U.S. NOAA/NWS Tsunami Program

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Pacific Tsunami Warning and Mitigation System
U.S. Tsunami Warning System

End-to-End System

Regional

National

Local

Deep-Ocean Assessment and Reporting of Tsunamis (DART) Observation System
Tsunami-Capable Water-Level Station
National Tsunami Warning Center
National Center for Tsunami Research
National Centers for Environmental Information
Pacific Tsunami Warning Center/International Tsunami Information Center
National Data Buoy Center
NWS Headquarters
Caribbean Tsunami Warning Program

Hazard Detection and Forecast
Warning Formulation
Warning Dissemination
Local Preparedness and Response

NOAA/NWS Tsunami Program
"Warn on Detection" Capability

- **Seismic Networks**
  - GSN + Alaska, Hawaii, Caribbean

- **Sea-Level Networks**
  - 39 US Deep-Ocean Assessment and Reporting of Tsunami (DART) systems
    - National Data Buoy Center
  - >20 international DART systems
  - Coastal sea-level stations
    - NOAA Center for Operational Oceanographic Products and Services (210)
    - Tsunami Warning Centers (23)
    - International locations
Deep-Ocean Assessment and Reporting of Tsunami — 2004

Global Tsunameter Array
Pre - Dec 26, 2004
- United States
- Chile

NOAA/NWS Tsunami Program
½ of operational budget goes to maintaining U.S. DART array

Most expensive locations
Due to cost constraints combined with rapid technological advances, NOAA is considering a future detection grid composed of (e.g.):

- U.S. DART
- International DART
- Seismic stations/density
- Cable observations
- Coastal gauges accompanied by Digital Elevation Models
- Advanced seismic processing (e.g. w-phase CMT)
- GNSS Sensors/Geodetic Analysis
- Coastal Radar

Would PTWS consider developing a Collective Sensing/Instrumentation Grid?
Forecasting and Warning

- U.S. National Tsunami Warning Center
- Pacific Tsunami Warning Center
- Pacific Marine Environmental Laboratory (models, sensors)
- National Centers for Environmental Information (archive, hazards assessment, Digital Elevation Models)
Maximum Tsunami Amplitudes
March 11, 2011 - Honshu, Japan

- Forecasted Maximum Amplitude
- Observed Maximum Amplitude
- Warning Amplitude
- Advisory Amplitude

Locations include:
- Crescent City, California
- Port San Luis, California
- Port Orford, Oregon
- Shemya, Alaska
- Humboldt Bay, California
- Point Arena, California
- Sitka, Alaska
- Santa Monica, California
- San Francisco, California
- La Jolla, California
- Point Reyes, California
- Charleston, Oregon
- Dutch Harbor, Alaska
- Westport, Washington
- Adak, Alaska
- Monterey, California
- Santa Barbara, California
- Sand Point, Alaska
Goal: “Deterministic” Tsunami Forecasts

• More accurate source measurements
  - Seismic analysis (e.g., CMT)
  - Bottom pressure
  - Sea Level
  - Geodesy/GNSS

• Improved propagation models to include Coastal flooding/inundation.
  - SIMs
  - Flooding models
GNSS Earthquake Source Model

Running in real-time on a fixed fault surface
Preparedness and Mitigation

- **National Tsunami Hazard Mitigation Program**
- **TsunamiReady Program**
  - 197 U.S. communities
- **Weather Forecast Offices**
States/Territories with TsunamiReady Communities

- 17 in Oregon
- 24 in Washington
- 51 in California
- 12 in Hawaii
- 3 in Guam
- 2 in American Samoa
- 3 in N. Mariana Islands
- 1 in Puerto Rico
- 46 in U.S. Virgin Islands
- 1 in Military Overseas

TsunamiReady Communities

197 total

NOAA/NWS Tsunami Program
NOAA supports the UN’s Intergovernmental Oceanographic Commission’s coordinated tsunami warning and mitigation systems in the Pacific and Caribbean, providing forecast and observation guidance and education and preparedness services:

- Pacific Tsunami Warning Center
- International Tsunami Information Center
- Caribbean Tsunami Warning Program
- National Weather Service Headquarters
Global Tsunami Warning System

NOAA/NWS Tsunami Program
Bilateral Activities

- Environment Canada
  - Tsunami Warning Services agreement
  - MT Workplan
- Chile—DART
  - 3rd 4G deployment
- UK—Tide gauges (Anguilla, Turks and Cacaos)
- BOM—collective sensing discussions
Research and Development

- Tsunami TestBed (PMEL)
  - Experiment with different data assimilation
  - Improve processing speeds through parallization
- GPS/GNSS (NASA)
- DART 4G (PMEL)
- HF Radar/CODAR (Industry)
- Tview (Decision Support Tool)
- International Capacity Building Initiative (ICW IOC)
  - Exercise Scenarios
  - Training Initiatives
  - Hazard level based on scenario runs using ComMIT (Forecast Models/country developed grids/available grids)
  - Tsunami Coastal Impact Tool

UNESCO/IOC Tsunami Ready Community
What about Non-Seismic Sources...?

How do we define a Tsunami?

• A shallow-water resonant long-wave where phase velocity \( c \) is a function of depth \( H \) such that:

\[
c = \sqrt{gH}
\]

• Tsunamis can be generated a number of ways including undersea seismic disturbances, Submarine Mass Failure (SMF), undersea volcanoes, or weather disturbances transiting bodies of water at speed \( U \) where \( U \sim c \)

• *The U.S. Tsunami Warning System acknowledges responsibility for non-seismic source tsunamis, but has no dedicated resources assigned—leverages “seismic sea wave” system, and other NWS activities (SPC, WFOs)*
June 13, 2013: Uncorrelated Tsunami Strikes NE Coast

NOAA Office of Ocean Exploration and Research tasks Okeanos Explorer to conduct re-survey on 27 June 2013

Survey Results: **Negative**

"...a boy and his father were seriously injured on the jetty that day, received medical treatment and were airlifted to a facility for further care."
2013 Animation

Tsunami Forecast Model Animation of the 13 June 2013 Atlantic Meteotsunami

**RIFT** Model by Dailin Wang
Animation by Nathan Becker

NOAA/NWS/Pacific Tsunami Warning Center

https://www.youtube.com/watch?v=ykABRe5Yt3c

NOAA/NWS Tsunami Program
Notional NE MT Detection Network?

MT Source Area

DART 44402

DART 44401

DART 41424

NOAA/NWS Tsunami Program
HF Radar

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Detection Possible | Detection Most Likely
“Meteotsunami events (height > 0.3 m) occur an average of 106 times per year...much more frequent than follow from historic anecdotal reports...”

Meteotsunamis in the Laurentian Great Lakes, *Scientific Reports* 6, article number: 37832 (2016)
- Adam J. Bechle
- Chin H. Wu
- David A. R. Kristovich
- Eric J. Anderson
- David J. Schwab
- Alexander B. Rabinovich

**Conclusion:** MT must be incorporated into “Total Water”

NOAA/NOS Great Lakes Water Level Stations

1. Grand Marais, MN
2. Duluth, MN
3. Ontonagon, MI
4. Marquette, MI
5. Point Iroquois, MI
6. Port Inland, MI
7. Menomonie, MI
8. Sturgeon Bay, WI
9. Green Bay, WI
10. Kewaunee, WI
11. Milwaukee, WI
12. Calumet Harbor, IL
13. Holland, MI
14. Ludington, MI
15. Mackinaw City, MI
16. De Tour Village, MI
17. Alpena, MI
18. Essexville, MI
19. Harbor Beach, MI
20. Lakeport, MI
21. Fermi Power Plant, MI
22. Toledo, OH
23. Marblehead, OH
24. Cleveland, OH
25. Fairport, OH
26. Erie, PA
27. Sturgeon Point, NY
28. Buffalo, NY
29. Olcott, NY
30. Rochester, NY
31. Oswego, NY
32. Cape Vincent, NY
‘It was like a tsunami’: Philippines stunned by Typhoon Haiyan’s devastation

NEWS NOV 10 2013, 8:38 PM ET

by WORLD NEWS
Is one centrally located DART sufficient to detect SMF source tsunamis?
In Summary...

NOAA’s Tsunami Warning Program is working toward:

- **Sustainable, Reliable Detection.** Move from a costly, unreliable DART-centric detection network to a more sustainable multi-sensor/multi-national sensing strategy.
- **“Deterministic” Forecasts.** Reduce uncertainty in forecasts through (1) more accurate source characterization and (2) development and incorporation of coastal flooding models.
- **Prepared Communities.** Increase focus on community preparedness tools to support both domestic and international customers.
- **Including Non-seismic Sources.** Considering how best to leverage existing capabilities to develop non-seismic source tsunami protocols.
Q&A

NOAA/NWS Tsunami Service Program
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http://tsunami.gov
NOAA’s Tsunami Warning Program is capable of detecting, analyzing, and provide alerts for tsunami waves independent of source.

- NOAA’s Tsunami Warning Program defines tsunami waves as depth constrained, and normally governed by the shallow water equations (noting the Boussinesq PDE sometimes applies).
- These waves are not addressed in any other NOAA/NWS forecasts, warnings or alerts (problem for storm surge calculations?)
- NWS TWS is tuned to detecting and characterizing seismic-source tsunamis.

AGT is difficult and probably represents a small subset of oceanic asteroid impact/airburst

- Airburst velocity > Tsunami phase velocity in most locations
- Impact normally only creates “splash”—however large—not tsunami waves unless on coastal margin
- No known objects large enough to create complete column disturbance in deep ocean

Uncertainties are significant related to AGT potential; nominal resource investments can provide “insurance”

- NOAA should continue to move toward an “all source” detection capability (eg densifying bottom pressure sensing capability away from known seismic source areas) as resources allow
- NOAA’s TWCs are dependent on outside cuing to be alerted to AGT potential formation. Cuing algorithm?
Typical Tsunami Response Timeline: Domestic Earthquake

- **Earthquake**: 0:00
- **Detect**: 0:10
- **Analyze**: 1:00
- **Warn**: 3:00
- **Respond**: 4:00

Seismic Data

Prepare and Distribute Products

Time in Minutes

NOAA/NWS Tsunami Program