Ionospheric Total-Electron Content Anomaly –Earthquake Precursor

Jiangwei Wang

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

GNS SCIENCE
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GOALS

Build a program for Pre-earthquake TEC anomaly (PETA) visualization analysis by using GPS Toolkit (GPSTk).

Employ deep learning methods, to recognize the underlying relationships between ionospheric TEC anomaly and earthquakes

Ionosphere and Total-Free Electron Content

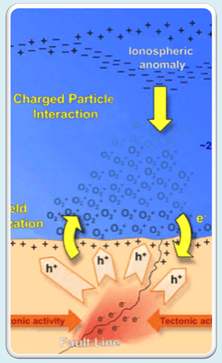
Ionosphere is the ionized part of Earth's upper atmosphere by solar radiation, from approximately 48 kilometres to 965 kilometres altitude.
The TEC or the ionization of the ionosphere primarily depends on the solar activity.

TEC Characters

- The amount of TEC varies with the amount of radiation received from the Sun.
- Seasonal variations, less radiation received from the Sun in winter, more in summer.
- Strong Daily fluctuations, high TEC value during daytime and near-zero tec at night-time
- Ionosphere imposes a dispersive delay on the GPS satellite ranging signals broadcasting
- Affection on signals varies with TEC values

Relationship Between TEC and Earthquakes

During earthquake preparation, free-electrons are released and change the local ionospheric TEC, the TEC anomaly time remains controversial, between 3 days to 2 weeks before and after the earthquake are discussed in different researches.



PETA Visualization Analysis Procedure

- Collect local GPS observation data from Geonet powered by land information new Zealand, navigation data from Scripps Orbit and Permanent Array Center (SOPAC).
- Use GPSTk computing suite to build TEC maps throughout new Zealand regions by remote sensing the ionosphere.
- Calculate daily correlation to a TEC anomaly at each gridded point thought tec map
- Plot an image of the gridded daily correlation values to detect TEC anomaly by visualization

Raw Data

Receiver Independent Exchange Format (RINEX)
enable users to post-process the GPS stations received data and generating more accurate results.

Observation data from geonet
e.g. yald2430.19o, contains all the related physical quantity observations in a 30 seconds intervals.
e.g. yald2430.19d, Hatanaka compressed file, 35% file size compression capability.

Navigation data from SOPAC
E.g. auto2430.19n, broadcast ephemeris data for the GPS constellation

GPS Toolkit

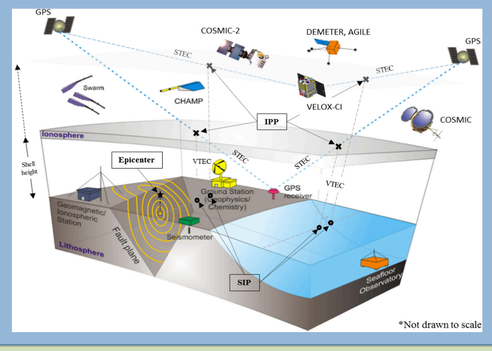
an open-source computing suite to the satellite navigation community produced by Space and Geophysics Laboratory within the Applied Research Laboratories of the University of Texas at Austin, to process GPS associated satellite navigation system data.

All applications are created by using ISO-standard C++ programming language, to ensure that the code is modular, extensible, and maintainable

enable us to compute TEC value in the ionosphere by following programs.

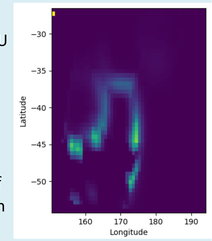
"ResCor"	"IonoBias"	"TECMaps"

'ResCor' program take the dual-frequency range data from the input RINEX data to compute the slant ionospheric delay, ØIPP and γIPP, and the elevation and azimuth of the satellite.
'IonoBias' program will carry over and read in all the processed files to collect the data during local nighttime by using solar ephemeris from the broadcast ephemeris navigation RINEX file.
Both simple models of the nighttime ionospheric TEC and all the biases will be fit to a least squares model.
All the estimated biases, with an uncertainty equal to the square root of the corresponding diagonal element of the covariance matrix, are in the output file. satellite plus receiver bias in a separate output file.
"TECMaps"
All outputs include output from "ResCor" are fed in, to estimate the ionospheric TEC on each point of a horizon grid at a fixed height of 350 kilometres.
It computes the average VTEC value at each time point first, then executes a double loop, over all grid points and all data values, to compute each grid value.



Visualization Analysis

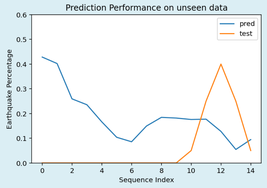
Once the daily TEC values collected, PETA correlation values can be computed by comparing each gridded TECU values to neighbour grid. If one or fewer grids' TECU values are standing out to its or their neighbour grids', there is more likely to be a TEC anomaly caused by local earthquake preparation. If many grids' TECU values are standing out from their neighbour grids together, this is more likely caused by solar activities or other geomagnetic effects. Daily PETA correlation image is showing the correlation values in a spatial structured image. Lighter the colour indicates the strong correlation. The image on the right is the correlation image of 2011-02-18, 3 days before Christchurch earthquake that occurred 3 days later with a magnitude of 6.2.



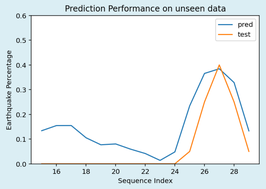
Deep Learning

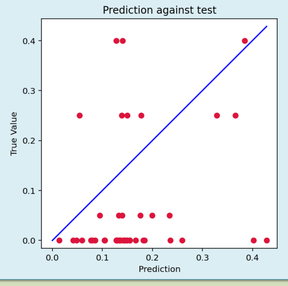
ConvLSTM2D method is going to be used, which is finding the correlations between the presentation images spatially and temporally combined. A 29 earthquakes events correlation images is the dataset. Sunspot numbers and day of the year are added as 2 extra layers to the images, which are reflecting how strong is the solar radiation, and how like they will affect the local TEC. These two layers are centered and scaled. 10 days sequences data are created to find the temporal pattern. This is a supervised regression problem, 26 events are used for training, and 3 for test. It is trying to predict the percentage of the sequences data will leading an earthquake. To label the data, 0.4 for the sequences ended on the event day, 0.25 for ending on 1 day before or after, 0.05 is for 2 days apart, and 0 for others. The sequences are largely imbalanced, most cases are 0. Resampling strategy is used to balance the cases.

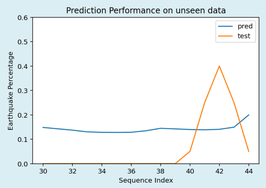
The best model showed on the right. Normalization, max pooling and dropout layers are used to increase training efficiency and prevent from over-fitting. It performed slightly better than a model with just 5 ConvLSTM2D layers.



For the three unseen events in the test dataset, model performed the best in the second case from the right. It didn't capture the 0 cases accurately, but it captured the event sequences quite well. The first event is peaked too early. In the last event test, model is confusing with a constant value throughout. The figure below showed one of the predicted values is close to the true 0.4 value. 0 'class' predicted with a high value of about 0.42.







This model didn't capture the underlying relationships between earthquakes and pre-earthquake ionospheric TEC anomalies overall. Statistically, it was not meaningful, and would not fit-for-purpose.