Lessons from the 2011 Tohoku tsunami and tsunami mitigation in Japan

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IRIDeS
International Research Institute of Disaster Science
災害科学国際研究所

TOHOKU UNIVERSITY

About IRIDeS

Disaster	Disaster Institute established in Major National University
1923 Great Kanto Earthquake	The University of Tokyo Earthquake Research Institute（1925-）
1950 Typhoon Jane	Kyoto University Disaster Prevention Research Institute（1951-）
2011 GEJE and Tsunami	Tohoku University International Research Institute of Disaster Science（2012-）

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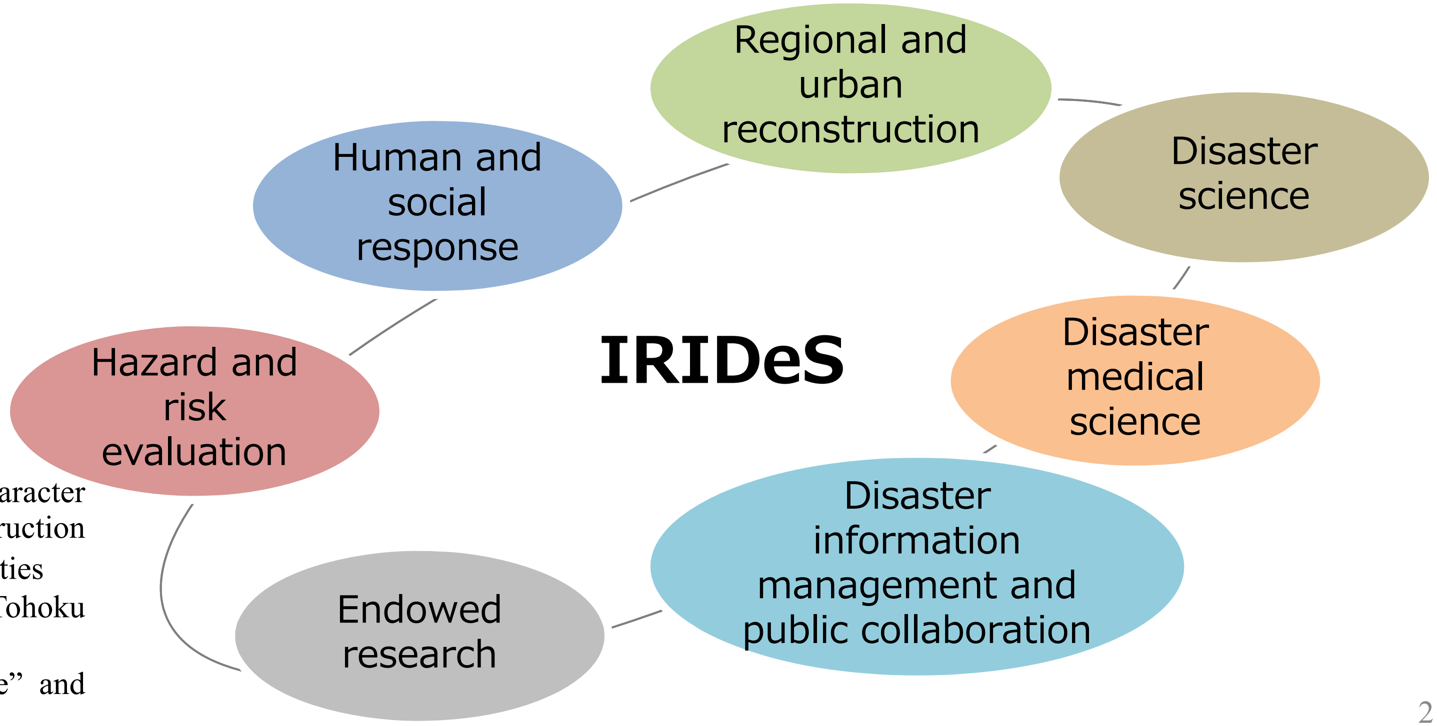
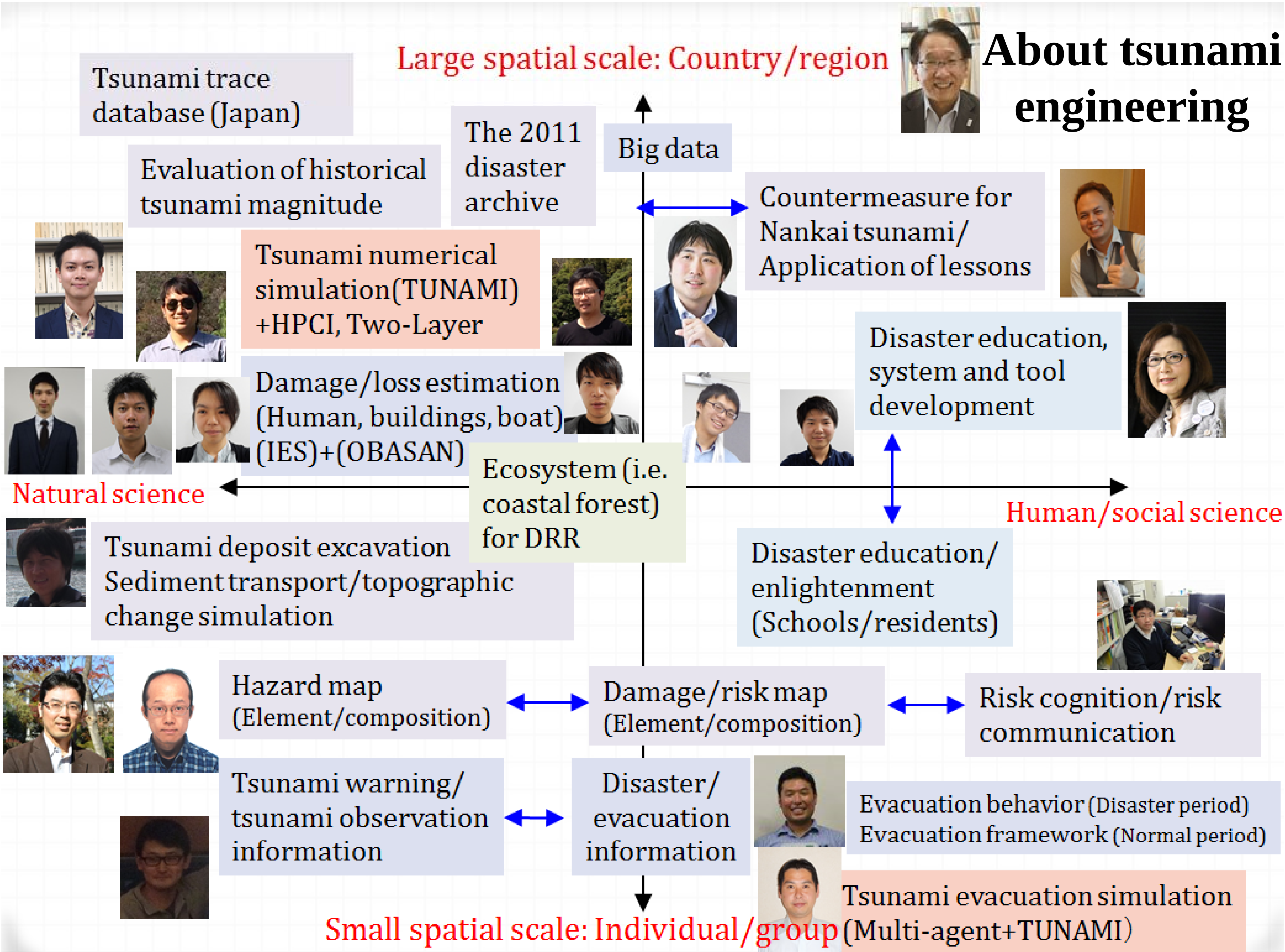
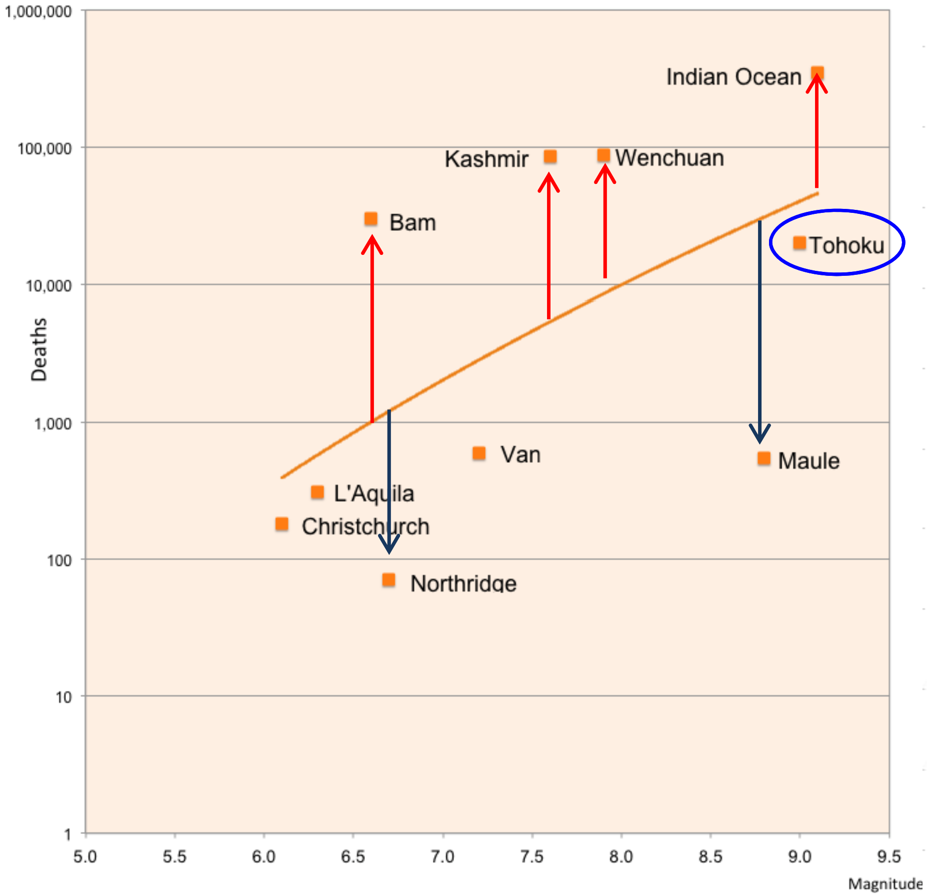
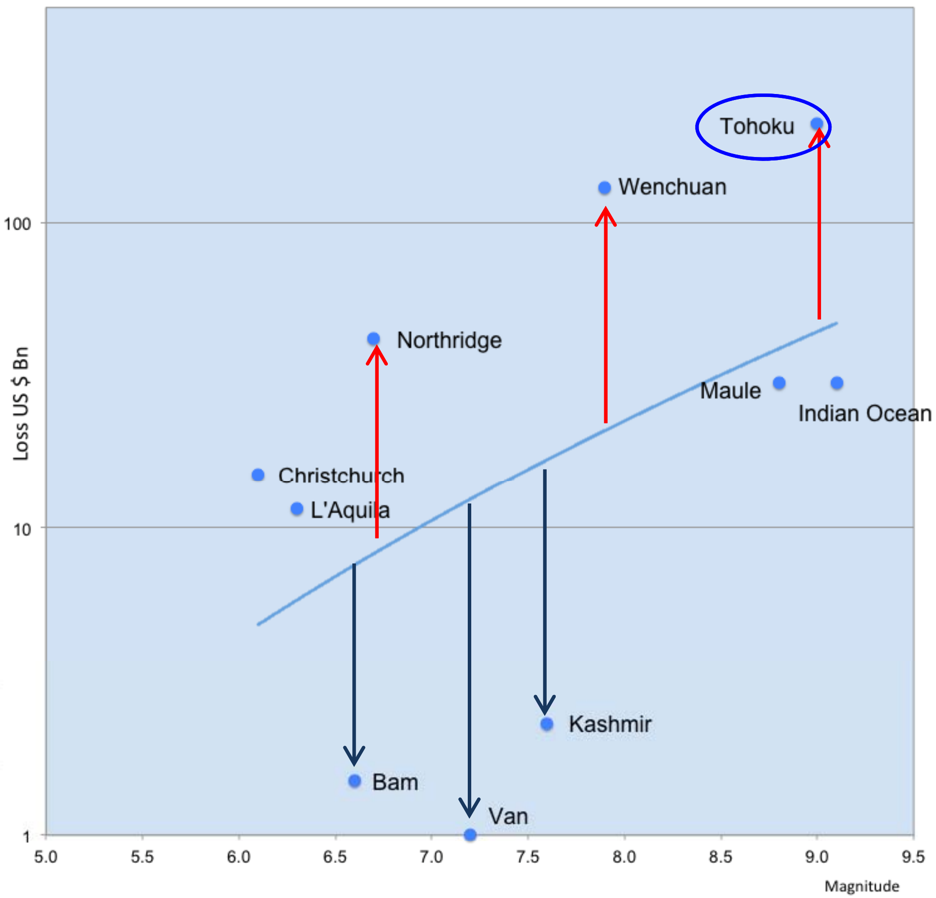
- Overturning the Japanese character meaning disaster「災」= reconstruction and sustainable and resilient societies
- Purple is the color of the Tohoku University
- The Iris is the symbol of "hope" and "dignity"




About tsunami engineering
Large spatial scale: Country/region
Small spatial scale: Individual/group
Natural science
Human/social science
Tsunami trace database (Japan)
Evaluation of historical tsunami magnitude
The 2011 disaster archive
Big data
Countermeasure for Nankai tsunami/ Application of lessons
Tsunami numerical simulation(TUNAMI) +HPCI, Two-Layer
Disaster education, system and tool development
Damage/loss estimation (Human, buildings, boat) (IES)+(OBASAN)
Ecosystem (i.e. coastal forest) for DRR
Tsunami deposit excavation Sediment transport/topographic change simulation
Disaster education/ enlightenment (Schools/residents)
Hazard map (Element/composition)
Damage/risk map (Element/composition)
Risk cognition/risk communication
Tsunami warning/ tsunami observation information
Disaster/ evacuation information
Evacuation behavior (Disaster period)
Evacuation framework (Normal period)
Tsunami evacuation simulation (Multi-agent+TUNAMI)

Size of event – casualties and economic loss





Logarithmic scales on vertical axes

DEATHS + MISSING

ECONOMIC LOSS US$ bn

Source: Dr. Stephen Platt, Cambridge Architectural Research (CAR)

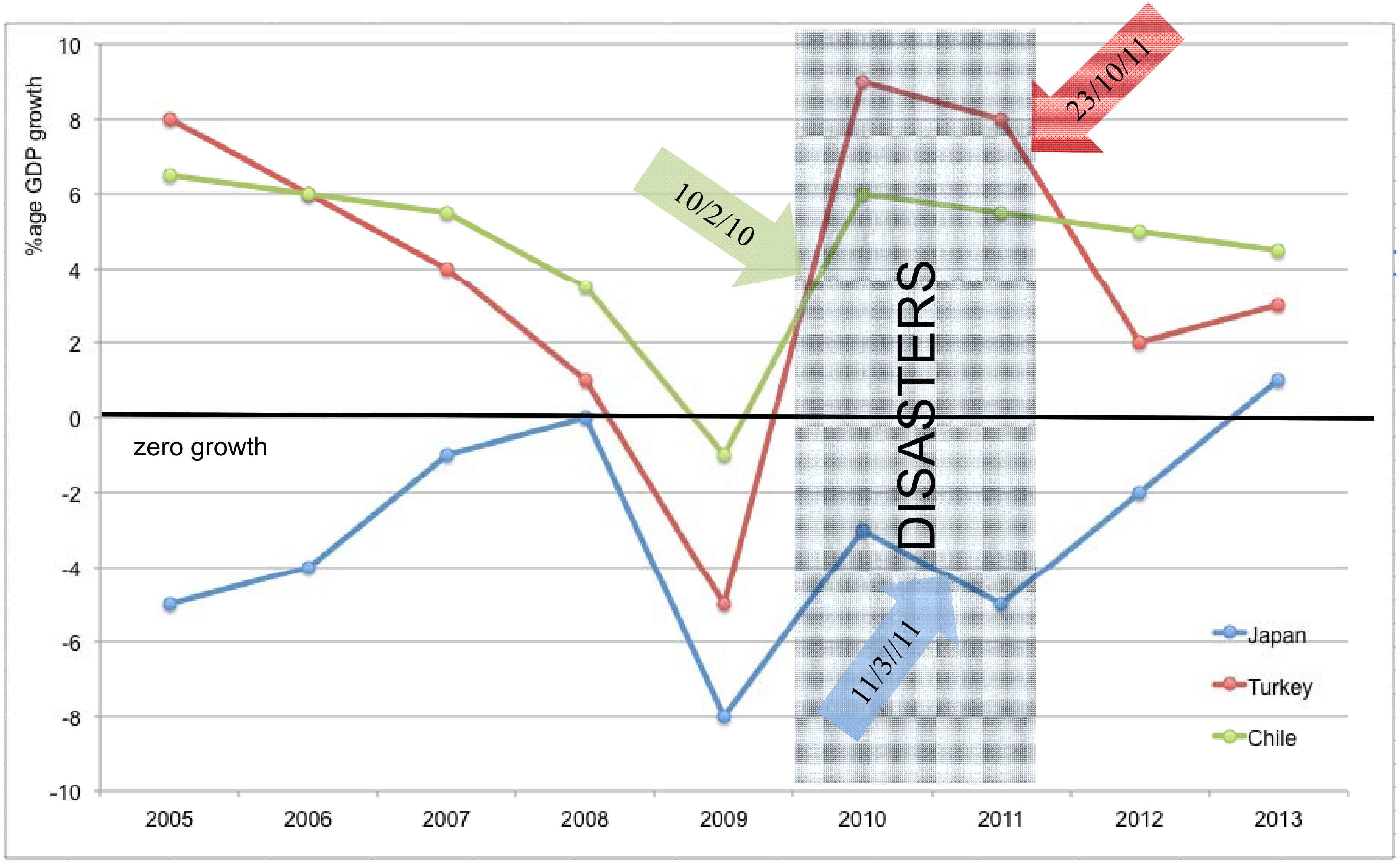
Size of disaster

size = (deaths + missing) x (loss / GDP)

Disaster	Deaths Missing	Loss US$bn	GDP US$bn	**Size of disaster**
China, Wenchuan 2008	87,587	130	9,240	1,232
Japan, Tohoku 2011	20,350	210	4,919	869
Pakistan, Kashmir 2005	87,000	2.3	232	863
Iran, Bam 2003	30,000	1.5	368	122
Chile, Maule 2010	547	30	277	59
New Zealand, Christchurch 2011	181	15	186	15
Thailand, Indian Ocean 2004	8,212	0.4	387	8
Italy, L'Aquila 2009	308	11.6	2,149	2
Turkey, Van 2011	601	1	819	1
USA Northridge 1994	72	41.8	16,768	0

Source: Dr. Stephen Platt, Cambridge Architectural Research (CAR)

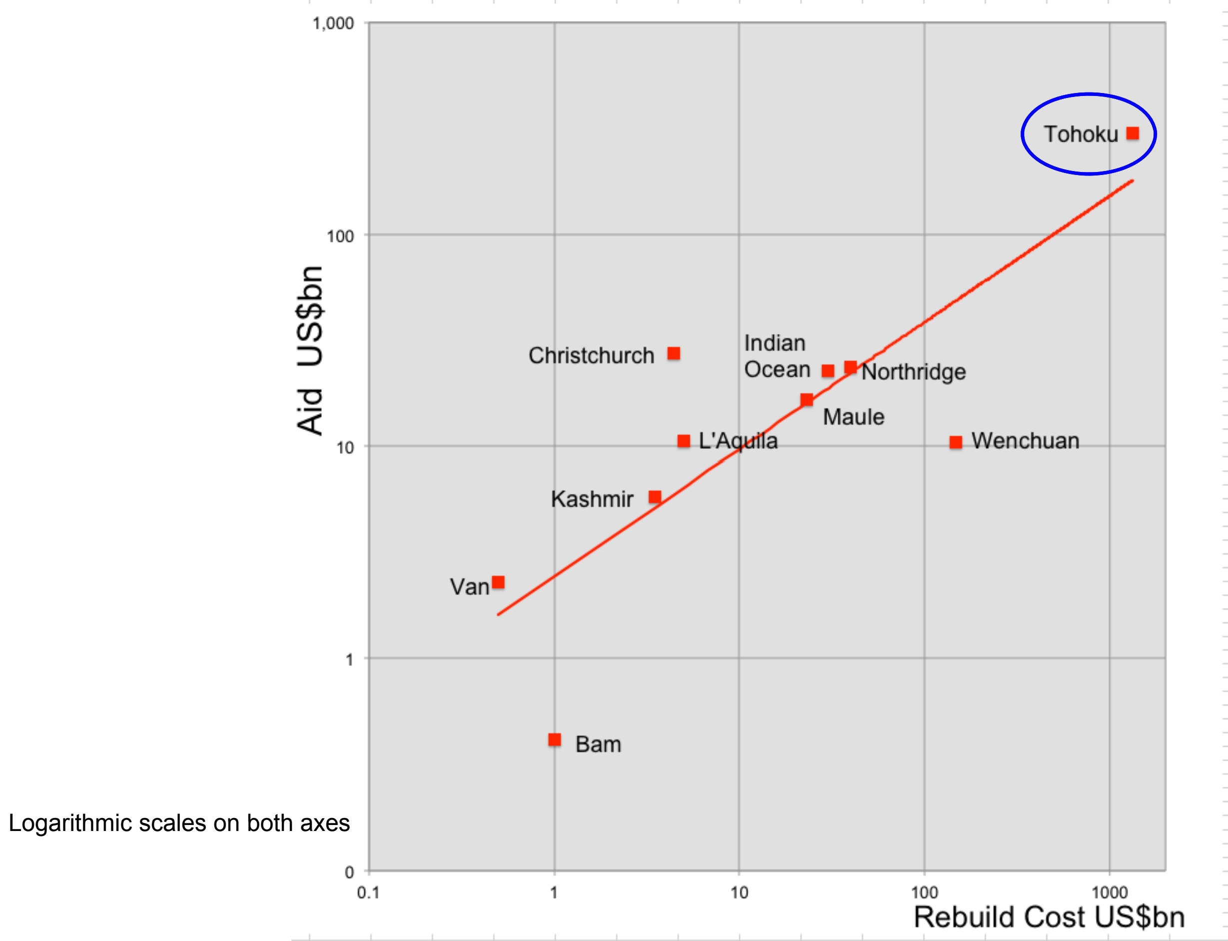
Economy



Sources: Japan – OECD; Turkey – IMF; Chile – Banco Central de Chile

Source: Dr. Stephen Platt, Cambridge Architectural Research (CAR)

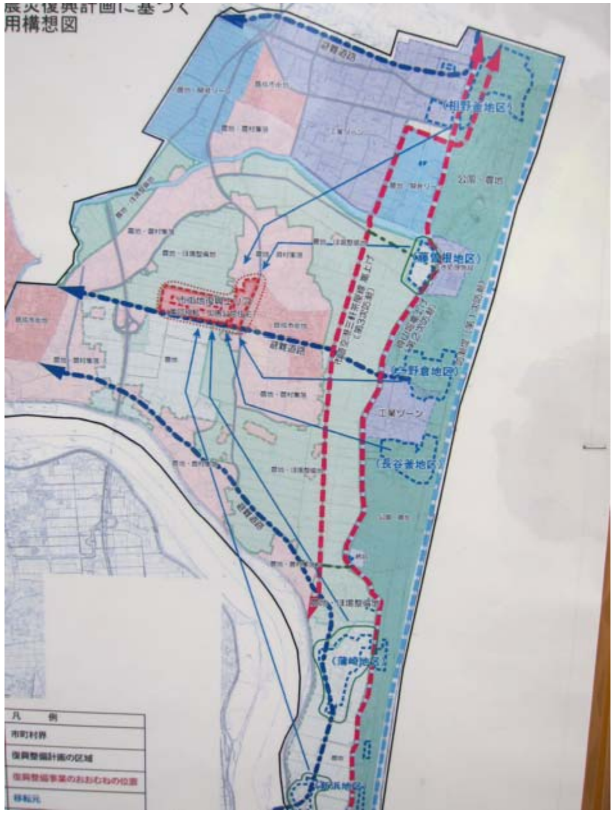
Money (total financial assistance from government, insurance and international aid)

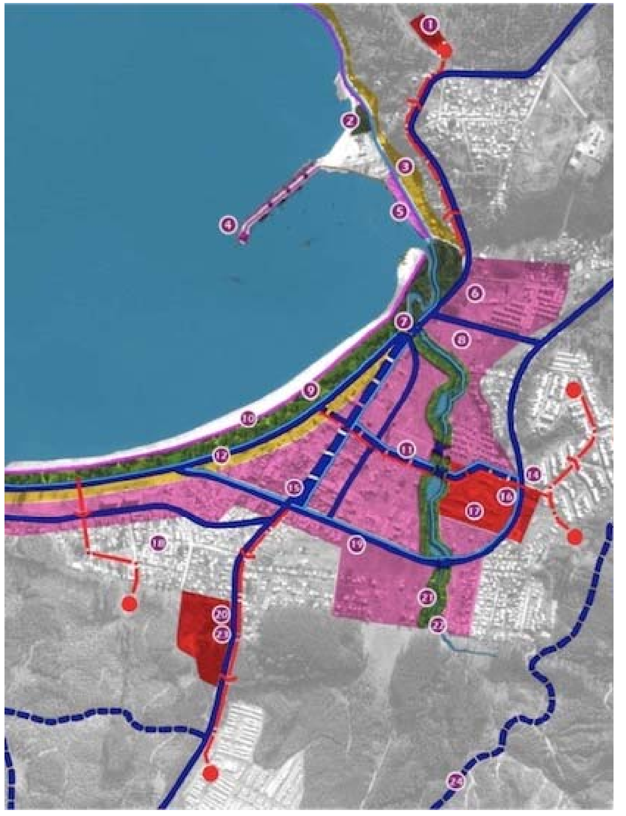


Rebuild Cost US$ bn

Source: Dr. Stephen Platt, Cambridge Architectural Research (CAR)

Planning strategy





Japan

Focus on Protection strategies

Two main protection strategies: Strategy A, moving homes to higher ground, used along the Rias Coast. Strategy B, providing barriers and concentrating housing on raised platforms, is being adopted in Sendai.

Turkey

Little planning for new housing

Within 15 months 10,000 new apartments were built in Van and 5,000 in Erçiş by the government housing agency, TOKI. But little urban planning, in town centres or new housing estates.

Chile

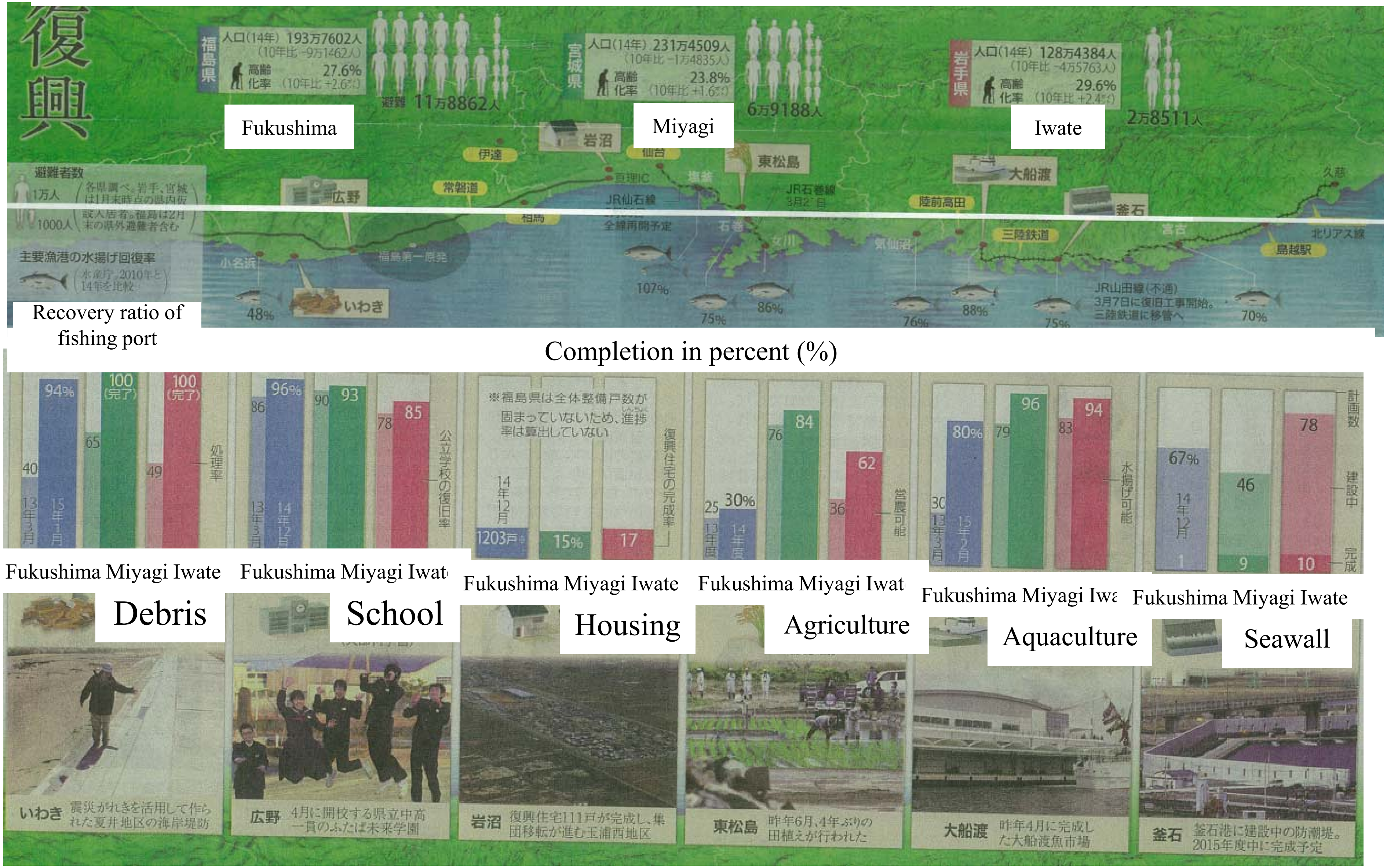
Comprehensive master planning

Moving buildings back from the beach and estuary and planting trees. Canalising the river. Creating a defensive esplanade. Building tsunami resistant housing and signing evacuation routes.

Source: Dr. Stephen Platt, Cambridge Architectural Research (CAR)

Local economic recovery: Situation after four years

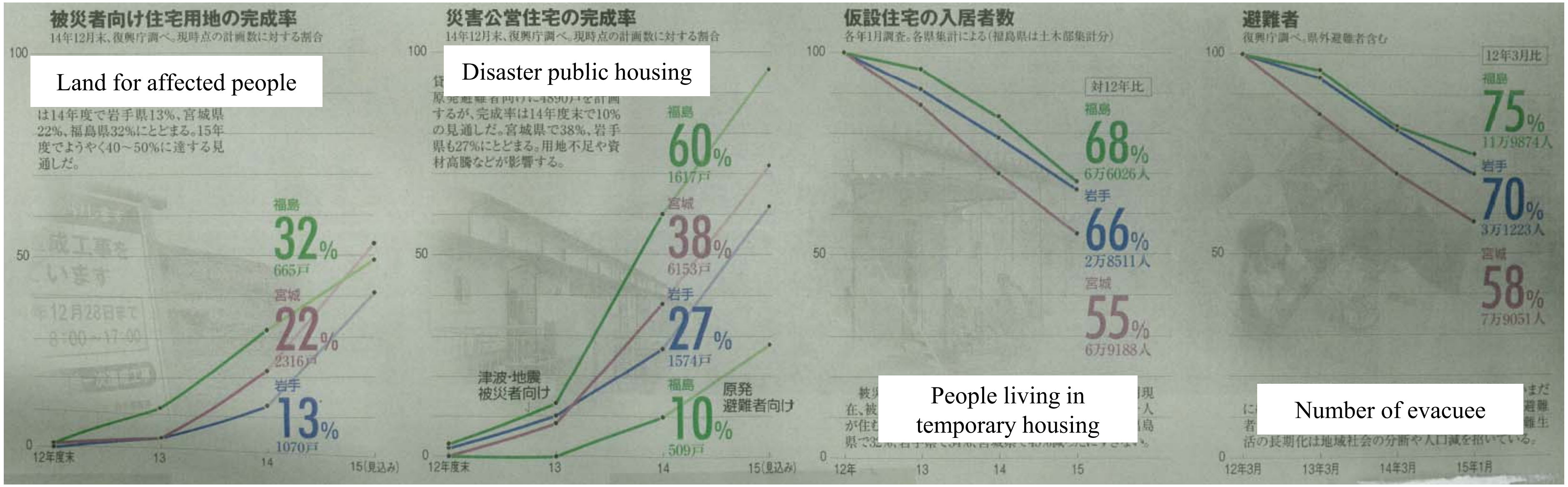
Total population and aged population

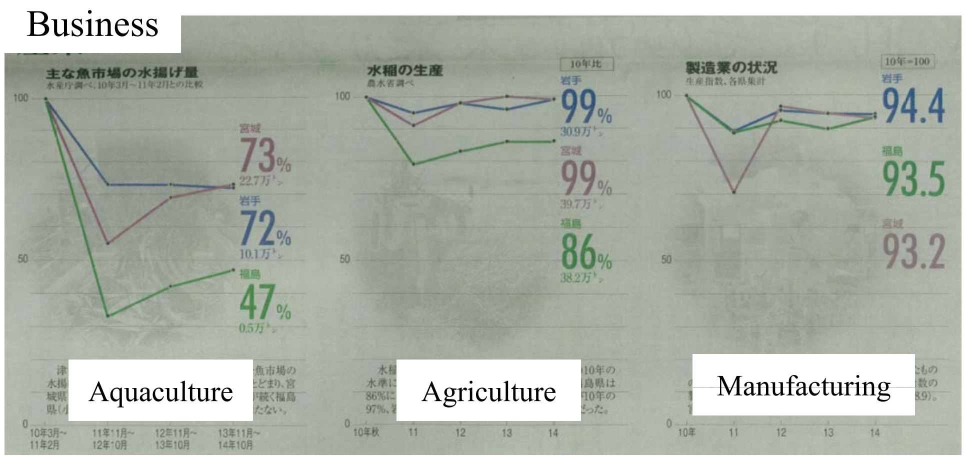


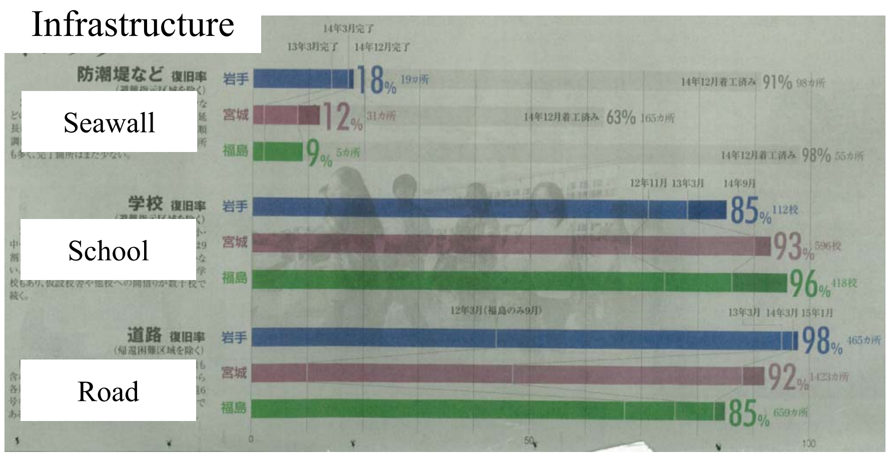
Source: Yomiuri newspaper (11 Mar 2015)

Local economic recovery: Situation after four years

Iwate Miyagi Fukushima

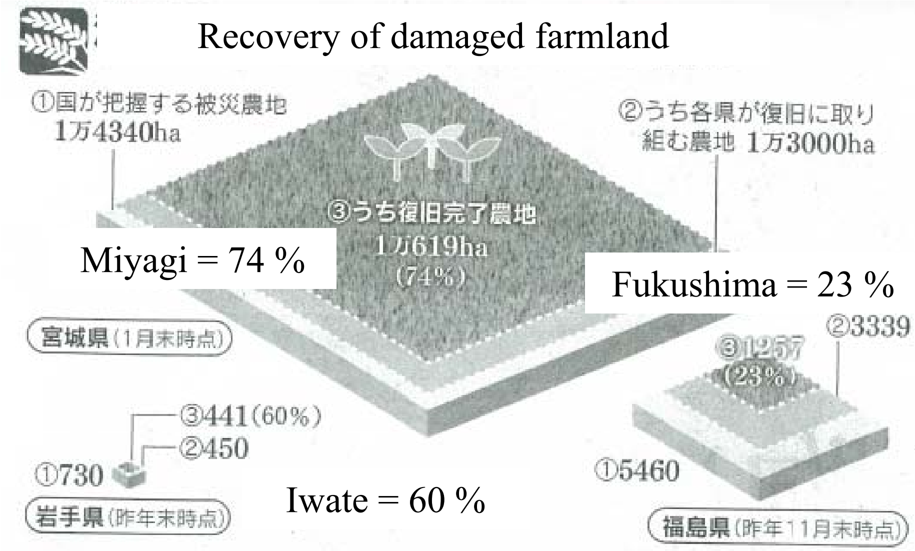


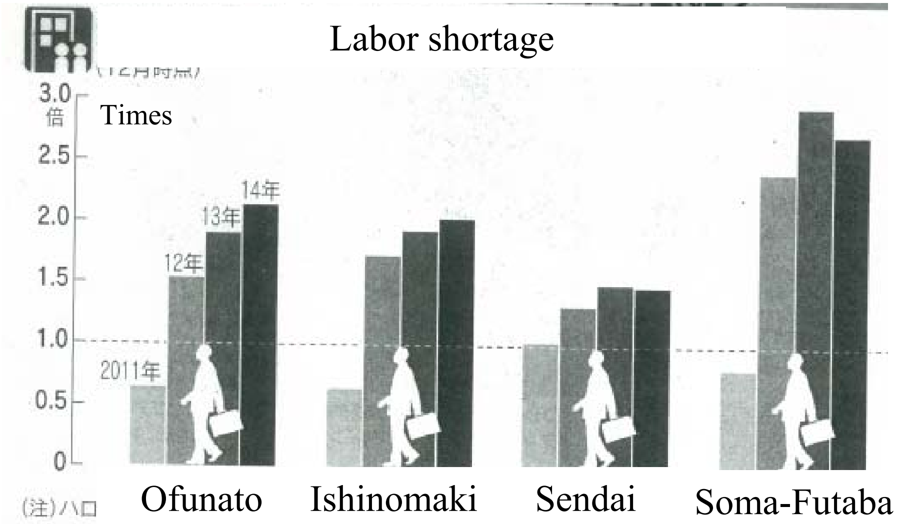


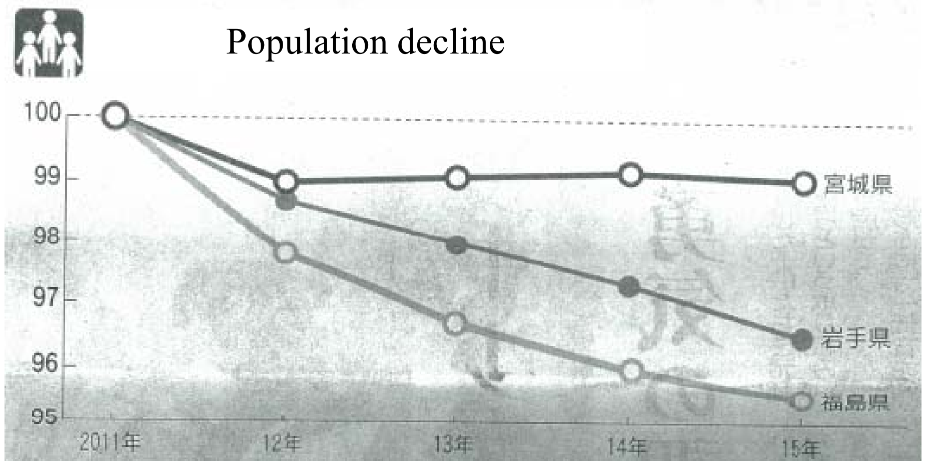


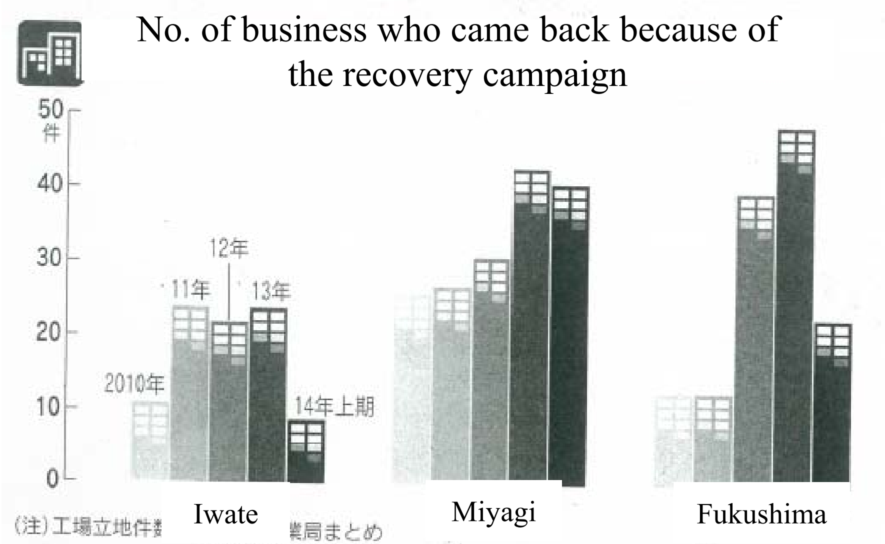
Source: Asahi newspaper (11 Mar 2015)

Local economic recovery: Situation after four years





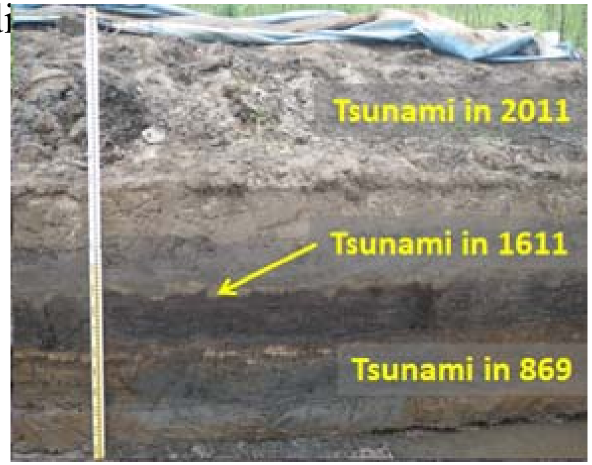


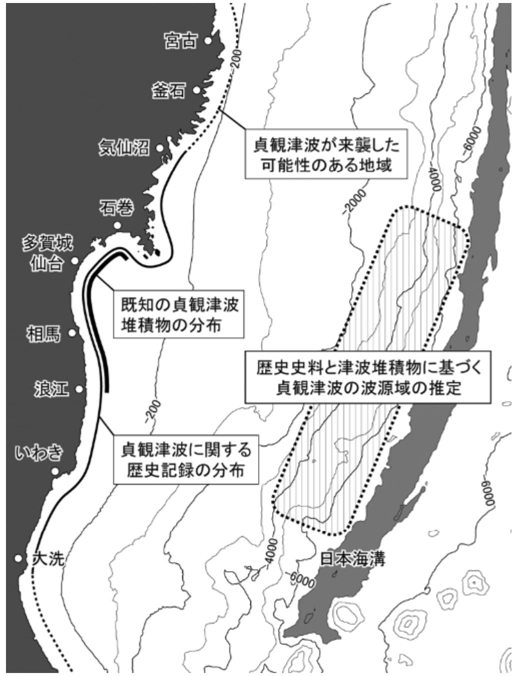


Source: Nikkei newspaper (11 Mar 2015)

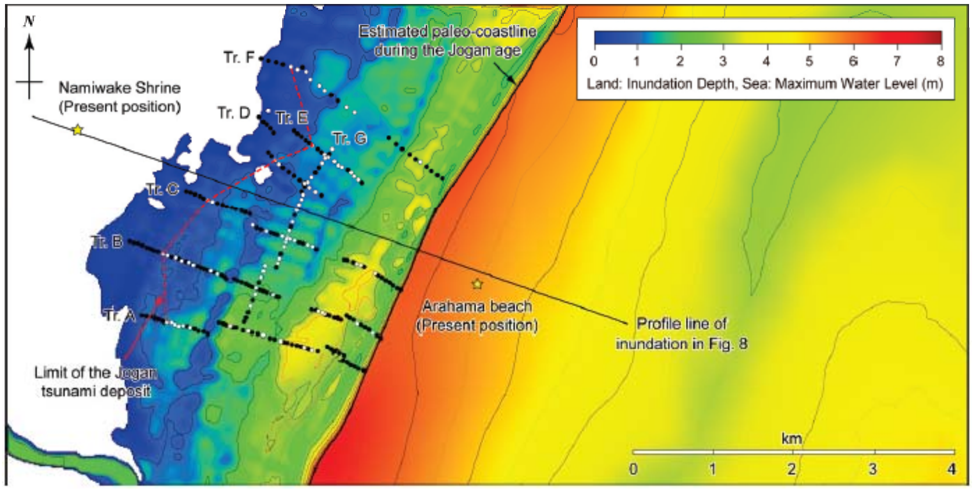
Underestimation of the earthquake magnitude. Sugawara et al. (2001) estimated magnitude of 8.3-8.6 and 2-3 km inundation di

869 Jogan tsunami





Record of May 26, 869



Source: 'Nihon Sandai-Jitsuroku'
(One of Six Official Chronologies of Ancient Japan)
Imperial Household Agency

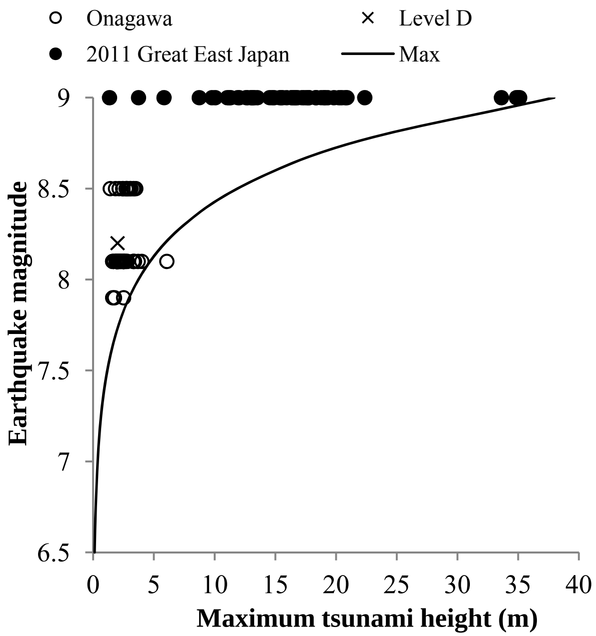
http://www.kunaicho.go.jp/e-okotoba/02/address/koen-h24az-mizuforum6th.html

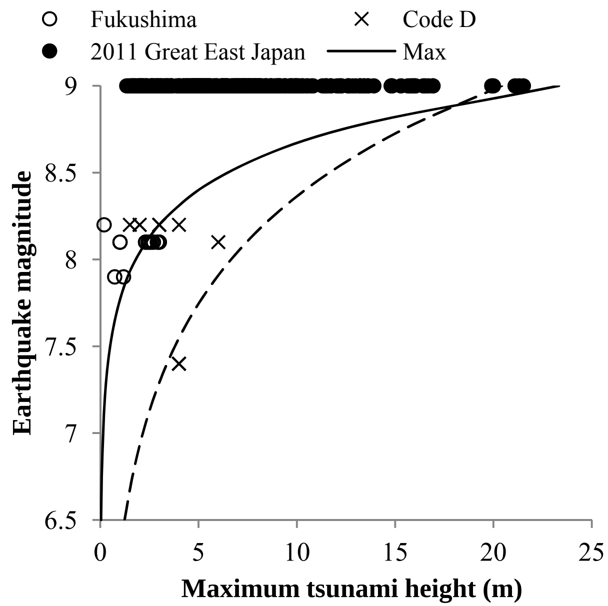
1611 Keicho-Sariku tsunami

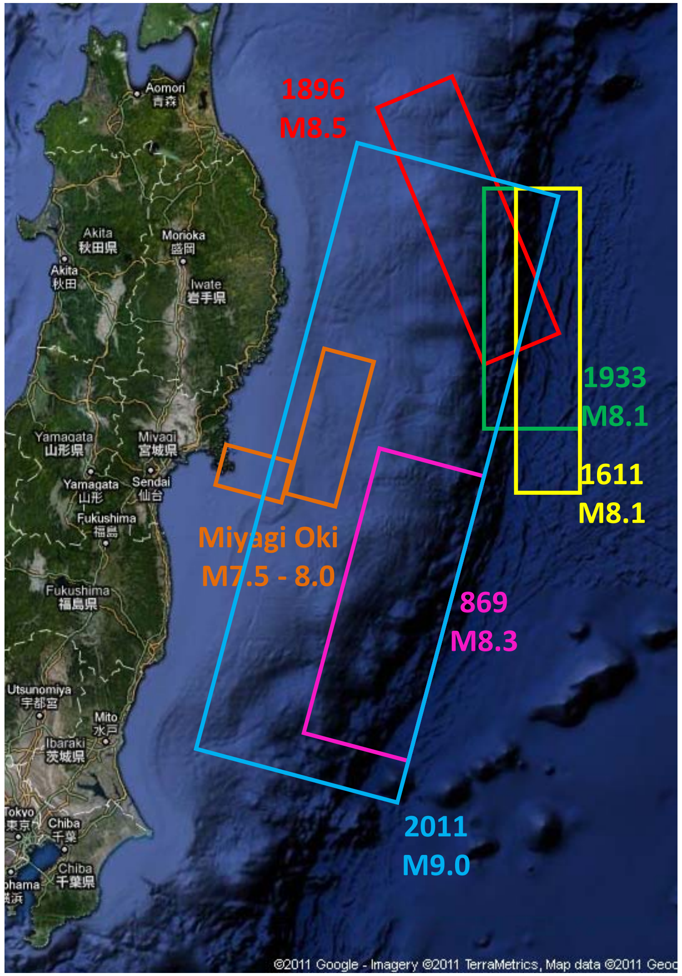
Villages in Edo period (1603-1868) were located outside inundation area of the 2011 tsunami

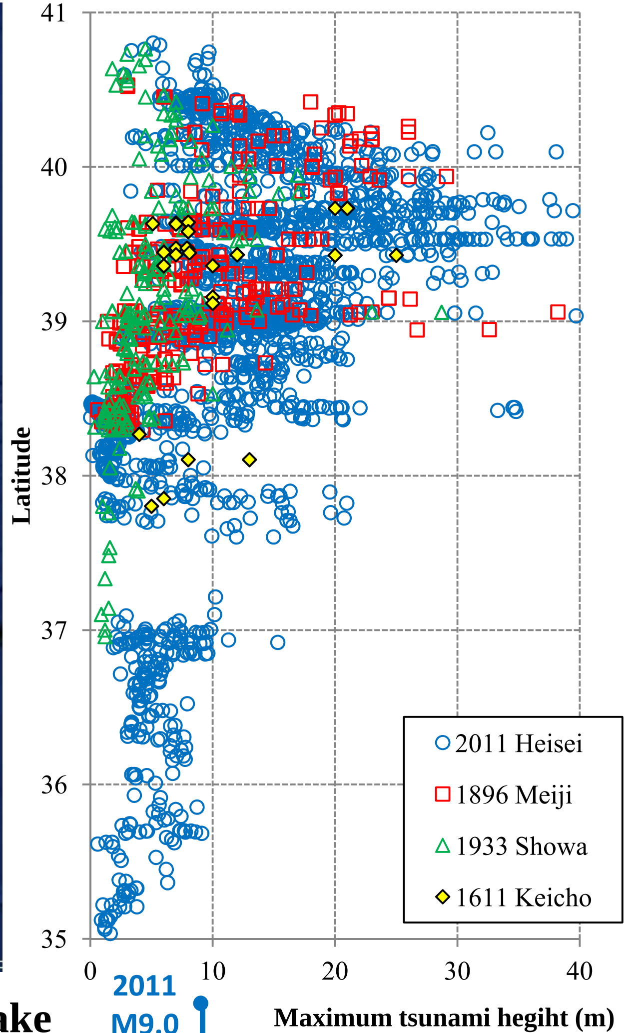
Hirakawa、2011

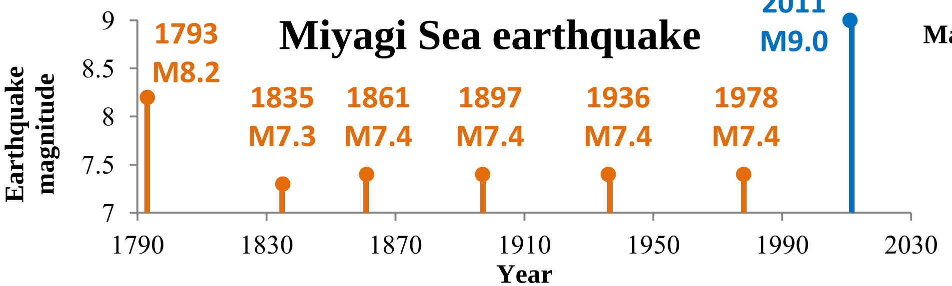
Sanriku tsunamis and Miyagi Sea tsunamis





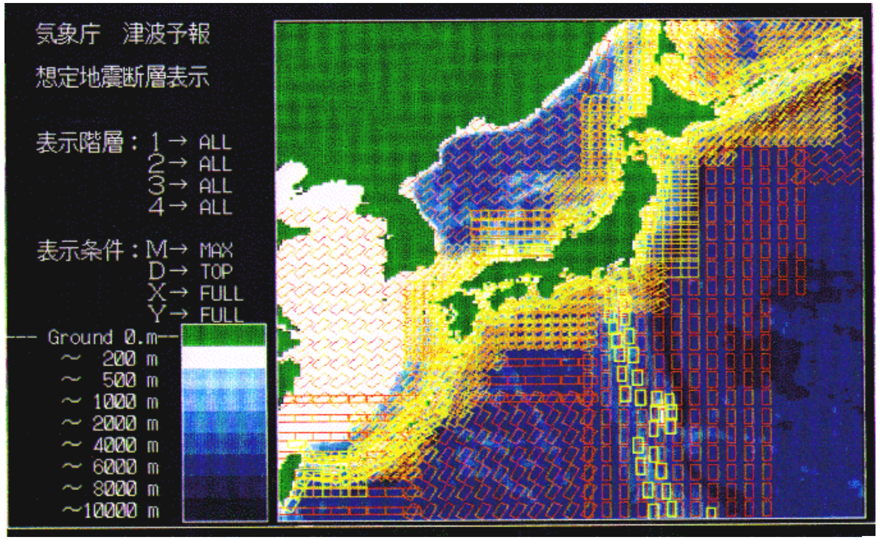




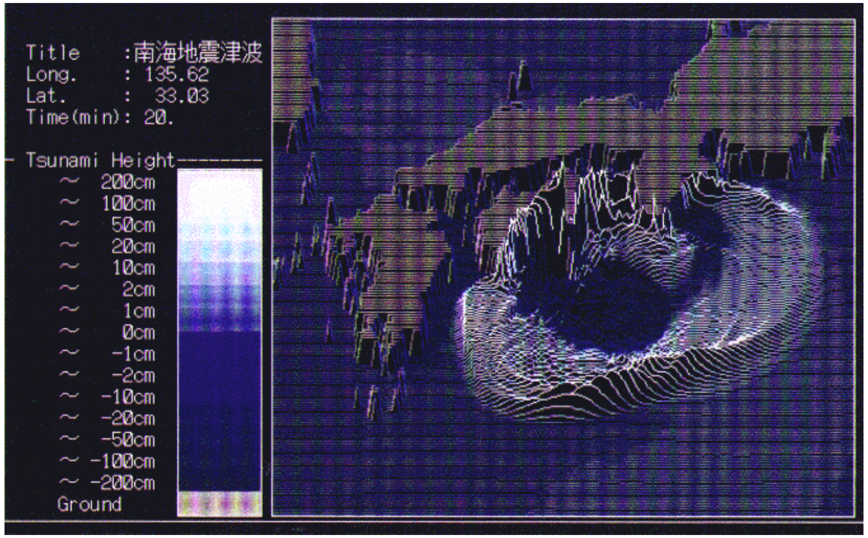


Tsunami warning systems in Japan

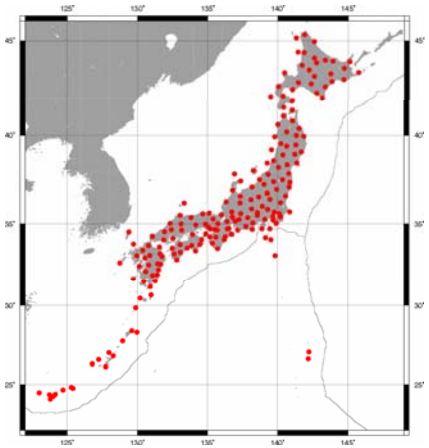
Assumed faults around Japan
(100,000 cases)



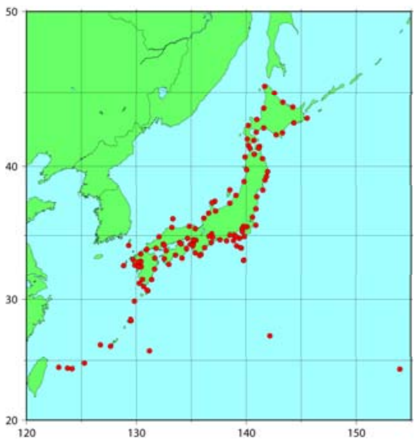
Numerical simulation results stored in database

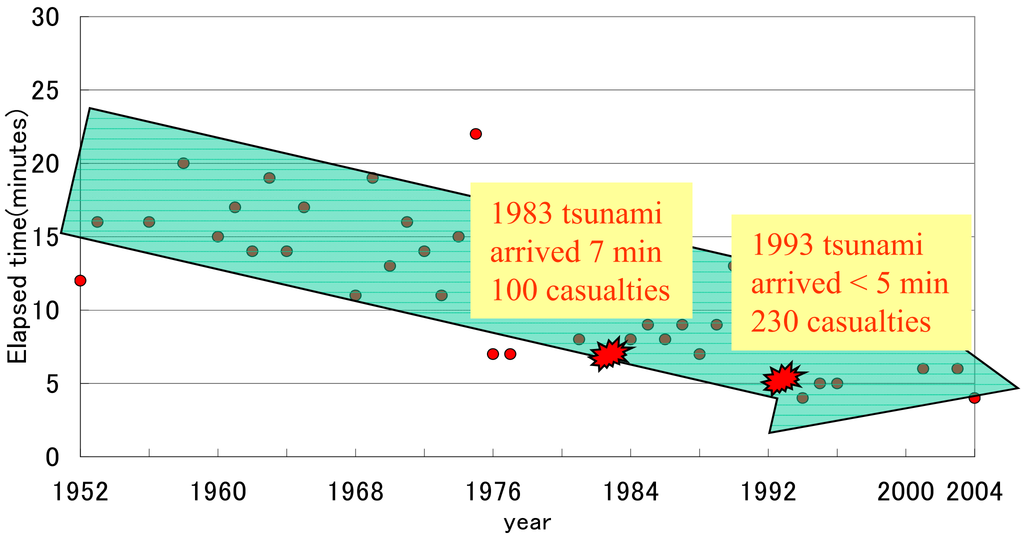


Seismic Network



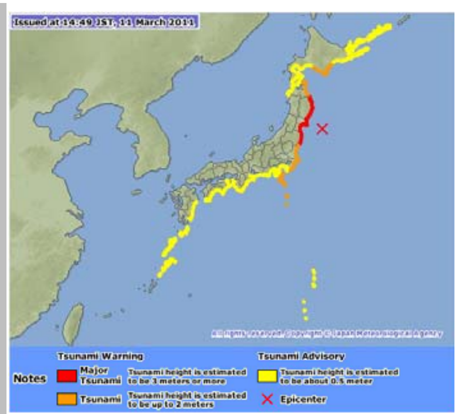
Sea Level Network

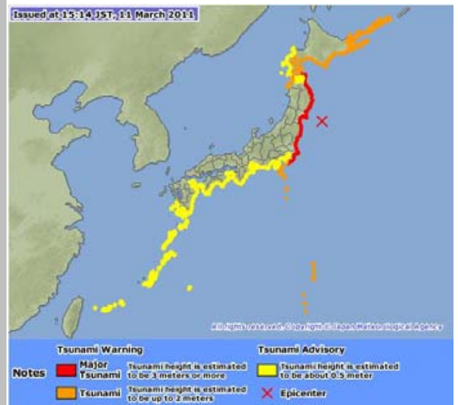


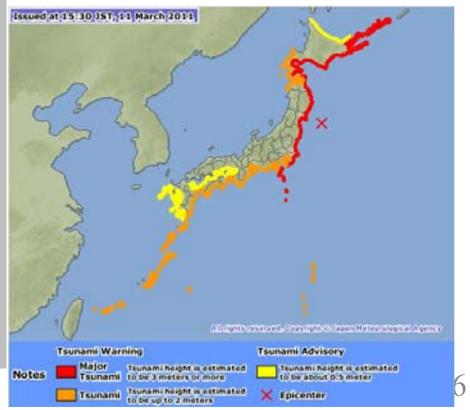


Tsunami warnings during the 2011 tsunami

Local	Event	Information
14:46	Earthquake	
14:49	Mjma = 7.9 Major	Tsunami Warning - Iwate, Miyagi and Fukushima
14:50		Tsunami Information - Iwate: 3m, Miyagi: 6m, Fukushima: 3m, etc.
		Only up to M8.0 in the database
15:10	GPS buoys > 3m	
15:14		Tsunami Warnings/Advisories extended
15:14		Tsunami Information - Iwate: 6m, Miyagi: over 10m, Fukushima: 6m, etc.
	Tsunami hit the nearest coast	
15:21	Tide gauges at Kamaishi (Iwate) > 4.1m (scale out)	
15:30		Tsunami Warning extended
15:31		Tsunami Information- Iwate, Miyagi, Fukushima: over 10m, etc.
16:00	Mjma = 8.4	
17:30	Mw = 8.8	
13th May	Mw = 9.0	

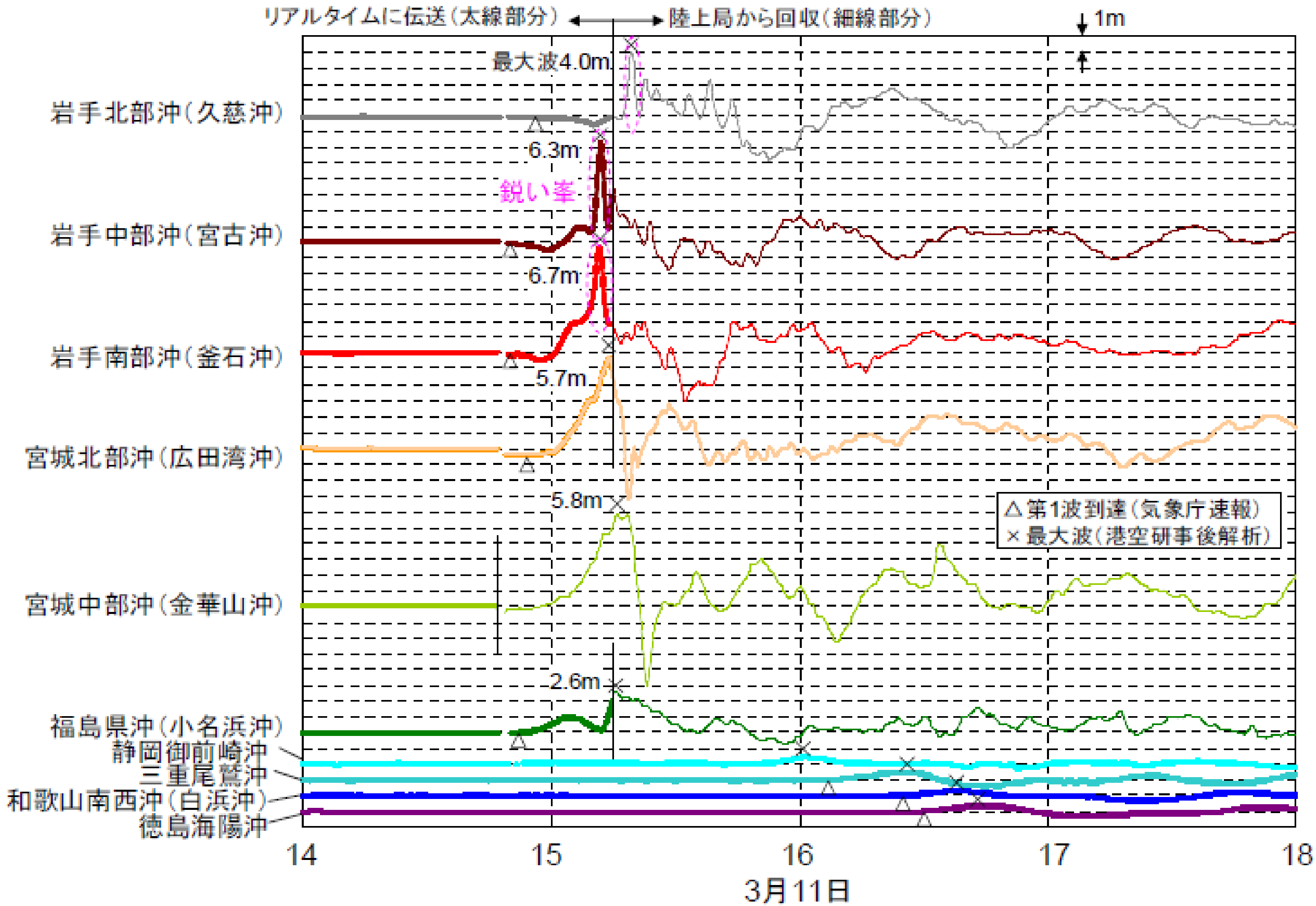






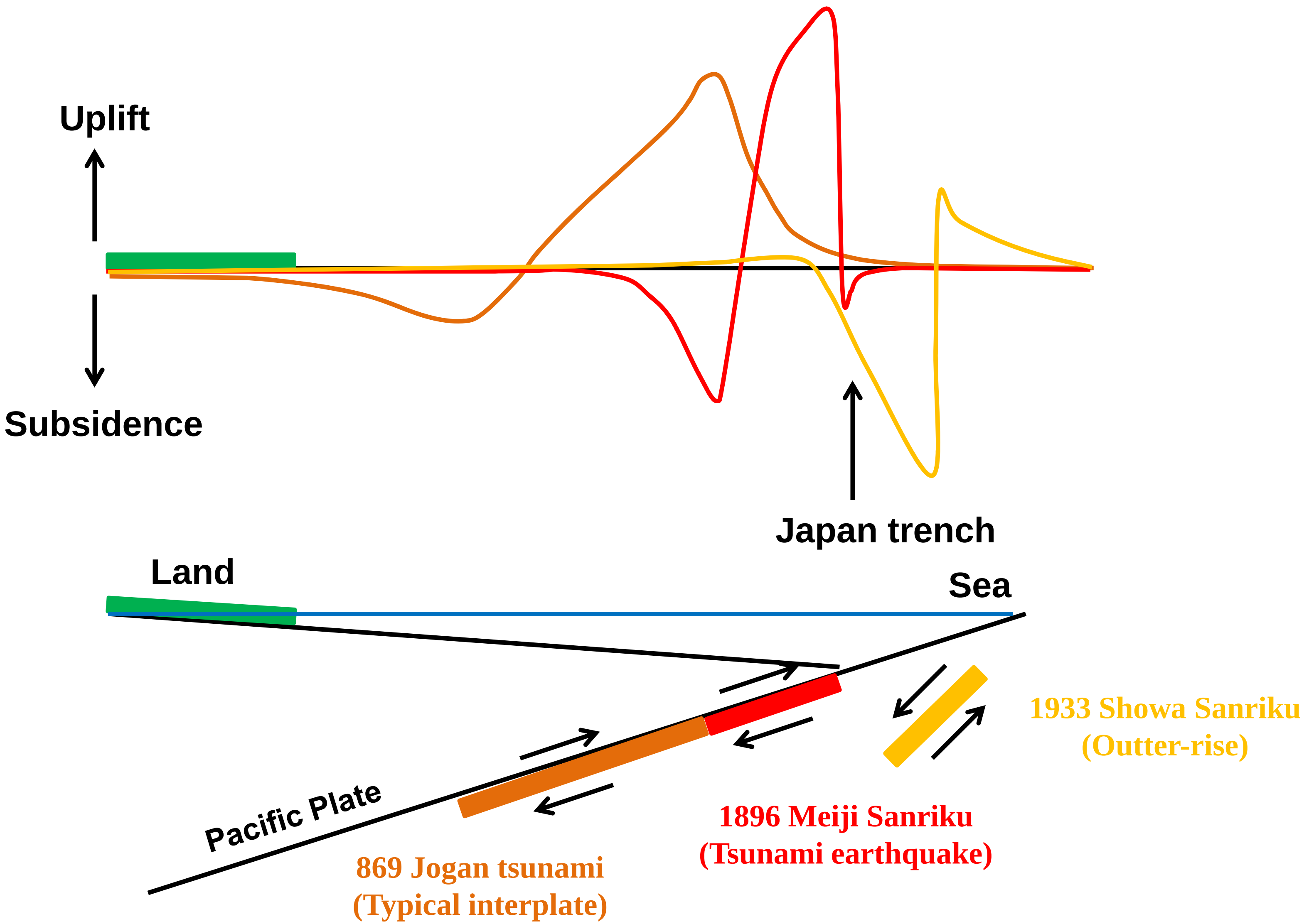
Hayashi et al (2011) and http://www.jma.go.jp/jma/en/2011_Earthquake.html

Observed tsunami waveforms

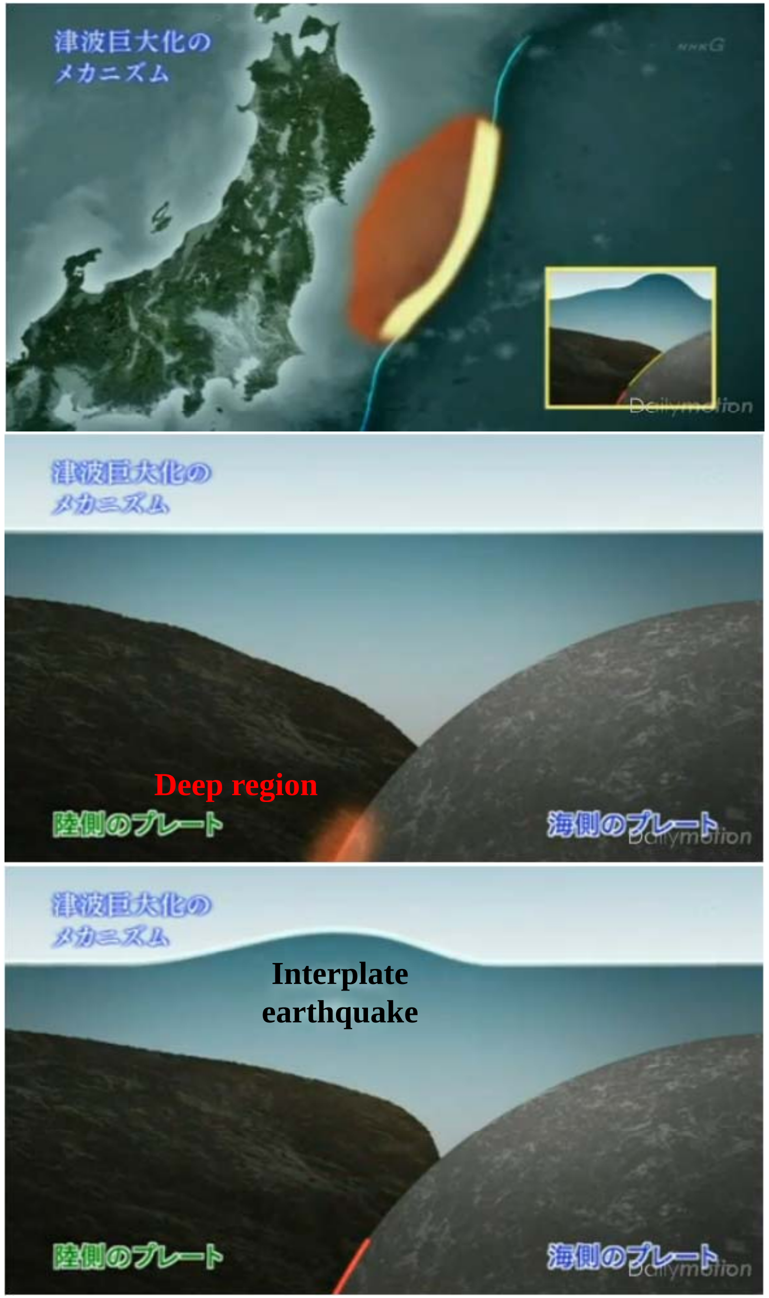


http://www.pari.go.jp/info/tohoku-eq/

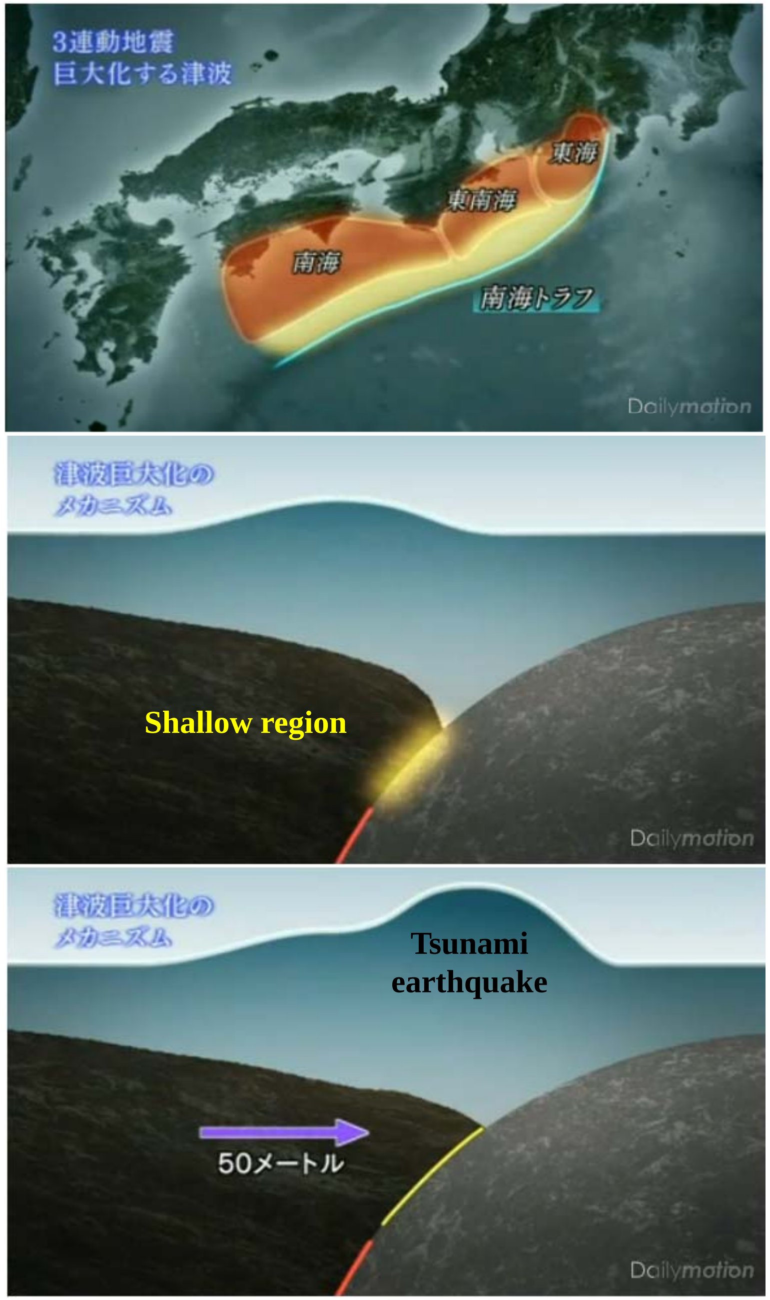
Earthquake generation mechanism and seafloor deformation



2011 Tohoku earthquake



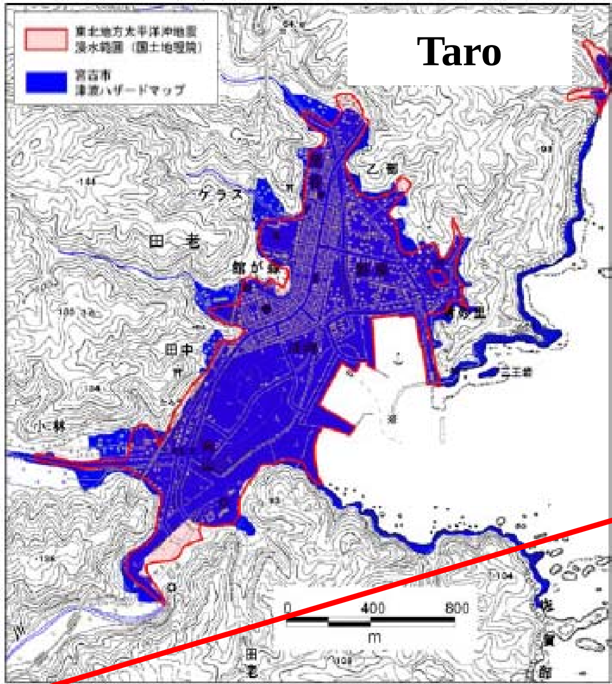
20xx Nankai earthquake

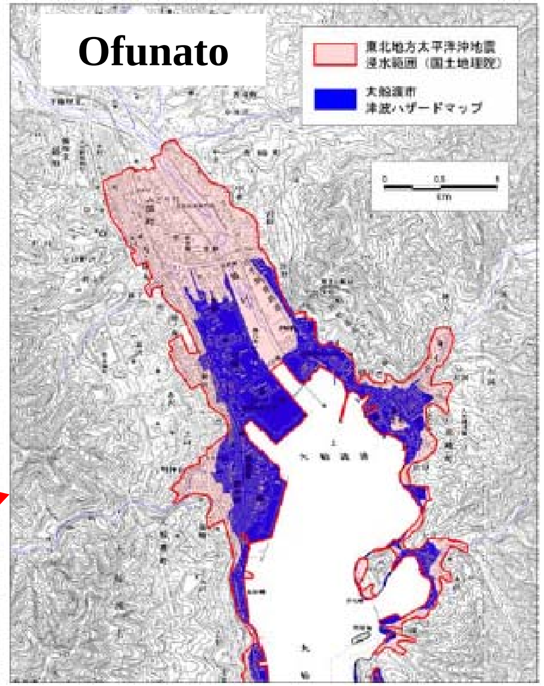


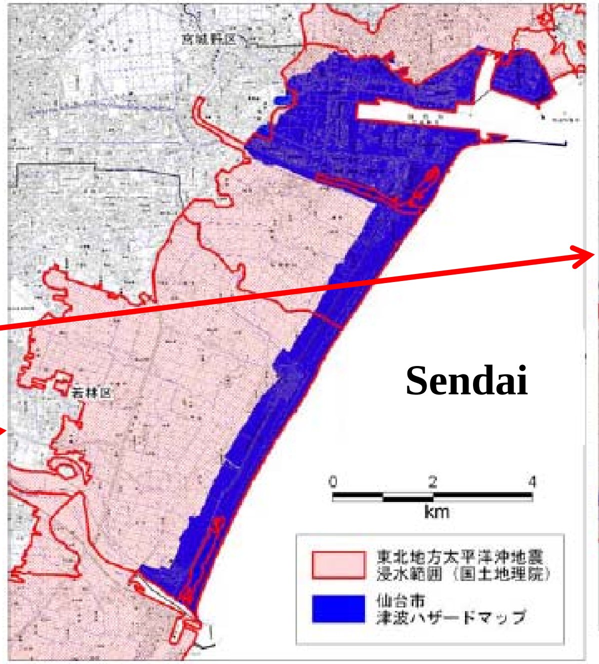
Source: NHK

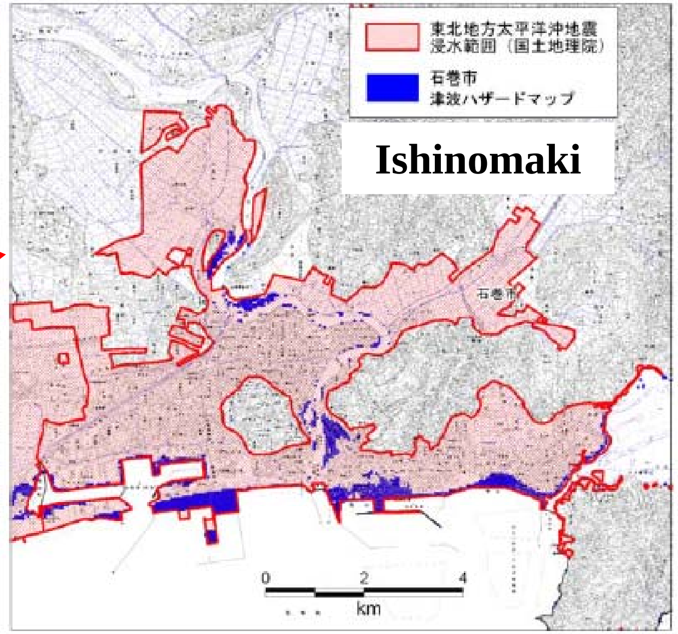
The 2011 tsunami: Large different in tsunami hazard map

Red: 2011 tsunami inundation area
Blue: Predicted inundation area





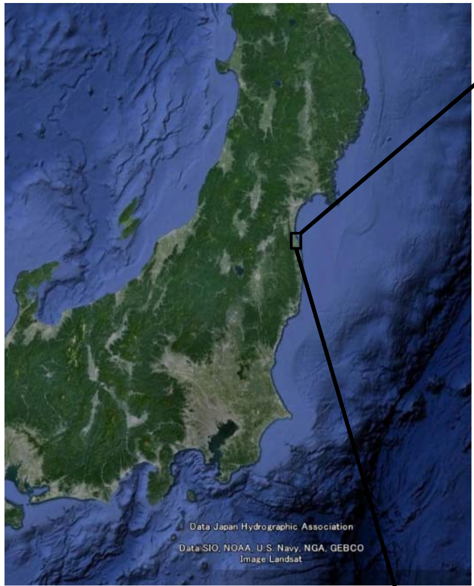


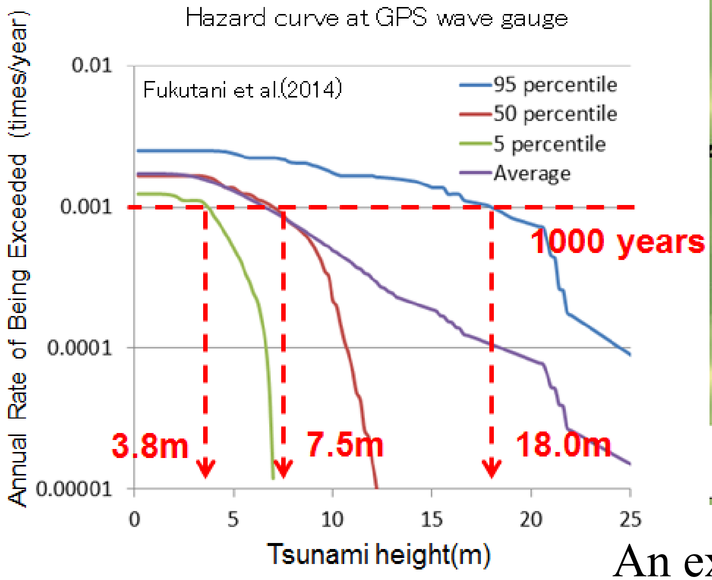


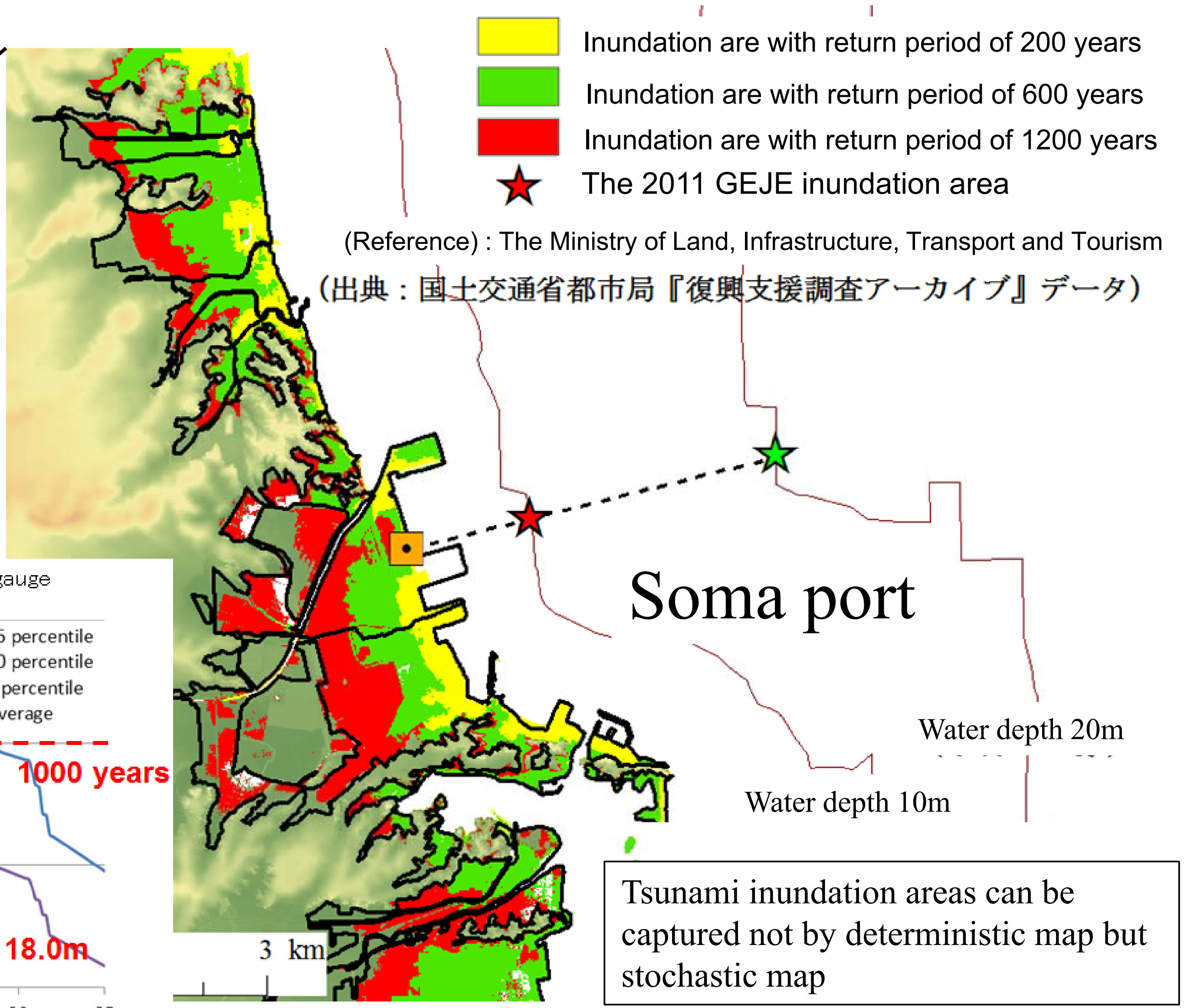
(出典)・東北地方太平洋沖地震浸水範囲:国土地理院資料より作図
・ハザードマップ:仙台市「仙台市津波ハザードマップ」、石巻市「石巻市津波ハザードマップ」

Stochastic tsunami hazard map

If we use the hazard curve data, we can estimate tsunami inundation area







Tsunami inundation areas can be captured not by deterministic map but stochastic map

An example of inundation map for Soma-city in Japan

Lessons : Unosumai Elementary and Junior high schools

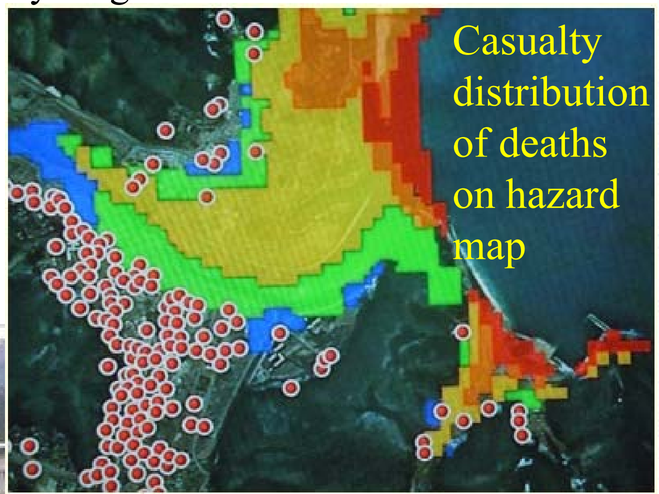
Miracle of Kamaishi…Awareness for expected event

- All nearly 3,000 students survived

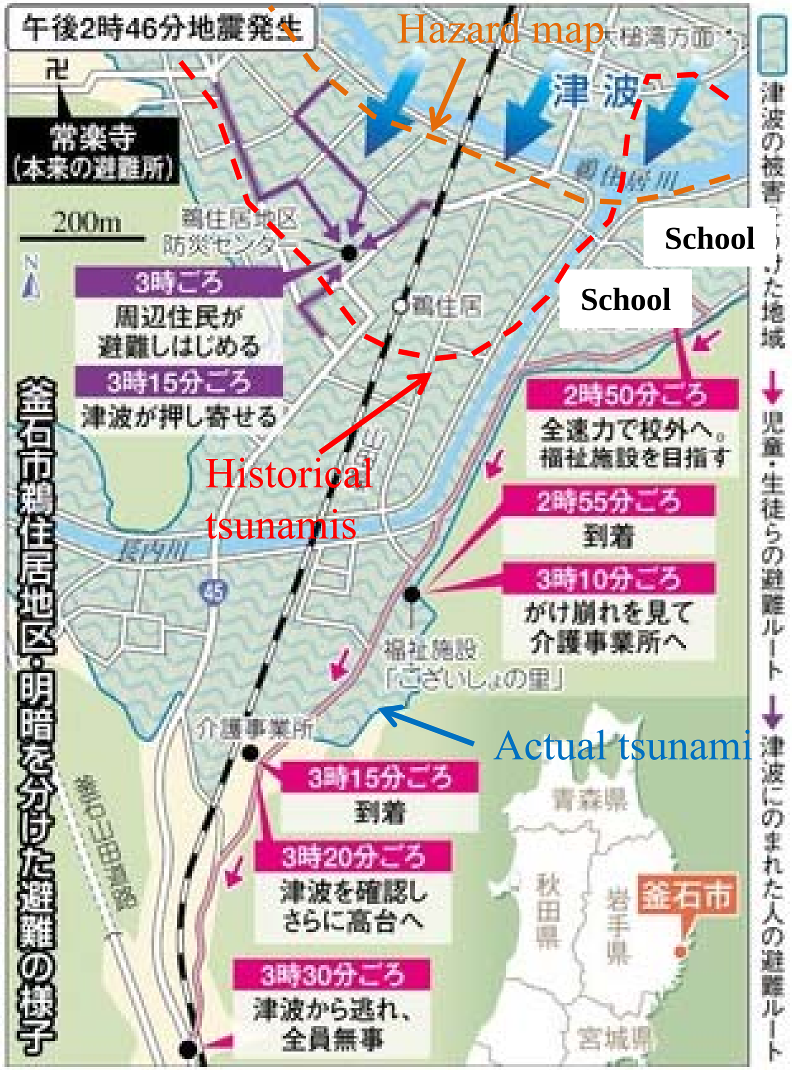
Three principles

- First, don't put too much faith in outdated assumptions. “In other words, don't trust hazard maps.
- The second rule of thumb is for people to make their best efforts to deal with the situation. They urged the teachers to keep moving higher, adding that the older kids also remembered to help the younger ones.
- And finally, to take the initiative in any evacuation.

http://mnj.gov-online.go.jp/kamaishi.html



http://insite.typepad.jp/.a/6a0120a6885bf1970b01543336c30e970c-320wi



http://www.chunichi.co.jp/article/earthquake/sonae/20120312/images/PK2012031202100063_size0.jpg

Questionnaire survey related to tsunami evacuation (1)

Source: Cabinet office of Japan

By Cabinet Office, Fire Agency and Japan Meteorological Agency

-Total answers: 870 (Iwate = 391, Miyagi = 385 and Fukushima = 94), period: During July 2011

-A: Soon evacuated (57%), B: Evacuated after some actions (31%), C: Tsunami came during doing some actions (11%) and D: Did not evacuated (they were already in high ground) (1%)

-[A+B] Main reasons for starting evacuation: large shaking (48%), were asked to evacuate by family or surrounding people (20%) and surrounding people start their evacuation (15%)

→ Less amount of calling out for evacuation

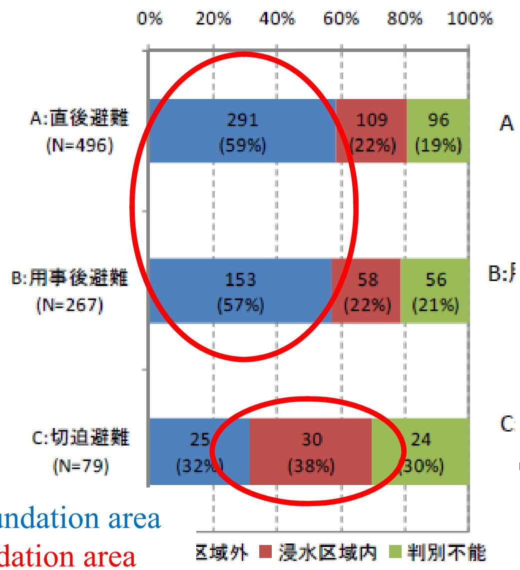
-[B+C] Why they did not evacuated as soon as possible: Went back home (22%), looking for family or picking up family (21%), tsunami did not come in the past (11%) and did not think about tsunami coming (9%)

→ Have to reduce the amount of people going back home or seeking family

Condition of evacuation shelter

- C has the highest ratio of people who were inside the inundation area (38%)
- A and B are both mostly evacuated to designated evacuation shelters but C is large on the highest floor of the same building

A: Soon evacuated
B: Evacuated after something done
C: Last minute evacuated



Blue = outside inundation area
Red = inside inundation area
Green = could not identify

Evacuation method

- In general, about 57% of people evacuated using car.
- Reason for using car: Not enough time without using car (34%), wanted to evacuate together with family (32%), far from safe place (20%)
- About 34% of them were trapped in the serious traffic.
- In general, limit distance for evacuation by walking was about 500 m and by car was 2 km.

Tsunami hazard map

- Number of people who had seen tsunami hazard map or had hazard map in their house was less than 20%

Questionnaire survey related to tsunami evacuation (2)

By Weathernews

- Target area: Hokkaido, Aomori, Iwate, Miyagi, Fukushima, Ibaraki and Chiba
- Total answers: 5,296 (3,298 from survivors and 1,998 related to people who were casualty)

1) Time from earthquake generation to starting evacuation
   - Survivor = 19 min and casualty = 21 min
2) Reason for starting evacuation
   - Major tsunami warning or tsunami warning and only 28 % of the survivors soon evacuated
3) Evacuation condition
   - Reason for not evacuated was they believe they were safe and 20% of victim could not evacuated
4) Selected evacuation place
   - 75% of survivor could evacuated to safe place while 75% of victim could not
   - 40% could not evacuate to high ground and 50% evacuated to non-designated evacuation place
5) Why they could not evacuate from the tsunami
   - 18% of victim was because they were obstructed during their evacuation
6) Evacuated elevation from tsunami
   - Approximately 2.9^{th} floor for survivor and 1.7^{th} floor for victim
7) Moving from evacuation place
   - 60% of victim moved to tsunami inundation zone again
8) Reason for moving from evacuation place
   - Looking for their family was the main reason

Tsunami countermeasures in Japan

- 1896 Meiji-Sanriku tsunami: by individual

  Moving high ground
- 1933 Showa-Sanriku tsunami: by country and prefecture

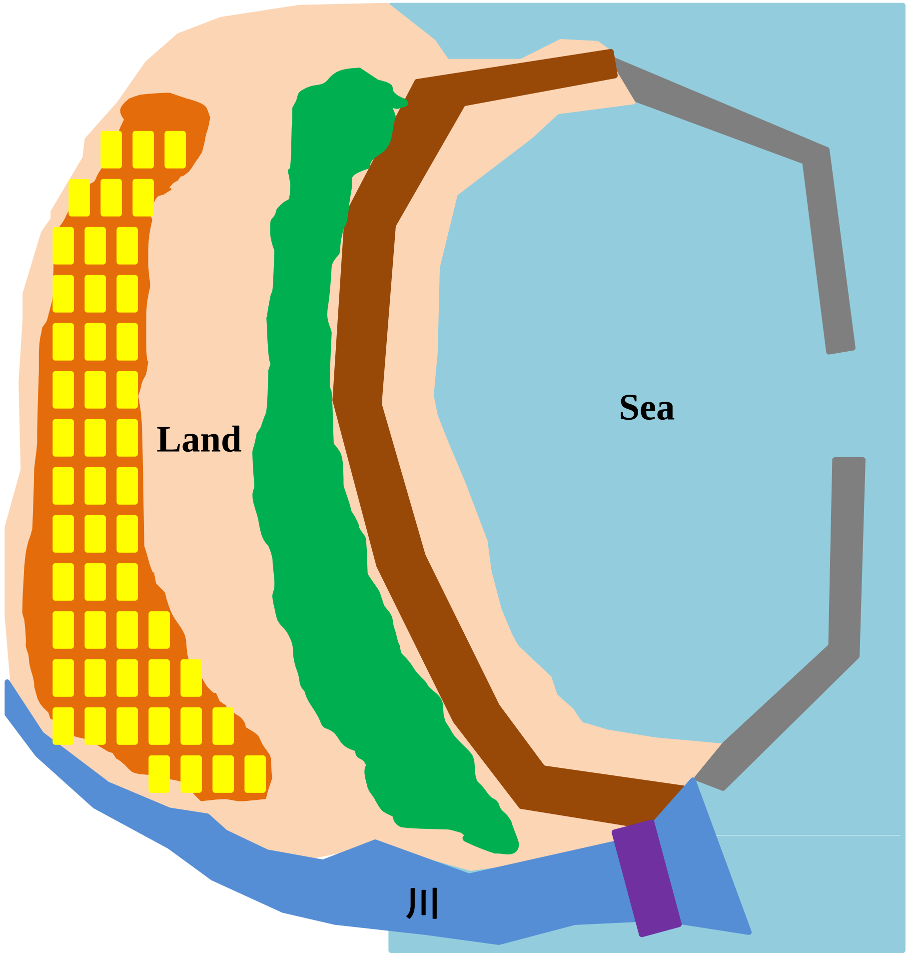
  Moving high ground + Seawall in some areas
- 1960 Chile tsunami: Structural measures

  Seawalls, breakwaters and tsunami gates
- 1993 Okushiri tsunami:

  Structural measures, town planning and combination with soft measures
- 2011 Great East Japan tsunami:

  Prevention → Reduction

Tsunami countermeasure system



Breakwater: Kamaishi

Water gate: Fudai

Seawall: Taro

Highland residence: Toni-hongo

Control forest: Rikuzenakata

Reconstruction plan of Miyagi prefecture

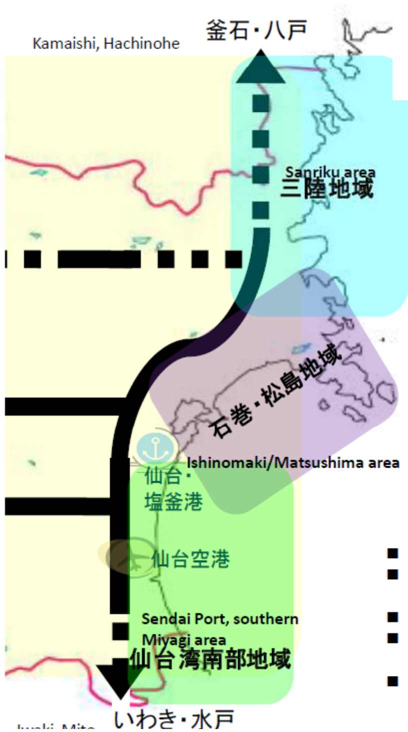
Period: 10 years (Goal: 2020)

Restoration 2011–2013 (3 years) → Reconstruction 2014–2017 (4 years) → Development 2018–2020 (3 years) → Miyagi's Recovery

Prefectural citizens 県民
NPO, etc. NPO等
Companies 企業
Local municipalities 市町村
National government 国
Prefectural government 県
University 大学
Groups 団体

県民一人ひとりが復興の主体
Each citizen is a key player in the recovery efforts

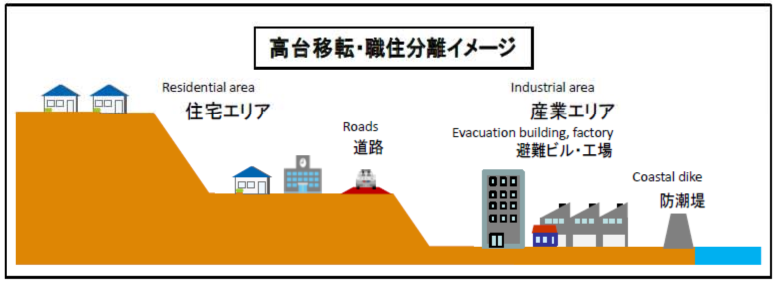
総力を結集した復興
Using all available resources

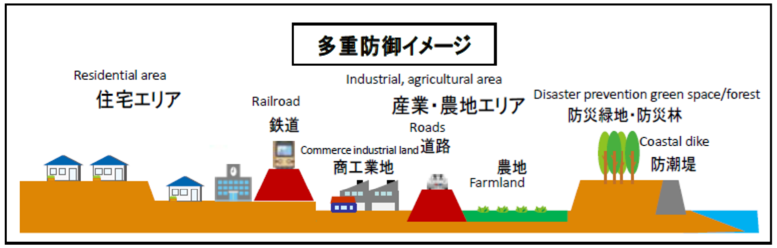


- Relocation to high ground, separation of business and residence
- Assemble and reorganize fishing ports, branding of marine processed products, "sixth industry"
- Tourism promotion that draws on the nature of the Sanriku area
- Promoting the maintenance of Sanriku expressway

- Relocation to high ground, separation of business and residence
- Multiple barriers
- Assemble and integrate fishing ports, assemble and advance industries
- Tourism promotion that makes use of Matsushima and Oshika peninsula

- Multiple barriers
- Advancing logistics function by utilizing airport and ports, and advancing business location to Miyagi
- Agricultural land accumulation, "sixth industry"
- Maintenance of national public park and disaster prevention green space
- Promoting the maintenance of Joban Expressway

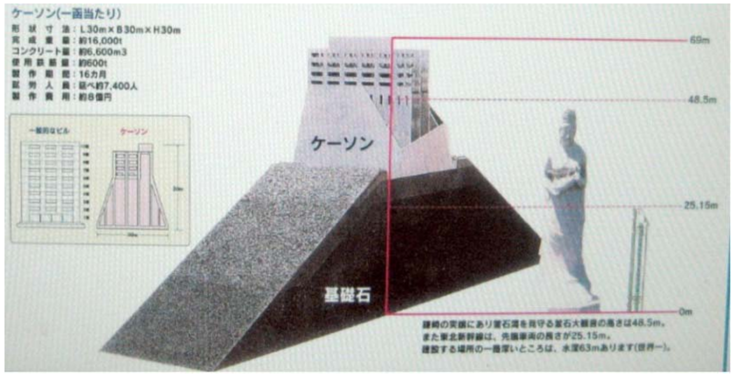


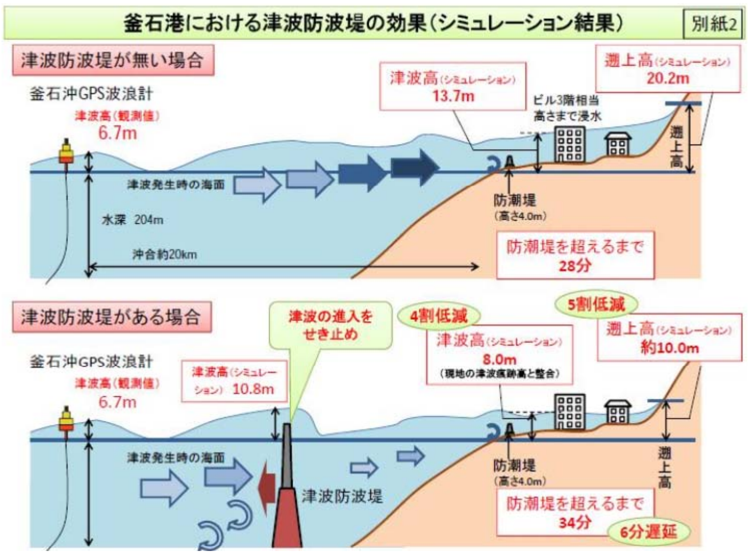


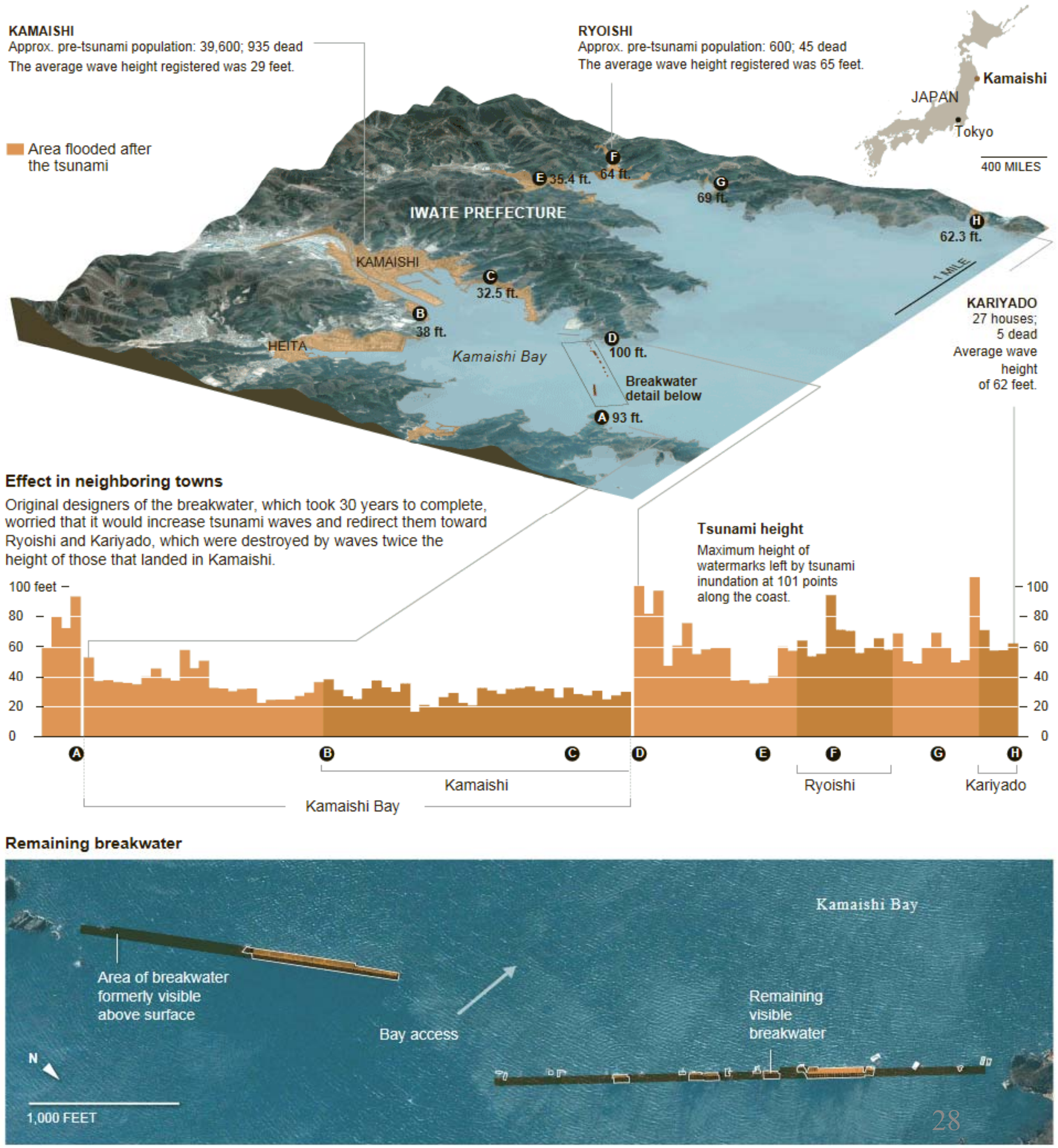
http://www.pref.miyagi.jp/seisaku/sinsaihukkou/keikaku/index.htm

The world's largest breakwater

Kamaishi breakwaters
@ sea depth = 63 m



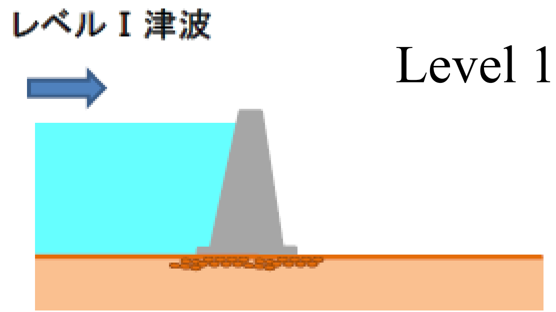




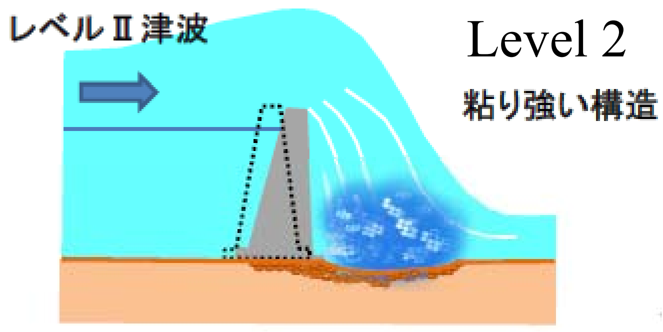
http://livedoor.blogimg.jp/shyougaiitisekkeisi2581/imgs/4/a/4aab1165.jpg
http://f.hatena.ne.jp/images/fotolife/k/kimkaz/20110401/20110401220511.jpg
http://www.physics.ohio-state.edu/~wilkins/energy/Resources/nuclear/japan/GIF/kamaishi-breakwater.png

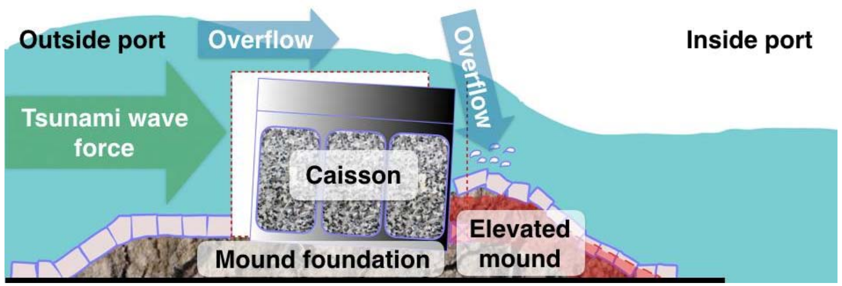
Level 1 & Level 2 tsunami

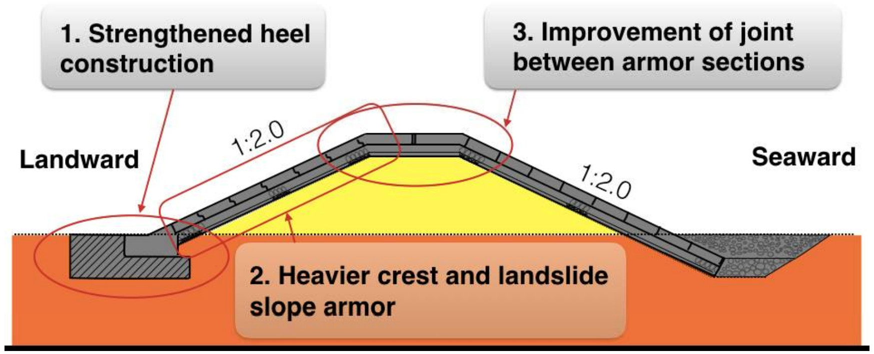
Level 1:
High frequency (30-200 years) but small to moderate tsunami.
Community should be mostly protected by coastal defense structures.
Height of coastal structures were decided by past Level 1 tsunami events



Level 2:
Low frequency (200-1,000 years) but very high tsunami.
Forget about properties but secure evacuation routes for safe evacuation.
Coastal structures should be strong enough even in case of the overtopping.



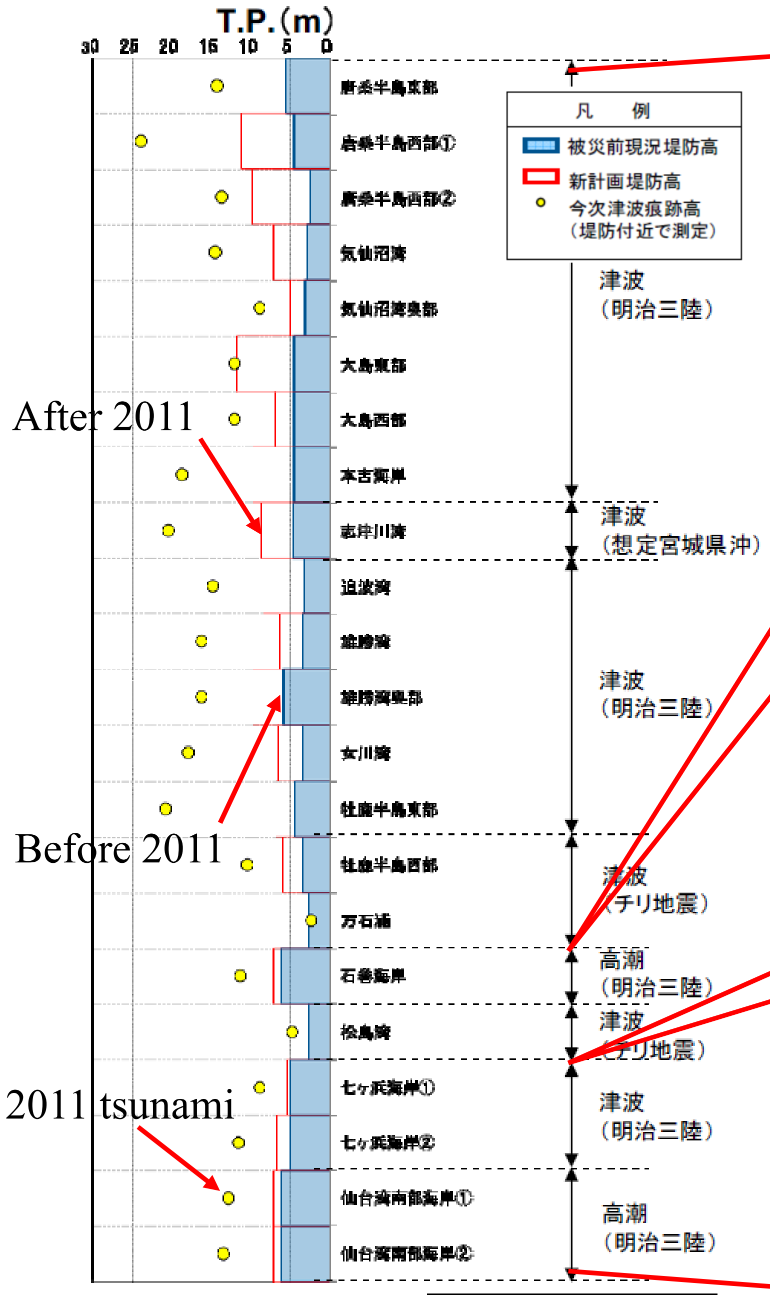




http://www.bousai.go.jp/kaigirep/chousakai/tohokukyokun/4/pdf/2-2.pdf

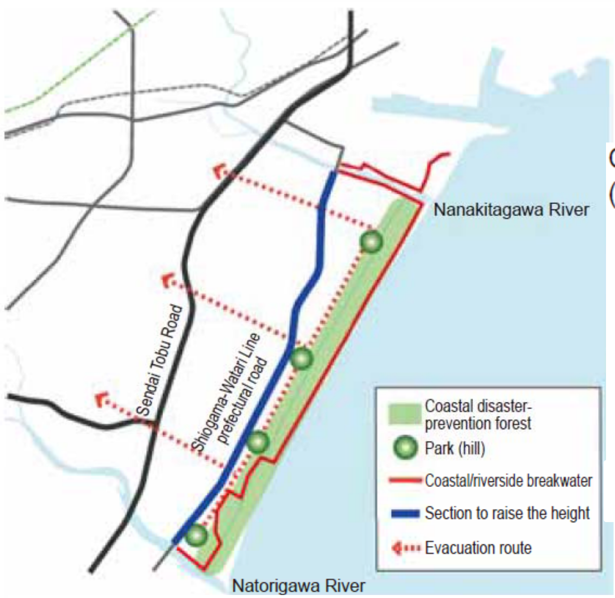
http://www.pa.thr.mlit.go.jp/kakyoin/PDF/sankou.pdf

New height of seawalls in Miyagi prefecture

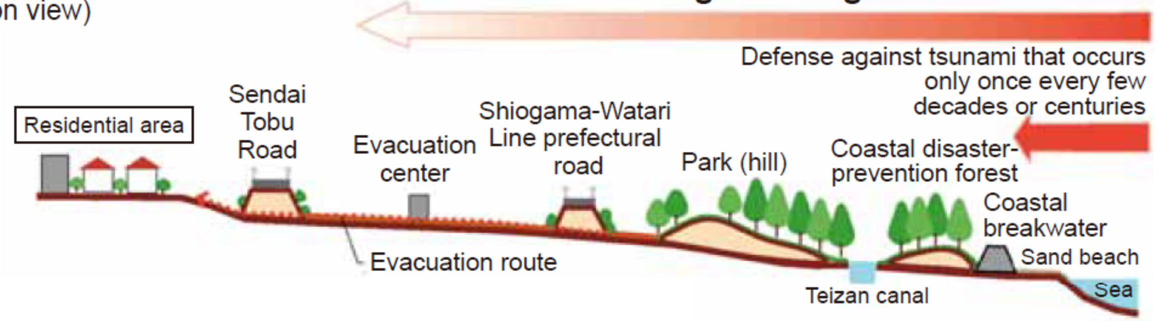


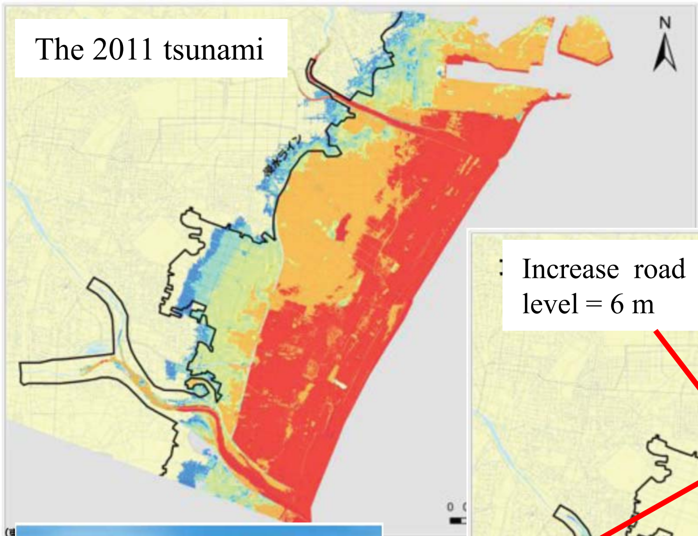
Sendai city plan: land use management

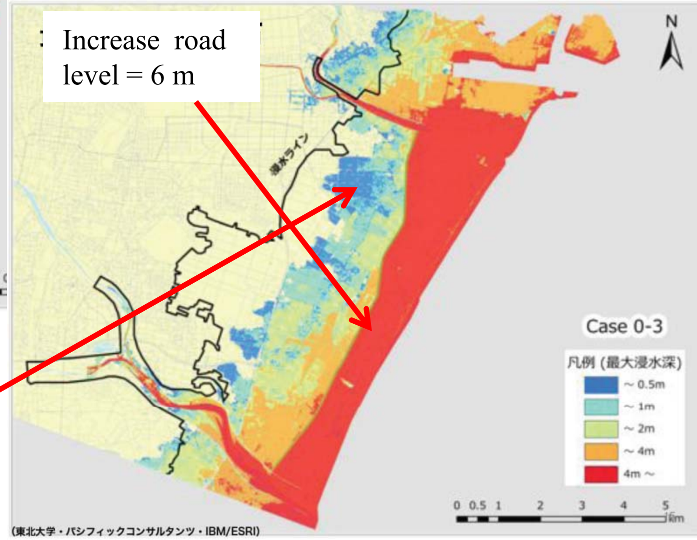
Conceptual image of disaster-prevention facilities against a tsunami (plan view)



Conceptual image of tsunami-prevention facilities (cross-section view)







http://www.city.sendai.jp/fukko/1198749_2757.html

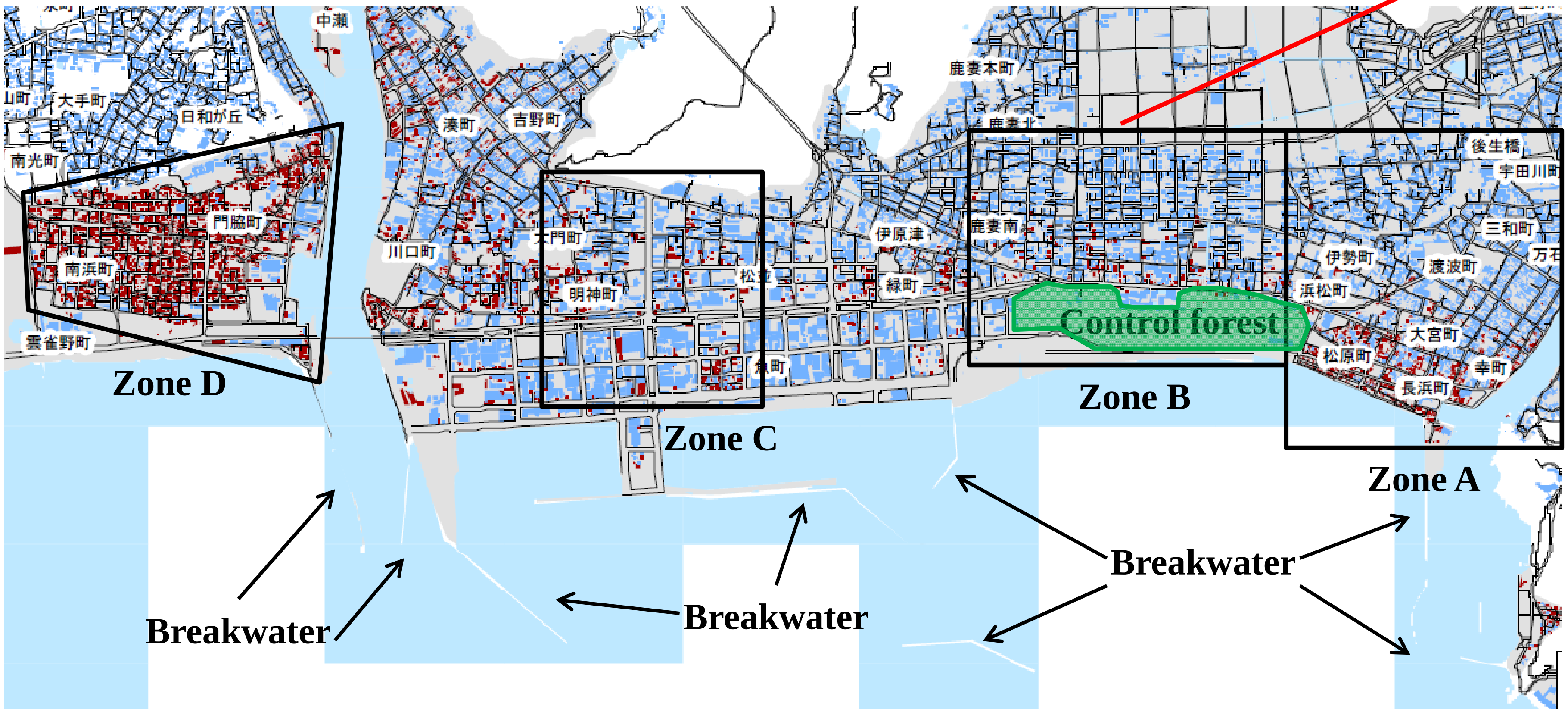
Reduction effect from control forest

防災林、津波軽減に効果…林野庁が再整備へ

3 B! 0 Recommend おすすめ チェック

東日本大震災で壊滅的な被害を受けた被災地の海岸防災林を、林野庁が「天然の防波堤」として再生する。同庁の調査で防災林に津波の威力を軽減させる効果があることが判明したためで、今後はより津波に流されにくい植林方法も導入する。

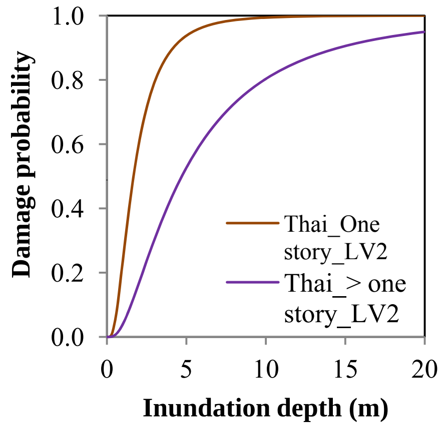
今回の被害面積は、東京ドーム約780個分に相当する約3660ヘクタールに上り、すべてを再生するには10年近い歳月がかかるが、今年度中には着手したい考えで、第3次補正予算案で関連費用数百億円を計上する方針。

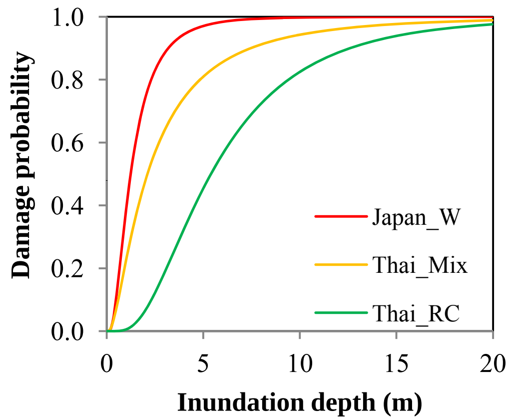


Building damage: Overturned building in Onagawa town

Building fragility and tsunami damage

Example from Ishinomaki city





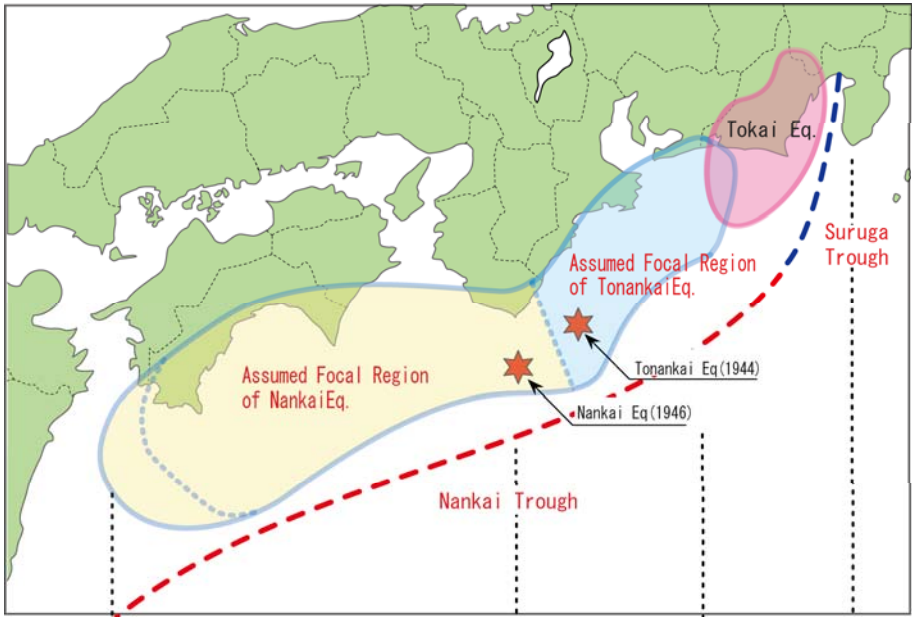
Before tsunami

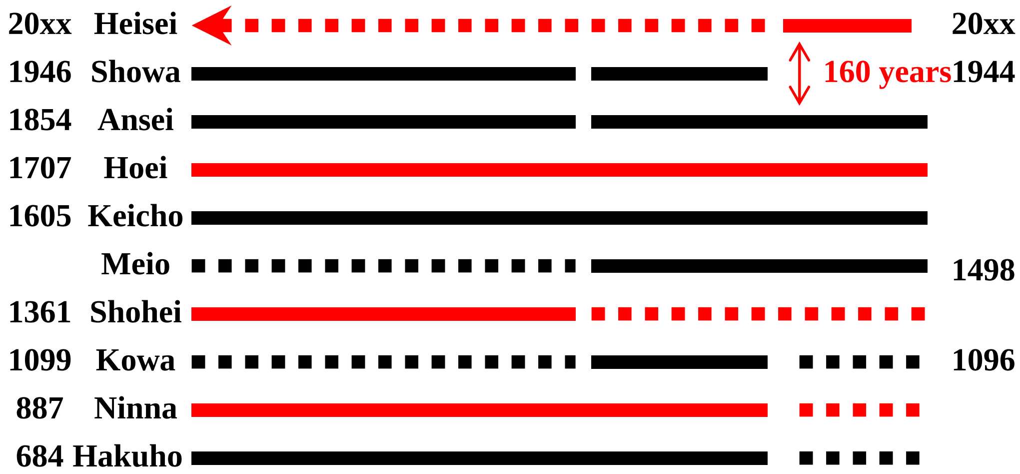
After tsunami

Condition before March 2011

Tokai-Tonankai-Nankai earthquake

Earthquake possibility in Japan



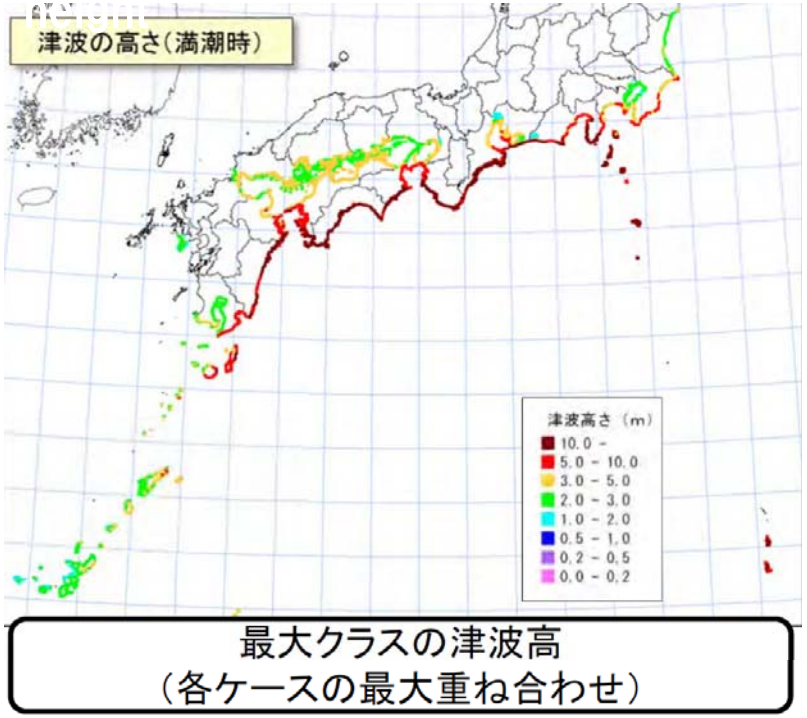


http://www.jishin.go.jp/main/chousa/07_yosokuchizu/img/f1-3-2.jpg

http://www.jma.go.jp/jma/en/Activities/earthquake.html

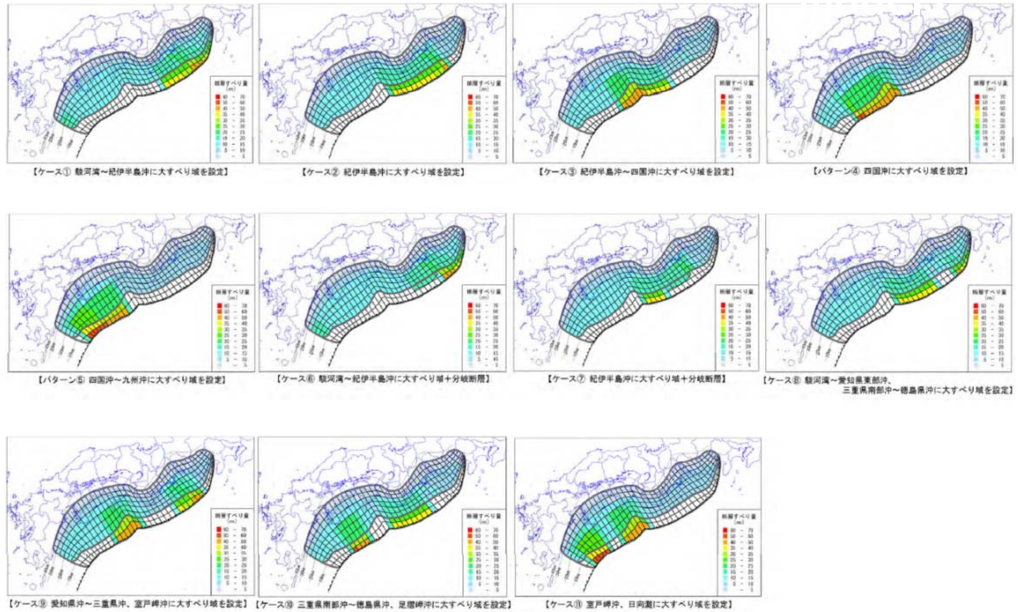
New estimated tsunami height (M9 earthquake) VS historical tsunami data

Maximum tsunami



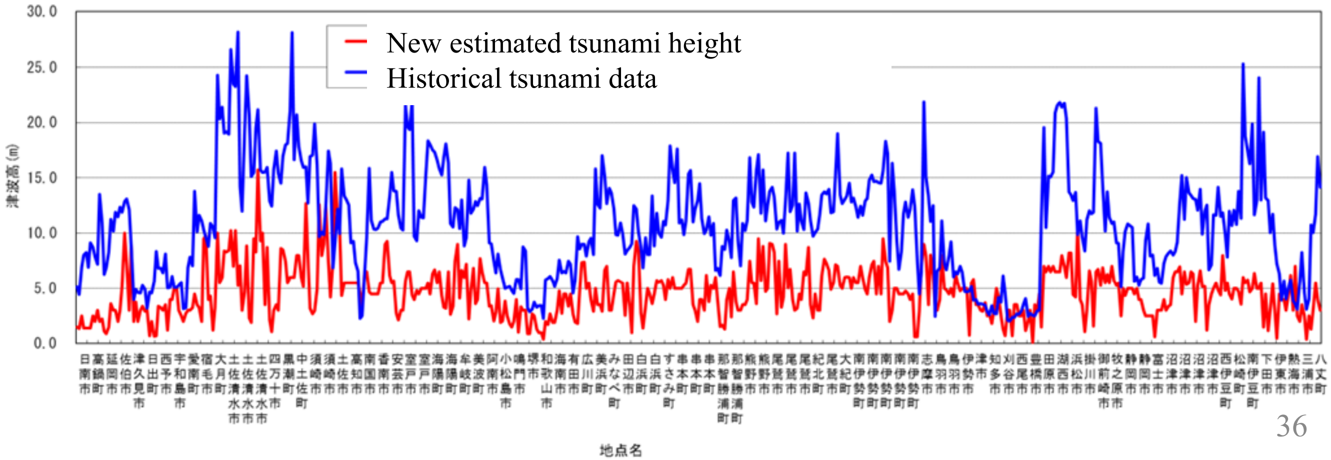
http://www.bousai.go.jp/jishin/chubou/nankai_trough/15/kisya_5.pdf

11 slip



http://www.bousai.go.jp/jishin/chubou/nankai_trough/15/kisya_4.pdf

http://www.bousai.go.jp/jishin/chubou/nankai_trough/15/kisya_6.pdf



Advance technology of earthquake and tsunami observation

JAMSTEC

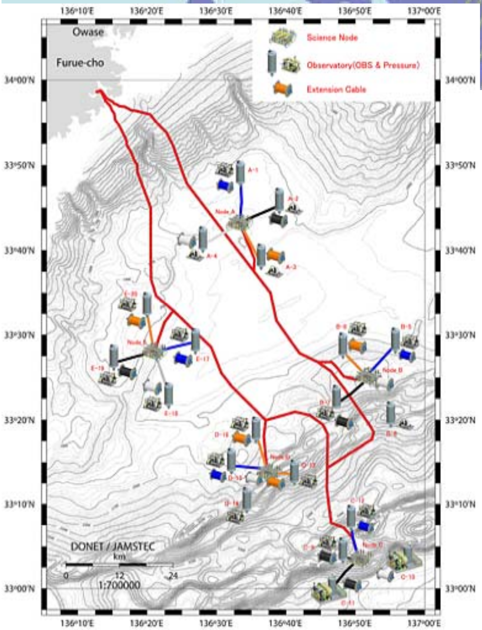
Japanese   Contact Us

DONET

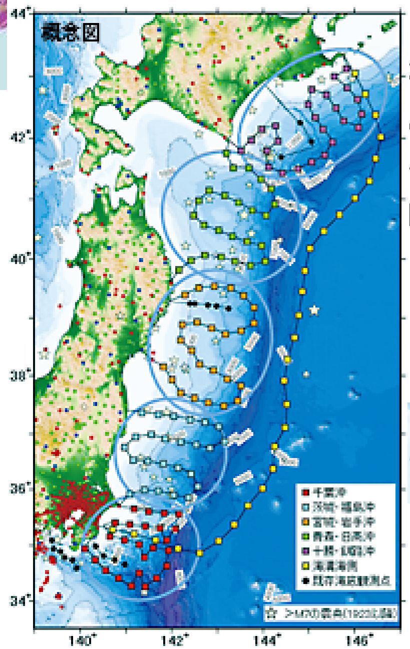
Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET)
-Concentrated Observation System for an Anticipated Tonankai Earthquake-

DONET (Dense Oceanfloor Network System for Earthquakes and Tsunamis) is a unique development program of submarine cabled real-time seafloor observatory network. This program has aimed to establish the technologies of large scale real-time seafloor research and surveillance infrastructure for earthquake, geodetic and tsunami observation and analysis. The first phase of this program has been carried out since 2006 with the purpose to monitor the hypocentral region close to Nankai trough and the installation of observational equipment on 20 stations at Kumanonada has been completed in 2011. The second phase (DONET2) has also started to cover a wider region in 2010. Totally 29 observatories are planned to be installed at offshore Kii peninsula for DONET2 and 2 additionally at Kumanonada for DONET.

http://www.jamstec.go.jp/jamstec-e/maritec/donet/index.html



State of Network as of July 31, 2011.



日本海溝沿いの海底約150カ所に、地震計と津波計で構成されるケーブル式観測網が整備されます。震源の近くで地震動と海面変動を精度よく迅速に捉え、大地震と津波のモニタリング、精度の高い警報の早期伝達、地殻構造の詳しい解明等に役立てられます。

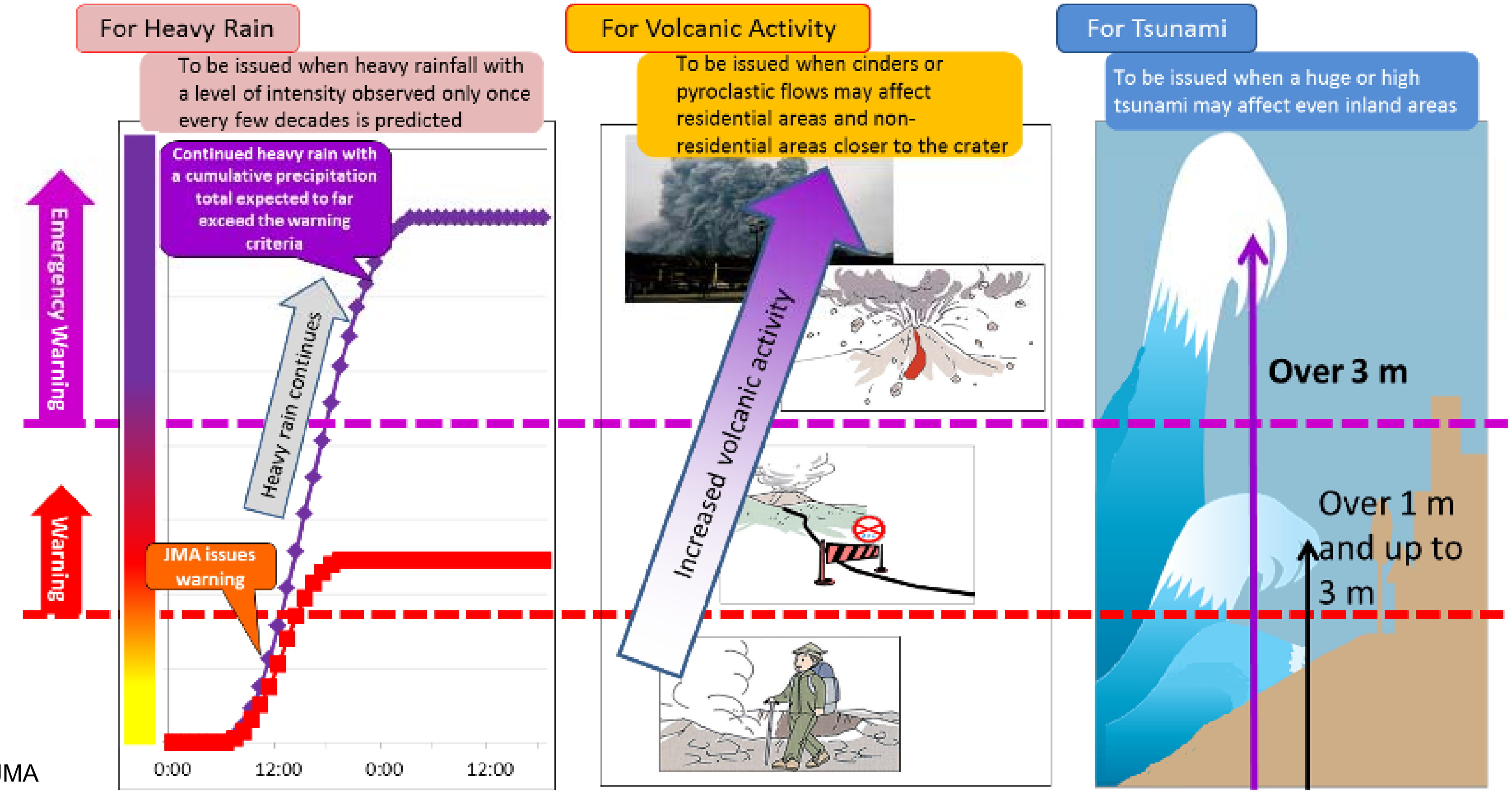
日本海溝沿いに整備される海底地震津波観測網(概念図)

NIED 独立行政法人 防災科学技術研究所
National Research Institute for Earth Science and Disaster Prevention

http://www.bosai.go.jp/activity_special/the_third/ev/earthvol-04.html

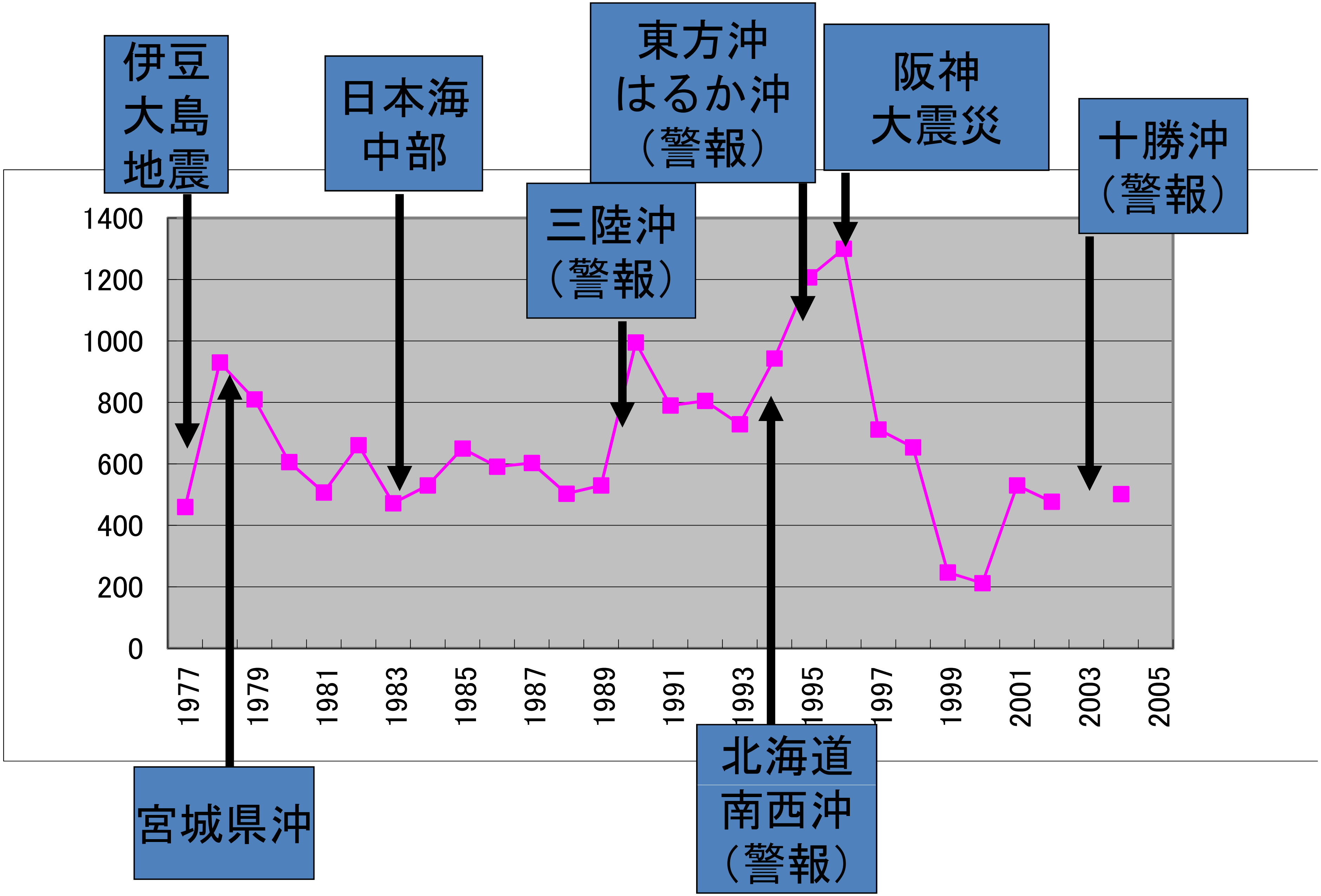
New tsunami warning classification

Tsunami warning and watch		Previous system (8 levels)	Present system (5 levels)		
		Announce tsunami height	Number	Message	Estimated tsunami height
Warning	Major tsunami	> 10 m	> 10 m	Major	> 10 m
		8 m, 6 m	10 m		5 m - 10 m
		4 m, 3 m	5 m		3 m - 5 m
	Tsunami	2 m, 1 m	3 m	High	1 m - 3 m
Advisory	Tsunami advisory	0.5 m	1 m	-	20 cm - 1m



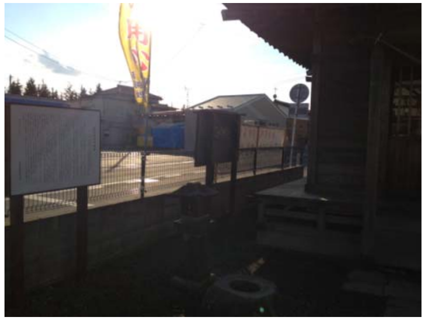
Source: JMA

No. of evacuation drill participants in Taro village



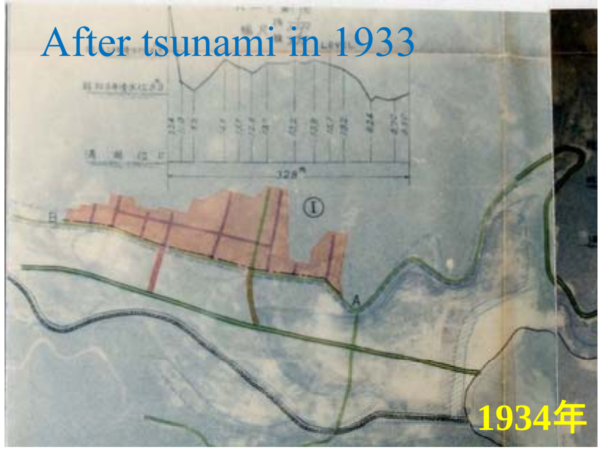
Preservation of buildings and other facilities destroyed by the tsunami

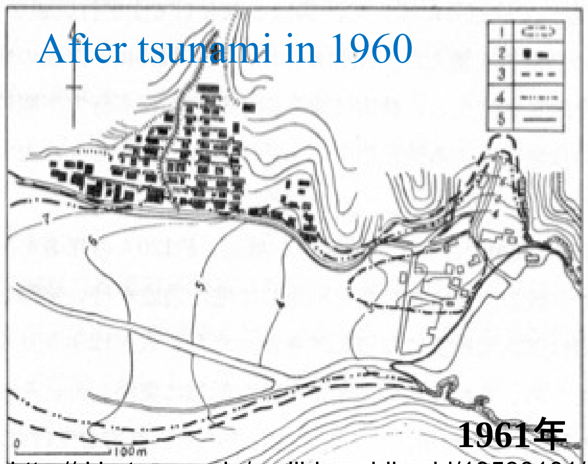
Several memorial in rocks, stones, shrines and temples before the 2011 event…



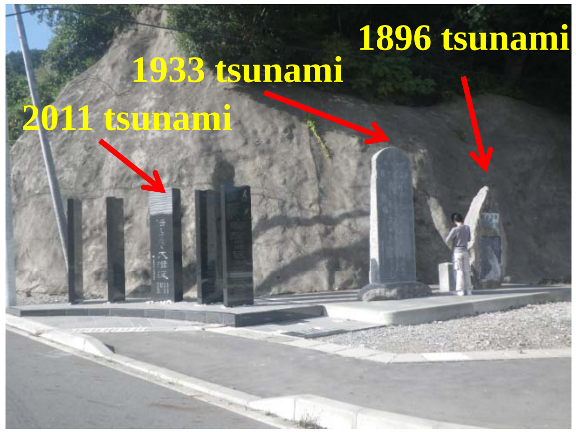
But…no preservation of damaged structures after the 2004 event

Toni Hongo village:
Highland residence

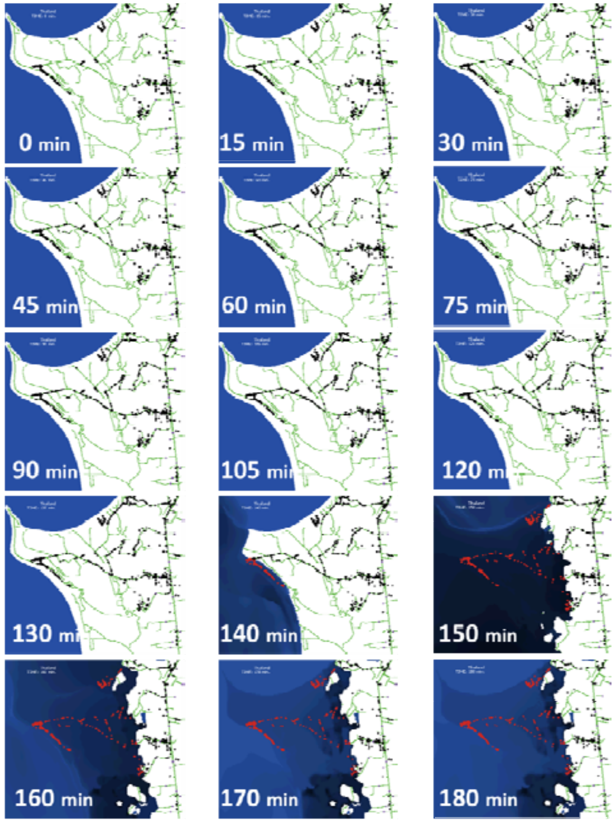




http://d.hatena.ne.jp/meiji-kenchikushi/19530101/p1



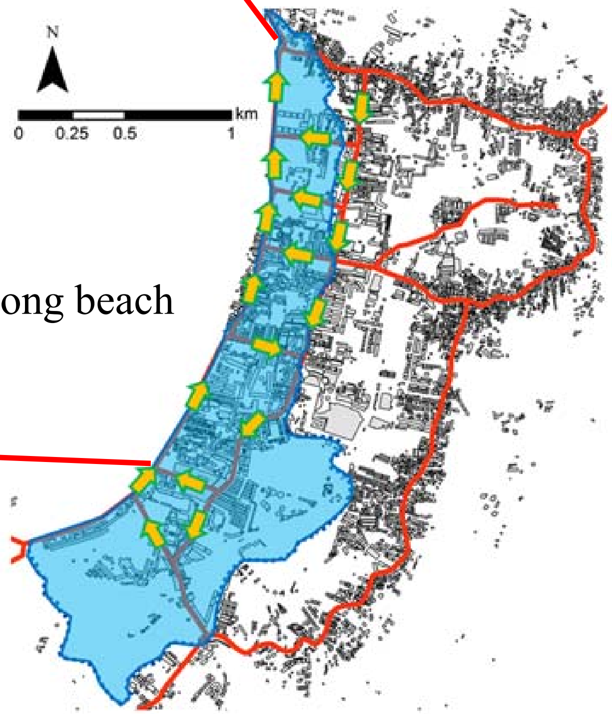
Tsunami evacuation problems in Thailand



V (%)	E (μ) (min)	F (%)
0	30	23%
0	60	26%
0	90	30%
0	120	34%
25	30	9%
25	60	14%
25	90	21%
25	120	26%
50	30	7%
50	60	10%
50	90	16%
50	120	22%
75	30	6%
75	60	10%
75	90	16%
75	120	21%
100	30	7%
100	60	11%
100	90	15%
100	120	22%

"V" is the percentage of population using vehicles for evacuation. Either as driver or passenger. It is assumed that each car has four passengers.
"E" is the mean of the distribution (μ) used to construct the evacuation start time curve.
"F" is the Fatality ratio

Patong beach



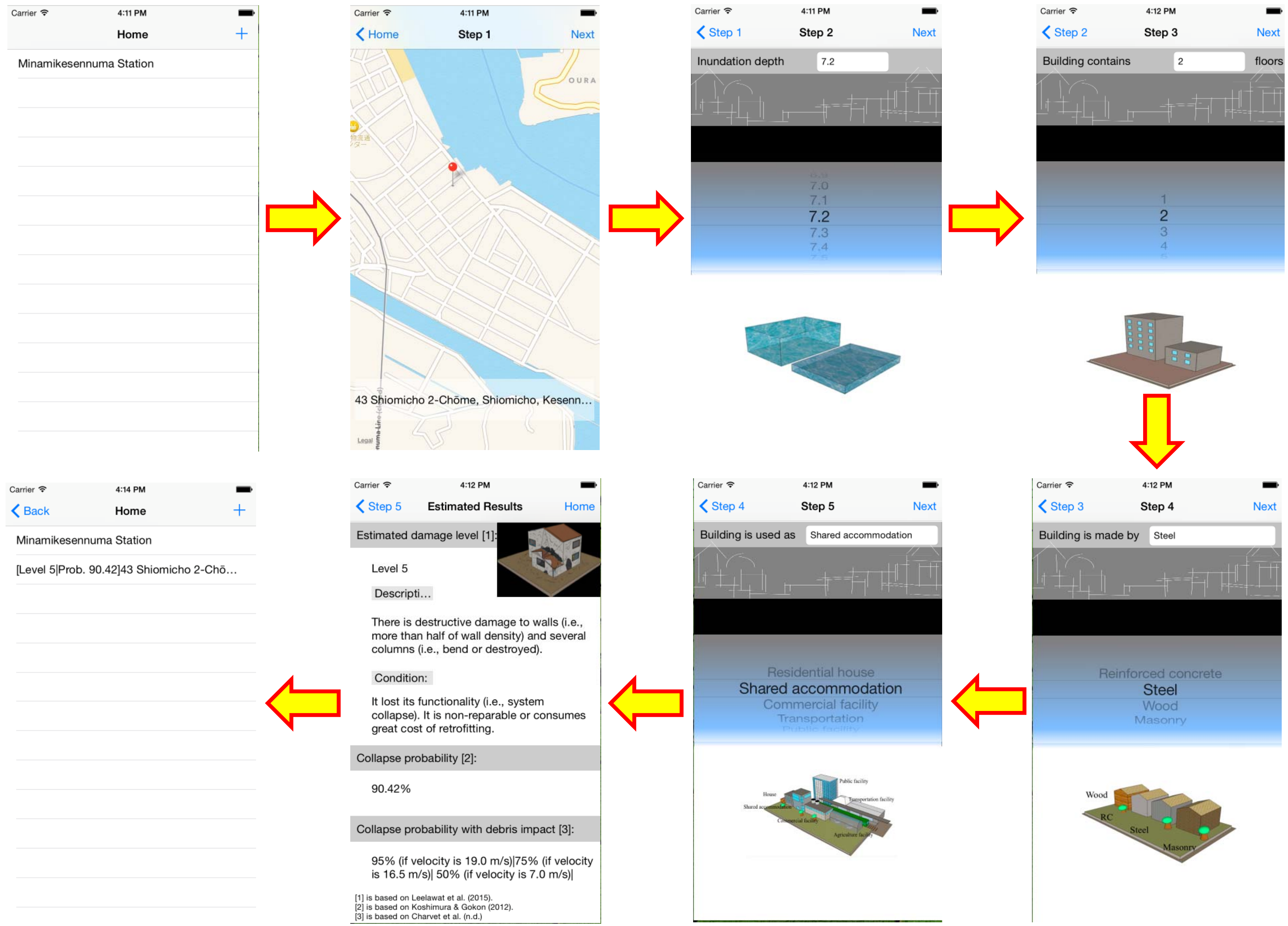
カケアガレ！日本
KAKE AGARE! JAPAN
Tsunami evacuation drill

カケアガレ！
KAKE AGARE!
THAILAND
Tsunami evacuation drill

KAKEAGARE! THAILAND (June 18,2014)

<u>Incorporation with: Southern Meteorological Department (West Coast),TMD</u>

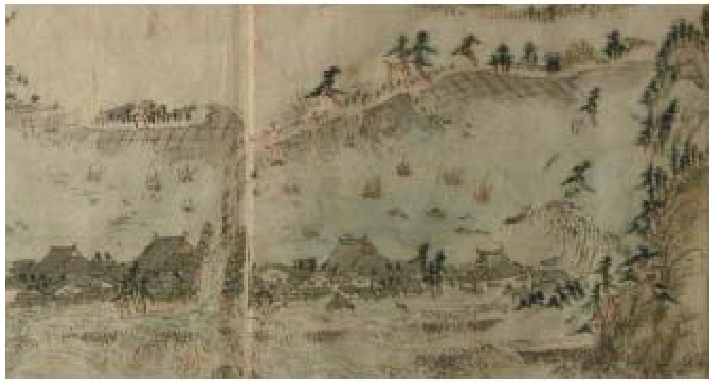
DamageEstimateApp: Pilot version for Kesennuma city



World Tsunami Day (5 November)

- The World Tsunami Day proposal materialized after the third U.N. World Conference on Disaster Reduction in Sendai in March.
- Japan hopes to play a leading role in the international community in the field of disaster reduction after the March 2011 earthquake and tsunami devastated the Tohoku region
- Japan designated Nov. 5 as Tsunami Disaster Prevention Day under a law on measures to deal with tsunami after the March 2011 disasters.
- The day was chosen in honor of a villager, Mr.Hamaguchi, in the region currently known as Wakayama Prefecture who saved the lives of many by evacuating them in anticipation of a massive tsunami spurred by the Ansei Nankai earthquake of Nov. 5, 1854.
- Inamura no Hi in your language from ADRC website

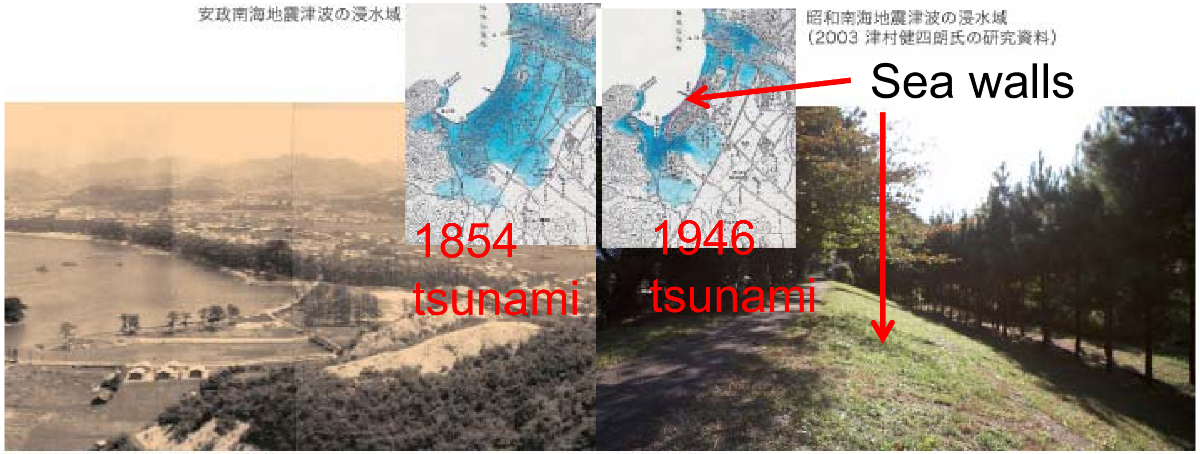
  http://www.adrc.asia/publications/inamura/phase1.html



古田庄右衛門「安政聞録」より（養源寺蔵）

安政南海地震津波の浸水域

昭和南海地震津波の浸水域
（2003 津村健四朗氏の研究資料）



昭和30年頃に撮影された広川町の海岸

史跡広村堤防