Ionospheric Detection of the 2022 Tonga Event Using Real-Time GDGPS Observations

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Outline

- Motivation and objective
- GDGPS capabilities relevant for natural hazards detection
  - GNSS networks
  - GDGPS Operation Centers (GOCs)
  - Redundancy and robustness
- Ionospheric detection of Tonga eruption using GDGPS measurements
- Validation using high-resolution JPL GIM processing
- Development of GUARDIAN
  - GNSS-based Upper Atmospheric Realtime Disaster Information and Alert Network
- Conclusions

Motivation and Objective

- **Motivation:** Use existing GNSS technologies to augment tsunami early warning systems

- **Objective:** show the current technical capability that GDGPS brings to enhance detection of natural hazards using recent Tonga eruption in January 2022.

Washington Post, Mar 13, 2022

CAPITAL WEATHER GANG

U.S. tsunami warning system needs major overhaul, report says

Current system is rife with outdated software, delayed alerts and poor communication to the public, according to expert panel
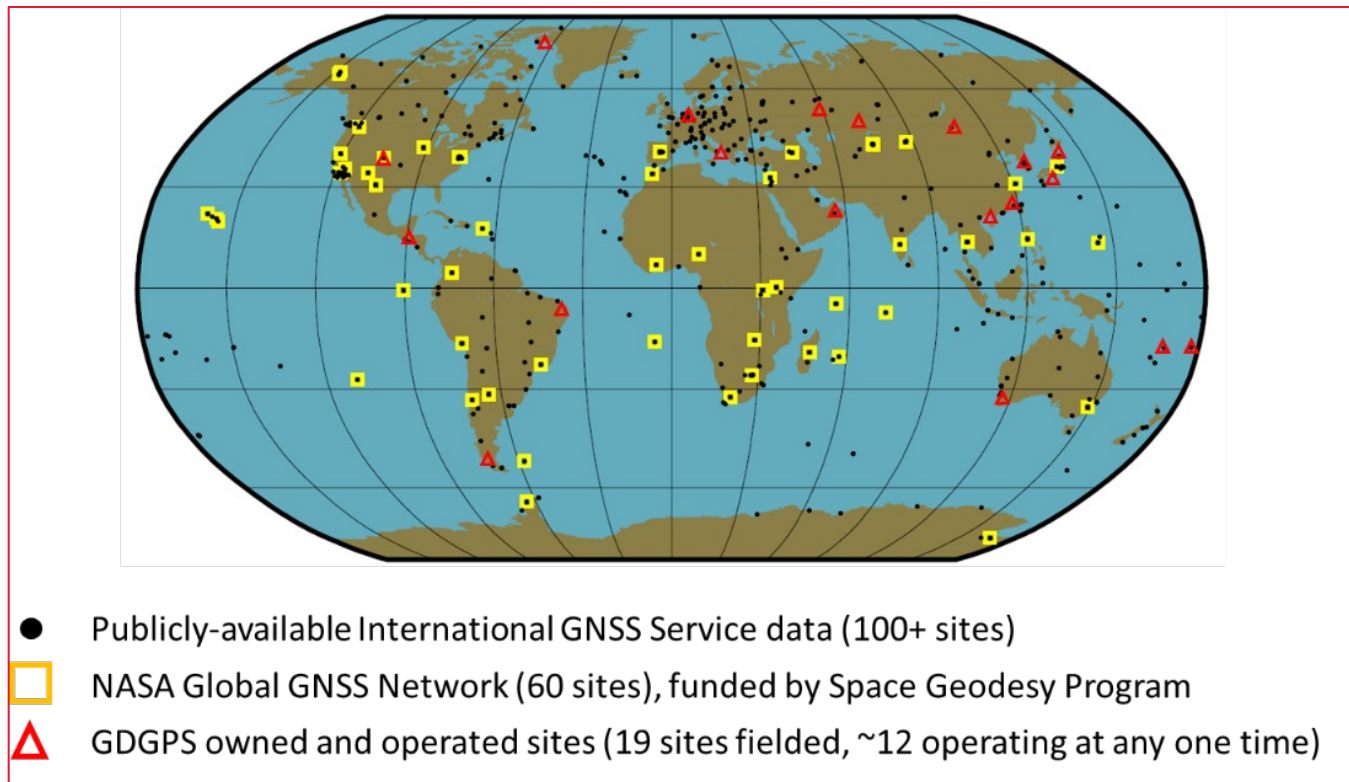
By Diana Leonard

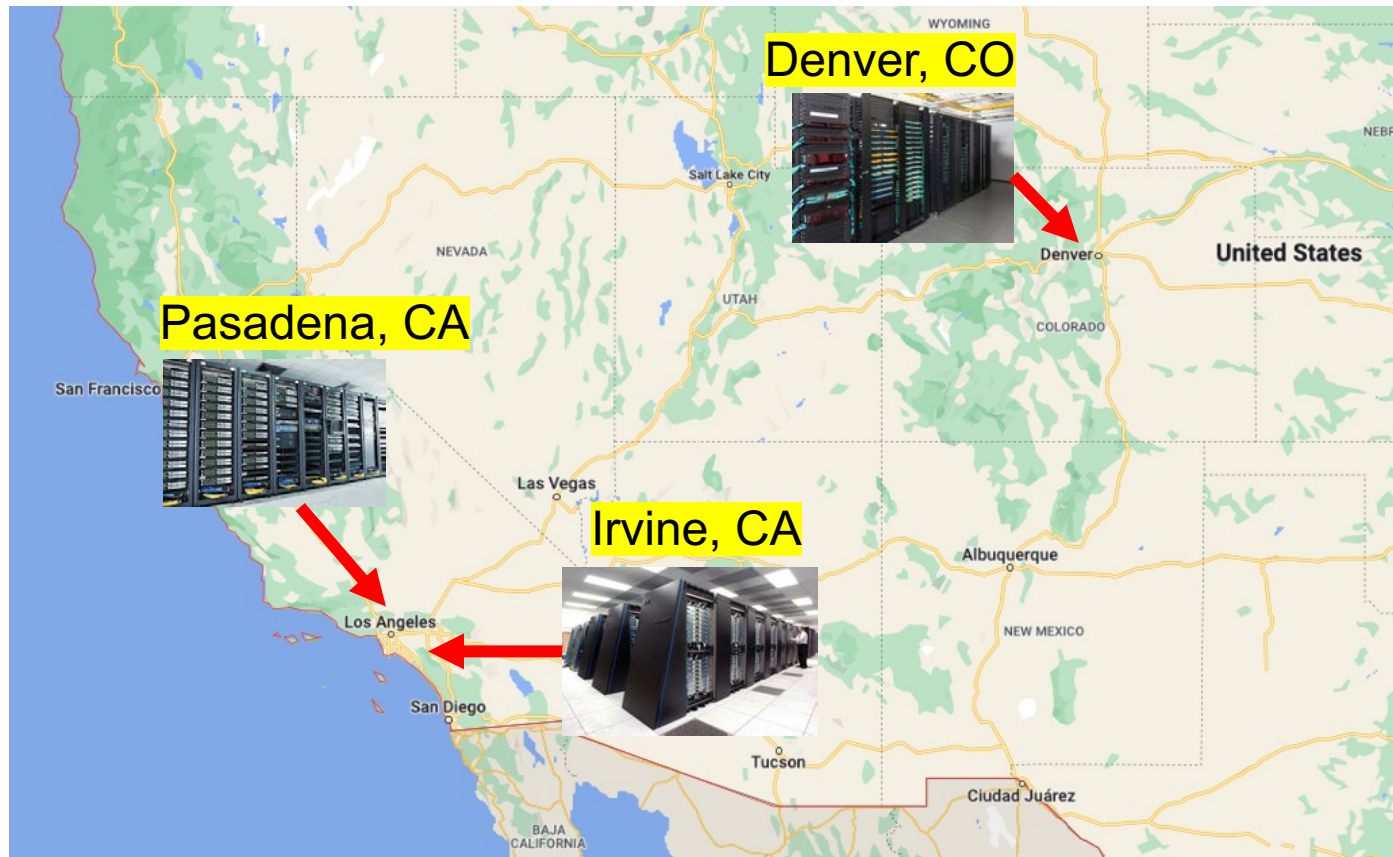March 13, 2022 | Updated March 13, 2022 at 11:57 a.m. EDT

Network of GDGPS-Processed GNSS Receivers

- GDGPS uses and supports NASA-owned JPL-operated GNSS receivers (GGN) □
- Network also augmented by a smaller set of GDGPS-operated sites △
- Publicly available IGS streaming data supplementing the global network ●

The available global tracking network undergoes continual review and upgrading.

● Publicly-available International GNSS Service data (100+ sites)

□ NASA Global GNSS Network (60 sites), funded by Space Geodesy Program

△ GDGPS owned and operated sites (19 sites fielded, ~12 operating at any one time)

Maintaining GDGPS Operations Centers (GOCs)

- Operational data processing is carried out in **three** independent GDGPS Operations Centers (GOCs) with **separate ISPs**.
- **Geographic separation** provides resiliency to single points of failure considering outages or natural hazards.

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June 29, 2022

Natural Hazards Detection Science Application

- Natural hazards (tsunamis, earthquakes, volcanoes, meteor impacts, *etc.*) **generate atmospheric waves**

- Atmospheric waves **propagate up to the ionosphere**, and cause electron density fluctuations

- Perturbations in total electronic content (TEC) can be **detected using GNSS observations** for each satellite-station pair

- Goal: use real-time GNSS-derived TEC data to **augment natural hazard early warning systems**

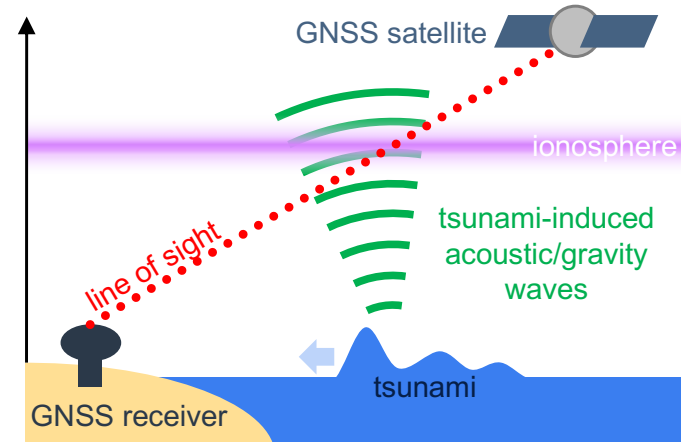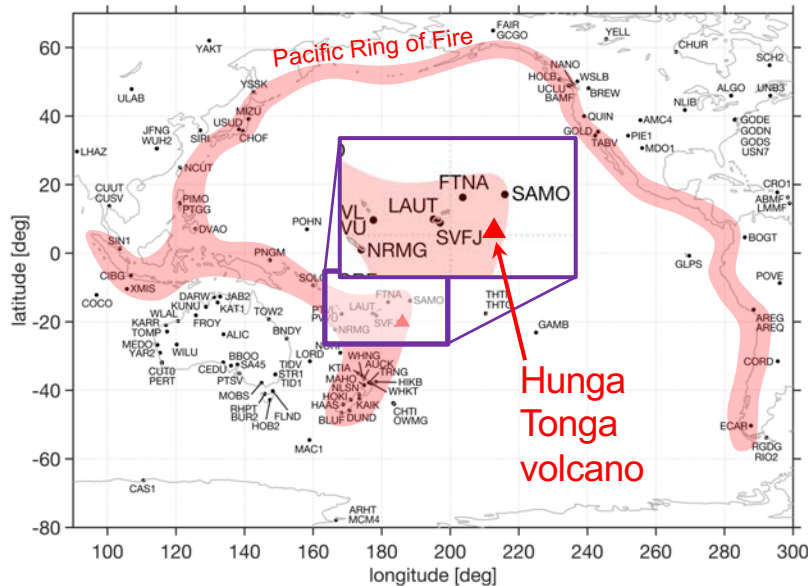- **Key infrastructure**: JPL's real-time GDGPS-processed network
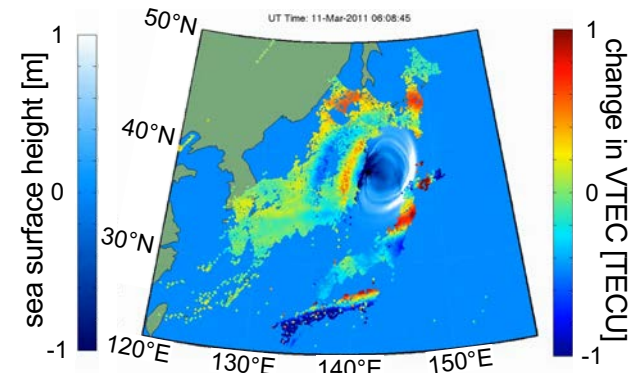
Figure: Ionospheric TEC and sea surface height map for the 2011 Tōhoku-Oki event (Galvan *et al.*, 2012).

June 29, 2022

Post-Processing vs. Real-Time Processing

*60 NASA GGN sites; 12 GDGPS-operated sites;
100+ IGS public sites

- Real-time stations: TEC-based analysis available **minutes after the event**

- JPL is currently developing the **GUARDIAN** system: a near-real-time early warning system for natural hazards in the Pacific region (Martire *et al.*, AGU FM 2021; Martire *et al.*, IEEE, in prep)

GNSS-based Upper Atmospheric Realtime Disaster Information and Alert Network

- GPS — GLONASS — GALILEO — BEIDOU
- Earthquake USGS Tsunami Watch GDGPS Station

Click and drag on to select stations (use mousewheel to zoom), then click on the station in the sidebar to see realtime slant TEC.
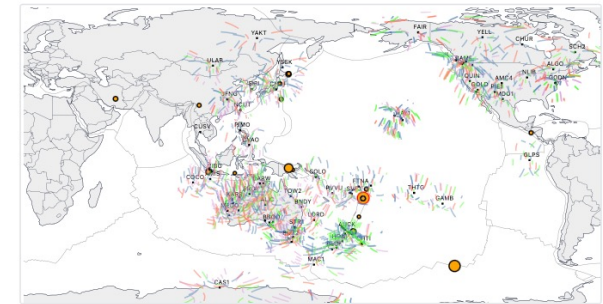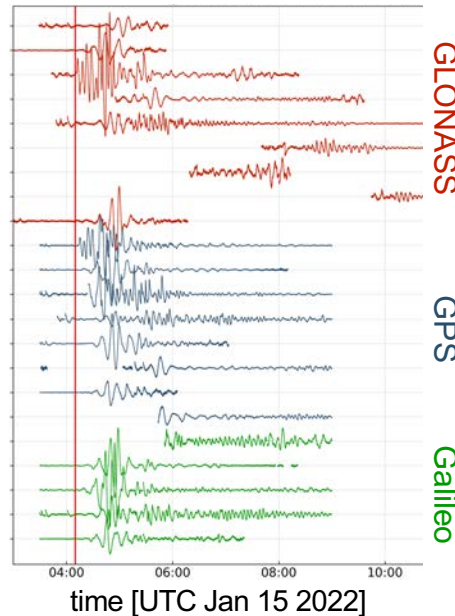
Powered by the JPL Global Differential GPS (GDGPS) System
GUARDIAN Contact: Siddharth Krishnamoorthy, Léo Martire
GDGPS Contact: Attila Komjathy

- Real-time processing of GNSS data
- Real-time analysis of TEC data
- Prototype automatic detection of TEC signals generated by tsunamis and volcanic eruptions under development
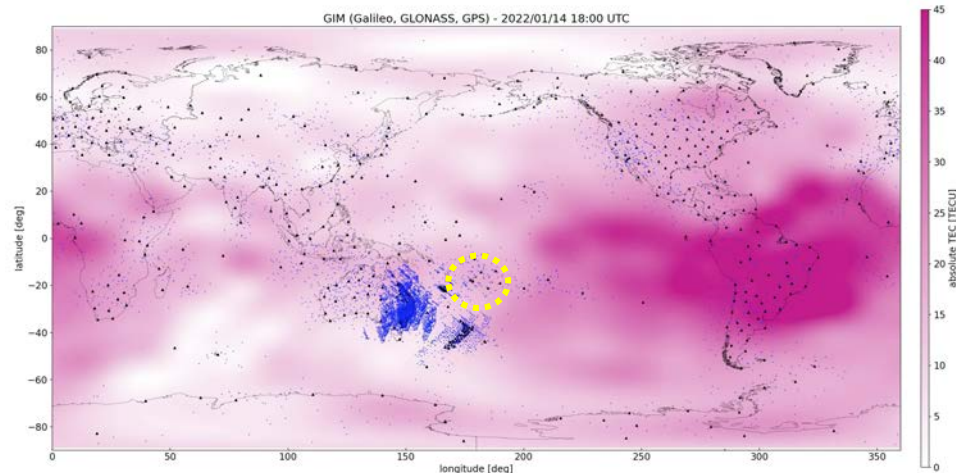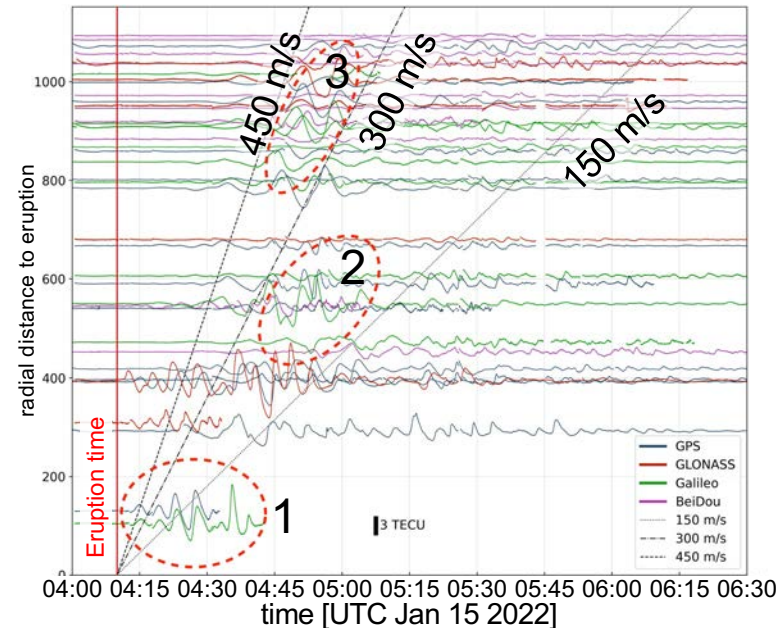
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Ionospheric Signals of the 2022 Tonga Eruption

- Multi-constellation GNSS signals **capture the strong ionospheric perturbations** due to the acoustic wave from the volcanic eruption

- **Simple signal processing methods** (*e.g.,* ordering data by radial distance) allows the identification of various signatures

- A **single ground-GNSS station** is sufficient to capture **signatures** up to ≃**1000 km away**

Raw Ionospheric Signals for station SAMO

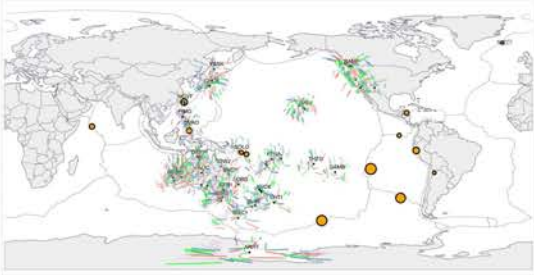Ordered Ionospheric Signals for stations FTNA, LAUT, SAMO

GIM (Galileo, GLONASS, GPS) - 2022/01/14 18:00 UTC

June 29, 2022

.nasa.gov

GUARDIAN Observing Tonga Eruption

Movie to Play During Talk

Conclusions

- GDGPS was demonstrated to provide high-accuracy GNSS ionospheric TEC measurements generated by the <u>Tonga volcano eruption</u> and ensuing tsunami in real time

  - Global network of GDGPS-processed sites available (~200)
  - GNSS-based Upper Atmospheric Realtime Disaster Information and Alert Network (GUARDIAN) is under development
  - Current real-time precision of GDGPS-processed TEC measurements are shown to be at the 0.03 TECU level; signal-to-noise ratio is between 10 to 100

- <u>Challenge</u>: installing new real-time GDGPS stations at key locations around the Pacific Ring of Fire

- GDGPS-measured TEC observations has a <u>unique potential</u> for effective early warning of impending natural hazards within ~15 min and for augmenting existing tsunami early warning systems

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The development of **ionospheric natural hazard early warning systems** is an international collaboration in geodesy:
- NASA's Science Mission Directorate
- International GNSS Service
- IAG Global Geodetic Observing System
- ITU Focus Group on AI for Natural Disaster Management
- Group on Earth Observations Geodesy4Sendai Pilot Initiative.

Jet Propulsion Laboratory
California Institute of Technology

IGS INTERNATIONAL G N S S SERVICE

IUGG

Global Geodetic Observing System

AI: **AI for Natural Disaster Management** **ITU Focus Group**

GROUP ON EARTH OBSERVATIONS

The GNSS data is made available by various international operators, science/space agencies, and educational institutions.

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