Intergovernmental
Oceanographic
Commission

UNESCO/IOC – NOAA ITIC Training Program in Hawaii (ITP-TEWS Chile)
TSUNAMI EARLY WARNING SYSTEMS
AND THE PACIFIC TSUNAMI WARNING CENTER (PTWC) ENHANCED PRODUCTS
TSUNAMI EVACUATION PLANNING AND UNESCO IOC TSUNAMI READY PROGRAMME
19-30 August 2024, Valparaiso, Chile

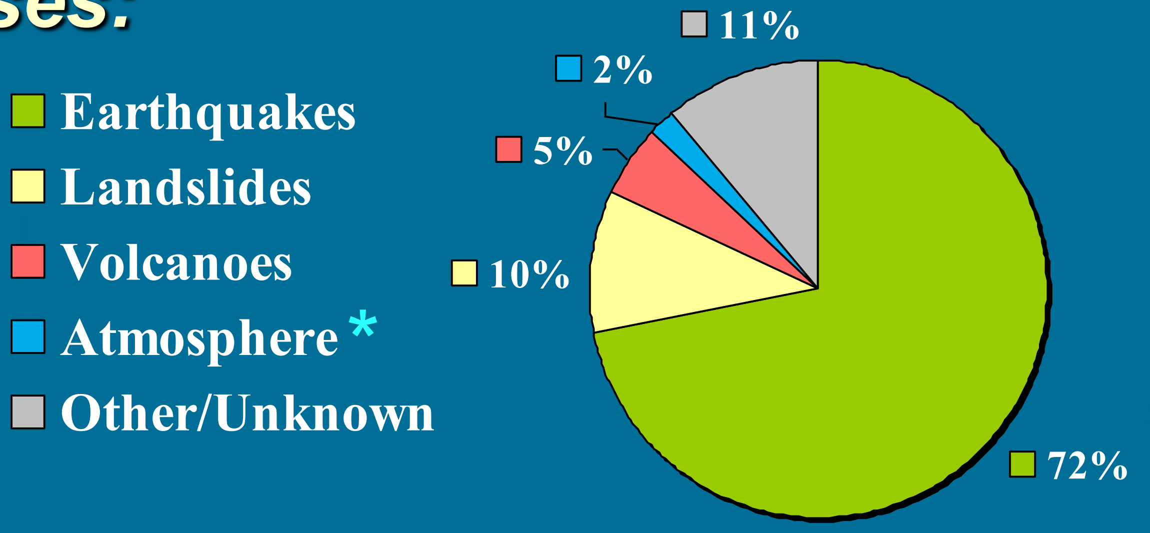
Tsunamis Generated by non-Seismic Sources

Stuart A. Weinstein
NOAA/NWS/PTWC

What is a tsunami?

A tsunami is a series of long-period waves created by an abrupt displacement of the ocean.

Causes:



Non-Seismic Sources

1. **Volcanos**

   Can trigger Classical tsunamis and Atmospheric (Lamb Wave) generated tsunamis

2. **Meteorological**

   Tsunamis generated by Meteorological Phenomena

3. **Landslides**

4. **Meteorites**

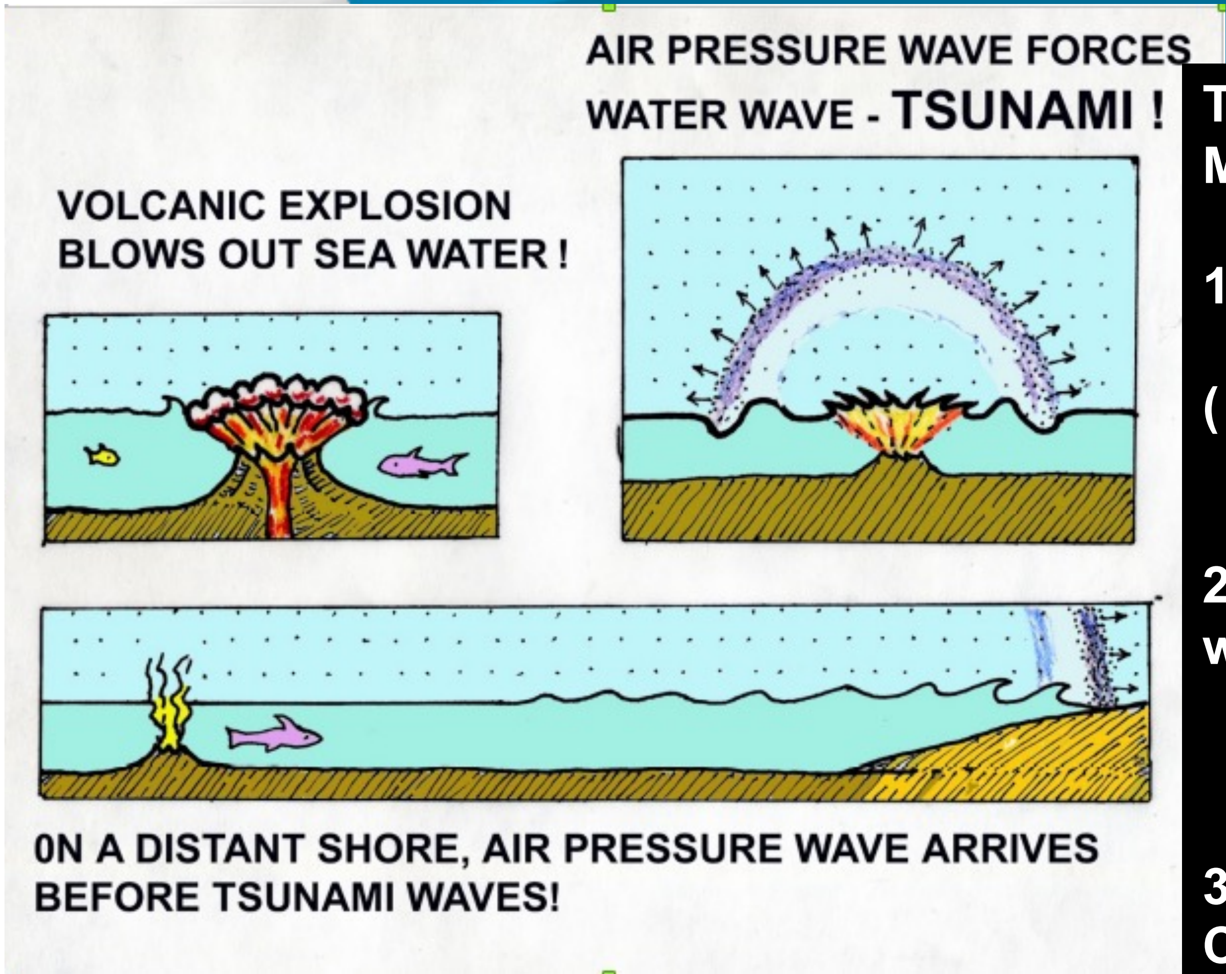
Non-seismic tsunami – 2018, 2022

- **Generated by landslide:**
  Aysen Fjiord 2007 (M6.2, 10 deaths)
  Palu 2018 (EQ subsidence, liquefaction)
- **Generated by volcanoes –**
  Krakatau 2018 (474 deaths) (1883, 35,000 deaths),
  Hunga Tonga, Hunga Ha’apai 2022 (4 deaths) – tsunami + lamb wave

Lessons Learned

- **Need to develop non-seismic Tsunami Early Warning System**
- **TW current: detect=>warn**
- **Increase awareness**
- **Multi-hazard EW**

1. Tsunami Generation by Volcanos



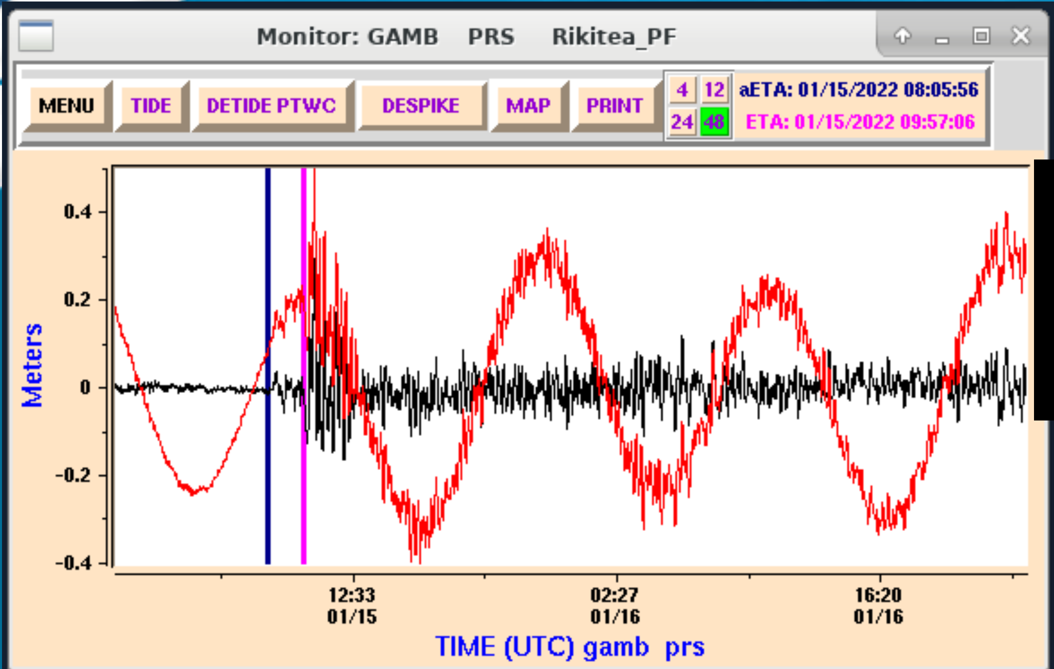
Three Tsunami Generation Mechanisms:

1. Caldera/Flank collapse
   => Near field
(This is what we thought was happening at first)

2. Sonic Boom, Air pressure waves (Lamb Waves), V ~300m/s
   => World wide (Atmosphere is vibrating)

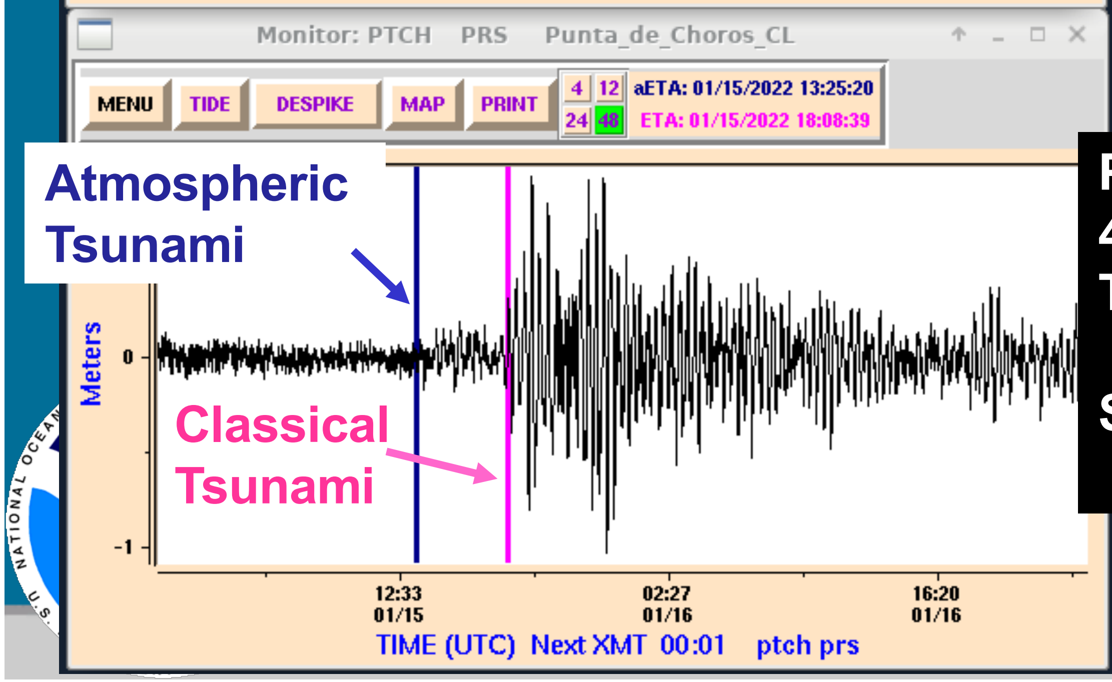
3. Volcanic explosion/Pressure Change deforming sea-surface
=> Classic Tsunami Waves

Tsunami Observations for HTHH



Rikitea, French Polynesia
2hrs separates Pressure Generated Tsunami from Classical Tsunami

Long Duration



Punta de Choros, Chile
4.5hrs separates Pressure Generated Tsunami from Classical Tsunami

South America was hardest hit

1. How big was the HTHH explosion ? NASA's first estimate was 10-18MTNs. Subsequent estimates put it on par with Pinatubo or Tsar Bomba. Today, estimates of the explosion yield are in the range 100-200MTNs (based on Infrasound analysis, Vergoz et al, 2022). On par with Krakatau (1883)

2. Largest event recorded by IMS infrasound

3. Ionospheric disturbances due to Lamb Waves and classical Tsunami waves detected. GNSS & Ionospheric afterglow variations
   => These can be used for tsunami modelling/forecasting

4. Air-Pressure wave generated tsunami can be hazardous

Hunga Tonga – Hunga Ha'apai Tsunami – 15 January 2022

- Volcano eruption generated tsunami and atmospheric pressure waves that also generated tsunami waves.

  => Tsunamis involve coupled air-sea interaction
- Acoustic 'boom' heard in Alaska, wave observed in Caribbean, Atlantic, Indian Ocean
- 4 deaths locally, 1 in Peru (related to fuel unloading)
- PTWC ad hoc messages. No TW, nor forecast (models unknown)
- Interim HTTH PTWC response implemented - March 2022

Lessons Learned

- Must detect, then warn. But Volcano eruption has more lead time. 'Faraway' countries should monitor wave for potential threat.
- 13 January event 'pre-alerted' (PTWC implemented tsunami detector)
- WTAD and other awareness made public aware

Due to Activity at LaSoufriere, PTWC developed a product (unofficial) in case an eruption occurred.

We monitor these sea-level stations:

CALQ - Calliaqua, St Vincent
STLU - Ganters Bay, St. Lucia
LERO - Le Robert, Martinique
FTFR - Fort de France, Martinique
PRIC - Prickley Bay, Grenada
ROSE - Roseau, Dominica
PTMD - Portsmouth, Dominica

Information Statement: If you observe a signal(s) no greater than 0.3 m amplitude at Calliaqua (the closest station) and/or other stations, then measure and record the signal(s) and issue an Information Statement.

Threat Message: If you observe any signal(s) greater than 0.3 m amplitude on any station then issue a Threat Message.

2. Meteotsunamis

They are actually fairly common. The Atlantic coast of the US may experience ~25 meteotsunamis per year. Back in 2013 A metetosunami struck the NE US coast injuring 12 people

Meteotsunamis produced in the US Great Lakes have also caused casualties. A Meteotsunami warning system for the Great Lakes has been under consideration.

Not just the US, but the Mediterranean, and other regions are also affected by meteotsunamis

June 13, 2013 East Coast Meteotsunami

Dailin Wang, Nathan Becker, Stuart Weinstein, Paul Whitmore

Hypothesis:

Tsunami was generated near the continental slope when the East-ward propagating Derecho reached the deep ocean.

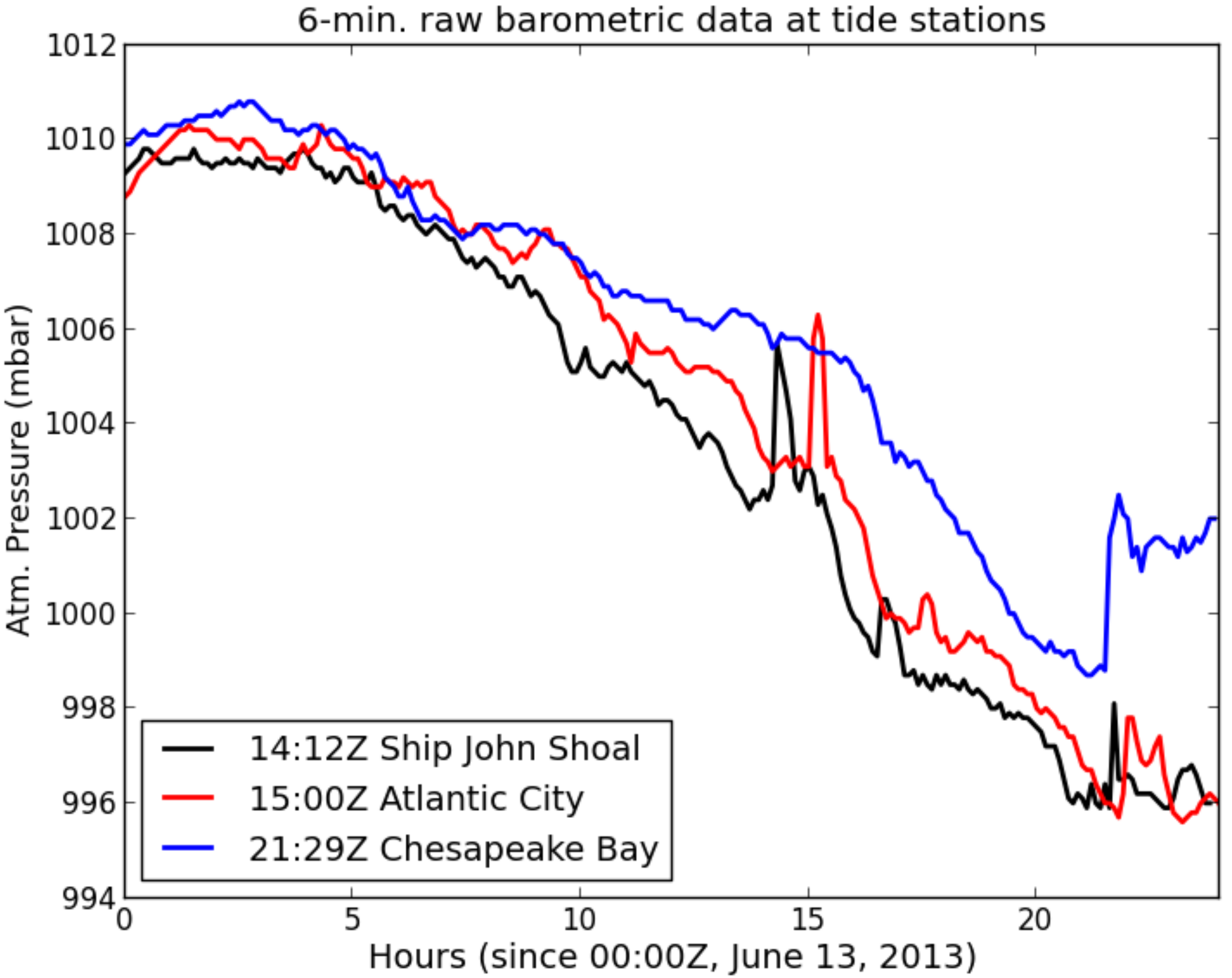
Data analysis:

- **Initial small tide station responses as the disturbance passes through**
- **Largest tide station response was due to the tsunami.**
- **Barometric pressure data suggests burst of atm. pressure over a period of 30 min. (temporal resolution is poor, at 6-min.).**

Model (2D) results with idealized atm. pressure forcing

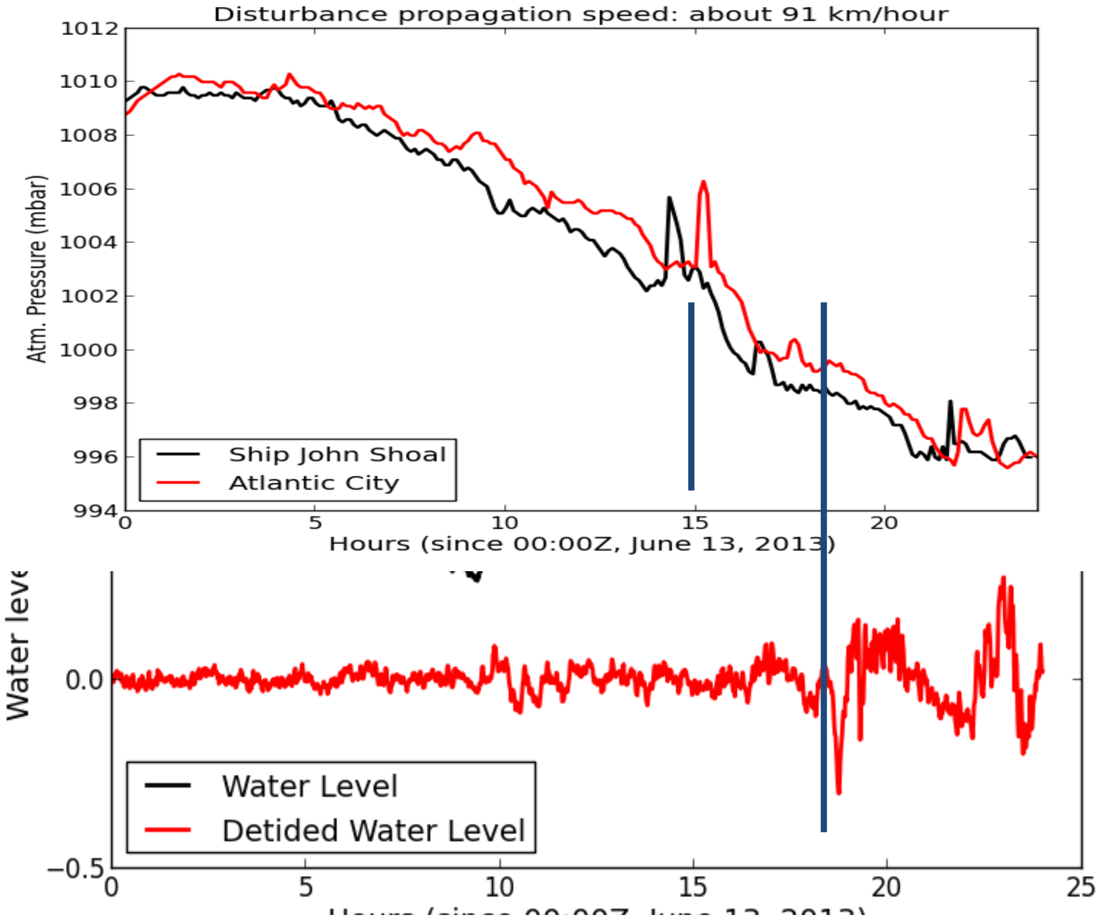
Inconclusive but promising, better forcing data are needed to further investigate.

Implications for meteotsunami warning


6-min. raw barometric data at tide stations
Atm. Pressure (mbar)
1012
1010
1008
1006
1004
1002
1000
998
996
994
0
5
10
15
20
Hours (since 00:00Z, June 13, 2013)
14:12Z Ship John Shoal
15:00Z Atlantic City
21:29Z Chesapeake Bay

Implications for tsunami warning

Pressure jump/disturbance arrived at acnj tide station at 15:00Z
Wave arrived at 18:33Z, about 3.5 hours later. This time lag is a window of opportunity for tsunami warning, if the disturbance Is large (only works if the continental shelf is very shallow and wide and the shelf-edge is far).
Precomputed model results with various scenarios can also be used.

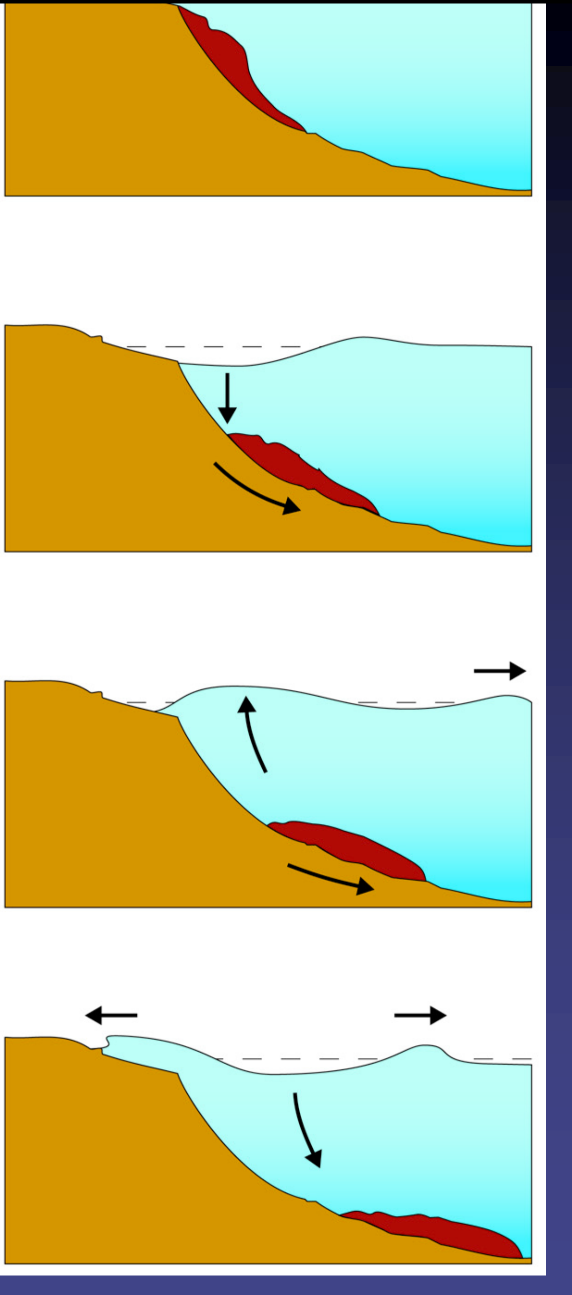


Need high frequency pressure data to define the temporal and spatial profile of the propagating disturbance over the ocean.

1-min. pressure data from offshore bprs will help.

3. Landslides

- Often triggered by earthquakes
- Rotational slumps (Papua New Guinea, 1998)
- Debris avalanches (Lituya Bay, Alaska; extreme local hazard)
- Common on volcanoes: Oshima Oshima 1742; Matuyama (Unzen) 1792; St. Augustine 1883; Ritter 1888.
- No distant hazard from oceanic island slides
- Highly dispersive tsunamis (i.e., no ocean-wide hazard) except from slides down gentle continental margins (e.g. Mauritania, Western Sahara)
- Shallow retrogressive failure (Grand Banks, 1929; Molokai, 1903): probably very common; very difficult to identify in bathymetry.



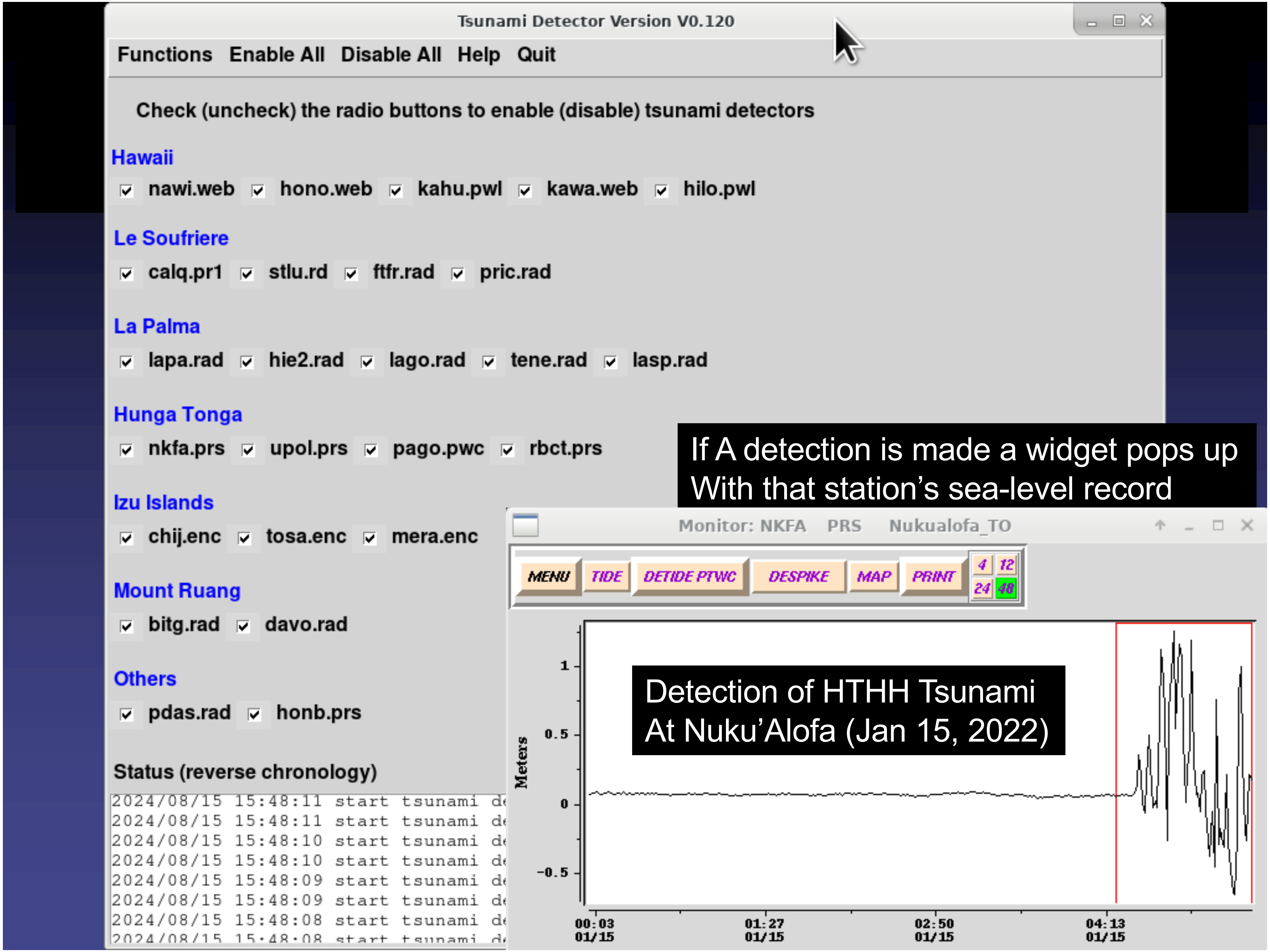
With sufficient data/modeling we might be able
to issue warnings for meteotsunamis before their
formation..

Tsunamis generated by landslides or volcanic activity… not
so much… So, try and detect the tsunami as soon as
possible. Also.. Try to identify areas where landslides
are a threat. In the US we are concerned about Barry's Arm
In Alaska

Following the eruption of La Soufriere and worries about
Kick'em Jenny, PTWC operationalized a tsunami detector
created by Dailin Wang and developed an unofficial
message product in case eruptions in this region generate
tsunamis

The detector examines real-time, de-tided sea-level data. If the de-tided signal exceeds a threshold (differs from station to station) the Duty scientist gets paged.

Due to volcanic activity occurring at HTHH, the tsunami detector was operationalized on the sea-level station at Nuku'Alofa on Jan 13, 2022. Two days later, the duty scientists were paged..

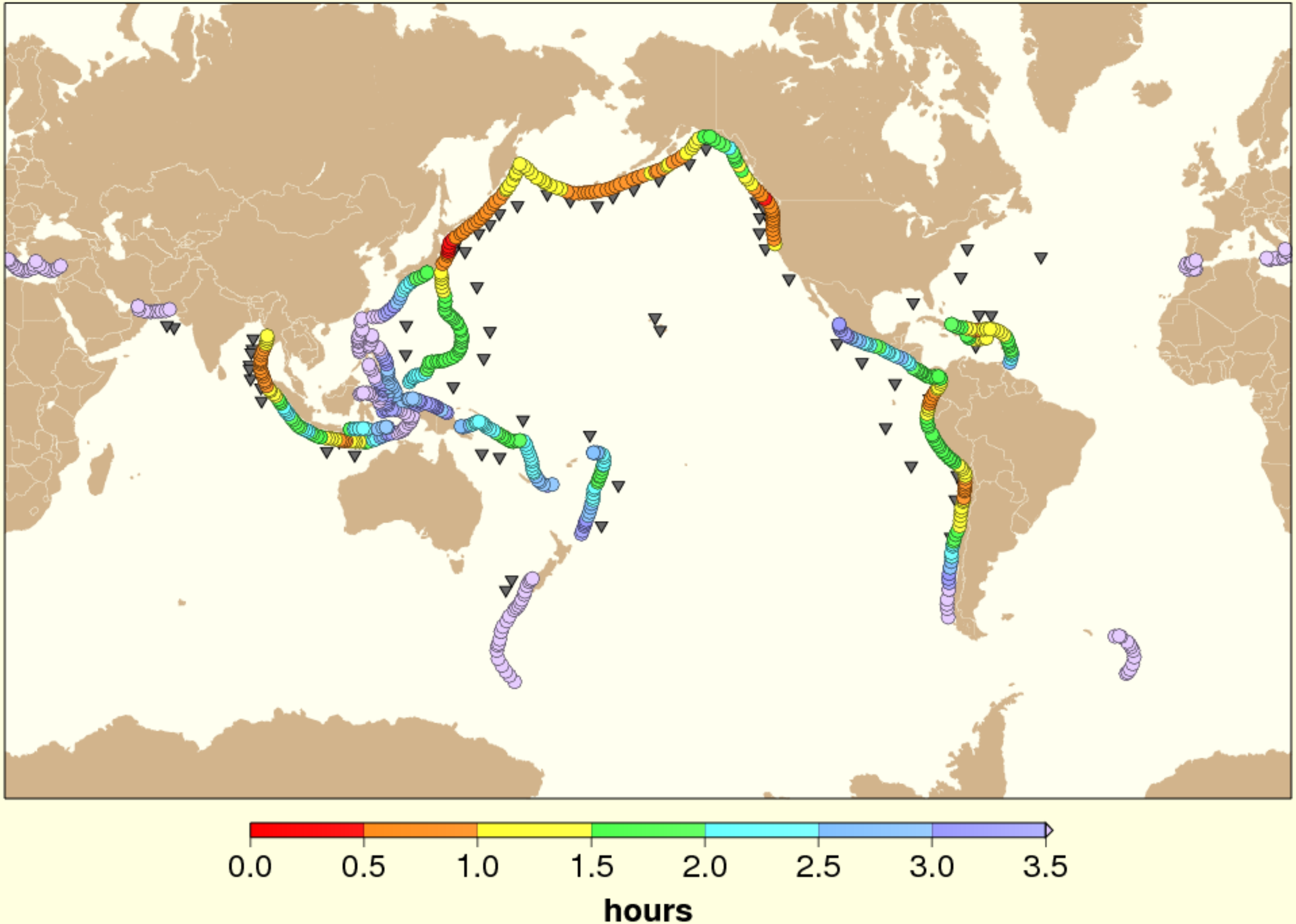

Tsunami Detector Version V0.120
Functions Enable All Disable All Help Quit
Check (uncheck) the radio buttons to enable (disable) tsunami detectors
Hawaii
nawi.web hono.web kahu.pwl kawa.web hilo.pwl
Le Soufriere
calq.pr1 stlu.rd ftfr.rad pric.rad
La Palma
lapa.rad hie2.rad lago.rad tene.rad lasp.rad
Hunga Tonga
nkfa.prs upol.prs pago.pwc rbct.prs
Izu Islands
chij.enc tosa.enc mera.enc
Mount Ruang
bitg.rad davo.rad
Others
pdas.rad honb.prs
Status (reverse chronology)
2024/08/15 15:48:11 start tsunami de
2024/08/15 15:48:11 start tsunami de
2024/08/15 15:48:10 start tsunami de
2024/08/15 15:48:10 start tsunami de
2024/08/15 15:48:09 start tsunami de
2024/08/15 15:48:09 start tsunami de
2024/08/15 15:48:08 start tsunami de
If A detection is made a widget pops up
With that station's sea-level record
Monitor: NKFA PRS Nukualofa_TO
MENU TIDE DETIDE PTWC DESPIKE MAP PRINT 4 12 24 48
Meters
1
0.5
0
-0.5
Detection of HTHH Tsunami
At Nuku'Alofa (Jan 15, 2022)
00:03 01/15
01:27 01/15
02:50 01/15
04:13 01/15

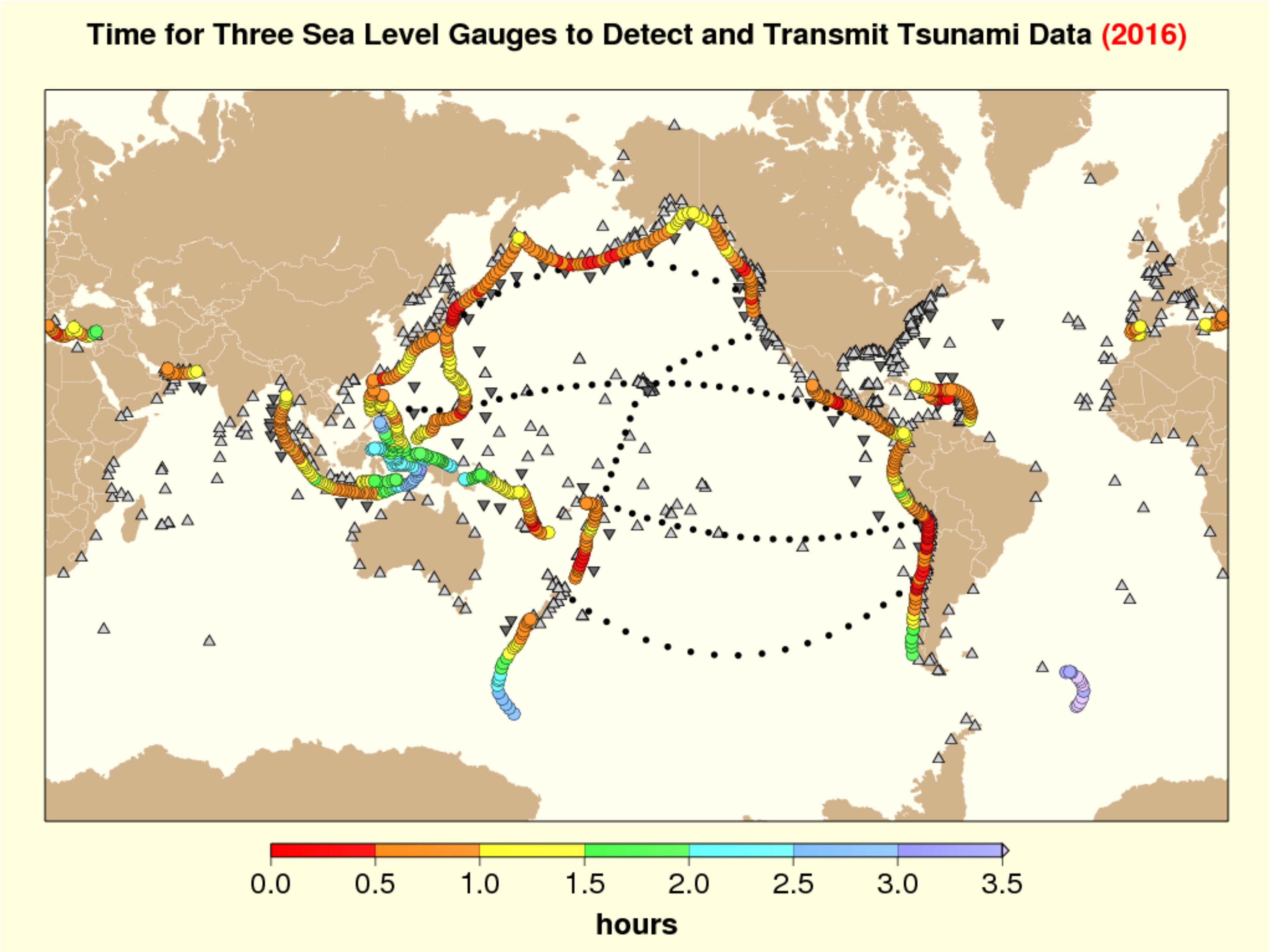
Another method we use for detecting tsunamis are run-up detectors.

Runup Gauge

<= solar panel
cell antenna
electronics,
battery
lwater activated
sensor

Time for Three Sea Level Gauges to Detect and Transmit Tsunami Data (2016)




Time for Three Sea Level Gauges to Detect and Transmit Tsunami Data (2016)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
hours

Ways to Improve Tsunami Detection

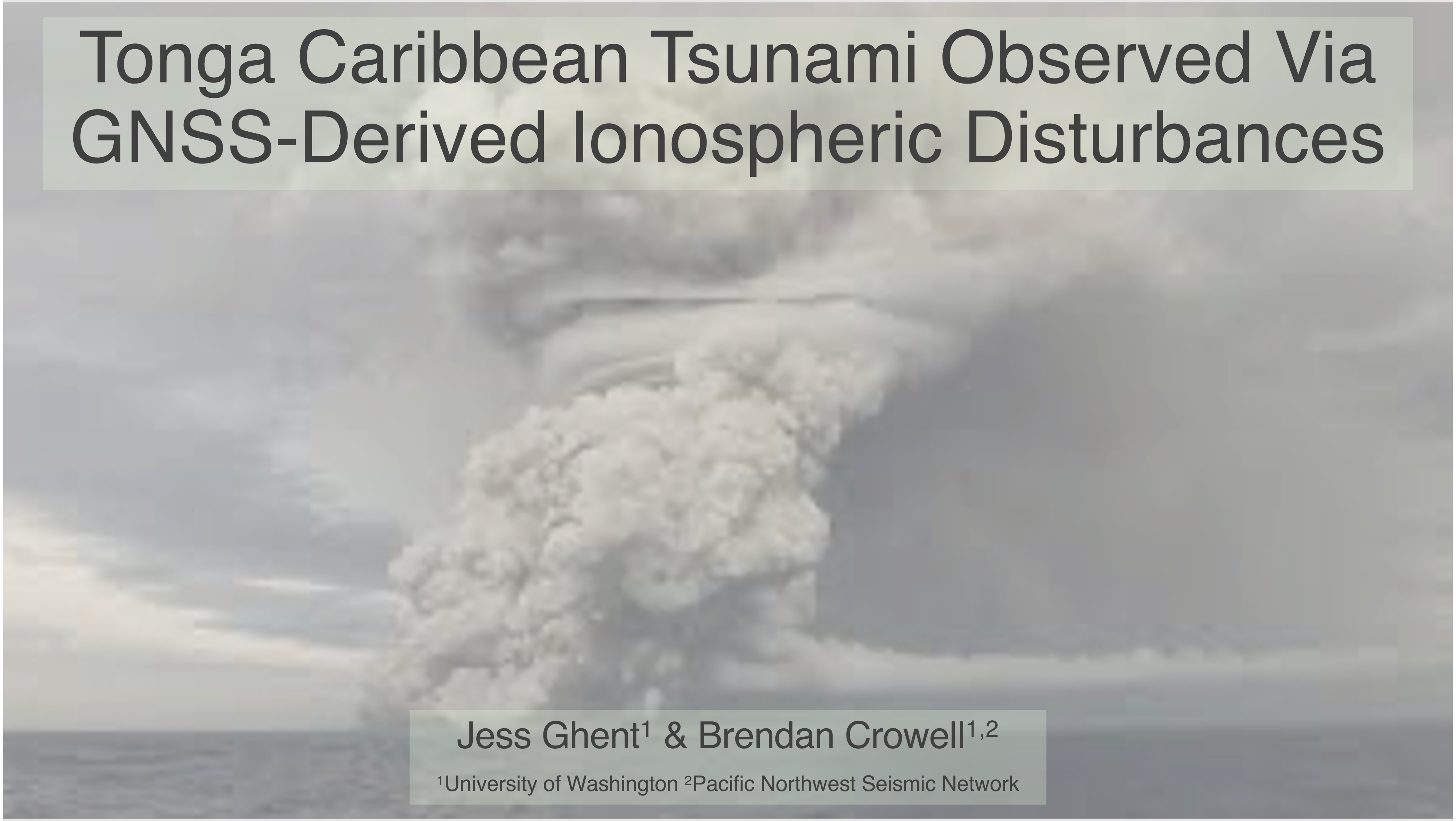
1. More Sea-Level Stations
   => More Coastal sea-level stations
   => More offshore BPRs

2. Tsunami Runup Detectors

3. More Barometric Data
   => Detect conditions which result in

What’s in The Near Future For Tsunami Detection?

Tonga Caribbean Tsunami Observed Via GNSS-Derived Ionospheric Disturbances



Jess Ghent[1] & Brendan Crowell[1,2]

[1]University of Washington [2]Pacific Northwest Seismic Network

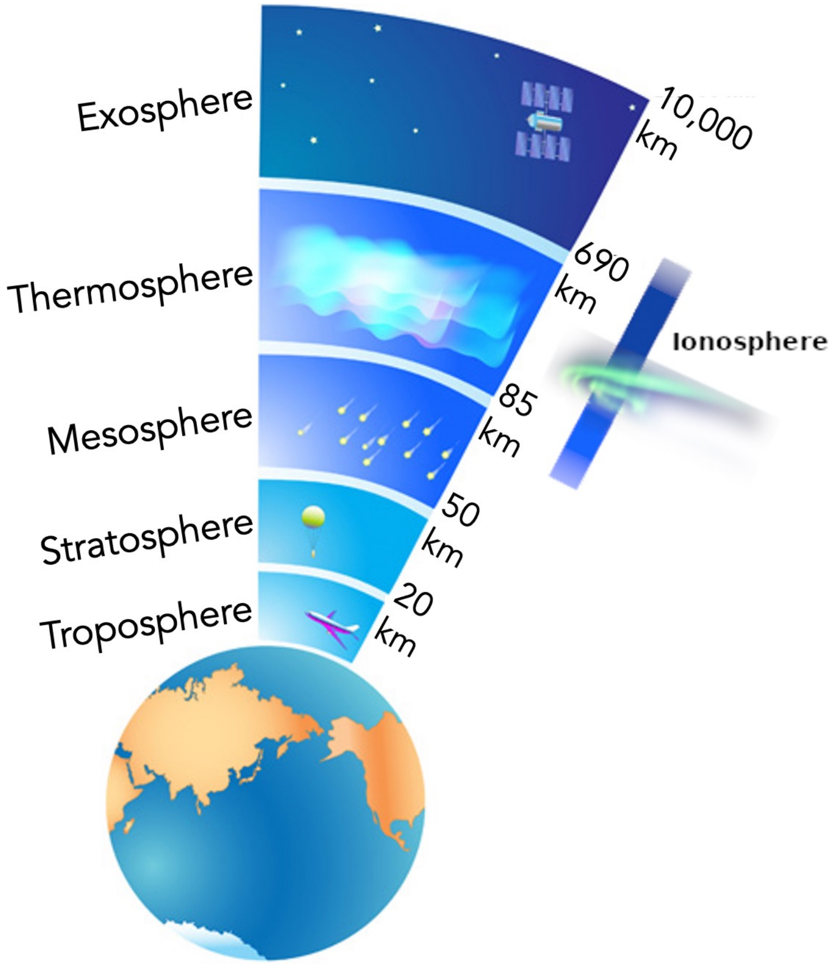
Ionosphere

Electrically charged layer

Disturbed by acoustic-gravity (AG) waves from:

- Volcanic eruptions
- Tsunamis

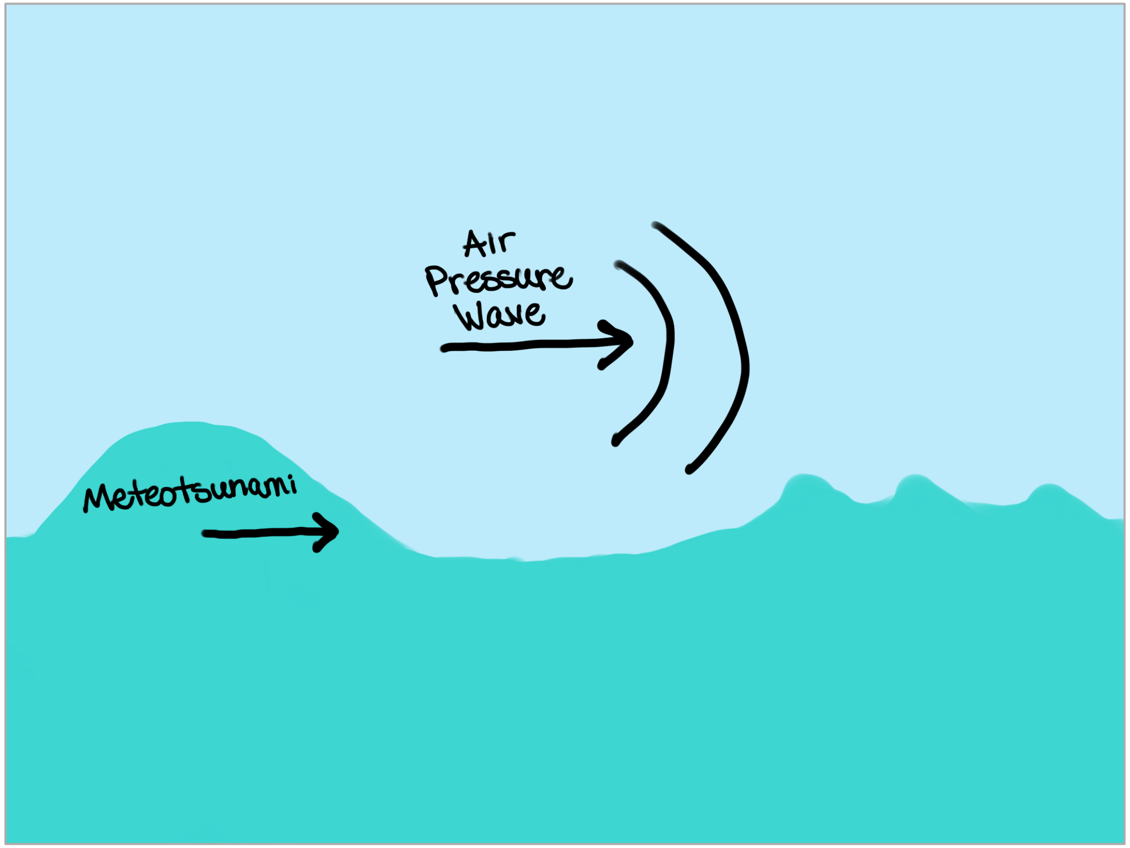
AG wave compresses layers of e^- as it passes



Modified from NASA CET

- Jess Ghent[1] & Brendan Crowell[1,2]
- [1]University of Washington [2]Pacific Northwest Seismic Network

Meteotsunami



Pressure wave / Lamb wave generates tsunami

→ Atmospheric waves & tsunami disturb ionosphere

Ionosphere AG waveforms are like ripples

Tsunamis and Atmosphere are Dynamically Coupled

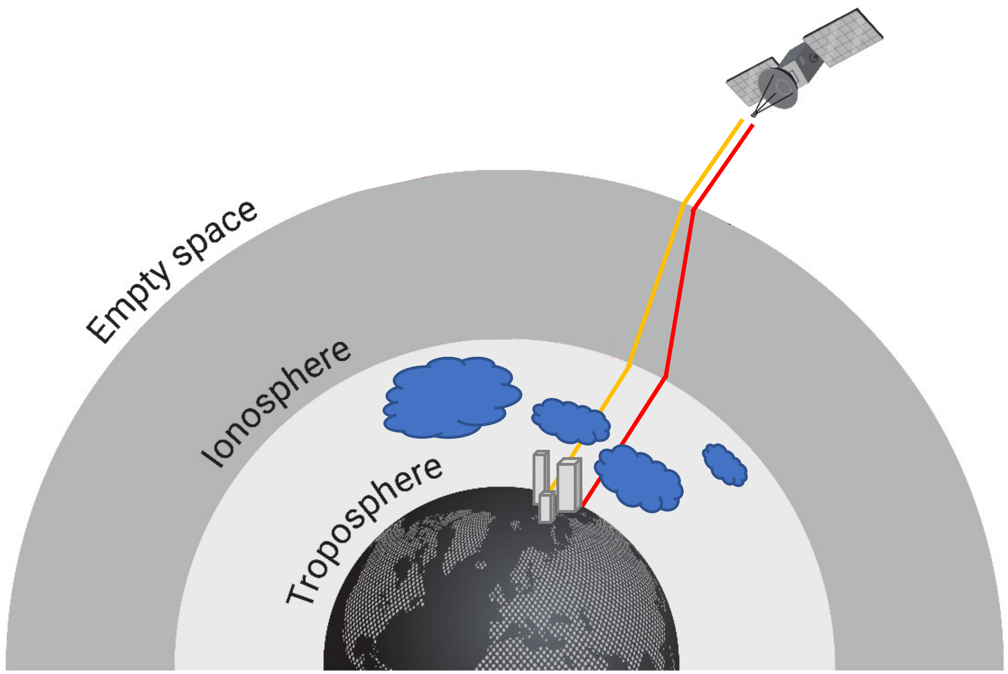
- Jess Ghent[1] & Brendan Crowell[1,2]
- [1]University of Washington [2]Pacific Northwest Seismic Network

Dual-Frequency GNSS

Satellite emits two signals at different frequencies

Ionosphere & other factors create signal delays

Difference observables across time to isolate ionospheric TEC



Thank You

Stuart Weinstein
NOAA/NWS/PTWC