GNSS Tsunami Early Warning in Oceania

Viliami Folau and the GNSS for Tsunami Early Warning System (GTEWS) for the South Pacific working group

12th Plenary Meeting of the UN-GGIM-AP, 6-10 November 2023, Bali

Geodetic Reference Frames and Applications for Disaster Workshop

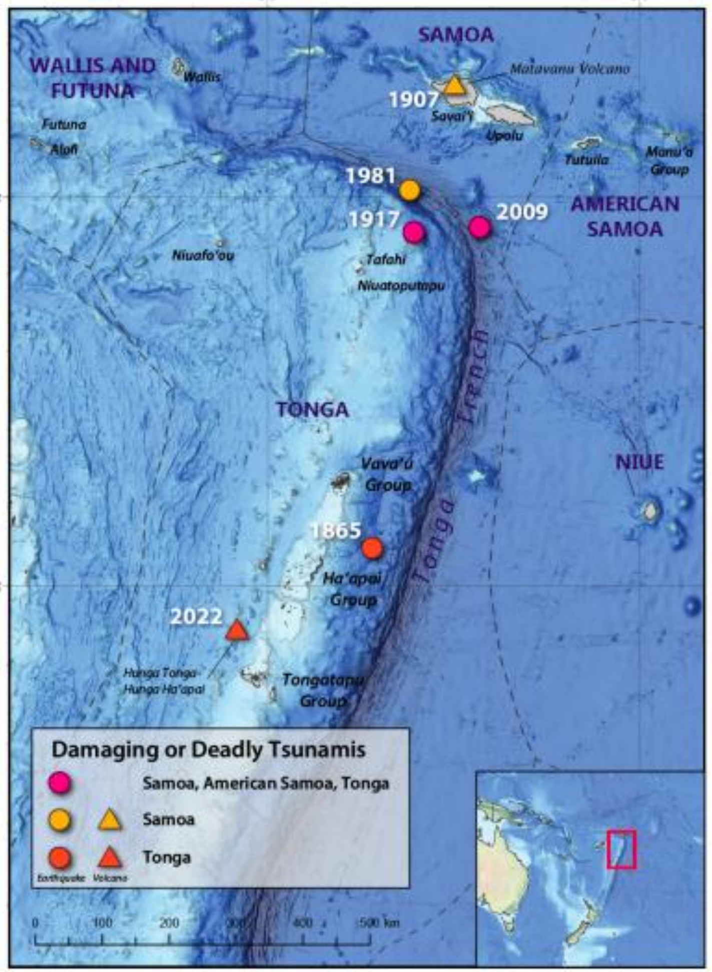
GTEWS Oceania working group participants

GTEWS chair: **John LaBrecque** - jlabrecq@mac.com

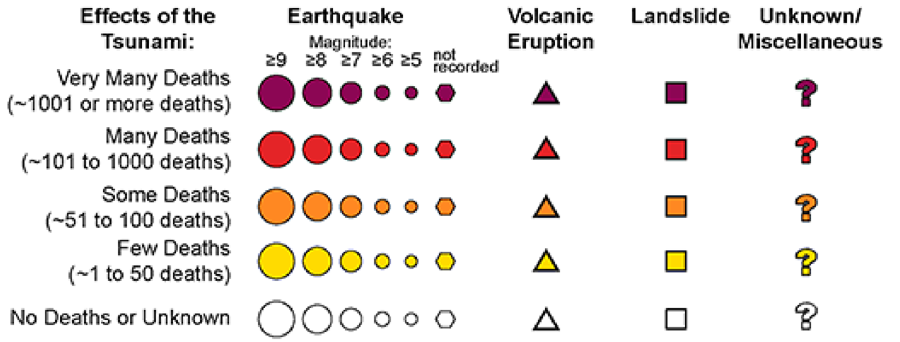
Thanks to IUGG Commission on Geophysical Risk and Sustainability for its continuing support of the GTEWS_Oceania Initiative

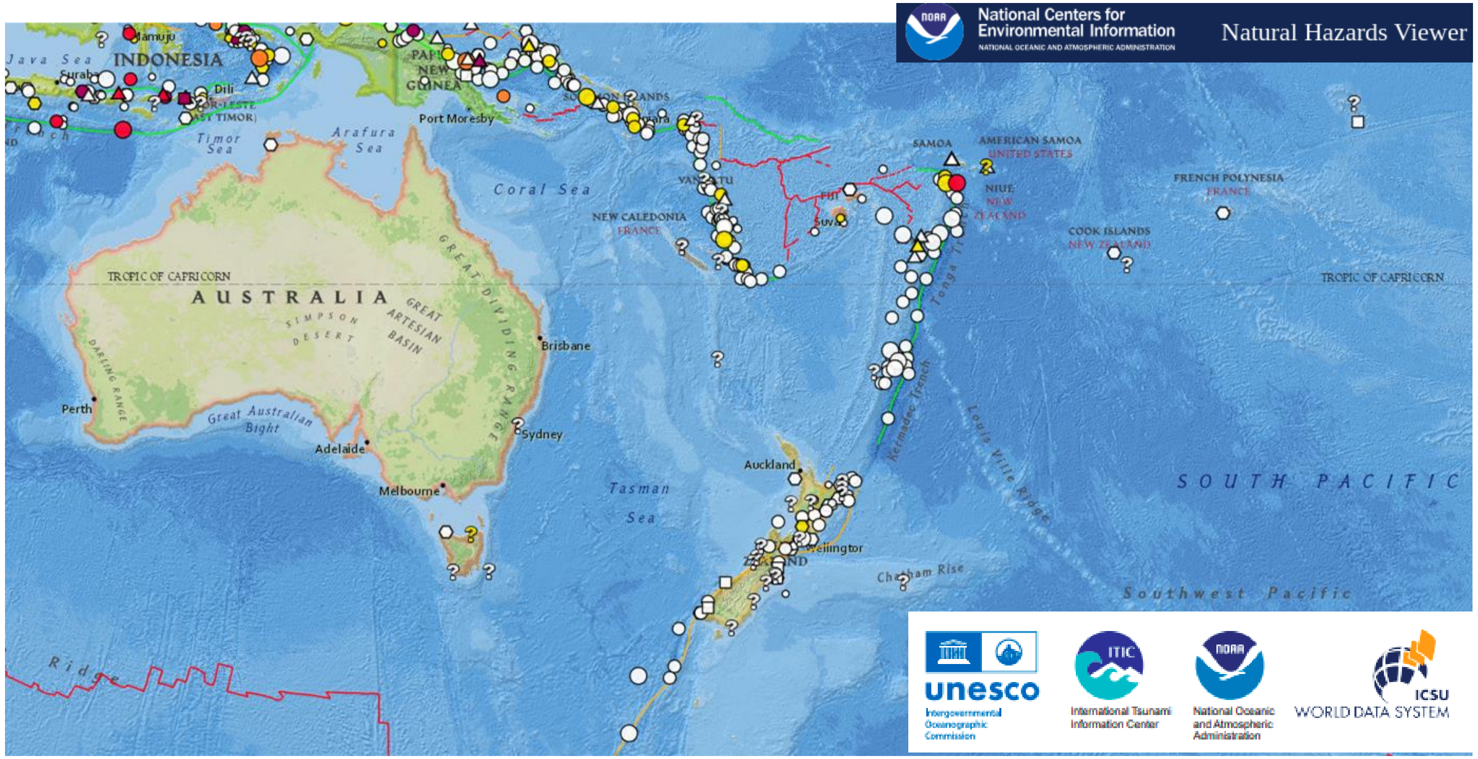
Tsunami risk in the Oceania region

The Tonga and Kermadec Trenches are two of the most tectonically active areas in the world. 69% of confirmed global tsunami sources are in the Pacific Ocean.



Source: National Geophysical Data Center / World Data Service: NCEI/WDS Global Historical Tsunami Database. NOAA National Centers for Environmental Information. doi:10.7289/V5PN93H7



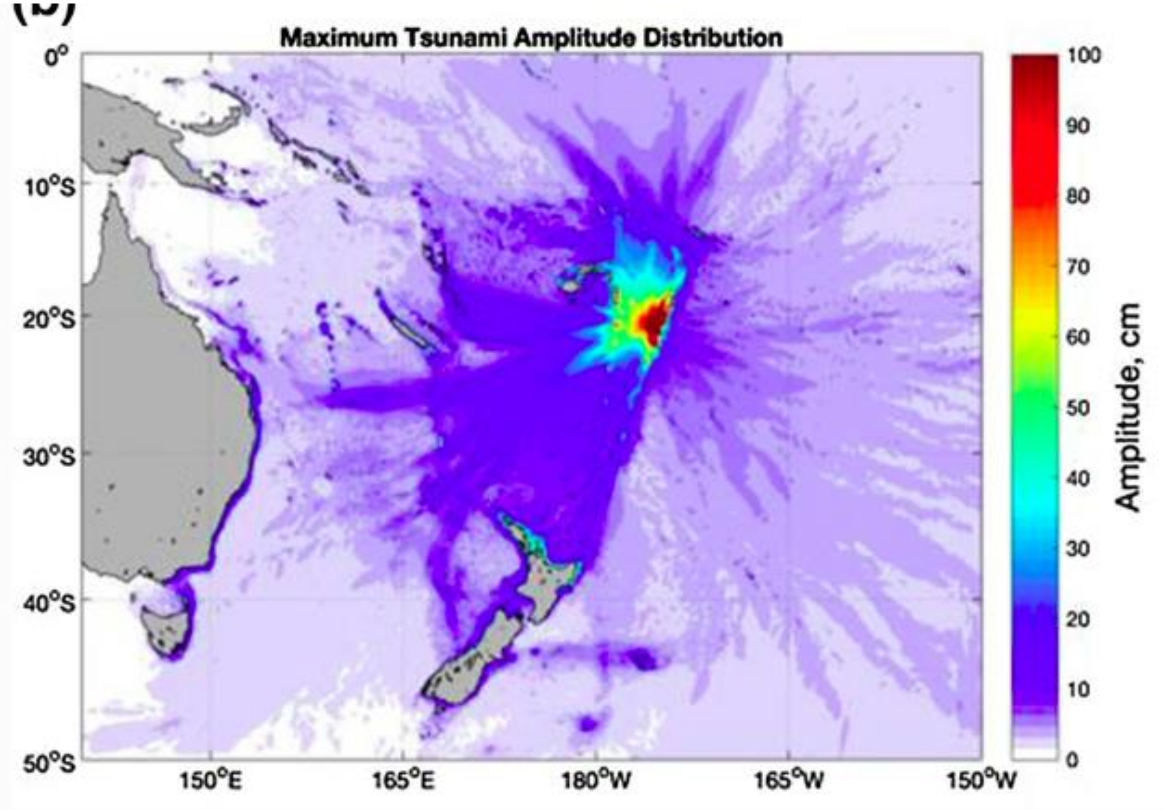


Tsunami observations in the Oceania region

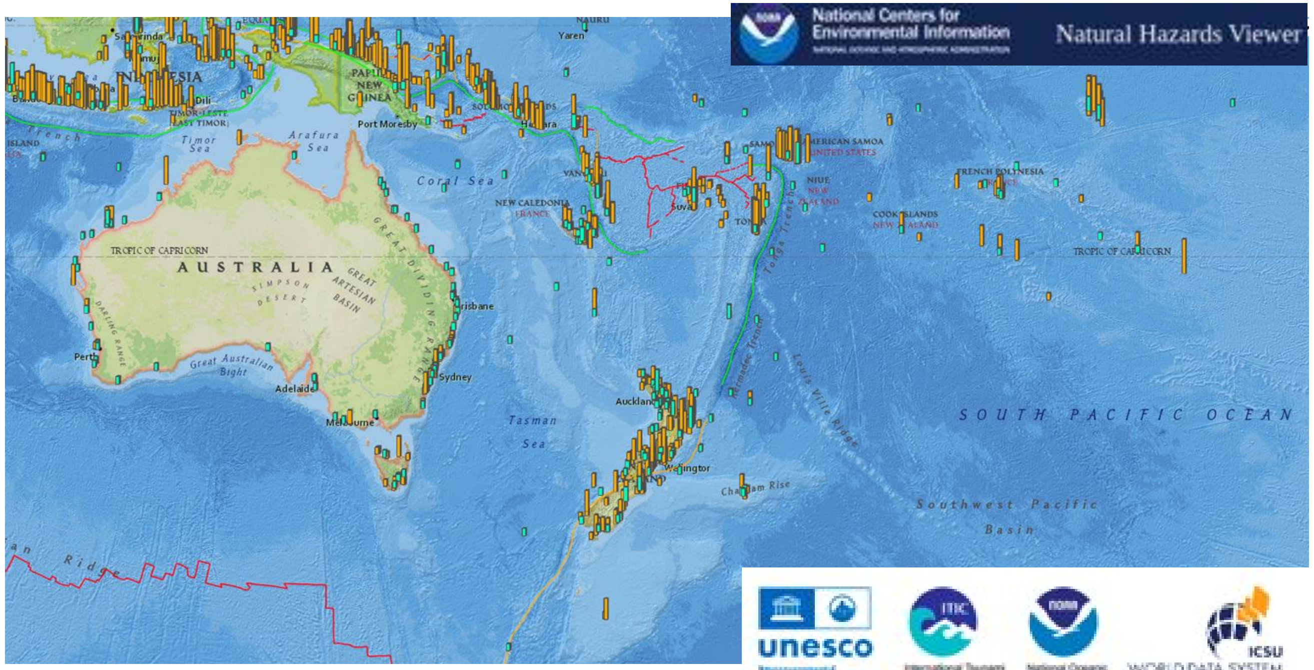
Tsunamis generated by local and distant sources in the Pacific Ring of Fire have historically impacted the Oceania region.

Recently, the 2022 Hunga Tonga-Hunga Ha'apai eruption generated a globally observed tsunami caused damage in the surrounding island nations including the Kingdom of Tonga and Fiji, as well as locations around the Pacific Rim including New Zealand, Japan, and Peru.

	Water Height				
	0-1m or unknown	1-2m	2-5m	5-10m	10+m
Tide Gauges/ Deep Ocean Gauges					
Eyewitness Observations/ Post-Tsunami Surveys					



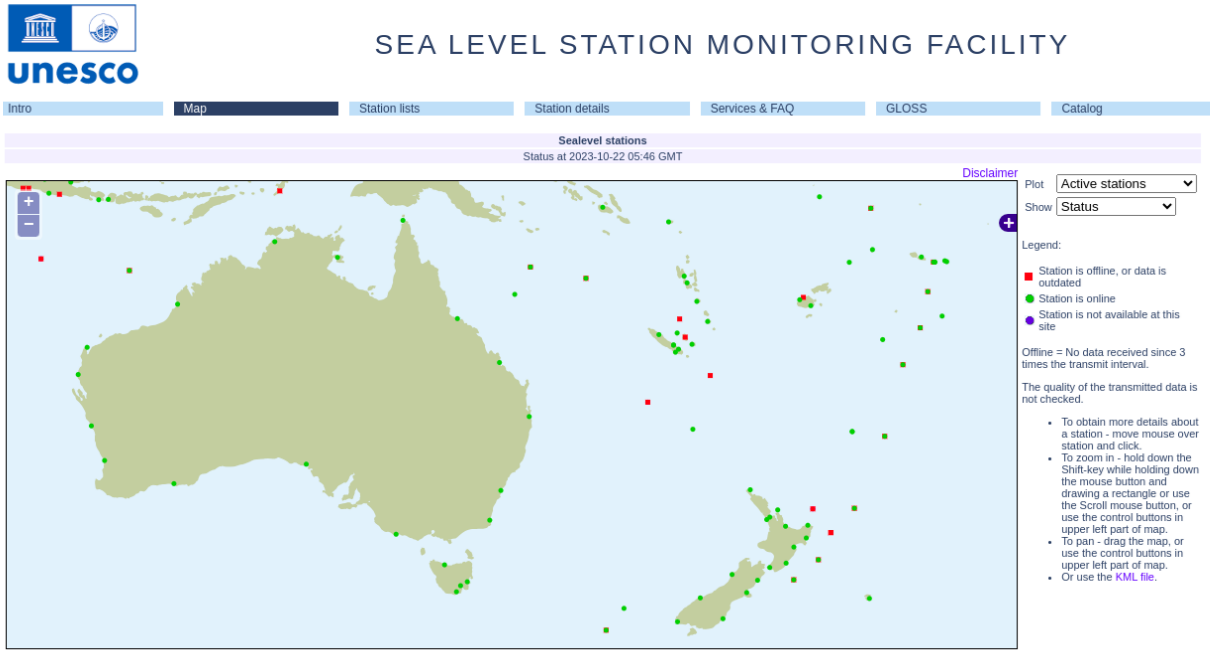
The 2022 Hunga Tonga-Hunga Ha'apai Volcano Air-Wave Generated Tsunami (source: Gusman et al., 2022)



Source: NCEI/WDS Global Historical Tsunami Database, doi:10.7289/V5PN93H7

Tsunami monitoring and detection

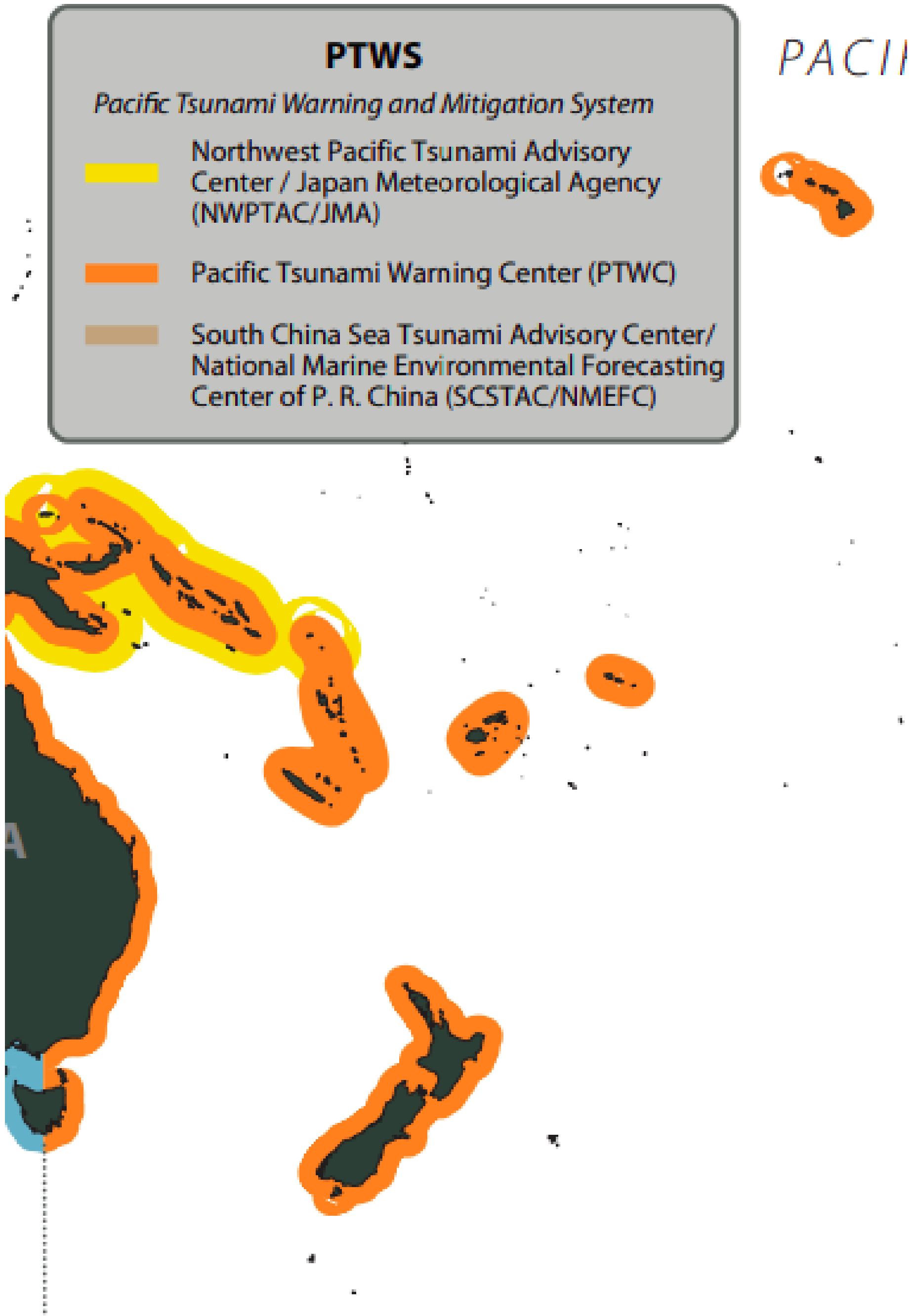
- Tsunami waves travel at a velocity of ~650-900 km/hour in the open ocean (tsunami travel time)
- 3 types of monitoring networks are currently used to detect and monitor tsunamis: Seismic stations (GSN, Global Seismographic Network) and sea level monitoring stations (coastal gauges and DART)



Tsunami warning agencies

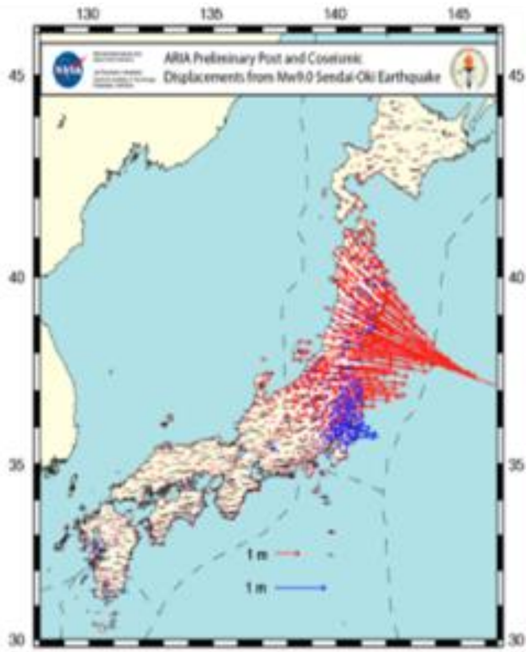
unesco Tsunami Programme

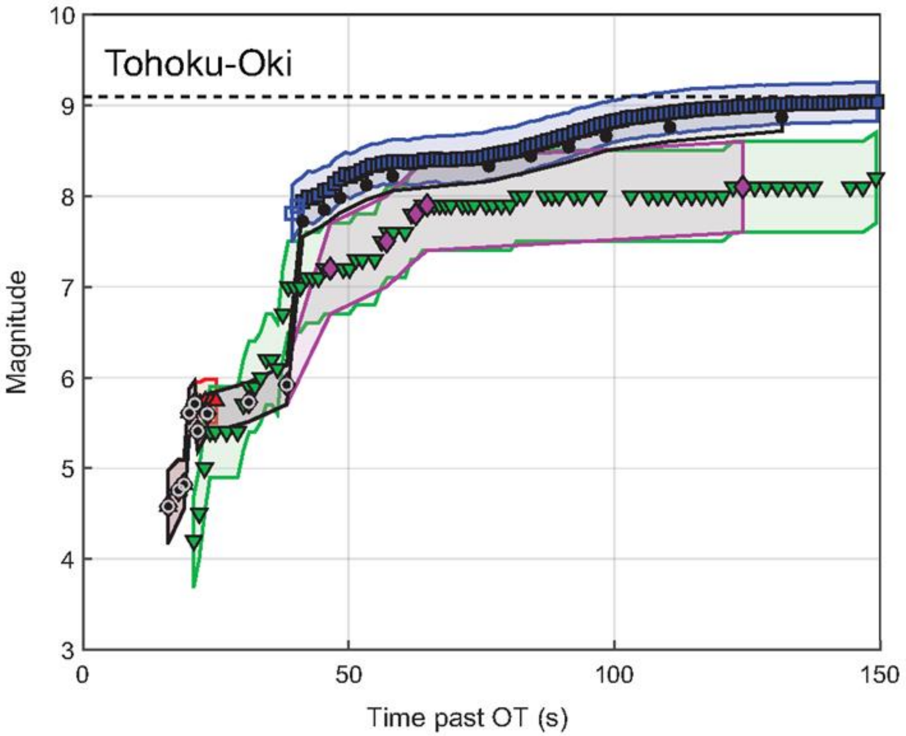
- The IOC-UNESCO Global Tsunami Warning System plays a critical role in protecting lives and supports Member States in assessing tsunami risk, implementing Tsunami Early Warning Systems (EWS) and in educating communities at risk about preparedness measures.
- Tsunami Service Providers (TSP) monitor seismic and sea level activity and issues timely tsunami threat information within an Intergovernmental Coordination Group (ICG) framework to National Tsunami Warning Centres/Tsunami Warning Focal Points and other TSPs operating within an ocean basin.
- The Pacific Tsunami Warning Center (PTWC) is the official Tsunami Service Provider (TSP) for the Oceania region.

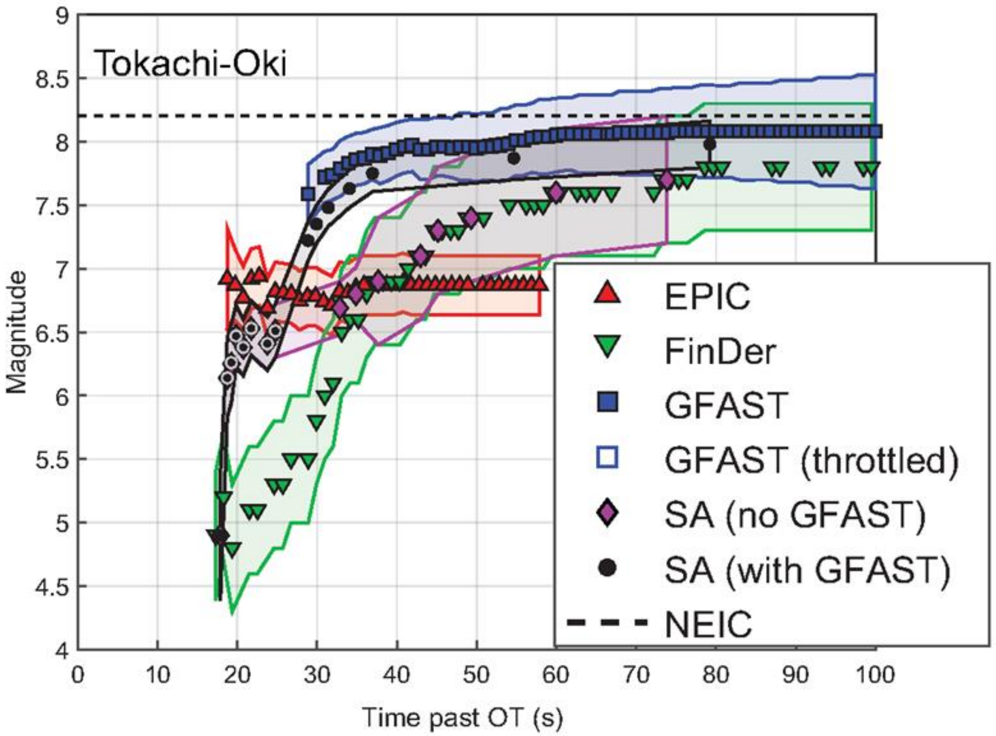


Use of GNSS for Tsunami Early Warning: land deformation

Real time GNSS Precise Point Positioning crucially improve characterisation of large local/regional earthquakes, providing rapid estimates of non-saturated magnitude and fault geometry/slip distribution. Currently used by USGS-ShakeAlert, NOAA, Japan-REGARD, etc)







EPIC, FINDER: algorithms for rapid magnitude estimations based on seismic data

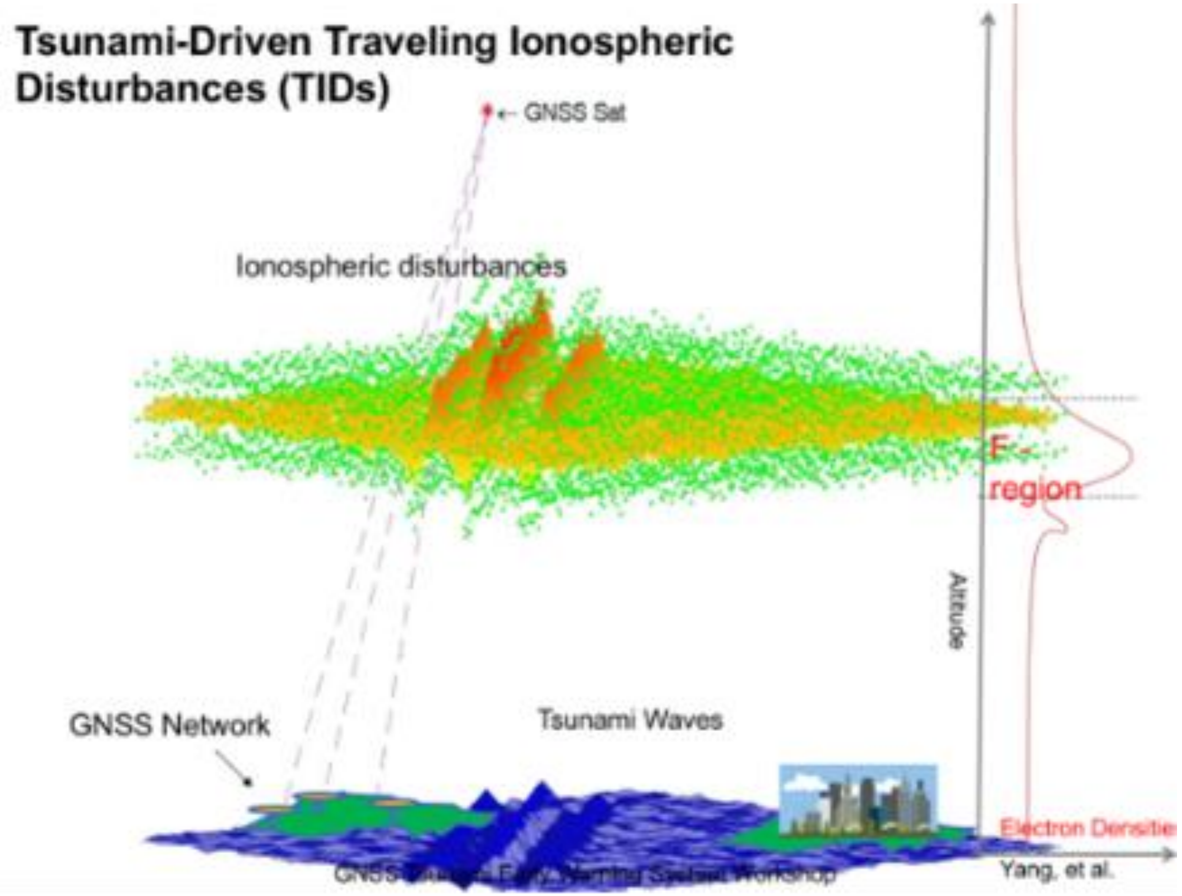
GFAST: algorithm for rapid magnitude estimation based on GNSS data

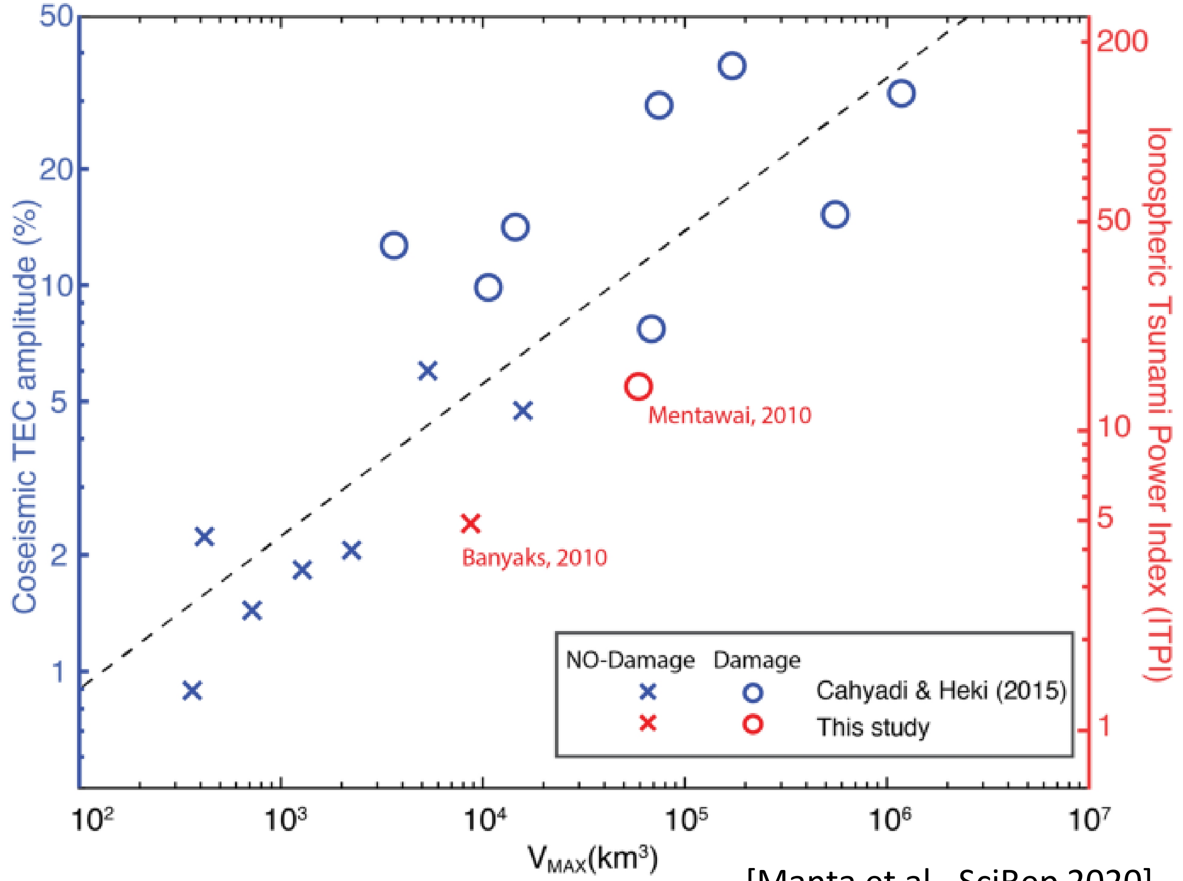
SA: algorithm for rapid magnitude estimation that can include GNSS data

[Murray et al., BSSA 2023]

Use of GNSS for Tsunami Early Warning: ionosphere perturbation

Source agnostic applications infer impact of gravity waves caused by ocean-wide tsunami on the ionosphere from "minimally processed" GNSS data: several examples in literature, currently in use at Nasa-JPL (Guardian)



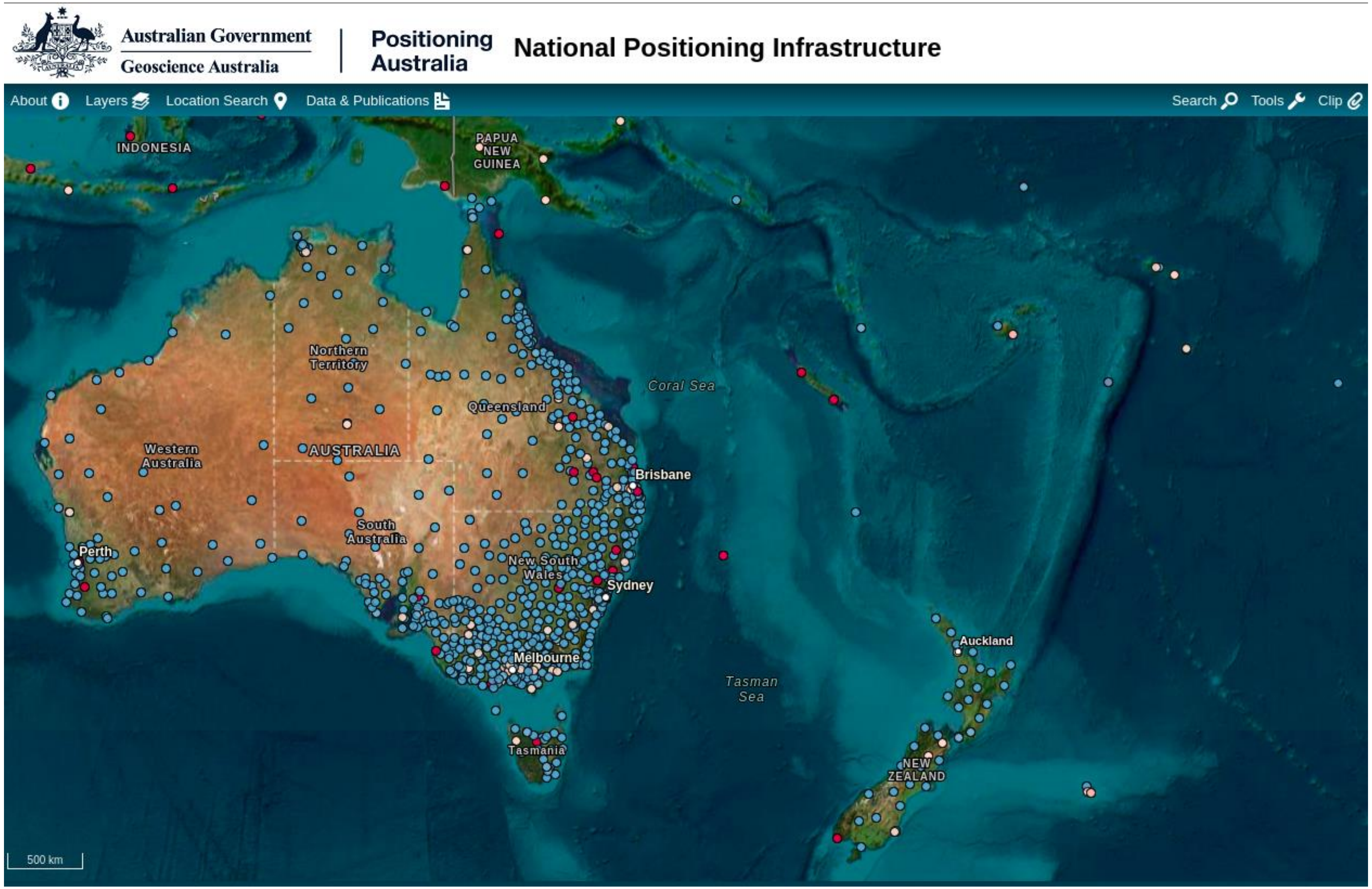


[Manta et al., SciRep 2020]

GTEWS components: ground network and data sharing

The Asia-Pacific Reference Frame (APREF) project purpose is to create and maintain an accurate geodetic framework to meet the growing needs of industries, science programs and the general public using positioning applications in the Asia-Pacific region.

APREF is a major activity of the UN-GGIM-AP Geodetic Reference Framework for Sustainable Development Working Group and the Reference Frame Sub-Commission 1.3e (SC1.3e) of the International Association of Geodesy (IAG).



GNSS Tsunami Early Warning System (GTEWS)

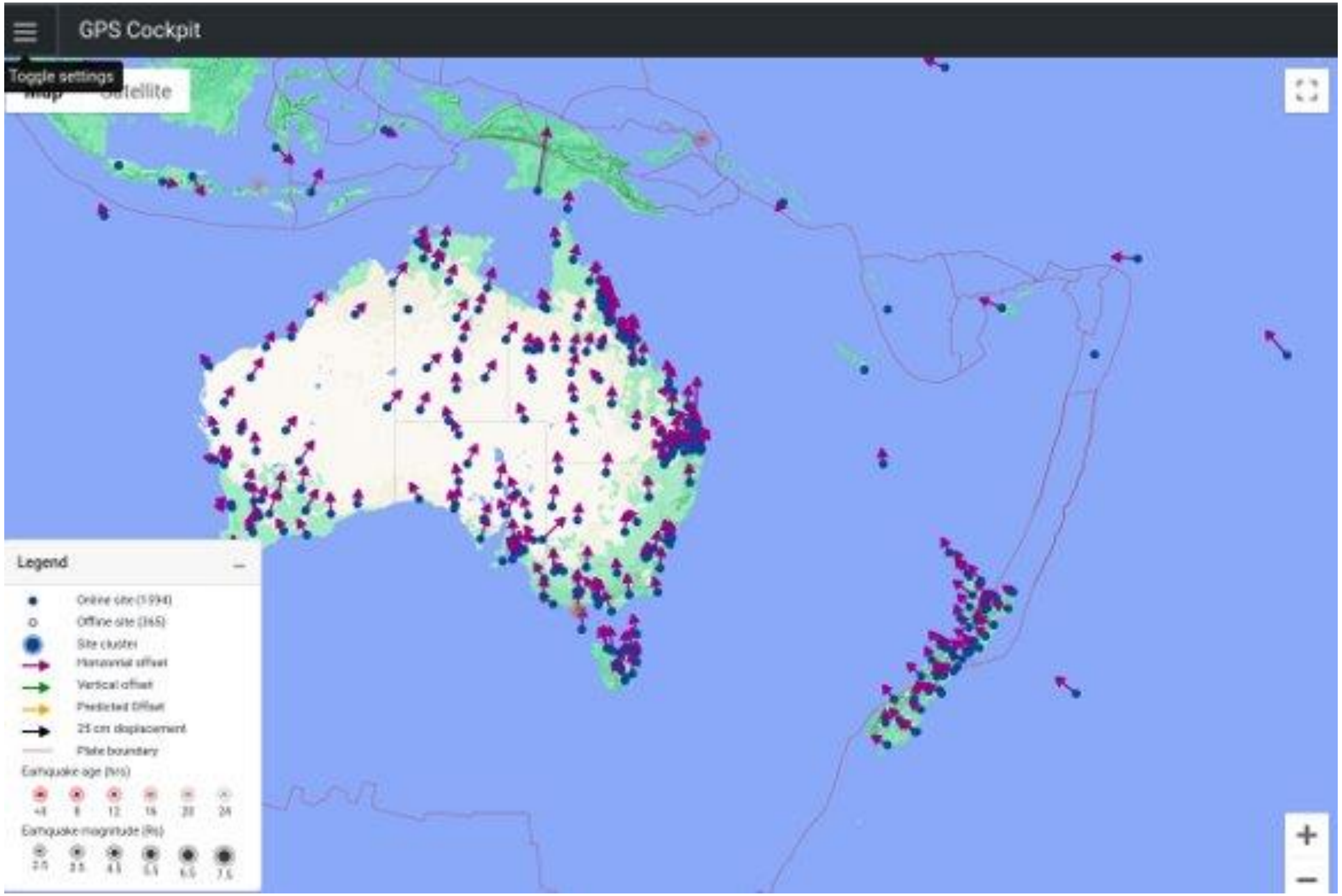
Land deformation

GNSS real time positioning: ground deformation

Scientific software to process GNSS data in real time are now available.

Most of them relies on real time products from the International GNSS Service Real Time Service.

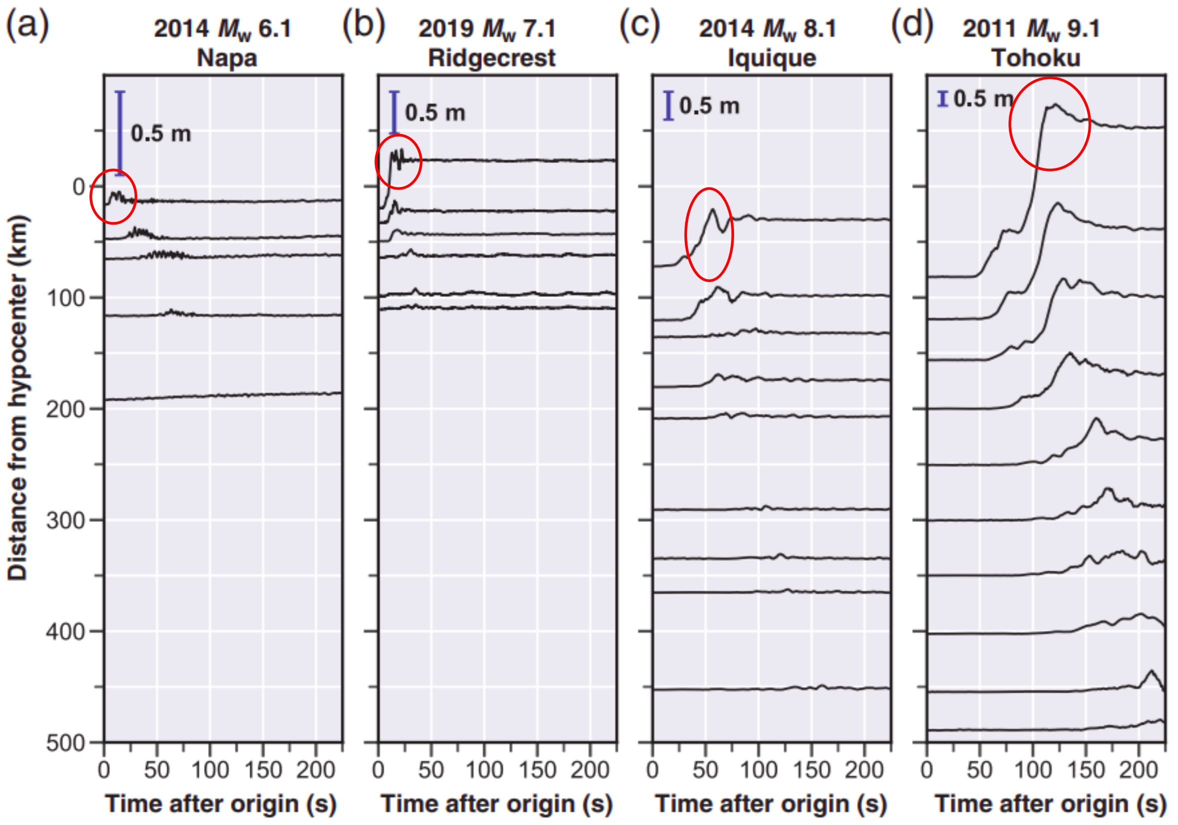
Central Washington University is running the first openly available system that provides real time GPS monitoring of crustal deformation on a global scale



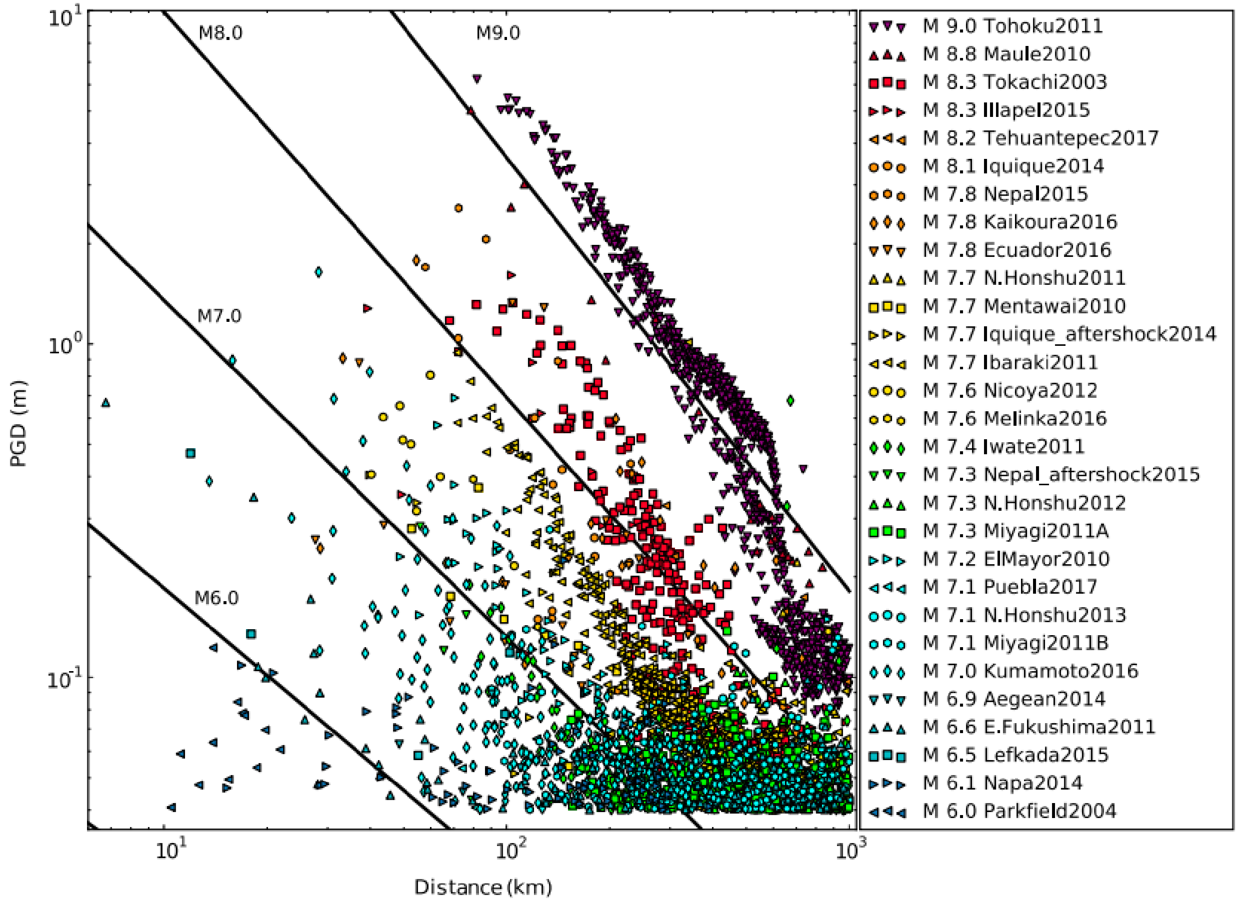
Melbourne et al., BSSA 2021

Rapid earthquake magnitude estimation from GNSS Peak Ground Displacement (PGD)

The maximum dynamic displacement measured by GNSS stations can be directly compared to the magnitude of the earthquake that caused it



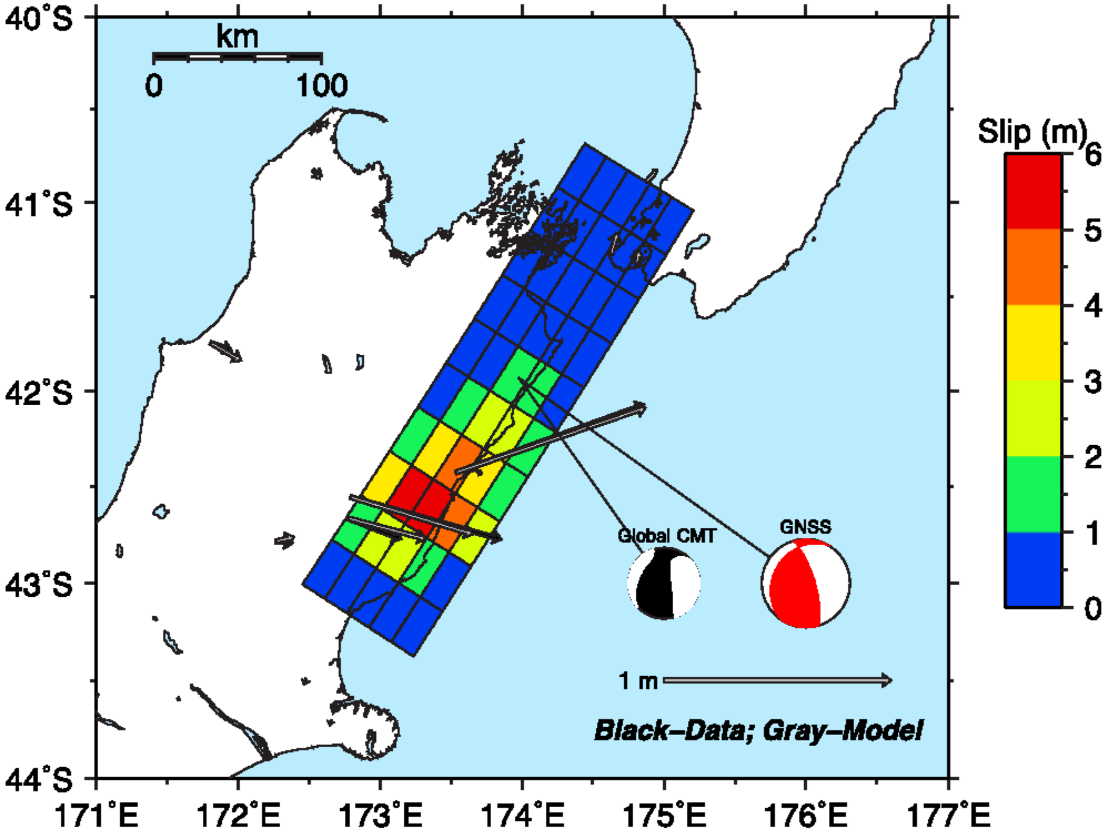
Goldberg et al, BSSA 2021

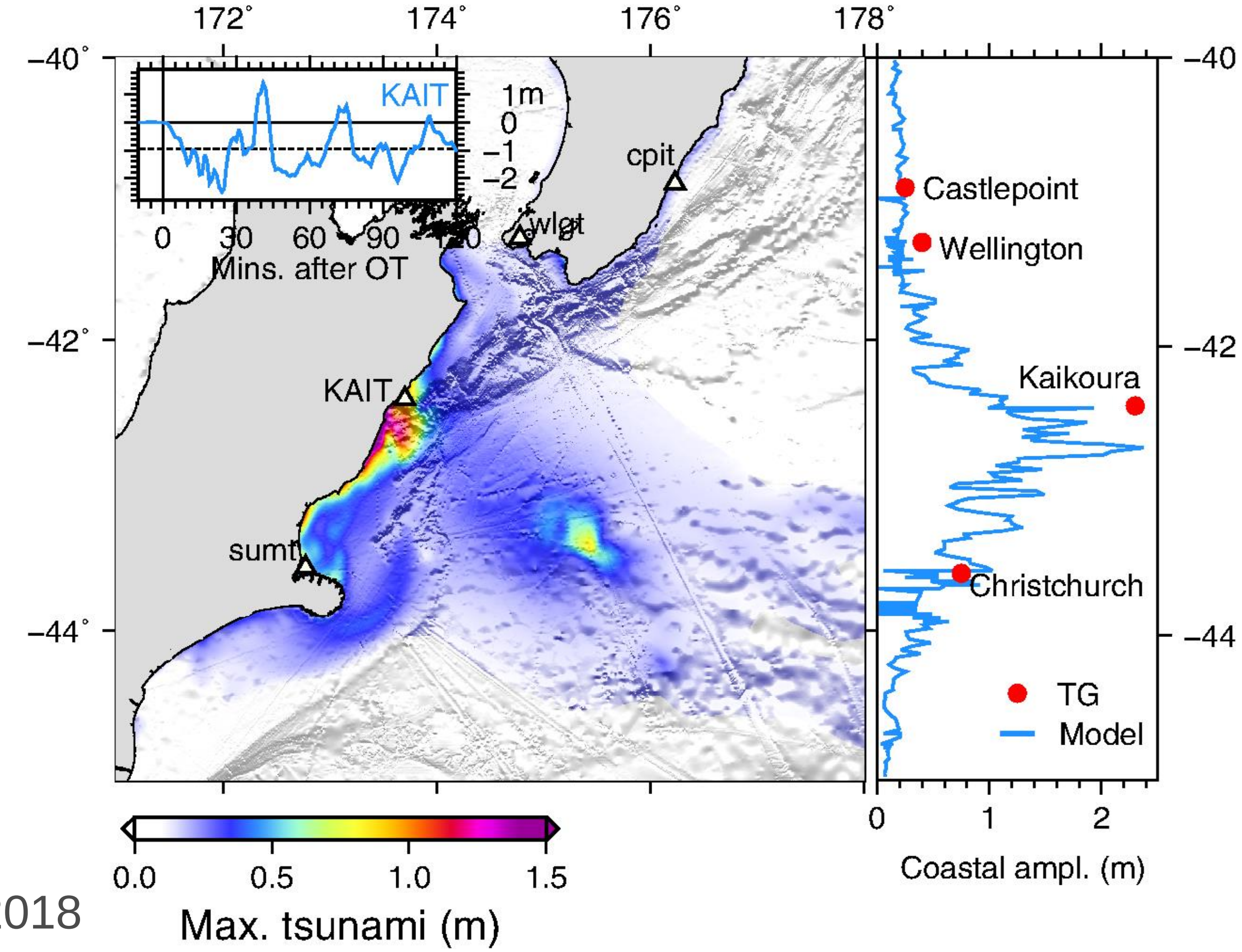


Ruhl et al, SRL 2019

GNSS for Rapid Earthquake Source Characterization

GNSS Peak Ground Displacements can then be used to obtain a simplified model of the earthquake source and modelled seafloor displacement. This in turn is used to simulate the tsunami wave propagation, as for the 2016 M7.8 Kaikoura earthquake (New Zealand)





Crowell et al., 2018

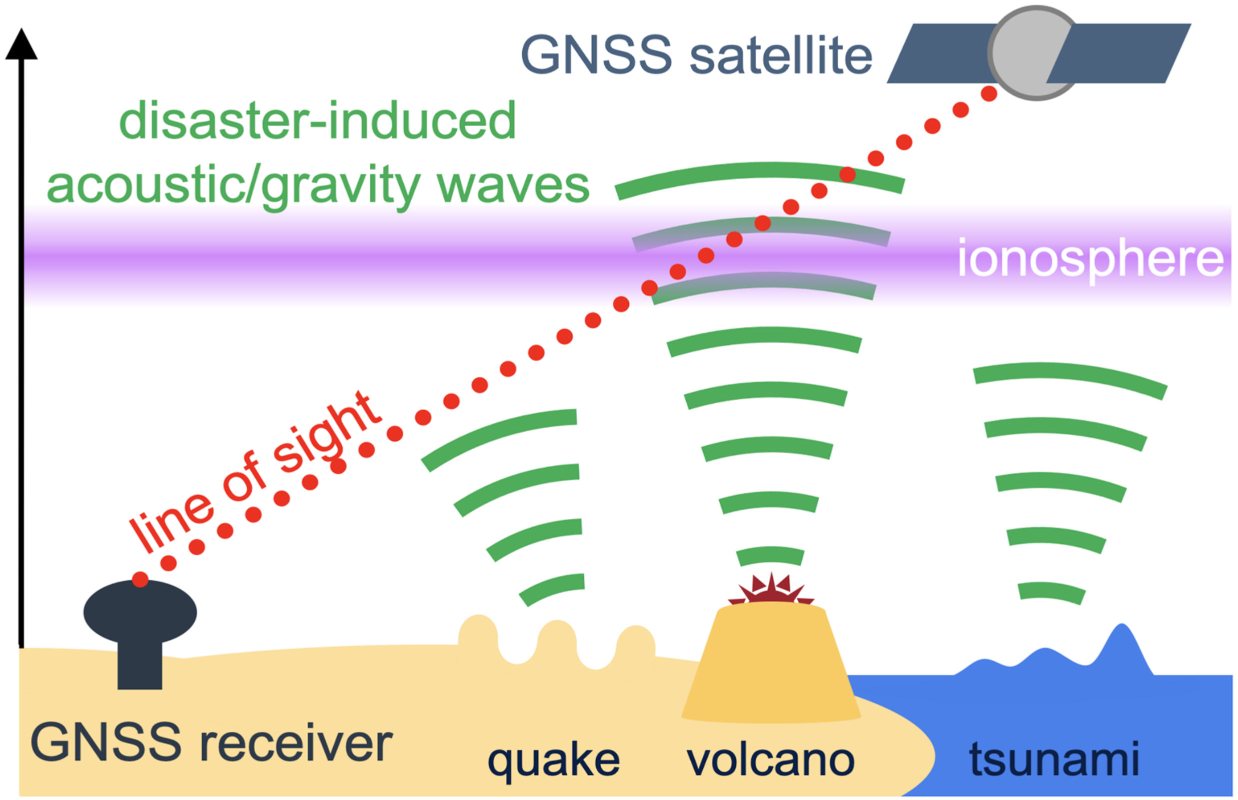
GNSS-Based Tsunami Early Warning System (GTEWS)

Ionospheric Perturbations

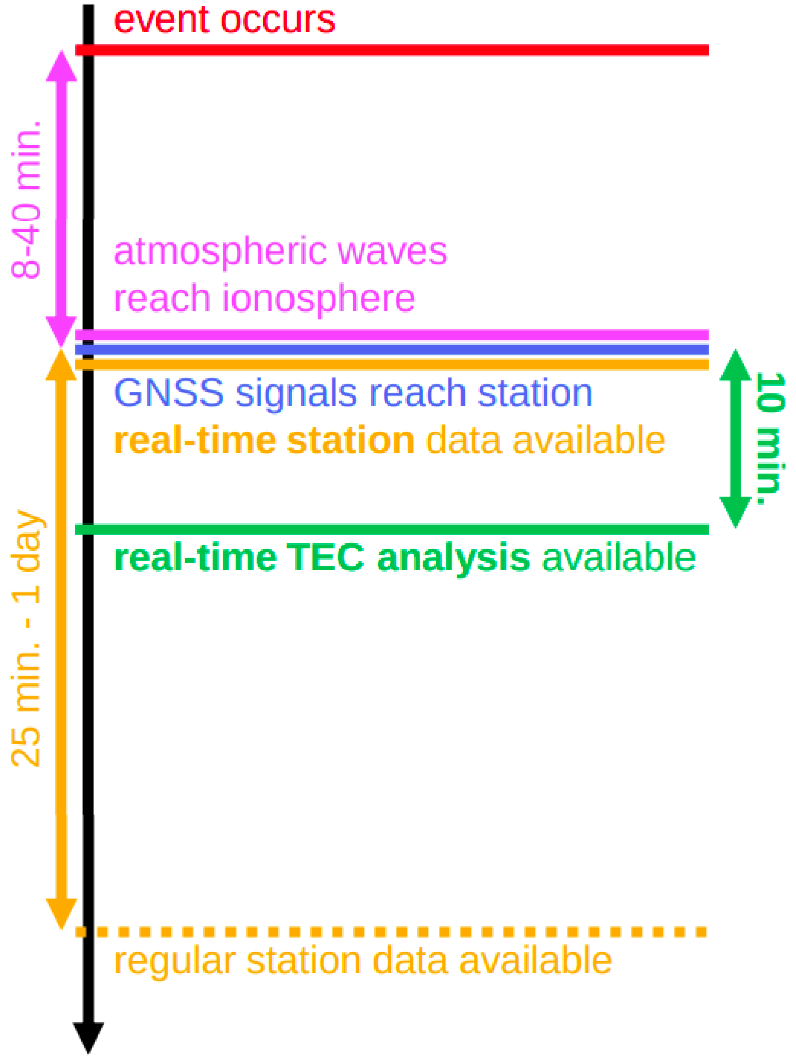
GNSS real time Total Electron Content (TEC) analyses

The GUARDIAN System (GNSS-based Upper Atmospheric Real-time Disaster Information and Alert Network) provides multi-GNSS estimates of GNSS-TEC in near-real-time from ~90 stations around the Pacific Ring of Fire. GUARDIAN builds on NASA's JPL Global Differential GPS capability and the International GNSS Service (IGS) network.

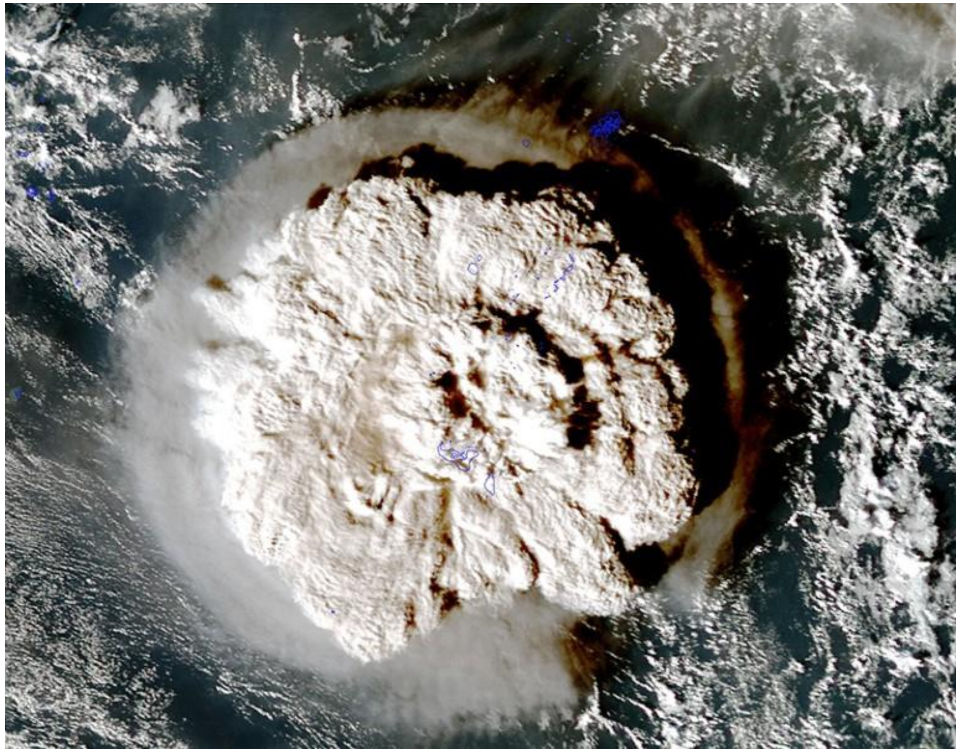
Jet Propulsion Laboratory
California Institute of Technology

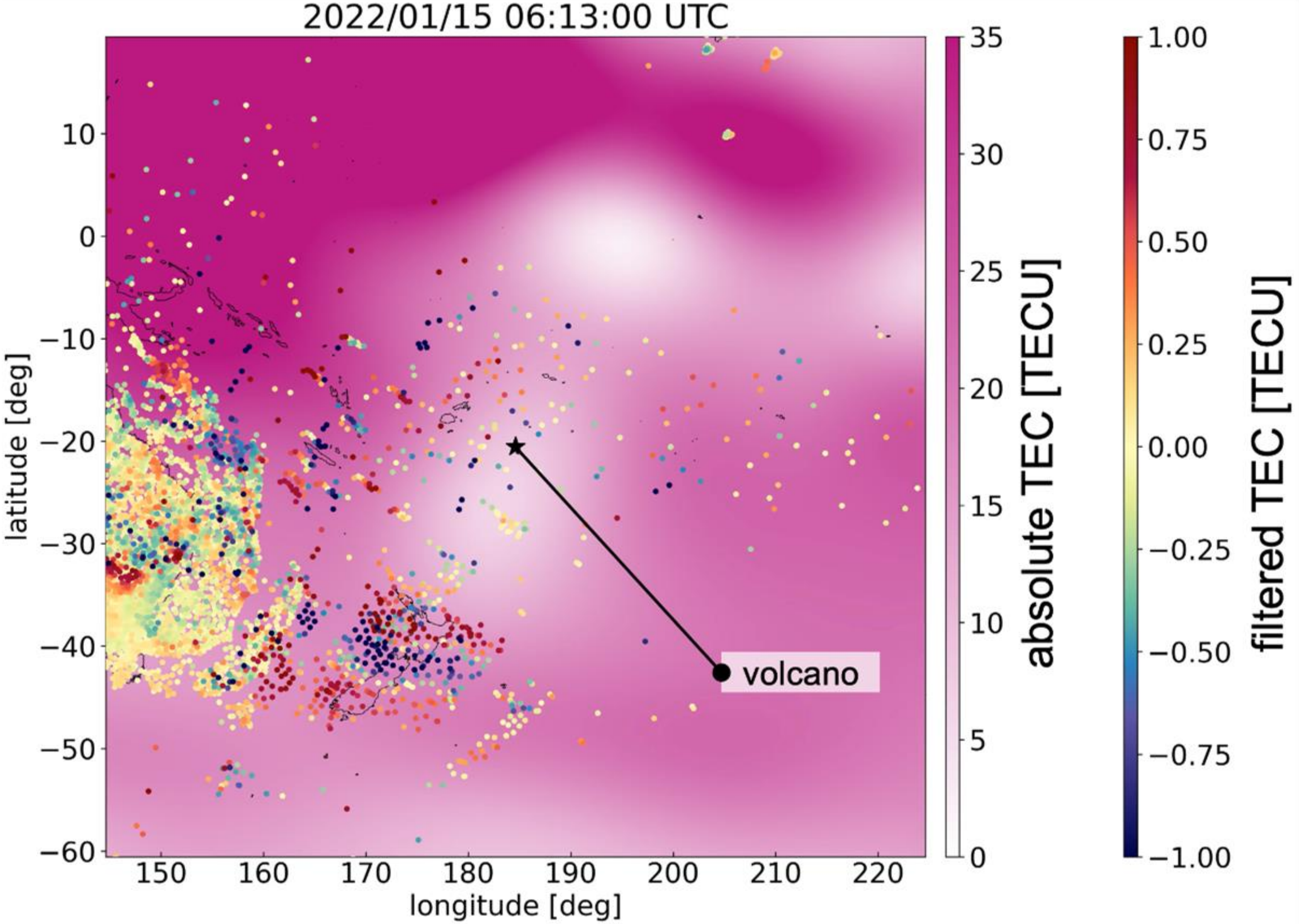


Martire *et al.*, GPS Solutions, 2023



Hunga Tonga Hunga Ha'apai 2022 eruption detected by GUARDIAN system





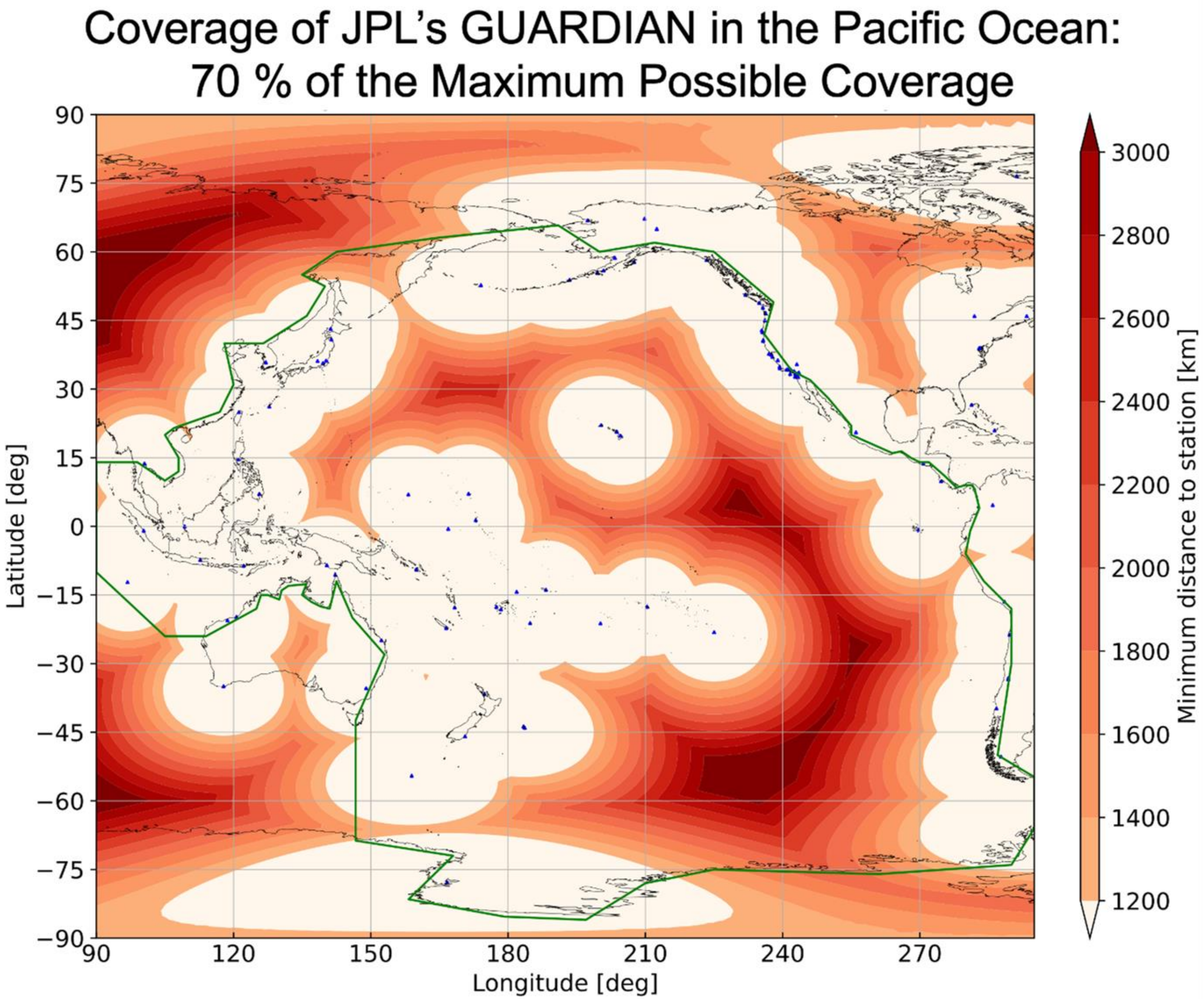
Krishnamoorthy, Martire, *et al.*, GUARDIAN Webinar, 2023

JPL's GUARDIAN System

A single ground-based GNSS station is sufficient to capture key TEC signals up to ≈ 1200 km away.

It takes ~40 minutes from the origin time for the tsunami generated ionosphere perturbance to be detected by a GNSS station.

The current network coverage in South-West Pacific is sufficient to apply this technique.



Krishnamoorthy, Martire, *et al.*, GUARDIAN Webinar, 2023

GNSS Tsunami Early Warning System (GTEWS)

Properly positioned GNSS receivers will measure both the ground displacement and the ionospheric dynamics induced by tsunami formation and propagation.

- GNSS land deformation can be used for local tsunami (within first 15-20 minutes from detection, if near source)
- GNSS ionosphere perturbation can be used for distant tsunami (2 hours before tsunami wave hits coastline, for distant source)

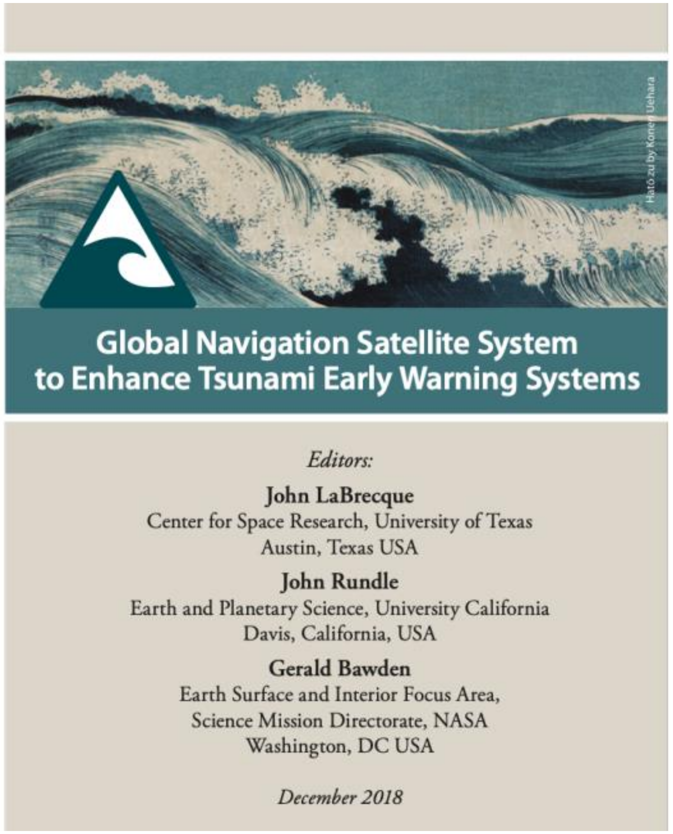
GNSS can be a 4th technique that contributes to already existing seismic and sea level tsunami monitoring network and can potentially be used by the Pacific Tsunami Warning Center (NOAA currently working with Central Washington University for that)

GTEWS Oceania initiative

The IUGG/GRC, GGOS, GEO, and the ICG are engaged in community discussions for the establishment of GTEWS_Oceania as a prototype International cooperative GTEWS. The IGS, GRC and the GGOS/Geohazards Focus Area worked with GEO to develop the Geodesy for Sendai framework to foster collaborations for the application of geodesy to goals of the Sendai Framework of the UNDRR. Geodesy for Sendai was codified in the GEO Work Programme of 2020-2022 and 2023 to 2O25.

First GRC Conference on Extreme Events and Their Impacts, 2012

GTEWS workshop (2017) and report (2019)



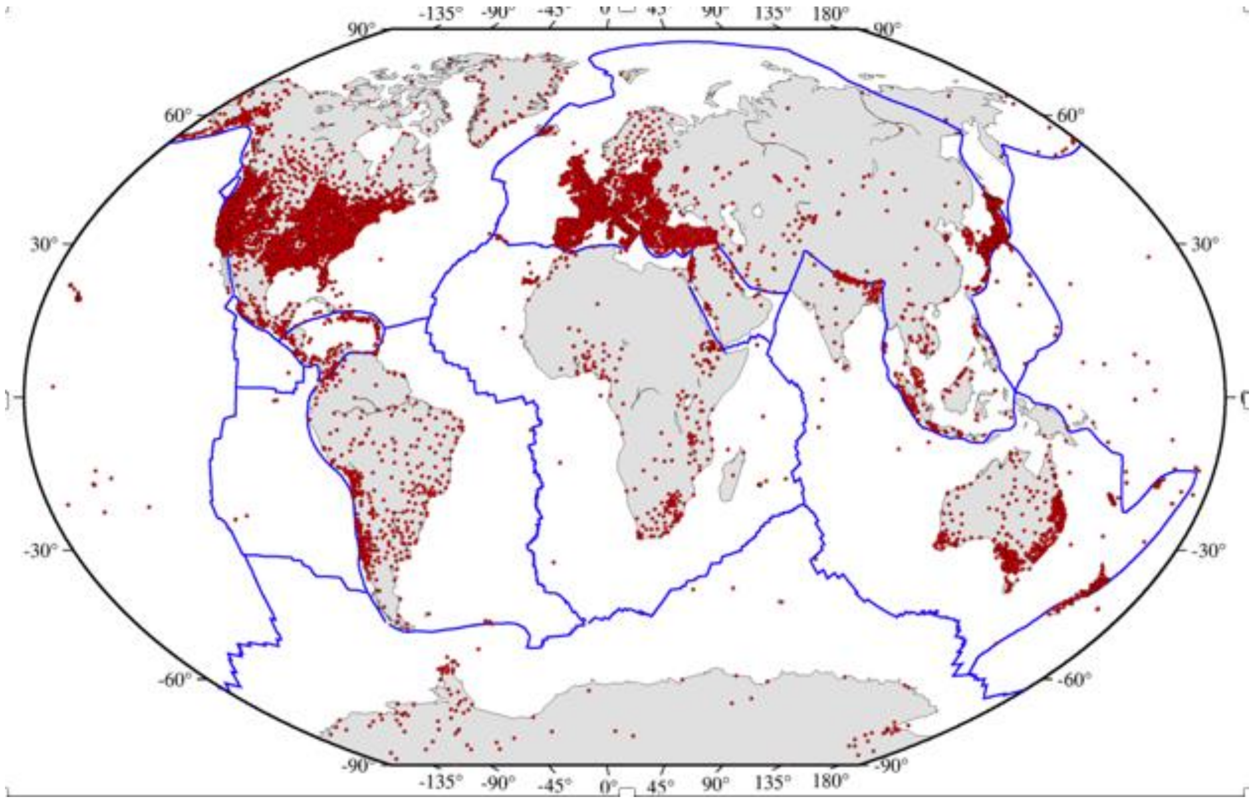
Requirements to achieve GNSS Tsunami Early Warning in Oceania

- International collaboration: data and software sharing
- Improved GNSS ground infrastructure: focus on real-time, multi GNSS data
- Local and regional agencies: knowledge sharing, funding for infrastructure operations (including data transport network)
- Collaboration with existing monitoring agencies (role of PTWC)

GNSS ground infrastructure requirements

- **Land deformation**: requires approximately 1700 real time GNSS receivers in optimized locations within the Indo-Pacific Basin. GTEWS 2017 workshop recommended three or more receivers every 100 km along the Pacific Ring of Fire (40000 km) to optimally capture fault displacements. (~1200 receivers)

- **Ionosphere perturbation**: a distribution (200-500km) of GNSS receivers to provide regional measure of ionospheric perturbations (~500 receivers).



Over 17,000 GNSS receivers provide open data access. About 2100 of these receivers stream data in real time. There are more such receivers with restricted data flows to registered users. These open and dark receivers could significantly reduce the GTEWS network development cost.

GTEWS Oceania future activities

- The Pacific Geospatial and Surveying Council (PGSC) has expressed interest in supporting the GTEWS_Oceania Initiative.

- The Oceania region has a significant number of GNSS receivers of varying quality and varying communications capability. Resources will be needed to upgrade many of these GNSS stations and provide the regional broadband communications as well analysis systems. We will petition GEO and Development Banks for resources to develop these capabilities. We will seek matching funds from the nations of Oceania when possible.

- The Central Washington University (Tim Melbourne) has expressed the possibility of providing a significant number of redundant GNSS receivers to the project.

- Discussions are underway to apply IUGG/GRC resources as a matching grant in support of a 2024 GTEWS_Oceania Workshop for capacity building.

- Initial discussions with Unesco IOC/ICG are underway to coordinate activities and avoid duplication of efforts

Role of UN-GGIM-AP

We propose that WG1 recommends the UN-GGIM-AP (member countries) to promote a GTEWS augmentation to existing tsunami early warning systems

Working Group 1 Resolution

g. Encourage Member States to participate in regional initiatives to embrace utilisation of geodetic data and technologies for disaster risk reduction including GNSS augmentation to existing tsunami early warning system in coordination with the bodies internationally response for tsunami early warning system mitigation such as the intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System (IOC/PTWS)

UN-GGIM-AP

REGIONAL COMMITTEE OF UNITED NATIONS GLOBAL GEOSPATIAL INFORMATION MANAGEMENT FOR ASIA & THE PACIFIC

WHY GTEWS for Oceania?

1. Low Lying islands & coastal communities
2. Lives were lost…more lives should have been saved
3. Unpreparedness due to lack of warning
4. Extra minutes makes a difference in Pacific islands
5. Key infrastructures, local resources and capabilities not there
6. People will be more confident of early warning system

Summary

- GTEWS can be implemented using currently available technology and measurement systems.
- GTEWS benefits are based upon currently available GNSS signals, commercial GNSS receivers, and analysis algorithms, broadband communications capability such as Generation 4 cell phone networks.
- Development of effective GTEWS enhancement for the Indo-Pacific requires:
  - Optimization of real time GNSS receiver networks;
  - International agreements for the distribution of GNSS real time data;
  - Cooperation with disaster reduction and response agencies;
  - Development of funding support.

<u>Join us in the development of GTEWS-Oceania</u>
=> Organizational discussions are scheduled the second Tuesday of every month at 1 PM (UTC +13) (New Zealand local time)
=> Register by sending email to: jlabrecq@mac.com with the subject “GTEWS_Oceania”

Thank you