Training/Workshop on

Tsunami Evacuation Maps, Plans, and Procedures and the UNESCO-IOC Tsunami Ready Recognition Programme for the Indian Ocean Member States

Hyderabad - India, 15-23 April 2025

Tsunami Inundation Modelling and MAP

TIMM #: Tsunami Science, Modelling and Forecasting - I

Science and the use of Modelling for Mitigation

Tsunamis and Tsunami Warning Systems: Talk Structure

Tsunamis:

- **Generation**
- **Hazard Mitigation/Long-term forecasting**
- Physical characteristics

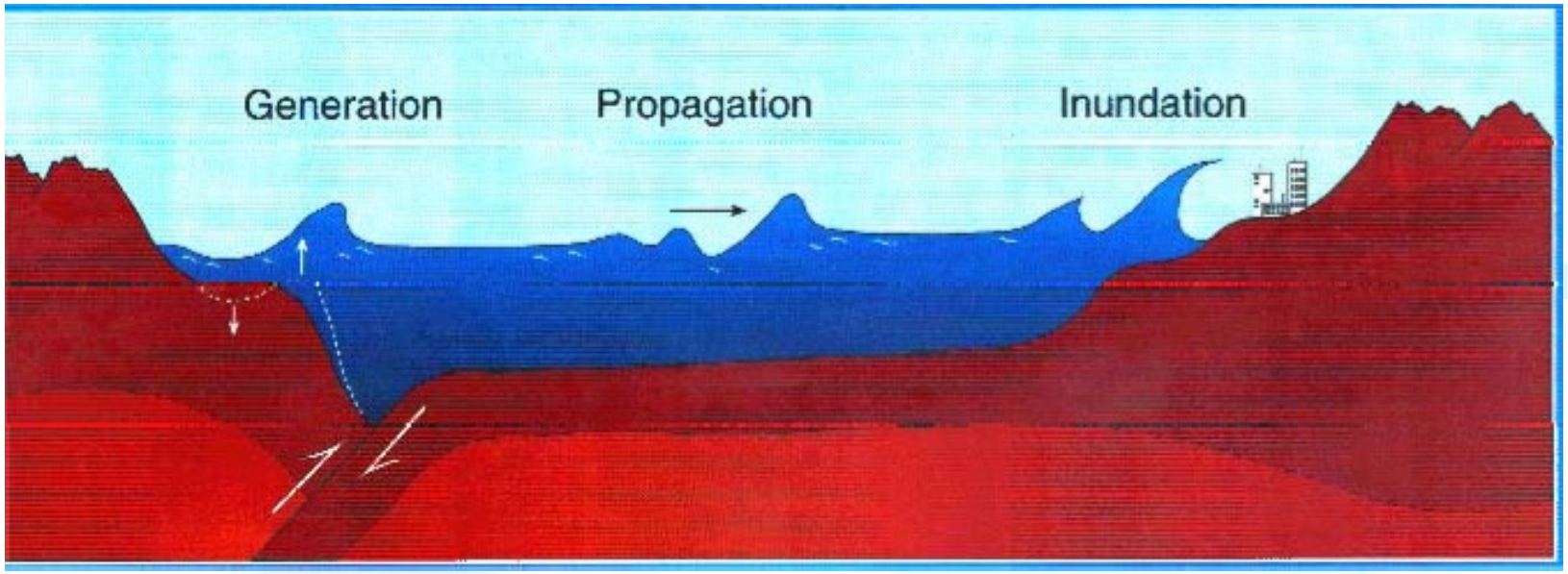
Tsunami Detection:

- Earthquake Based
- Tsunami Based

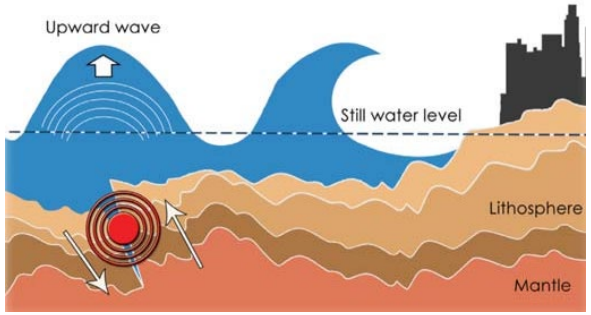
Tsunami Modeling:

- Linearity in deep water
- Inversion of DART data
- Forecast Model Development
- Early events
- Chile, February 2010

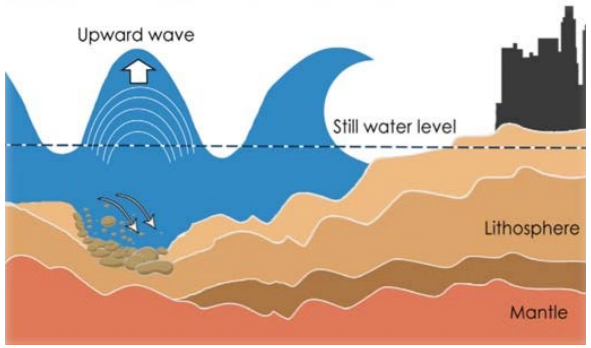
Three phases of tsunamis:

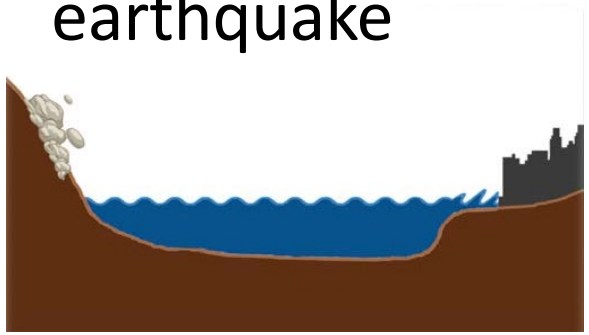


Tsunami Generation

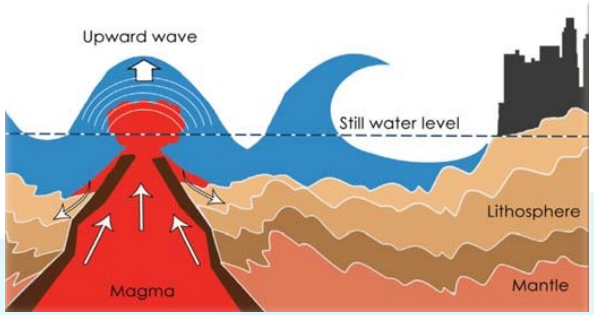


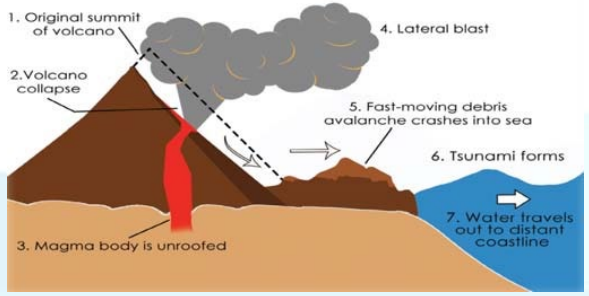
- Commonly, Shallow undersea earthquake

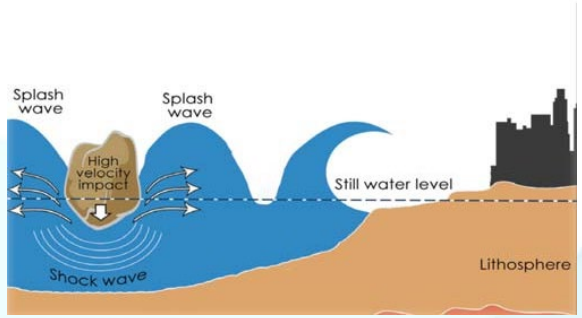




- Landslide - Submarine,
- Subaerial



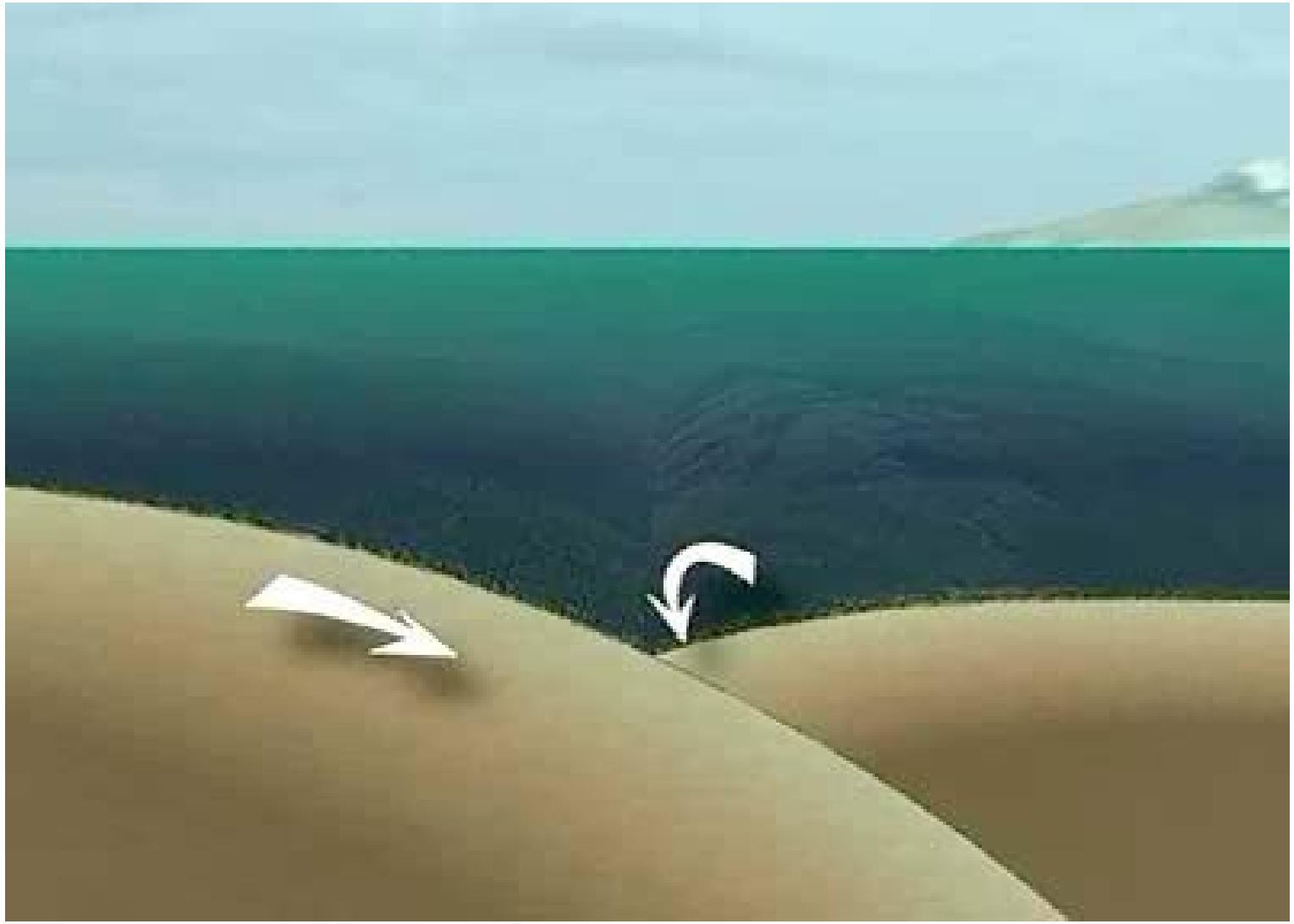




Volcanic eruption - submarine, subaerial

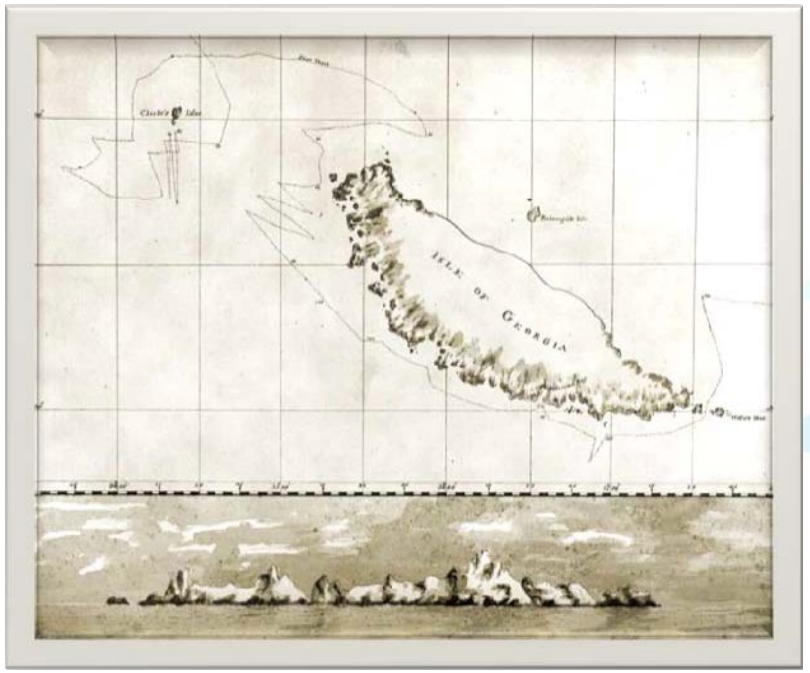
Typical method: earthquake at plate boundary

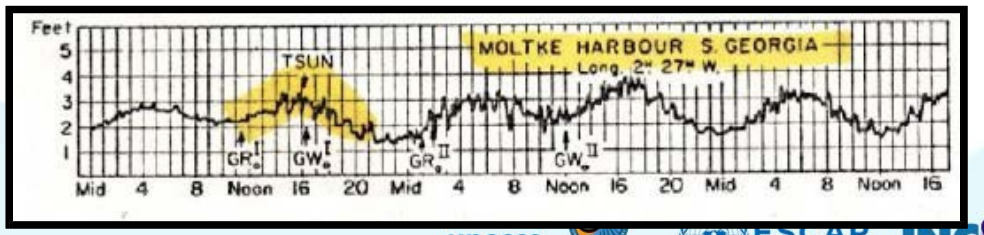
Tsunami Generation



Tsunamigenic Phenomena

- Tsunamis generated by volcanic explosions: Krakatoa, 1883

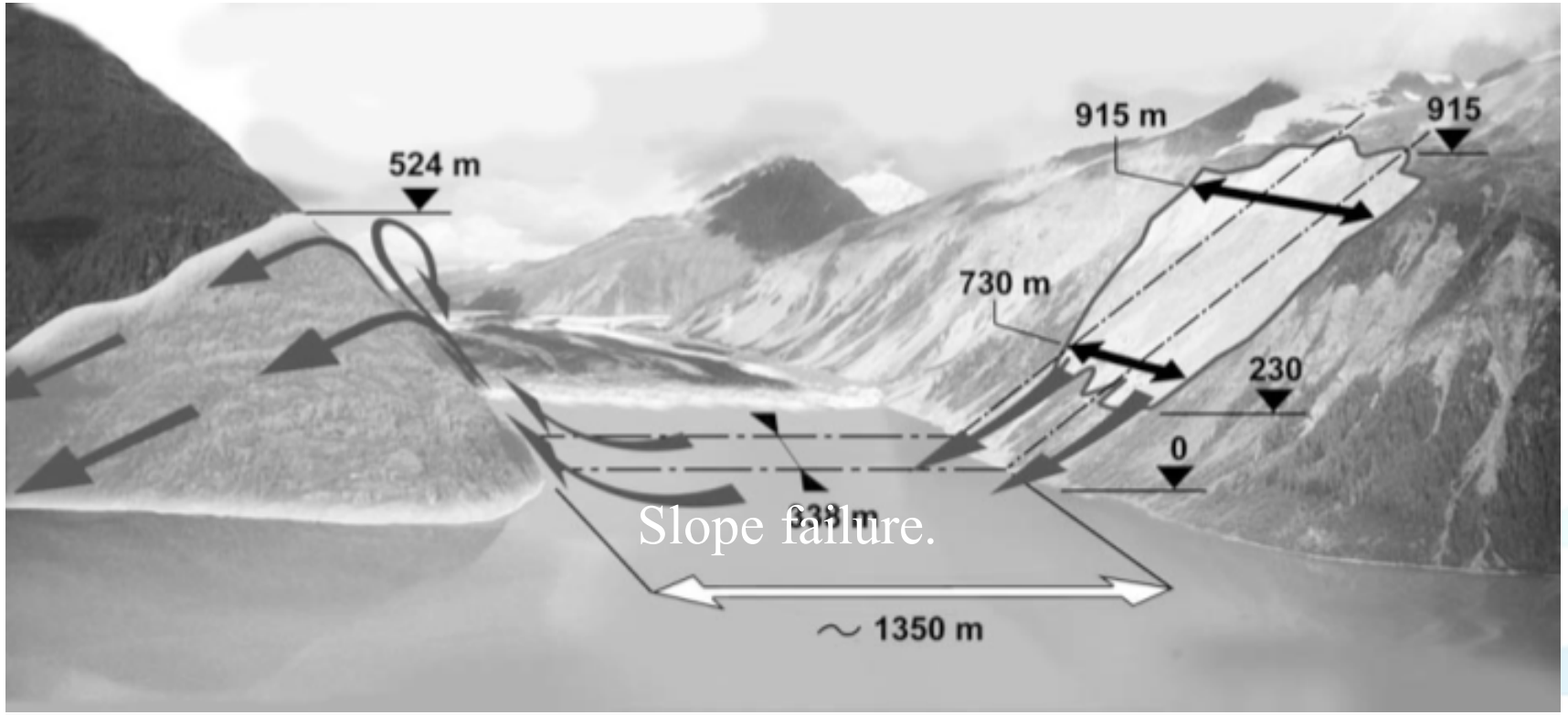




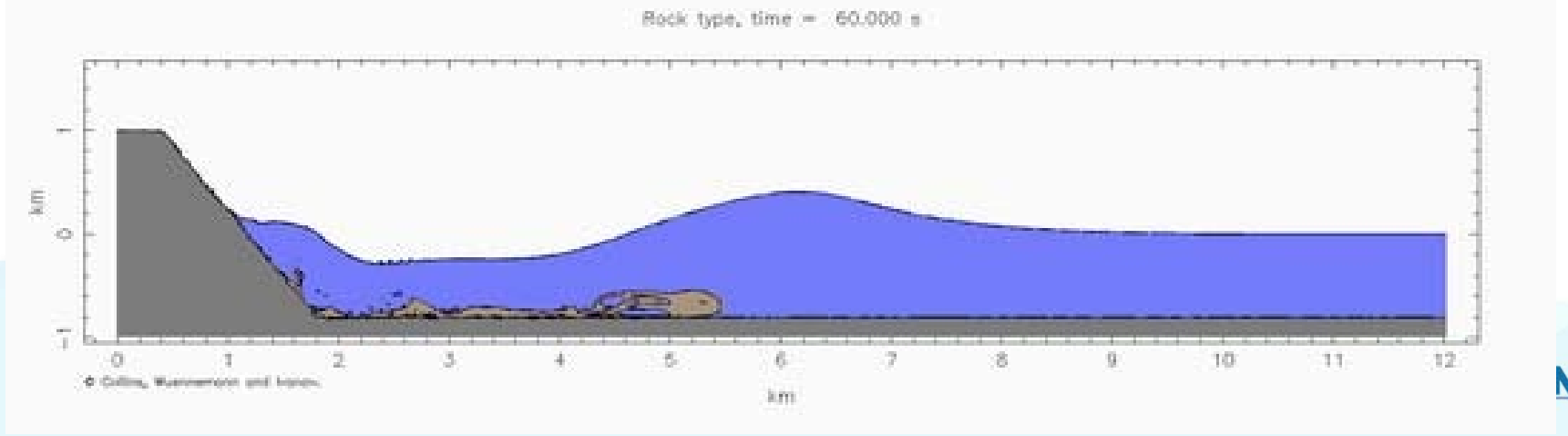
Tsunamigenic Phenomena

- Tsunamis generated by subaerial land-slides: Lituya Bay, AK

Tsunamigenic Phenomena



Slope failure.



Tsunamigenic Phenomena

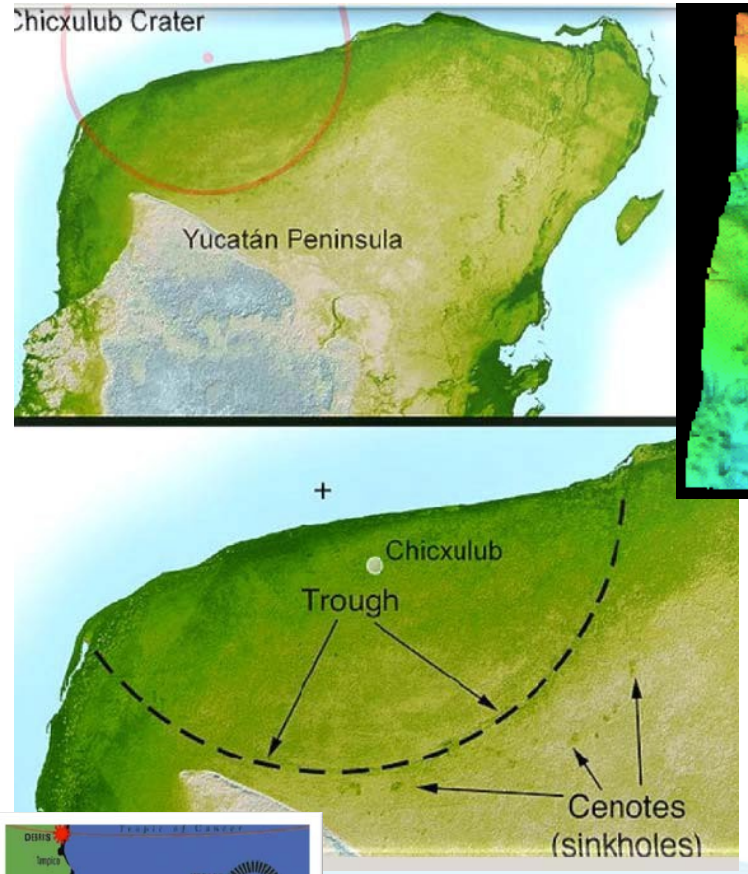
- Tsunamis generated by underwater land-slides: Aisén, Chile
- Slope failure.

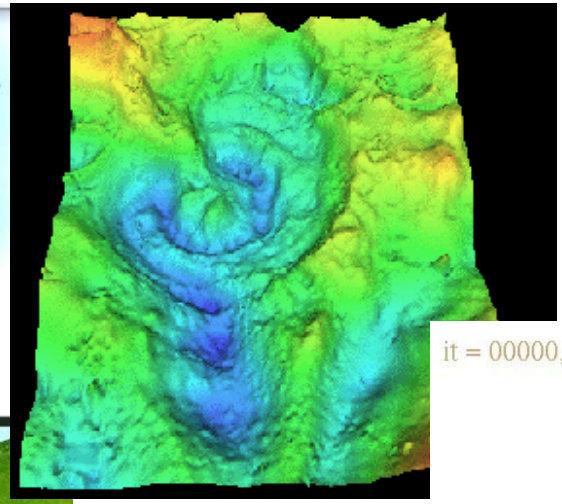
Tsunamigenic Phenomena

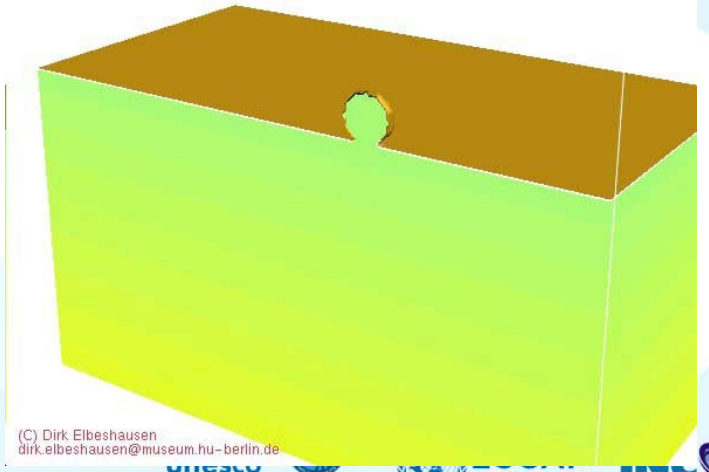
- Tsunamis generated by subaerial land-slides: Aisén, Chile.

Tsunamigenic Phenomena

- Tsunamis generated by meteorite impacts: Chicxulub Crater, Mexico

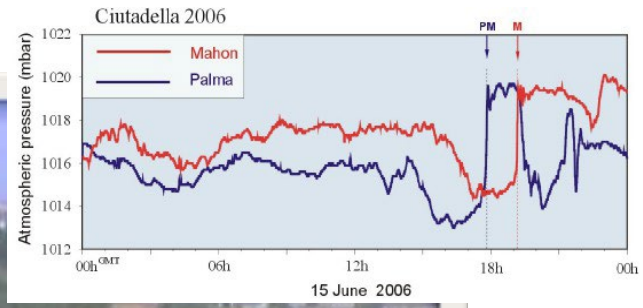






Tsunamigenic Phenomena

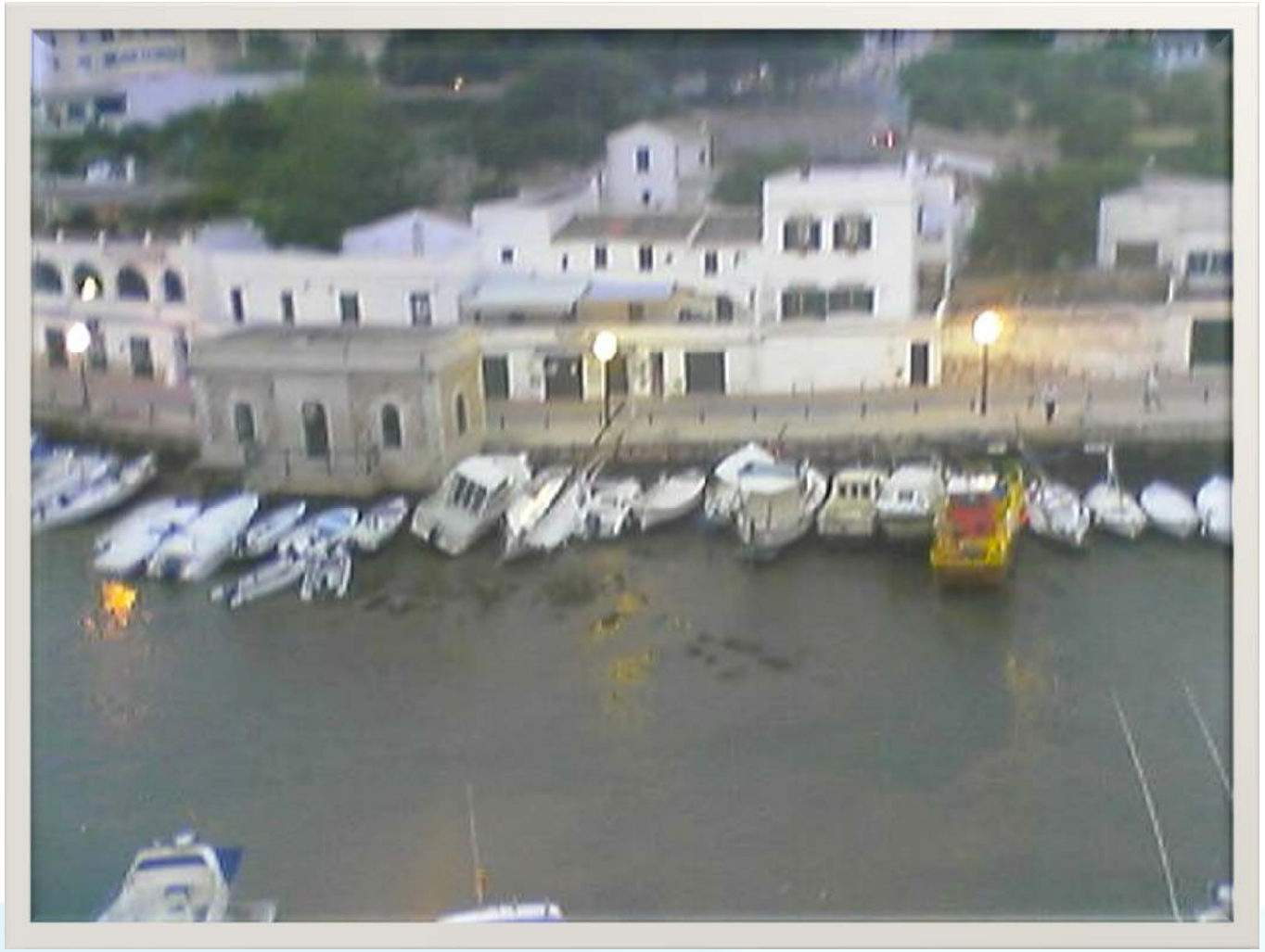
- Meteorological Tsunamis



Ciudadella, Spain, Tsunami June 15, 2006: Slide1

Tsunamigenic Phenomena

- Meteorological Tsunamis



Ciudadella, Spain, Tsunami June 15, 2006 : Slide 2

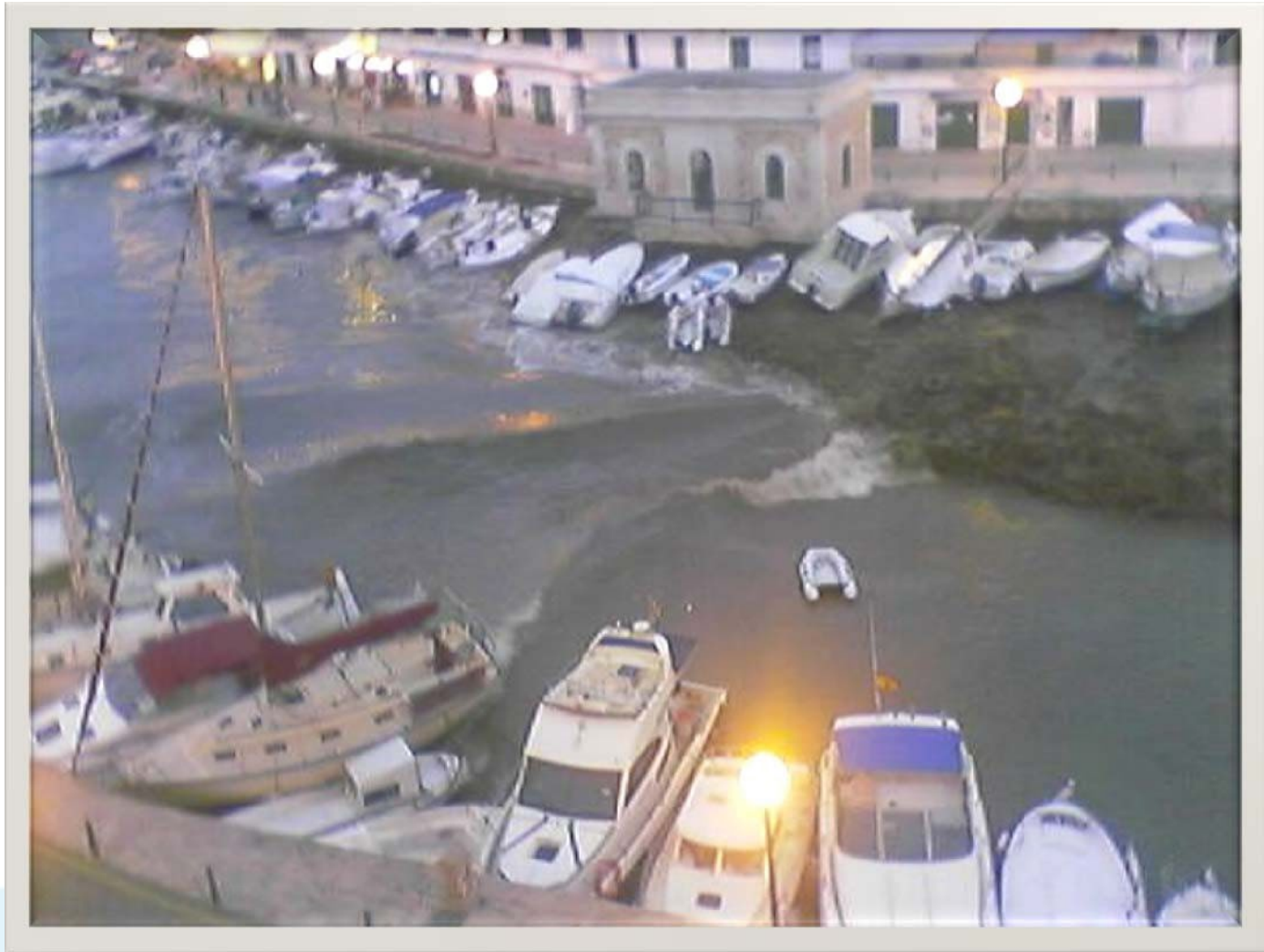
Tsunamigenic Phenomena

- Meteorological Tsunamis

Ciudadella, Spain, Tsunami June 15, 2006 : Slide 3

Tsunamigenic Phenomena

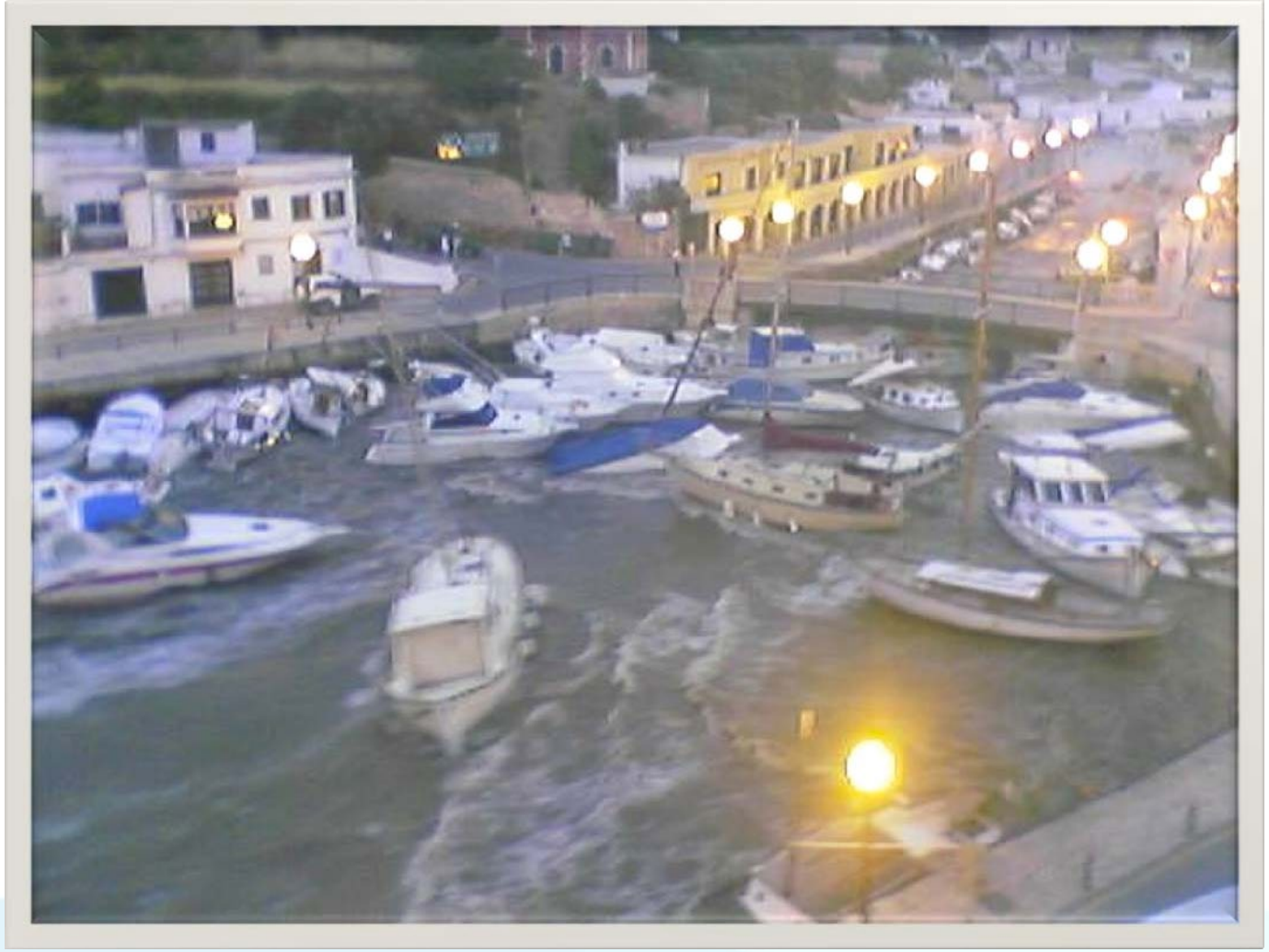
- Meteorological Tsunamis



Ciudadella, Spain, Tsunami June 15, 2006 : Slide 4

Tsunamigenic Phenomena

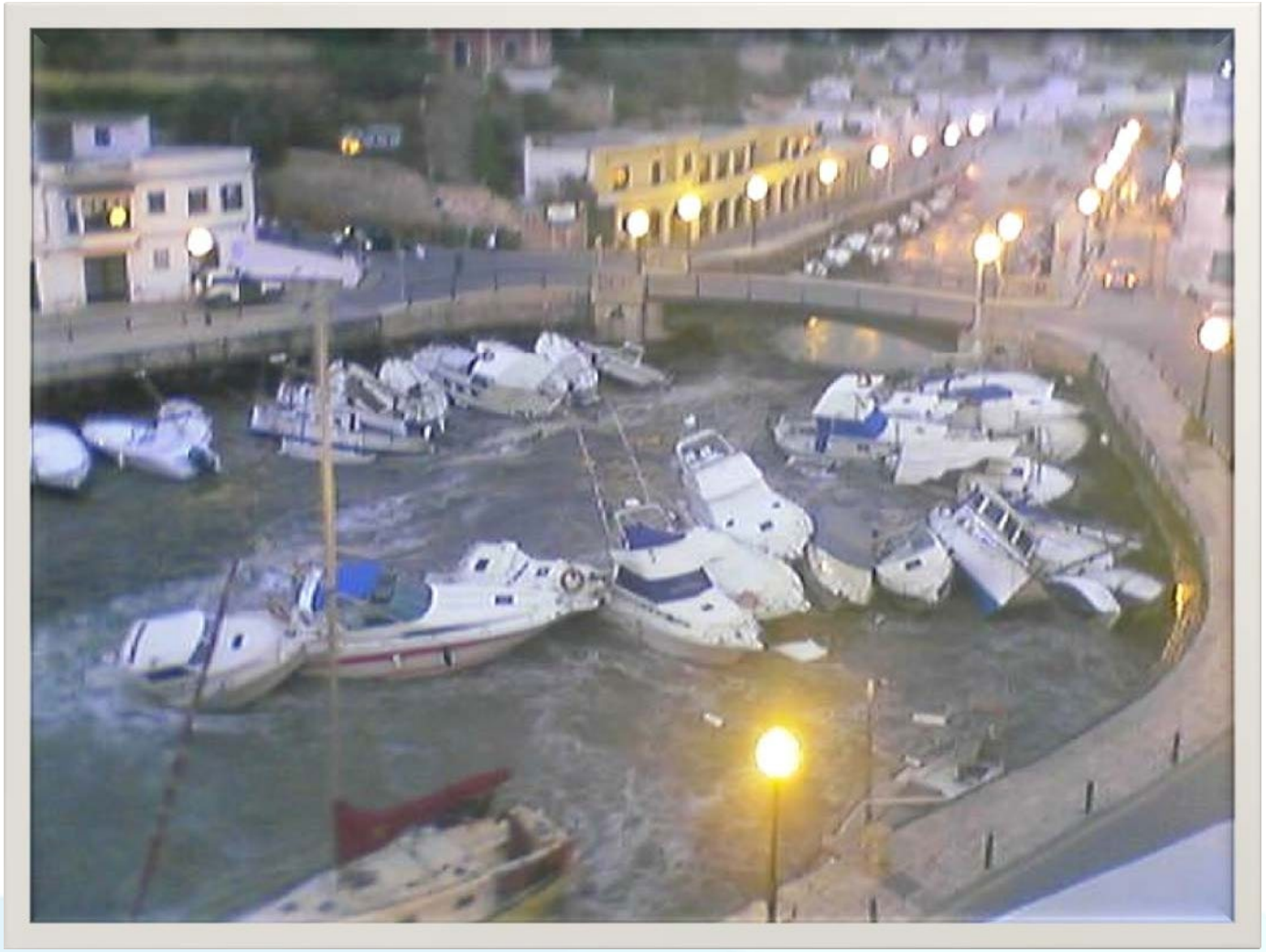
- Meteorological Tsunamis



Ciudadella, Spain, Tsunami June 15, 2006 : Slide 5

Tsunamigenic Phenomena

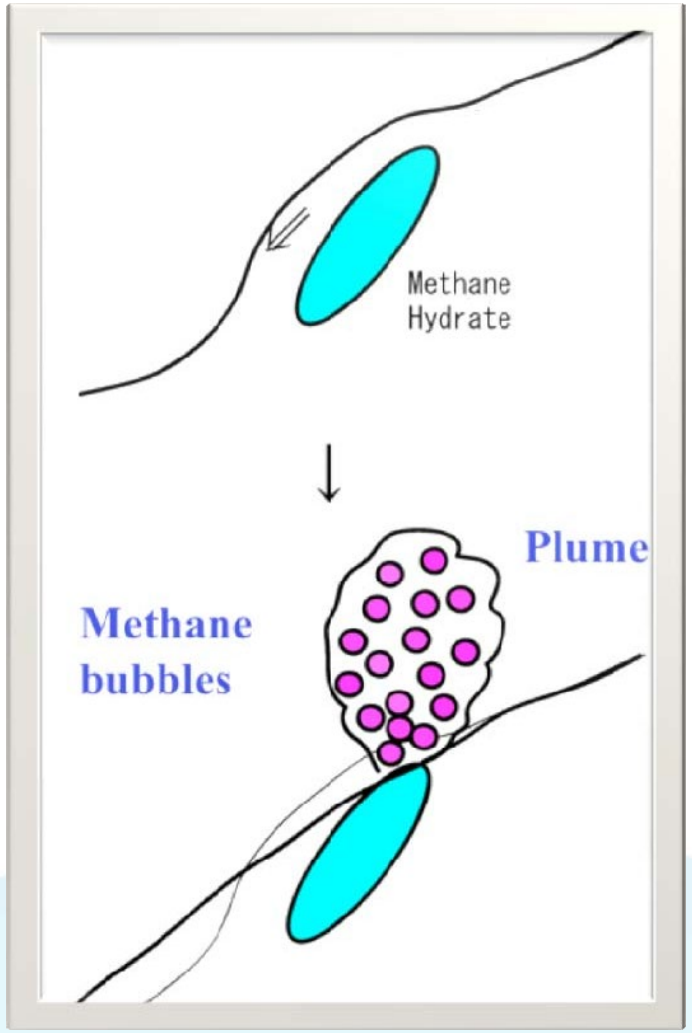
- Meteorological Tsunamis

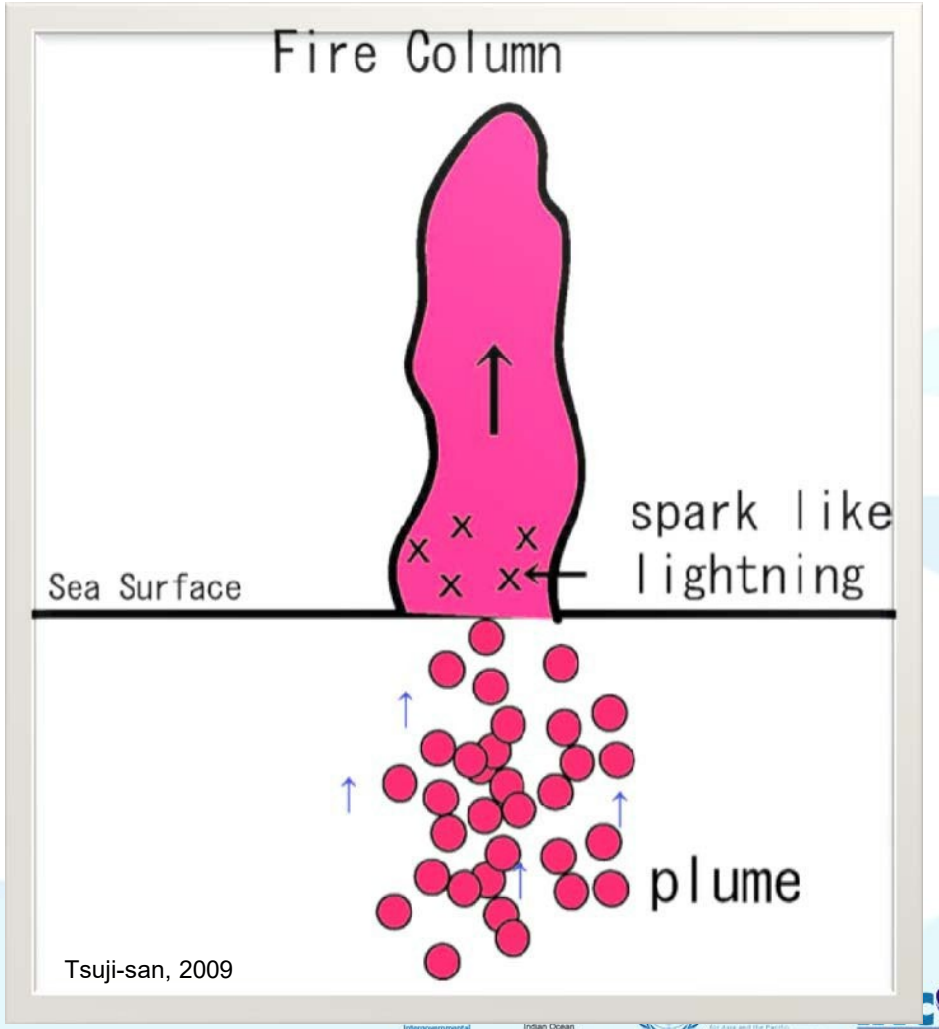


Ciudadella, Spain, Tsunami June 15, 2006 : Slide 6

Tsunamigenic Phenomena

- Tsunamis generated by explosion of underwater methane deposits: Deep Water Horizon?





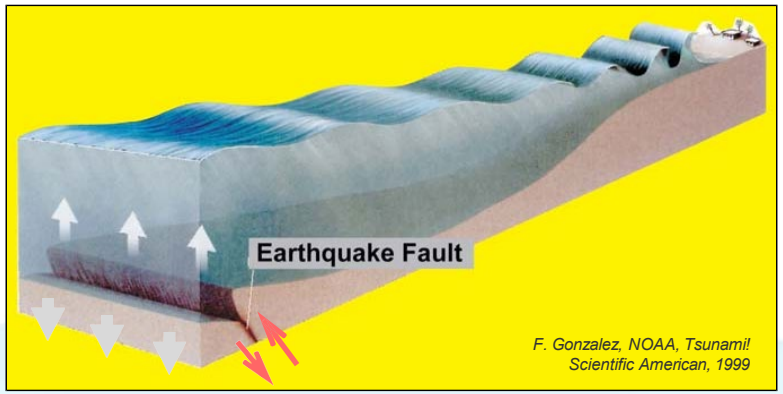
Tsuji-san, 2009

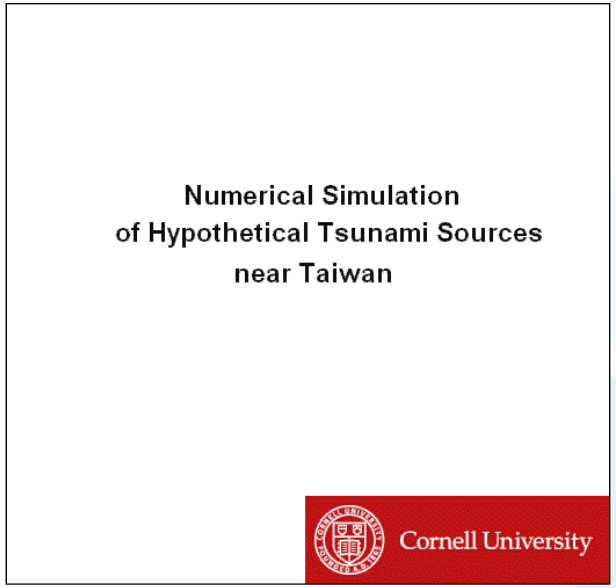
Science and Public Safety
Tsunami Hazard Assessment

- **What is the likelihood of occurrence?**
  - Historical and Future Hazard
- **What is expected tsunami impact at coast**

=> Numerical modeling

  - Source, tsunami propagation
  - Runup, Inundation





Tsunami Modeling – Why?

- Historical tsunamis allow scientists to understand how tsunamis behave
- Tsunamis are high impact, but infrequent
- Therefore, modeling scenarios essential
  - –Simulate:
    - When and how tsunami will hit coast?
    - Where highest? How far floods inland?
    - Where strong currents are?

➢ **Science Result: Hazard Assessment, Inundation map**

➢ **Public Safety Result: Evacuation maps - community**

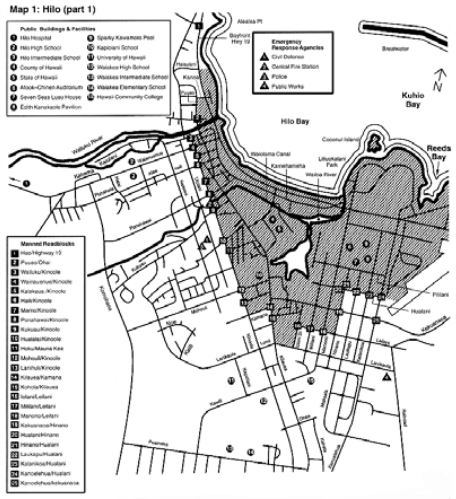
Numerical Modeling for Hazard Assessment (Long-term Forecasting)

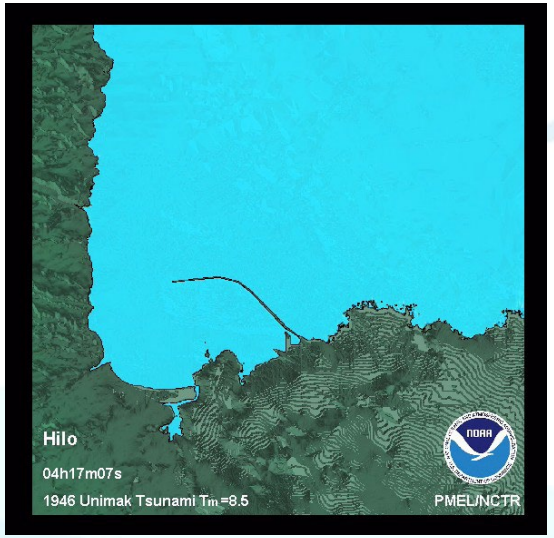
It is the use of the tsunami simulation model to identify the long term impact of tsunamis

… the use of *Modeling* for *Mitigation*

Long Term Forecast

Inundation Map





Hypothetical Short Term Forecast

Who needs Long-term Forecasting?

Hazard / damage Time scale

60 year time-span:	Government facilities / building life span
100-500 year time-span:	Flood Insurance maps
10000 year time-span:	Nuclear Power Plant siting
60-10000+ year time-span: Worst Case Scenario	Community tsunami evacuation map

How is Long-term Forecasting performed using the numerical models and database?

1. Use of tested and validated tsunami numerical model Standards, Criteria and Procedures for NOAA Evaluation of
   Tsunami Numerical Models (NOAA Tech Memo OAR PMEL-135)

2. Development of high resolution, state of the art digital elevation models. DEM, 10 to 30 meter resolution topo/bathy models

3. Data acquisition (observations) and validation with historical events. Tsunami deposits, tide gauge data, probabilistic sources

4. Analysis and interpretation of the results.
   Hazard Assessment Report (NOAA Technical Memorandum)

Long-term Forecast - Examples

Deterministic Approach (Pearl Harbor, HI study)

- Probabilistic Approach (Seaside Pilot, OR study)

1. Validated Numerical Code

Method of Splitting Tsunami (MOST)
Software Manual

7/6/2006

The National Oceanic & Atmospheric Administration
Pacific Marine Environmental Laboratory
Tsunami Research Program

NOAA Technical Memorandum OAR PMEL-135

STANDARDS, CRITERIA, AND PROCEDURES FOR NOAA EVALUATION OF TSUNAMI NUMERICAL MODELS

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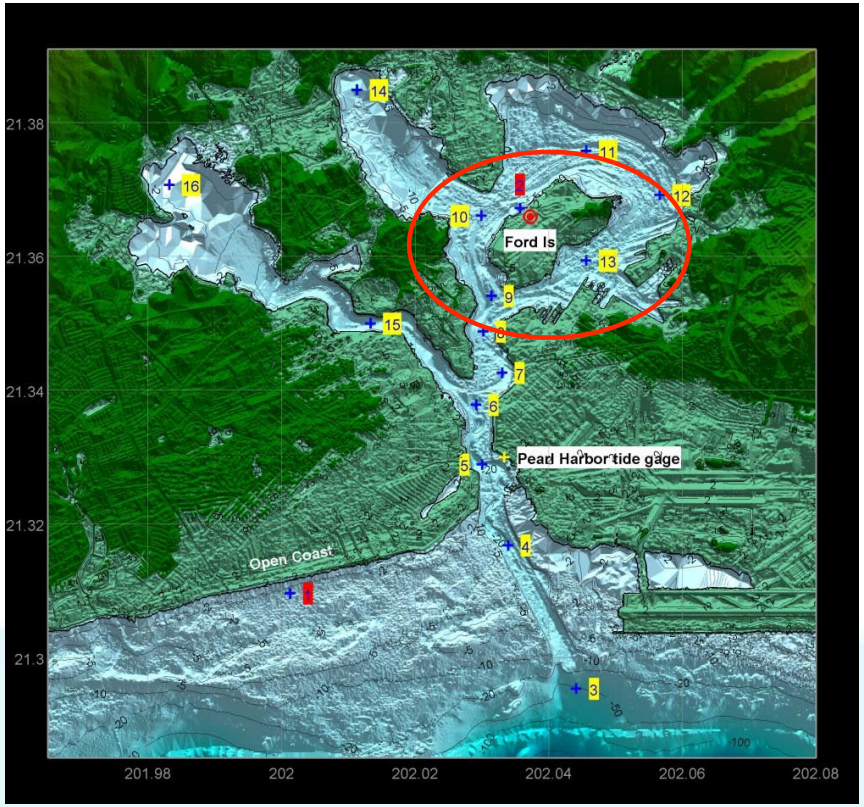
May 2007

UNITED STATES DEPARTMENT OF COMMERCE
Carlos M. Gutierrez
Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
VADM Conrad C. Lautenbacher, Jr.
Under Secretary for Oceans and Atmosphere/Administrator

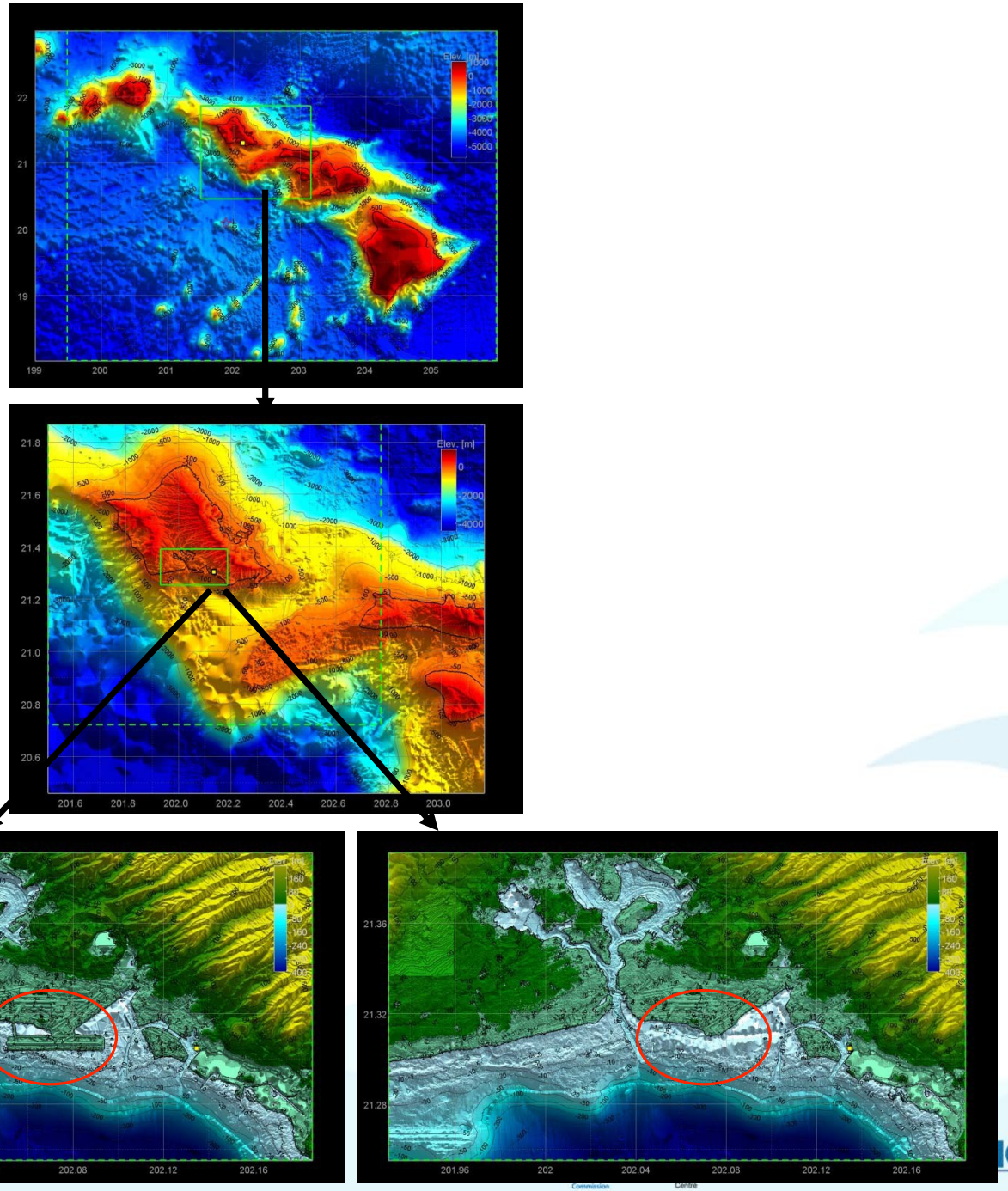
Office of Oceanic and Atmospheric Research
Richard W. Spinrad
Assistant Administrator

Relocation of emergency facilities and vital infrastructure: NOAA's Pacific Tsunami Warning Center



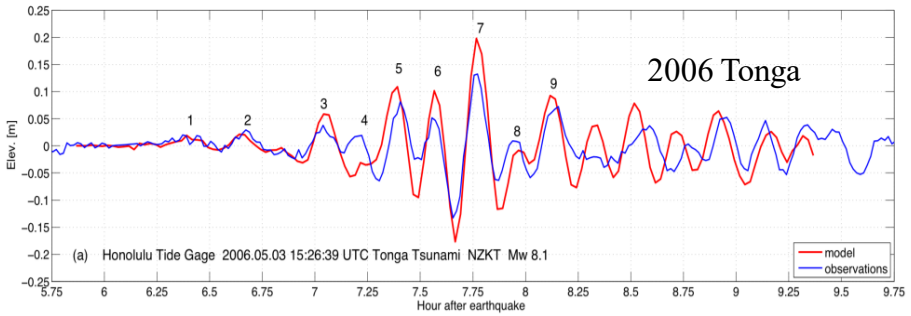
TEMPP 2025

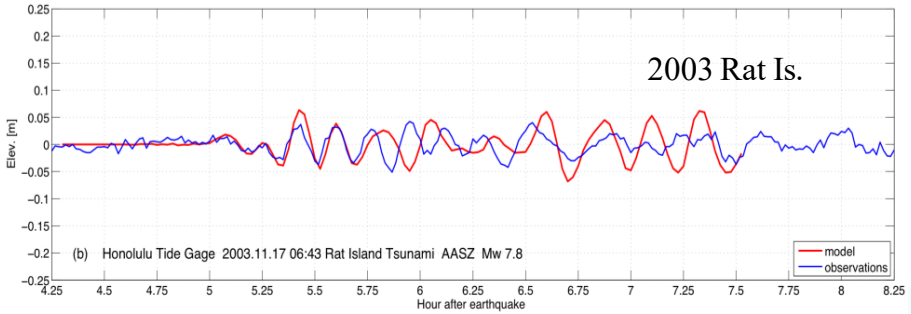
2. Development of high resolution, bathy/topo DEMs

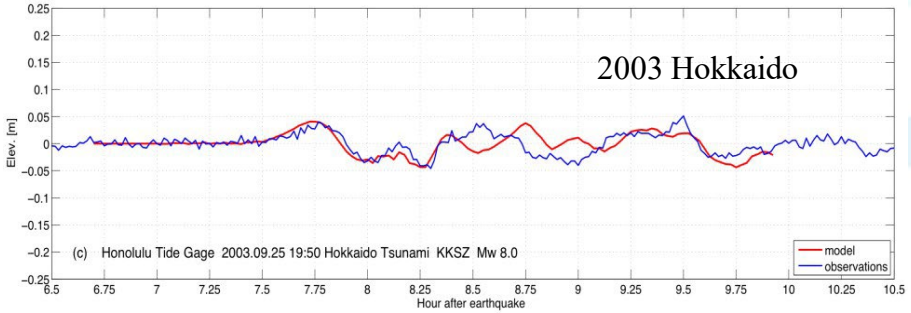


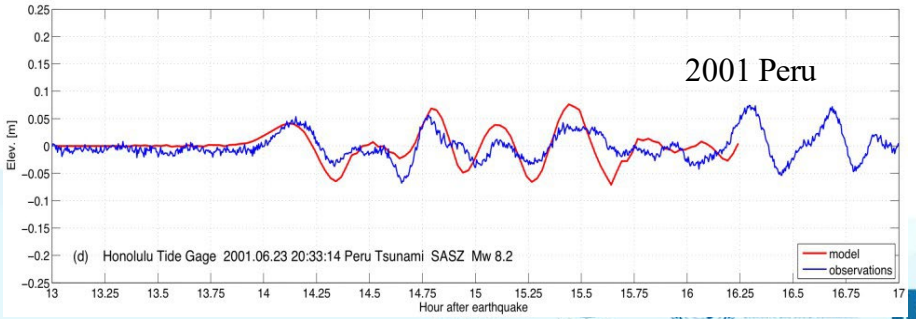
3. Data Acquisition for Model Validation

Invert
DART observations
for tsunami source for
recent events.

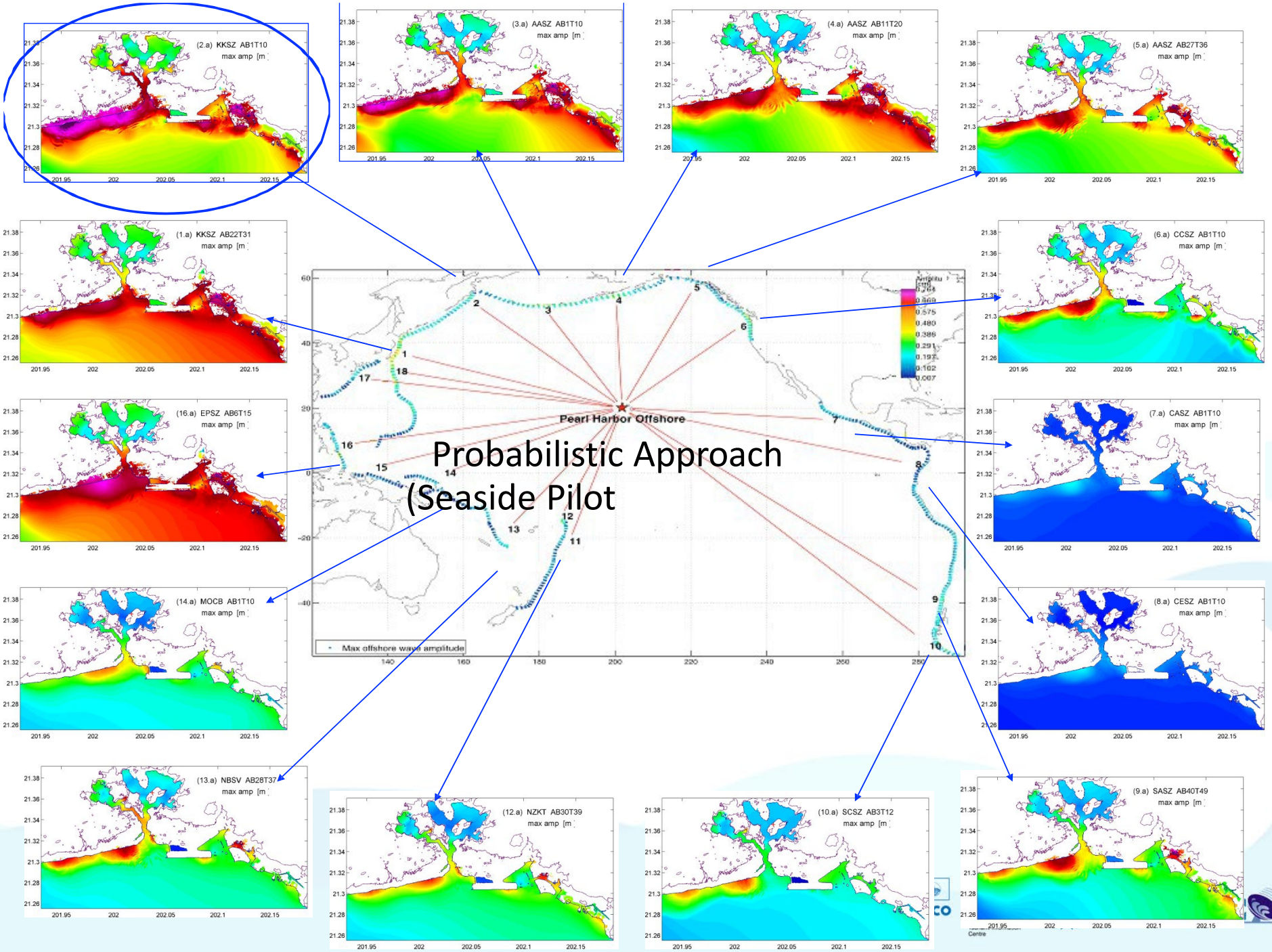








observations
model

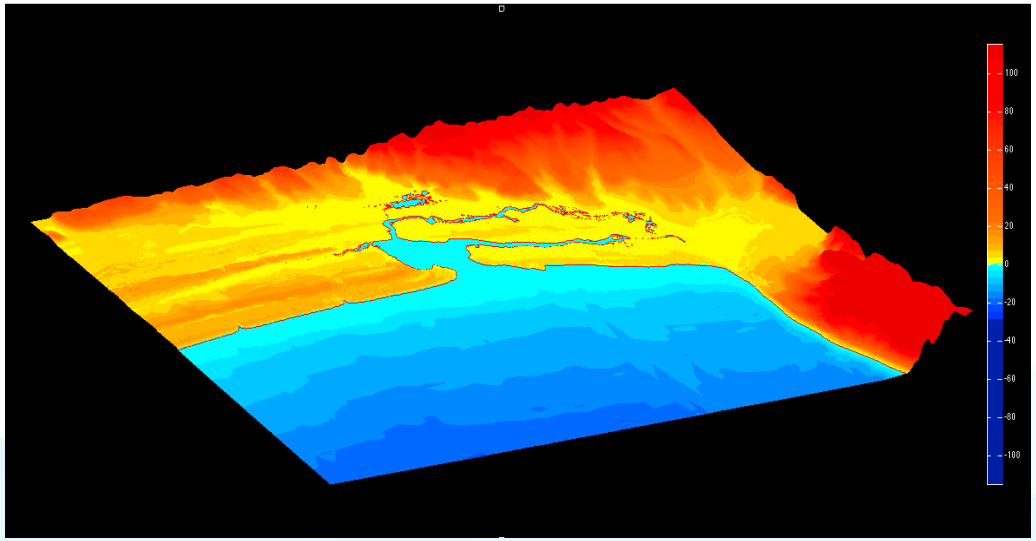

(2.a) KKSZ AB1T10
max amp [m]
(3.a) AASZ AB1T10
max amp [m]
(4.a) AASZ AB11T20
max amp [m]
(5.a) AASZ AB27T36
max amp [m]
(1.a) KKSZ AB22T31
max amp [m]
(6.a) CCSZ AB1T10
max amp [m]
Pearl Harbor Offshore
Probabilistic Approach
(Seaside Pilot
(16.a) EPSZ AB6T15
max amp [m]
(7.a) CASZ AB1T10
max amp [m]
(14.a) MOCB AB1T10
max amp [m]
(8.a) CESZ AB1T10
max amp [m]
(13.a) NBSV AB28T37
max amp [m]
(12.a) NZKT AB30T39
max amp [m]
(10.a) SCSZ AB3T12
max amp [m]
(9.a) SASZ AB40T49
max amp [m]
Max offshore wave amplitude

Long-term Forecast - Examples

Deterministic Approach (Pearl Harbor, HI study)

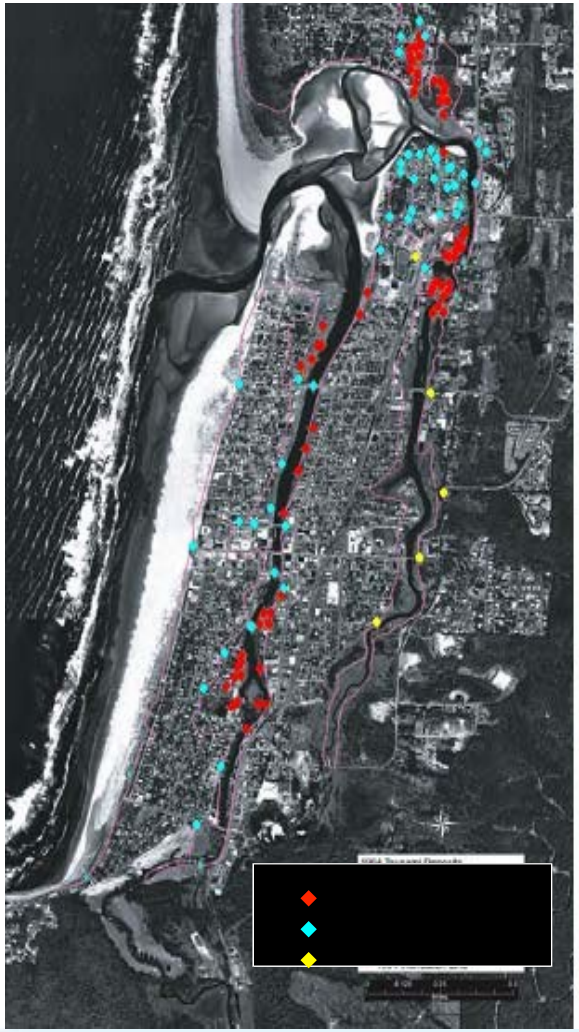
- Probabilistic Approach (Seaside Pilot, OR study)

2. Development of a high resolution Digital Elevation Model

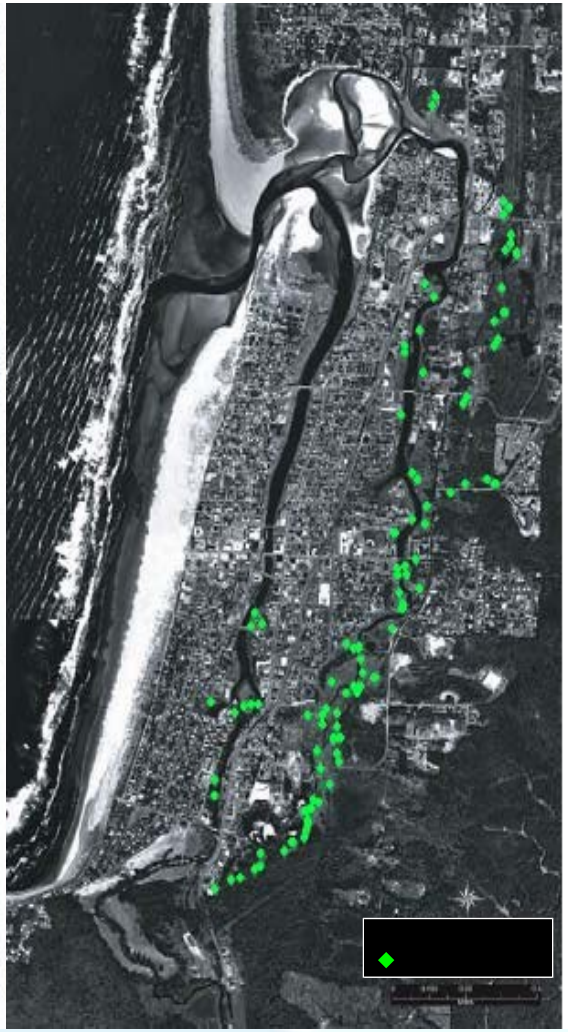


- 1/3 arc sec resolution is necessary for high quality simulations.
- Grids should cover deep (1000 m) and shallow areas.
- DEM is generated in partnership with NGDC, USGS…

3. Data Acquisition for Model Validation



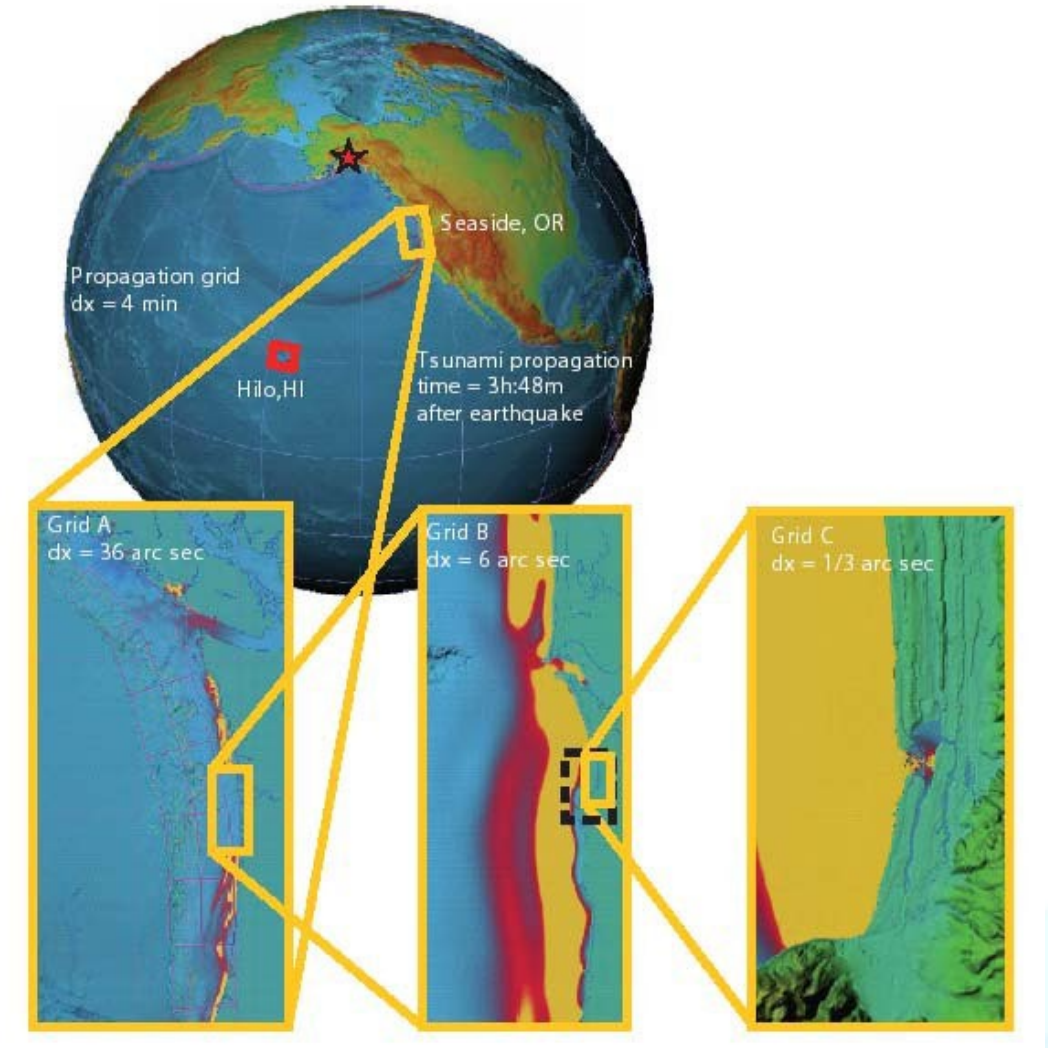
1964 Alaska



1700 Cascadia

- No tide gauge available.
- Tsunami deposits and eye-witness reports provided needed validation data.
- Source available for the 1964 event inverted from HI gauges.

3. Data Acquisition for Model Validation



March 28, 1964 Alaskan Tsunami

Model comparisons:

- Inundation field data at Seaside, Oregon
- Tide gage measurement at Hilo, Hawaii

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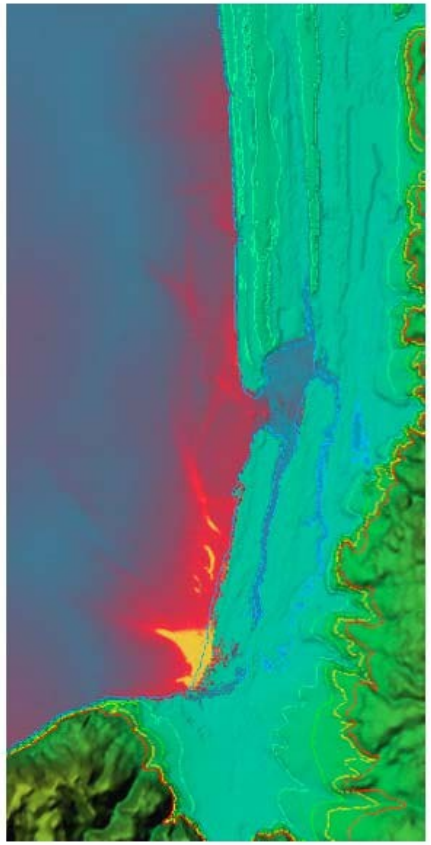
3. Data Acquisition for Model Validation

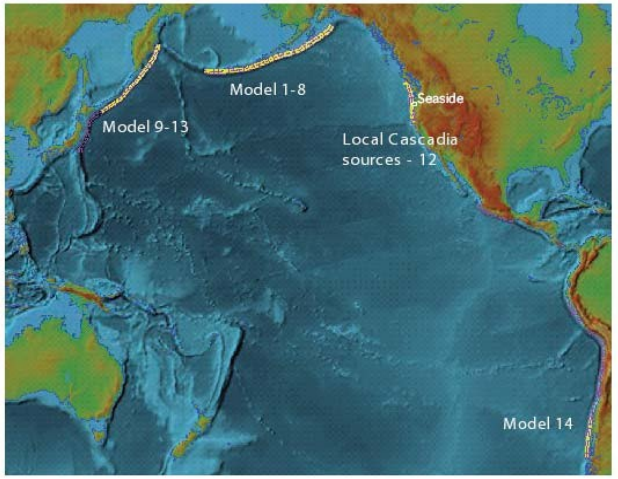


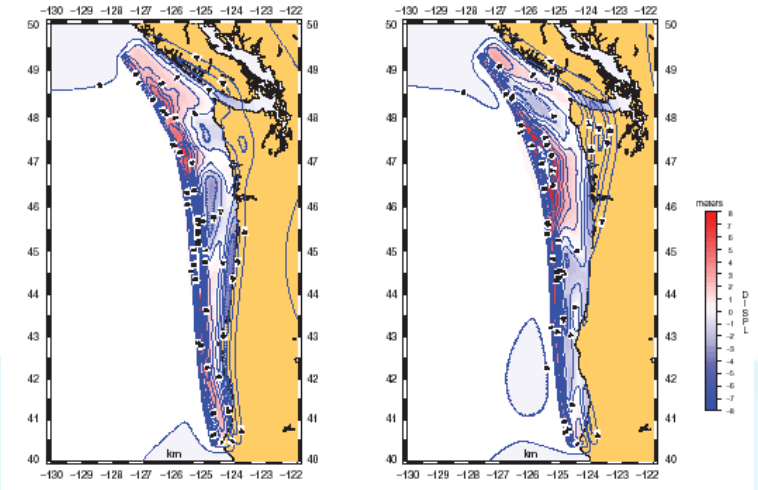
1964 tsunami at Seaside

- Eyewitness reports of 1964 tsunami inundation at Seaside (compiled and measured by T. Horning) are best available tsunami field data for this location.
- Inundation field measurements compared with tsunami simulation results to ensure accuracy of tsunami inundation predictions.
- **Test showed high- resolution grid of at least 10m resolution required** for the Seaside tsunami inundation model.

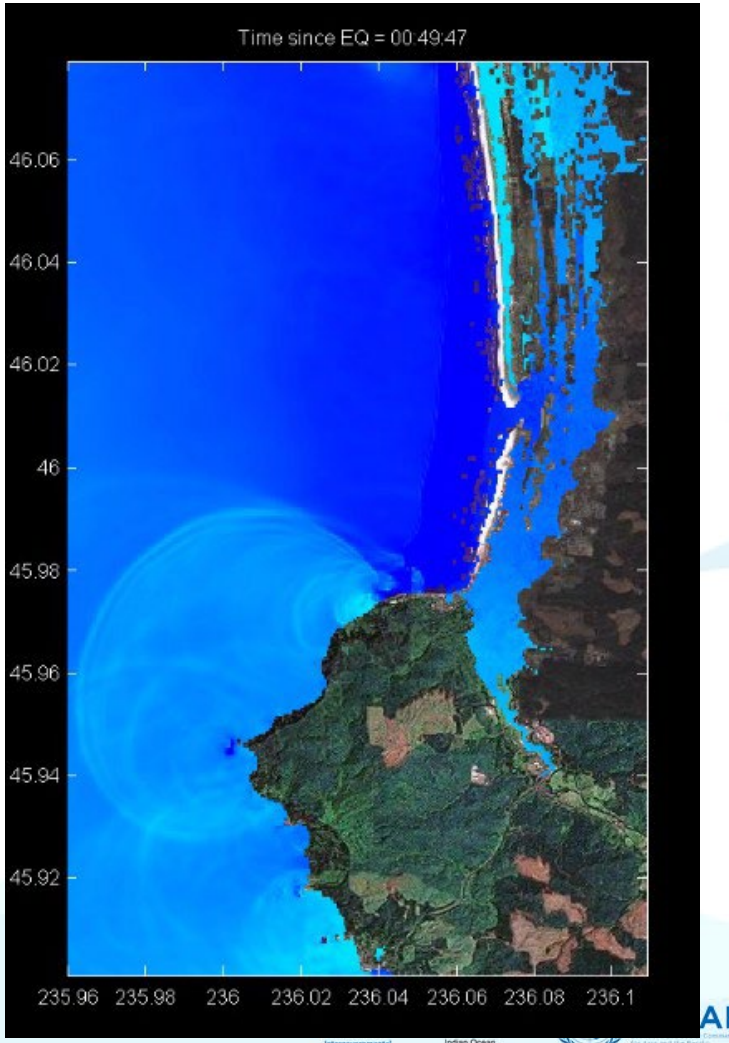
Probabilistic Simulations

Ensemble of potential sources selected



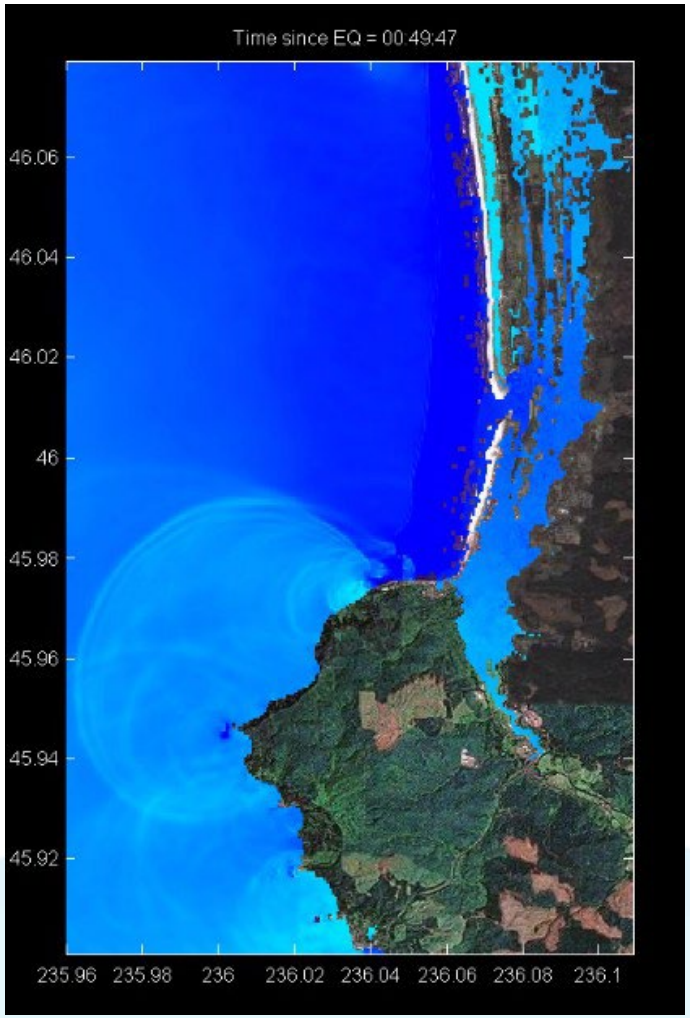


Associated tsunami modeled

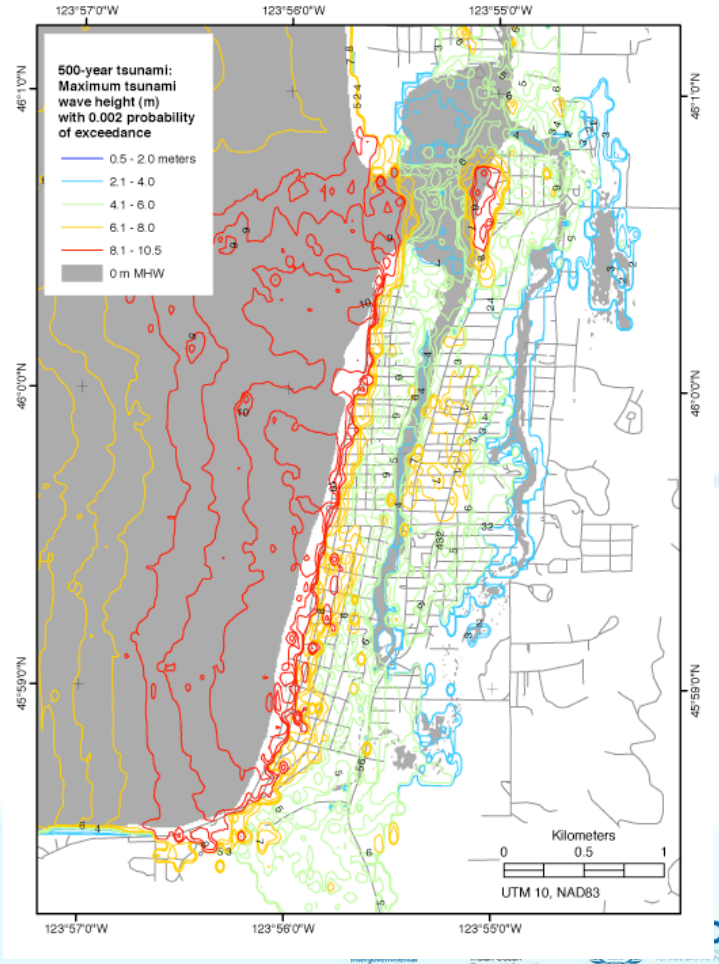


500 Year Tsunami Map

Associated tsunami modeled

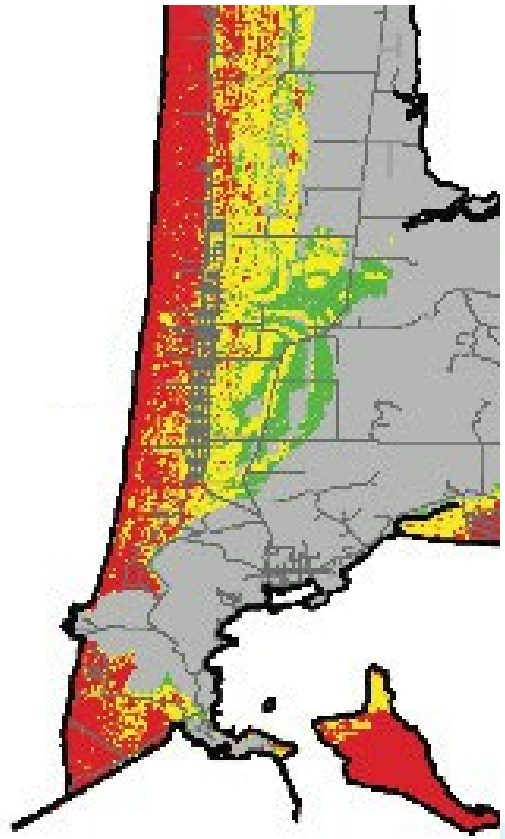


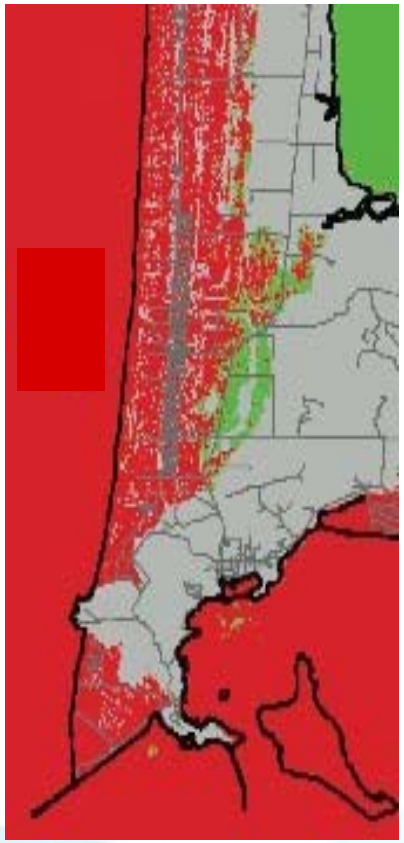
Tsunami inundation probability inferred



Modeling to Inundation Map

Max Inundation + Currents → Inundation map





Long Beach, Washington
(NOAA, WA EMD)

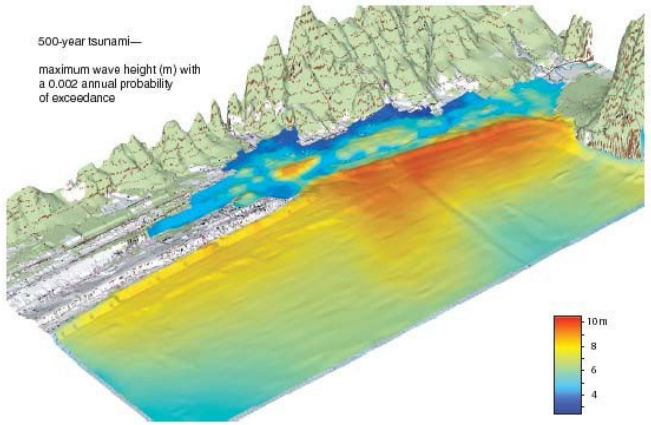
Multiple scenarios/events used in Inundation map

4. Product generation:

Hazard Assessment Report
Inundation Map => Tsunami Evacuation maps

Seaside, Oregon Tsunami Pilot Study—Modernization of FEMA Flood Hazard Maps

By Tsunami Pilot Study Working Group



Joint NOAA/USGS/FEMA Special Report

U.S. National Oceanic and Atmospheric Administration
U.S. Geological Survey
U.S. Federal Emergency Management Agency

USGS science for a changing world

FEMA

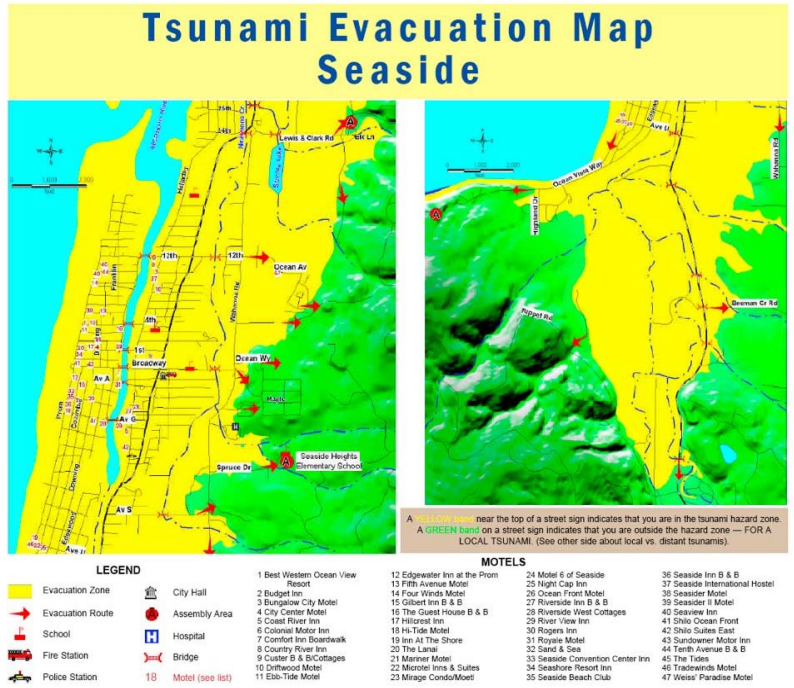
IF YOU FEEL THE GROUND SHAKE,
MOVE QUICKLY TO HIGHER GROUND
AND SAFETY!
DO NOT WAIT FOR AN OFFICIAL WARNING!

TSUNAMI EVACUATION ROUTE

NOTICE

The evacuation zone on this map was developed by the Oregon Department of Geology and Mineral Industries in consultation with local officials. It is intended to represent a worst-case scenario for a tsunami caused by an undersea earthquake near the Oregon coast. Evacuation routes were developed by local officials and reviewed by the Oregon Department of Emergency Management.

The Oregon Department of Geology and Mineral Industries is publishing this brochure because the information furthers the mission of the Department. The map is intended for emergency response and should not be used for site-specific planning.



http://nctr.pmel.noaa.gov/education/science/docs/tsun2975/tsun2975_front_matter.pdf

Science and Public Safety
Saving Lives - Tsunami Evacuation

Inundation Modeling for Evacuation Planning

1. Identify scenarios – historical, probabilistic possible, credible, worst case
2. Numerical Model scenarios
3. Combine results – envelope of all scenarios
4. Inundation Map (all scenarios)

=> Evacuation Map (DMO – community input)

Summary - Modelling for Mitigation

- USES: Long-term Forecasting has multiple applications. Customers range from National to Local governments and Private Sector - diversity of “customers” and stakeholders E.g., NOAA, FEMA, NRC, State, Community

- QUALITY: Standard Methodology ensures authoritative results. E.g., use of validated numerical model, high resolution DEMs, site-specific validation calculations

- PMEL MOST / ComMIT: Numerical Model algorithm and Interface work together to provide user-friendly tool to efficiently conduct hazard assessment for mitigation / evaucation planning. E.g., use of pre-calculated unit-source propagation database, Stand-by Inundation Models (SIM), GIS outputs

Thank you