Tsunamis and countermeasures in Tohoku Region

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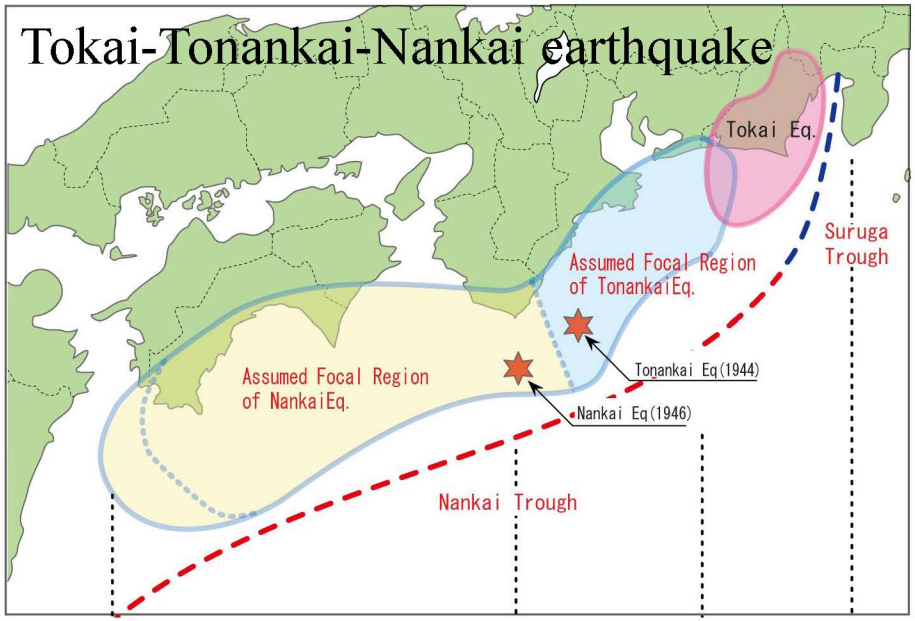
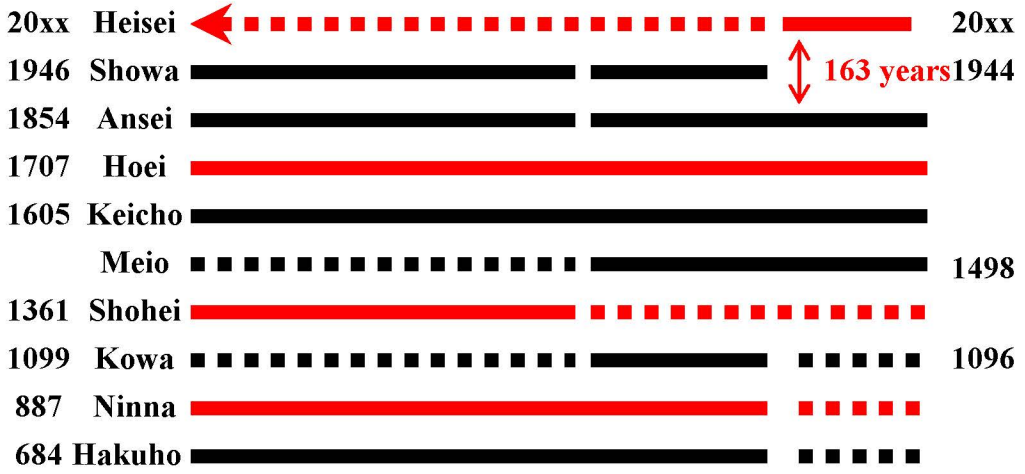
TOHOKU UNIVERSITY

Earthquakes in Japan

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

Learning step by step from historical tsunamis in Japan

- Early period:

  → Felt a shake = tsunami is coming & No tsunami in Japan Sea side

- 1896 Meiji Sanriku tsunami: tsunami-earthquake type

  → Small shake but large tsunami (38.2 m / 22,000 deaths)

- 1933 Showa Sanriku tsunami: Outer-rise earthquake

  → Large shake and large tsunami (28.7 m / 3,000 deaths)

- 1960 Chile tsunami: Far-field tsunami from M9.5 earthquake

  → No shake but large tsunami (10.7 m / 142 deaths)

- 1983 Japan Sea tsunami: The first recent tsunami in Japan Sea

  → Warning after 14 mins but tsunami arrived after 12 mins (14.9 m / 104 deaths)

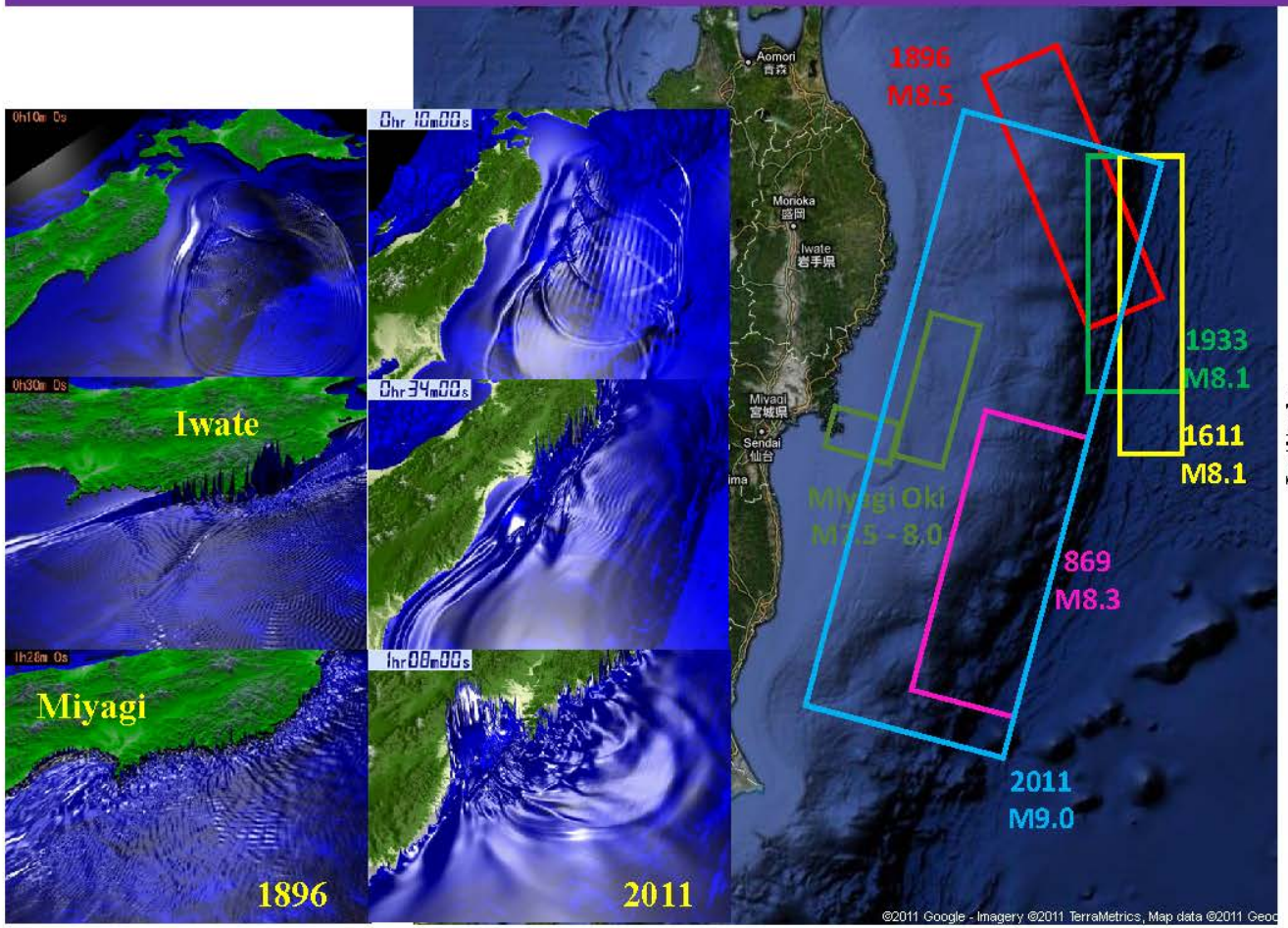
- 1933 Okushiri tsunami: Just 10 years after the 1983 event

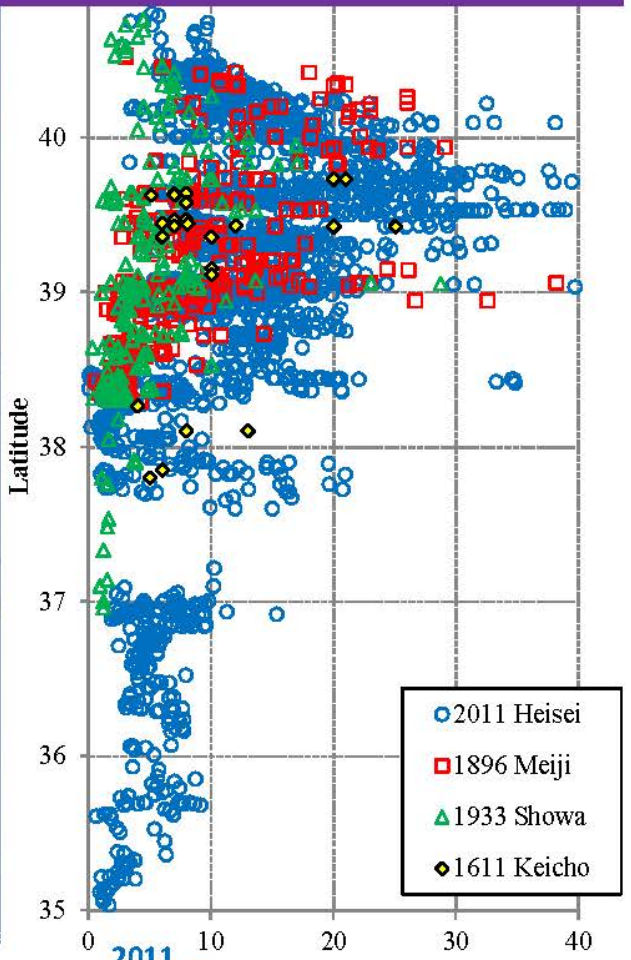
  → Waning after 5 mins but tsunami arrived after 2-7 mins (32.0 m / 230 deaths)

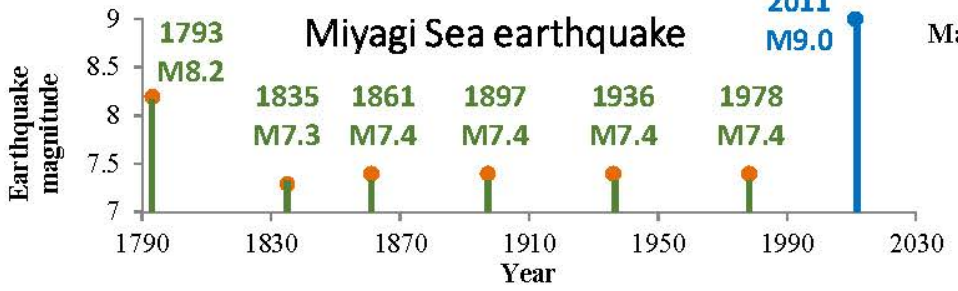
- 2011 Tohoku tsunami: M9.0 never record in Japan

  → Large shake and large tsunami (40.5 m / 19,000 deaths)

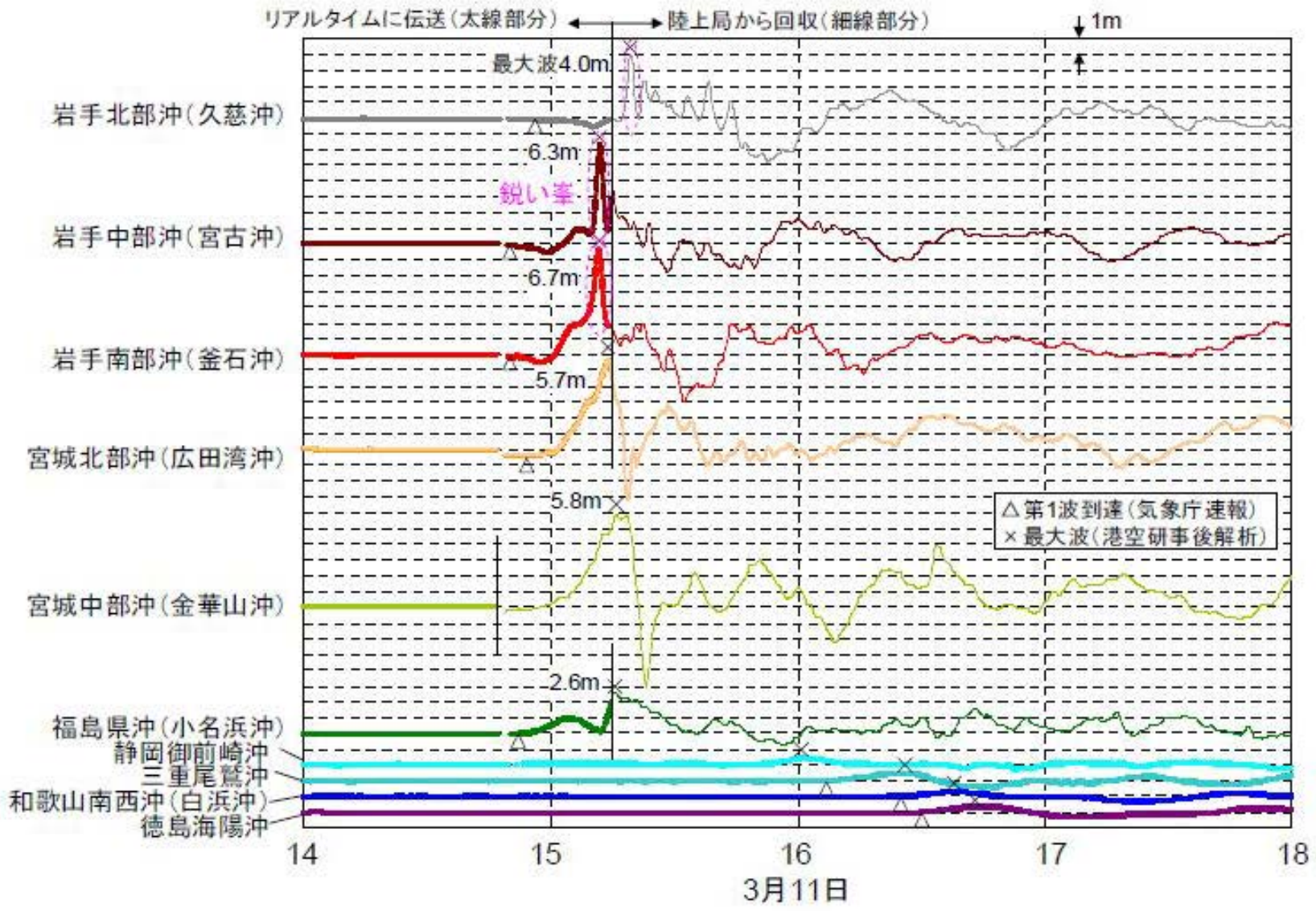
Tsunamis in Tohoku Region





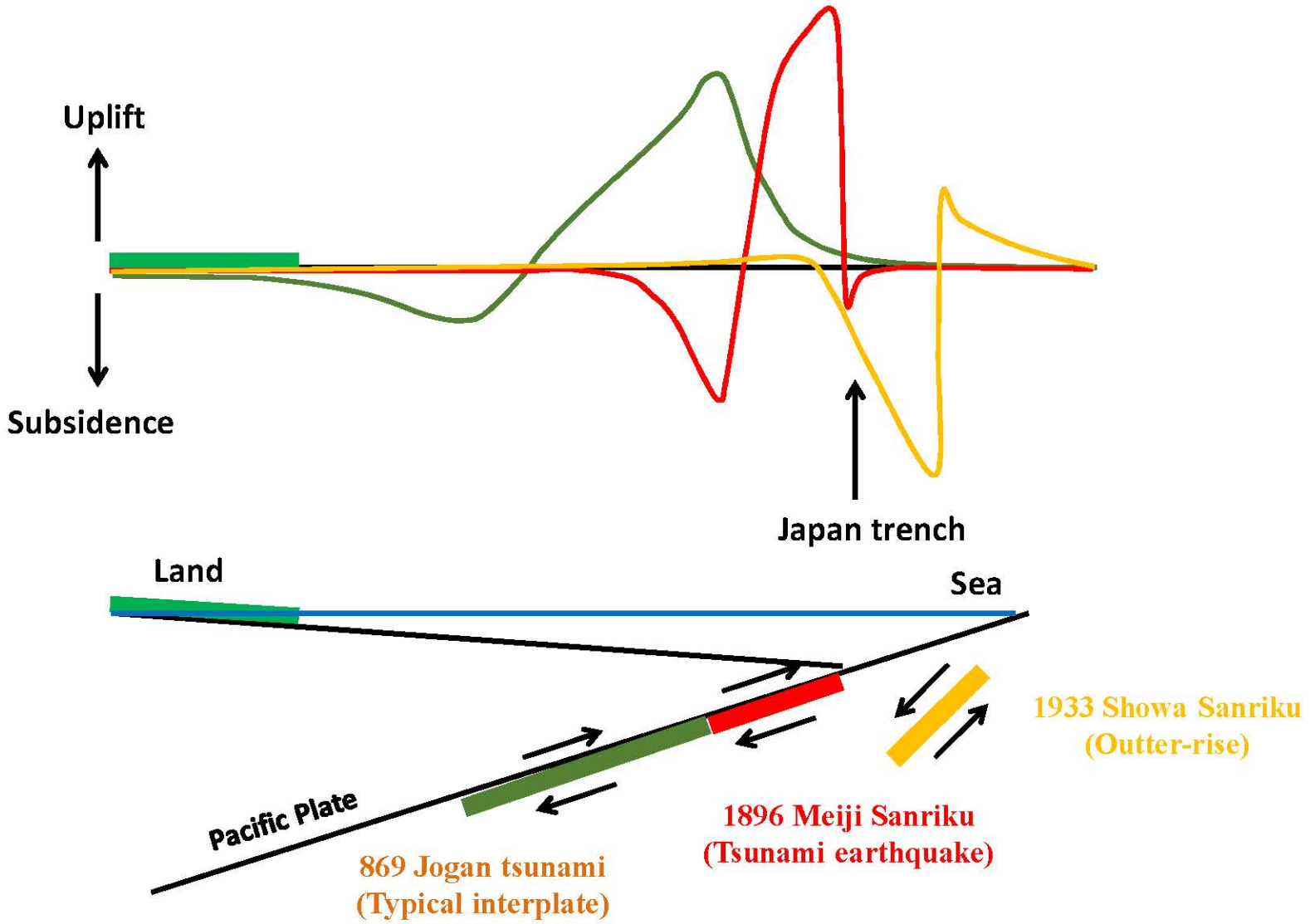


Observed tsunami waveforms

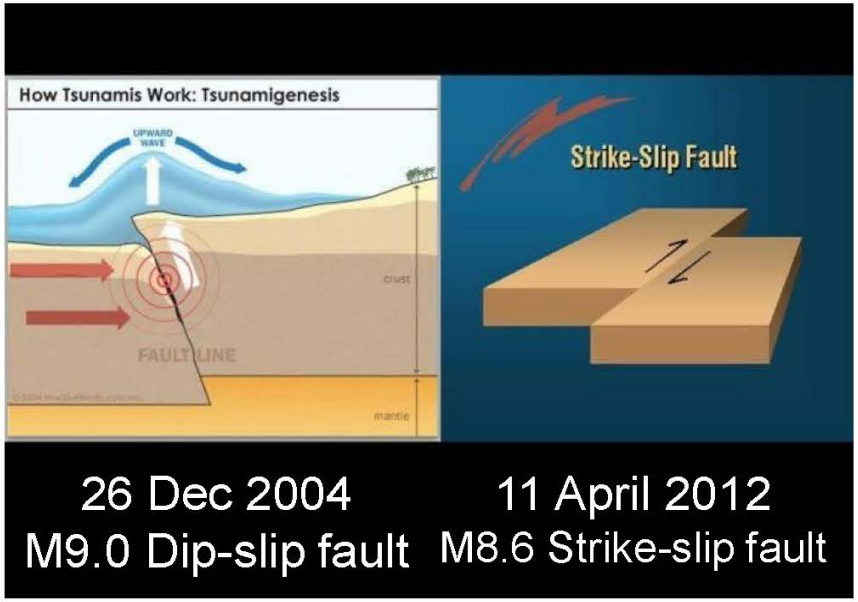


http://www.pari.go.jp/info/tohoku-eq/

Earthquake generation mechanism and seafloor deformation



Strike-slip fault: No or small tsunami

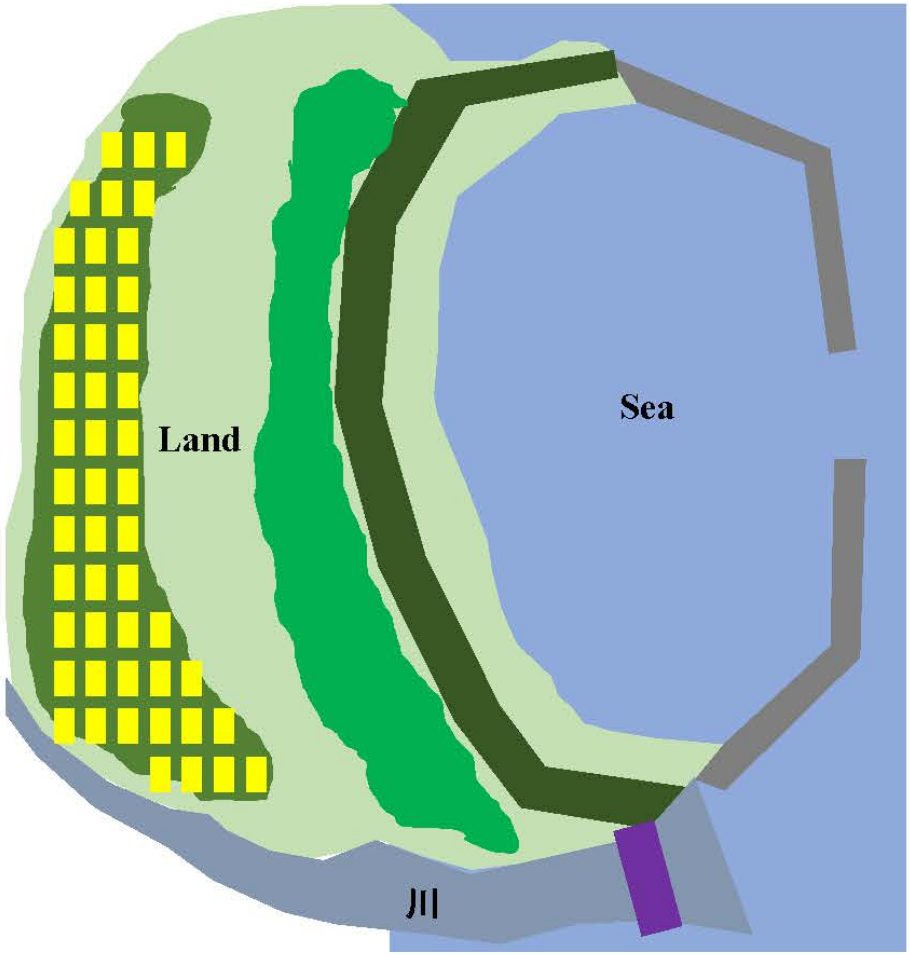


26 Dec 2004
M9.0 Dip-slip fault

11 April 2012
M8.6 Strike-slip fault

No tsunami but very serious traffic jam

General tsunami countermeasures



Breakwater: Kamaishi

Water gate: Fudai

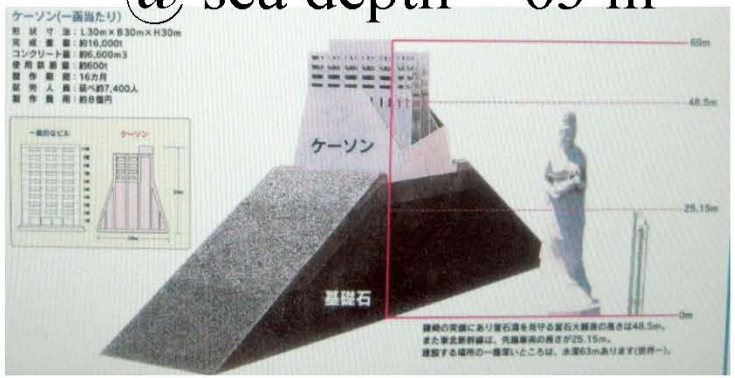
Seawall: Taro

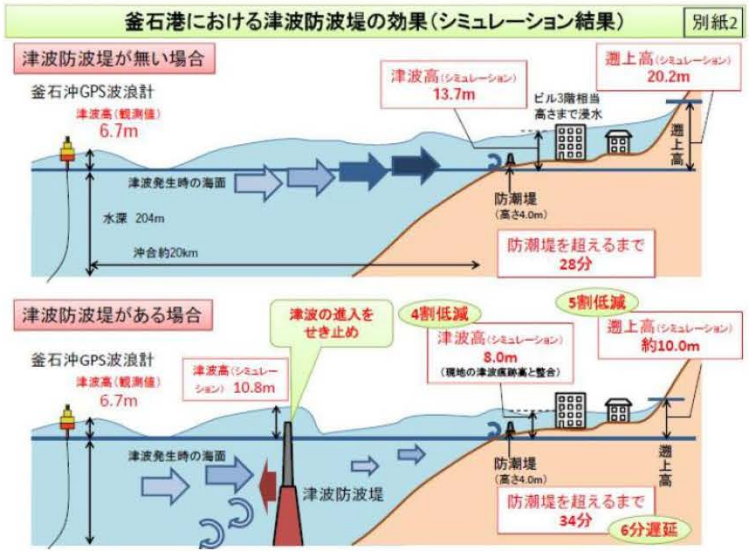
Highland residence: Toni-hongo

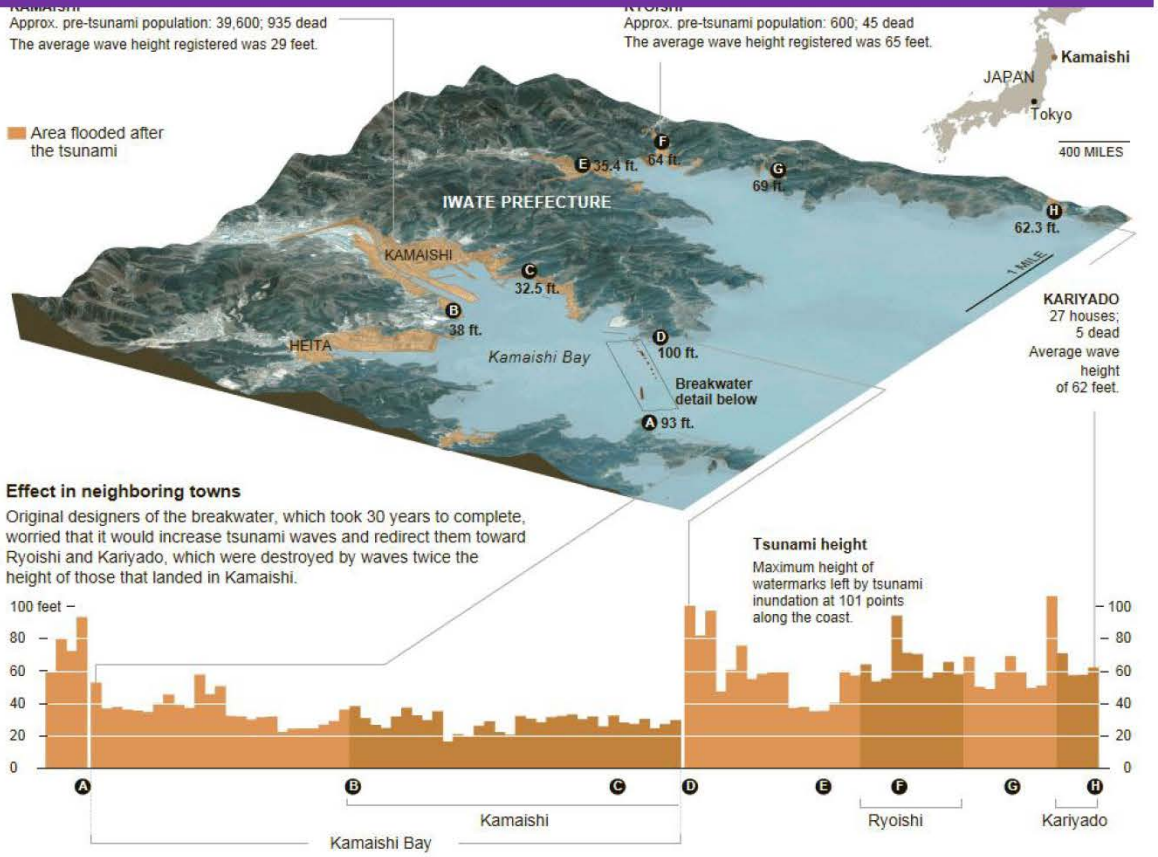
Control forest: Rikuzenakata

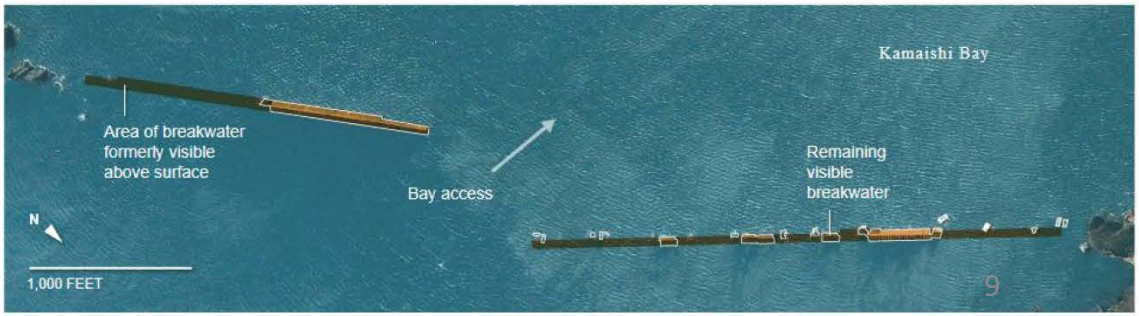
The world's largest breakwater

Kamaishi breakwaters @ sea depth = 63 m







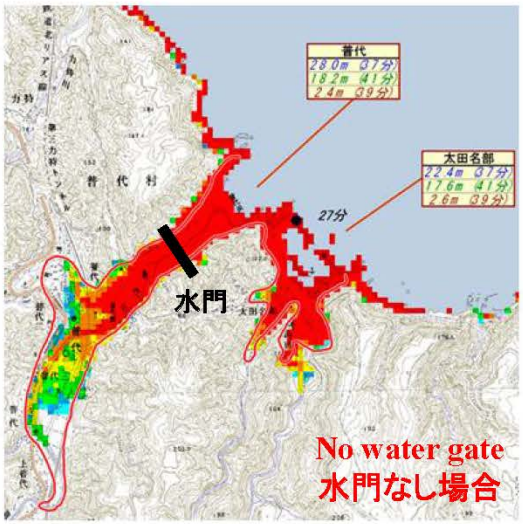


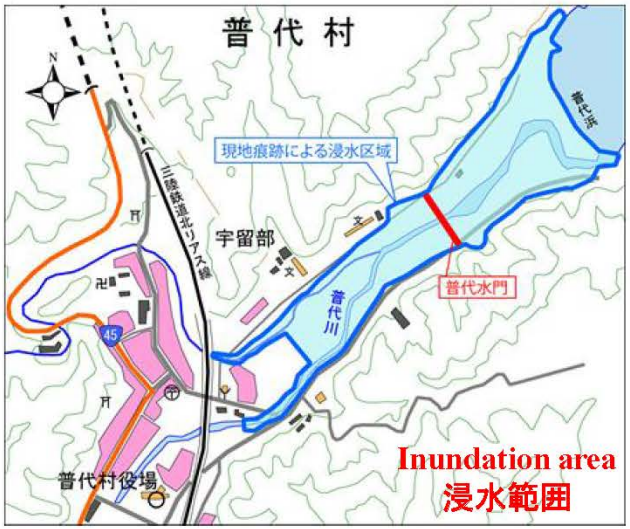
http://livedoor.blogimg.jp/shyougaiitisekkeisi2581/imgs/4/a/4aab1165.jpg
http://f.hatena.ne.jp/images/fotolife/k/kimkaz/20110401/20110401220511.jpg
http://www.physics.ohio-state.edu/~wilkins/energy/Resources/nuclear/japan/GIF/kamaishi-breakwater.png

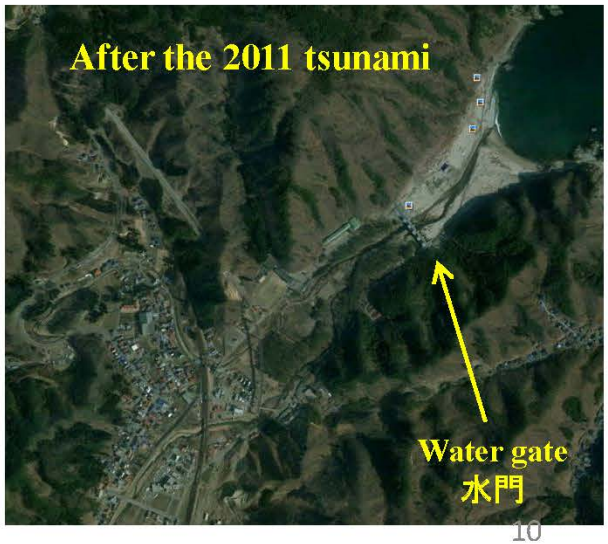
Tsunami gate – Zero casualty in Fudai

Before the 2011 tsunami

Water gate
水門

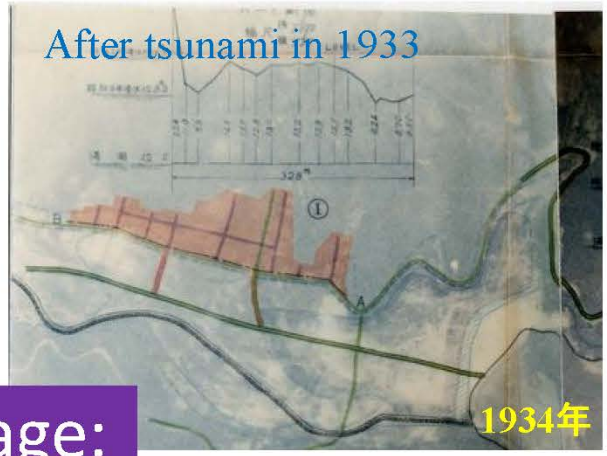






http://www.tokencon.co.jp/technology/topics/akg7b200000024ca.html

Toni Hongo village: Highland residence



明治三陸津波(1896)

波高:14.5m*

死者:2136人(唐丹村)

流失倒壊戸数:224戸(同上)

再生形態:集団移動

昭和三陸津波(1933)

波高:9.3m*

死者:209人

流失倒壊戸数:101戸

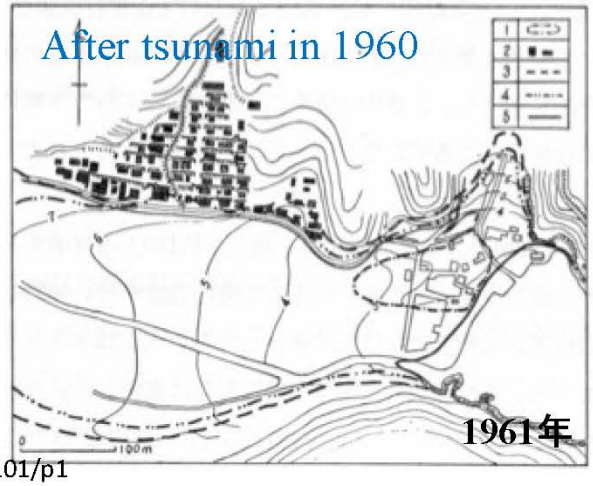
家屋流失倒壊区域(坪):25500坪*

浸水家屋:101戸

再生形態:集団移動

移動戸数:101戸

達成面積(坪):5637坪

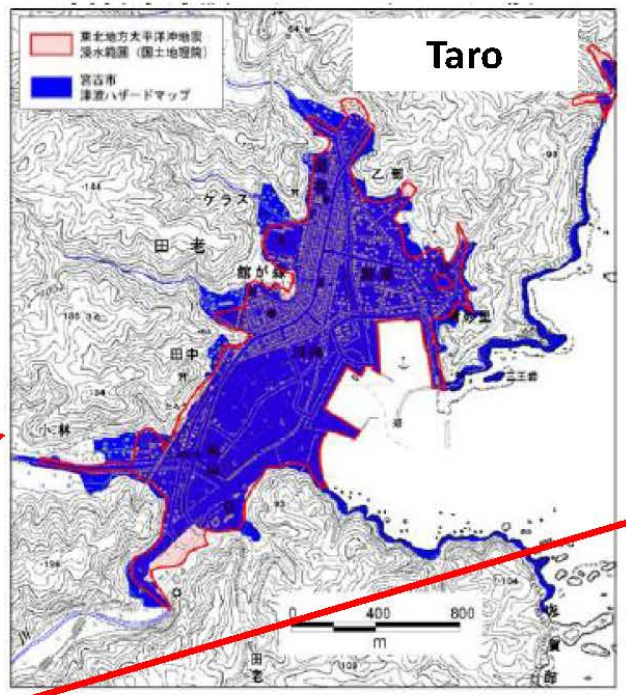


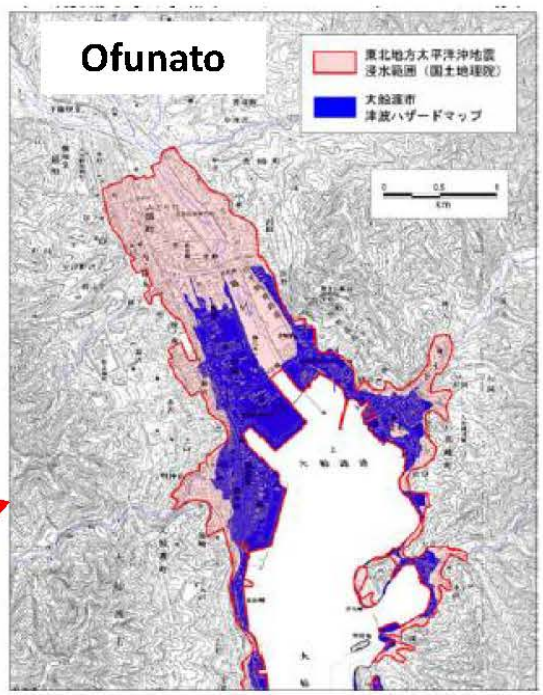
http://d.hatena.ne.jp/meiji-kenchikushi/19530101/p1

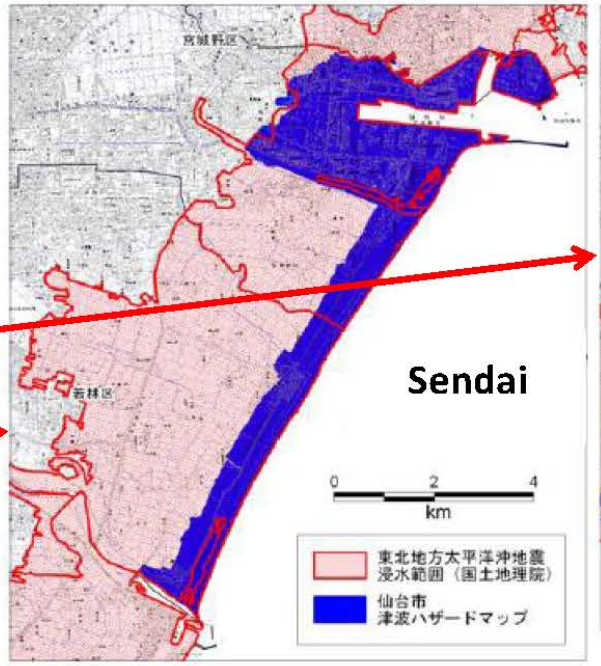
Hazard maps

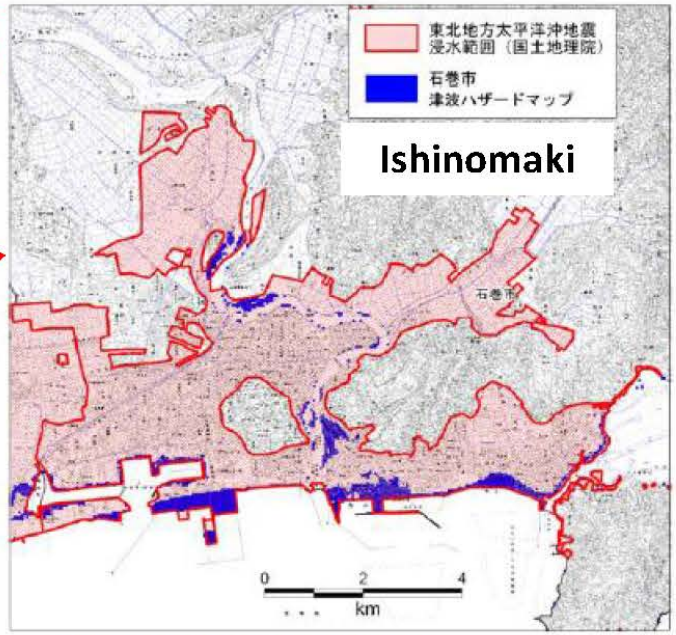
Red: 2011 tsunami inundation area

Blue: Predicted inundation area



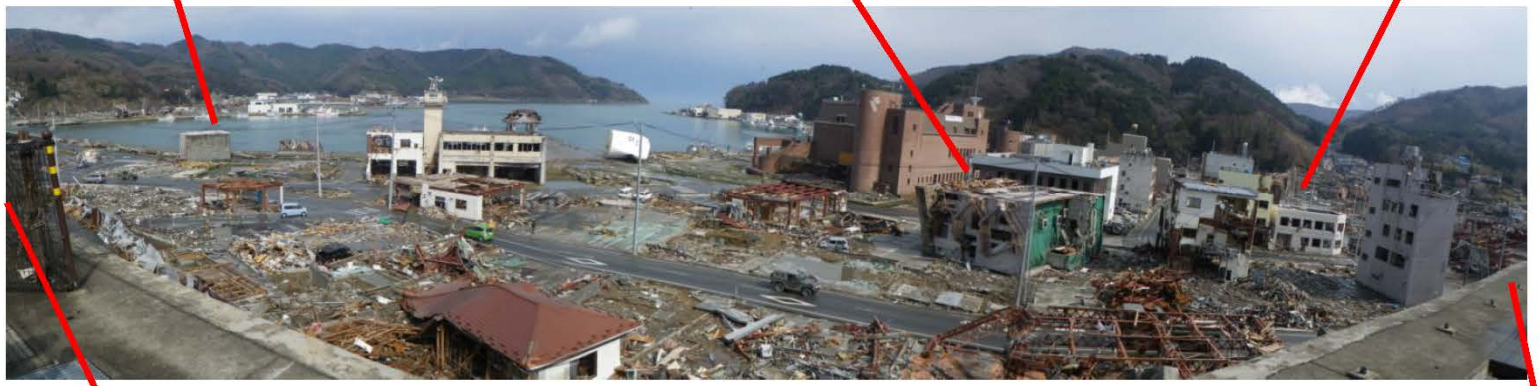






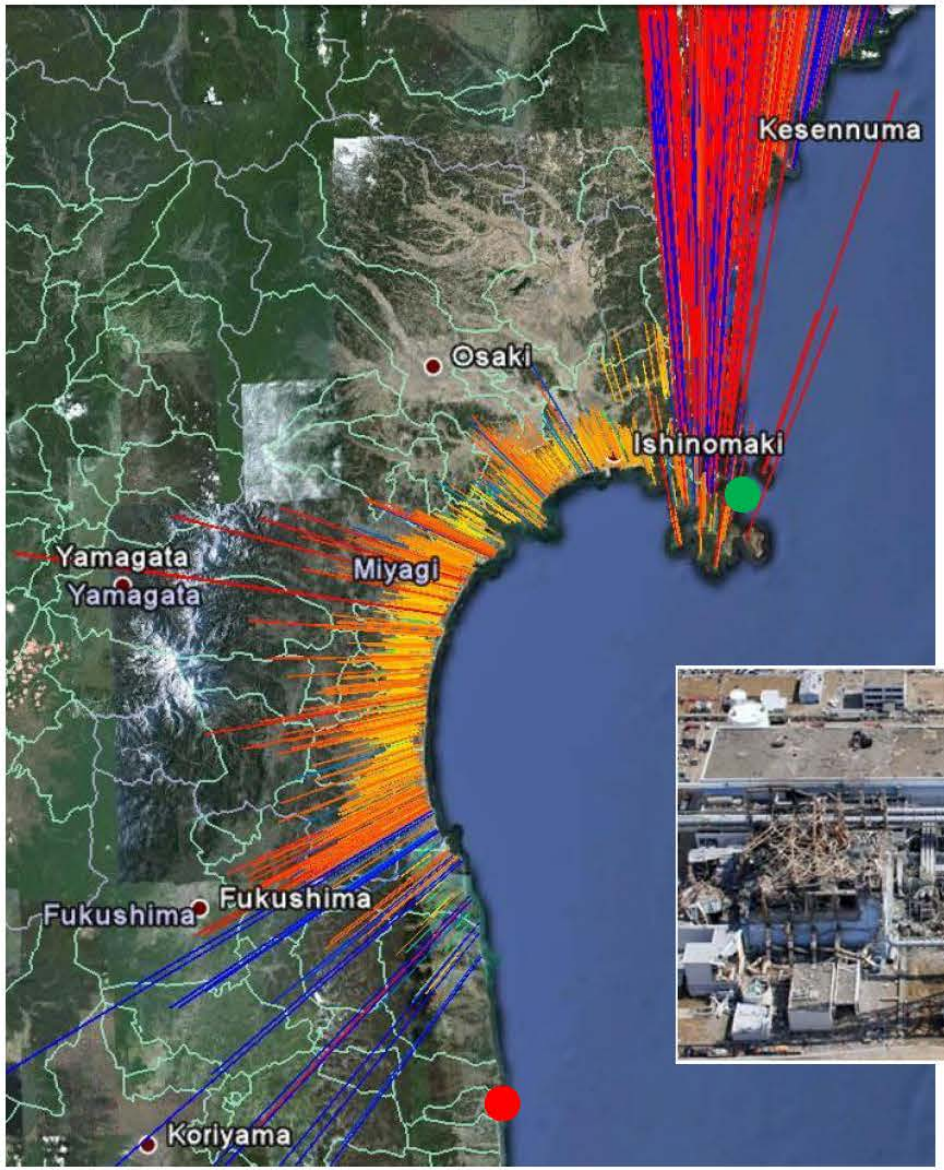
（出典）・東北地方太平洋沖地震浸水範囲：国土地理院資料より作図
・ハザードマップ：仙台市「仙台市津波ハザードマップ」、石巻市「石巻市津波ハザードマップ」

Overturned buildings in Onagawa



Onagawa town 女川町
Max. inundation depth = 18 m
最大津波浸水深＝18 m 程度

Fukushima Dai-ichi and Onagawa NPPs



Height (m)	Fukushima	Onagawa
Estimated tsunami	5.7	9.1
Plant elevation	10	14.8
The 2011 tsunami	13	13

Fukushima: Less impact from 1896 and 1933 Sanriku tsunami. Original land elevation was 30 m but cut off to the present elevation of 10 m considered hard foundation

Onagawa: Closer to affected areas from historical Sanriku tsunami (About 3 m at Onagawa)

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

Date Masamune's intelligence (1611 tsunami lessons)

In 1935 http://yaplog.jp/sendai_kaze/monthly/200807/

Won the Siege of Osaka in 1615 !!!

1. Control forest
2. Navigation canal
3. Land use management

Reduction effect from coastal forest

森林で津波の減衰力確認 仙台で地盤工学シンポ

東日本大震災で被害を受けた沿岸部や丘陵部の復旧・復興策を、地盤技術の視点から探るシンポジウムが1日、仙台市内で開かれた。地盤工学会東北支部（支部長・飛田善雄東北学院大教授）の主催で、研究者や市民ら約350人が参加した。

総括報告で宮城県の海岸林の被災状況を調査した宮城豊彦東北学院大教授（地形学）は、森林による一定の津波減衰力が確認された一方、抜けたり折れたりして流木となり、集落を襲った事例を紹介した。

流木の原因として津波だけでなく、震動と地下水上昇による地盤の沈降や液状化の影響も指摘。「海岸林の残存状況は、地盤が50センチから1メートル程度高いだけで大きな違いが出た。1～2メートルの盛り土で、流木防止にかなりの効果がある」と述べた。

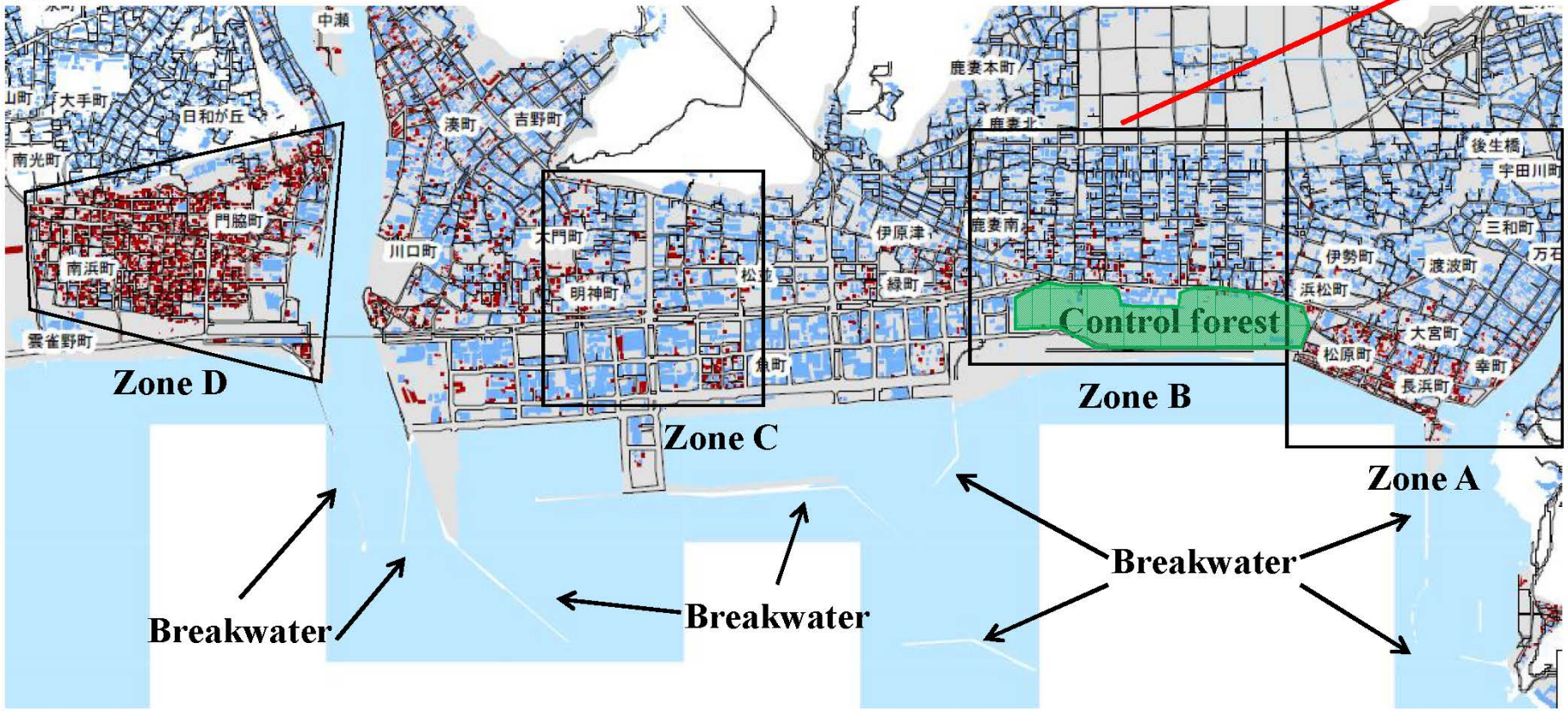
丘陵部の宅地被害では、森友宏東北大助教（地盤工学）が宮城県の実態を発表。造成年代との関連に着目し、現行の都市計画法で宅地開発が許可制になった1968年以降の造成地では、全半壊家屋が少なかったことを報告した。岩手、福島両県の被災宅地の事例や復旧策などの解説もあった。

防災林、津波軽減に効果…林野庁が再整備へ

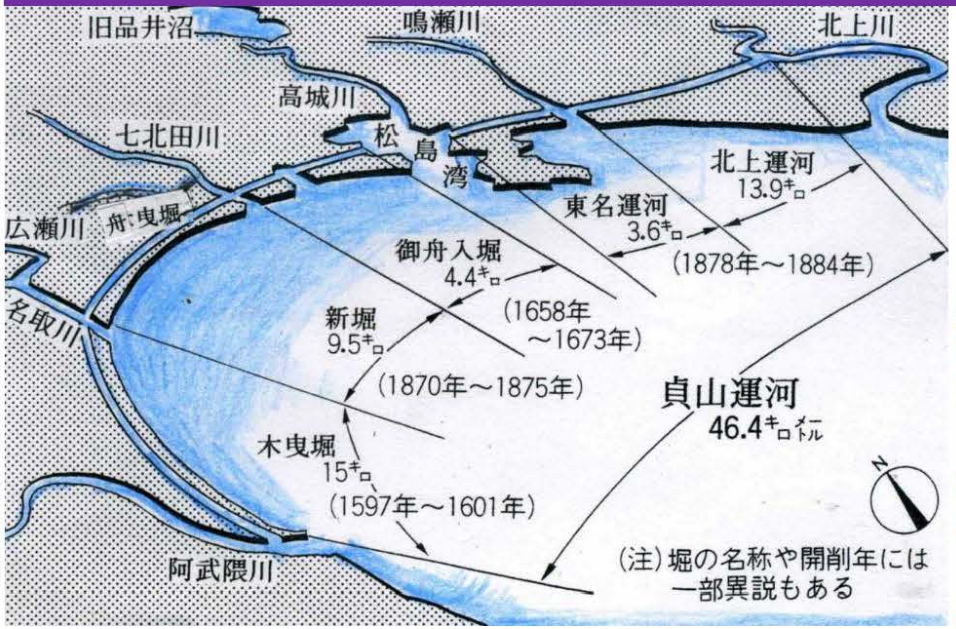
3 B! 0 Recommend おすすめ チェック

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。



Reduction of the flow velocity in the Teizan canal



The longest man-made canal in Japan

http://takakura.fd531.com/teizannbori.html

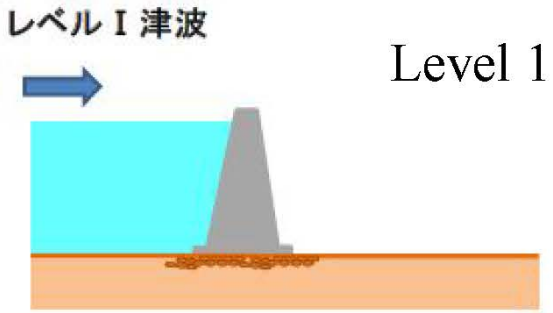
Land use planning

Towns and villages in Edo period (1603-1868) were located outside inundation area

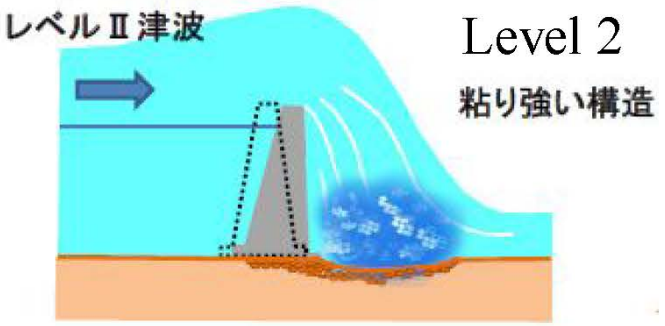
平川、2011

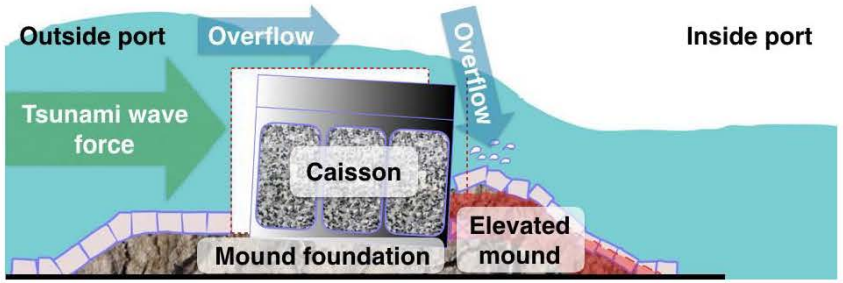
Level 1 & Level 2 tsunami

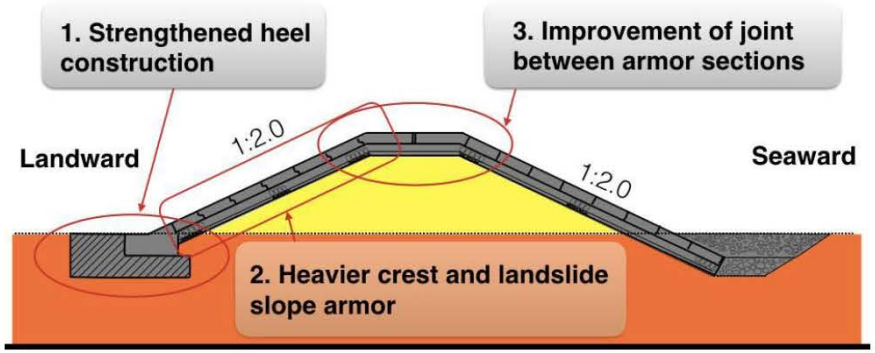
Level 1:
High frequency (30-200 years) but small to moderate tsunami.
Community should be mostly protected by coastal defense structures.
Height of coastal structures were decided by past Level 1 tsunami events



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.



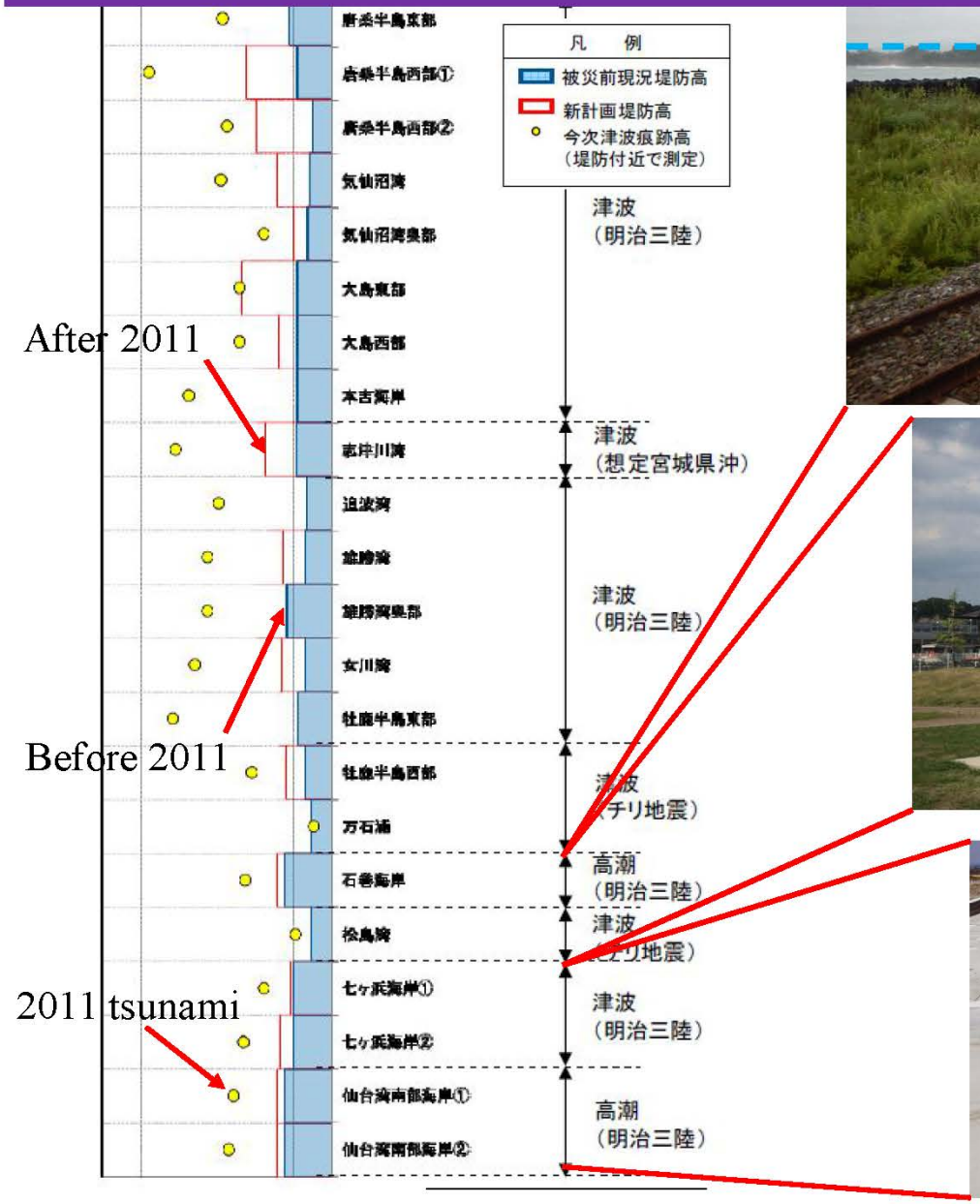




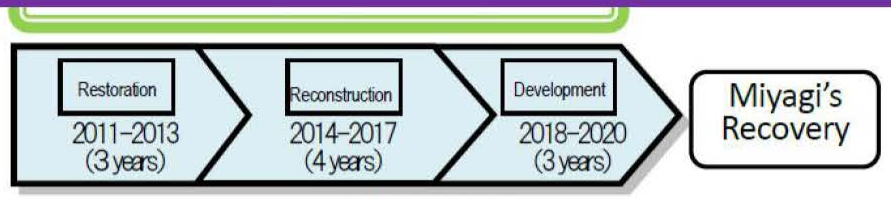
http://www.bousai.go.jp/kaigirep/chousakai/tohokukyokun/4/pdf/2-2.pdf

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

New height of seawalls in Miyagi prefecture



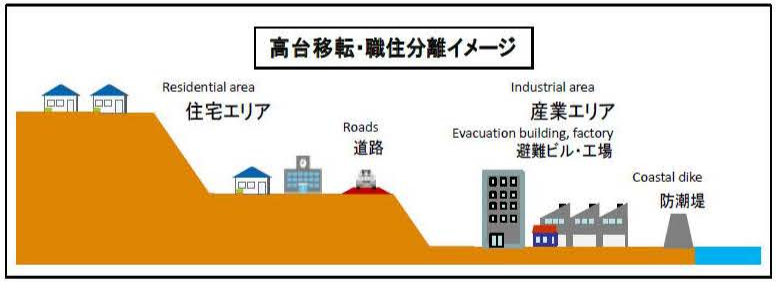
Reconstruction plan of Miyagi prefecture

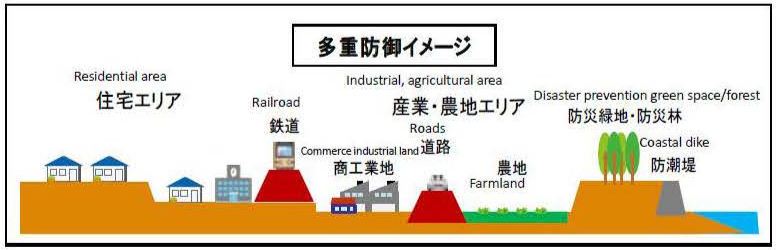


- Relocation to high ground, separation of business and residence
- Assemble and reorganize fishing ports, branding of marine processed products, "sixth industry"
- Tourism promotion that draws on the nature of the Sanriku area
- Promoting the maintenance of Sanriku expressway

- 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

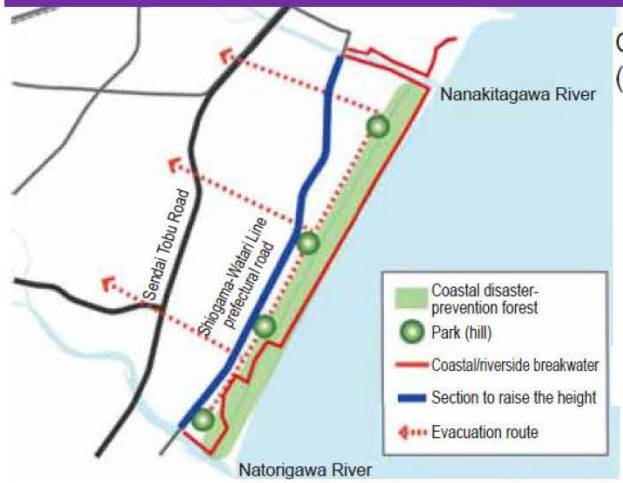




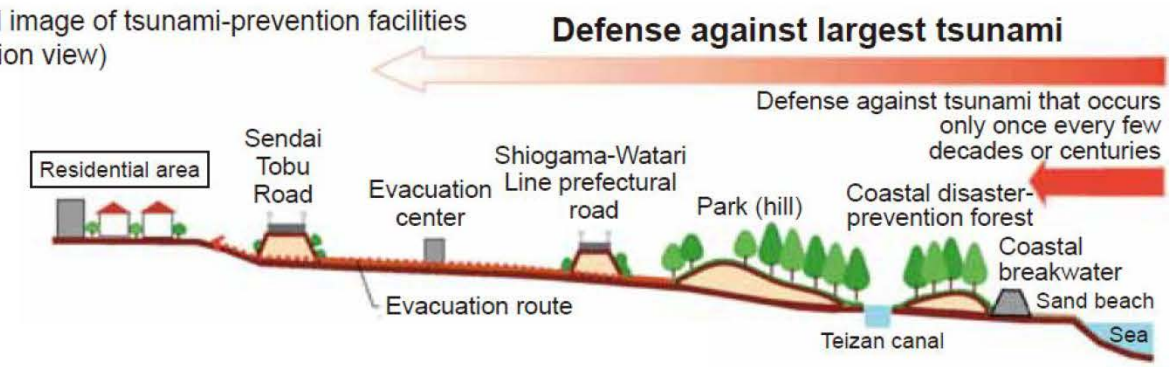
http://www.pref.miyagi.jp/seisaku/sinsaihukkou/keikaku/index.htm

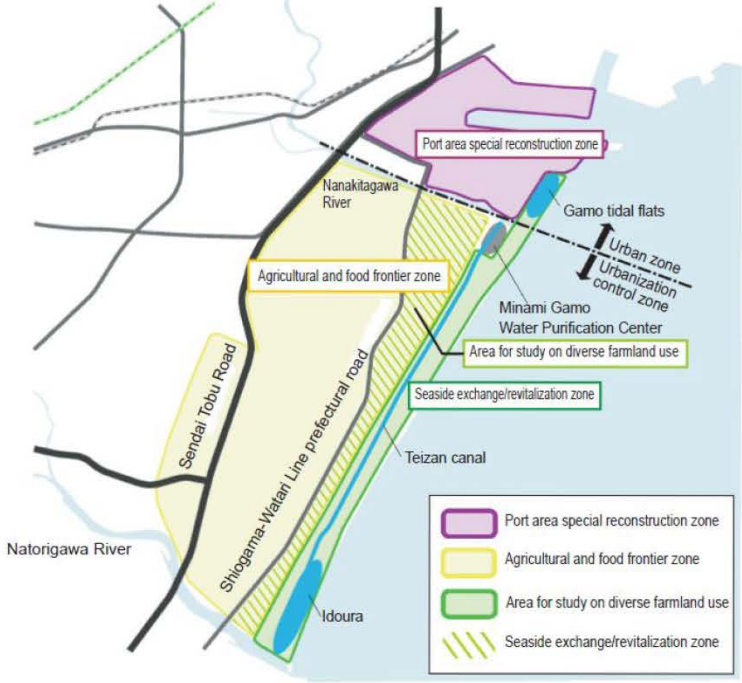
Conceptual image of disaster-prevention facilities against a tsunami

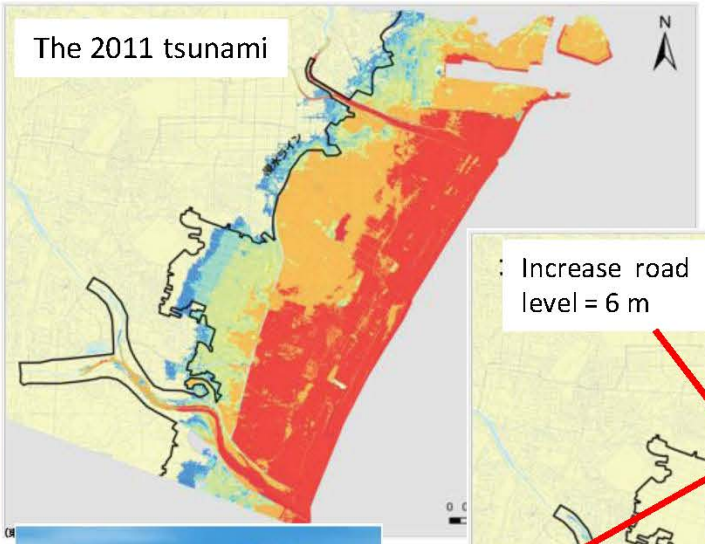
Sendai city plan: land use management

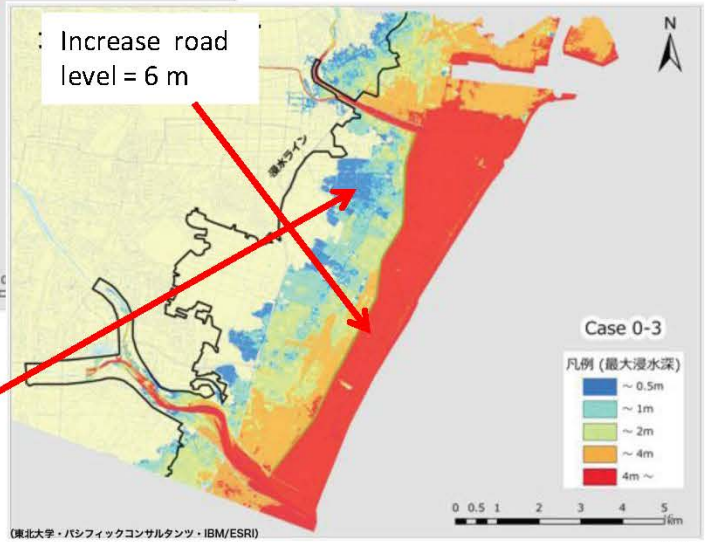


Conceptual image of tsunami-prevention facilities (cross-section view)





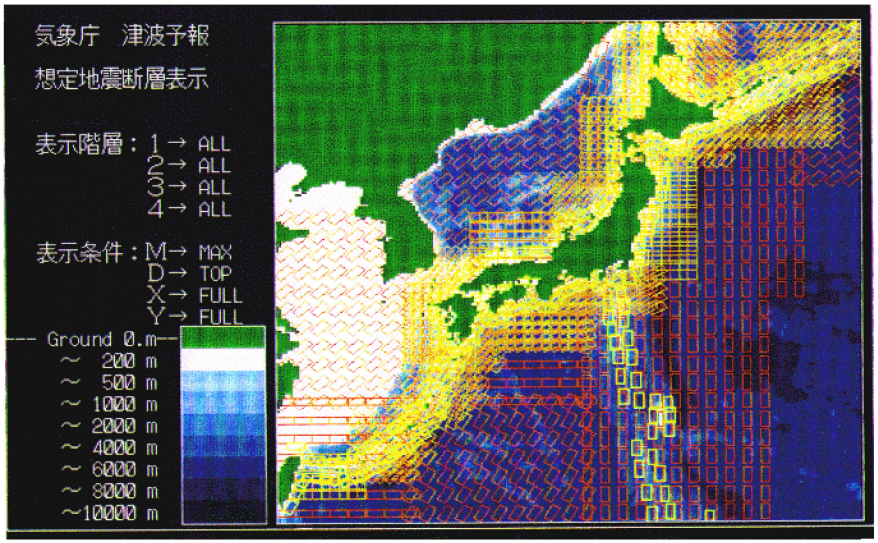




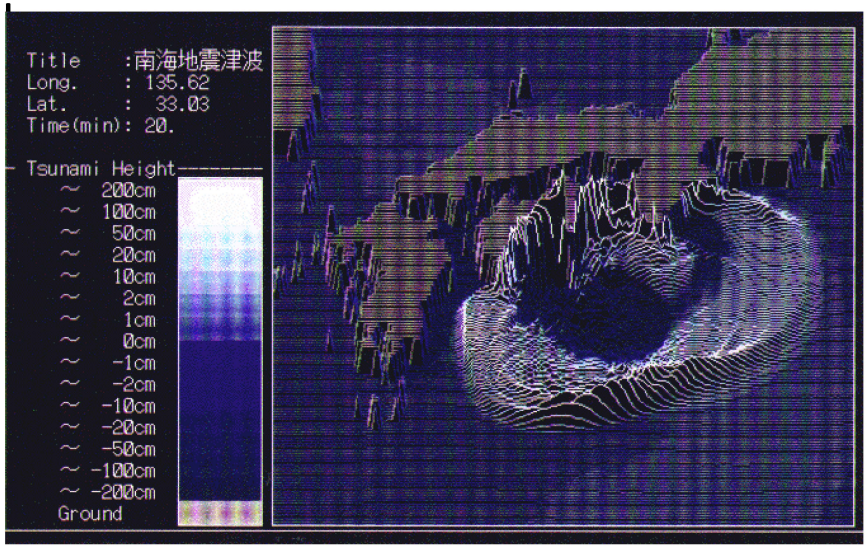
http://www.city.sendai.jp/fukko/1198749_2757.html

Tsunami warning system in Japan

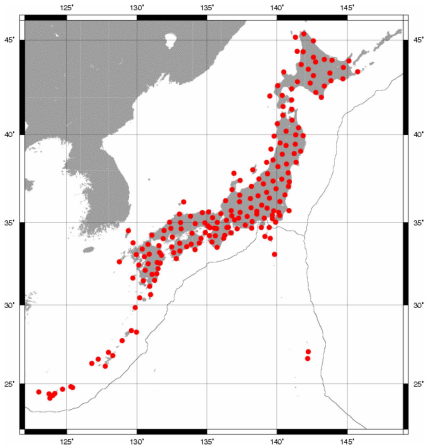
Assumed faults around Japan
(100,000 cases)



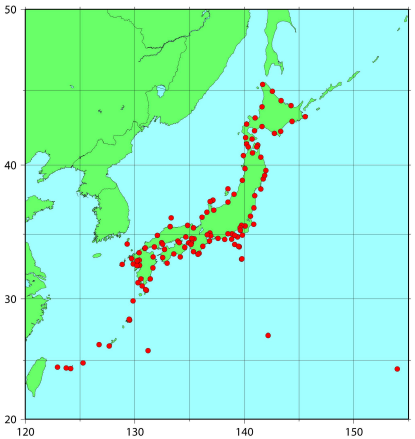
Numerical simulation results stored in data

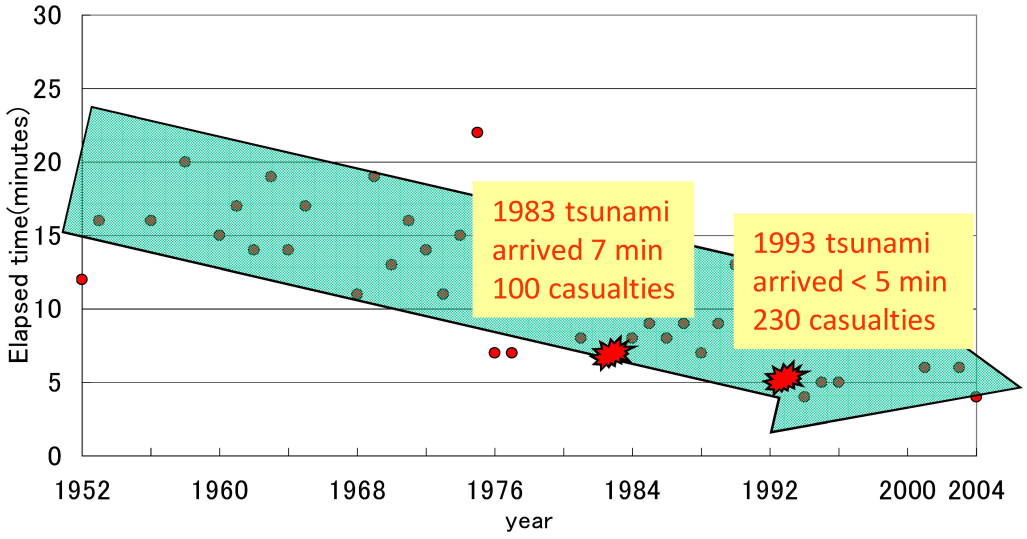


Seismic Network



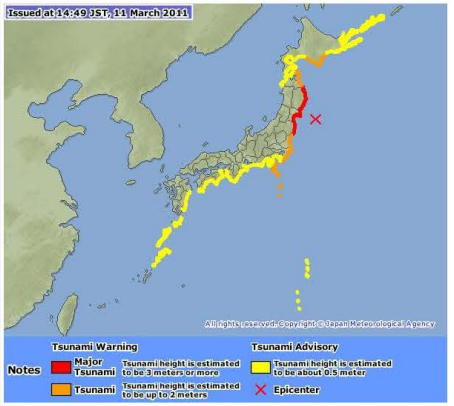
Sea Level Network

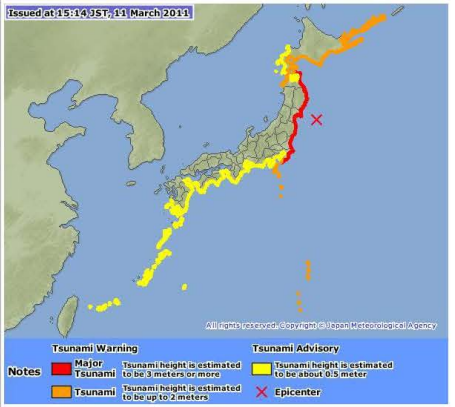


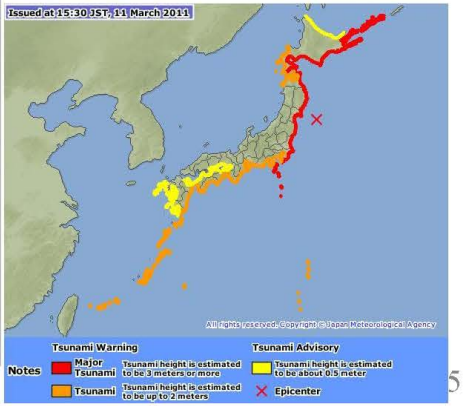


Tsunami warnings during the 2011 tsunami

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	



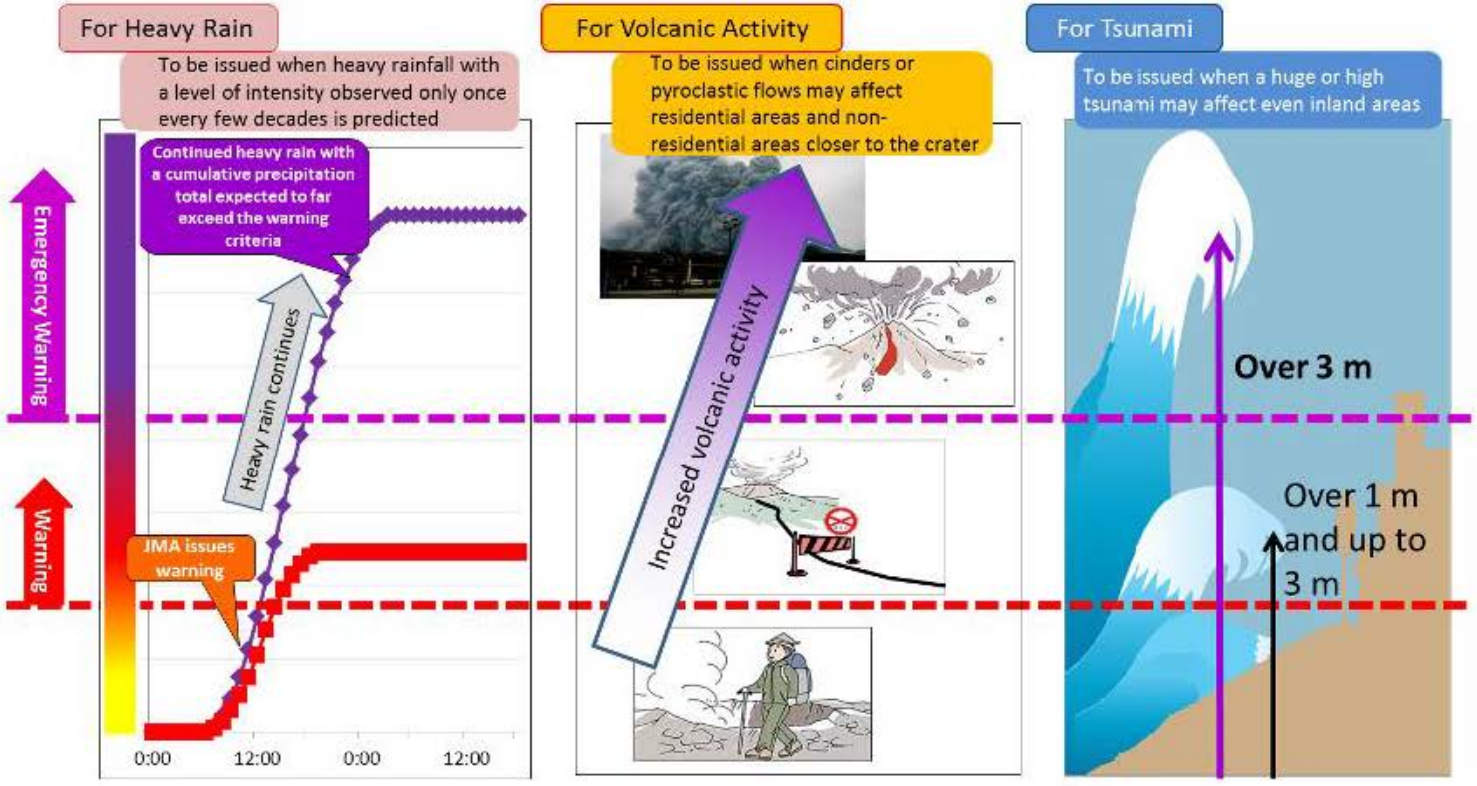




Hayashi et al (2011) and http://www.jma.go.jp/jma/en/2011_Earthquake.html

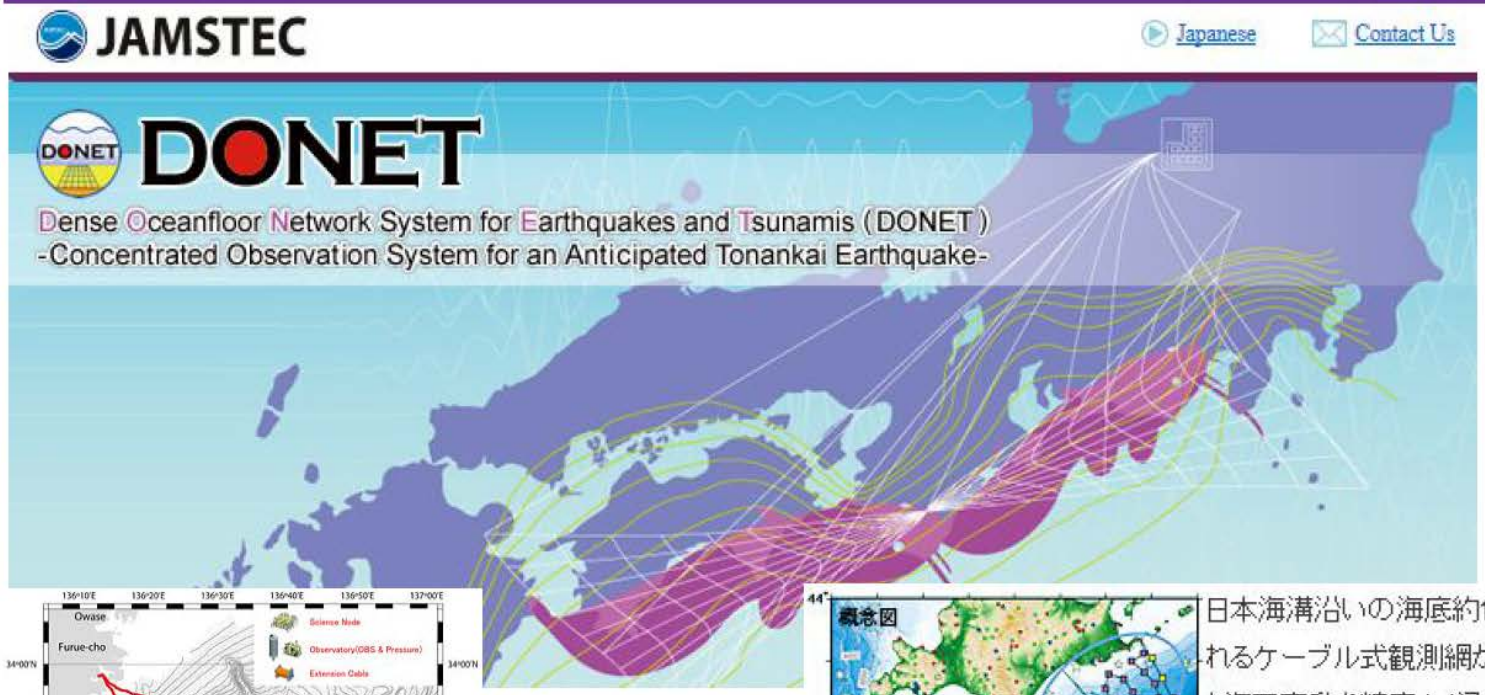
Improvements from the 2011 tsunami

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

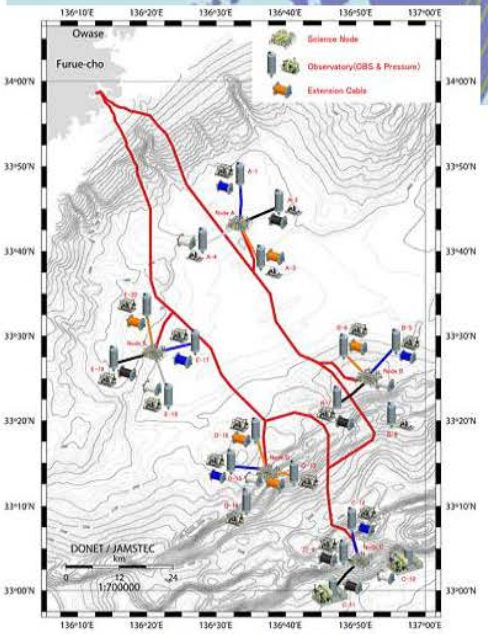


Source: JMA

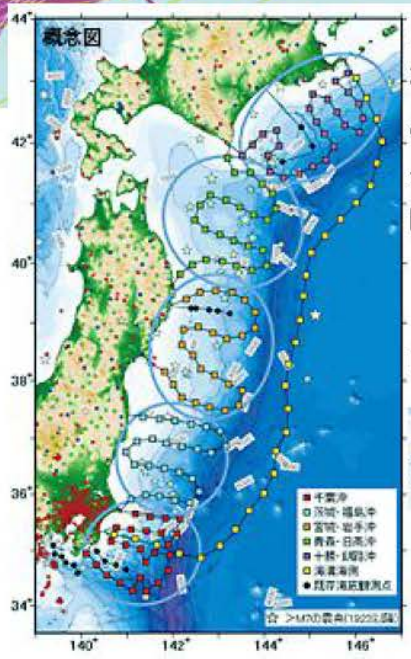
Advance observation technology



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

Characteristics of the 2016 Fukushima tsunami

① The highest observed tsunami was in Sendai

② The second wave was the largest

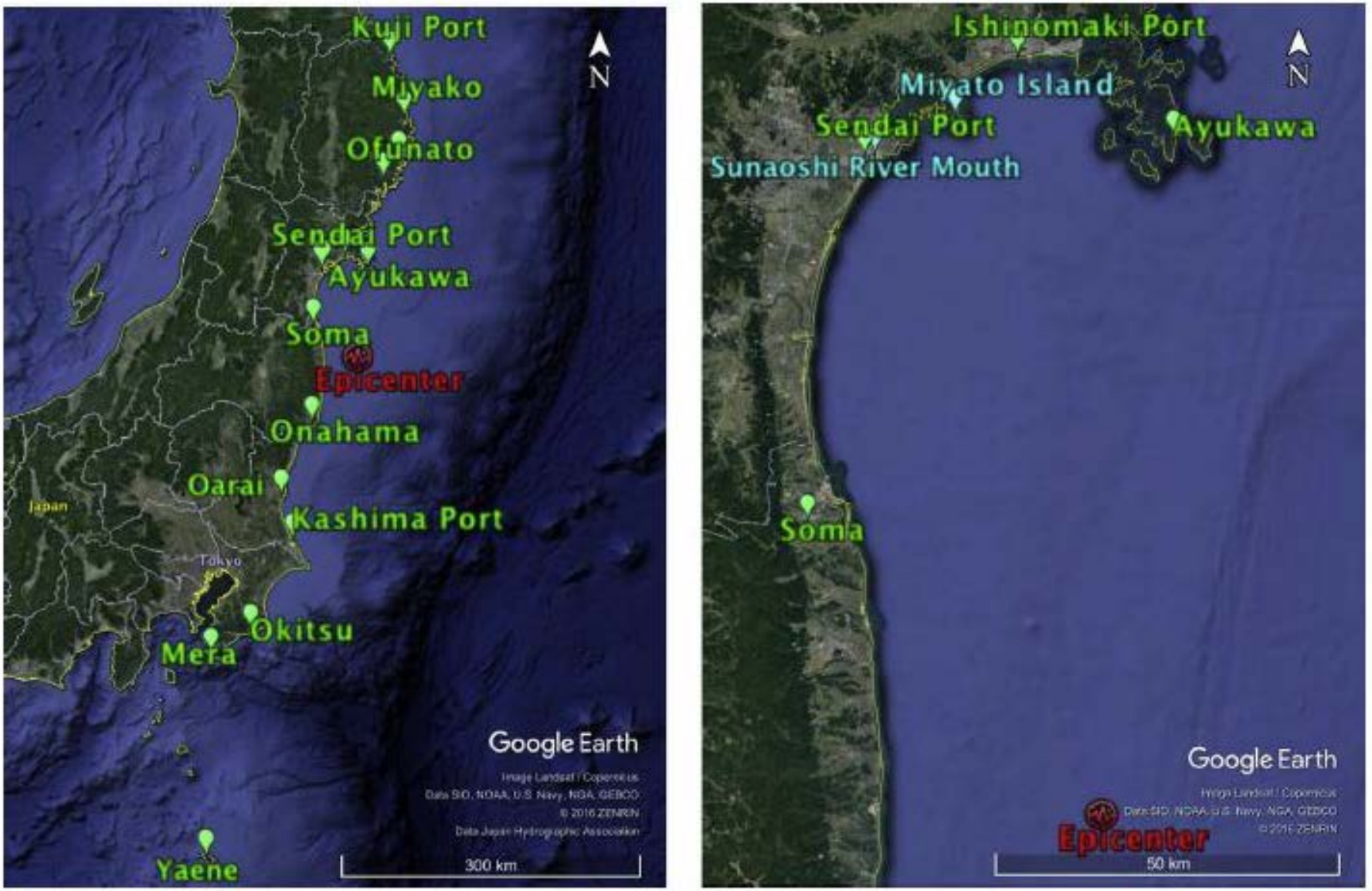
③ Tsunami threat level was elevated from “advisory” to “warning”

④ Local runup was higher than the observed amplitude

⑤ Tsunami intrusion into rivers

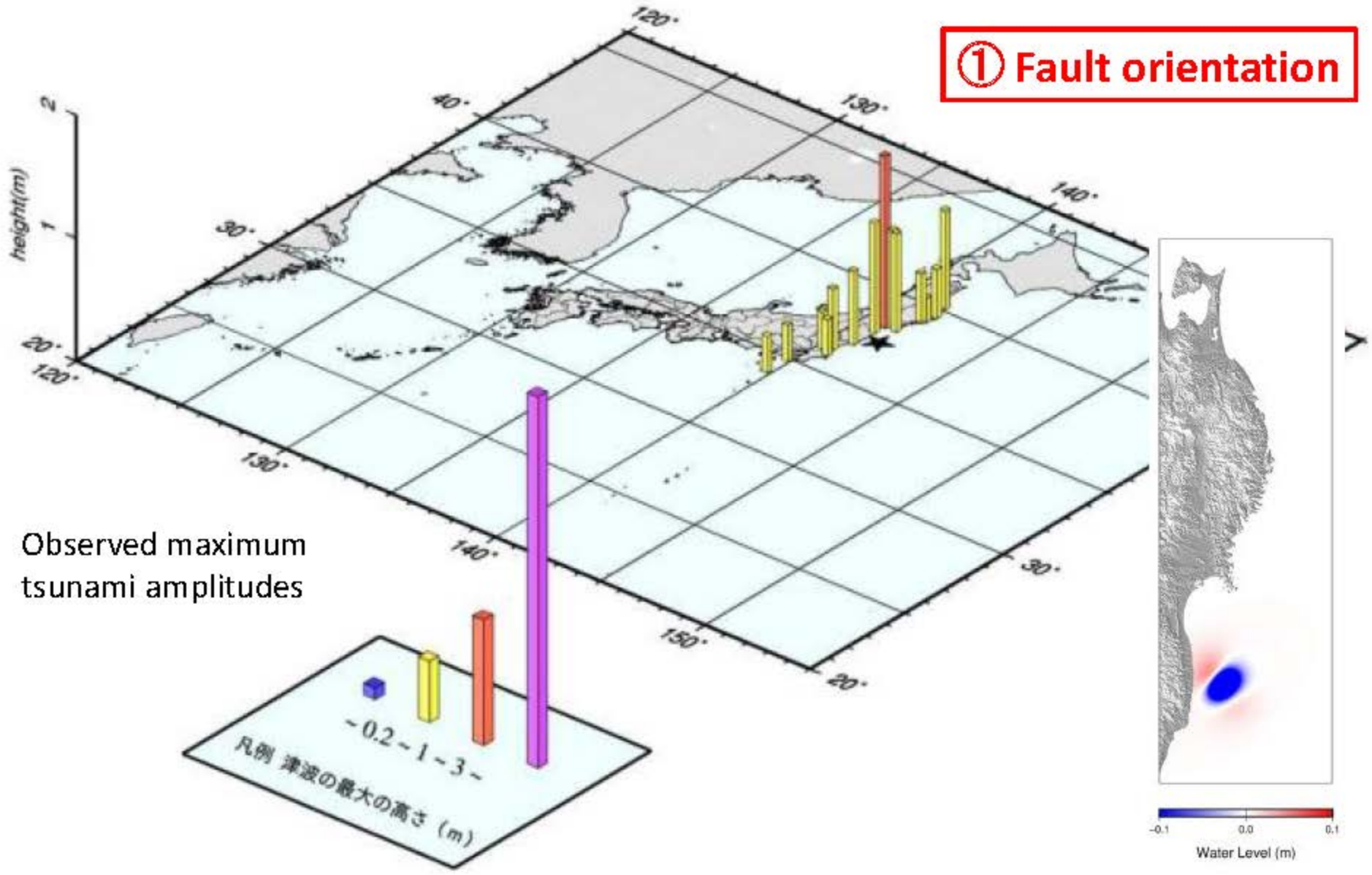
⑥ Tsunami warning and broadcasting

① The highest observed tsunami was in Sendai

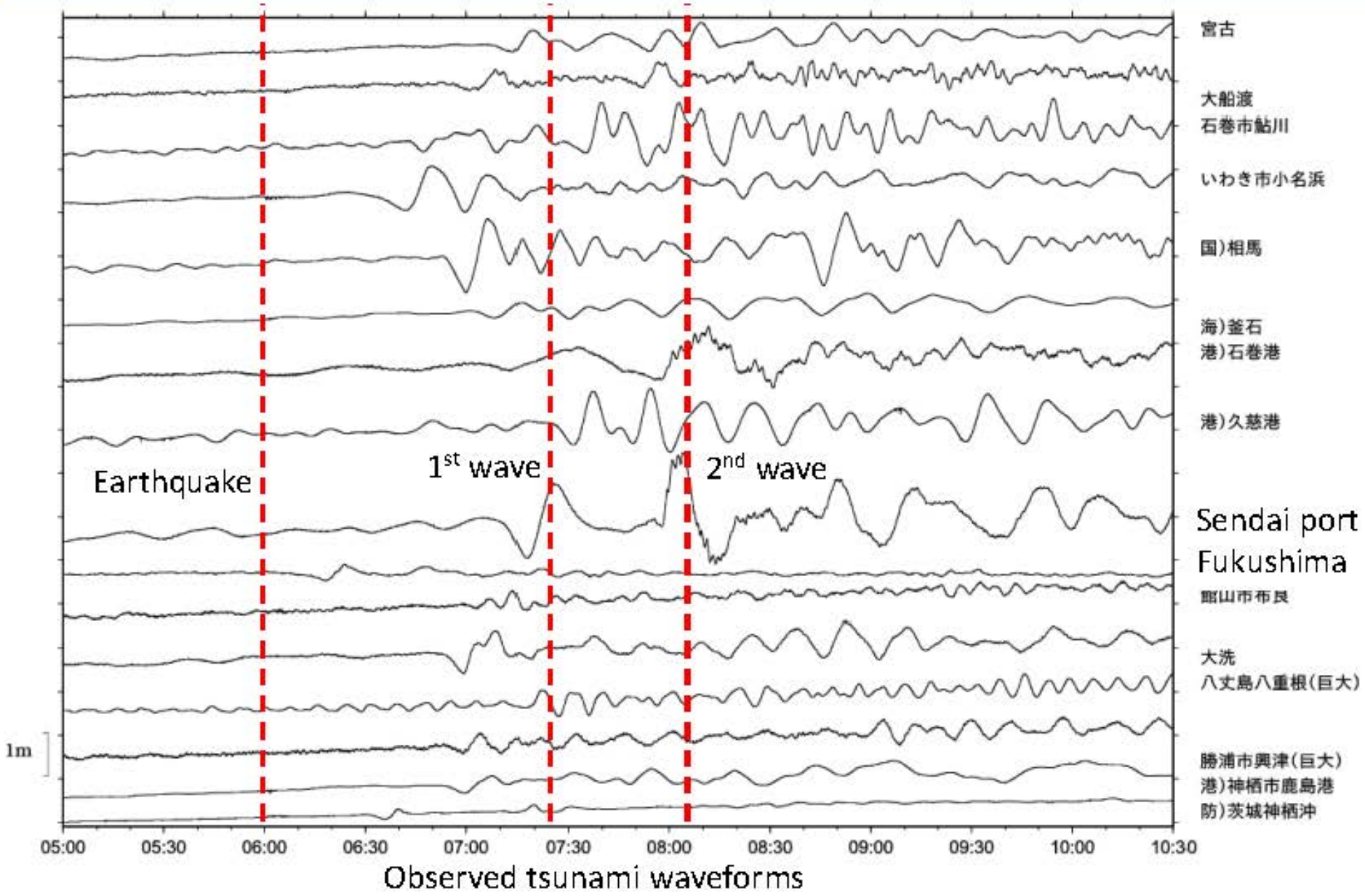


Locations of study area, tide gauges and surveyed areas

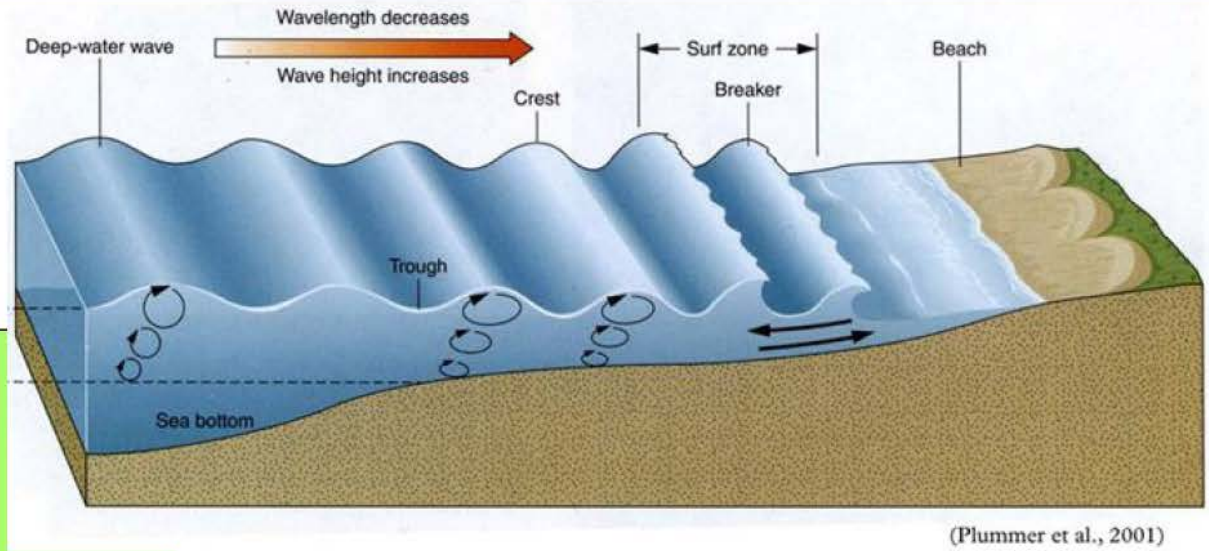
① The highest observed tsunami was in Sendai



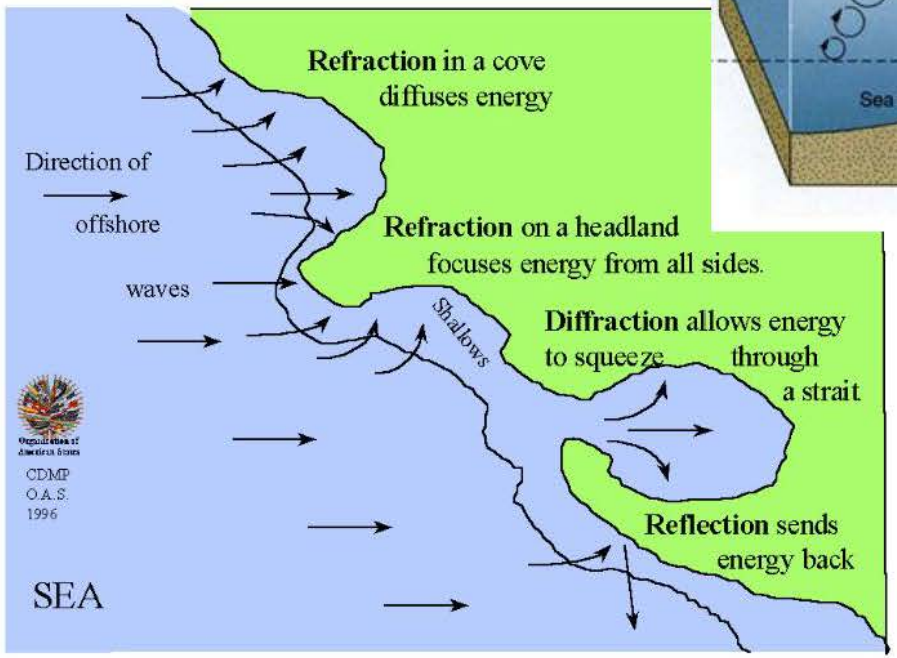
② The second wave was the largest



② The second wave was the largest



(Plummer et al., 2001)

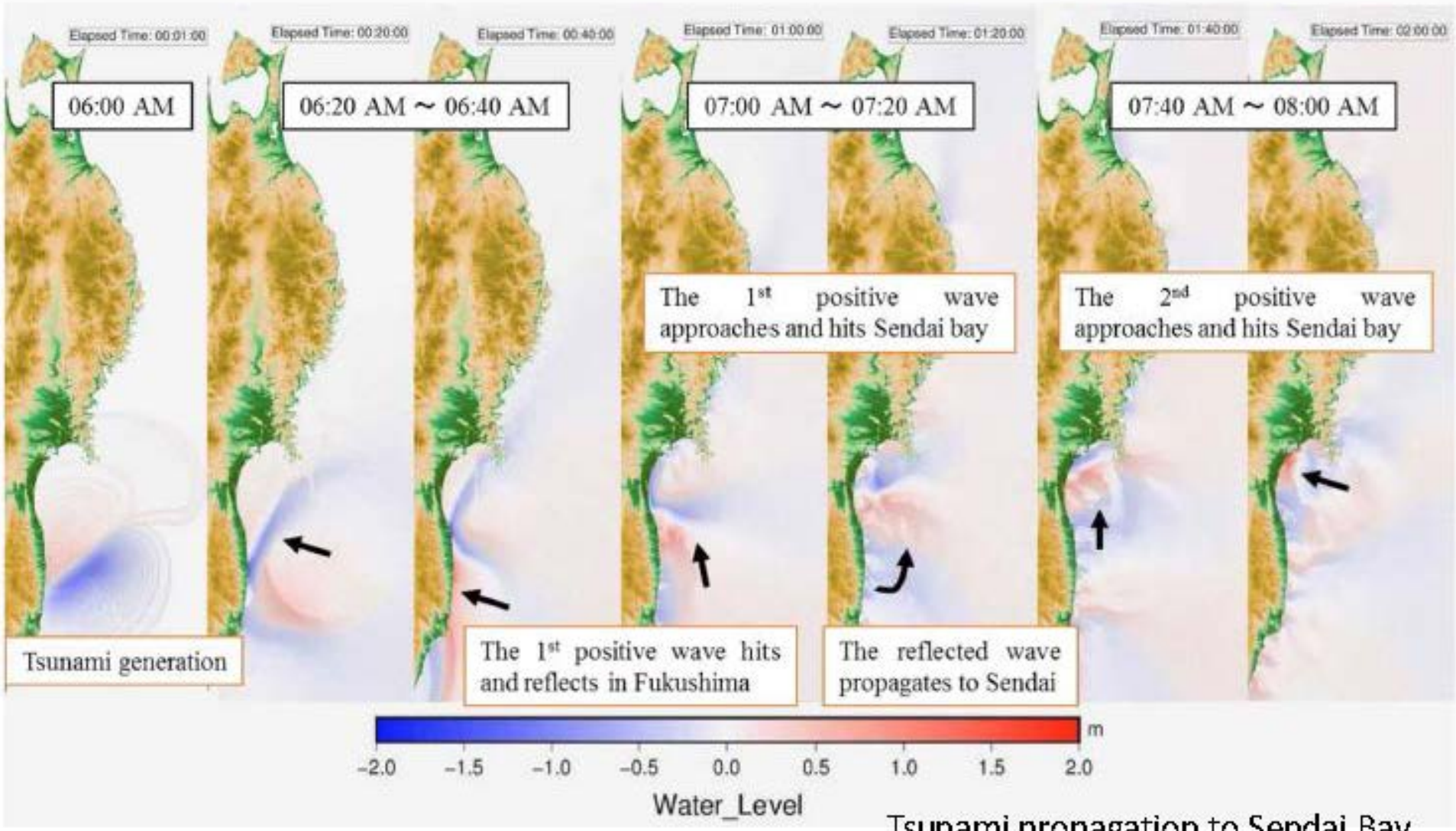


② Wave properties

- **Wave reflection**
- **Wave refraction**
- **Wave shoaling**

In addition to the fault orientation, which focused the tsunami into Sendai Bay, wave reflection and refraction were other contributors. Sendai Bay is a very shallow (average water depth is less than 50 m) and wide bay. Due to this coastal topography, the waves are amplified due to wave shoaling and refraction inside the bay. Also, superposition of the incoming and reflected waves from the Fukushima coast played a role.

② The second wave was the largest



Tsunami propagation to Sendai Bay

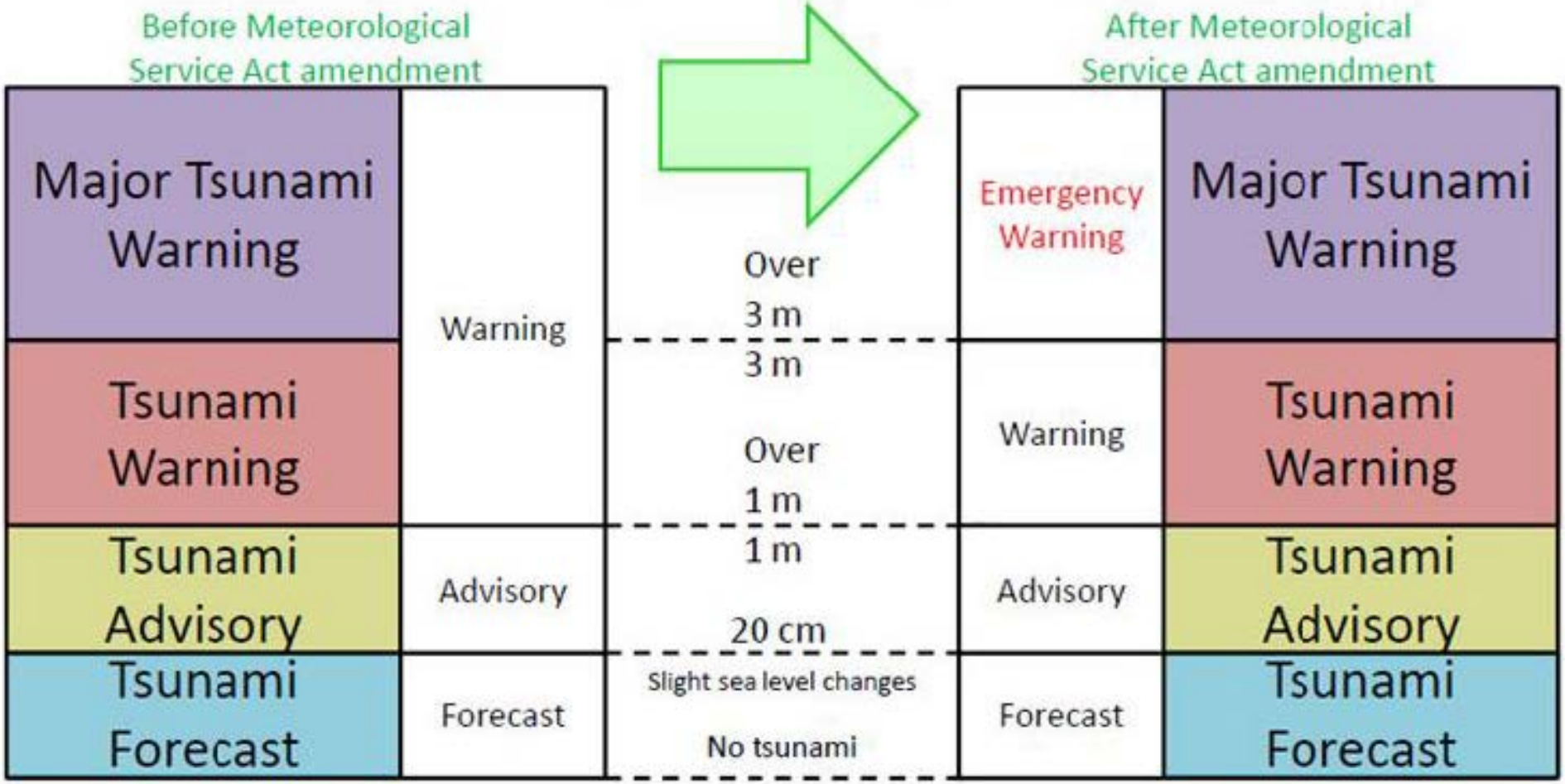
③ Tsunami threat level was elevated from “advisory” to “warning”

津波予報区	発表時刻			
	22日06時02分	22日07時26分	22日08時09分	22日09時46分
青森県太平洋沿岸	津波注意報	津波注意報	津波注意報	若干の海面変動
岩手県	津波注意報	津波注意報	津波注意報	津波注意報
Miyagi Prefecture	津波注意報	津波注意報	Tsunami warning	津波注意報
Fukushima Prefecture	Tsunami warning			津波注意報
Ibaraki Prefecture	津波注意報	津波注意報	津波注意報	津波注意報
千葉県九十九里・外房	津波注意報	津波注意報	津波注意報	若干の海面変動
千葉県内房	若干の海面変動	津波注意報	津波注意報	若干の海面変動
伊豆諸島	若干の海面変動	津波注意報	津波注意報	若干の海面変動

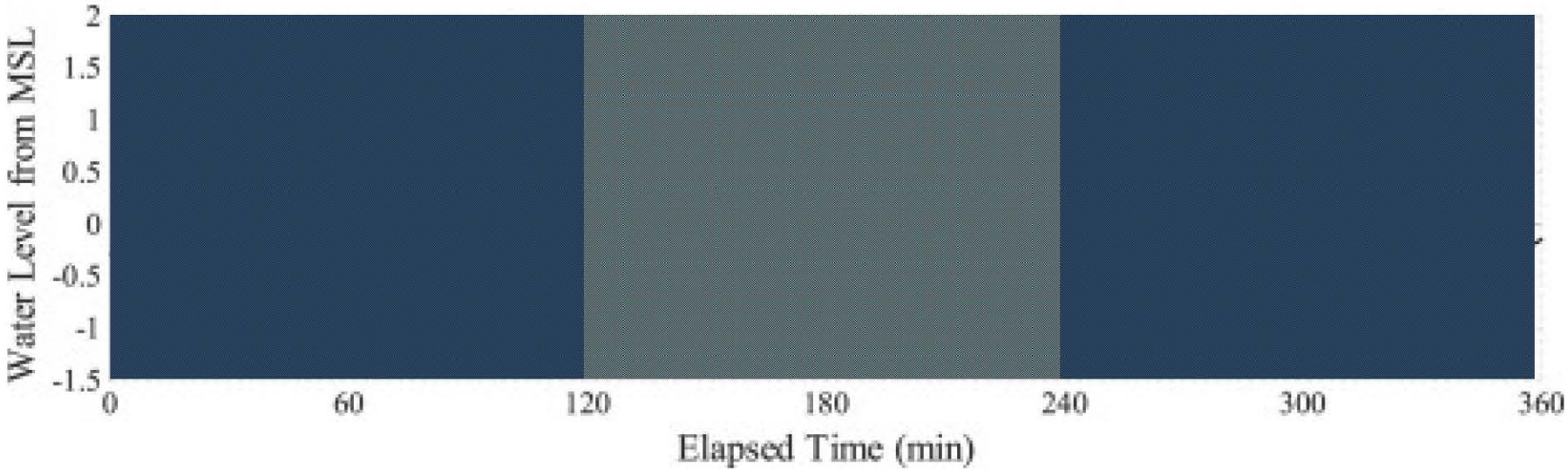
Status of the tsunami warnings and advisories

③ Tsunami threat level was elevated from “advisory” to “warning”

Change in Tsunami Warning System classification with the establishment of Emergency Warnings

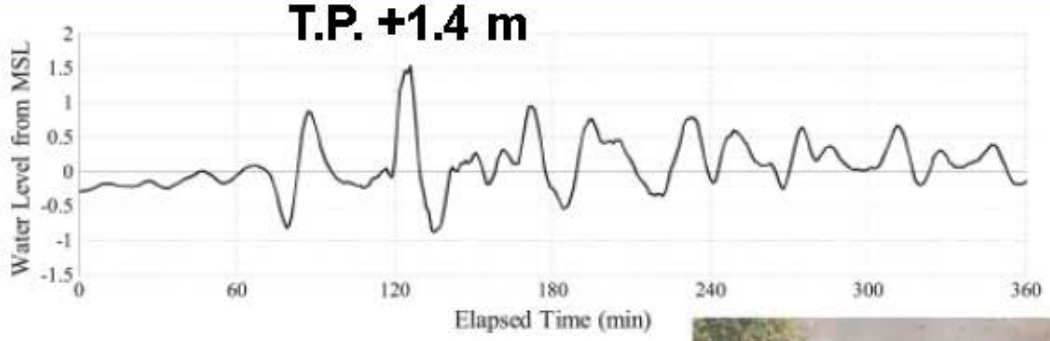


③ Tsunami threat level was elevated from “advisory” to “warning”



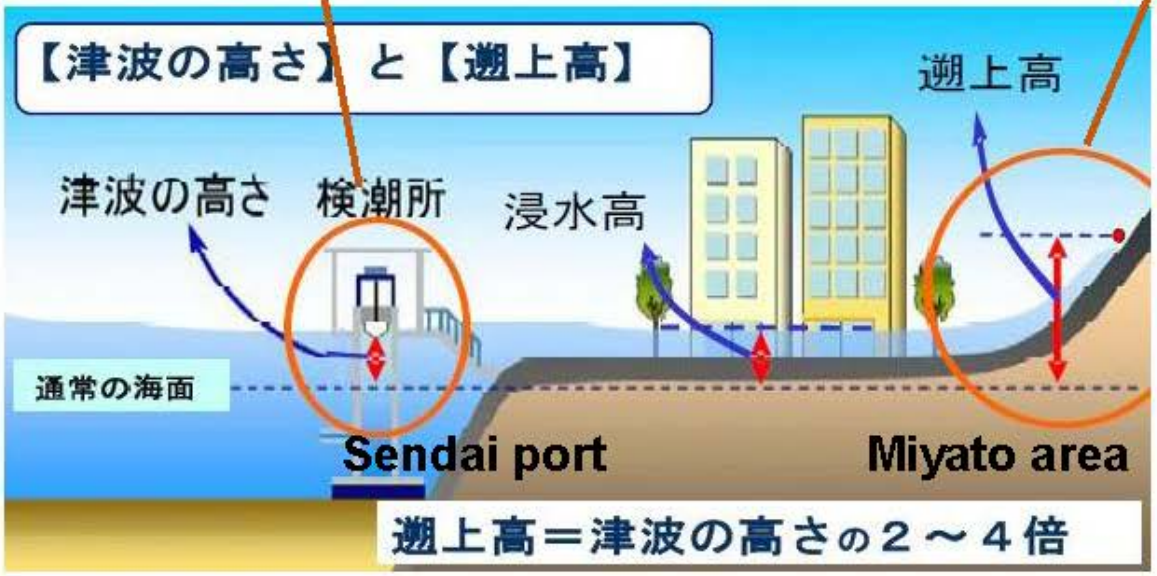
1. When a tsunami with the height ranging from 20 cm to 1 m is expected, a tsunami advisory is issued (indicated by a yellow color; advisory).
2. When a tsunami is expected to be between 1 m and 3 m, a tsunami warning is issued (indicated by a red color; warning).
3. If a tsunami is expected to be greater than 3 m, a major tsunami warning is issued (indicated by a purple color; emergency warning).

④ Local runup was higher than the observed amplitude



Observed tsunami amplitude

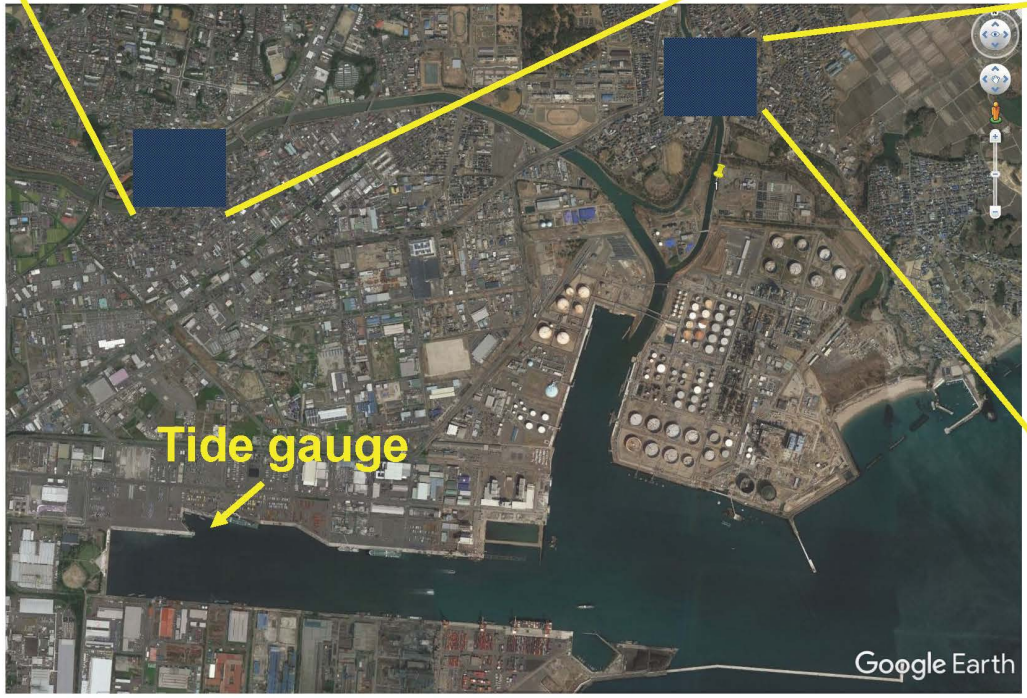
Local tsunami runup

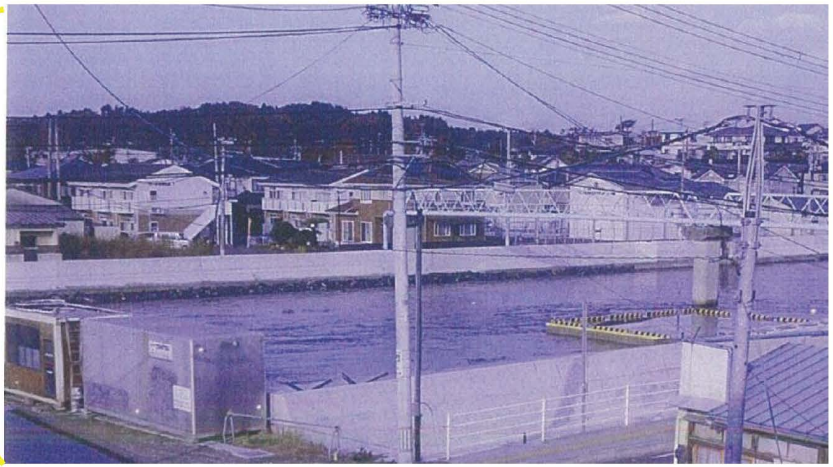


Based on our preliminary survey, tsunami runup higher than the observed tsunami wave amplitude of 1.4 m at Sendai Port was measured at several sites. In the Miyato area of Higashi-Matsushima City in Miyagi Prefecture, tsunami runup heights of more than 2–3 m were found caused by nearshore processes over the coastal topography.

⑤ Tsunami intrusion into rivers

This phenomenon was clearly observed at Sunaoshi River in Tagajo City, where the tsunami propagated over 3 km into the river. The tsunami speed is estimated to be about 14 km/s and the maximum rising of the river level reached 0.9 m (0.6–0.7 m above the normal level).





⑥ Tsunami warning and broadcasting

In contrast to the calm voice used during the 2011 tsunami, terms such as “Evacuate immediately!”, “Tsunami! Evacuate!”, etc. were used to warn people to evacuate from locations expected to be hit by the tsunami. Also, some phases such as “Please remember the Great East Japan Earthquake and move to higher ground”, were used to remind the audience of the 2011 devastation. The warnings were also released in Chinese and Korean languages.

World Tsunami Awareness Day

WORLD TSUNAMI AWARENESS DAY
5 NOVEMBER 2016

In December 2015, the UN General Assembly designated 5 November as World Tsunami Awareness Day.

World Tsunami Awareness Day was the brainchild of Japan, which due to its repeated, bitter experience has over the years built up major expertise in areas such as tsunami early warning, public action and building back better after a disaster to reduce future impacts.

The date for the annual celebration was chosen in honor of the Japanese story of "Inamura-no-hi", meaning the "burning of the rice sheaves". During an 1854 earthquake a farmer saw the tide receding, a sign of a looming tsunami. He set fire to his entire harvest to warn villagers, who fled to high ground. Afterwards, he built an embankment and planted trees as a buffer against future waves.

Goryo setting fire to his rice shaves