Lecture 13

Tsunamis

John Rundle GEL/EPS 131

Topics

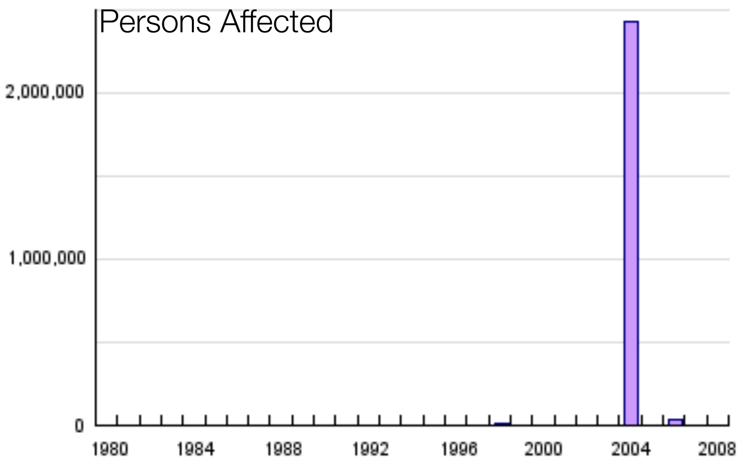
- Tsunamis
- Generation
- Propagation
- Runup

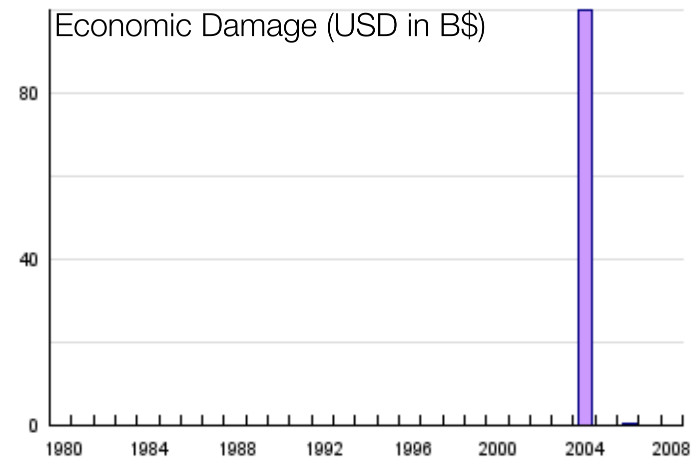
Tsunami Animation Links:

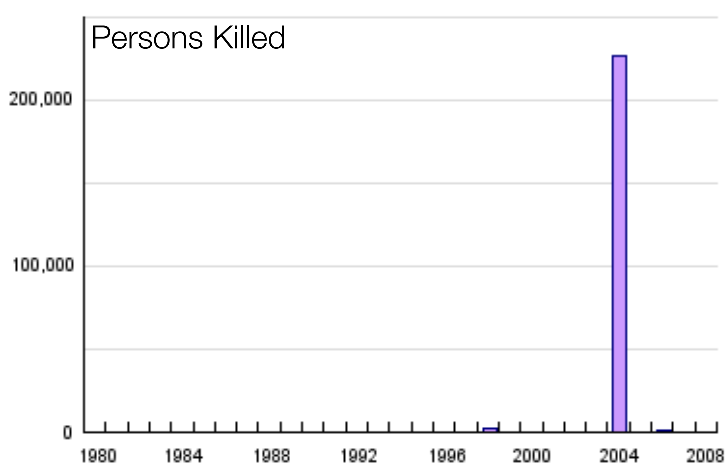
http://serc.carleton.edu/NAGTWorkshops/hazards/visualizations/tsunami.html

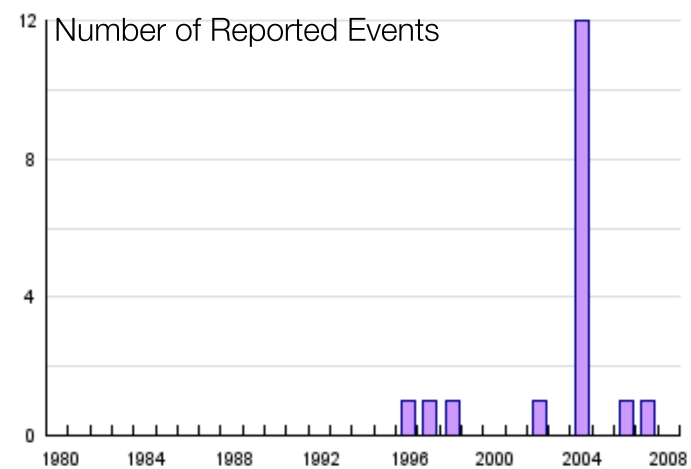
Global Tsunami Statistics, 1980-2008

http://www.preventionweb.net/english/hazards/statistics/?hid=71









Global Tsunamis

Summary Statistics, 1980-2008

http://www.preventionweb.net/english/hazards/statistics/?hid=71

Tsunami disasters from 1980 - 2008

Overview

No of events:	18
No of people killed:	229,551
Average people killed per year:	7,916
No of people affected:	2,481,879
Average people affected per year:	85,582
Ecomomic Damage (US$ X 1,000):	10,046,000
Ecomomic Damage per year (US$ X 1,000):	346,414

Top 10 Disasters Reported

Affected people

Disaster	Date	Affected (no. of people)
Sri Lanka	2004	1,019,306
India	2004	654,512
Indonesia	2004	532,898
Somalia	2004	105,083
Thailand	2004	67,007
Indonesia	2006	35,543
Maldives	2004	27,214
Myanmar	2004	15,700
Papua New Guinea	1998	9,867
Malaysia	2004	5,063

Killed people

Disaster	Date	Killed (no. of people)
Indonesia	2004	165,708
Sri Lanka	2004	35,399
India	2004	16,389
Thailand	2004	8,345
Papua New Guinea	1998	2,182
Indonesia	2006	802
Somalia	2004	298
Maldives	2004	102
Vanuatu	1997	100
Malaysia	2004	80

Economic damages

Disaster	Date	Cost (US$ X 1,000)
Indonesia	2004	4,451,600
Sri Lanka	2004	1,316,500
India	2004	1,022,800
Thailand	2004	1,000,000
Bangladesh	2004	500,000
Malaysia	2004	500,000
Myanmar	2004	500,000
Maldives	2004	470,100
Kenya	2004	100,000
Somalia	2004	100,000

Tsunamis: General Facts

http://en.wikipedia.org/wiki/Tsunami

- “Tsunami = Japanese for “Harbor Wave”
- About 80% of tsunamis occur in the Pacific Ocean, but they are possible wherever there are large bodies of water, including lakes.
- They are caused by earthquakes, landslides, volcanic explosions, glacier calvings, and bolides.
- Tsunamis cause damage by two mechanisms:
  - The smashing force of a wall of water travelling at high speed
  - And the destructive power of a large volume of water draining off the land and carrying a large amount of debris with it, even with waves that do not look large.”
- In the March 11, 2011 tsunami, victims died from “sandblasting”, being battered to death by water-borne debris, drowning, and hyperthermia

Near Sendai Airport, Japan

The Largest Earthquake Since 869 AD in this Region

Image Courtesy NHK

View of the Tohoku Coastline

Sendai Airport at Right

Image Courtesy NHK

Sendai Airport

Image Courtesy NHK

July, 2013: Field Trip to Tohoku Coastline

On the 4 Meter Seawall Tsunami Barrier

July, 2013: Field Trip to Tohoku Coastline

Remains of the Treeline Barrier

July, 2013: Field Trip at Onegawa Town Harbor

Looking Down on Harbor Area from Hospital Parking Lot

(17 Meters above the harbor)

Onegawa Town

Destroyed Building from Ground Level, Hospital at Top Right

Hospital parking lot is 17 meters above the harbor

Onegawa Town Hospital Entrance

The Water was 2 Meters High at the Hospital Entrance (19 meters above the Harbor)

September 22, 2012, Takenoura, Japan

Mr. Shigeo Suzuki and Me

Mr. Suzuki's Dock is Now Underwater

The Entire NorthEast Coast of Japan has Subsided ~1 to 2 Meters

Takenoura Wonders Whether to Rebuild

TheNational

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News | Business | Sport | Lifestyle | Arts & Culture | Opinion | Enter search terms

News » World » Asia Pacific

Connect: Radio: Feed:

Villagers in Japan decide whether to rebuild

Danielle Demetriou

Mar 11, 2012

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TAKENOURA, JAPAN // Standing before a small red shrine on a leafy hillside, Shigeo Suzuki looked down towards the expanse of grey, flat concrete that stretched monotonously to the sea.

"This was once my village," he said quietly. "We used to have 60 houses. I was standing on this very spot when the tsunami came and washed away 58 of them. Only two houses remain," he said.

For Mr Suzuki, 63, a retired government official, the emptiness of Takenoura village in Miyagi prefecture is heartbreaking. Not only was the 120-year-old family home in which he was born washed away, but the community was torn apart.

Topic Japan earthquake Japan

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ASIA PACIFIC

India's Kingfisher Airlines labour talks stall

Hong Kong's worst boat collision in decades kills at least 36

China's Bo faces long list of criminal charges and expulsion

Australian tensions run high over anti-Islam protest

Short South Korean man arrested for stealing high-heeled shoes

Zheng He's replica ship sailing into the future on wave of past glory

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2. Three years jail for men who took turns to rape woman in UAE desert
3. RAK hiker who fell to his death was Emirates pilot
4. iPhone 5 prices drop in UAE, but trimming sim card is owner's risk
5. Golden rules for climbing RAK's treacherous Stairway

POLL

Who will be the next US president?

- Mitt Romney
- Barack Obama

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EDITOR'S PICKS

Catalan independence 'impossible to stop'

The Spanish government is already struggling economically and can scarcely afford to deal with rebellious provinces, yet this is the moment when Catalonia, its wealthy northeastern state, has decided to strike off on the road to secession.

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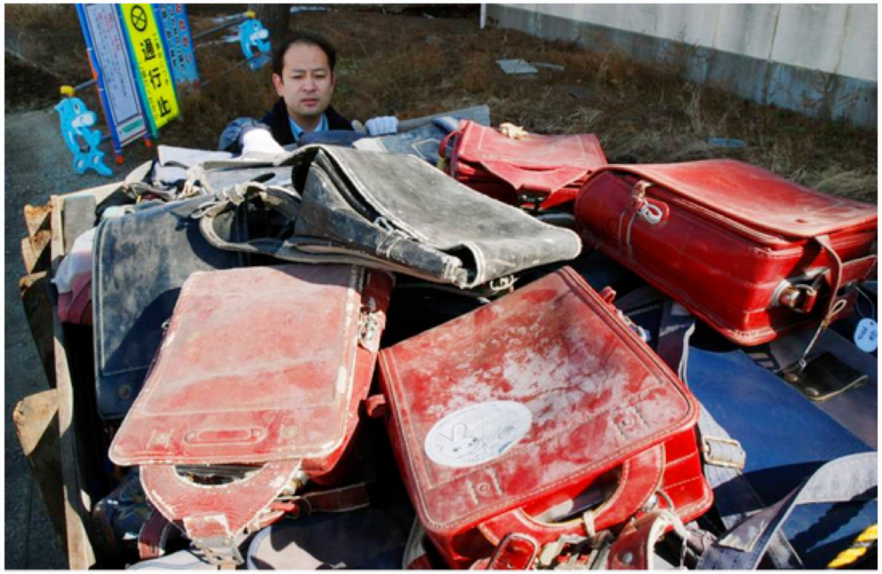
The Human Cost was Staggering

September 22, 2012

Fresh Grave Markers Dot the Landscape (Ishinomaki Town)



Hiroshi Ogasawara, who oversaw the collection of debris from the March 2011 tsunami, carries backpacks that were washed ashore in Natori, Miyagi Prefecture, on Thursday.. | KYODO

NATIONAL

Unclaimed school backpacks pulled from 3/11 tsunami debris incinerated

KYODO

SENDAI – Authorities in Natori, Miyagi Prefecture, said Thursday they have begun to incinerate about 3,000 backpacks and other school pupils' belongings washed ashore in the March 2011 earthquake and tsunami after their owners could not be found.

The items, including leather rucksacks, other bags and musical instruments, had been kept at the former site of Yuriage Elementary School after being retrieved by Self-Defense Forces personnel and volunteers raking through tsunami debris in the months following the disaster.

The authorities had held regular viewings of the items and took requests from people wishing to look through them, but received only two such requests since April last year.

The city said it decided to dispose of the items due to diminishing public interest and the lack of a suitable storage facility, with the current site scheduled to be demolished in the near future as part of land rezoning.

Incineration began Wednesday and is scheduled to run through Friday.

FEB 4, 2016

PHOTOS

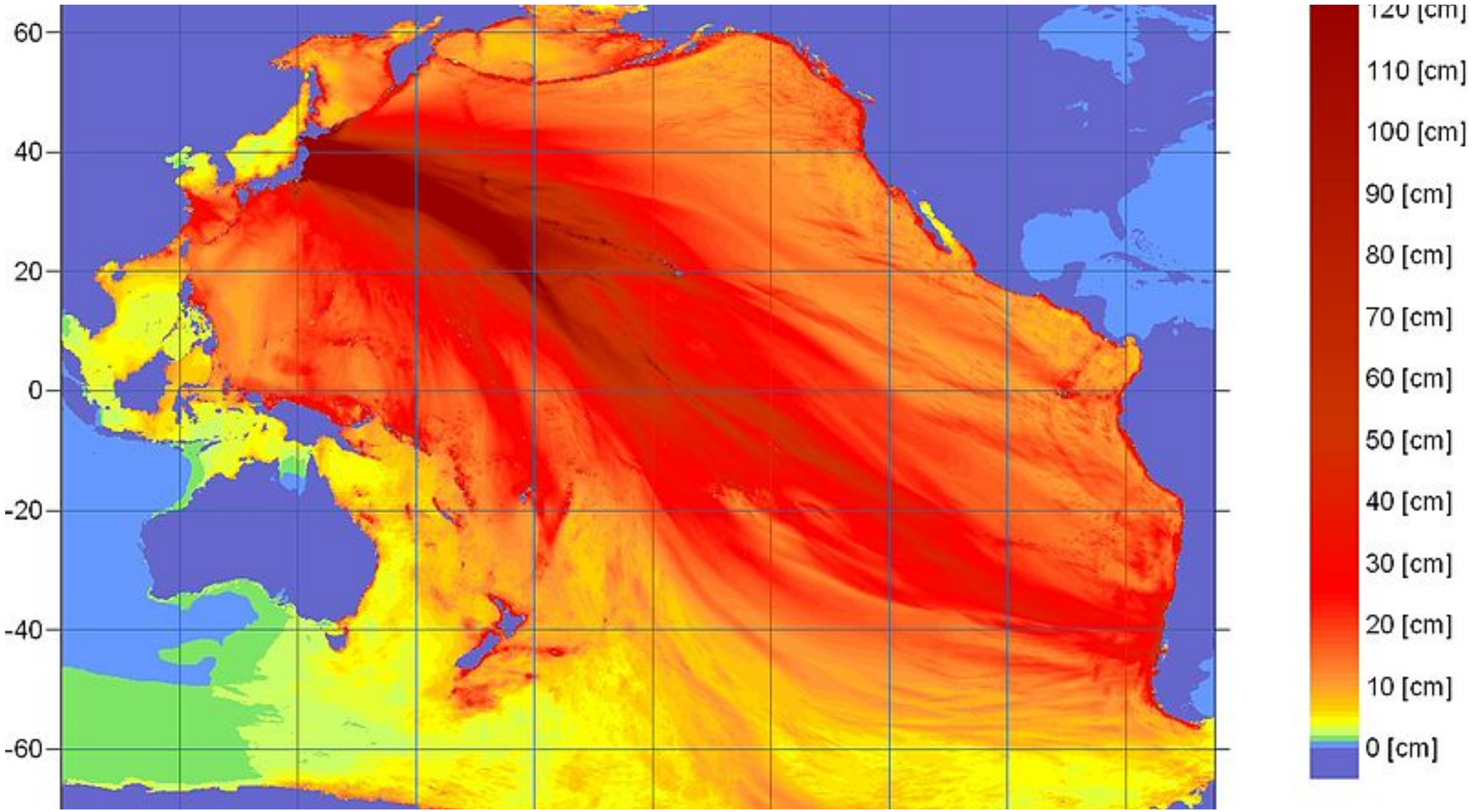
CLICK TO ENLARGE

KEYWORDS

A warning from history. Tsunami stone near Aneyoshi, Japan. Carved into its weather-worn rock is a warning - 'Do not build your homes below this point!' - because they would be at risk from floods in a tsunami. The villagers obeyed the ancient warning and the tiny community of just 11 houses and 34 residents were rewarded with survival at a key geographical point. Some of these stones are more than 600 years old
(UK Daily Mail Online)

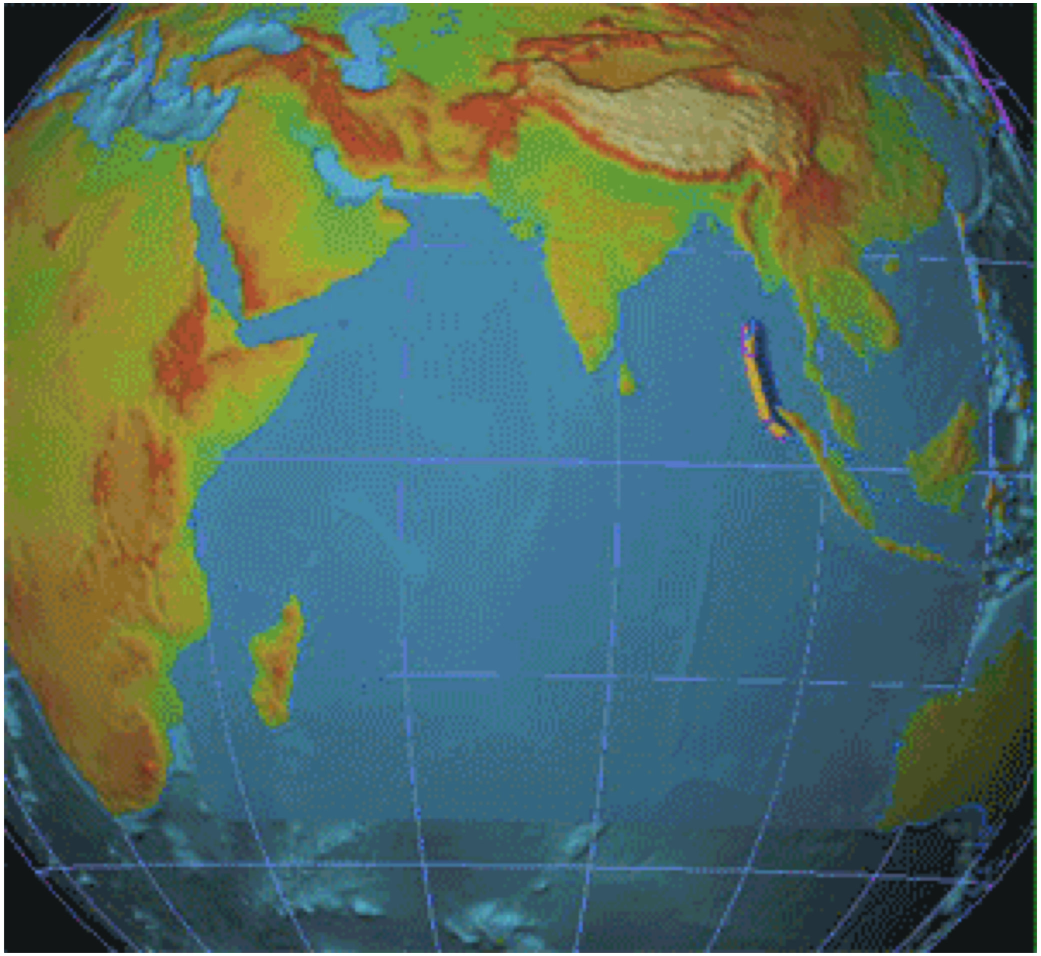
Tohoku Earthquake (Energy Map)

http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami



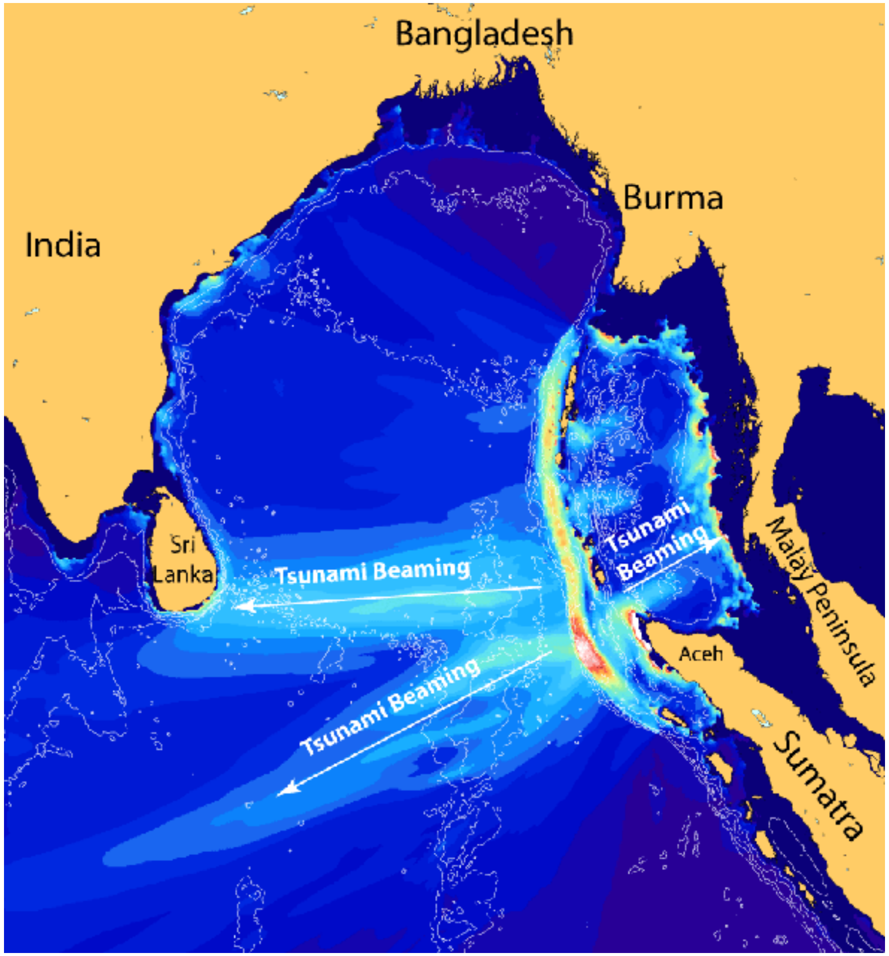
Sumatra-Andaman Tsunami, December 26, 2004

http://en.wikipedia.org/wiki/File:2004-tsunami.jpg



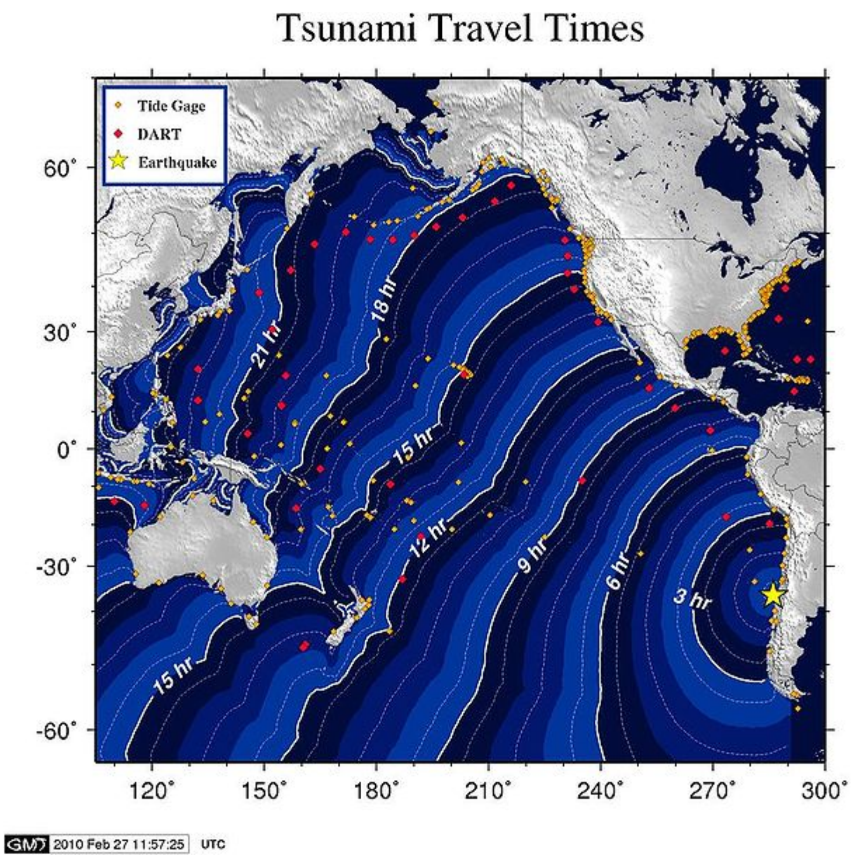
Tsunamis Focus Energy

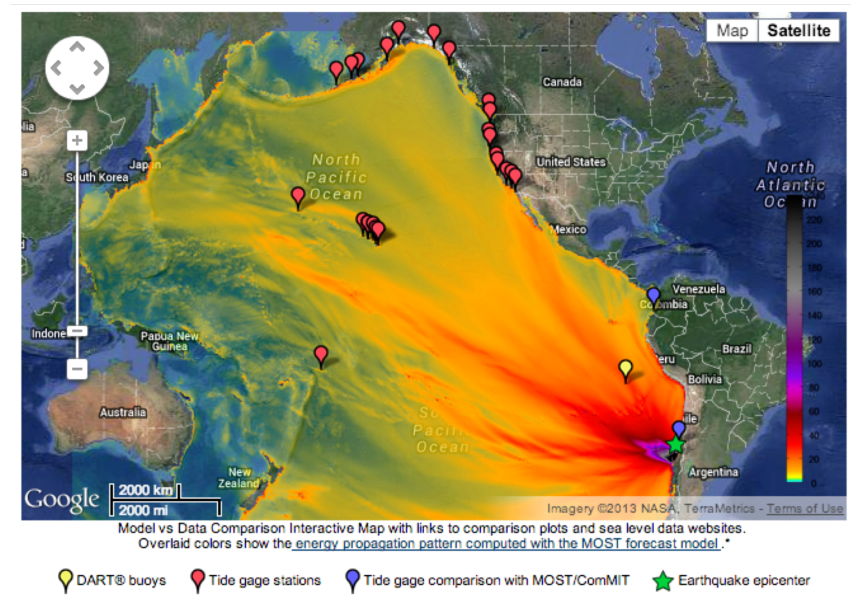
http://walrus.wr.usgs.gov



27 February 2010 Chile Earthquake

http://en.wikipedia.org/wiki/2010_Chile_earthquake



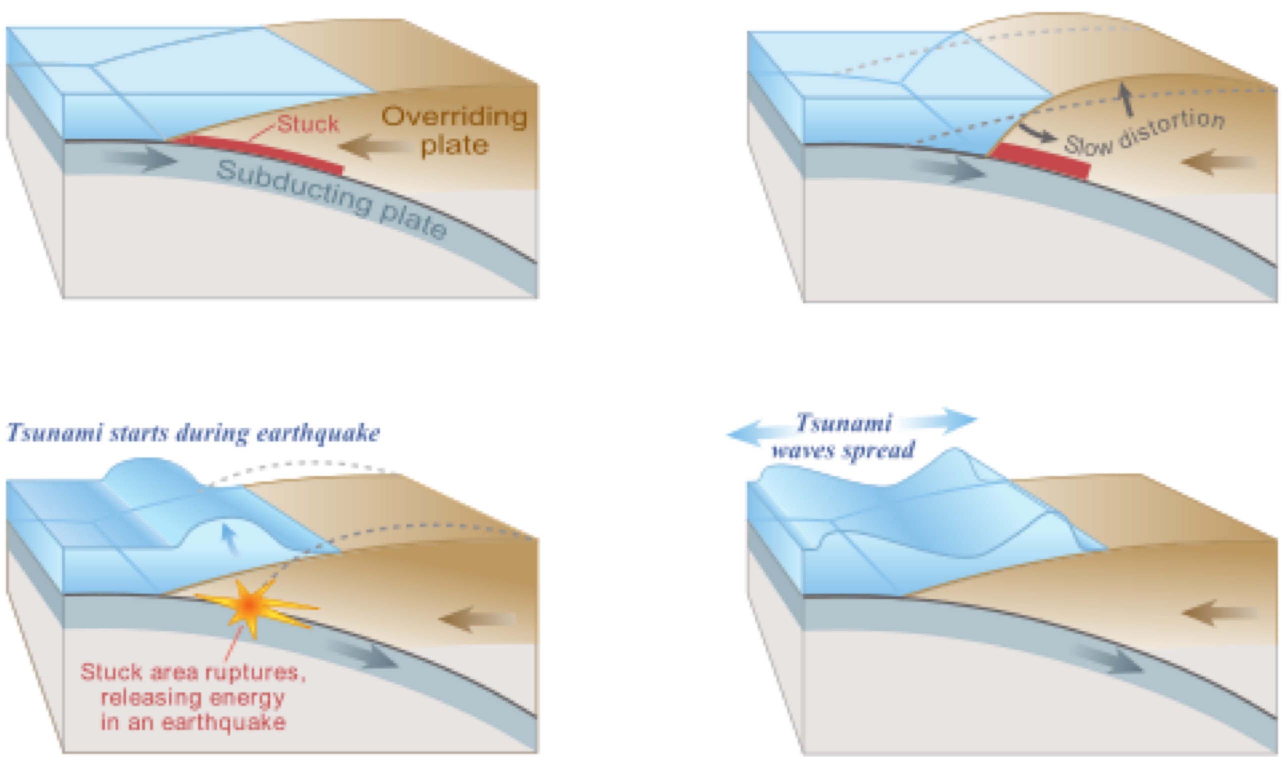


Energy Propagation

http://nctr.pmel.noaa.gov/chile20100227/chile20100227-modeldata.html

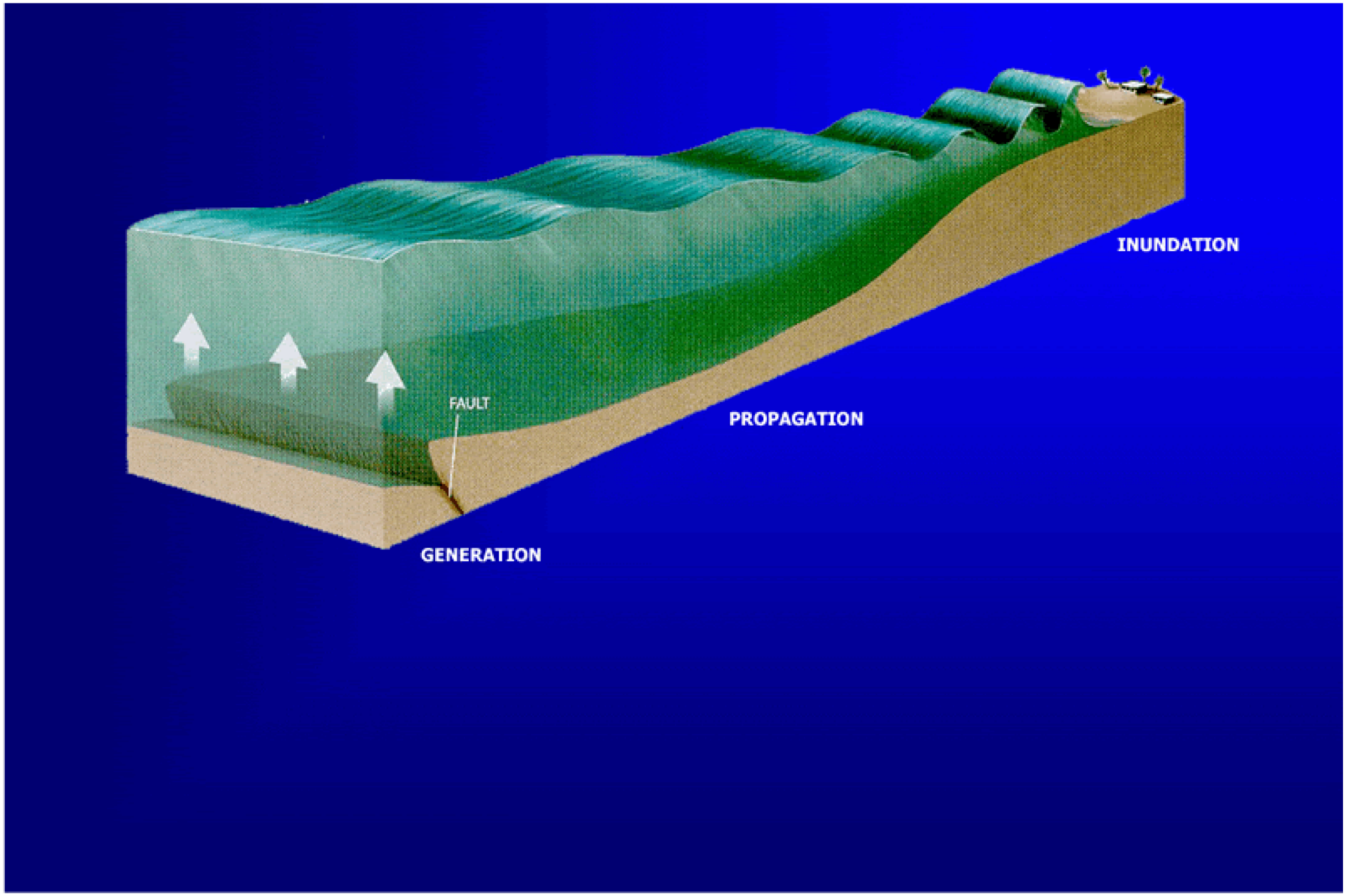
Tsunami Generation from Thrust Earthquakes

http://en.wikipedia.org/wiki/Tsunami



Model for Tsunami Generation

http://www.ga.gov.au/hazards/our-techniques/modelling/how-do-we-model-hazard.html#



Tsunami Waves in the Open Ocean

http://en.wikipedia.org/wiki/Tsun

- “Everyday wind waves have a wavelength (from crest to crest) of about 100 metres (330 ft) and a height of roughly 2 metres (6.6 ft).
- However, a tsunami in the deep ocean has a much larger wavelength of up to 200 kilometres (120 mi).
- Such a wave travels at well over 800 kilometres per hour (500 mph)
- Owing to the enormous wavelength, the wave oscillation at any given point takes 20 or 30 minutes to complete a cycle and has an amplitude of only about 1 metre (3.3 ft)
- This makes tsunamis difficult to detect over deep water, where ships are unable to feel their passage.”

Tsunami Propagation near Shore

http://en.wikipedia.org/wiki/Tsunami

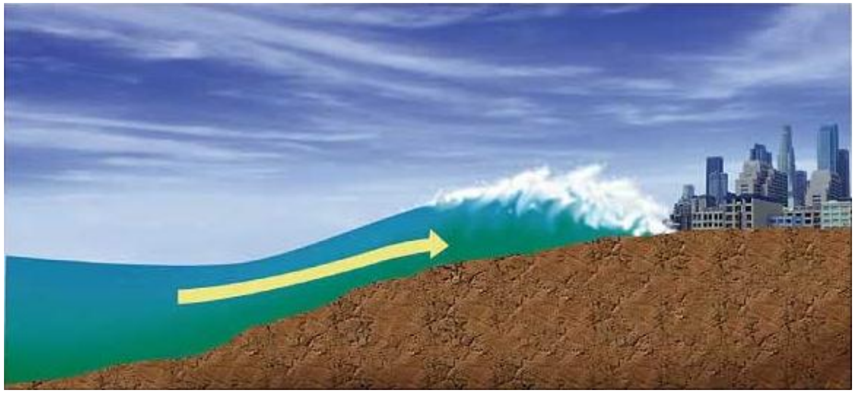
- “As the tsunami approaches the coast and the waters become shallow, wave shoaling compresses the wave and its speed decreases below 80 kilometres per hour (50 mph).
- Its wavelength diminishes to less than 20 kilometres (12 mi) and its amplitude grows enormously.
- Since the wave still has the same very long period, the tsunami may take minutes to reach full height.
- Except for the very largest tsunamis, the approaching wave does not break
- Rather it appears like a fast-moving tidal bore.”

- “Some meteorological conditions, such as deep depressions that cause tropical cyclones, can generate a storm surge, called a meteotsunami
- These can raise tides several metres above normal levels.
- The displacement comes from low atmospheric pressure within the centre of the depression.
- As these storm surges reach shore, they may resemble (though are not) tsunamis, inundating vast areas of land.”

Tsunami “Runup”

http://en.wikipedia.org/wiki/Tsunami

- “When the tsunami's wave peak reaches the shore, the resulting temporary rise in sea level is termed ‘run up’.
- Run up is measured in metres above a reference sea level.
- Run up is the height reached by the wave on shore above sea level
- A large tsunami may feature multiple waves arriving over a period of hours, with significant time between the wave crests.
- The first wave to reach the shore may not have the highest run up.”



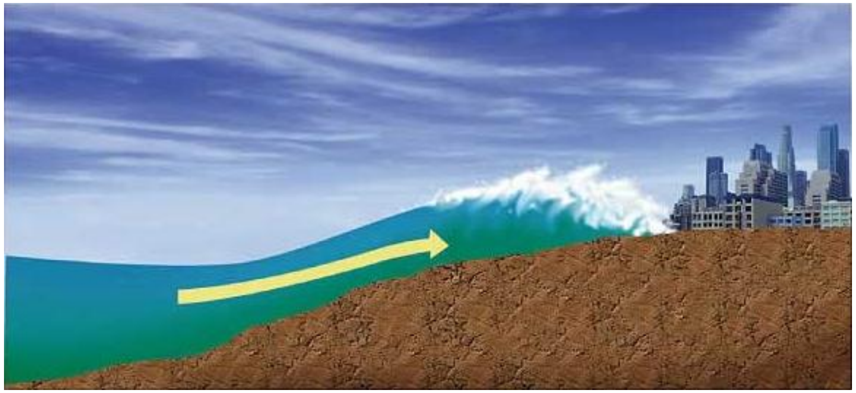
Tsunami Speed and Runup

http://en.wikipedia.org/wiki/Tsunami

- Tsunami speed *c* depends upon ocean depth as:

$$c = \sqrt{gH}$$

where *c* is speed, *g* is surface acceleration of gravity, and *H* is ocean depth



- Tsunamis are detected in the open ocean by DART buoys (next slide)
- Tsunami wave heights in shallow and deep water are related by:

$$\frac{h_s}{h_d} = \left(\frac{H_d}{H_s}\right)^{1/4}$$

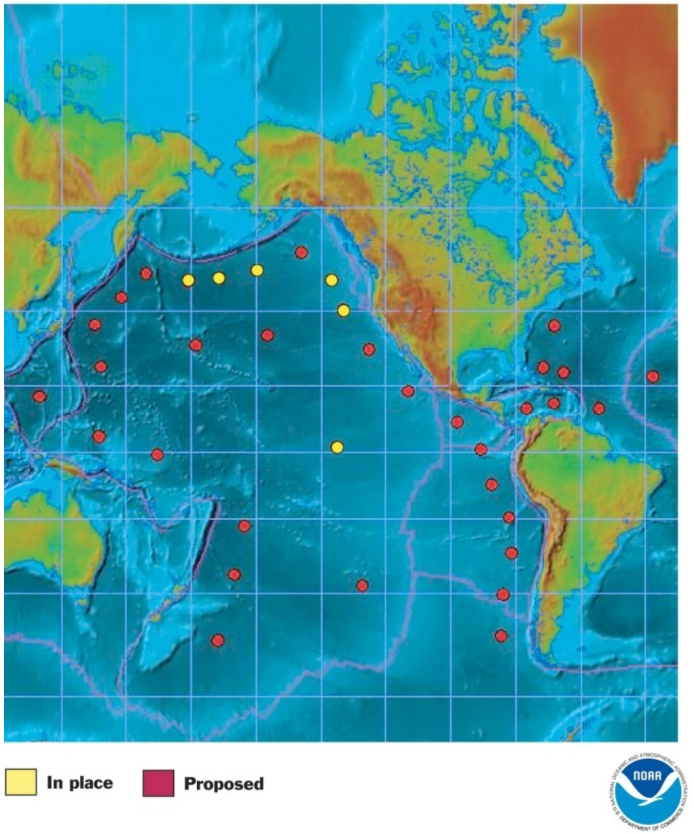
where *H* is water depth, and *h* is wave height, *d* denotes deep water and *s* denotes shallow water.

Current Tsunami Warning System

Earthquake-Magnitude-Based Tsunami Warnings
DART: Deep ocean Assessment and Reporting of Tsunamis (NOAA's PTWC)

Mw less than 6.5 (Mw: Moment Magnitude)	**Earthquake Message Only**
Mw 6.5 to 7.5	**Tsunami Information Bulletin**
Mw 7.6 to 7.8	**Regional Tsunami Warning**
Mw > 7.8	**Expanding Warning / Watch**
Confirmed Teletsunami	**Pacific-Wide Warning**

Proposed DART Buoy System



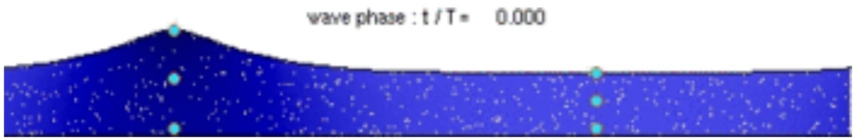
Unfortunately,

1. Earthquake magnitude is not a good indicator of a resulting tsunami;
2. DART system has inherent delays of as long as 60 minutes
3. Seismic Mww estimates require at 20 minutes or more from the W phase

Tsunami “Drawback”

http://en.wikipedia.org/wiki/Tsunami

- “All waves have a positive and negative peak, i.e. a ridge and a trough.
- In the case of a propagating wave like a tsunami, either may be the first to arrive.
- If the first part to arrive at shore is the ridge, a massive breaking wave or sudden flooding will be the first effect noticed on land.
- However if the first part to arrive is a trough, a drawback will occur as the shoreline recedes dramatically, exposing normally submerged areas.
- Drawback can exceed hundreds of metres, and people unaware of the danger sometimes remain near the shore to satisfy their curiosity or to collect fish from the exposed seabed.”



- “A typical wave period for a damaging tsunami is about 12 minutes.
- This means that if the drawback phase is the first part of the wave to arrive, the sea will recede, with areas well below sea level exposed after 3 minutes.
- During the next 6 minutes the tsunami wave trough builds into a ridge, and during this time the sea is filled in and destruction occurs on land.
- During the next 6 minutes, the tsunami wave changes from a ridge to a trough, causing flood waters to drain and drawback to occur again.
- This may sweep victims and debris some distance from land. The process repeats as the next wave arrives.”

Other Tsunami Mechanisms

http://en.wikipedia.org/wiki/Tsunami

- “In the 1950s, it was discovered that larger tsunamis than had previously been believed possible could be caused by giant submarine landslides.
- These rapidly displace large water volumes, as energy transfers to the water at a rate faster than the water can absorb.
- Their existence was confirmed in 1958, when a giant landslide in Lituya Bay, Alaska, caused the highest wave ever recorded, which had a height of 524 metres (over 1700 feet).
- The wave didn't travel far, as it struck land almost immediately.
- Two people fishing in the bay were killed, but another boat amazingly managed to ride the wave.
- Scientists named these waves megatsunami.
- Scientists discovered that extremely large landslides from volcanic island collapses can generate megatsunamis that can cross oceans.”

Tsunamis are Quantified by Intensity and Magnitude

http://en.wikipedia.org/wiki/Tsunami

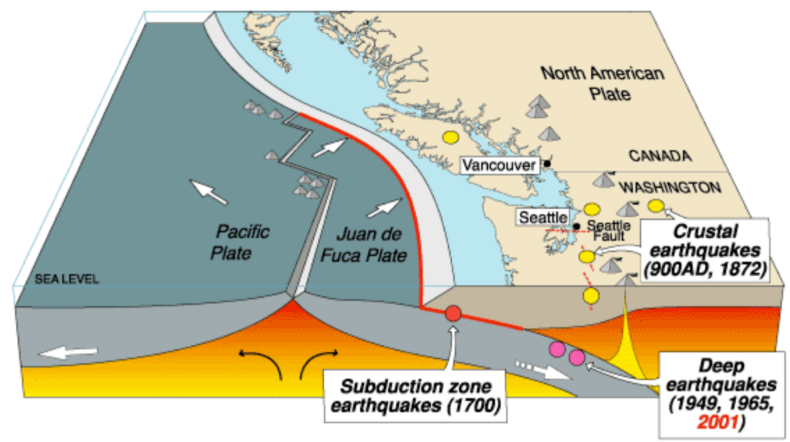
- Intensity scales are used routinely to measure the intensity of tsunami.
- They were first proposed by Sieberg and Ambraseys scale, and used in the Mediterranean Sea, and by Imamura and Iida, used in the Pacific Ocean, later modified by Soloviev
- The intensity is specified mathematically by the average wave height along the coast for each specified location
- This scale, known as the Soloviev-Imamura tsunami intensity scale, is used in the global tsunami catalogues compiled by the NGDC/NOAA
- Magnitude scales, as in earthquakes, measure the energy of the tsunami rather than its local effects
- The first scale that genuinely calculated a magnitude for a tsunami, rather than an intensity at a particular location was proposed by Murty & Loomis based on the potential energy.
- Abe introduced the tsunami magnitude M_T scale which depends on the maximum tsunami-wave amplitude (in m) measured by a tide gauge at a distance R from the epicentre.
- The equation has constants a, b & D that are used to make the M_T scale match as closely as possible with the moment magnitude scale.[30]

Cascadia Earthquake and Tsunami
January 26, 1700 AD ~2100 hrs

http://en.wikipedia.org/wiki/1700_Cascadia_earthquake

- The 1700 Cascadia earthquake was a magnitude 8.7 to 9.2 megathrust earthquake that occurred in the Cascadia subduction zone on January 26, 1700.
- The earthquake involved the Juan de Fuca Plate underlying the Pacific Ocean, from mid-Vancouver Island in British Columbia, Canada, south along the Pacific Northwest coast as far as northern California, USA.
- The length of the fault rupture was about 1,000 kilometers with an average slip of 20 meters.
- The earthquake caused a tsunami that struck the coast of Japan, and may also be linked to the Bonneville Slide.

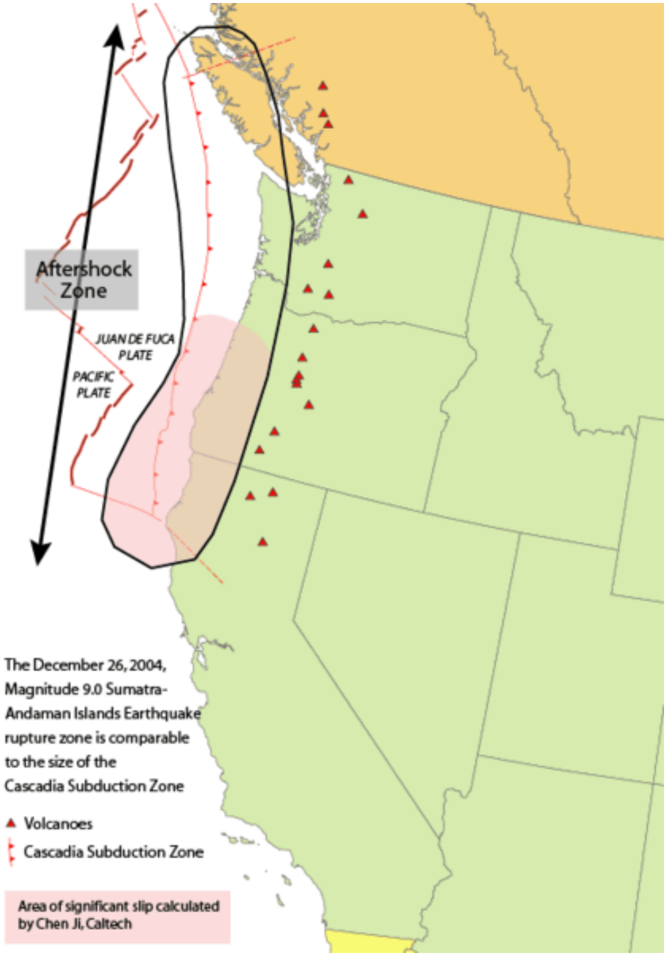
Cascadia earthquake sources



Source	Affected area	Max. Size	Recurrence
Subduction Zone	W.WA, OR, CA	M 9	500-600 yr
Deep Juan de Fuca plate	W.WA, OR,	M 7+	30-50 yr
Crustal faults	WA, OR, CA	M 7+	Hundreds of yr?

Great Earthquakes in the Pacific NW

http://en.wikipedia.org/wiki/1700_Cascadia_earthquake

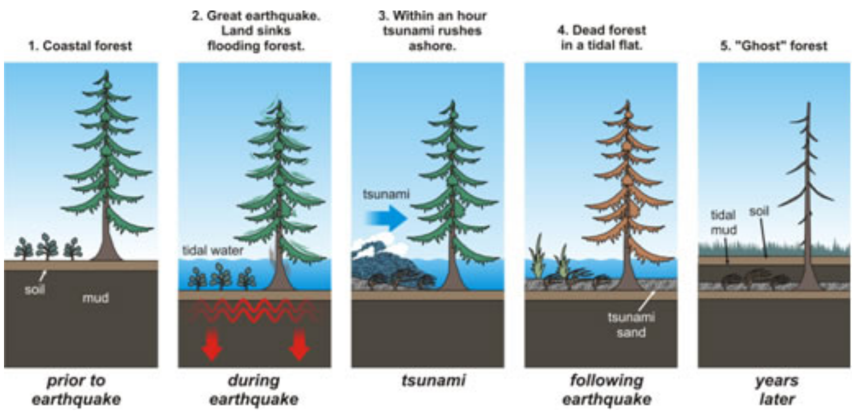


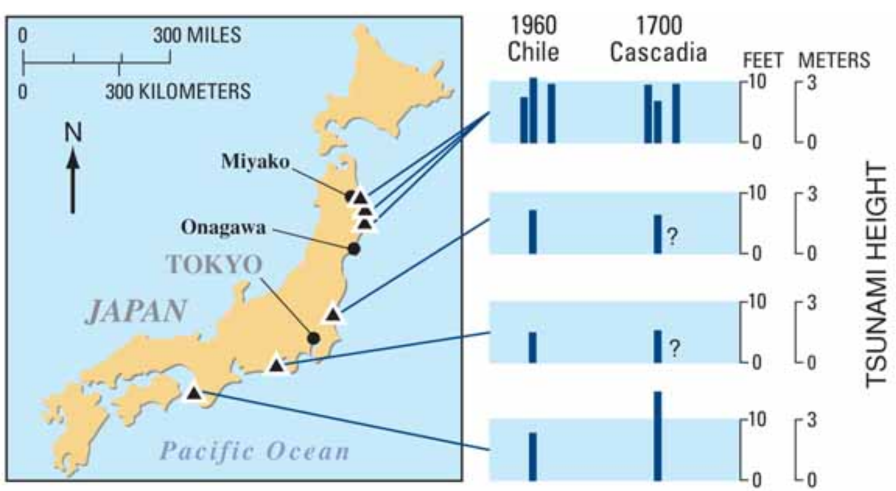
Great Earthquakes

estimated year		interval
2005 source[9]	**2003 source[10]**	**(years)**
about 9 pm, January 26, 1700 (NS)		780
780-1190 CE	880-960 CE	210
690-730 CE	550-750 CE	330
350-420 CE	250-320 CE	910
660-440 BCE	610-450 BCE	400
980-890 BCE	910-780 BCE	250
1440-1340 BCE	1150-1220 BCE	unknown

Evidence for M9 Cascadia Earthquake

http://en.wikipedia.org/wiki/1700_Cascadia_earthquake
http://www.usgs.gov



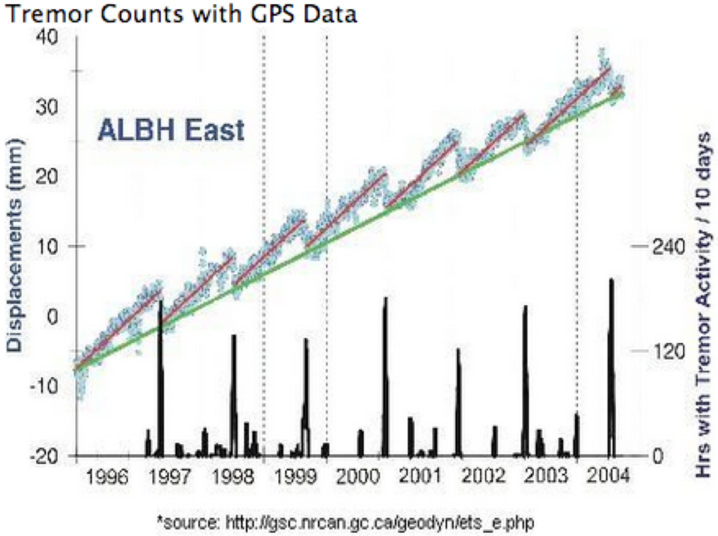


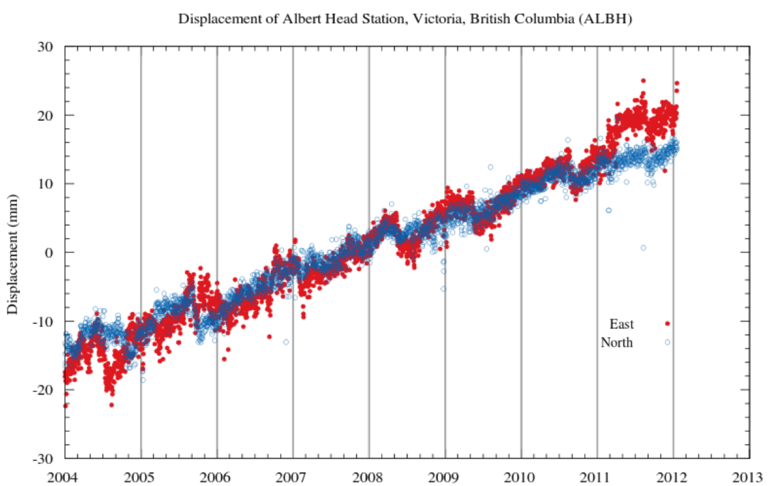
- Suddenly drowned Cascadia forests, sometime between end growing season 1699 AD, and beginning of growing season 1700 AD
- An “Orphan Tsunami” in Japan

The Clock May be Ticking…

http://en.wikipedia.org/wiki/Episodic_tremor_and_slip

- Episodic tremor and slip (ETS) events are characterized by non-earthquake seismic rumbling, or tremor, and slow slip along the plate interface.
- Nonvolcanic, episodic tremor was first identified in southwest Japan in 2002.
- The Geological Survey of Canada coined the term "episodic tremor and slip" to characterize observations of GPS measurements in the Vancouver Island area.
- Slow slip and tremor have been detected in other subduction zones around the world, including Japan and Mexico, but not in the Hikurangi Subduction Zone.
- Every five years a year-long quake of this type occurs beneath the New Zealand capital, Wellington. It was first measured in 2003, and has reappeared in 2008 and 2013.





Cascadia (Simulation)

http://serc.carleton.edu/NAGTWorkshops/hazards/visualizations/tsunami.html