Coastal Hazards

TSUNAMIS

The Great Wave Off Kanagawa by Katsushika Hokusai, 1823 – 29; a colour woodcut

What is a Tsunami ?

- A series of ocean waves. 5-6 waves of which 1st is small & 2nd/3rd the high most destructive waves.
- Of extremely long wave length & period.
- Variable height. Increases as tsunami reaches the coast and dependant on source nearness.
- Generated in a body of water by an impulsive disturbance that displaces the water.

Why do tsunamis occur ?

Impulsive disturbances that alter equilibrium sea level:

- ***Submarine landslides***
  by sediment moving along the sea-floor.

- ***Marine volcanic eruption***
  an impulsive underwater force.

- ***Submarine earthquakes***
  an abrupt deformation of the sea floor.

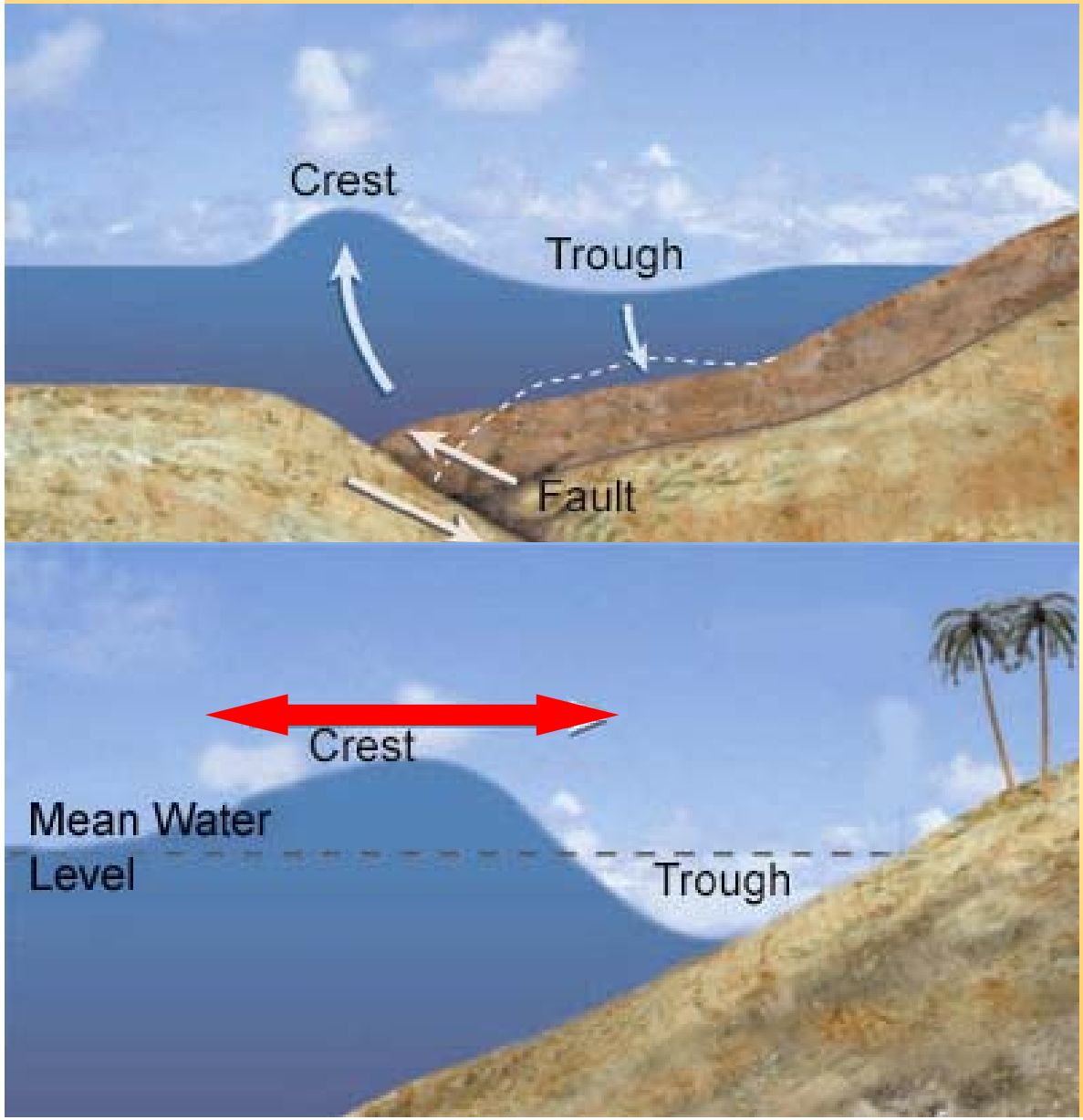
- ***Above water landslides***
  disturb water from above the water surface.

- ***Space born objects***
  disturb water from above the water surface.

EARTHQUAKE GENERATED TSUNAMIS

- When sea floor abruptly deforms & displaces over-lying water from its equilibrium position.
- Underneath / near ocean fault causing vertical movement of seafloor over a large area.
- Shallow focus earthquakes along subduction zones responsible for most destructive tsunamis.

TSUNAMIS



1. Tsunami initiating event pushes water above sea level.

2. Resultant potential energy in mass of water above sea level

3. Transferred to kinetic energy as tsunami wave propagation

Case study: Chile, 1960

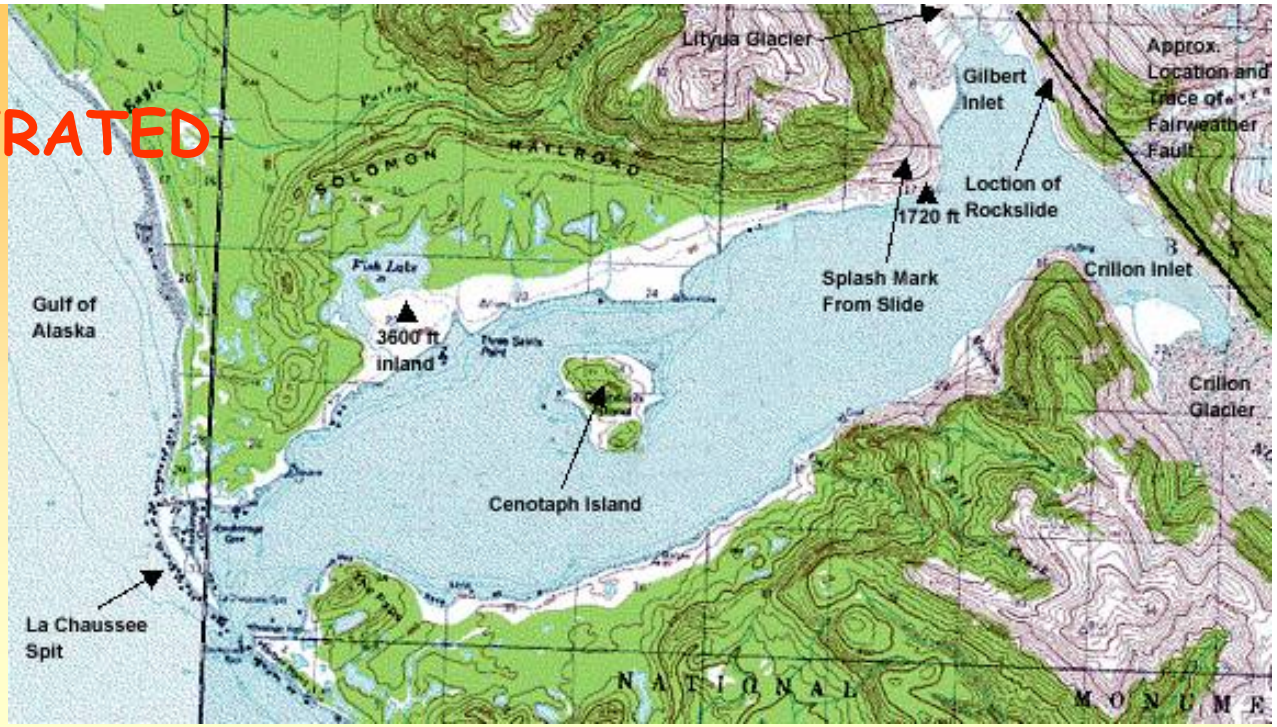
- One of the most powerful earthquakes and destructive tsunamis in recent history.
- 9.5 magnitude coastal epicentre; 33km hypocentre, generating up to 25 m. high waves.
- Waves as high as 10.7 m recorded 10,000 km from the epicenter.
- Death toll estimates: >2000 – 6,000.
- Monetary cost estimates: 400 M to 800 M US $.

Case study: Japan, 2011

- Magnitude 9.0 undersea megathrust earthquake off coast of Japan.
- Epicenter ~ 70 km offshore; hypocentre ~ 32 km depth.
- Most powerful quake in Japan; one of the 5 most powerful quakes since modern record-keeping began.
- Triggered tsunami waves of up to 38.9 m, in some cases traveling up to 10 km inland.
- 15,421 dead, 5,367 injured, 7,937 missing & > 125,000 buildings damaged or destroyed
- Nuclear accidents at 3 nuclear reactors.
- Possibly > US$300 B damage, (most expensive natural disaster on record).

LANDSLIDE GENERATED TSUNAMI

Lituya Bay, Alaska 1958



Case study:

- 81M tones of ice / rock shaken loose by an quake.
- Landslide created tsunami across the bay.
- Waves splashed up to 350 - 500 m – highest recorded.
- Scrubbed mountain slope clean of trees / shrubs.
- Two fishermen killed.

VOLCANO GENERATED TSUNAMI

Case study: INDONESIA.

- Lake Toba (74,000 BP): supervolcanic eruption responsible for six years of volcanic winter.

- Mount Tambora, 1815: most violent eruption in recorded history -harvest failures in N. Europe, N.E. USA & E. Canada

- Krakatau, 1883: volcanic eruptions with global effects & Tsunami:

- sank more than 5,000 boats.
- waves as high as a 12-story buildings
- wiped out ~300 villages & small islands
- killed > 40,000 people.

IMPACT GENERATED TSUNAMI

- Rare for a meteorite or an asteroid to reach the Earth. No impact generated tsunami documented.
- Evidence of the meteoritic & asteroid fall to Earth suggests that this might well have occurred.
- Ocean impact has potential to cause tsunamis of cataclysmic proportions.

TSUNAMI DYNAMICS

Propagation of Tsunamis

- Tsunami travel speed depends on water depth.
- Tsunami speed decreases as water depth decreases.
- In the mid-Pacific, where the water depths reach 4.5 km, tsunami speeds can be > 900 km/hr.
- Refraction and diffraction of waves are important to the tsunami propagation.

TSUNAMI DYNAMICS

Refraction / Diffraction of Tsunamis

- Wave refraction:

  As depth determines long wave velocity, different wave parts travel with different velocities, causing the waves to bend.

- Diffraction:

  the bending of waves around objects.

TSUNAMI DYNAMICS

Distantly generated tsunamis

As a tsunami approaches a coastline, the waves are modified by various offshore and coastal features:

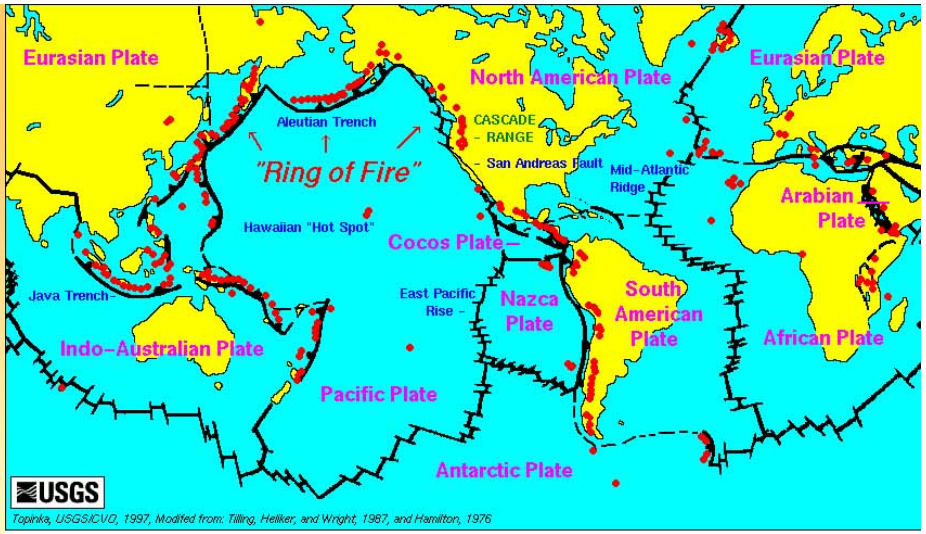
- submerged ridges and reefs
- the continental shelf
- headlands
- bay configuration
- beach steepness

TSUNAMI DYNAMICS

Locally generated tsunamis

- Locally generated tsunamis impact coastal areas a very short time after impulse.
- Tsunami warning systems are useless in this type of event.
- Need for advance preparation of Tsunami response plans.

Where do tsunamis occur?



Pacific: most active tsunami zone: *Pacific Ring of Fire.*
Samoa, 2009; Japan, 2011.

Mediterranean, Black and Red Seas:

- Second most common tsunami source region after the Pacific with 98 observed tsunamis.

- Tsunami warning systems in this region must mitigate against local tsunamis that will hit coasts within 10's of minutes.

- Island of Santorini in 1400 BC with estimated 100,000 deaths.

Indian ocean:

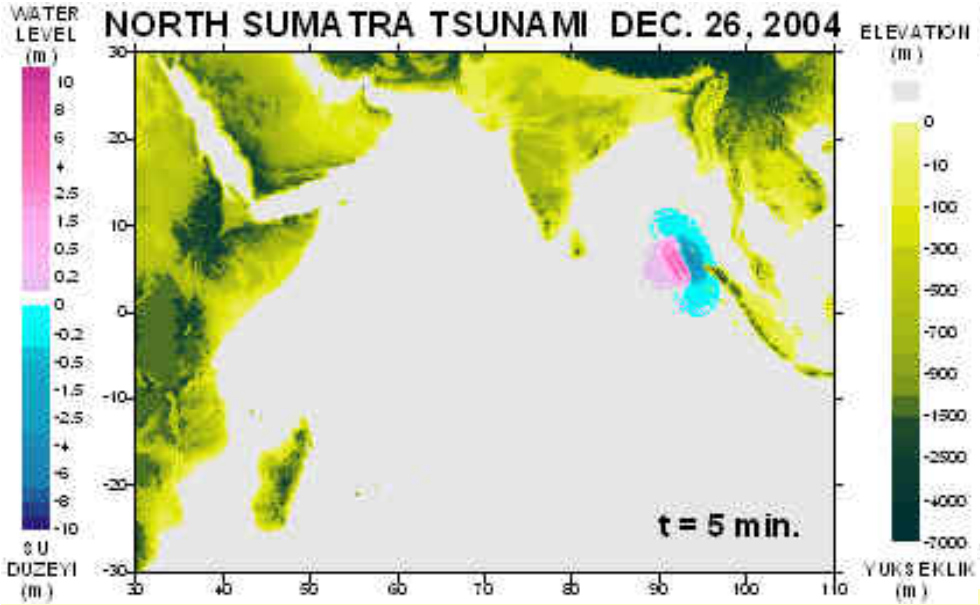
- 2004 Indian Ocean earthquake (9.1 – 9.3; epicentre off west coast Sumatra, Indonesia).
- Triggered giant (30m) tsunami waves.
- Flooding, extensive damage, loss of property and life (>230,000 dead; 108,878 missing) along coasts of 14 countries.

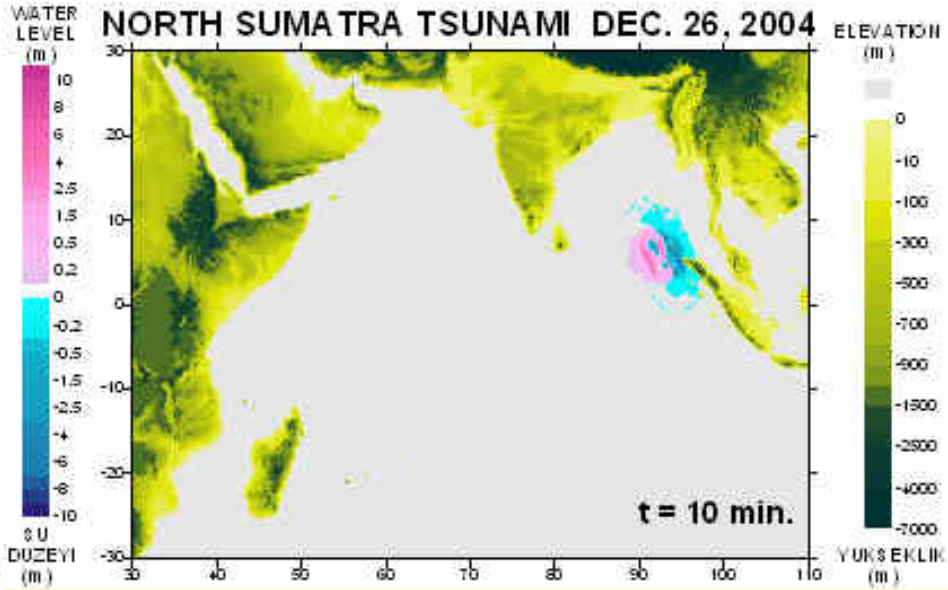
Atlantic Oceans:

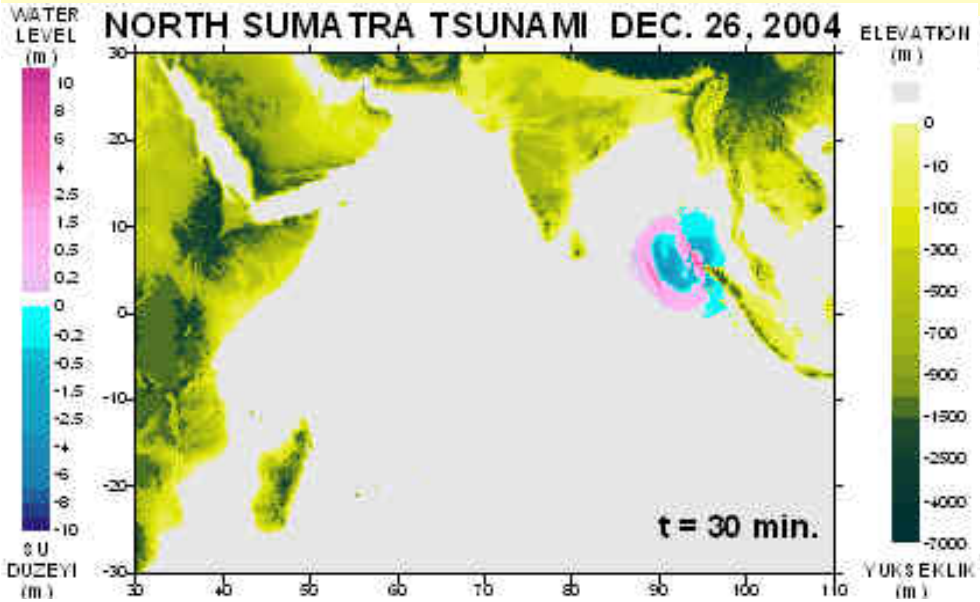
North Atlantic tsunami of 1775 after Lisbon earthquake: > 60,000 dead in Portugal, Spain, and North Africa - caused a tsunami as high as 7 m in the Caribbean.

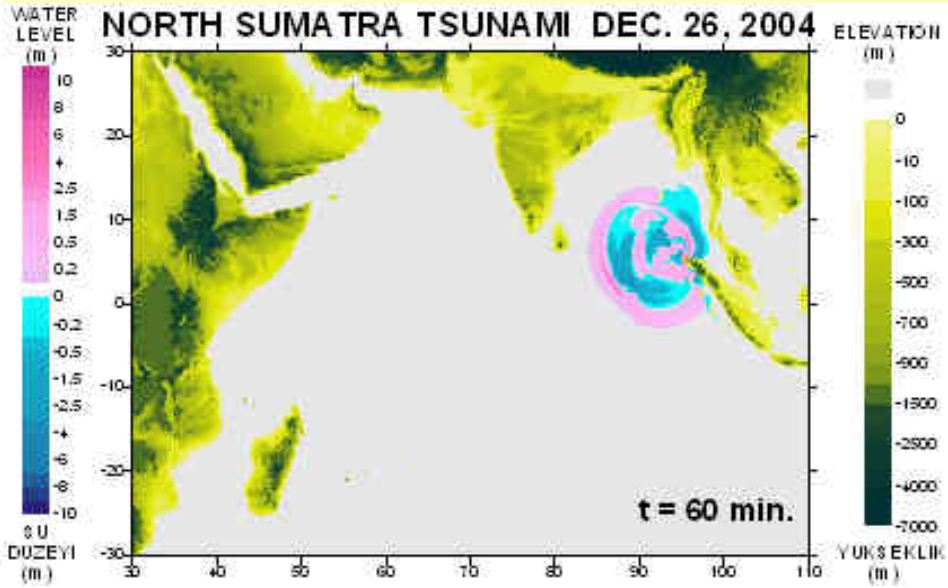
The Caribbean:

Hit by 37 verified tsunamis since 1498. The combined death toll from these Caribbean tsunamis is about 9,500.


NORTH SUMATRA TSUNAMI DEC. 26, 2004
WATER LEVEL (m)
ELEVATION (m)
SU DUZEYI (m)
YUKSEKLIK (m)
t = 5 min.


NORTH SUMATRA TSUNAMI DEC. 26, 2004
WATER LEVEL (m)
ELEVATION (m)
SU DUZEYI (m)
YUKSEKLIK (m)
t = 10 min.


NORTH SUMATRA TSUNAMI DEC. 26, 2004
WATER LEVEL (m)
ELEVATION (m)
SU DUZEYI (m)
YUKSEKLIK (m)
t = 30 min.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WATER LEVEL (m)
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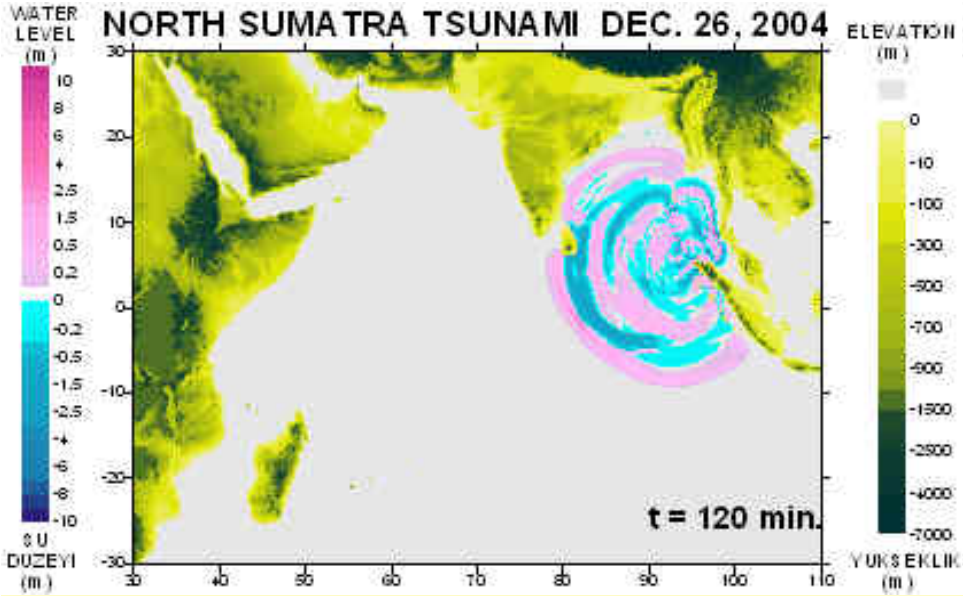
SU DUZEYI (m)
YUKSEKLIK (m)
t = 60 min.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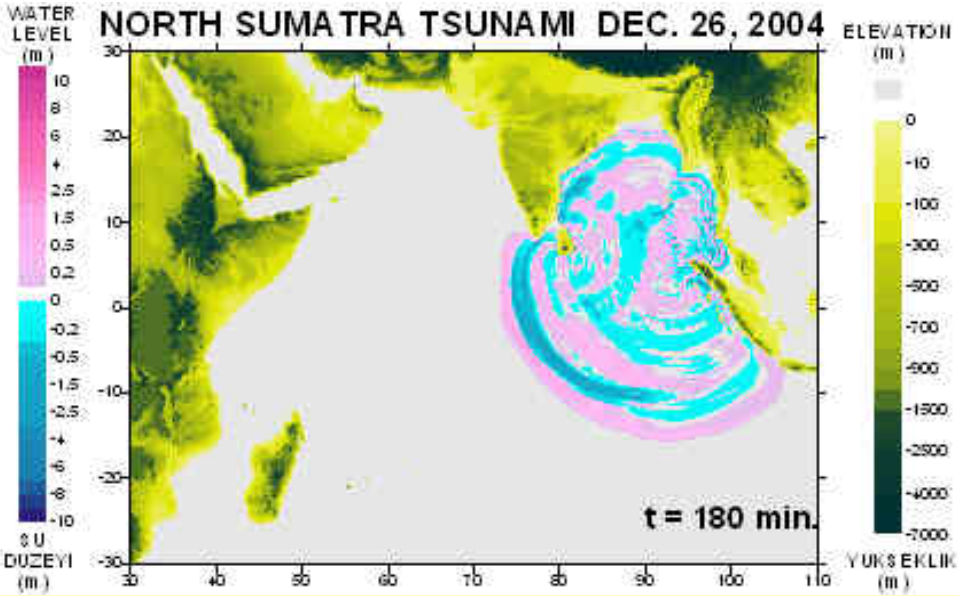
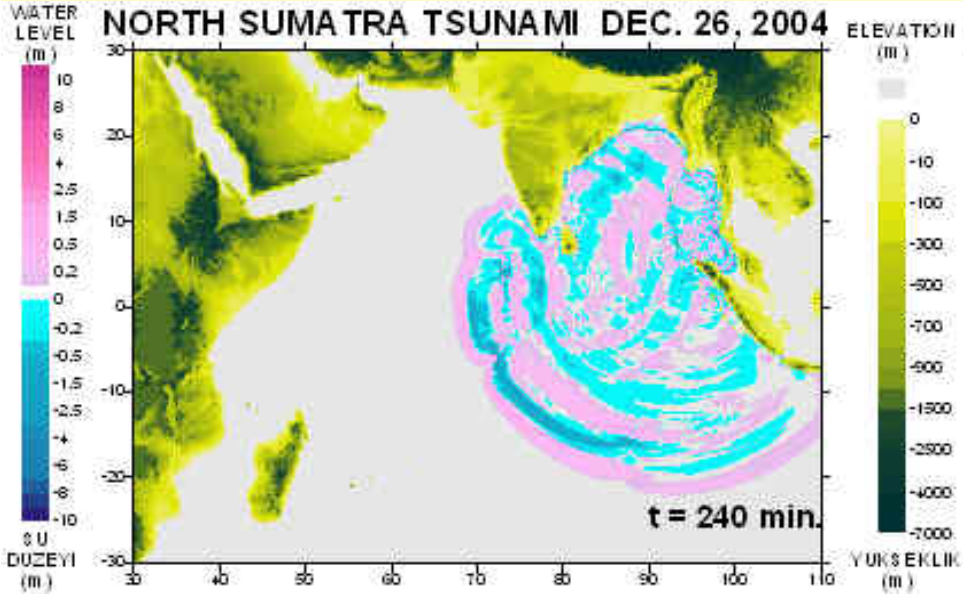
WATER LEVEL (m)
ELEVATION (m)
SU DUZEYI (m)
YUKSEKLIK (m)
t = 120 min.


NORTH SUMATRA TSUNAMI DEC. 26, 2004
WATER LEVEL (m)
ELEVATION (m)
SU DUZEYI (m)
YUKSEKLIK (m)
t = 180 min.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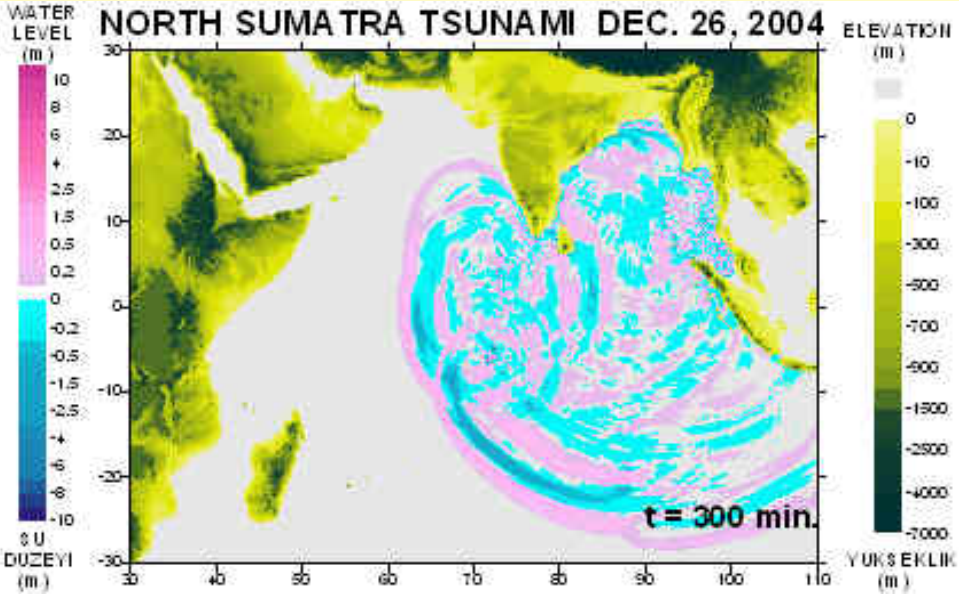
WATER LEVEL (m)
ELEVATION (m)
SU DUZEYI (m)
YUKSEKLIK (m)
t = 240 min.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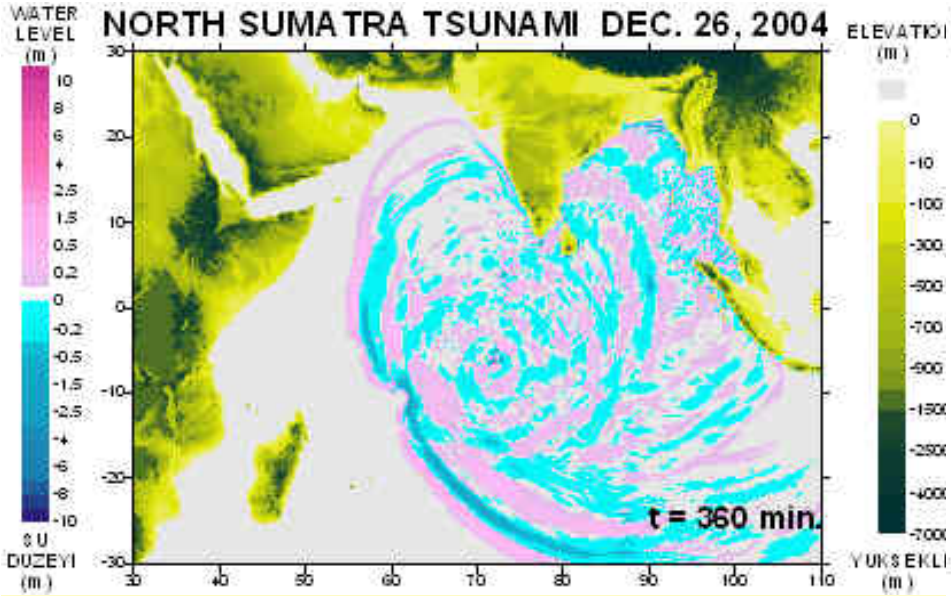
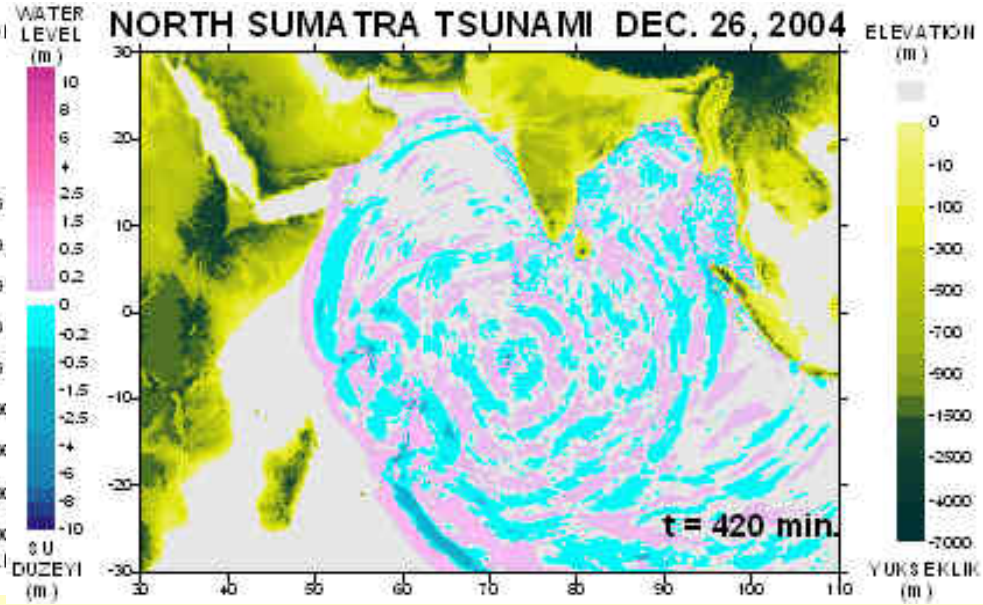
WATER LEVEL (m)
ELEVATION (m)
SU DUZEYI (m)
YUKSEKLIK (m)
t = 300 min.


NORTH SUMATRA TSUNAMI DEC. 26, 2004
WATER LEVEL (m)
ELEVATION (m)
SU DUZEYI (m)
YUKSEKLIK (m)
t = 360 min.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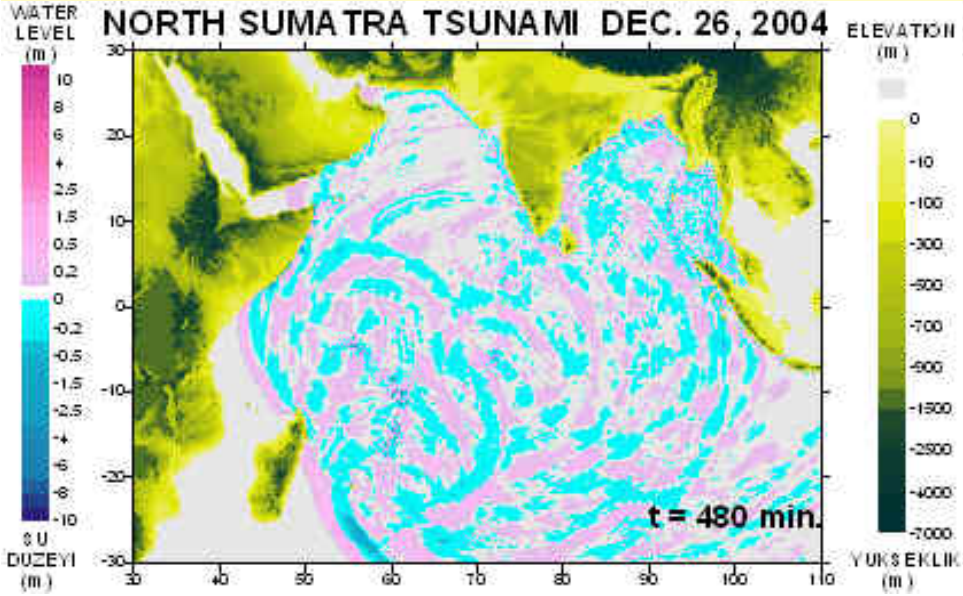
WATER LEVEL (m)
ELEVATION (m)
SU DUZEYI (m)
YUKSEKLIK (m)
t = 420 min.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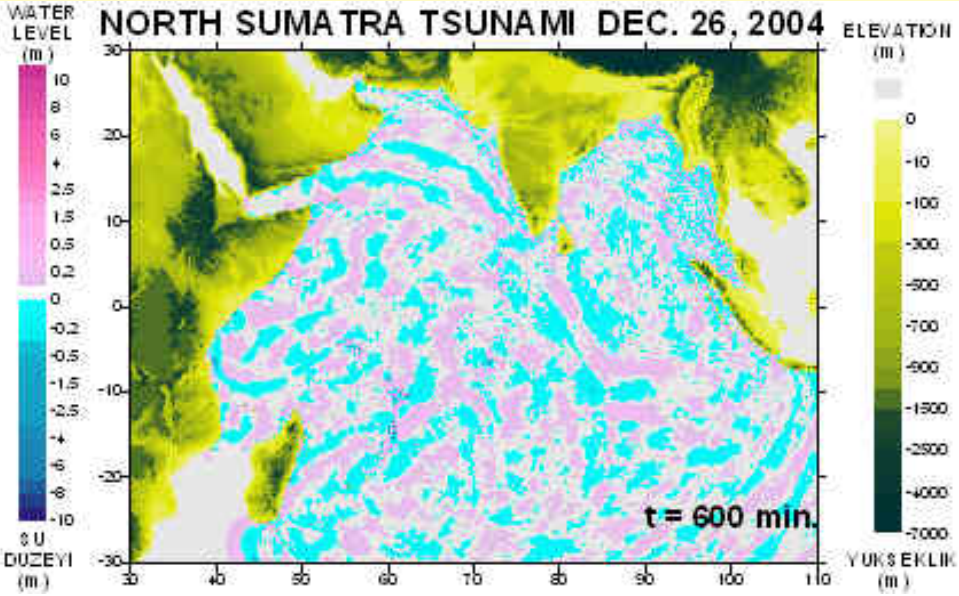
WATER LEVEL (m)
ELEVATION (m)
SU DUZEYI (m)
YUKSEKLIK (m)
t = 480 min.


NORTH SUMATRA TSUNAMI DEC. 26, 2004
WATER LEVEL (m)
ELEVATION (m)
SU DUZEYI (m)
YUKSEKLIK (m)
t = 600 min.

Tsunami consequences – flooding with a huge impulsive force

Human loss

Socio-economic

Environmental

Cultural heritage

Destruction	Figure
People killed	231,452
Ration of women & children killed to men	3 : 1
Number of people displaced	2,089,883
Number of people who lost their livelihood	1,500,000
Number of houses reduced to rubble	392,544
Number of boats destroyed	103,829
Total damage costs	$10.73 billion
Rebuilding costs	$10.375 billion

Destruction figures for 2004 Indian Ocean Tsunami

Socio-economic consequences

Three factors of destruction from tsunamis:

Inundation; Wave impact on structures; Erosion

- Agricultural areas are flooded and destroyed beyond recovery for many years to come.
- Strong, tsunami-induced currents lead to erosion of foundations, collapse of bridges, seawalls.
- Flotation and drag forces move houses and overturn railroad cars.

Environmental consequences

- Ground water contamination.
- Damage to coral reefs, sea grass beds and mangrove ecosystems.
- Salinisation of soils and damage to vegetation and crops.
- Tsunami-generated waste and debris.
- Impacts on sewage collection and treatment systems.
- Damage to protected areas.
- Coastline erosion and inundation.
- Changes in river hydrology.
- Loss of livelihoods based on natural resources or ecosystem services.

Mitigation: Protect the natural environment

Tropical coastal ecosystems have natural mechanisms to mitigate storm waves of typhoons and tsunamis:

- Coral reefs: natural breakwaters
- Mangrove forests: natural '*shock absorbers*' against erosion.
- Marshes, tidal inlets, mangrove channels limit extent of inundation by floodwaters / enable flood waters to drain quickly.

Mitigation of Tsunami consequences

- Protect the natural environment
- Education
- Hazard Assessment: understanding vulnerability
- Effective planning
- Tsunami Mitigation Plan
- Tsunami Early Warning Systems
- Hazard / vulnerability maps

Mitigation: Education is critical

- Indian Ocean tsunami demonstrated value of information.

- Despite no warning, thousands survived in cases where tsunami knowledge existed and was used.

- Warnings of little use if people do not know how to respond.

- If warning times are short / no warning at all – people must know how to react immediately !

- *Value of indigenous knowledge:* Simuelue islanders

Education

After an earthquake, a tsunami may follow.
Move quickly to higher ground.

Mitigation 1: Mitigation Plan

- Quickly confirm potentially destructive tsunamis & reduce false alarms.
- Improve awareness & preparedness of communities for tsunamis
- Address local tsunami mitigation & the needs of coastal residents.
- Improve coordination & exchange of information to better utilize existing resources.
- Sustain support at state & local level for long-term tsunami hazard.

Mitigation 2: Early warning systems

- Detect potentially dangerous earthquakes & provide early warning to countries that might be hit.
- Employ advanced technological instrumentation for data collection / warning communications.
- Japan, Soviet Union, Canada, USA developed sophisticated warning systems & accepted responsibility to share warning information with other countries of the Pacific.

Mitigation 3: information maps

Hazard maps (hazard potential).

Vulnerability maps (Max. water level and inundation depth map).

- Key tool to ascertain vulnerability of coastal areas to tsunamis.

- Computer modeling of potential tsunami inundation:
  - areas likely to be flooded during tsunami;
  - routes to reach pre-determined safe areas.

Tsunami vulnerability maps

Maps outlining tsunami inundation zones can assist planners and decision makers in designating:

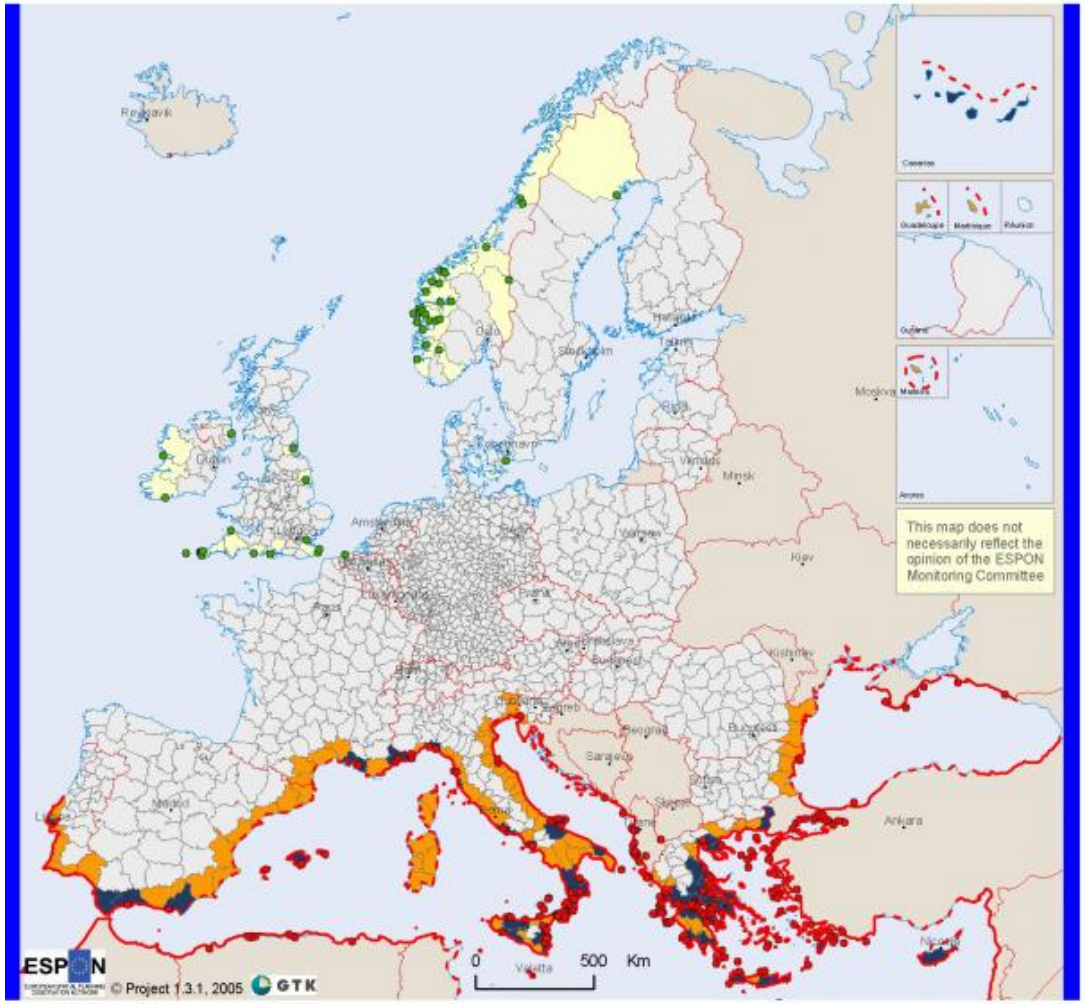
- evacuation zones;
- routes to safety.

Observations of run-up and inundation from past events are essential to validate modelling-based inundation maps.

Tsunami Hazards in Europe

(http://www.gsf.fi/projects/espon/Tsunamis.htm)

- Several geological and historical records of tsunamis.
- Tectonically induced tsunamis in Europe mainly in Med & Black Sea.
- Endangered zones: close to main volcanoes / along seismically active zones.
- Tsunamis by (submarine) landslides mainly in Norway but also in other areas in Europe.
- No devastating tsunamis in Europe in last 100 yrs, but potential hazard still high.



Historically recorded tsunami runups

- Earthquake/volcano/submarine landslide accociated
- Terrestrial landslide associated

Tsunami hazard potential

- Probable tsunami hazard areas
- Tsunami hazard areas
- Espon space
- Regions experienced landslide associated tsunami
- Tsunami potential coastal areas close tectonically active zones
- Regions experienced earthquake/volcano/landslide associated tsunami
- Non ESPON space

Origin of the data: © EuroGeographics Association for the administrative boundaries
Northern coast of Africa and Spain: Hébert, 2003
Greece: Institute of Geodynamics, National Observatory of Athens
Spain: Instituto Geografico Nacional
Italy: Istituto Nazionale di Geofisica e Vulcanologia, Roma
World Tsunami data: National Geophysical Data Center (NGDC)
World Map of Natural Hazards: Munich Reinsurance Company

Source: ESPON Data Base

Tsunami Hazard Map of Europe

12.00 ม. บ้านน้ำเค็ม
10.00 ม.
ระดับความสูง
ของสึนามิ
เมื่อ 26 ธันวาคม 2547
26 December 2004
Tsunami Heights
6.00 ม. แหลมปะการัง
4.00 ม. อุทยานหาดรินกา

2004 (ocean earthquake tsunami): 216,000 killed in a dozen nations along Indian Ocean rim - more than a half of them on Sumatra island's Aceh province.

God's invisible hand'

2006 (Earthquake tsunami): 341 people killed, > 200 missing.

Tsunami hazard / vulnerability maps

In high-risk areas where the maximum potential source of a tsunami is known – e.g. offshore active earthquake subduction zone:

- tsunami generation
- propagation
- runup

can be mathematically modelled and wave heights estimated.

Historical records of previous tsunamis charting earthquake magnitudes, and wave heights & runup and inundation patterns, can be used to support tsunami hazard predictions.