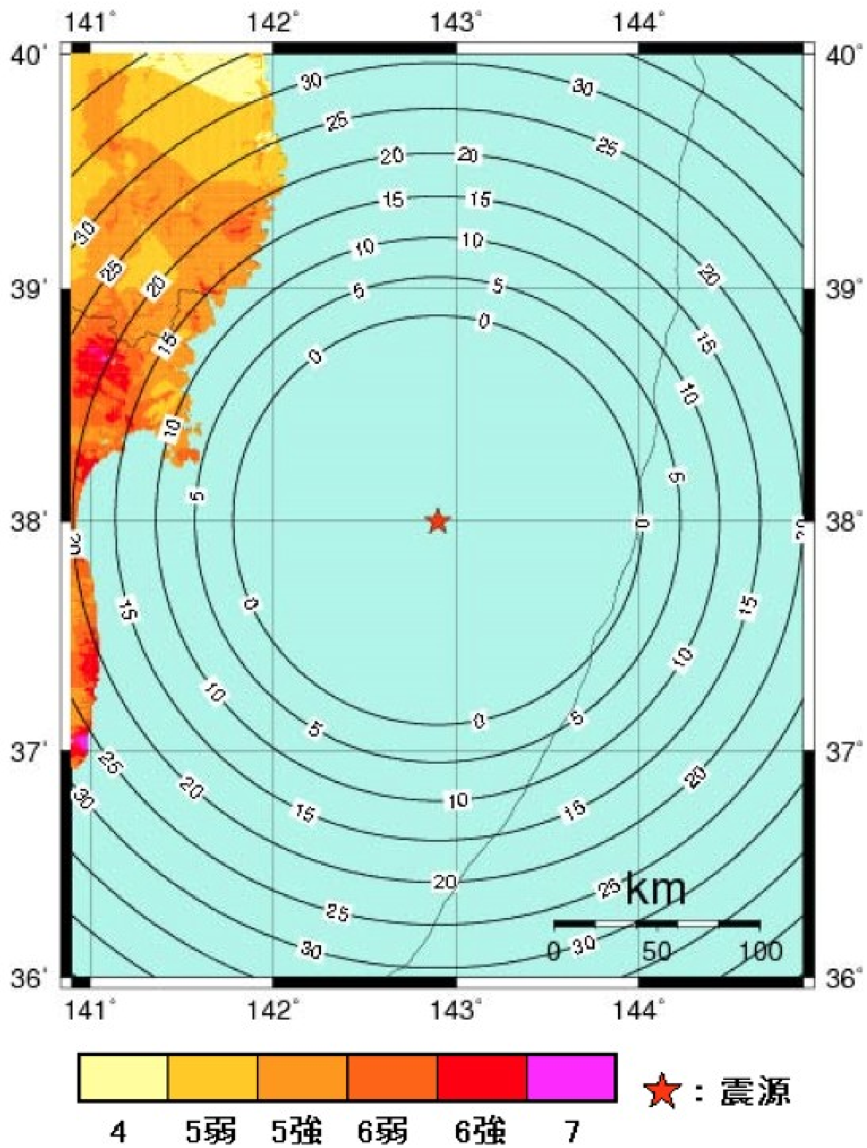
JMA

Earthquake Warning

M9.0 Pacific coast of Tokohu

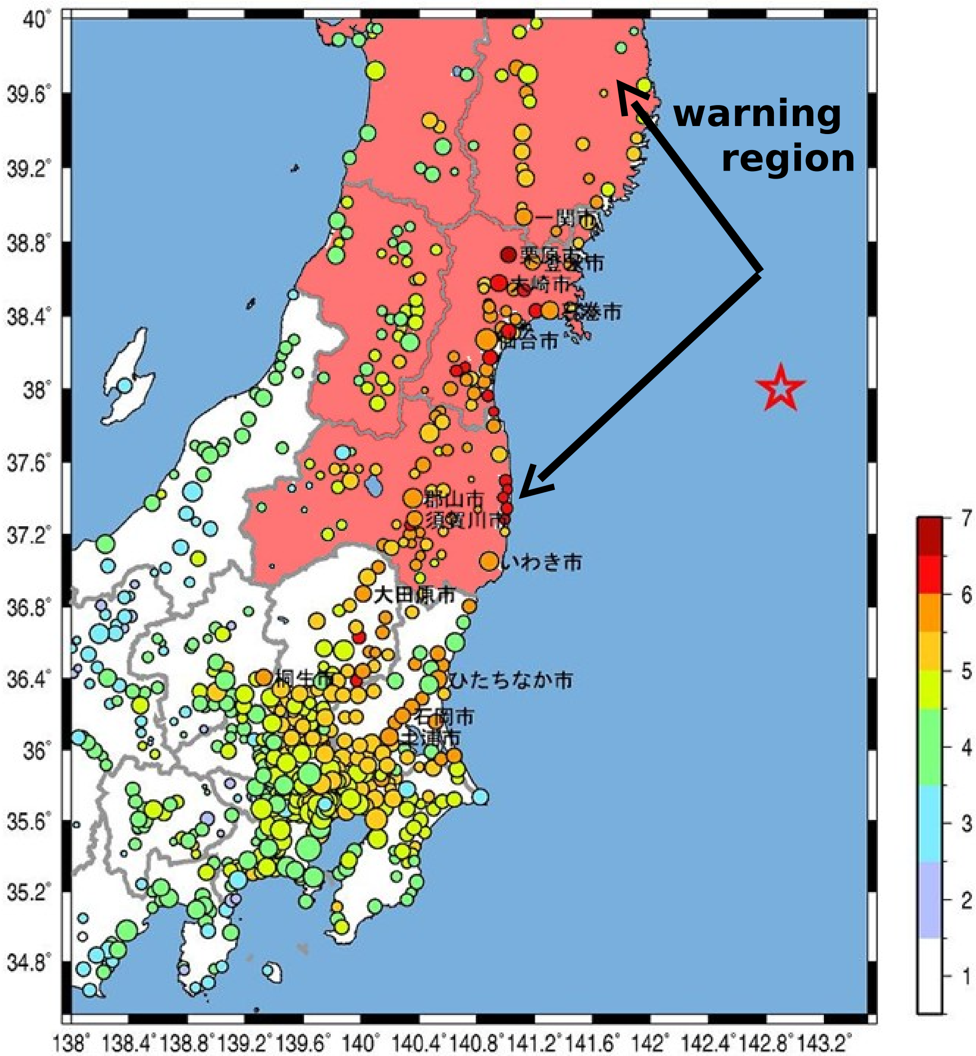
Origin time:14:46:18.1
First detection: +22.1 s (M4.3)
EEW Warning issued: +30 s (M7.2)
Tsunami warning issued: +3 min

➔ Sendai had 15-20 sec warning before the strong motion, and 15 minutes warning before tsunami



Richard Allen
Warning information:
http://www.seisvol.kishou.go.jp/eq/EEW/kaisetsu/joho/20110311144640/content/content_out.html

Cellphone, TV and radio warnings

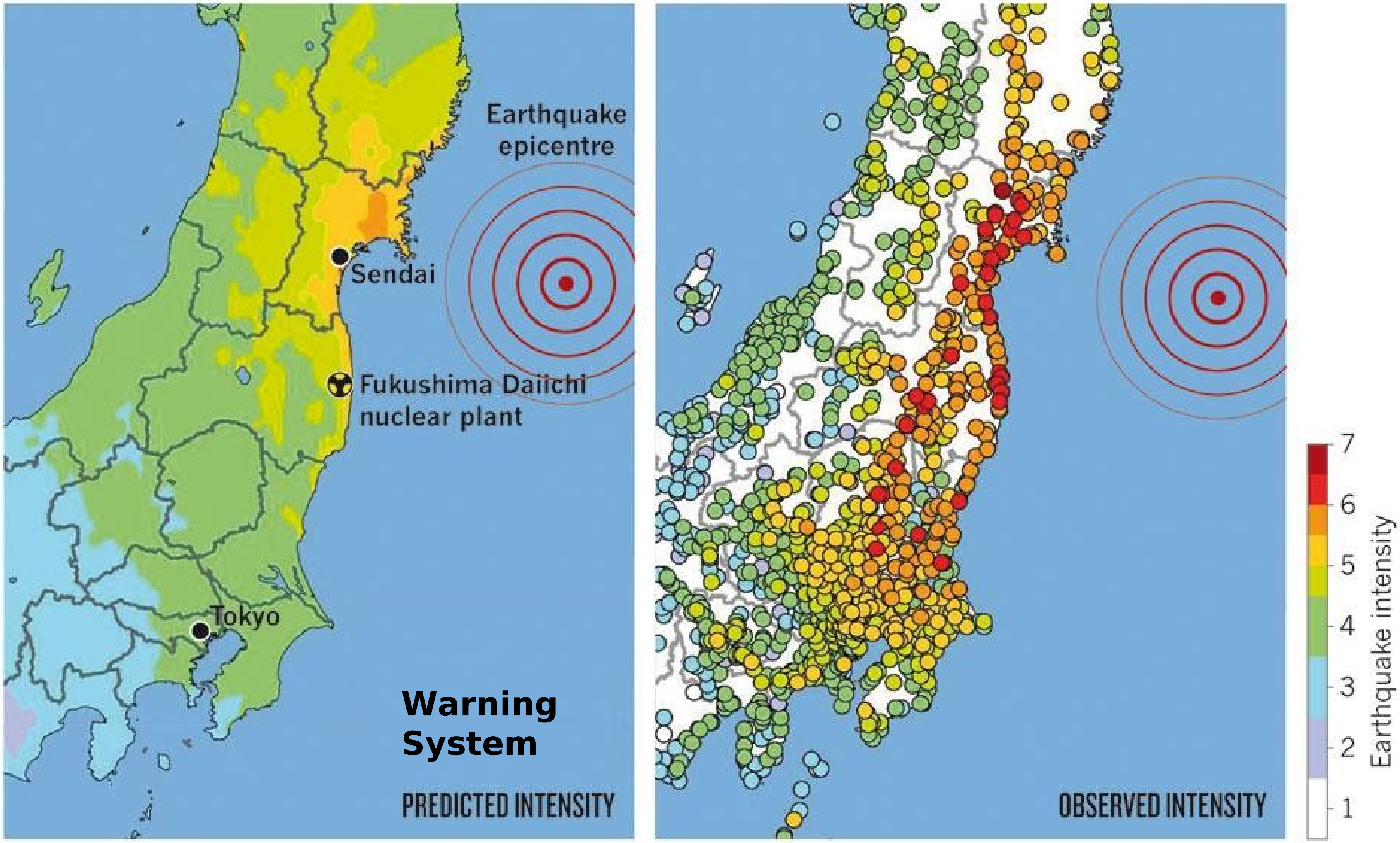


JMA Intensity (MMI)	Population Exposure
7 (11-12)	80k
6+ (10)	510k
6- (9)	4247k
5+ (8)	11163k
5- (7)	20614k
4 (6)	18206k
3 (5)	25906k

- 52 million people received warning over cellphones
- Shinkansen trains stopped without derailment
- Warning info used effectively at schools
- Control rods inserted at nuclear plant

courtesy of Masumi Yamada, Richard

No warning in Tokyo?

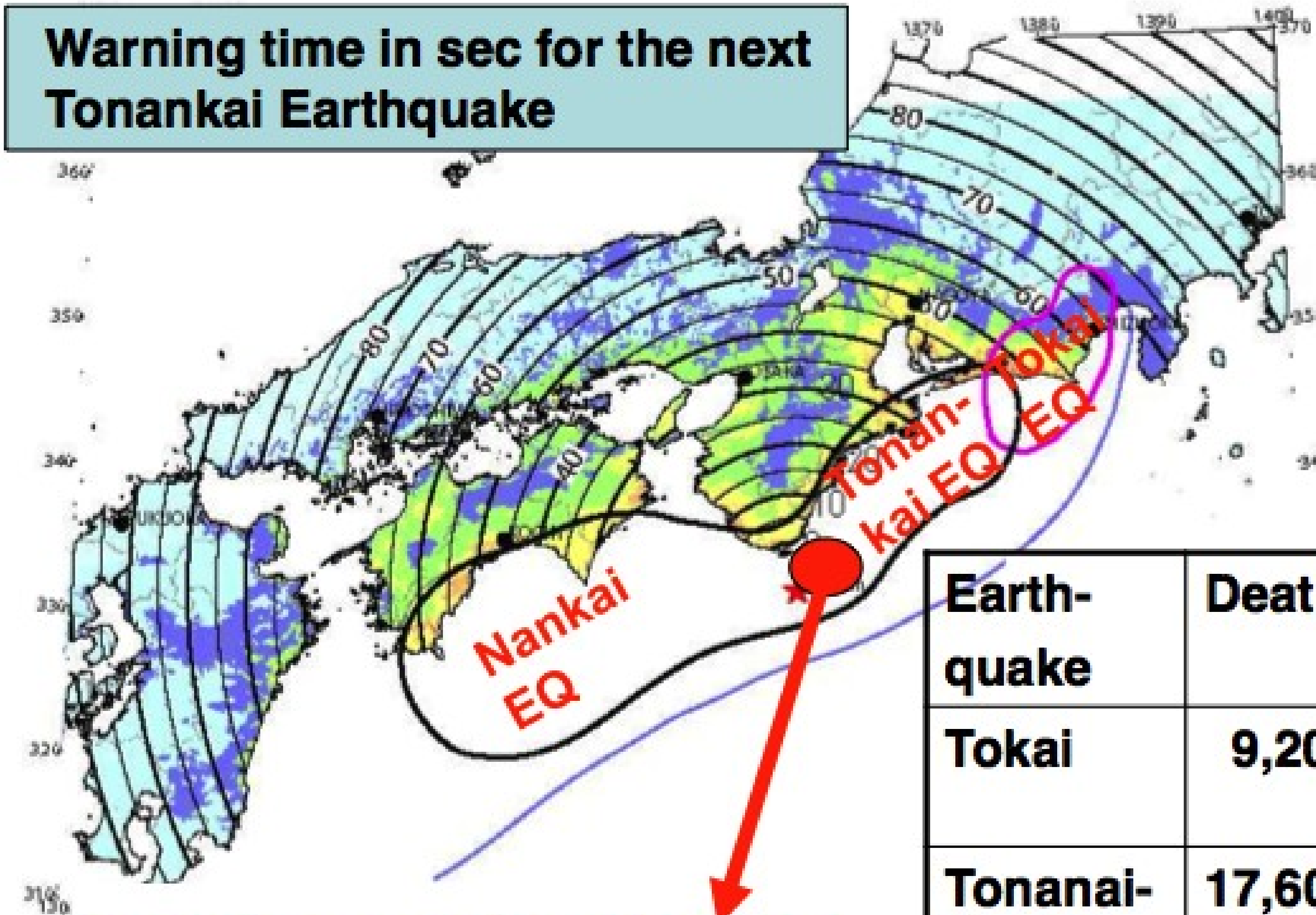


Yamada, 2011

Summary of M9.0 Tokohu event (future challenges for EEW)

- First of all, EEW was in general successful
- Need to develop methods to estimate fault finiteness in real-time
- Need to improve robustness of system in aftershock sequences (concurrent events)
- Improved integration of all data, better ocean-floor observation

Warning time in sec for the next Tonankai Earthquake

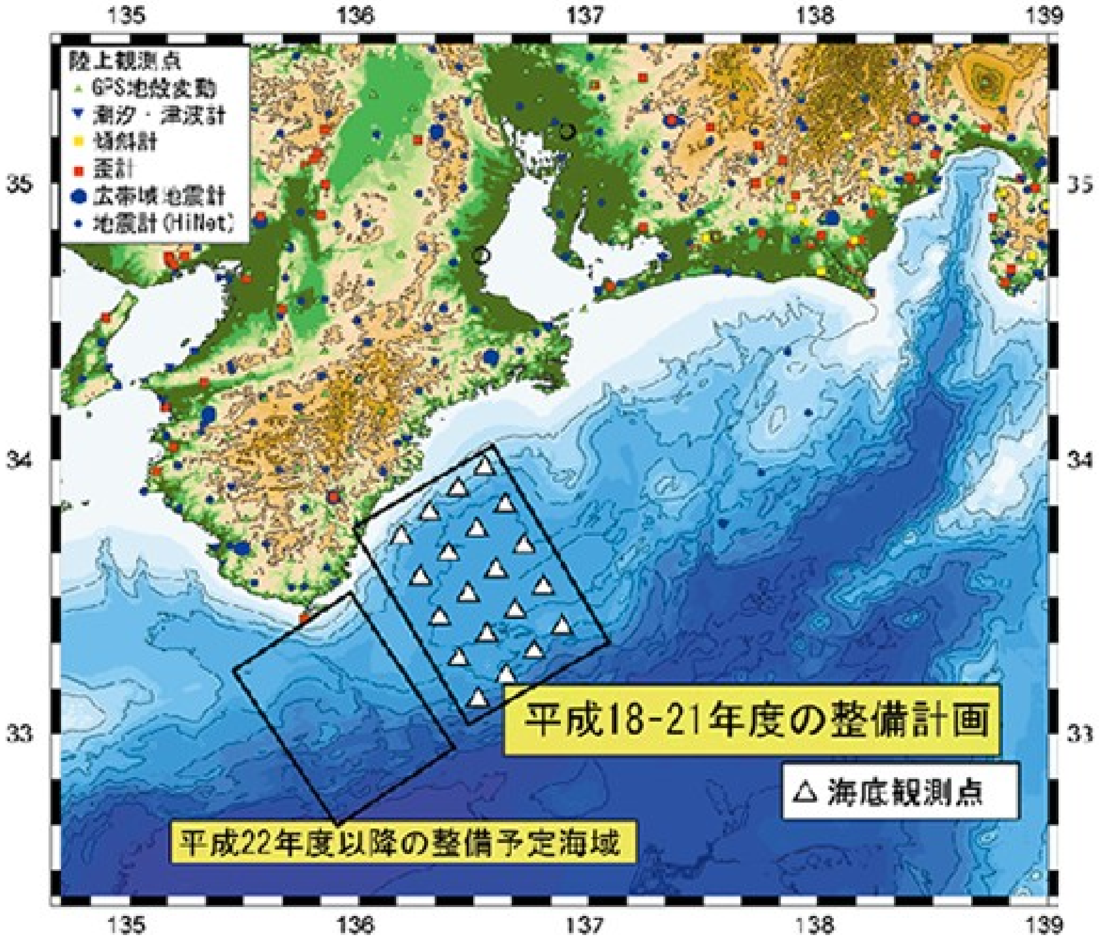


Issue information that the Tonankai Earthquake occurs when small part of its fault area is ruptured. Its brings long warning time.

Earth-quake	Deaths	Damage (Yen)
Tokai	9,200	37 trillion
Tonanai-Nankai	17,600	57 trillion

Meguro(2004) pointed out that the installation of EEW decreases death tolls by the next Tokai EQ by 82%.

Dense Ocean Floor Network Systems for Earthquakes and Tsunamis (DONET)



DONET stations could provide 5-10 sec additional warning time

CISN ShakeAlert

Currently testing components of a warning system in California

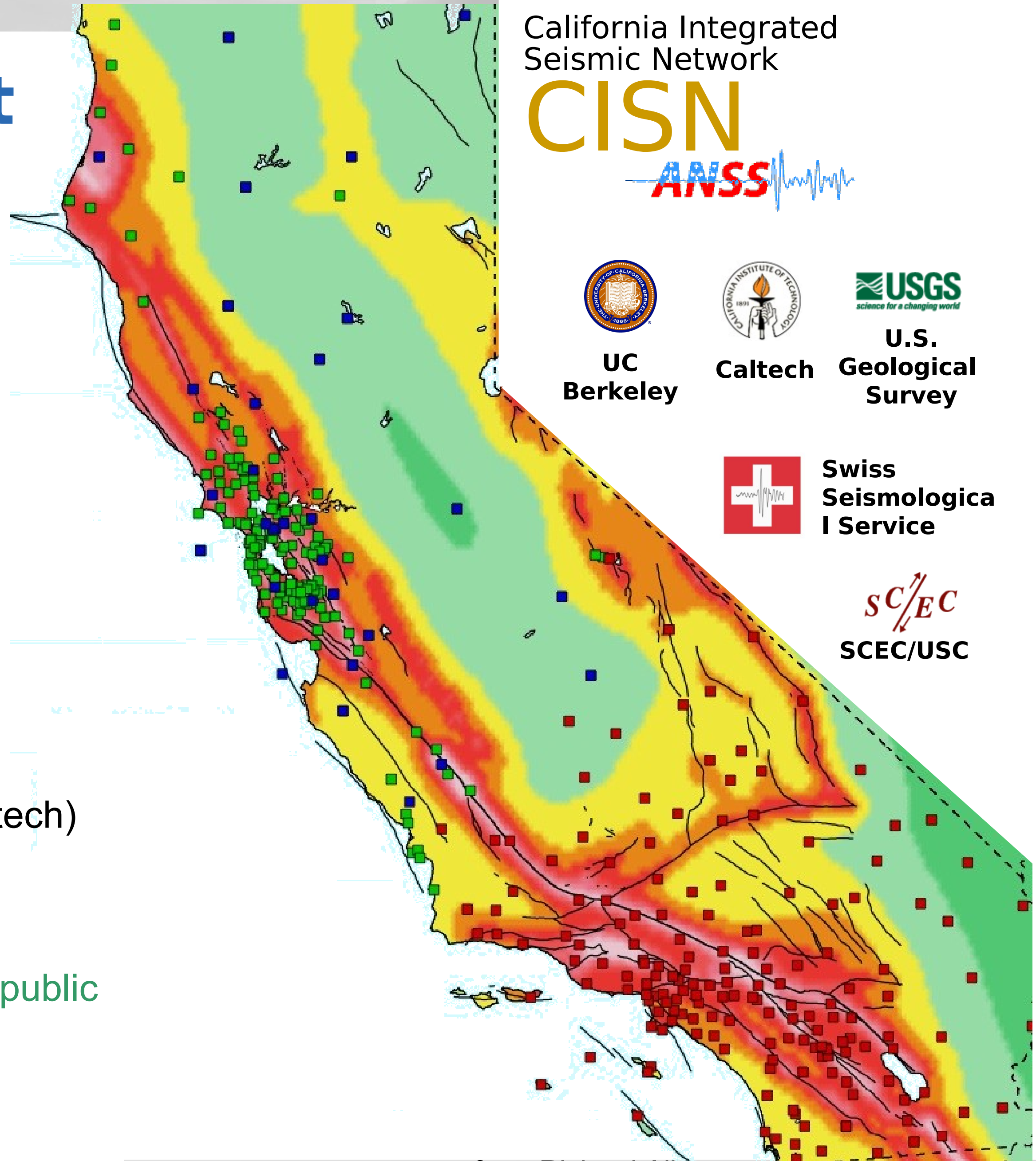
- 400 seismic stations
- warning received on computer desktops
- warnings to small test user group this year

3 algorithms

- On-site (Caltech/U. Taiwan)
- Virtual Seismologist (ETH/Caltech)
- Elarms (UC Berkeley)

Implementation of a Japan-type public statewide system (starting from current networ):

- will take 5 years
- cost $80 million



California Integrated Seismic Network

CISN

ANSS

UC Berkeley

Caltech

U.S. Geological Survey

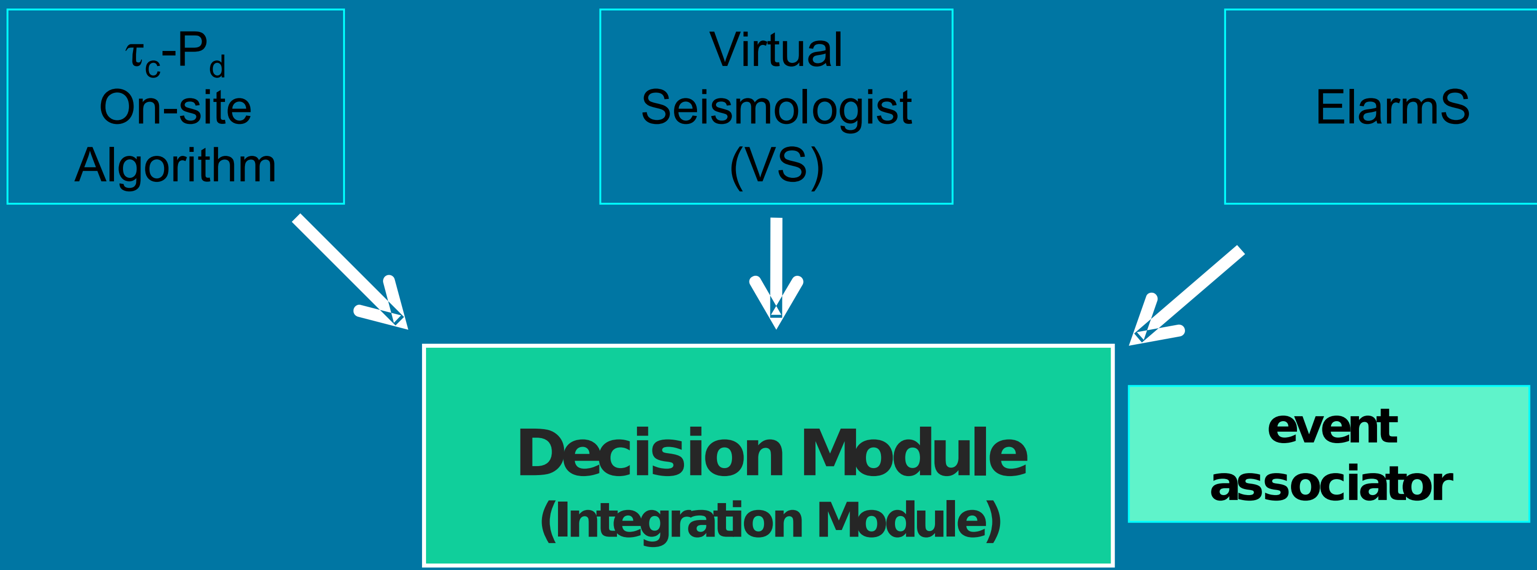
Swiss Seismologica l Service

SCEC/USC

from Richard Allen

CISN ShakeAlert

M. Boese



Current output from the DM:

weighted averages and uncertainties of

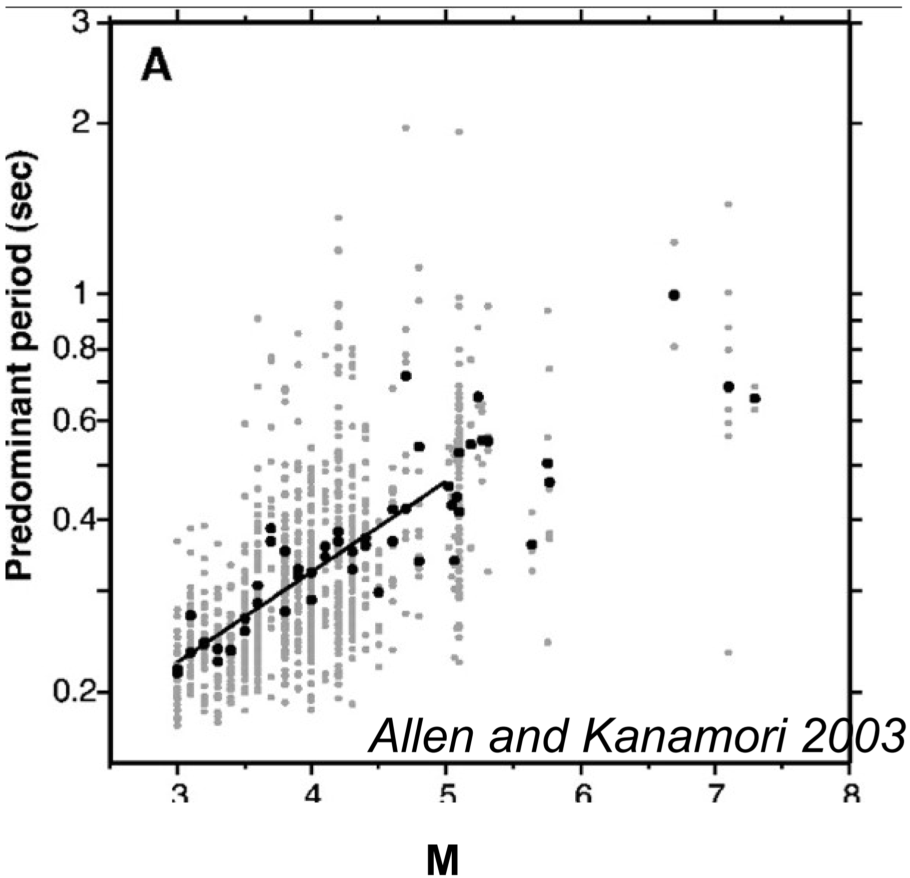
- magnitude
- location
- O.T.

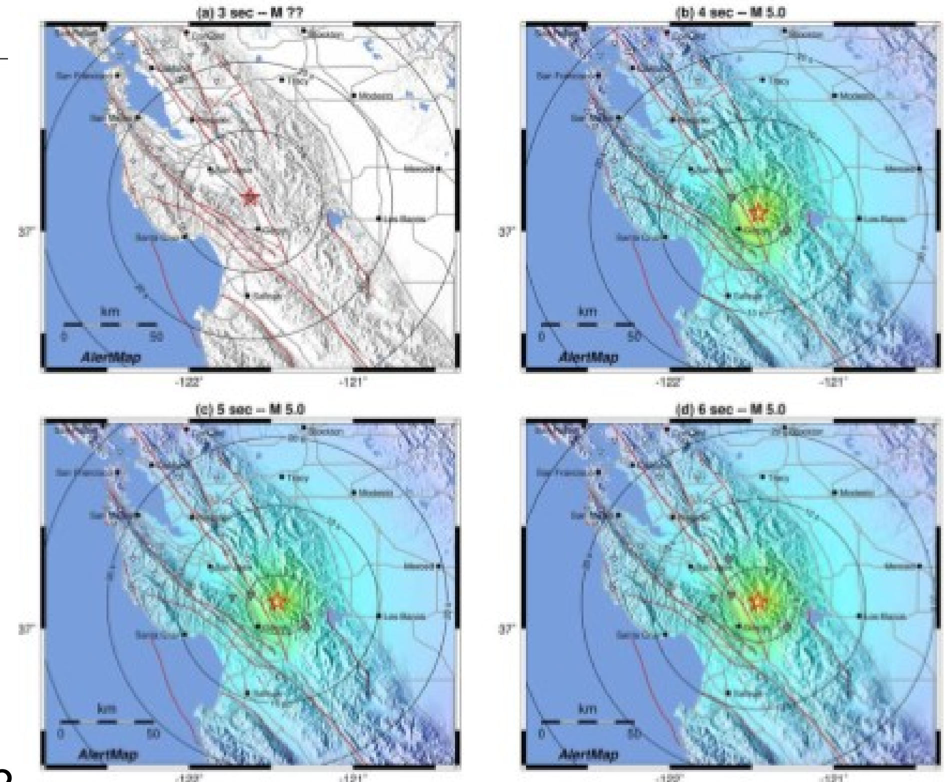
probability of false alert

event cancelation

To do:
Bayesian framework
include
a priori
probabilities

Predominant period as estimator for M





PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Single station approach

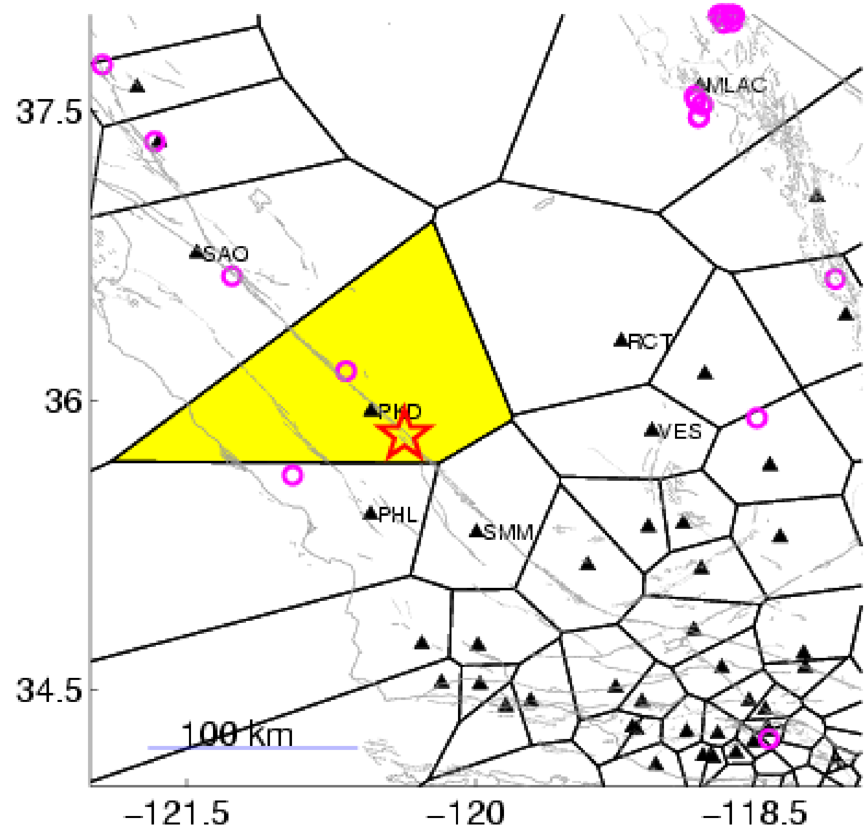
OnSite (Caltech) algorithm predicts PGM at same site

Network approach

ElarmS (UCB) predicts PGM throughout region

Virtual Seismologist EEW algorithm

- Regional, network-based Bayesian approach
- Shape and frequency content of envelopes / “background” information
- Implemented by ETH via SAFER
- Real-time testing via CISN EEW project
- Real-time in So.Cal. July 2008, in No.Cal. March 2009
- Real-time in Switzerland since August 2010



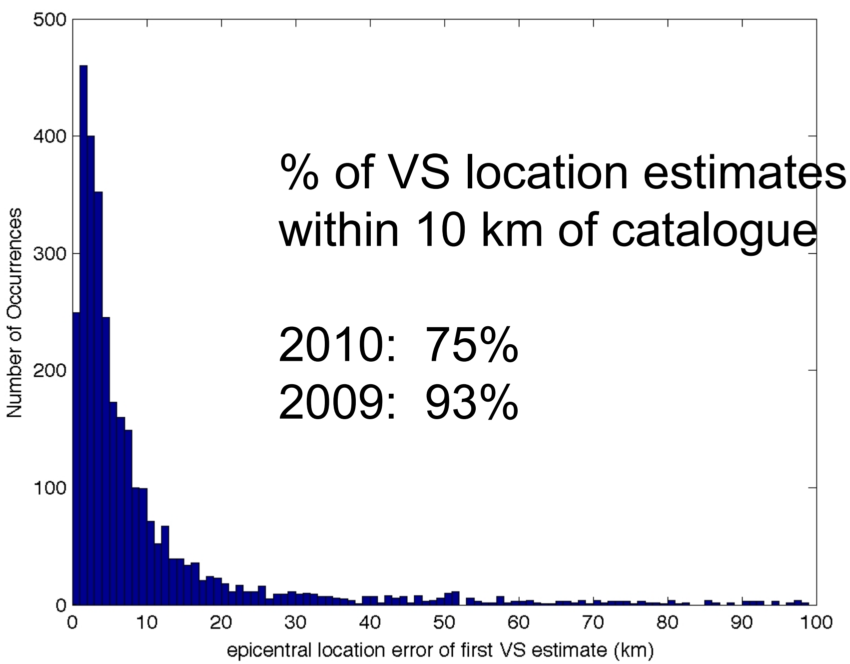
Bayes’ Theorem in EEW

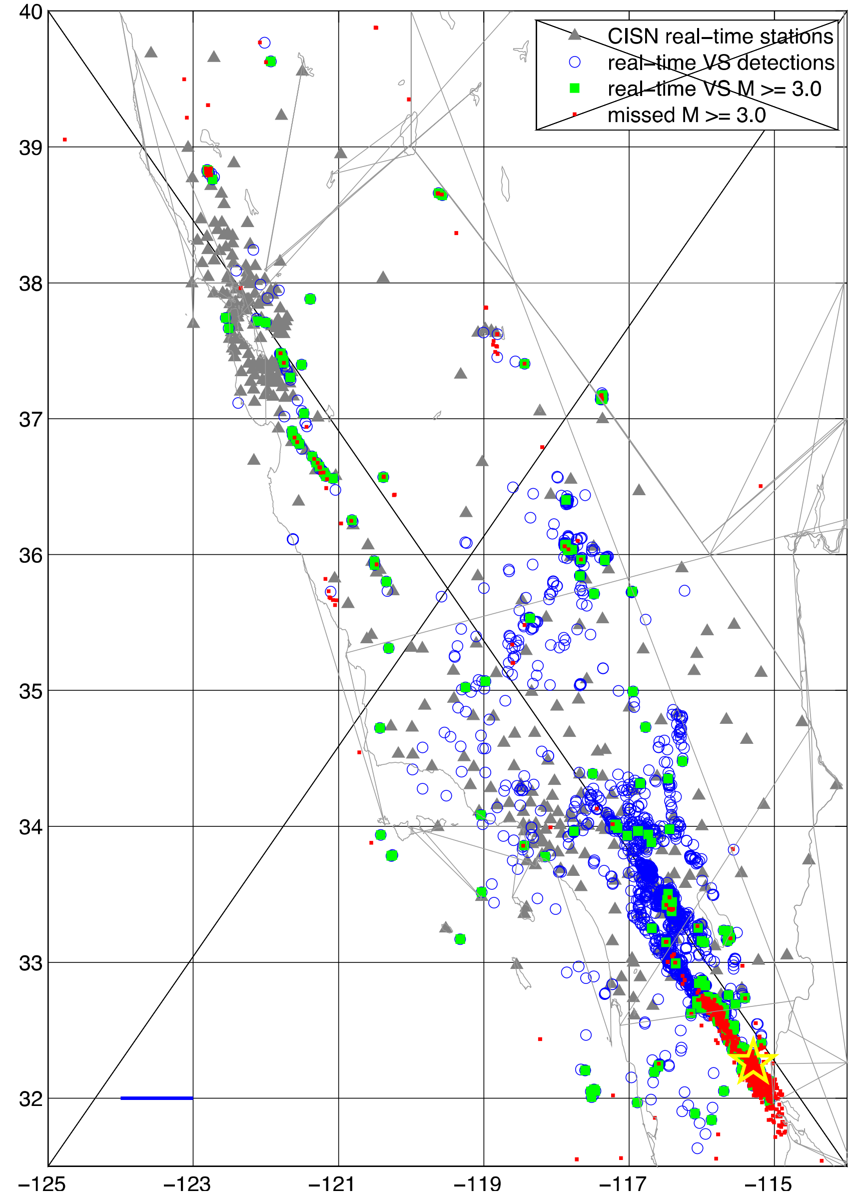
$$prob(M, lat, lon \mid obs) \propto prob(obs \mid M, lat, lon) \cdot prob(M, lat, lon)$$

Posterior (“answer”) Likelihood (“data”) Prior (“other” information)

Current Status

- Current “operational” version in ShakeAlert requires minimum of 4 stations for first estimate (available ~20 sec after OT)
- Correctly detected more than 3000 events in real-time in CA in 2010, 469 with M≥3.0 (including M7.2 Sierra El Mayor)
- Real-time testing of VS-MTED





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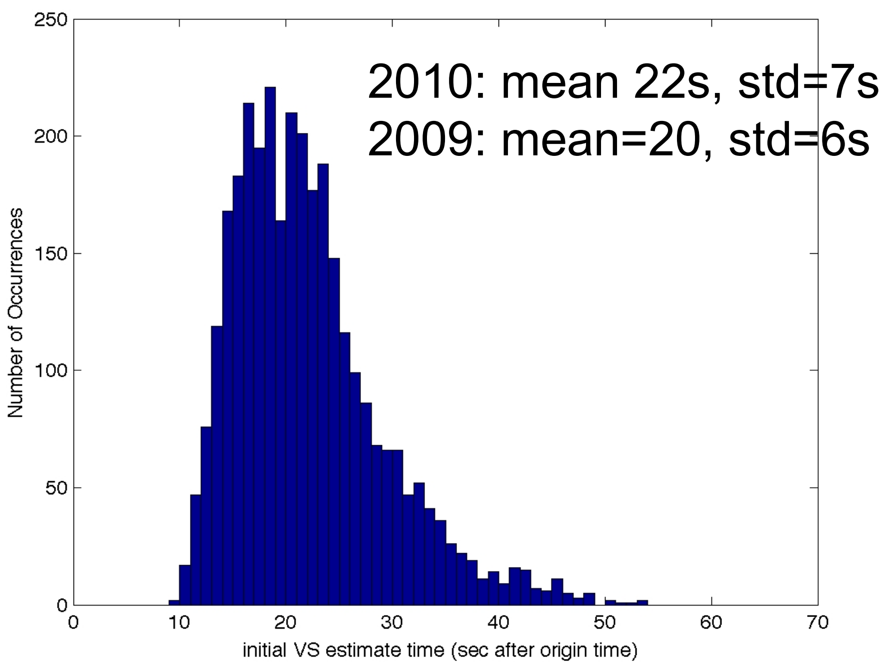
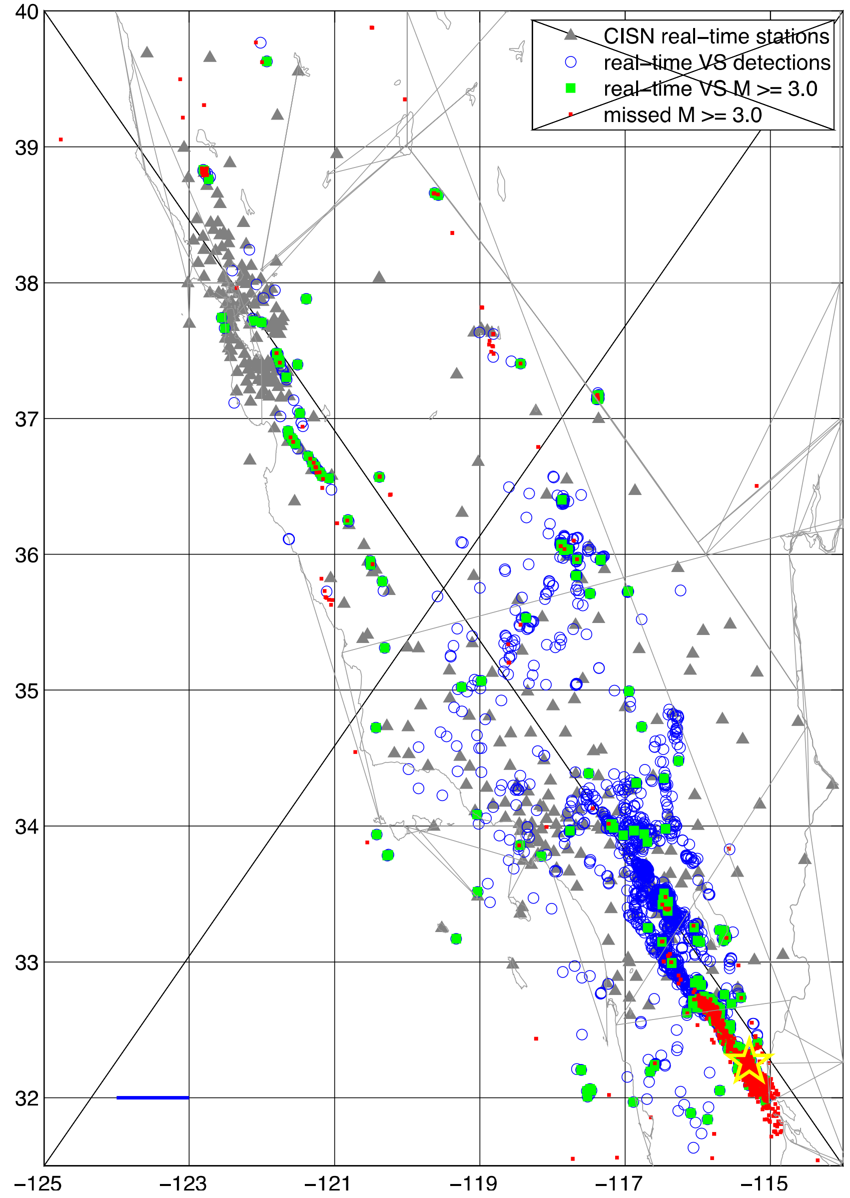
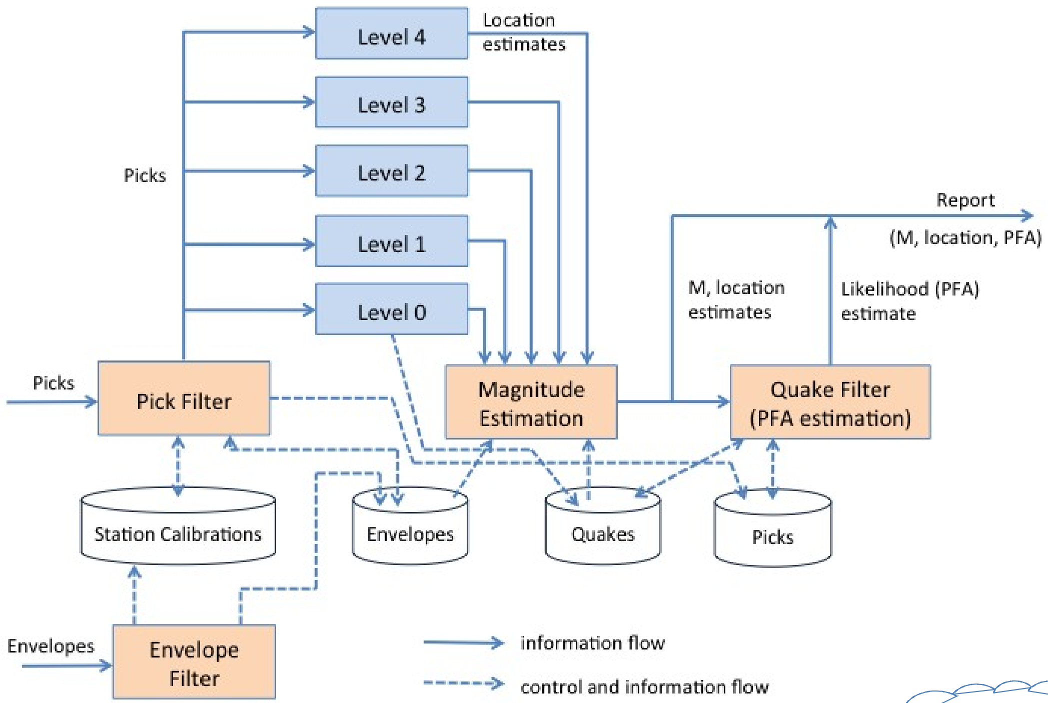
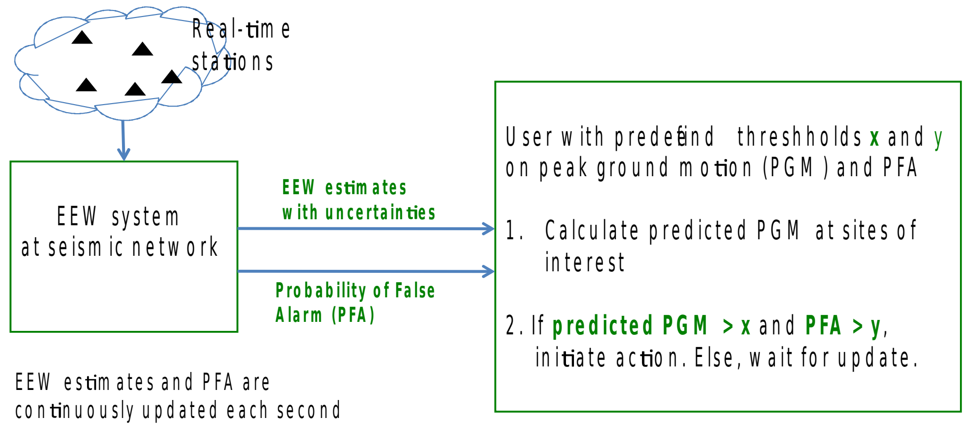




VS-MTED (Multiple Threshold Event Detection)



- Single station event declaration if amplitudes are high enough
- Evolves to "standard" VS as additional data available
- Requires estimates of probabilities of false alarms



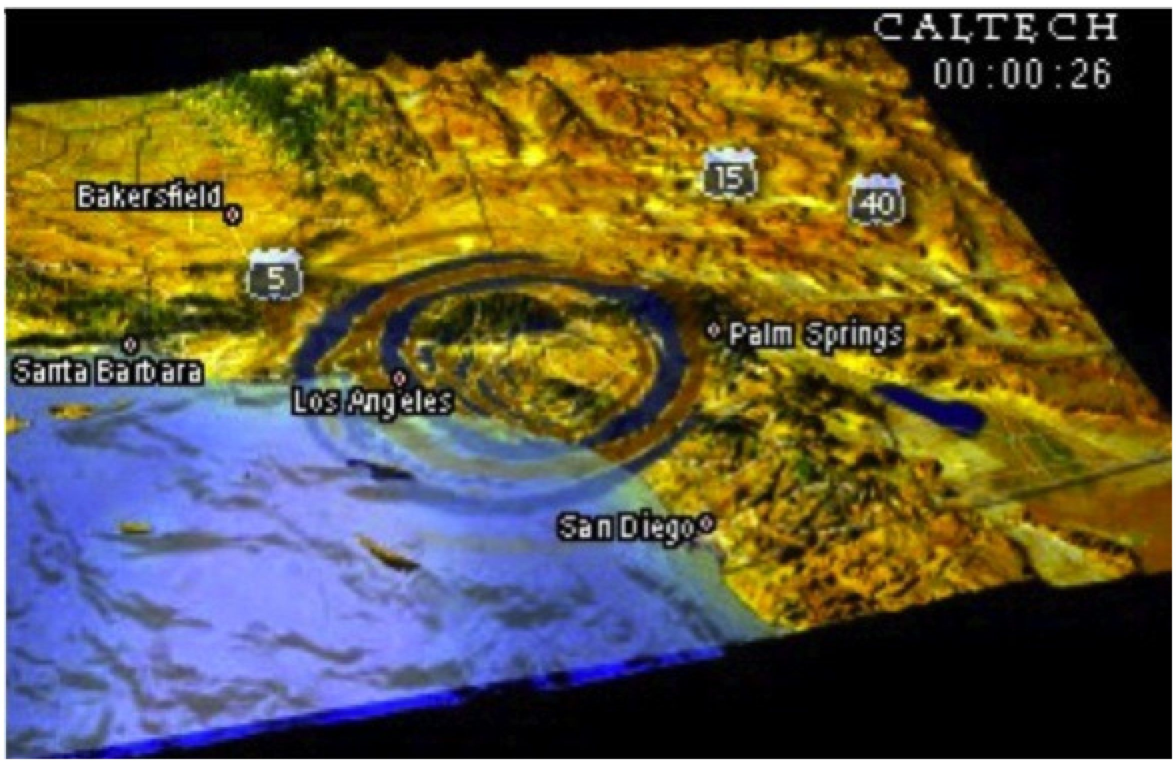
VS coming soon to Europe

- Real-time testing in Switzerland since Aug 2010
- Integration into SeisComP3 and earthworm through NERA JRA2
- Additional real-time installations in Naples, Istanbul,

  Iceland, Patras through REAKT WP4 & WP7

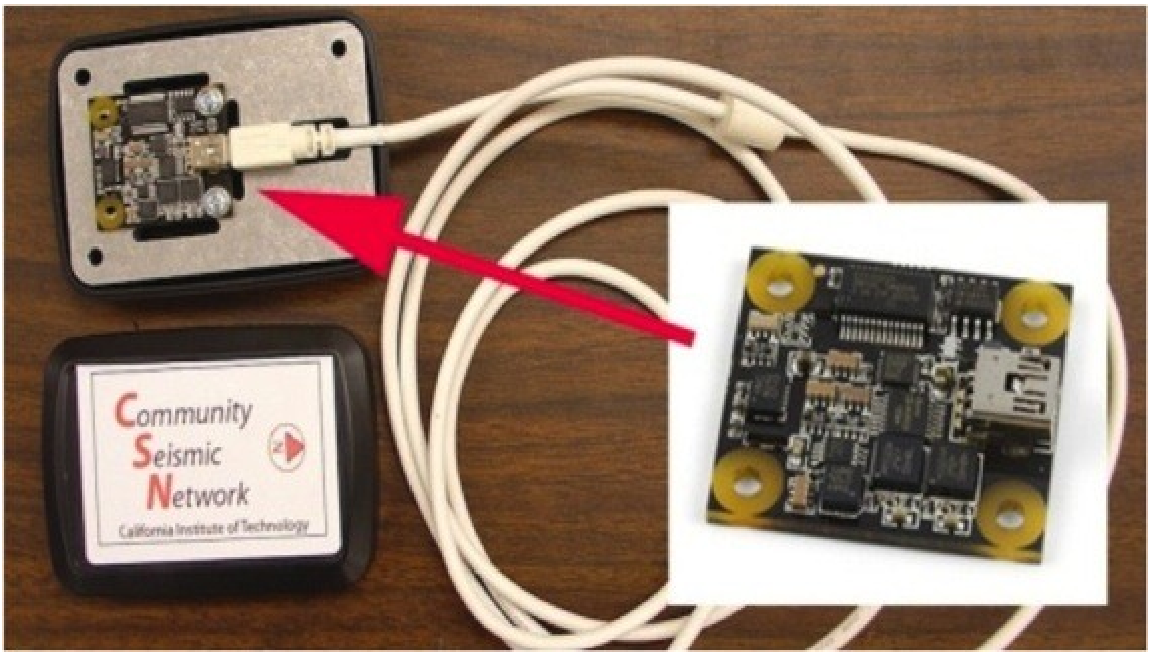
Community Seismic Network (CSN)

Detect and monitor earthquakes using smart phones, USB sensors, and cloud computing.



from Andreas Krause

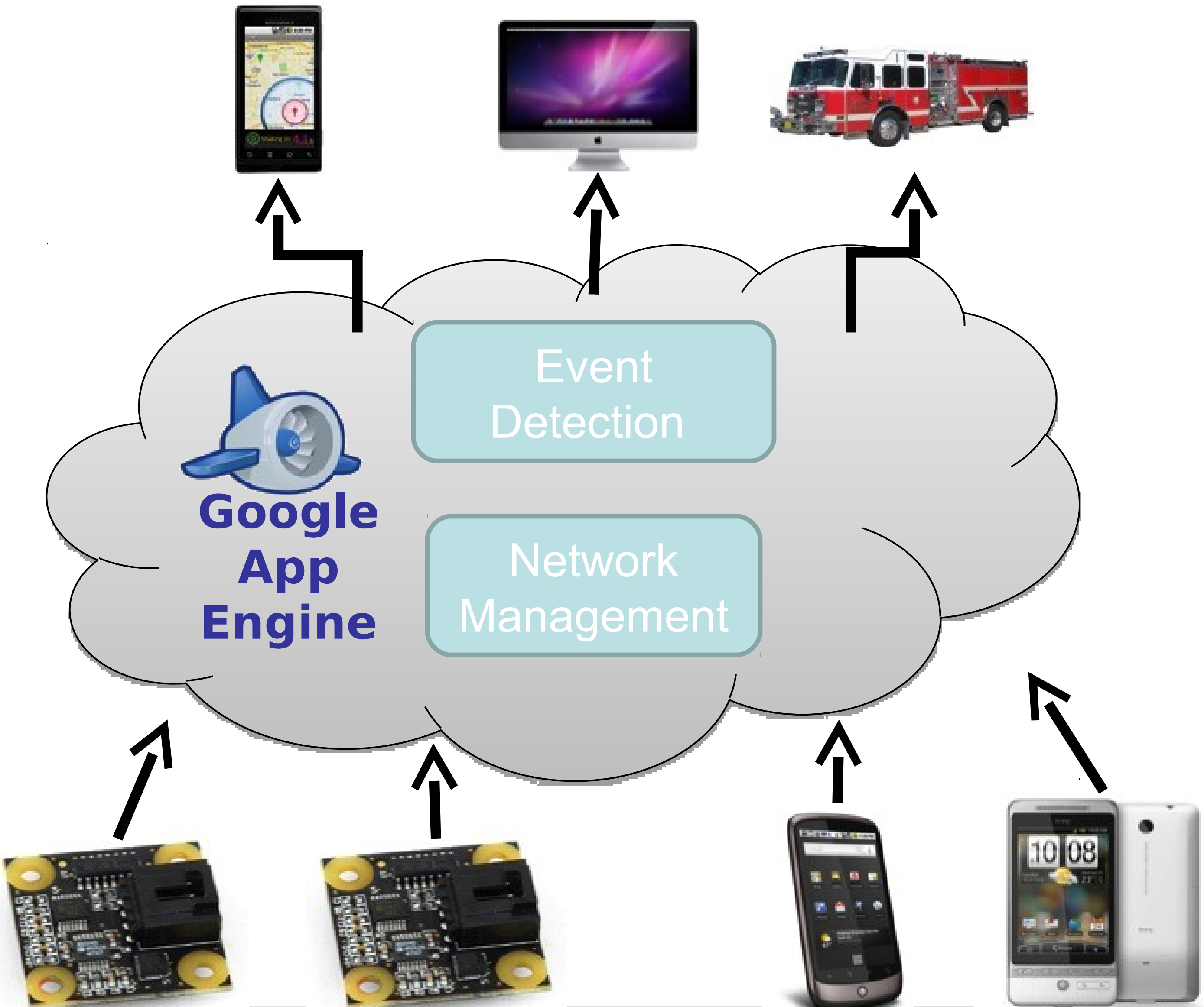
Community Sensors



Phidgets, Inc. 16-bit USB accelerometer

Android phones and tablets

CSN Network Overview



from Andreas Krause

CSN Applications

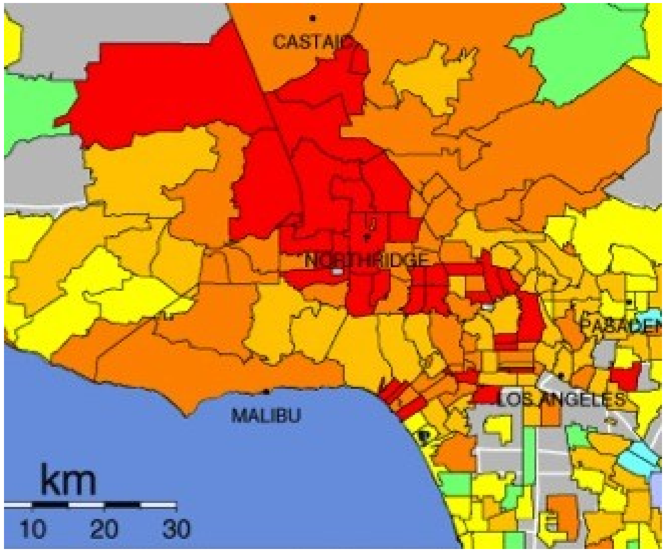
Earthquake early warning tens of seconds of warning

Rapid, detailed ShakeMaps block-by-block maps of acceleration guide emergency teams after quake

Detailed subsurface maps
Determine subsurface structures and soil conditions that enhance ground shaking.

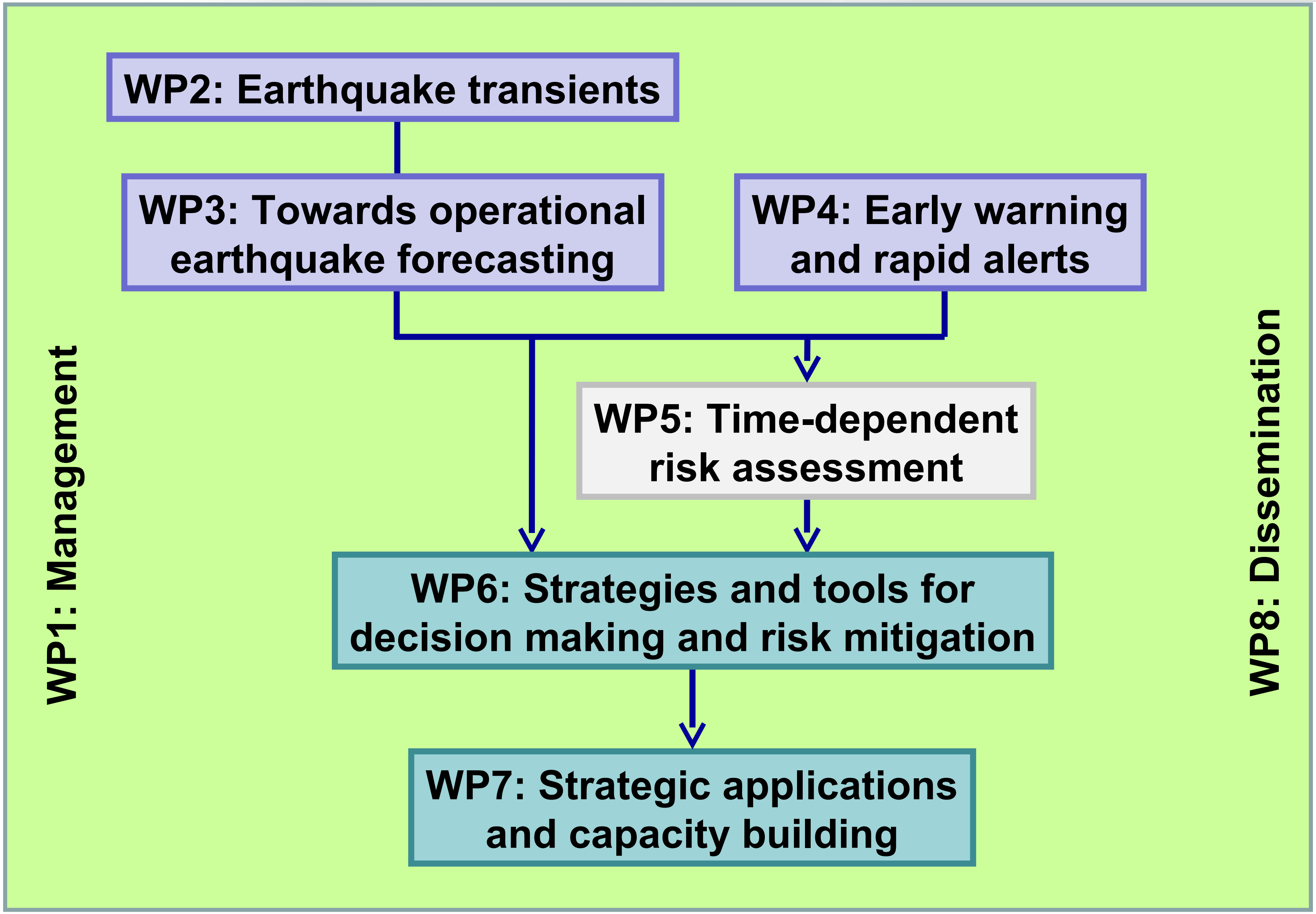
Images of Fault Rupture

Building/Structure Monitoring



Didyoufeelit.com

REAKT Strategies and Tools for Real-Time Earthquake Risk Reduction



Important Features of the Project

- **Relates earthquake early warning to real-time risk reduction** („end to end" EWS: from data to risk reduction)**!**
- **Includes concept development for real-time risk reduction related to a few specific and strategic structures (railway system, large school, port authority, ……) or applications (civil protection,..) in a few areas in partnership with end users** (from the beginning on)
- **End users should not only be "civil protection", but also others (director of a large school, security officer of a high rise building, security officer of a railway system,…..)**

WP7: Strategic applications and partnerships

- SwissNuclear (ETHZ)
- SINES Industrial Complex, Portugal (IST)
- Circumvesuviana Railways (AMRA)
- EEW in schools (AMRA, GFZ)
- Department of Civil Protection Italy (AMRA, DPC)
- IGDAS Natural Gas Network, Istanbul (KOERI)
- Thessaloniki Port (AUTH, GFZ)
- AHEPA Hospital, Thessaloniki (AUTH, GFZ)
- Iceland (IMO, ETHZ)
- Regional EEW for eastern Carribbean (EUCENTRE, UWI)
- Patras EEW, Rion Antirion bridge (UPAT, ETHZ)
- Fatih Sultan Mehmet Bridge (KOERI)

Closing thoughts…

- EEW systems are slowly but steadily becoming a reality
- Still some methodology developments required
  - Real-time finite fault characterization
  - Robust performance during aftershock sequences
  - Faster warning times (methodology, decreasing data latencies)
  - Optimal use of different types of data (possibly OBS, GPS, strainmeters, cell phones, low cost but dense deployments, mobile aftershock deployments, etc..)
- Let’s learn from each other’s efforts!

Thank You


考えよう、数秒間で、出来ること
緊急地震速報
平成19年10月1日スタート!
©TSUBURAYA PROD.
緊急地震速報とは?
地震をすばやくキャッチし、強いゆれが始まることを数秒~数十秒前にお知らせする新しい情報です。
テレビ・ラジオなどを通じて受けられる予定。
※ただし、震源に近い場所では強い揺れに間に合わないことがあります。
詳しくは気象庁のホームページ(http://www.jma.go.jp/)をご参照ください。
あたまをまもる
かぐからはなれる
へいからはなれる
落ちてくる
ものにちゅうい
あわてて外に
とびださない
近くの階でおりる
急ブレーキを
かけない
ハザードランプ
をつけて減速
国土交通省 気象庁

EEW in California

Goal: evaluate real-time performance of early warning methods

Three algorithms:

1. **Onsite warning** (Caltech/U. Taiwan)
2. **Virtual Seismologist** (Caltech/ETH)
3. **ElarmS** (UC Berkeley)

Algorithm Evaluation:

Alert information and summaries (SCEC/USC)

CISN (California Integrated Seismic Network) EEW

a. Distributed waveform processing
b. Each algorithms runs at one datacenter
c. Reporting to SCEC