Real-Time Detection of Tsunami-TIDs: an Integration of GPS and Galileo Systems

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Introduction

It has been shown that **tsunamis** generate gravity waves that propagate up to the ionosphere and produce **Travelling Ionospheric Disturbances** (TIDs) in the E and F regions. These electron density disturbances can be studied in detail using ionospheric **total electron content** (TEC) measurements collected by continuously operating ground-based receivers from the **Global Navigation Satellite Systems** (GNSS)[1]. Here, we present results using a new approach, named **VARION** (Variometric Approach for Real-Time Ionosphere Observation), and estimate slant TEC (sTEC) variations in a **real-time scenario**.

VARION Algorithm

The **VARION** algorithm was derived from the **VADASE** algorithm that is used for real-time GNSS seismology [2]. **VARION** is based on single **time differences of geometry-free combinations** of GNSS carrier-phase measurements using a **stand-alone GNSS receiver** and standard **GNSS broadcast products** (orbits and clock corrections) that are available in **real-time** [3].
The physical quantity estimated by the algorithm is the **total derivative** of the function $\delta TEC(t,s)$ with respect to time t (Eqn. 1).

$$\frac{d\,\delta TEC(t,s)}{dt} = \frac{\partial\,\delta TEC(t,s)}{\partial t} + \frac{\partial\,\delta TEC(t,s)}{\partial s}\frac{\partial s}{\partial t} \tag{1}$$

Subsequently, Eqn. 1 is **integrated over time** (from t_0 to t_f) in order to estimate **TEC time variations** while the **IPP is moving** along its path.

$$\Delta TEC(t_f, t_0) = \int_{t_0}^{t_f} d\,\delta TEC(t,s) \tag{2}$$

Eqn. 2 is used to **detect tsunami-TIDs in real-time**. The results are filtered using a **finite duration impulse response** (FIR) high-pass filter.

Results

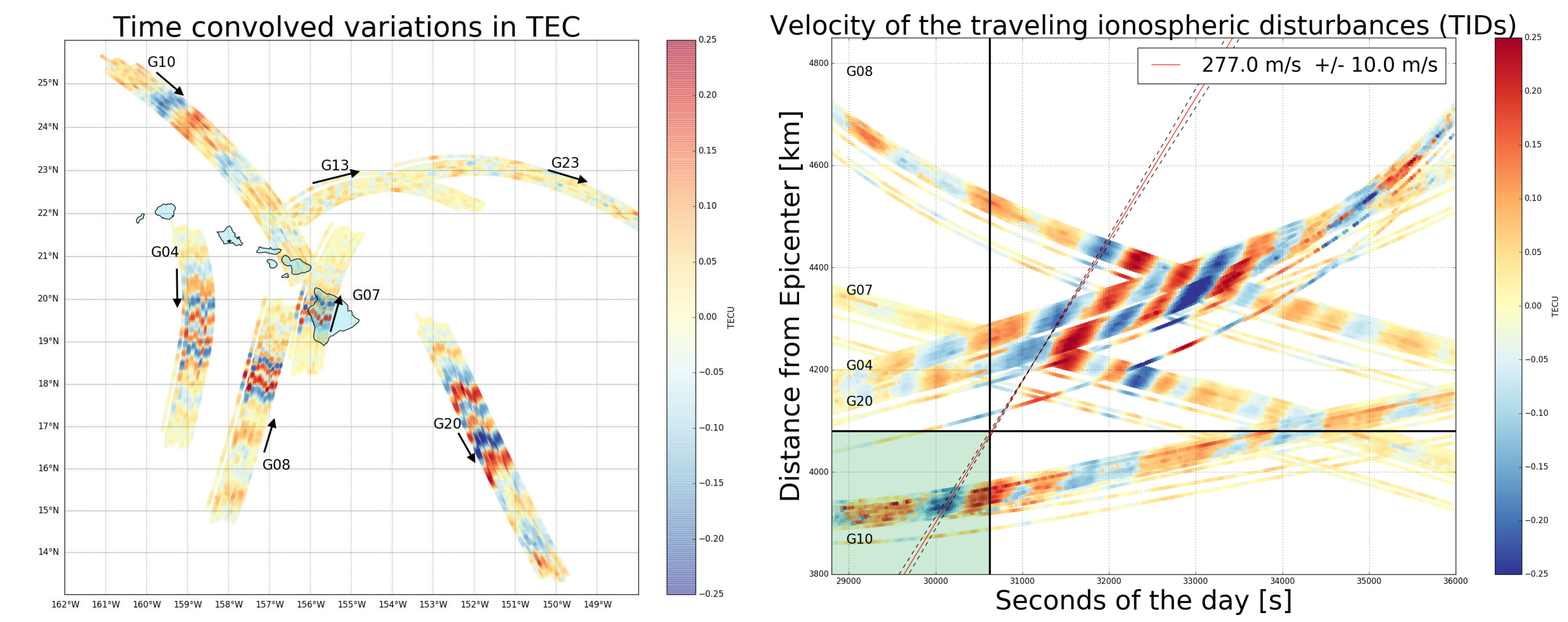

Figure 1: Space-time sTEC variations for two hours at the IPPs for the 7 satellites seen from the 56 Hawaiian Islands GPS permanent stations, after the Haida Gwaii earthquake (left); sTEC variations at the IPPs vs. distance from the Haida Gwaii earthquake epicenter, for the 5 satellites observed from the 56 Hawaii Big Island's GPS permanent stations (right).

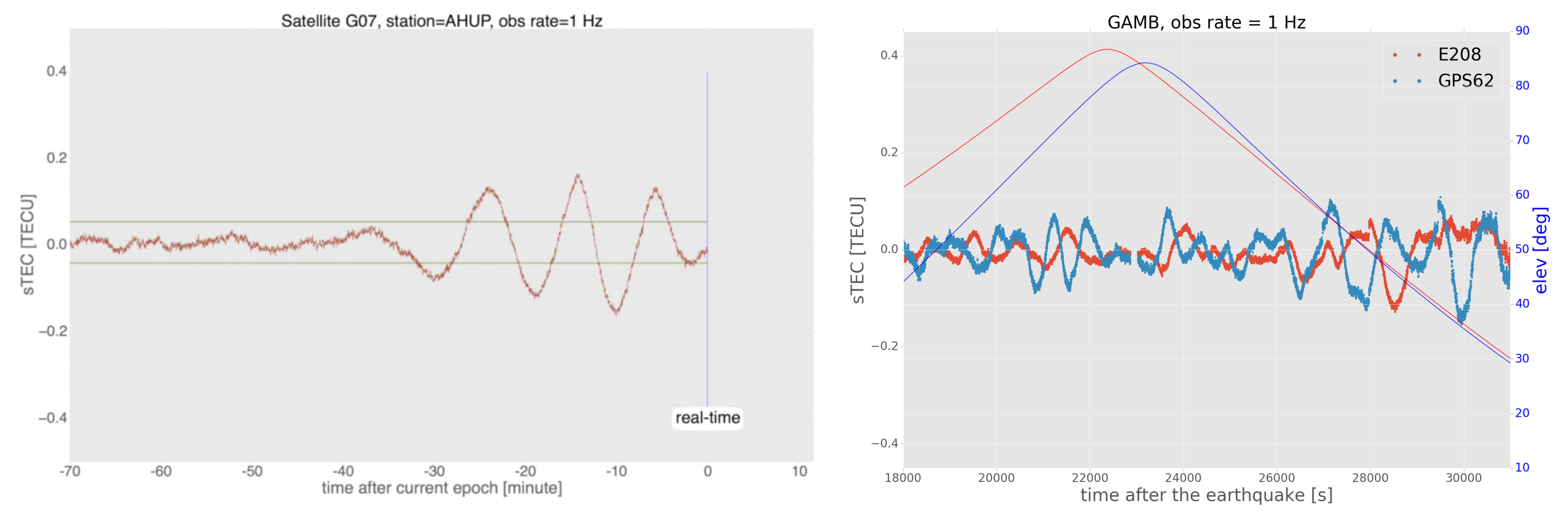

Figure 2: Frame from the a real-time tsunami detection test. The horizontal green lines represent the 5 sigma level of confidence (background noise) computed in real-time from the first half of the time series. Scan QR code below for full video; Comparison between Galileo and GPS sTEC time series for the 2016 New Zealand event (right)

Scan and watch a video about a real-time tsunami detection from the ionosphere

Datasets

GNSS processing. The **VARION** algorithm was applied for two specific events:

- 2012 Haida Gwaii event, with **56 GPS** receivers in Hawaii
- 2016 New Zealand event, with **real-time** data recorded from multiple GNSS receivers

Tsunami model. **Real-time MOST** (Method of Splitting Tsunami) model provided by the **NOAA Center for Tsunami Research** (NCTR) has been used for verifying the **correlation** in time and space of the estimated **TEC variations with the tsunami**.

Conclusions

- **Real-time** detection of **tsunami-TIDs before** the tsunami arrival (Fig. 1)
- **Stand-alone** operational mode (Fig. 2, left)
- **Multi-constellation** GNSS capability (Fig. 2, right)

Future Work

- **VARION** implementation in the **JPL's GDGPS system**
- Augmentation of existing **tsunami early warning systems**

References

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VARION software was designed in 2015 at the University of Rome La Sapienza, Geodesy and Geomatics Division, and subsequently, in 2016, further developed in collaboration with the Ionospheric and Atmospheric Remote Sensing Group, JPL/Caltech.
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