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

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Outline

- Motivation and objective
- Background
- 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

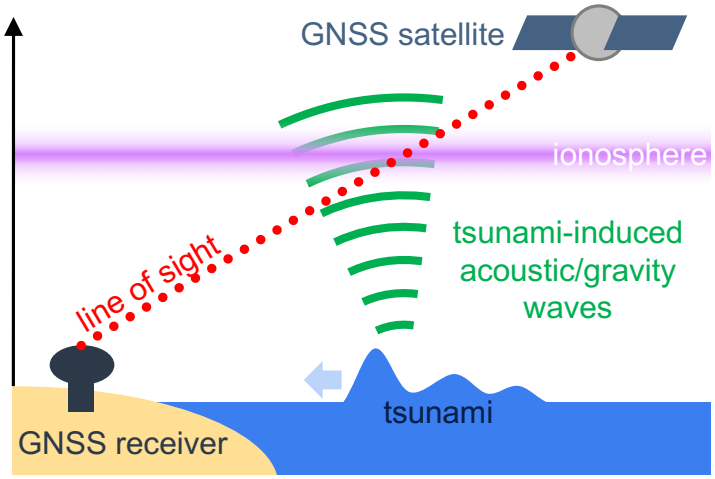
Current system is rife with outdated software, delayed alerts and poor communication to the public, according to expert panel

By Diana Leonard

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

Background

- 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



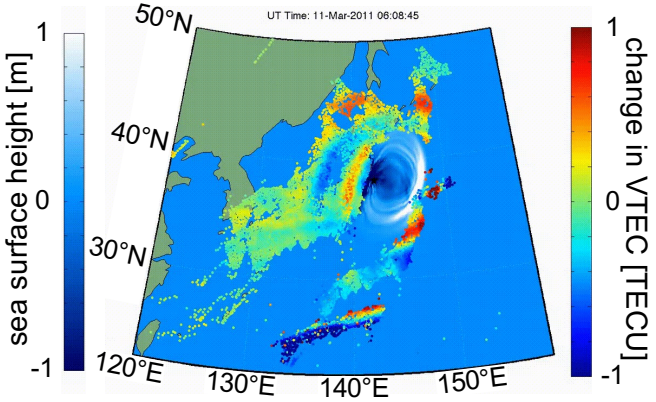
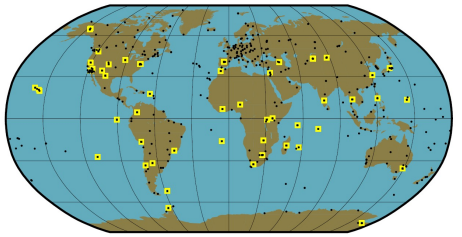


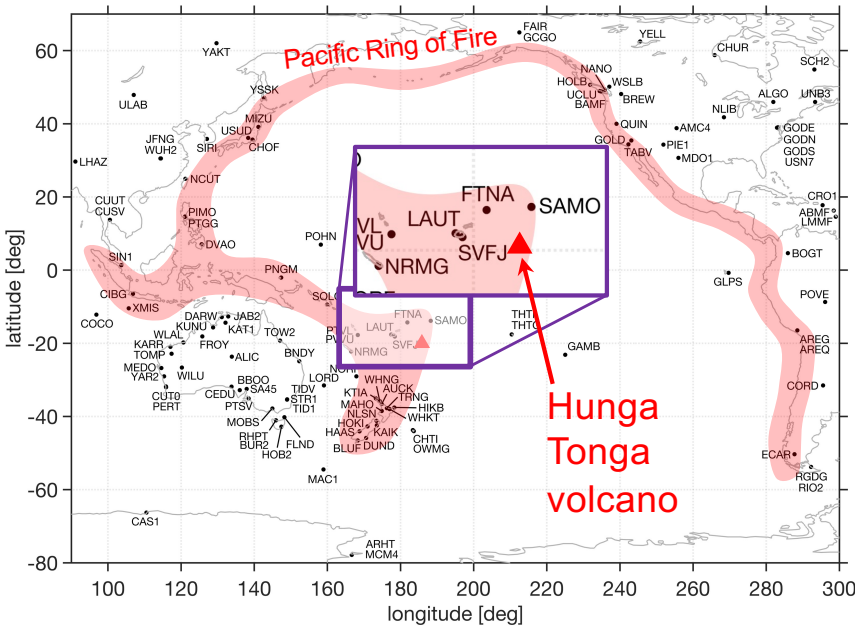
Figure: Ionospheric TEC and sea surface height map for the 2011 Tōhoku-Oki event (Galvan *et al.*, 2012).

Global Ground Stations Coverage

- GNSS monitoring relies on links between **satellites** and **ground stations**
- **Multiple constellations** processed in real time (BeiDou, Galileo, GLONASS, GPS)
- Station coverage:
  - >6000 public stations available through, *e.g.*, the IGS network, and operated by various international partners,
  - including 200+ GDGPS-processed stations **streaming data in real time***
- Case study: Honga Tonga eruption on Jan 15, 2022

GDGPS-Processed Global Network (200+ Sites)

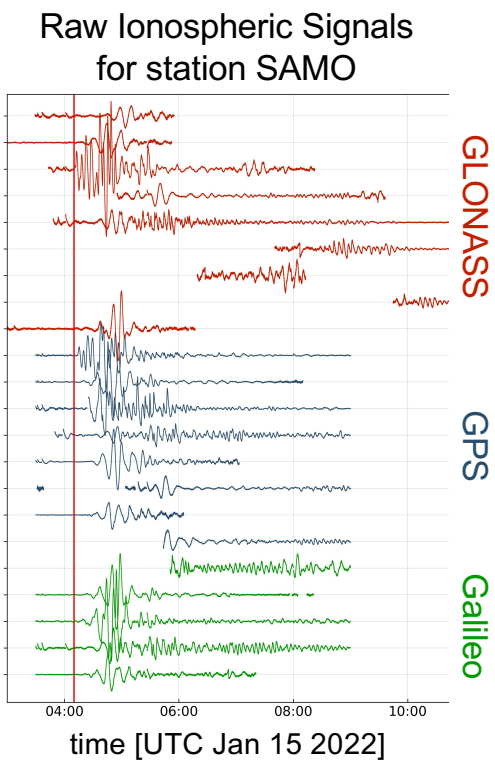


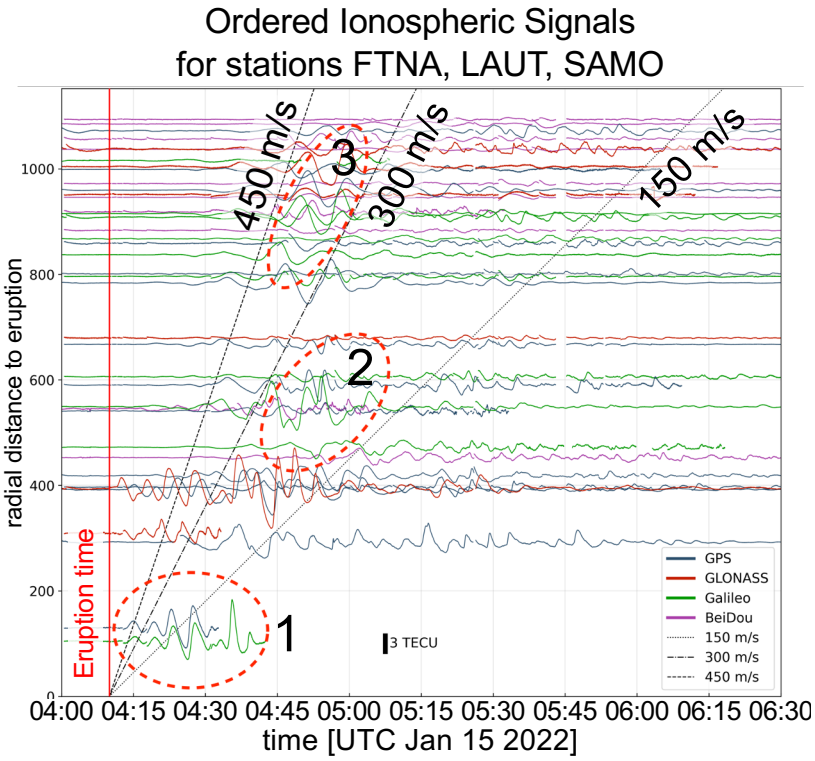


*60 NASA GGN sites
12 GDGPS-operated sites
100+ IGS public sites

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**

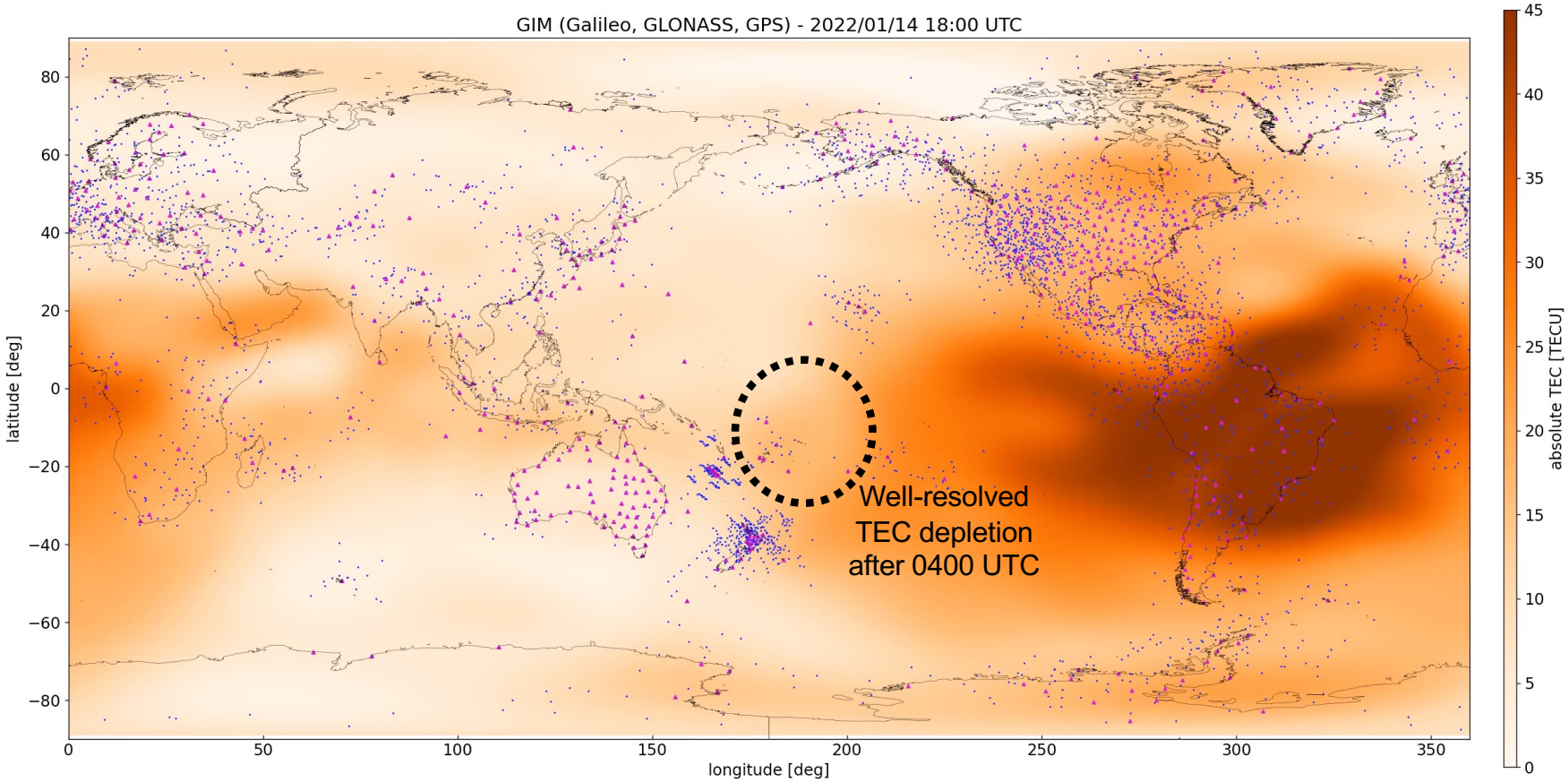




Post-Processed High-Resolution JPL GIM

Global Ionospheric Map

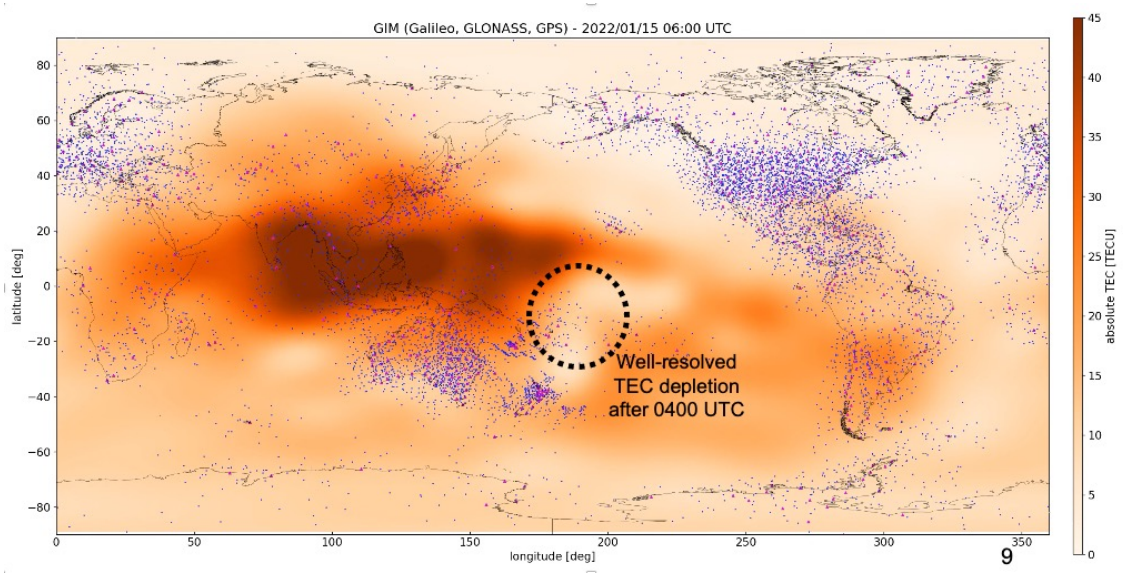
3-Shell Model (k8s3)

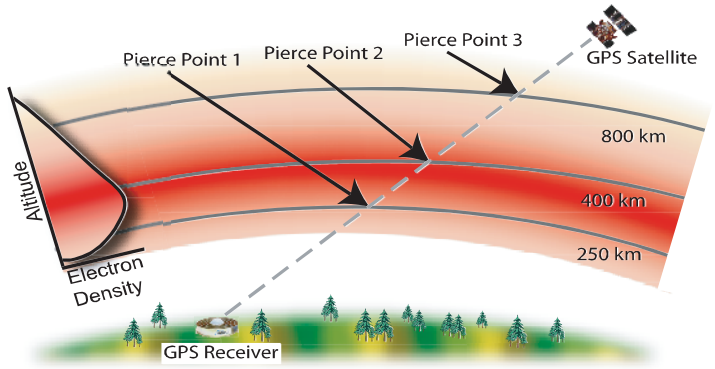


600 selected (out of a set of ~6000) using GPS+GAL+GLO

Movie to play during talk

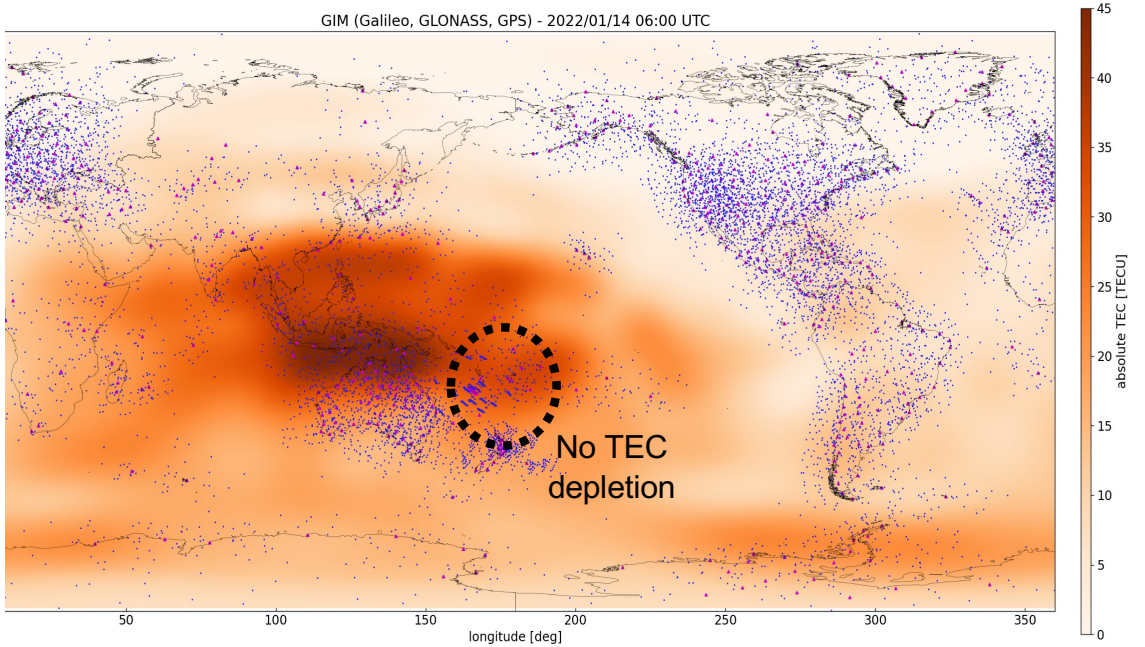
Comparison of GIM Maps with Day Before





Post-processed 3-shell ionospheric model resolved TEC depletions following the eruption

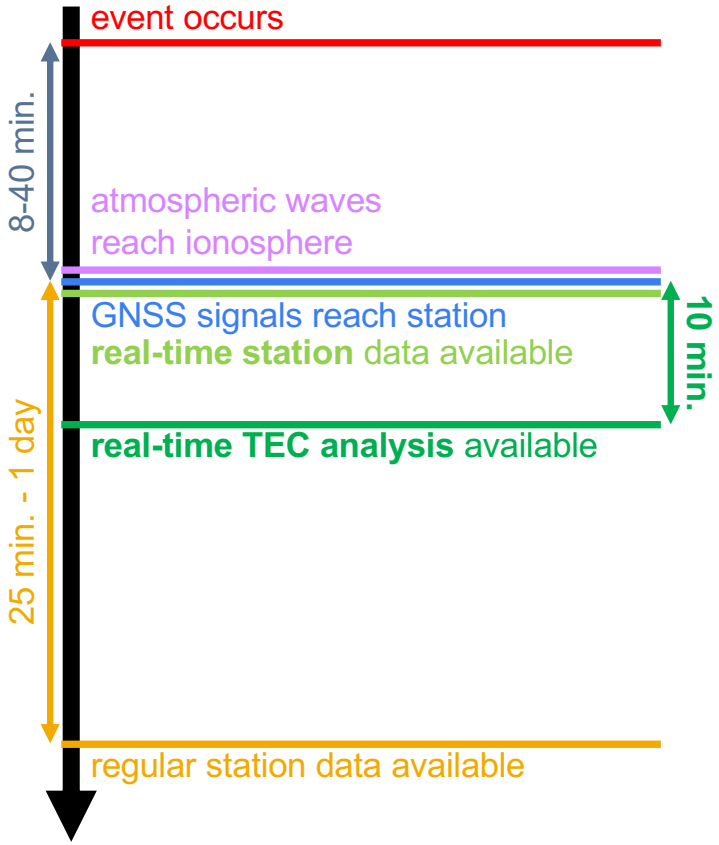
$$TEC = M(h_1, E)\sum_i C_{1i}B_i(lat, lon) +$$
$$M(h_2, E)\sum_i C_{2i}B_i(lat, lon) +$$
$$M(h_3, E)\sum_i C_{3i}B_i(lat, lon) + b_r + b_s$$



May 4, 2022

Post-Processing vs. Real-Time Processing

- Regular GNSS stations: data usually available the following day at the earliest and it is only beneficial for post-processing of past events
  - Not ideal for natural hazard warnings
- Real-time stations: TEC-based analysis available **minutes after the event**



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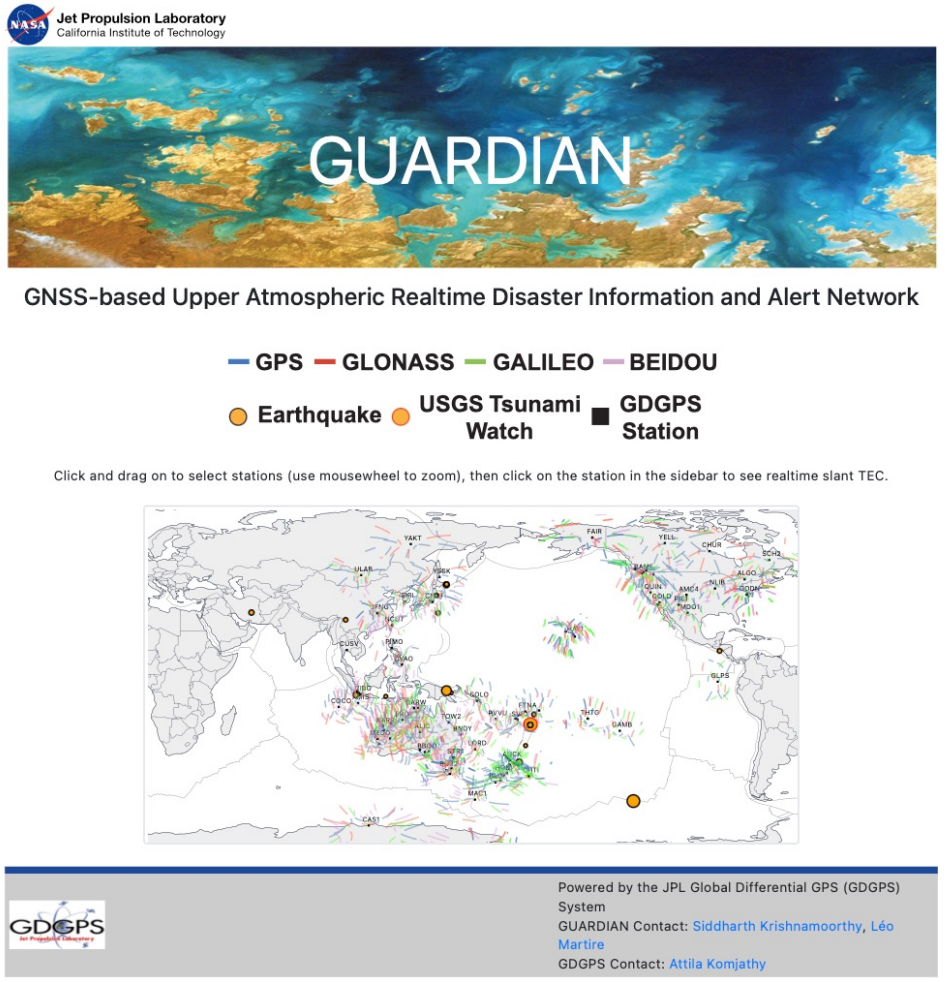

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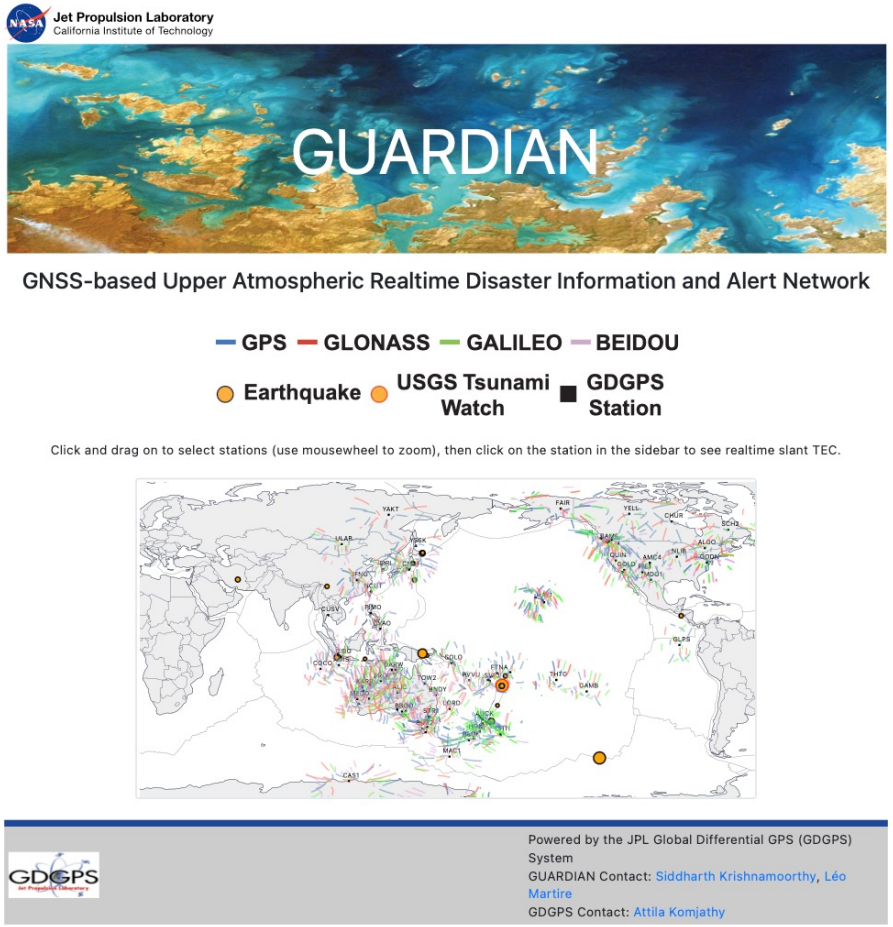
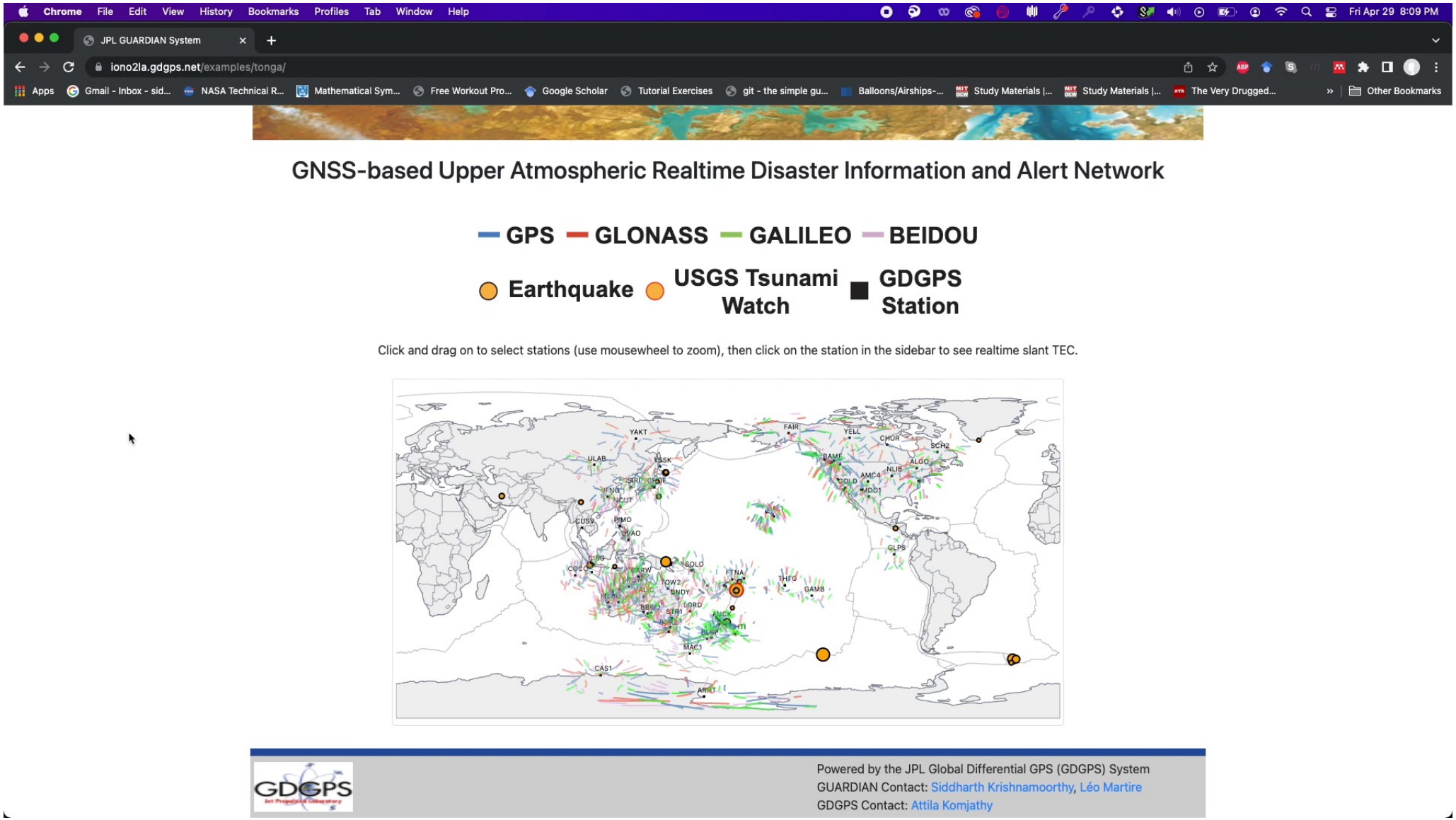
- Adding **new real-time GNSS stations**:
  - Positioning for crustal deformation
  - **Real-time TEC products** for natural hazards early warning



- 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

GUARDIAN Observing Tonga Eruption



Movie to Play During Talk

Conclusions

- GDGPS was demonstrated to provide high-accuracy GNSS ionospheric TEC measurements generated by the Tonga volcano eruption 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
- Challenge: installing new real-time GDGPS stations at key locations around the Pacific Ring of Fire
- GDGPS-measured TEC observations has a unique potential for effective early warning of impending natural hazards within ~15 min and for augmenting existing tsunami early warning systems

On-Going Collaborations

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.

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

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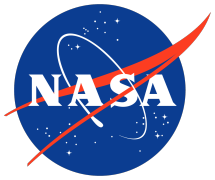

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