UNESCO/IOC – NOAA ITIC Training Program - International (ITP-Intl)
TSUNAMI WARNING AND EMERGENCY RESPONSE
9-12 January 2023, Rarotonga, Cook Islands

Tsunami Science

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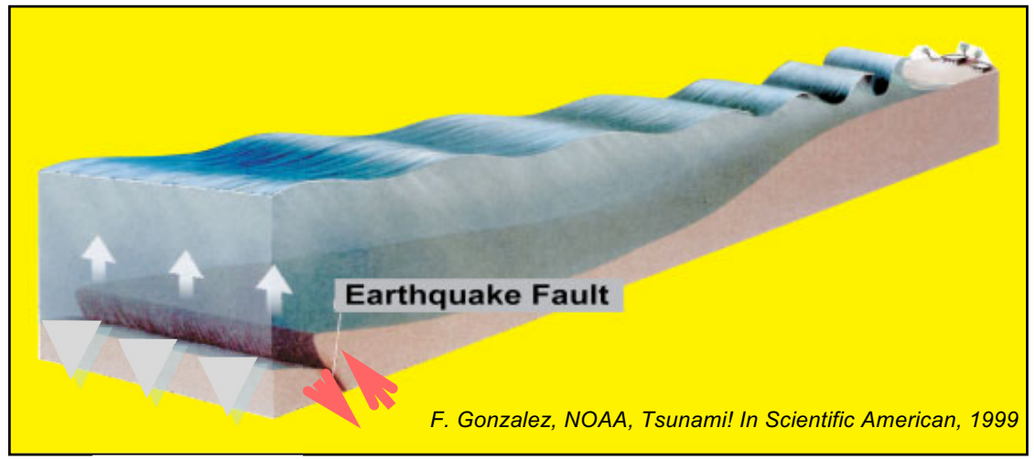
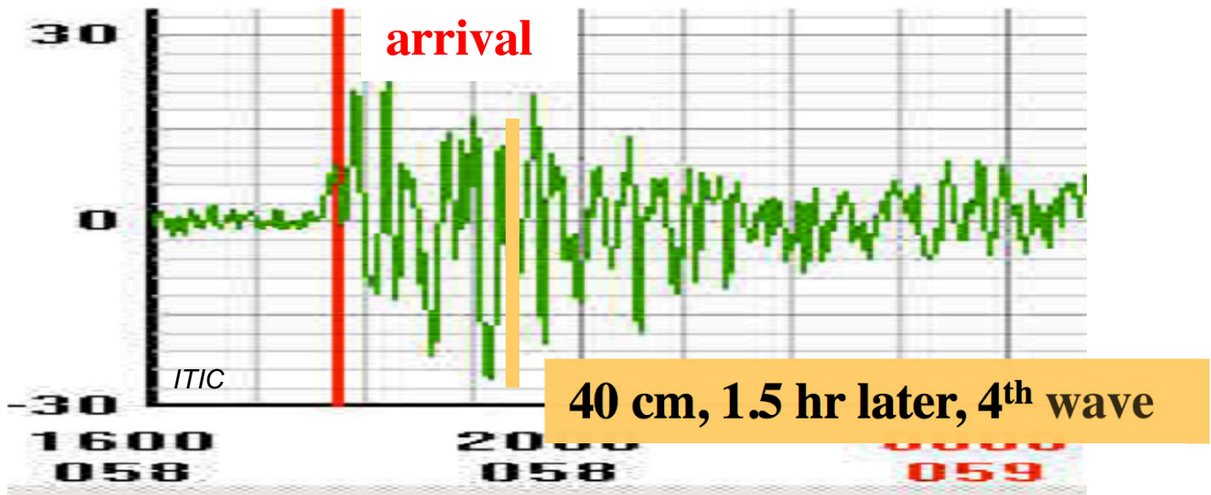
What is a tsunami?
How does a tsunami wave act?

What is a tsunami?

- Japanese for “harbor wave”
  No connection with tides. Not tidal wave.
- Series of long-period waves for hours.
  1st wave may not be largest.

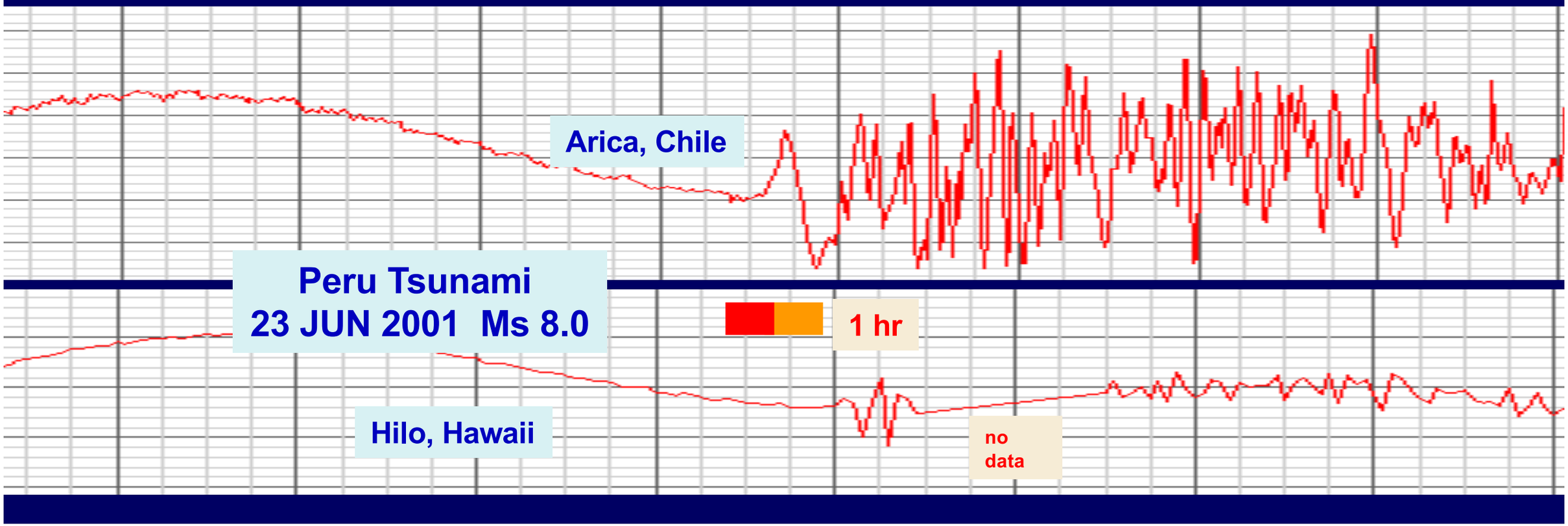




TSUNAMIS - What and How

- *SERIES OF LONG-PERIOD OCEAN WAVES*

  5 TO 60 MINUTES BETWEEN WAVE CRESTS



TSUNAMIS - What and How

- ***SPEED DEPENDS ON WATER DEPTH***

  Fast in deep ocean (>1000 km/h)
  Slows near shore (30-50 km/h)

- ***HEIGHT DEPENDS ON WATER DEPTH***

  Small in deep ocean
  (few cm to 1 m)
  Grows near shore
  (can be >30 m)

April 1, 1946 Tsunami , Hilo, Hawaii
Maximum flooding 6 meters

TSUNAMIS - How fast

Speed $= \sqrt{gh}$

g = acceleration of gravity
= 9.81 meters / second^2

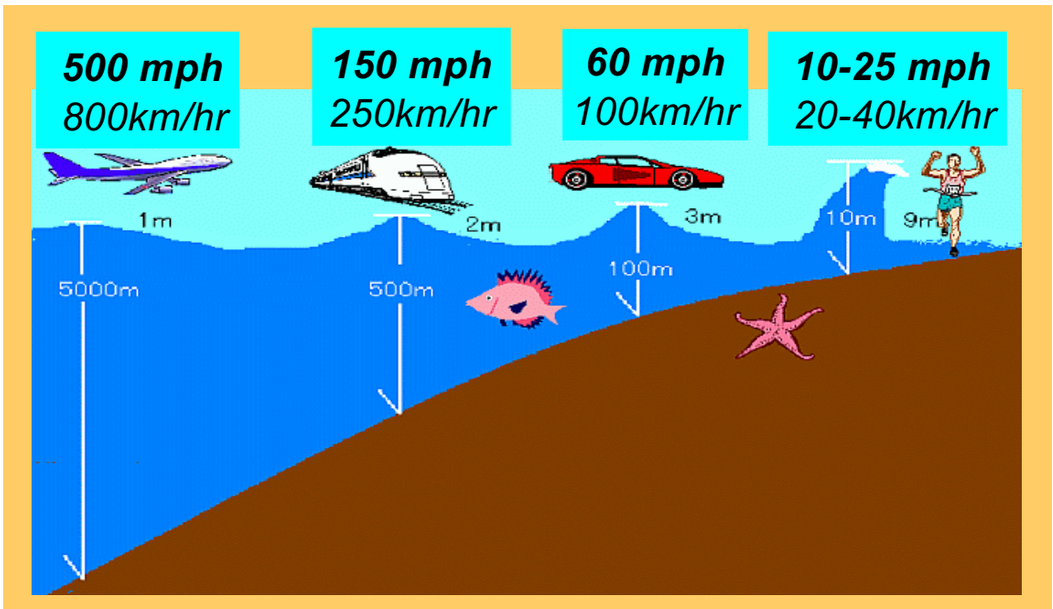
h = water depth

If water depth is
5500 meters, then

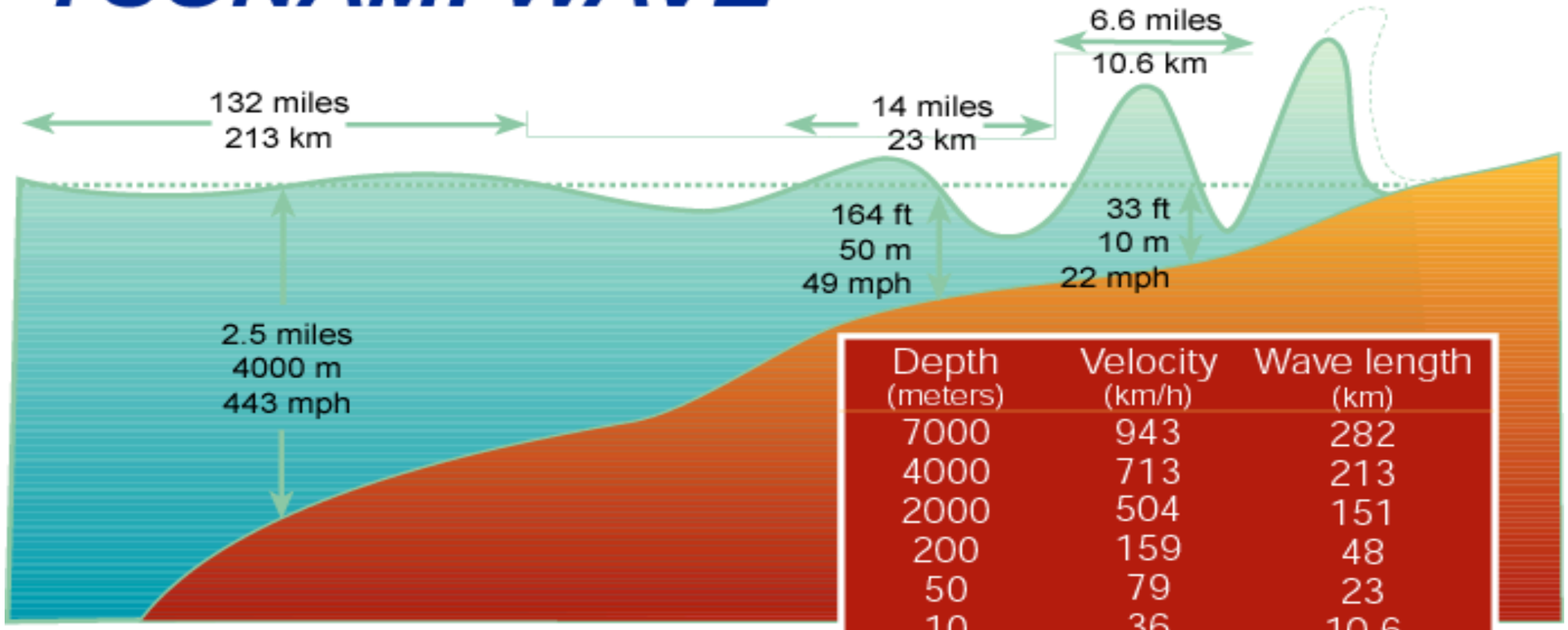
Speed $= \sqrt{9.81 \times 5500\ m^2/s^2}$
$= 232$ m/s
$= 519$ miles/hour!
about 835 km/hour

What is a tsunami?

- Wavelength long (10s-100s km), so cannot see next wave.
- Grows in height at coast. Few inches in deep ocean. Can grow to 10s of feet at coast.
- Travels fast in deep ocean (jet airplane), but slows down at coast (but cannot outrun).



TSUNAMI WAVE



Depth (meters)	Velocity (km/h)	Wave length (km)
7000	943	282
4000	713	213
2000	504	151
200	159	48
50	79	23
10	36	10.6

As it enters shallow water, tsunami wave speed slows and its height increases, creating destructive, life-threatening waves.

Depth (miles)	Velocity (mph)	Wavelength (miles)
4.4	586	175
2.5	443	132
1.2	313	94
635 ft	99	30
164 ft	49	14
33 ft	22	6.6

Tsunami vs wind waves vs tides

- Wave frequency every 5-60 minutes.

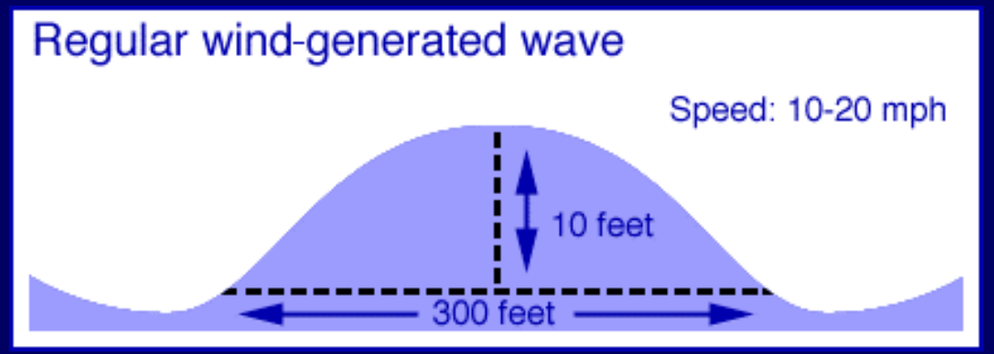
TYPE	*CAUSE*	*TIME / CYCLE*
SEA & SWELL	WIND	2 - 25 SEC
TSUNAMIS	RAPID OCEAN DISPLACEMENT	5 - 60 MIN
TIDES	ASTRONOMICAL CYCLES	> 12 HRS

Ocean waves: Speed, wavelength height

Sea & Swell:

Short period: 2 - 25 sec

Wind-generated



Tsunamis:

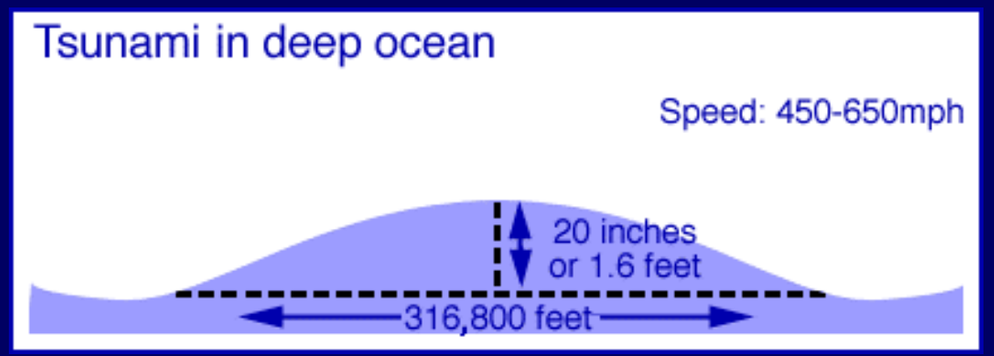
Long period: 5 - 60 min

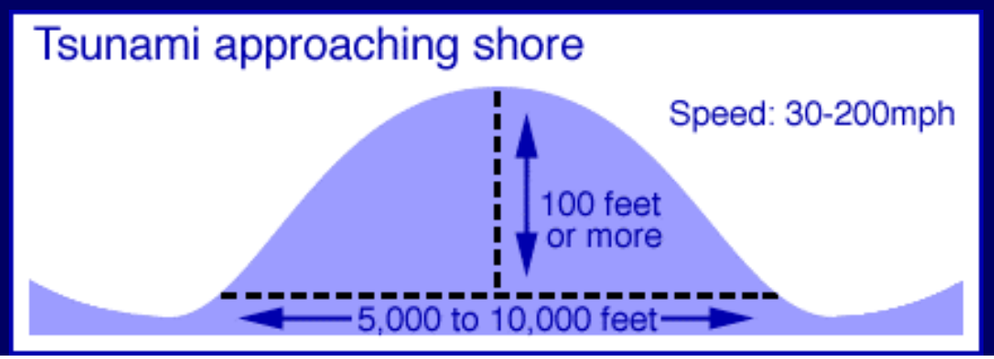
Earthquake-generated

In the deep ocean, less than 1 m, so cannot be

⇒ felt on ship

⇒ seen by air.

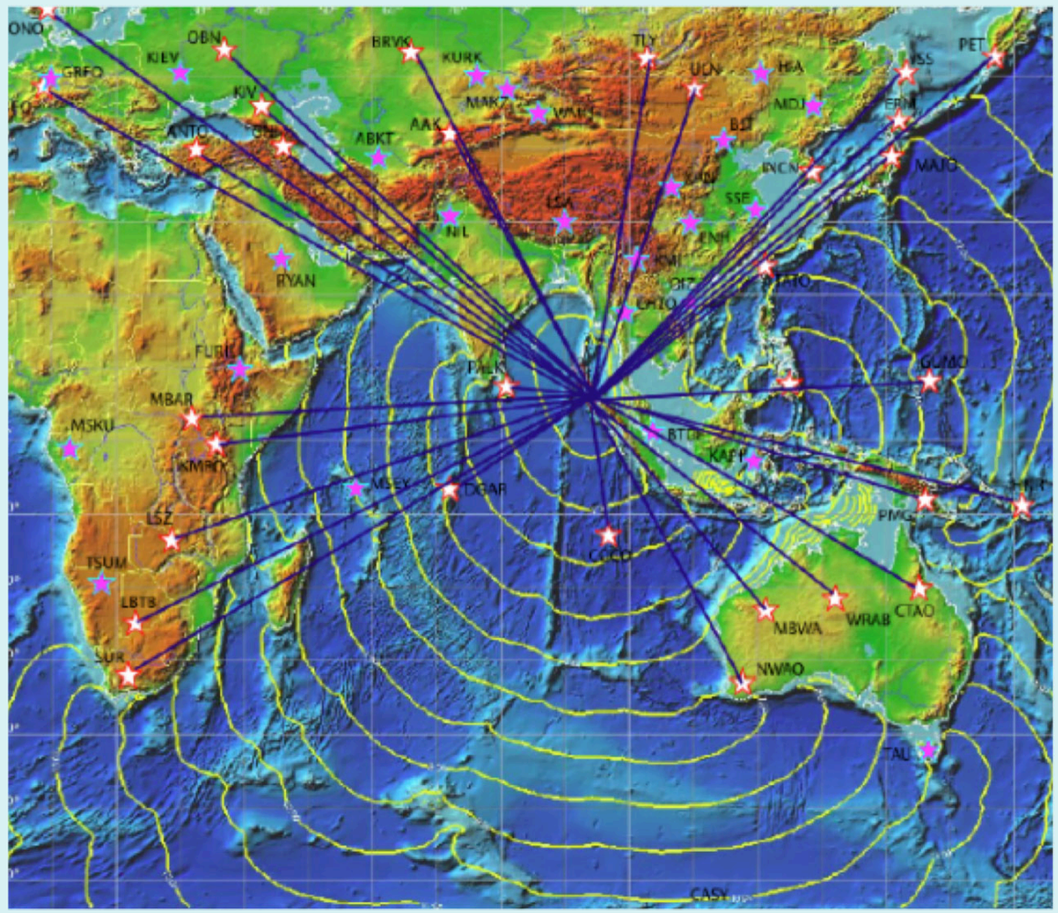


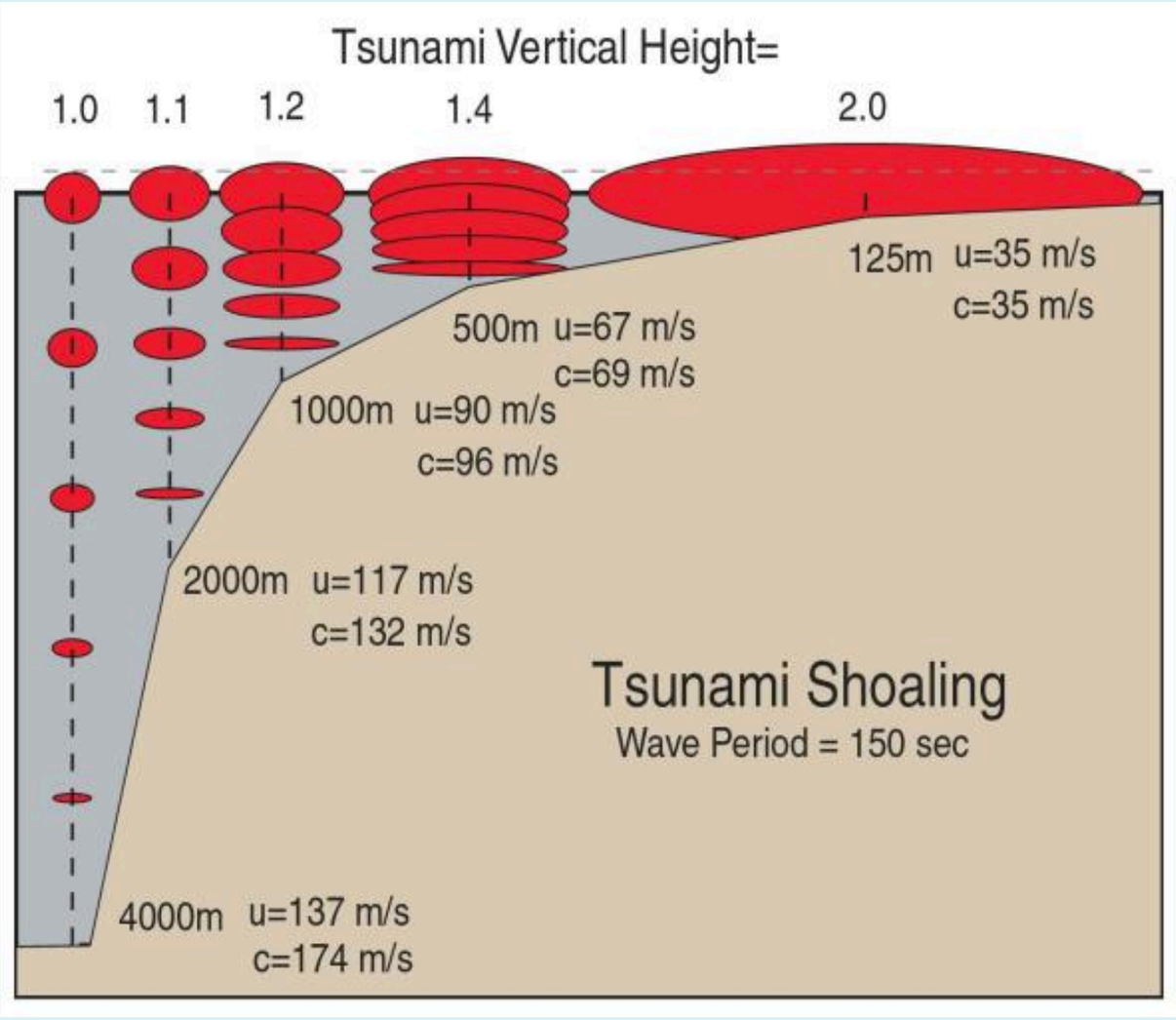


Seismic and Tsunami Waves

Seismic Waves
~20,000 mph

Tsunami Waves ~
500 mph

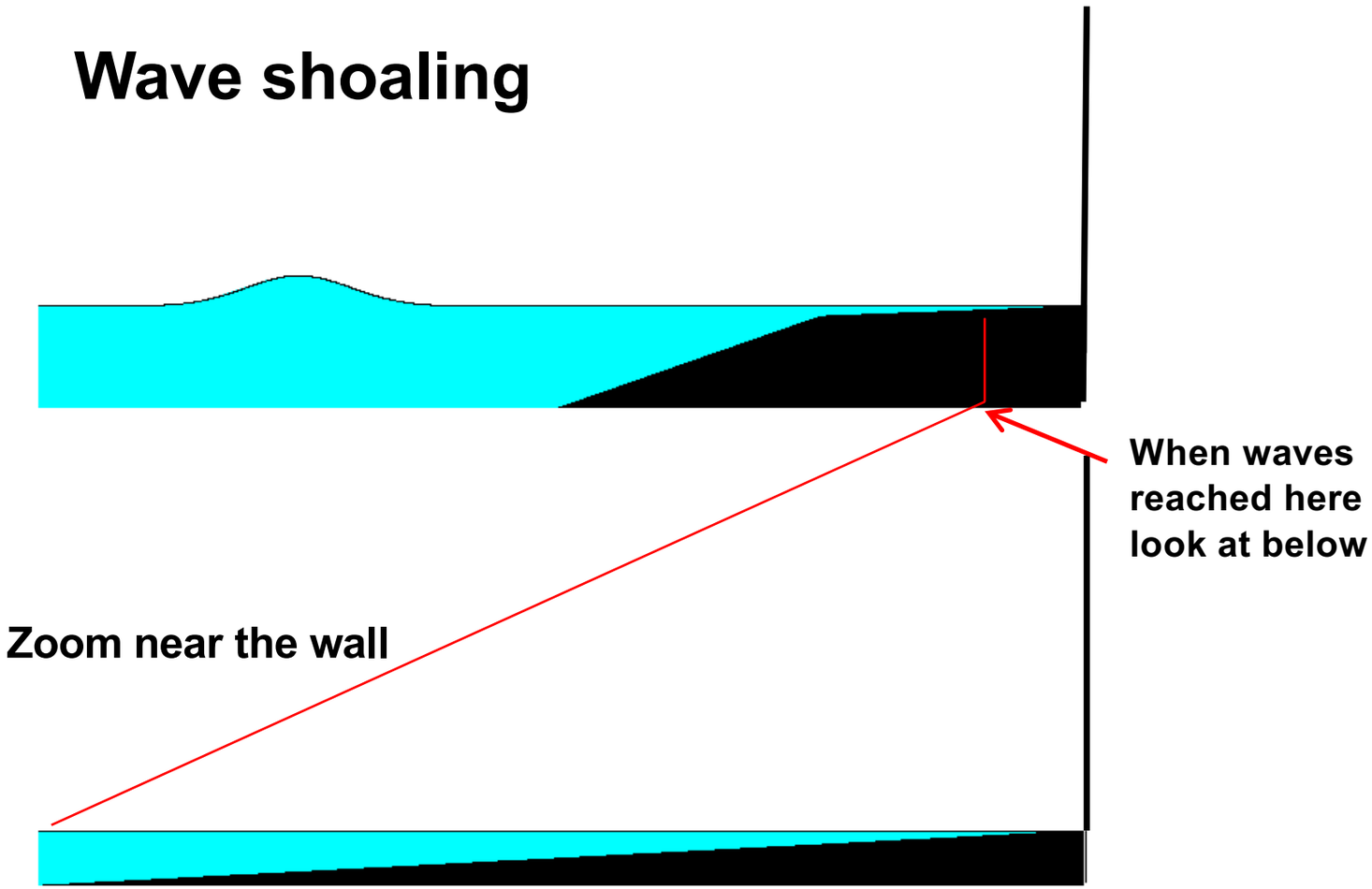




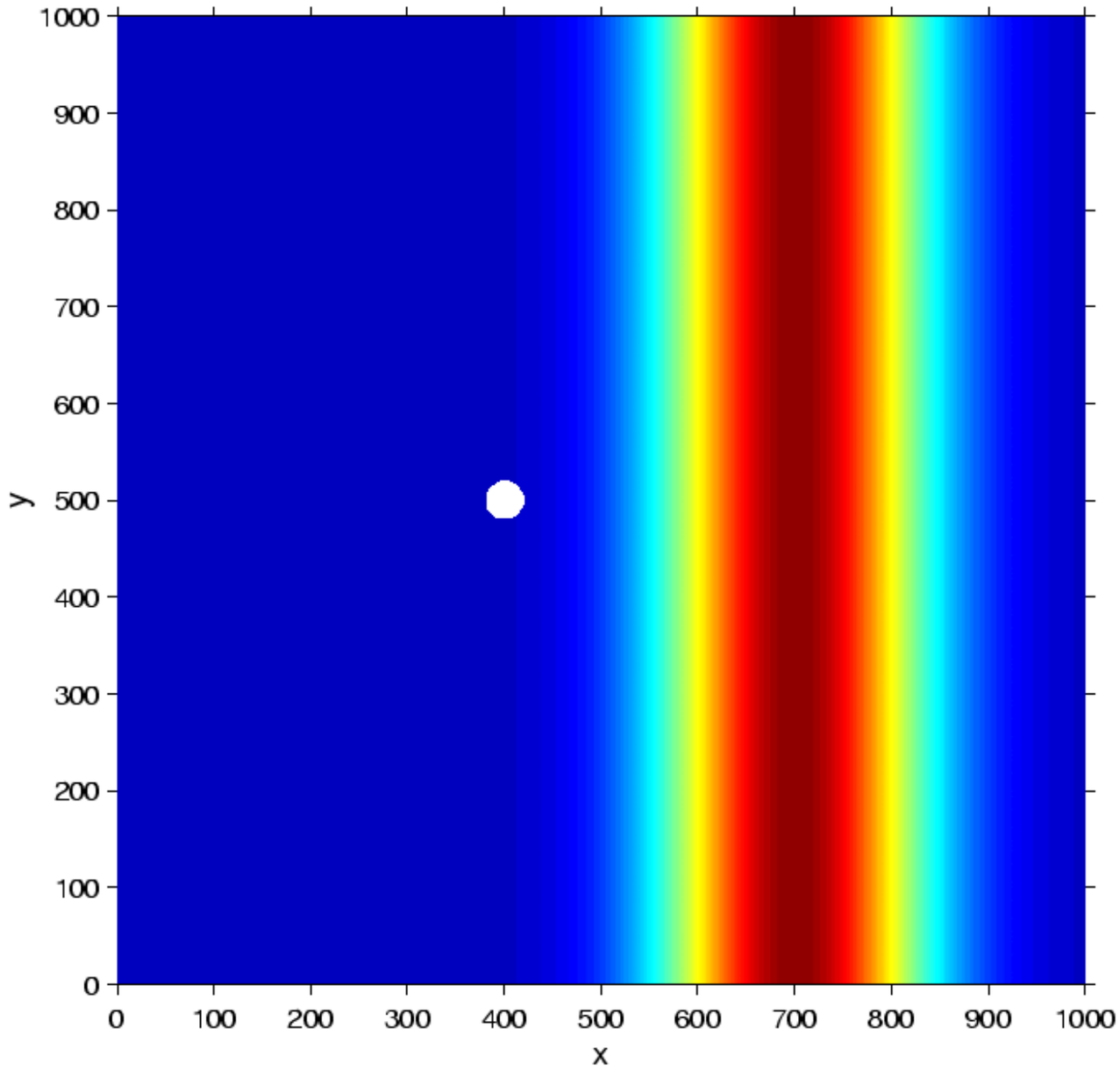
- Tsunami steepen in shallow water, but generally do not become steep enough to break.
- **Tsunami slow and grow as they near the coast.**
- **In deep water, V~500 mph**
- **They come ashore ~ 30-50 mph.**

➔ **Still – Cannot outrun tsunami to high ground.**

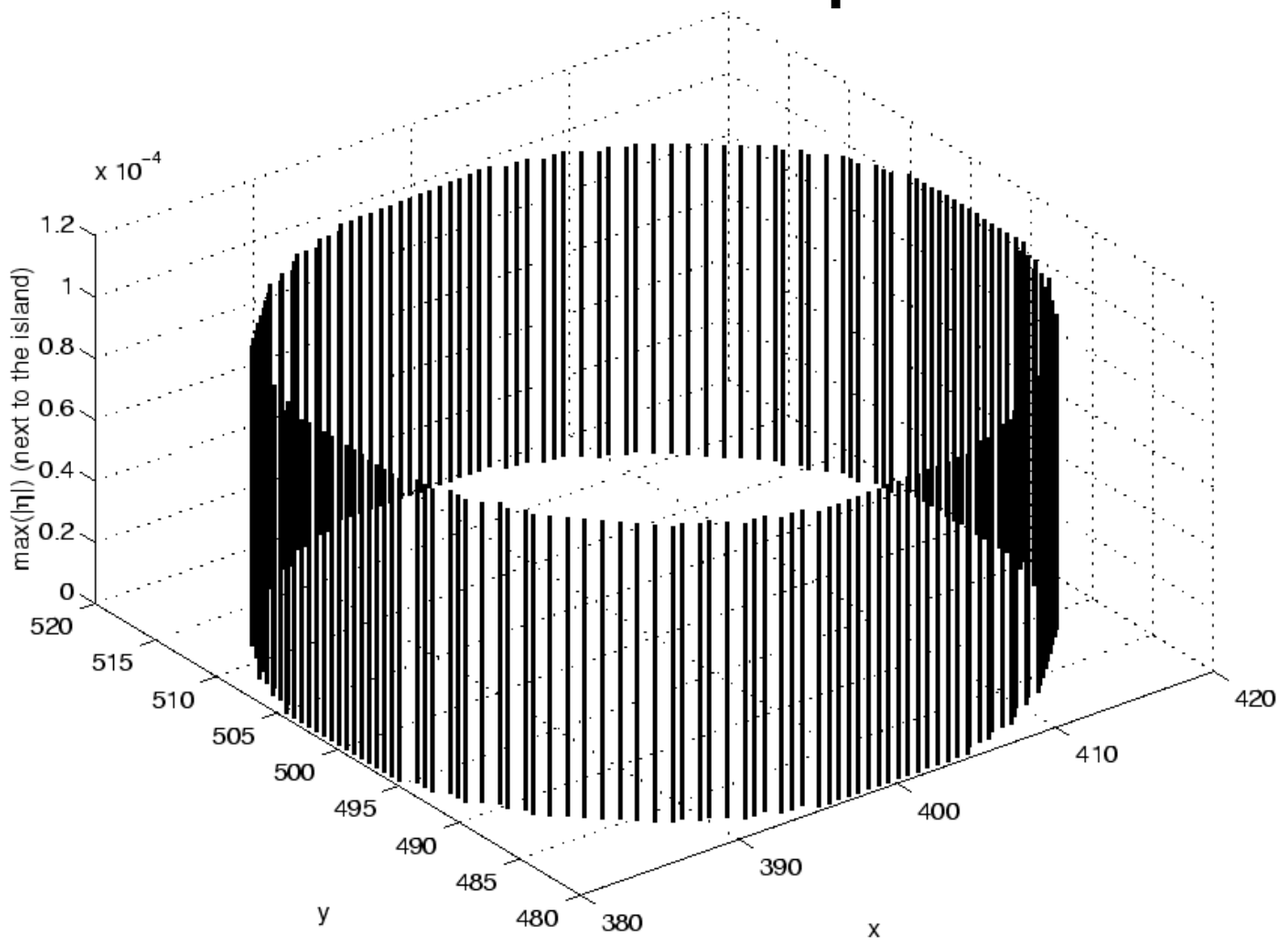
Wave shoaling



Waves wraps around a skinny cylinder without much runup

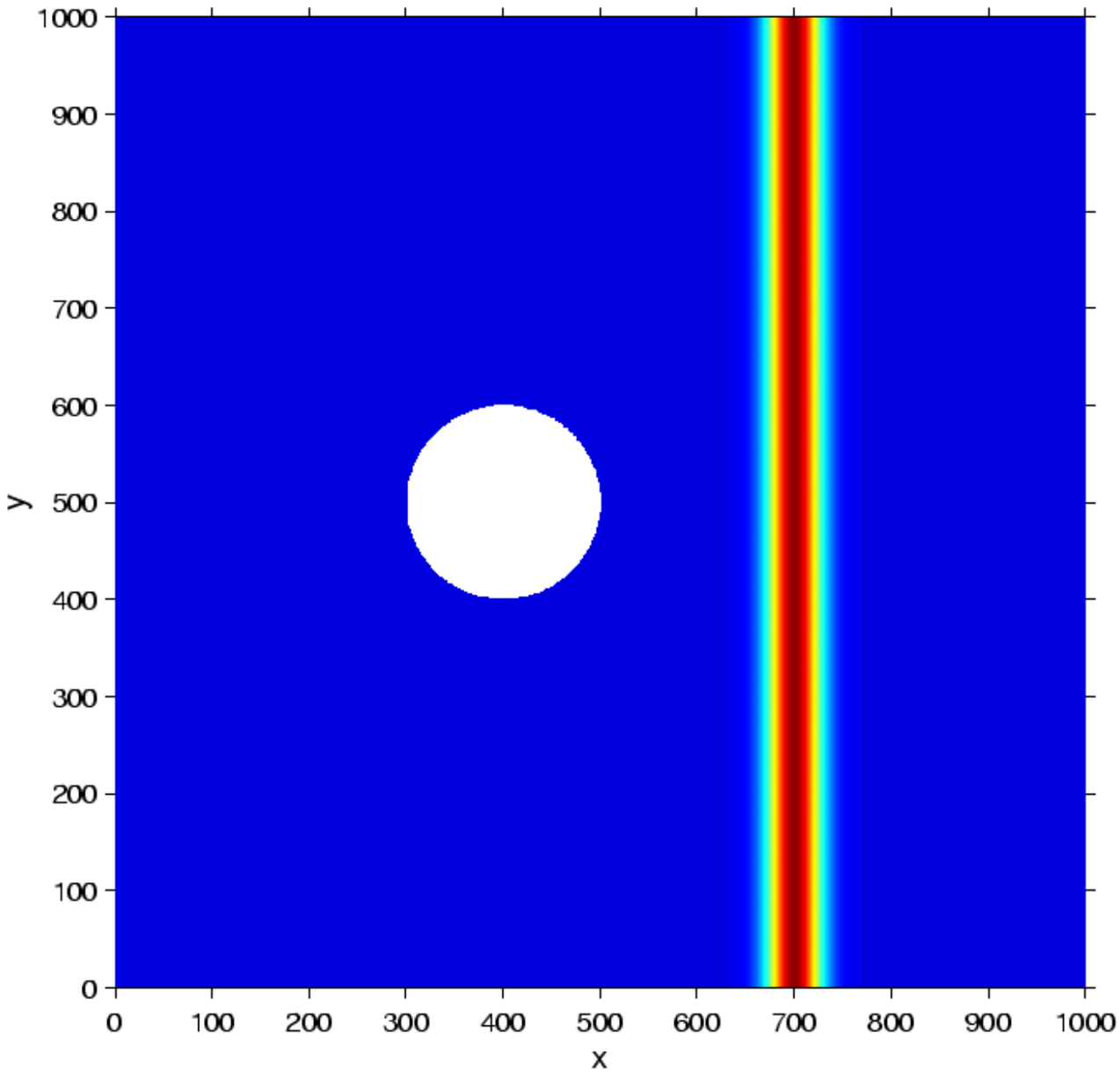


For a skinny island/cylinder (compared to wavelengths), there will be minimal wave runup.



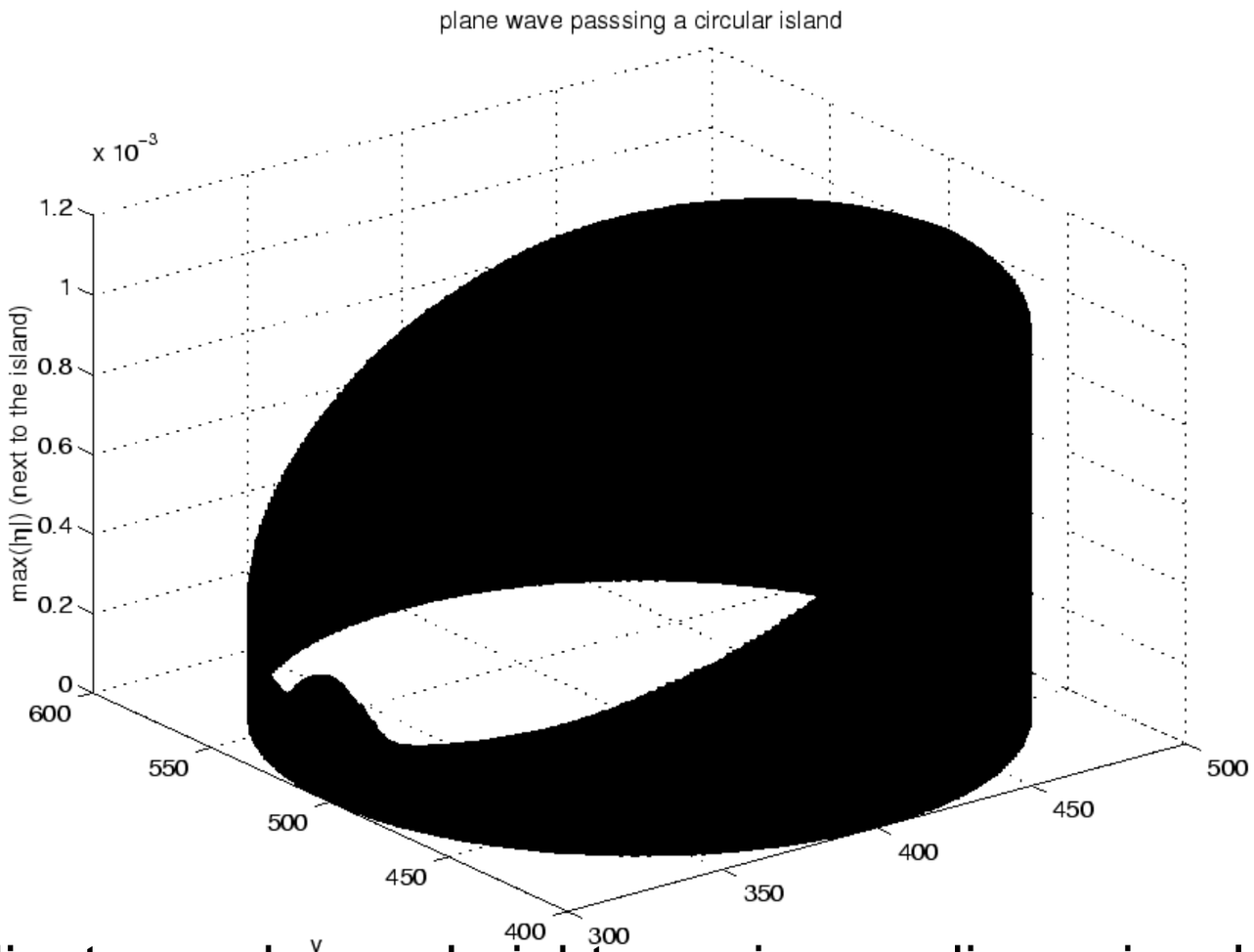
Coordinates and wave heights are in non-dimensional units

Waves wraps around a conic island



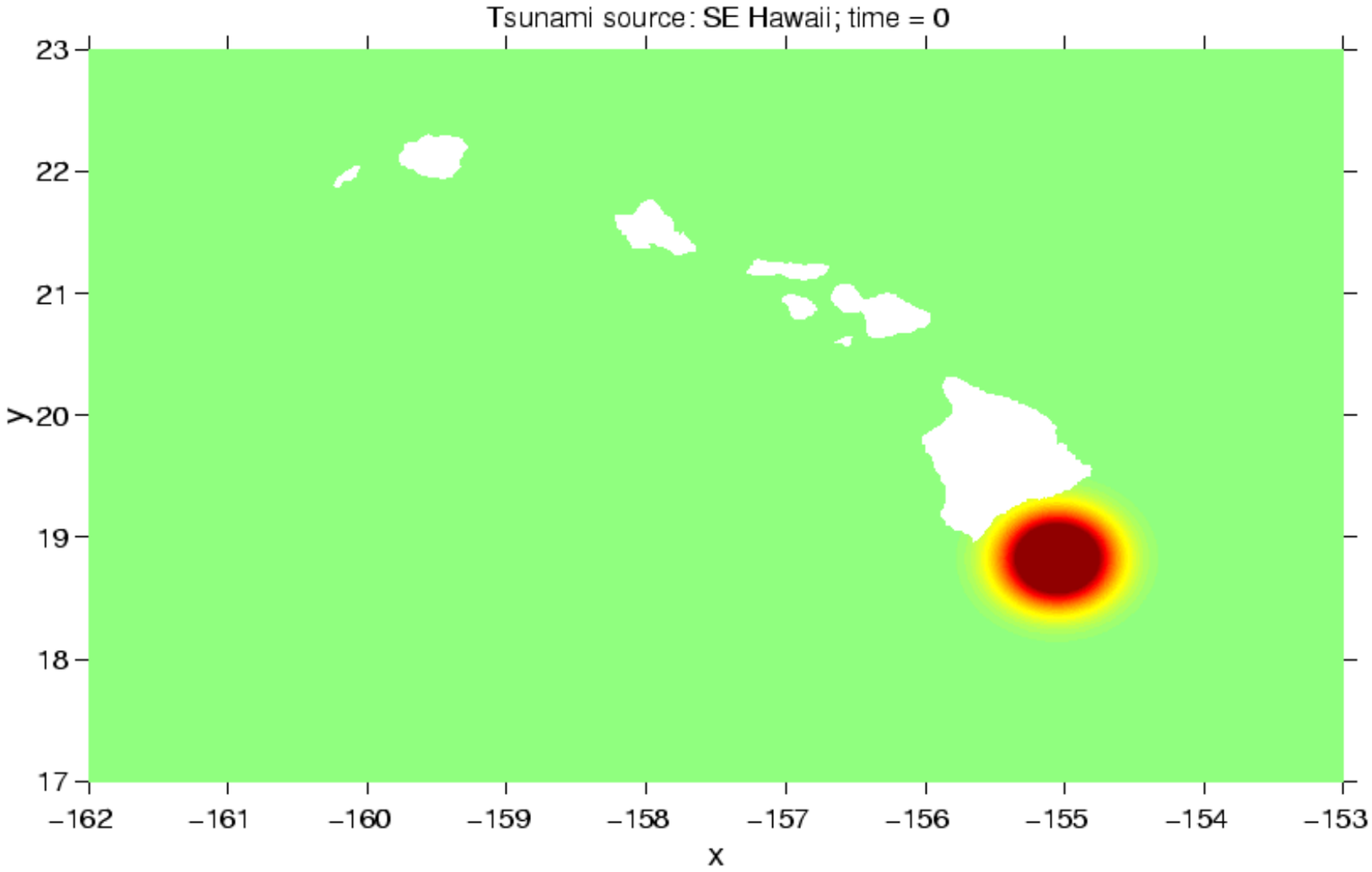
Wave run-up on a conic island.

The under water portion of the island is in conic shape but the landmass is assumed to be vertical walls.



Coordinates and wave heights are in non-dimensional units

Waves wraps around Hawaii island

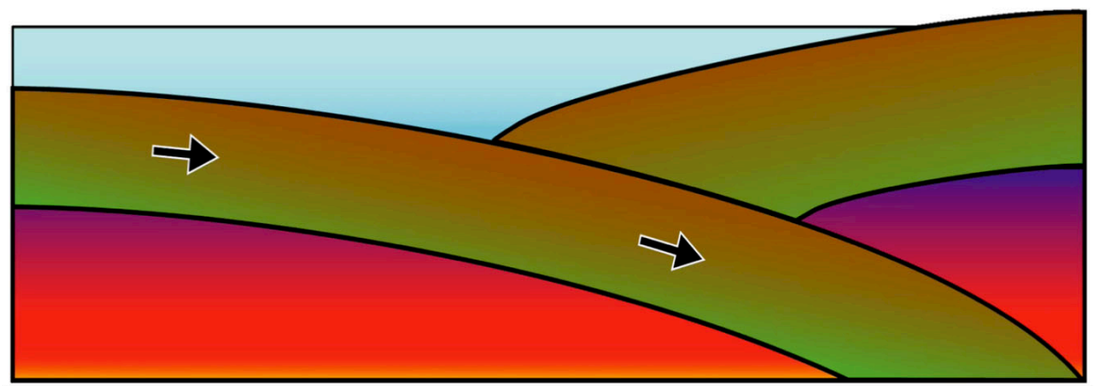


How are tsunamis generated?

How are tsunamis generated?

Created by an abrupt displacement of the ocean, such as from

- Shallow, undersea earthquakes (most common)
- Underwater or sub-aerial landslides (less common)
- Volcanic eruptions (infrequently)
- Meteor impact (rarely)

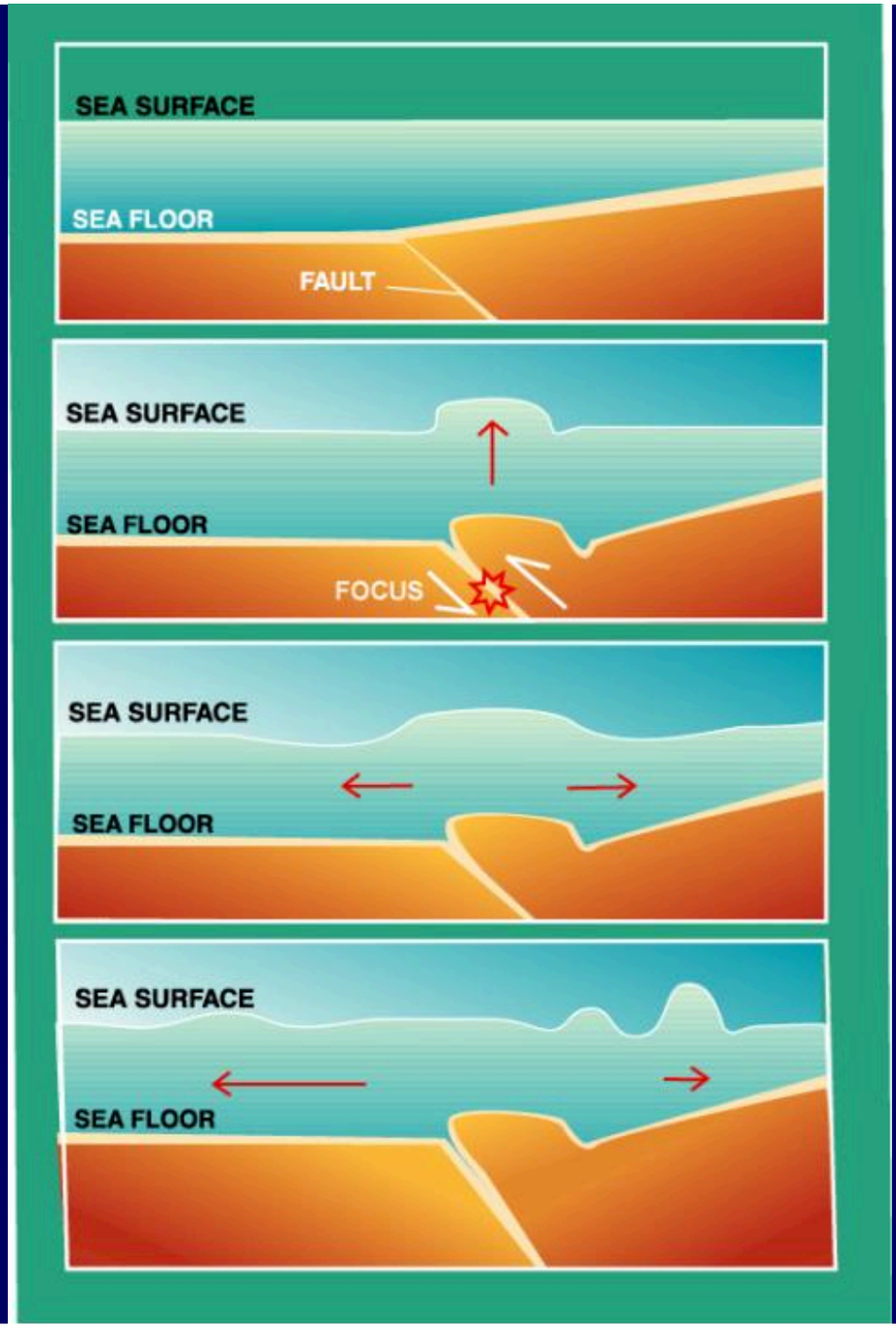


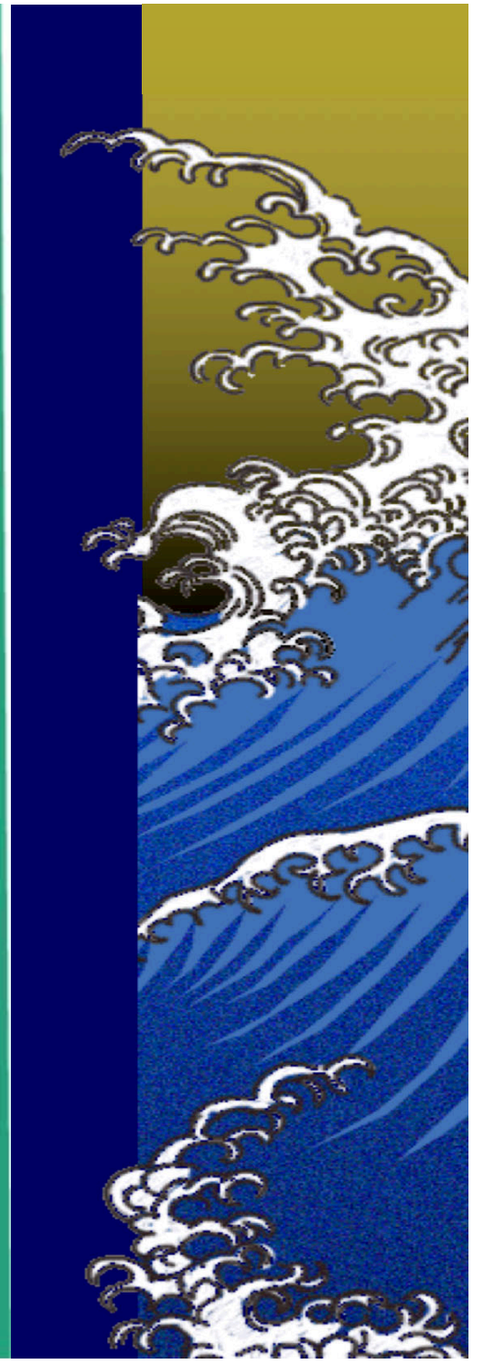
Subduction Zone Tsunami

TSUNAMIS
GENERATED BY EARTHQUAKES

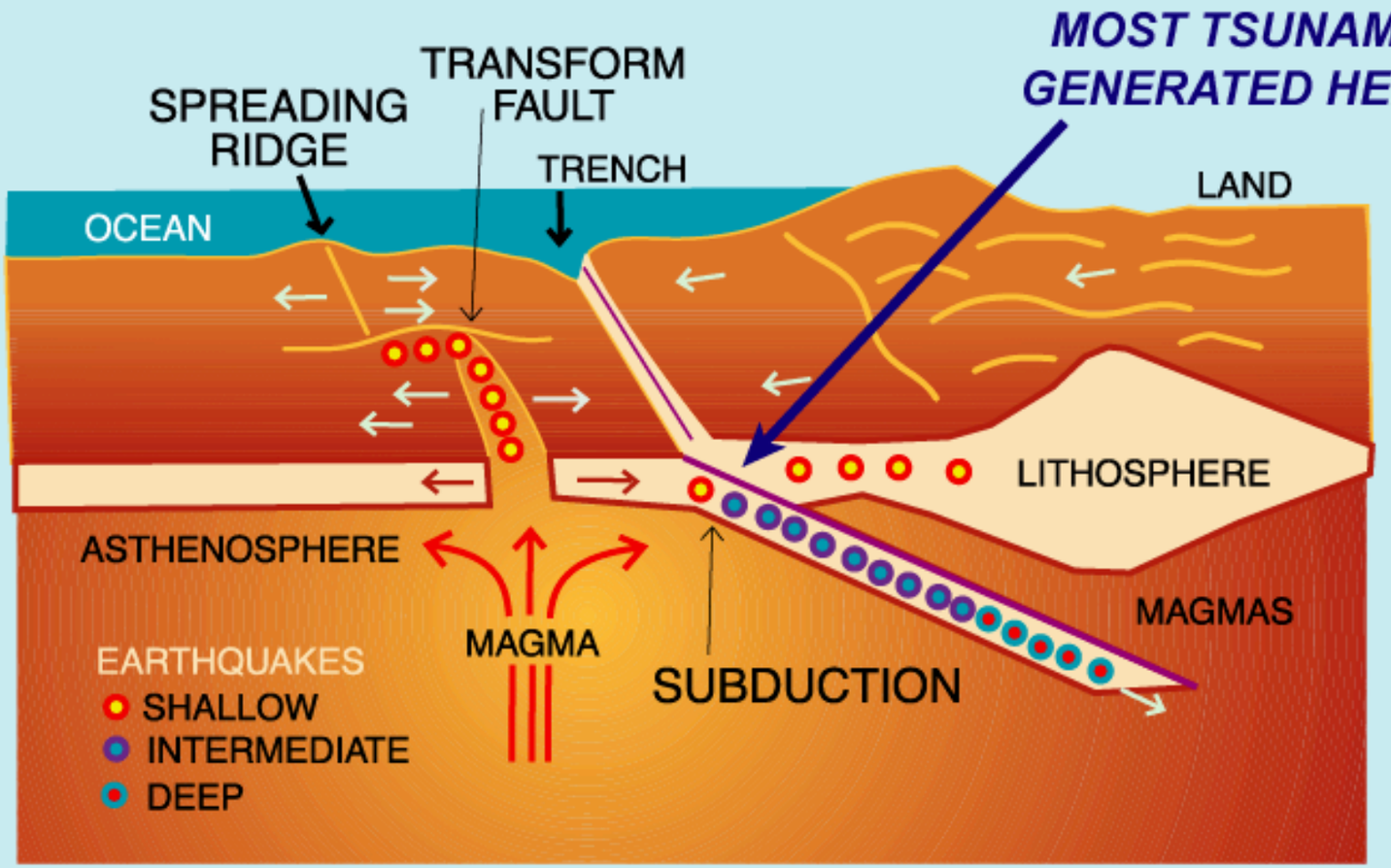
Large EQ (>7.5)
Shallow EQ – at or near the seafloor (< 50 km)
Subduction zones

Sudden displacement moves overlying column of water generating wave

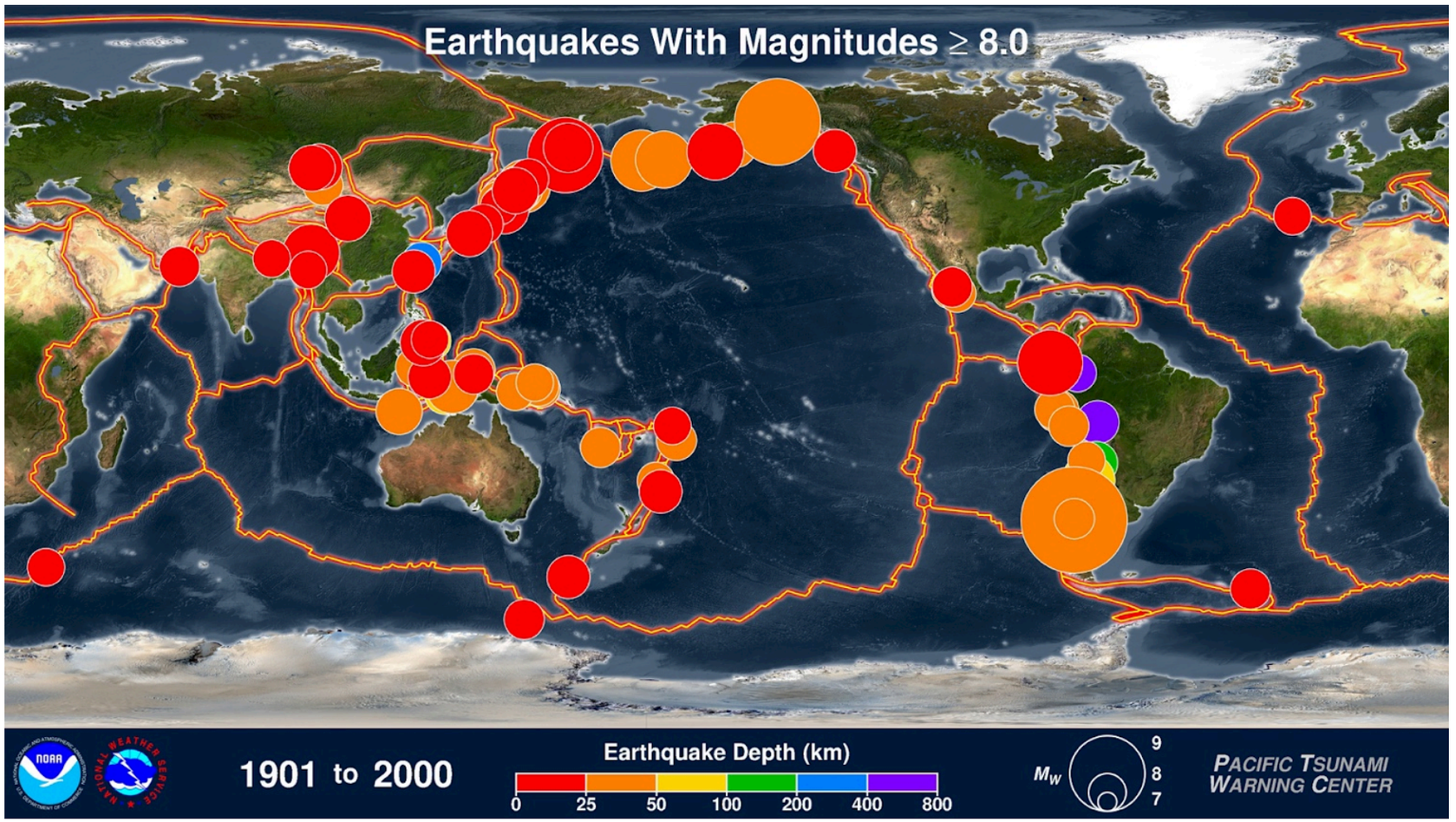




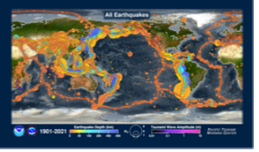
TSUNAMI GENERATION AROUND PACIFIC RIM



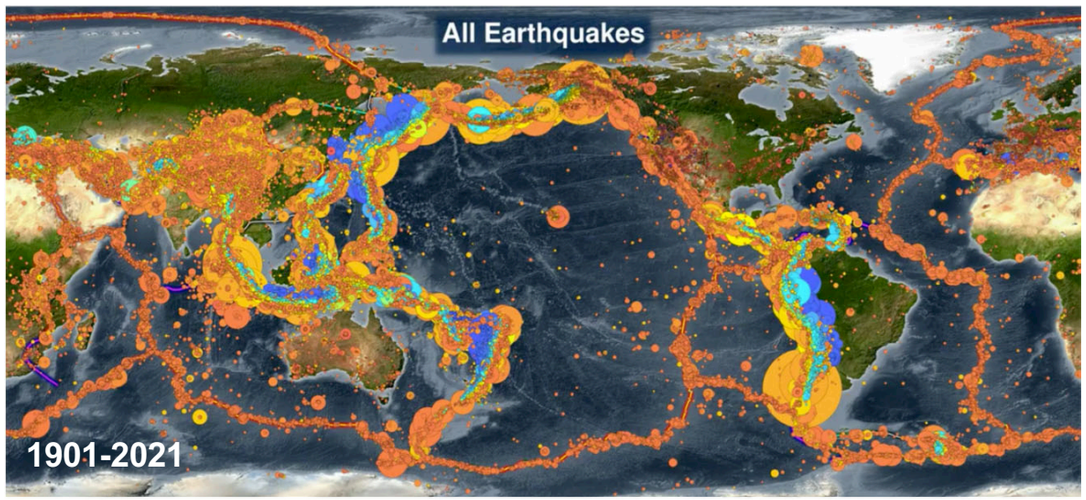
DANGEROUS EARTHQUAKES & TSUNAMIS

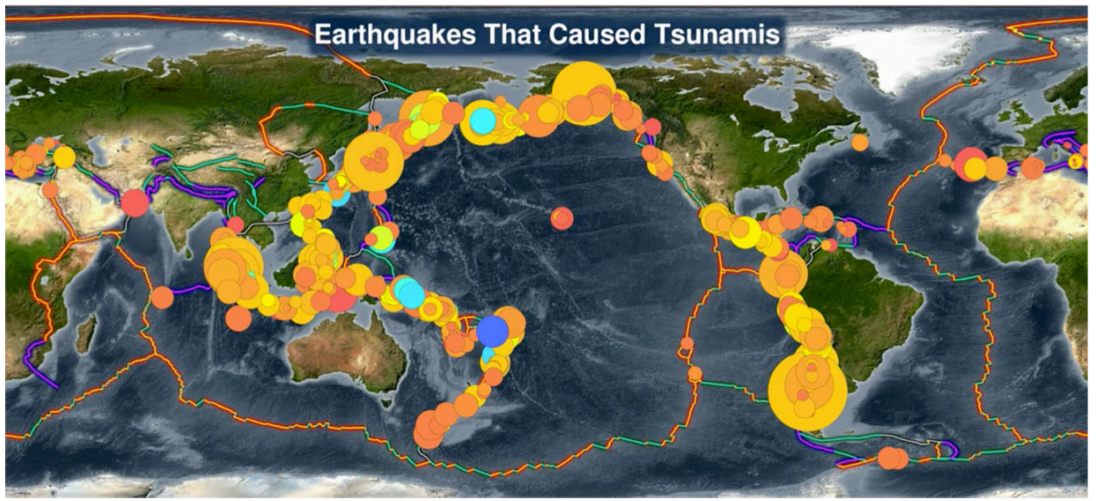


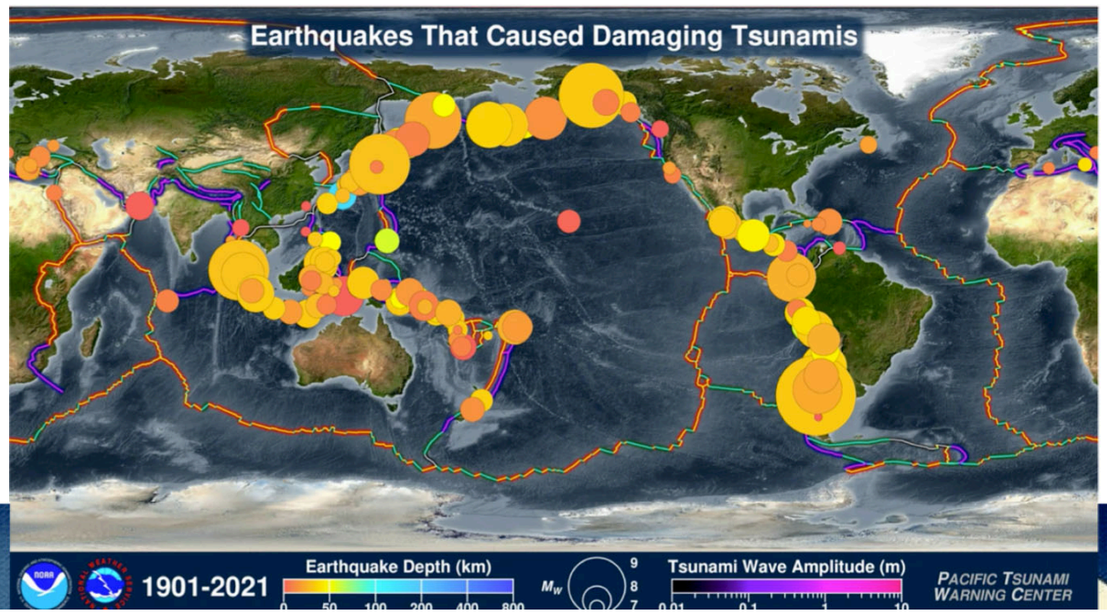
Click for video
EQ-Tsunam1901-2021



DANGEROUS EARTHQUAKES & TSUNAMIS

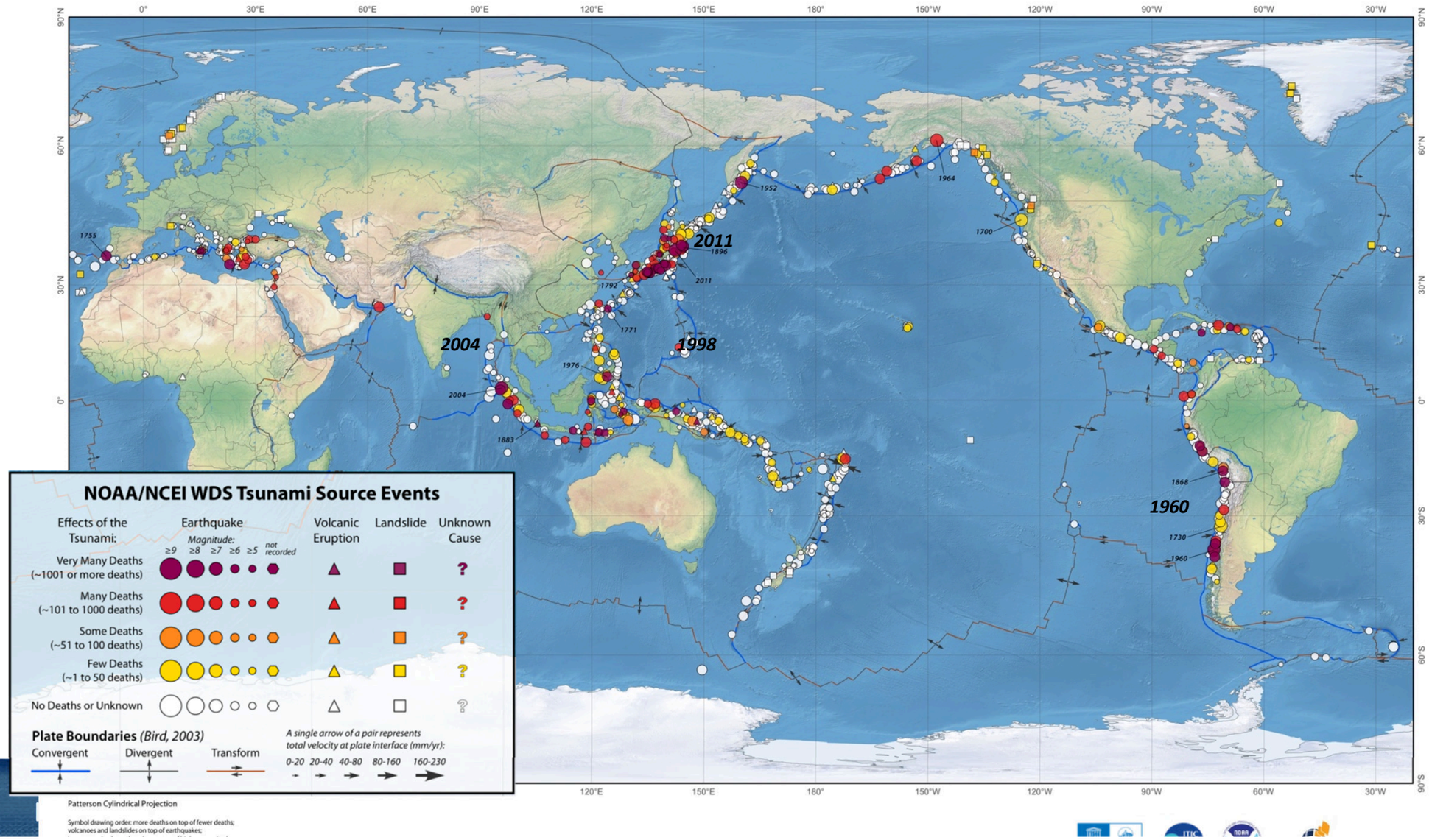




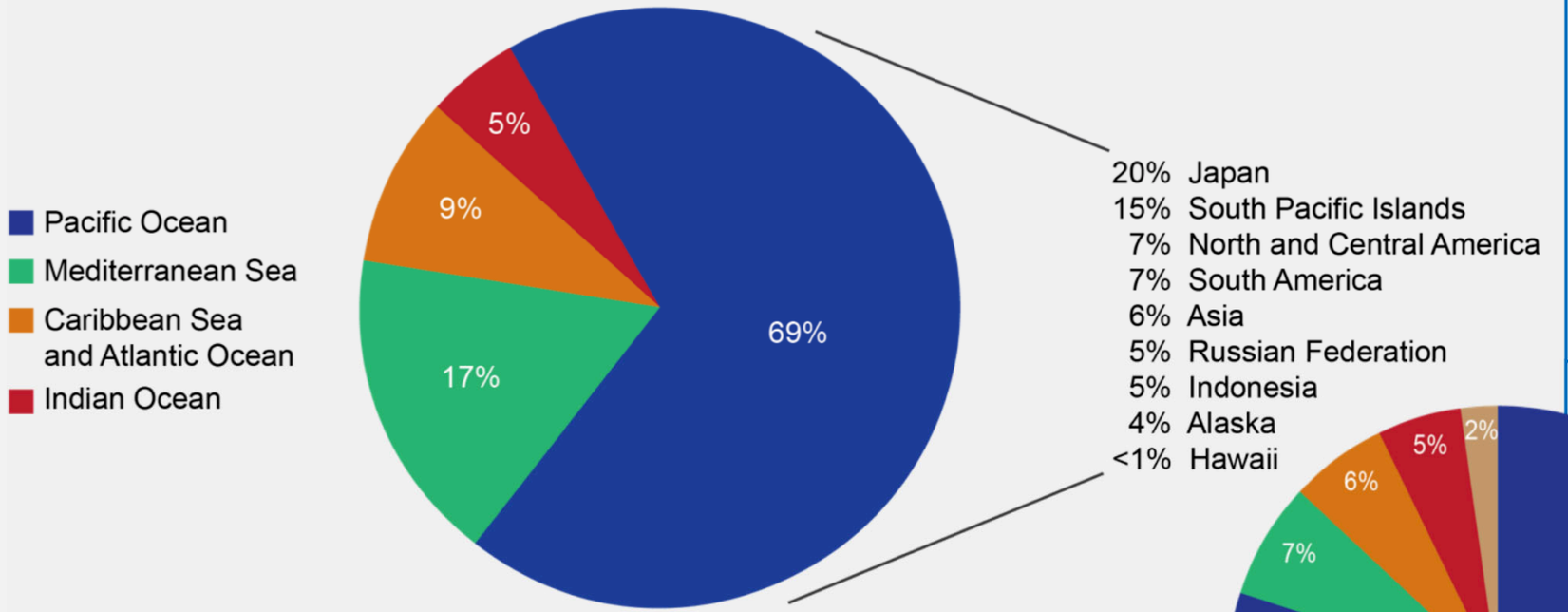


- 80% caused by earthquakes
- Shallow, undersea/near coast
- Magnitude 8+ (M7+)

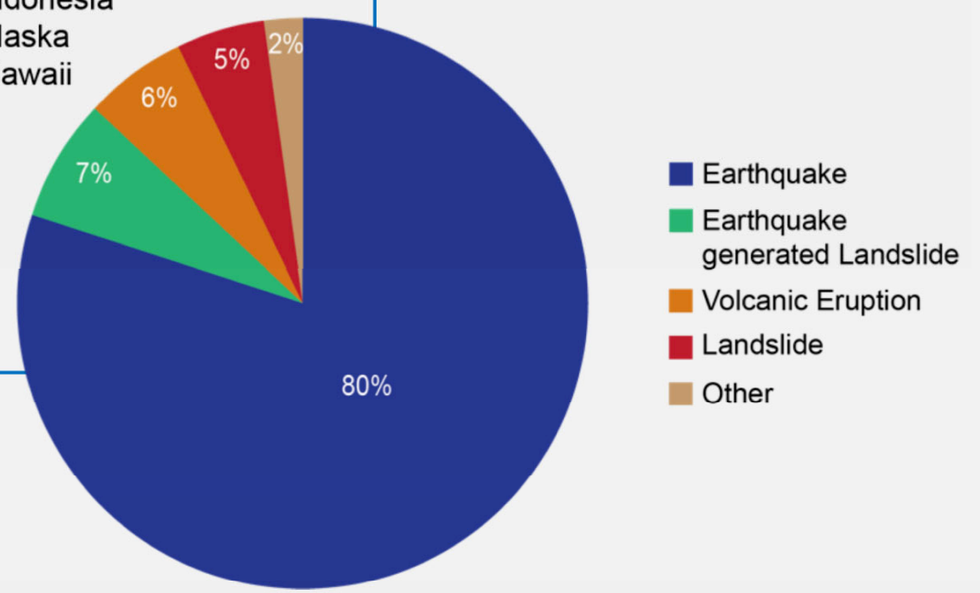
DEADLY TSUNAMIS – GLOBAL (1620 B.C to A.D. 2022)



DEADLY TSUNAMIS – GLOBAL (1620 B.C to A.D. 2022)



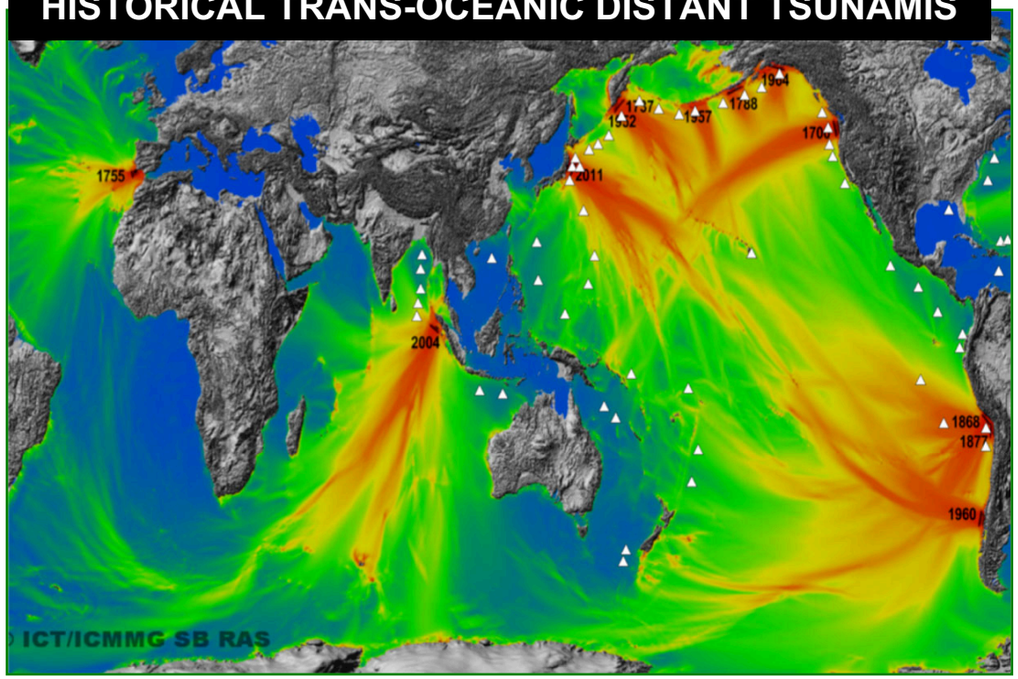
SOURCE LOCATION



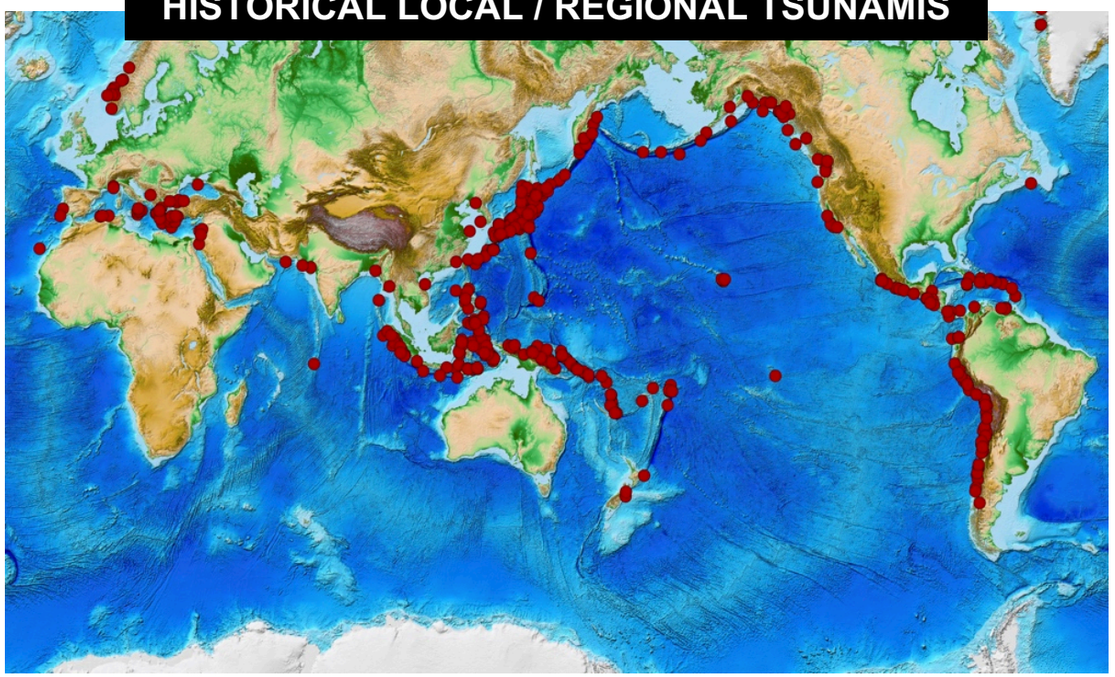
SOURCE GENERATION

DEADLY TSUNAMIS – DISTANT to LOCAL

HISTORICAL TRANS-OCEANIC DISTANT TSUNAMIS



HISTORICAL LOCAL / REGIONAL TSUNAMIS



- Most tsunamis are local (< 1 hr) or regional (1-3 hrs)
- Globally, 90% of deaths from local or regional tsunamis (Pacific, 99% of deaths)

What does a tsunami look like?
What does a tsunami do?
Why is a tsunami a hazard?

What does a tsunami look like?

- Rapidly rising/falling sea level
- Wall of water (not breaking surf wave)
- Receding wave (seafloor exposed)
- Fast flowing, debris-laden river

What does a tsunami look like?

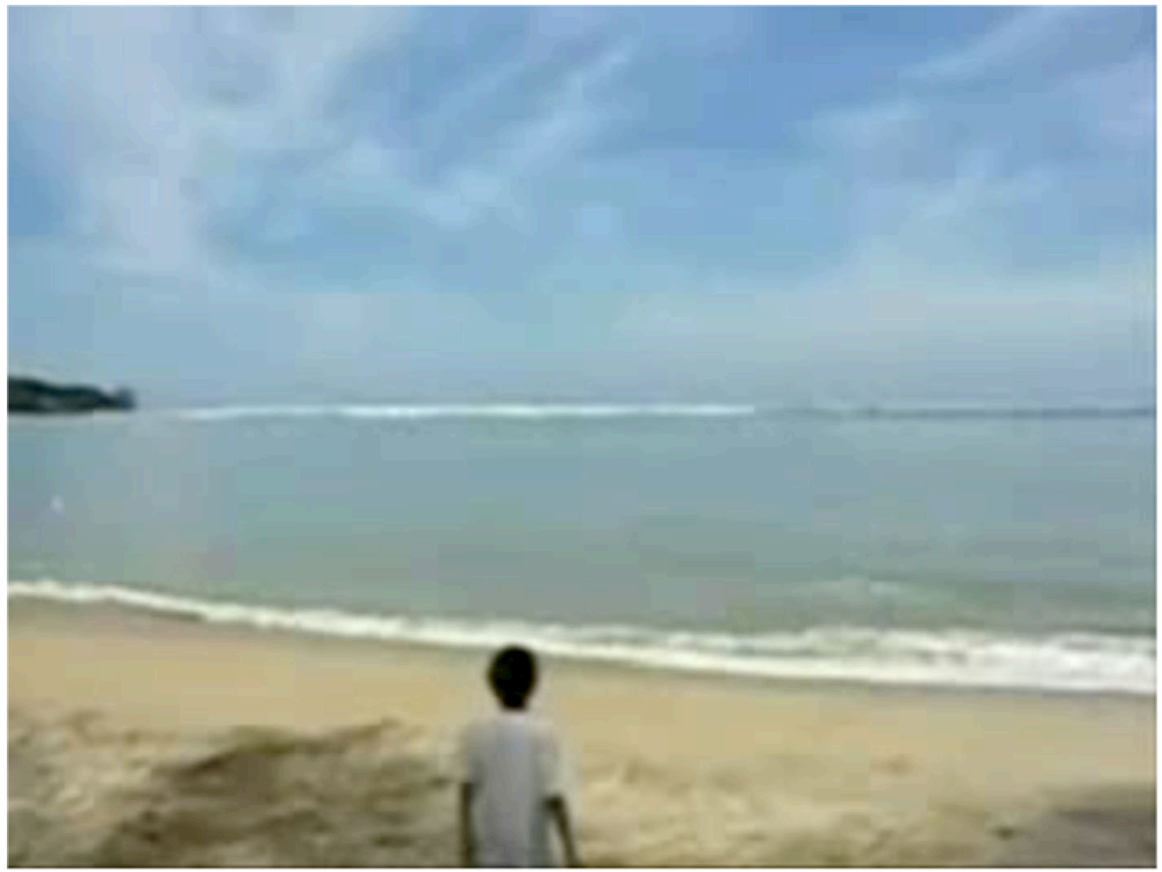
Indian Ocean Tsunami, December 26, 2004

Thailand Video

Indonesia Video

Asian Tsunami: Disaster of the Century, Asia-Pacific Broadcasting Union, 2005

Indian Ocean Tsunami, December 26, 2004

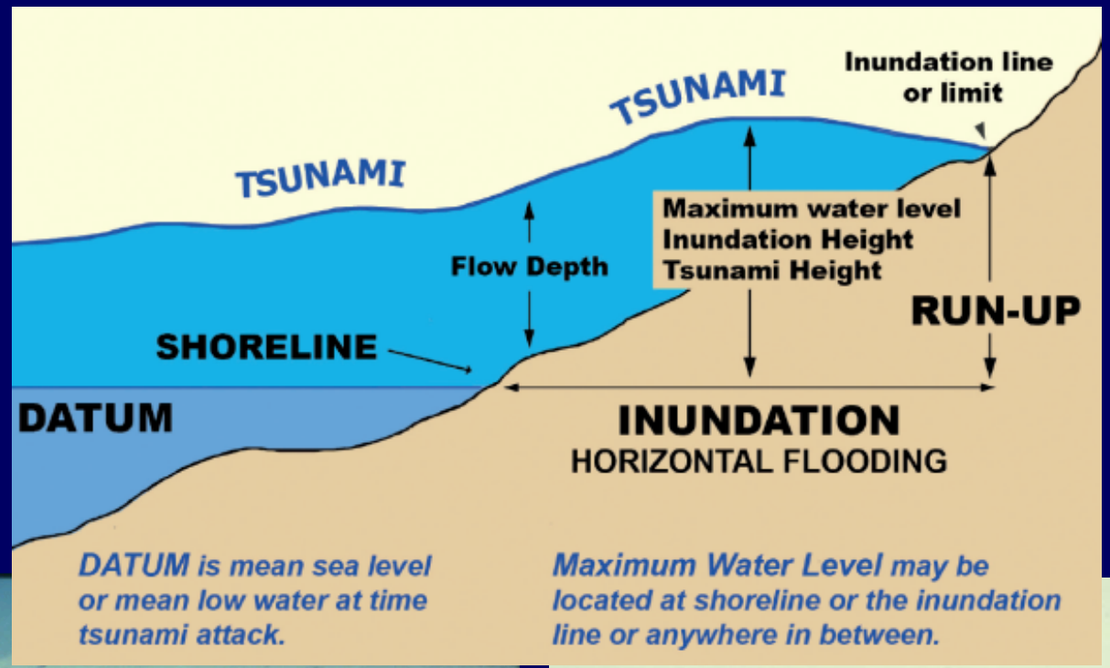


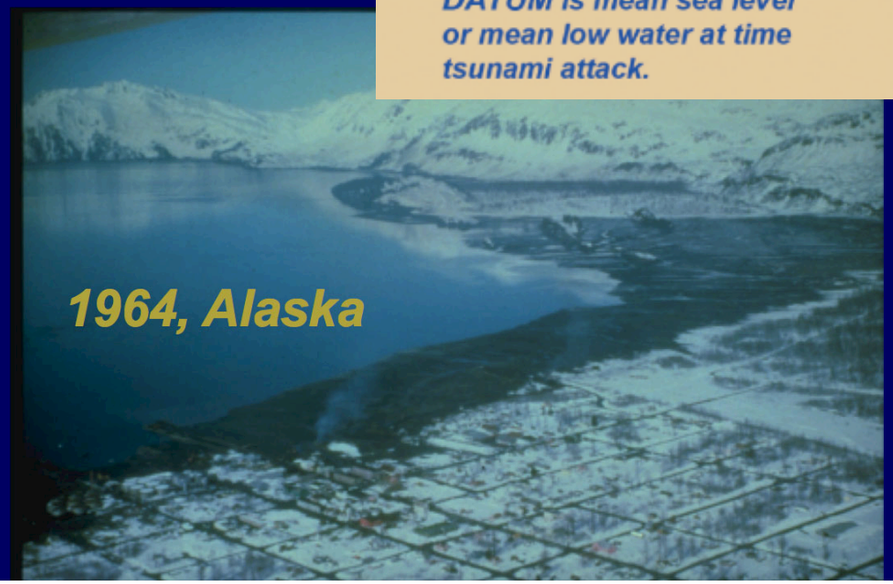
Penang, Malaysia: Relentless surge

High-tide, Arorae, Kiribati

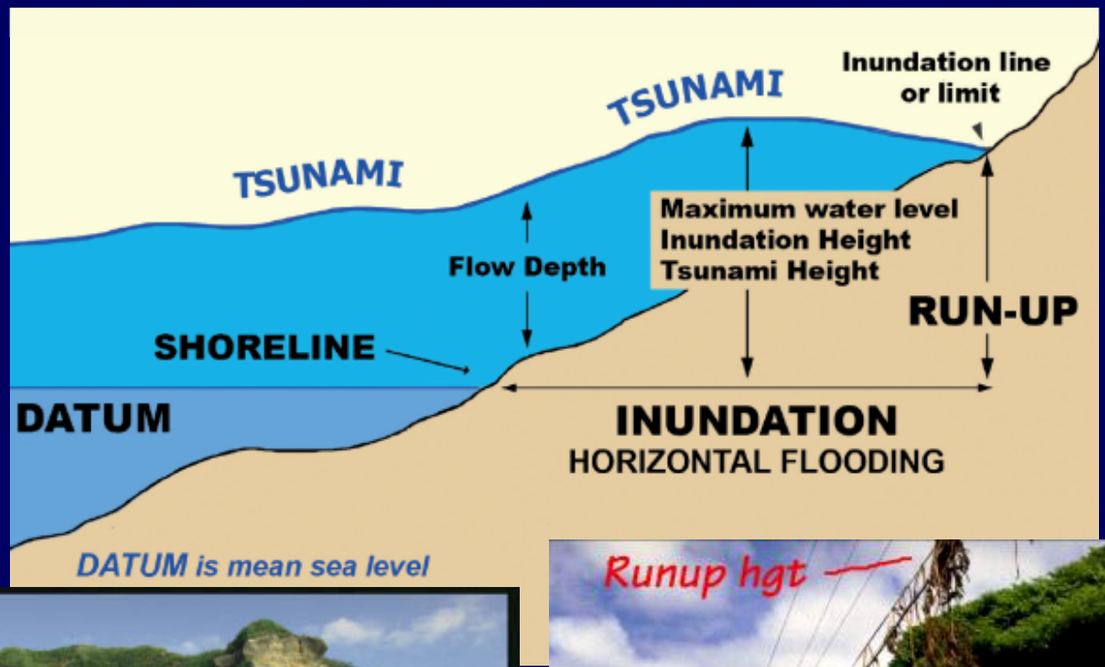
- Surge

TSUNAMI TERMS - INUNDATION

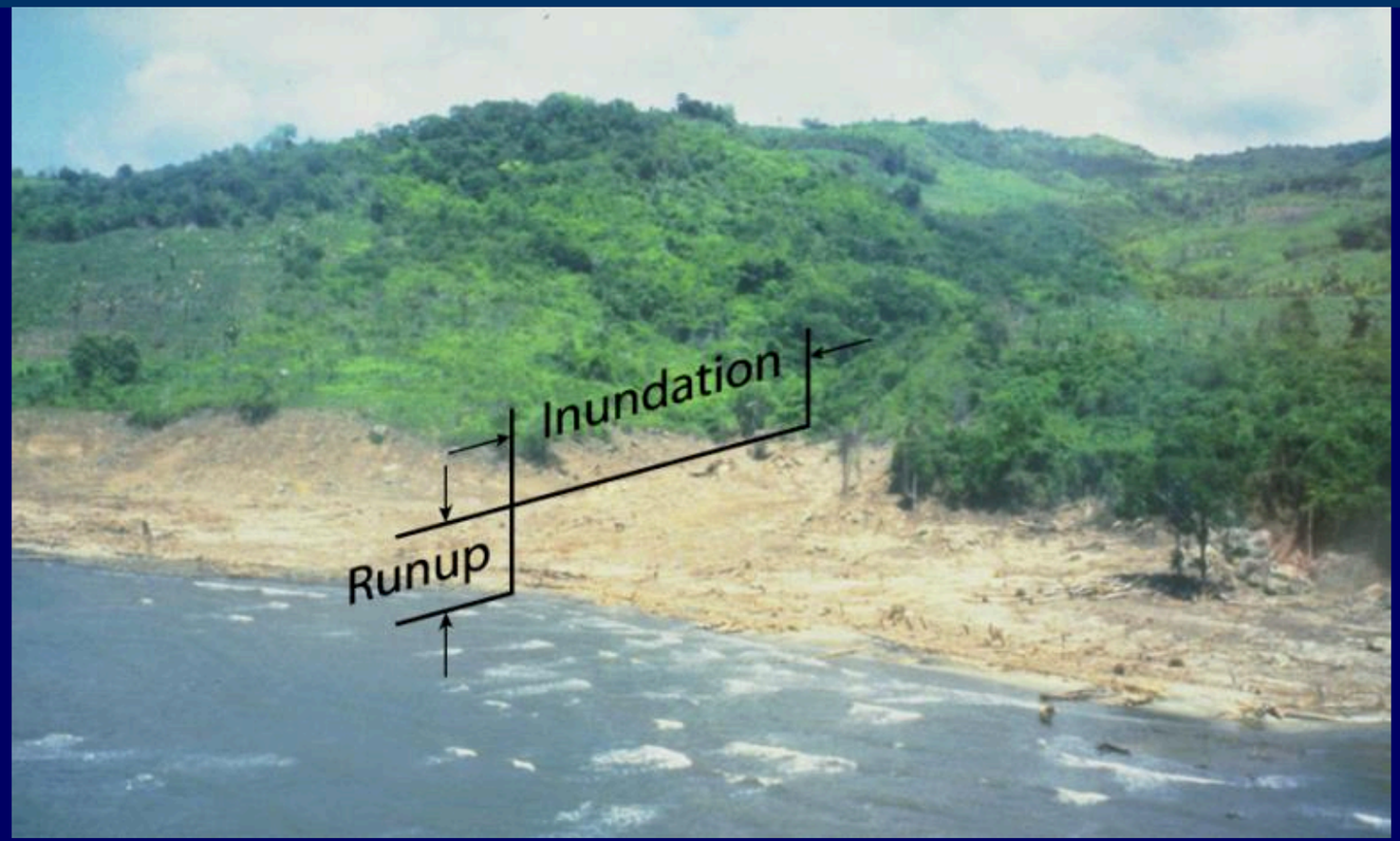




TSUNAMI TERMS - RUNUP



RUNUP and INUNDATION



- Runup: height above sea level reached by water
- Inundation: how far inland water reaches

What does a tsunami do?

- Objects become battering rams
- Erode, scour, deposit mud

⇒Death, debris

⇒Structures/utilities collapse

⇒Fire, HAZMAT

American Samoa, R. Madsen, G. Yamasaki, 2009

Fukushima, Japan, 2011, UN IAEA

What does a tsunami do?

- Quickly inundates low-lying areas

Before After

Banda Aceh, Indonesia Dec 26, 2004

- Flooding, strong currents

Largest wave draining

Pago Pago, American Samoa Sept 29, 2009

John Pughnat

Thank You

Dr. Laura Kong
Director, ITIC

Dr. Dailin Wang
Oceanographer, PTWC