AN EFFECTIVE TECHNIQUE FOR ISOLATION OF TRAVELING IONOSPHERIC DISTURBANCES FROM GNSS-DERIVED TOTAL ELECTRON CONTENT MEASUREMENTS

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ABSTRACT

Recalling the dispersive nature of the ionosphere to the VHF radio signals, Global Navigation Satellite System (GNSS) can be advantageous to investigate Traveling Ionospheric Disturbance (TID) following a natural hazard by extracting Total Electron Contents (TEC) from dual-frequency observations. Due to the low amplitude of TID waveforms and uncertainties of the GNSS observations, an advanced signal processing technique is required to isolate the TIDs from TEC measurements. One of the most critical steps in the advanced signal processing technique is the detrending process. The TEC detrending procedure is extremely challenging considering the high levels of dynamic activities in the ionosphere. Specially, frequent oscillations and abrupt disturbances following a natural hazard make the detrending procedure more complicated. To effectively mitigate the difficulties of the detrending process, here we developed an efficient TID isolation method by combining the natural neighbor interpolation as the trend estimator with the leave-one-out technique as the cross-validator. Investigating the TIDs excited by a sub-marine earthquake and low-yield volcanic eruption reveals that low SNR signatures can be achievable which verifies the performance of the developed methodology.

TEC EXTRACTION FROM GNSS OBSERVATIONS

- Calculation of TECs from the dual-frequency carrier phase GPS observations
- The geometry-free (or ionospheric) linear combination of GNSS carrier phase observables is proportional to the integral of electron density along the signal ray:

$$TEC = \left[c\left(\frac{\Phi_1}{f_1} - \frac{\Phi_2}{f_2}\right) - (N_1 - N_2) + (b_r + b_s)\right]\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}\frac{1}{40.3}$$

CASE STUDY

- A volcanic eruption and several earthquakes with magnitudes of 5.3-7.9 Mb occurred on ring of fire on 23 January 2018 (DOY023).
- The highlights of SWPC PRF 2213 for January 23, 2018 indicated low k_p indices ranging between 0-2 and very low level of Sun activity.
- Chosen natural hazards to investigate their impacts on the ionosphere, as well as to distinguish between the induced signatures from different sources:
  1) 7.9Mb Gulf of Alaska earthquake, in Alaska
  2) Kusatsu-Shirane volcanic eruption, in Japan

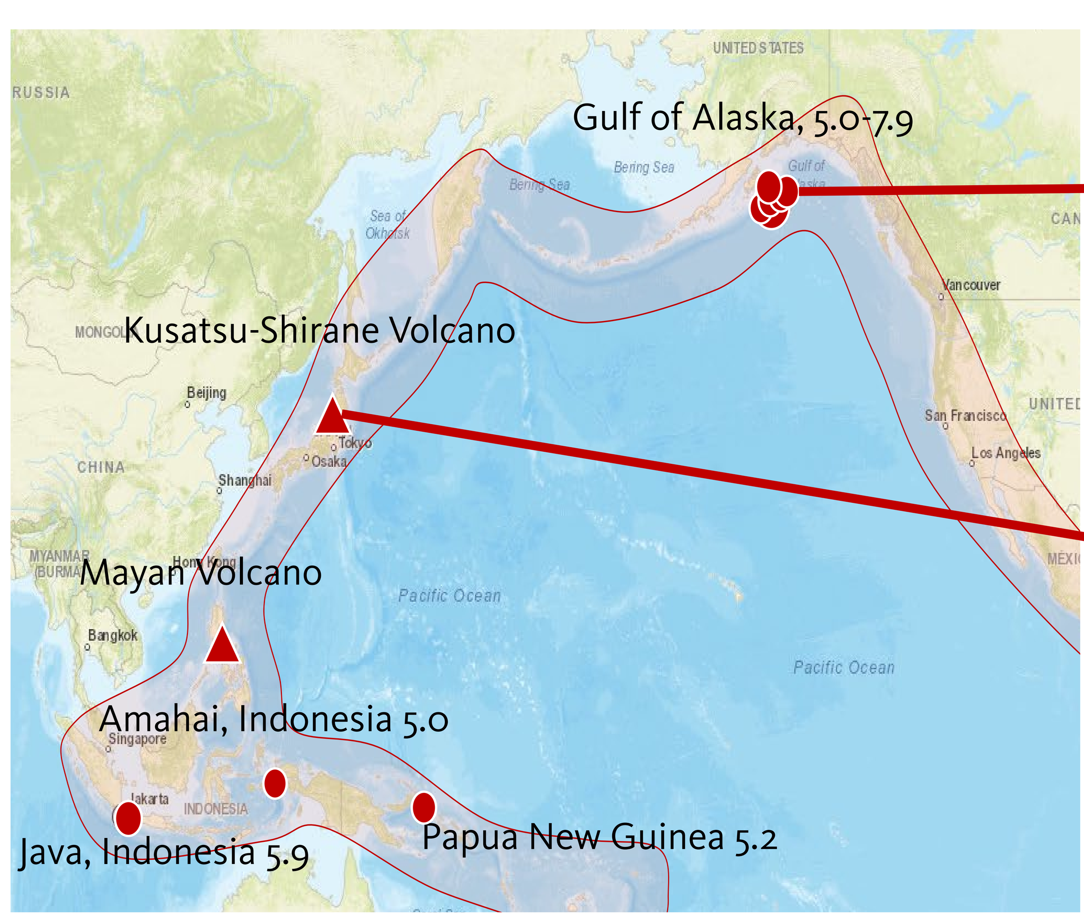
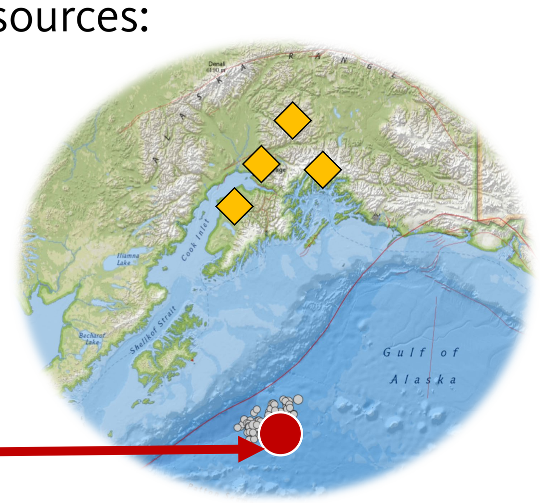
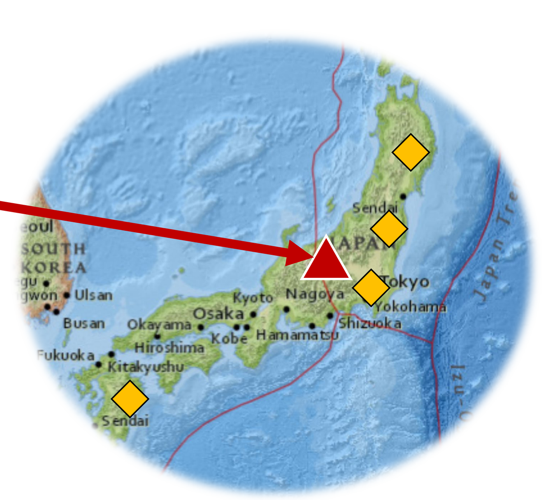


Figure 1. Geophysical hazards on DOY023 on ring of fire



Gulf of Alaska earthquake and network of applied CORS sites



Kusatsu-Shirane volcanic eruption and network of applied IGS sites

ADVANCED SIGNAL PROCESSING TECHNIQUE

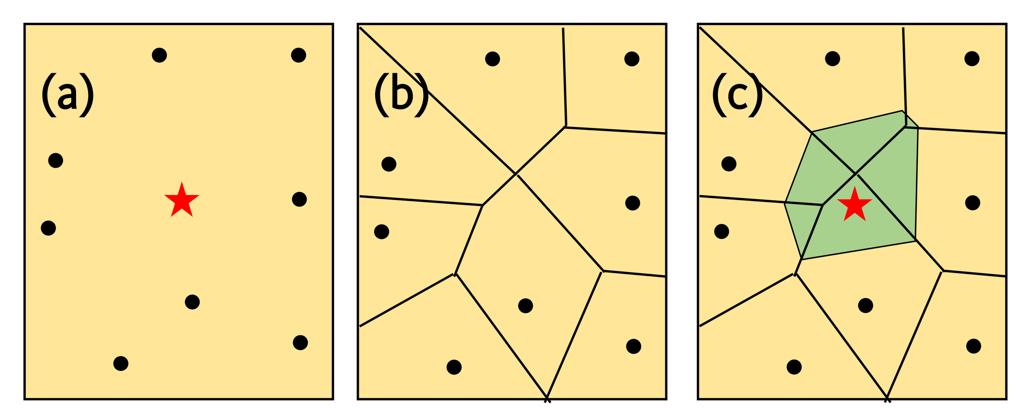


Figure 2. (a) All the available points. (b) Creation of the Voronoi cells after excluding the query point. (c) Creation of a new Voronoi cell around the excluded query point.

- An acceptable performance natural neighbor interpolation in ionospheric map computations (Kotulak et al., 2017).
- Natural neighbor interpolation in the three dimensional space R^3:

$$f(TEC_i^{obs}) = \sum_{k=1}^{N} w_k(q)\, f(TEC_{NN}^{(q_i)})$$

- The weight coefficient is proportion of the overlapping volume between the new and the initial cells to the volume of the new cells:

$$w_k(TEC_i^{obs}) = \frac{Vol\left(V_{TEC_{NN}^{(q_i)}} \cap V^{+}_{TEC_i^{obs}}\right)}{Vol\left(V^{+}_{TEC_i^{obs}}\right)}$$

Step 1: Exclude i^{th} data point from the vector of TEC observations and consider it as the query point in natural neighbor interpolation → $q_i = TEC_i^{obs}(x_i, y_i, z_i)$

Step 2: Find the natural neighbors of q_i from the remained observations → $TEC_{NN}^{(q_i)}$

Step 3: Interpolate the TEC value for q_i from $TEC_{NN}^{(q_i)}$ using natural neighbor interpolation technique → TEC_i^{NNI}

Repeat steps 1-3 for the entire dataset: $i = 1, 2, \ldots, n$

Step 4: Consider the interpolated TECs as the dominant trend → $TEC_{trend} = [TEC_1^{NNI}, TEC_2^{NNI}, \ldots, TEC_n^{NNI}]$

Step 5: Detrend the TEC observations by defining: $TEC_{residual} = TEC_{obs} - TEC_{trend}$

Figure 3. Flowchart illustrating the advanced signal processing based on the combination of natural neighbor interpolation and leave-one-out technique.

ABSTRACT

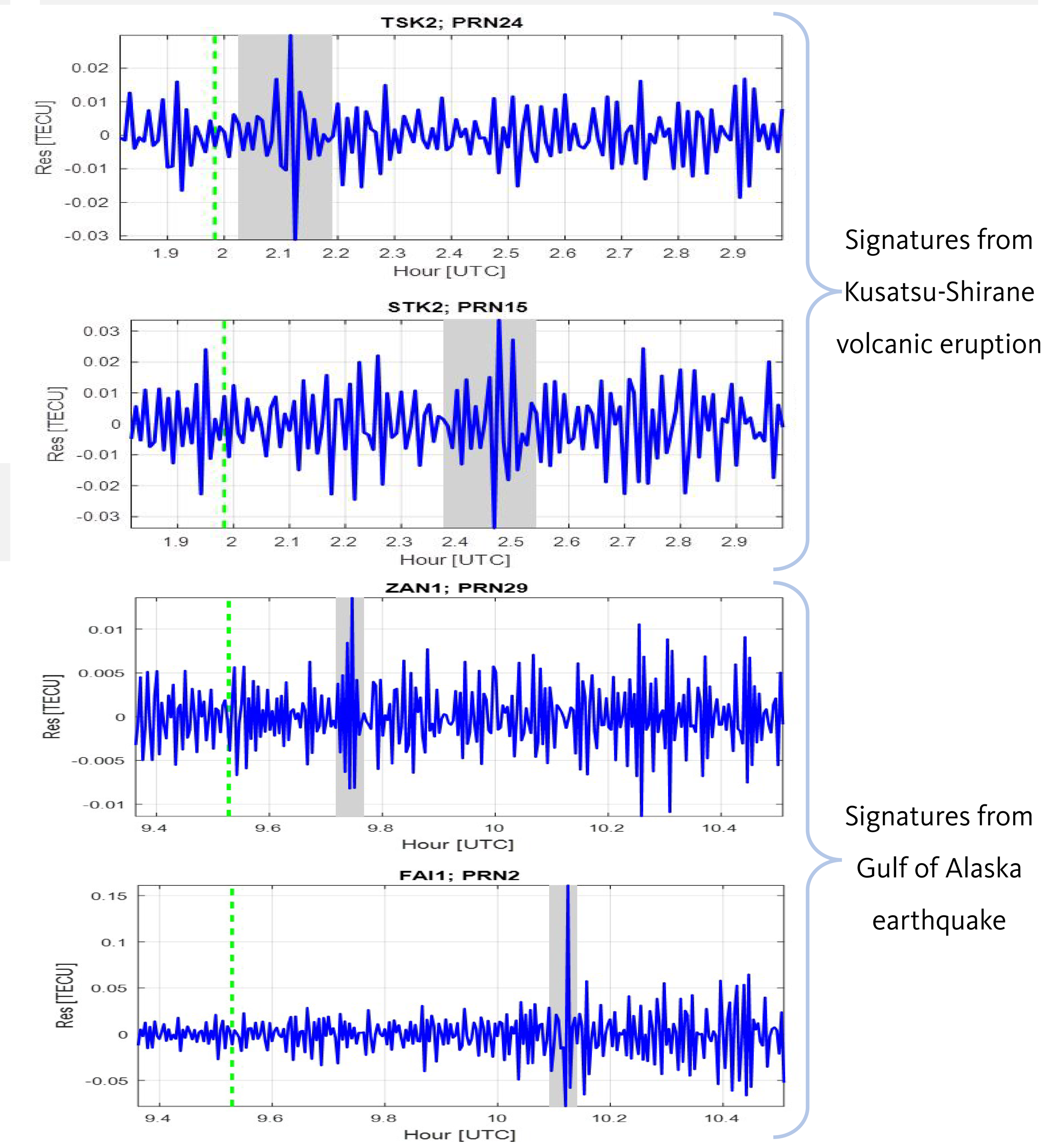
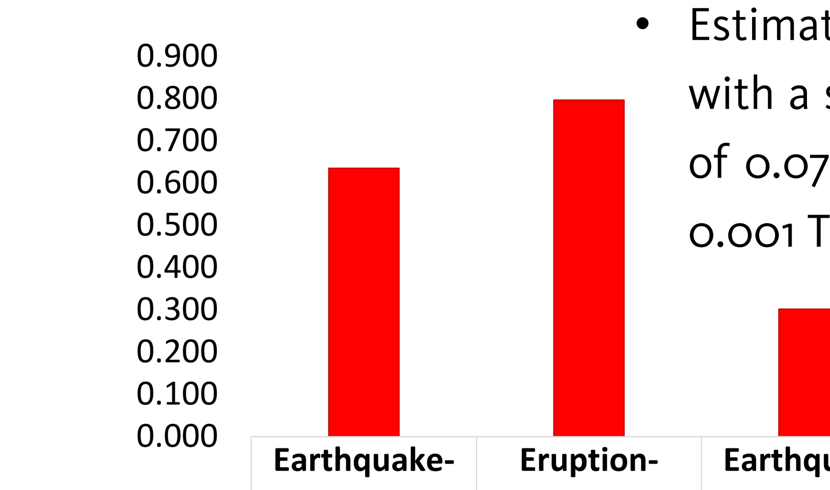


Figure 4. Detrended TECs and potential TIDs

- Propagation of eruption-induced TIDs with an average velocity of 529.894 m/s
- Propagation of earthquake-induced TIDs with an average velocity of 723.655 m/s
- Estimation of TEC trends with a standard deviation of 0.075 and average of -0.001 TECU



	Earthquake-Earthquake	Eruption-Eruption	Earthquake-Eruption
Correlation	0.635	0.797	0.302

REFERENCE

[1] Park et al. (2012). Discriminating underground nuclear explosions and earthquakes in GPS-detected traveling ionospheric disturbances: case study. Proceedings of the ION GNSS 2012, Nashville, TN, USA.

[2] Kotulak et al. (2017). Sibsonian and non-sibsonian natural neighbor interpolation of the total electron content value. Acta Geophys. 65: 13-28.