# A Complex Systems Perspective on Deceleration in Propagation Velocity of Medium Scale Traveling Ionospheric Disturbances Before Large Earthquakes: Unified Physical Mechanism and Multi-GNSS TEC Correlation Analysis

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**Abstract**

Capability of TEC 's CoRrelation Analysis (CRA) (Iwata and Umeno, JGR-Space Physics, 2016) for detecting preseismic anomalies is explained from the view point of the increase in signal-to-noise ratio to amplify preseismic TEC's small anomaly signals with multiple sensor data synchronization and correlation. Furthermore, deceleration at propagation velocities of MSTID before the 2016 Kumamoto earthquake firstly observed by CRA (Iwata and Umeno, JGR-Space Physics, 2017) as velocity reduction of MSTID propagation in the F Layer of the ionosphere is then elucidated as a candidate of preseismic anomalies. A new physical model (Umeno, Nakabayashi, Iwata, Kao, 2021,DOI: 10.4236/ojer.2021.104008 ) which is recently constructed from the first principle to explain such ionospheric anomaly ($\Delta V=\alpha\Delta E$, Linear response theory of deceleration $\Delta V$ in propagation velocities of MSTID before large earthquakes with electric field change $\Delta E$) is also presented to characterize preseismic ionospheric TEC anomalies by associating deceleration, acceleration, moving to the inverse direction of macroscopic ionic velocities before various large earthquakes such as our existing findings on ionospheric TEC anomaly before 2016 Tainan earthquake (Goto, Uchida, Igarashi, Chen, Kao, Umeno, JGR-Space Physics, 2019). In particular, this physical model predicts that the 35 m/s change in MSTID propagation velocities estimated by TEC's CRA for 2016 Kumamoto earthquake requires 0.58 mV/m electric field change in the F Layer ionosphere, which is almost consistent with the estimation (Kelley et. al. JGR-Space Physics, 2017) in that the E[?]B/Bˆ2 drift of 12 m/s for dislocations of electrons requires 0.5 mV/m electric field in the E Layer to explain Heki's finding of TEC anomaly behavior before the Tohoku-Oki earthquake. The 10000 times amplification effect of weak signals such as 0.5-0.58 mV/m in electrical field to affect MSTID propagation velocity change as is firstly observed by Iwata and Umeno, 2017 by CRA which means a significant signal amplification capability in this multi-sensor TEC correlation analysis (CRA). To summarize, various interrelation between physical models to exhibit TEC anomalies and observed TEC anomalies as above will be presented to understand preseismic ionospheric anomaly before large earthquakes.

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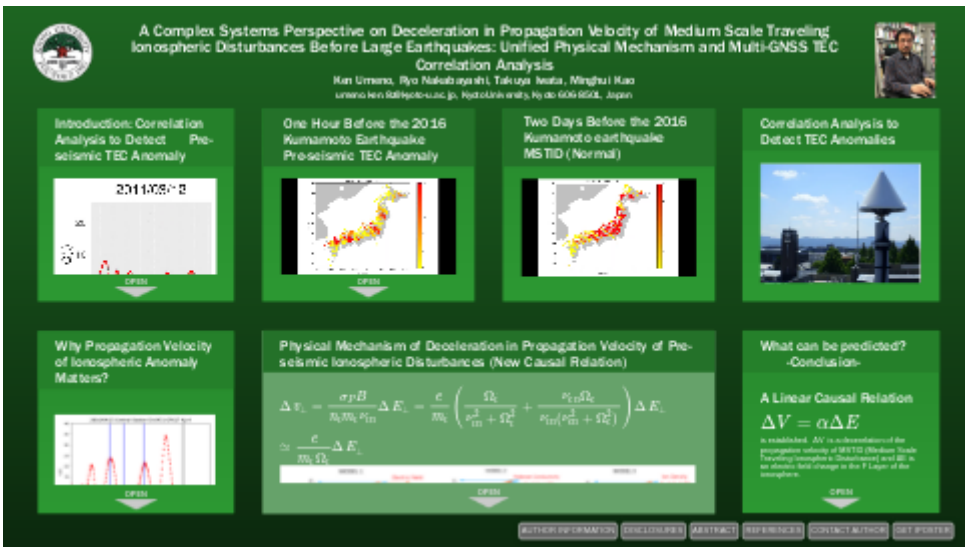


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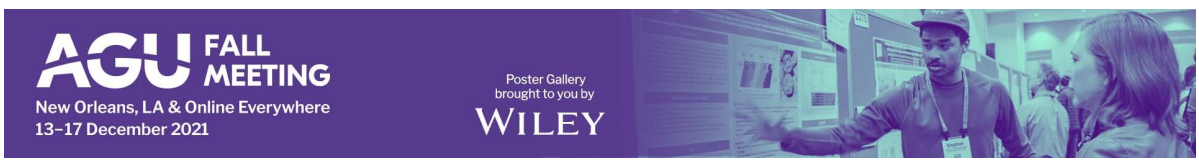

# INTRODUCTION: CORRELATION ANALYSIS TO DETECT PRE-SEISMIC TEC ANOMALY

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Key point: Take Correlation of Multiple TEC Data Anomalies

Correlation Analysis to Detect Pres-seismic TEC Anomalies before the following earthquakes:

2011 Tohoku-Oki Earthquake (March 11, 2011) →Iwata and Umeno, Journal of Geophysical Research (2016)

2016 Kumamoto Earthquake (April 15, 2016)→Iwata and Umeno, Journal of Geophysical Research (2017)

2016 Tainan Earthquake (Feb 5, 2016)→Goto, Uchida, Igarashi, Kao, Umeno, Journal of Geophysical Research (2019)

This presentation provides a new insight of pre-seismic TEC anomalies; a deceleration of propagation velocities of medium scale traveling ionospheric disturvances (MSTID) where space weather phenomena are affected by preseismic ionospheric anomalies.

# ONE HOUR BEFORE THE 2016 KUMAMOTO EARTHQUAKE  PRE-SEISMIC TEC ANOMALY

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1638978548/agu-fm2021/85-E0-F9-66-8E-FA-7B-EF-95-FD-6A-86-67-59-17-77/Video/mov_s1_xw3le5.mp4

Correlation values at all the GNSS stations in Japan before the 2016 Kumamoto earthquake on 2016/04/15. Every GNSS station as a central station and mapped the results into the Japan map. The GPS satellite PRN 17 is used here.

The black x marks the epicenter. The earthquake occurence time is 16:25 UTC on April 15. Deceleration in the propagation velocity of MSTID (Medium Scale Travelling Ionospheric Anomalies) can be seen about one hour before the Earthquake as a preseismic anomaly.

# TWO DAYS BEFORE THE 2016 KUMAMOTO EARTHQUAKE MSTID (NORMAL)

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1638978673/agu-fm2021/85-E0-F9-66-8E-FA-7B-EF-95-FD-6A-86-67-59-17-77/Video/mov_s2_rflicz.mp4

Correlation values at all the GNSS (Geonet) stations in Japan around 16:00 (UTC) on 2016/4/13.

No earthquakes occured on the day while MSTID was observed. We use every GNSS station as a central station and mapped the results of C(T) into the Japan map. The GPS satellite PRN17 is used here.

# CORRELATION ANALYSIS TO DETECT TEC ANOMALIES

**Key Point of Correlation Analysis (CRA):**

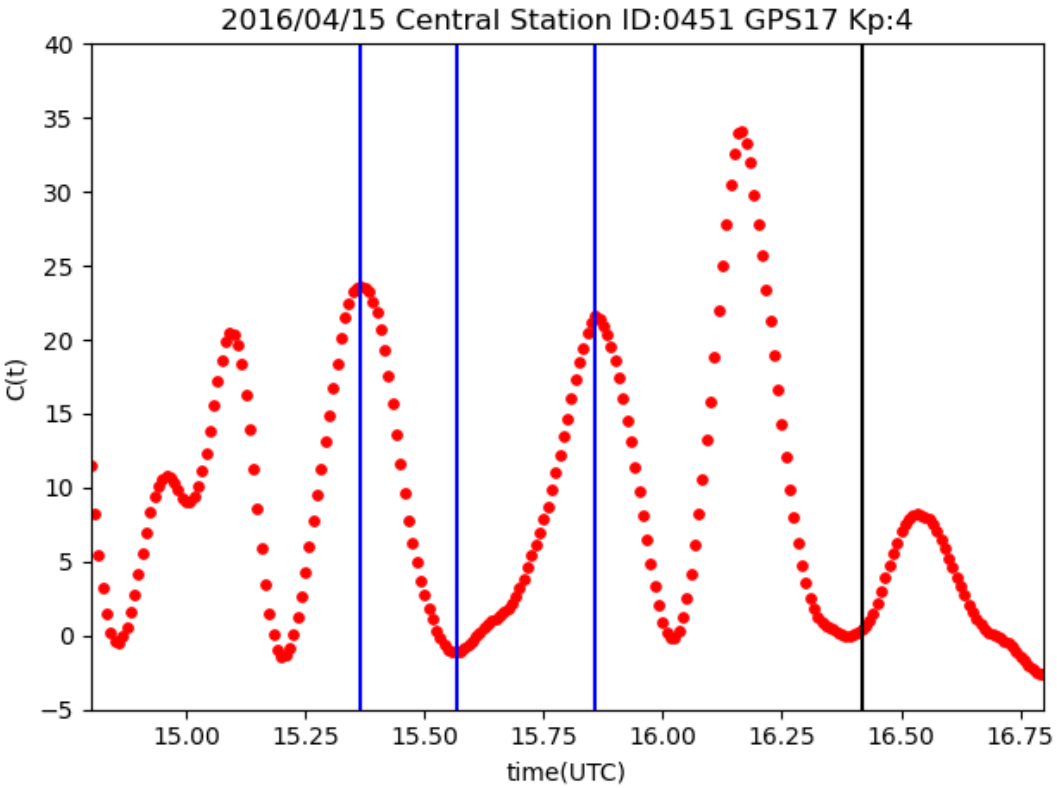
**Take multiple signals data from multiple GNSS stations. Take time-correlations *C(T)* among them such as spectrum spread technology, VLBI (Very Long Baseline Interferometer) to regist noise. Even when a signal level is weaker than noise level, correlation *C(T)* can recover the signal component taken as a correlation value.**

$$C(T) = \frac{1}{NM} \sum_{j=0}^{N-1} \sum_{i=1}^{M} X_{0,t+t_S+j\Delta t} \cdot X_{i,t+t_S+j\Delta t}$$

The signal to noise ratio is:

$$\mathrm{SNR} = \frac{(O(1))^2}{\left(O\left(\frac{1}{\sqrt{N}}\right)\right)^2} = O(N).$$

# WHY PROPAGATION VELOCITY OF IONOSPHERIC ANOMALY MATTERS?




Propagation Velocity (Direction, Speed) is the KEY factor to distinguish preseismic TEC anomaly from normal space weather phenomena (like MSTID).

This figure is taken from the reference [4] (K. Umeno, R. Nakabayashi, T. Iwata and M-H. Kao, 2021).

Correlation values before the 2016 Kumamoto earthquake. The vertical axis shows the correlation C(T) and the horizontal one the time t (UTC). The black line indicates the exact time 16:25 (UTC) when the 2016 Kumamoto earthquake occured. The blue lines indicate the times when C(T) has extremal values. A deceleration at propagation velocity of MSTID is clarified. The GNSS station 0087 (Koga, Fukuoka Prefecture) is used as the central station and GPS satellite RRN17 is selected for the analysis.

# PHYSICAL MECHANISM OF DECELERATION IN PROPAGATION VELOCITY OF PRE-SEISMIC IONOSPHERIC DISTURBANCES (NEW CAUSAL RELATION)

$$\Delta v_{\perp} = \frac{\sigma_P B}{n_i m_i \nu_{in}} \Delta E_{\perp} = \frac{e}{m_i} \left( \frac{\Omega_i}{\nu_{in}^2 + \Omega_i^2} + \frac{\nu_{en}\Omega_e}{\nu_{in}(\nu_{en}^2 + \Omega_e^2)} \right) \Delta E_{\perp}$$

$$\simeq \frac{e}{m_i \Omega_i} \Delta E_{\perp}$$

**A New Linear Causal Relation between Propagation Velocities of MSTID and**

***Generated*** **Electric Fields**

**Our physical model [4] explaining deceleration at propagation velocities with MSTID on the mid-latitude northern hemisphere in the nighttime are depicted. The southward direction of MSTID propagation is crude approximation for simplicity of presentation. In reality, the nighttime propagation of MSTID on the mid-latitude northern hemisphere is southwestward direction while the daytime propagation of MSTID on the mid-latitude northern hemisphere is southward.**

# WHAT CAN BE PREDICTED? -CONCLUSION-

## A Linear Causal Relation $\Delta V = \alpha \Delta E$

is established. ΔV is a decerelation of the propagation velocity of MSTID (Medium Scale Traveling Ionospheric Disturbance) and ΔE is an electric field change in the F Layer of the ionosphere.

Here

$\alpha \simeq 6 \times 10^4 \ \mathrm{T}^{-1}$

## In the case of the 2016 Kumamoto earthquake,

## ΔE is estimated to be 0.58mV/m as

## ΔV is estimated to be 35m/s

by the correlation analysis (CRA) [1-3].

# DISCLOSURES

Ken Umeno (Presentor) of the chief inventor of the US Patent No. 11,016,206 "Abnormality Detection Apparatus, Communication Apparatus, Abnormality Detection Method, and Recording Medium" granted on May 25, 2021.

# AUTHOR INFORMATION

Ken Umeno has been Professor at  Department of Applied Mathematics and Physics, Kyoto University, Japan since 2012.

He received his Ph.D in Physics, at the University of Tokyo, Japan in 1995. Picture below is his team taken on Nov. 11, 2021.

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for detecting preseismic anomalies is explained from the view point of the increase in signal-to-noise ratio to amplify preseismic TEC's small anomaly signals with multiple sensor data synchronization and correlation.

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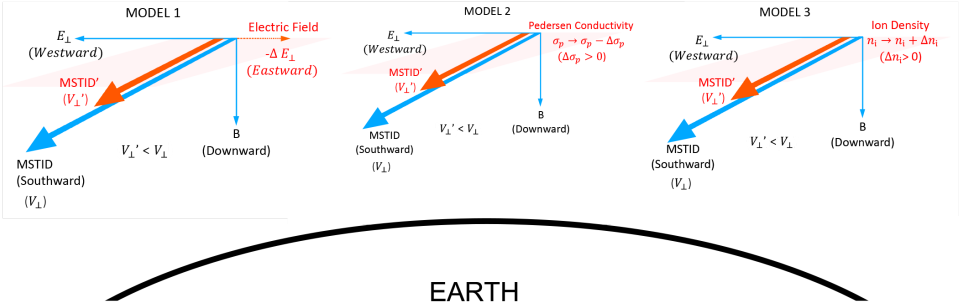


(https://agu.confex.com/data/abstract/agu/fm21/3/8/Paper_877183_abstract_811681_0.png)

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[4] Umeno, K. , Nakabayashi, R. , Iwata, T. and Kao, M. (2021) Capability of TEC correlation Analysis and Deceleration at Propagation Velocities of Medium-Scale Traveling Ionospheric Disturbances: Preseismic Anomalies before the Large Earthquakes. *Open Journal of Earthquake Research*, **10**, 105-137. doi: 10.4236/ojer.2021.104008 (https://doi.org/10.4236/ojer.2021.104008).