Crustal Motion of Active Plate Convergence in Eastern Taiwan, 2007-2018: Agglomerative Clustering based on Dynamic Time Warping

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Abstract

Global Positioning System (GPS) measurements reveal rapid incoherent crustal motions at various points in the longitudinal valley along the eastern coast of Taiwan, exhibiting a strong effect of the collision between the Philippine sea plate and the Eurasian plate. Dynamic Time Warping (DTW) can identify the subtle crustal motion patterns by comparing two GPS position daily fluctuations (non-tidal, non-seasonal and non-CME). We applied a nonparametric, hierarchical agglomerative clustering algorithm based on the DTW for 27 three-component, GPS daily fluctuations from 2007 to 2018 near the eastern coast of Taiwan. Agglomerative Clustering algorithm categorized the east coast tectonics of Taiwan into 3 geographical clusters based on pairwise DTW distance metrics - on the Chengkung Fault (related to 2003 Mw6.8 Chengkung Earthquake), inside Longitudinal Valley, others. Principal Component Analysis on the clustered three-component time series delineates their group movement patterns.

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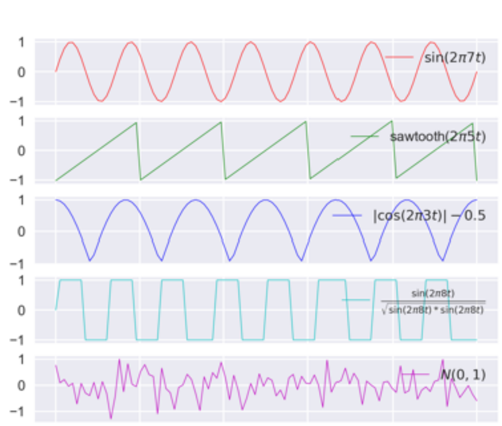
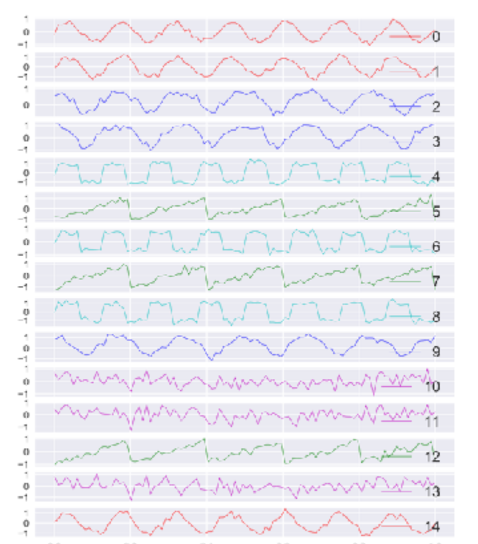
BACKGROUND

Global Positioning System (GPS) measurements reveal rapid incoherent crustal motions at various points in the longitudinal valley along the eastern coast of Taiwan, exhibiting a strong effect of the collision between the Philippine sea plate and the Eurasian plate[1].

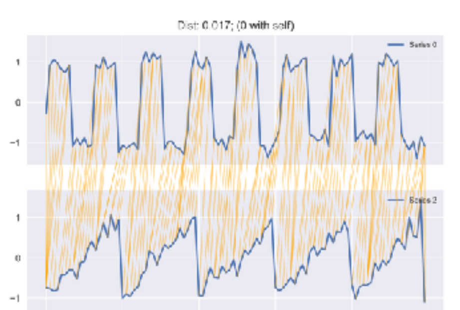
In this study, we introduce **Dynamic Time Warping**[2] (DTW) as a new method to identify the subtle crustal motion patterns by comparing two GPS position daily fluctuations (non-tidal, non-seasonal and non-CME). We applied nonparametric, hierarchical **agglomerative clustering**[3] algorithm on 27 three-component, GPS daily fluctuations from 2007-2018 near the eastern coast of Taiwan. The aim of the clustering is to partition the data set into clusters of stations based on the degree of similarity calculated by the DTW.

Synthetic Tests

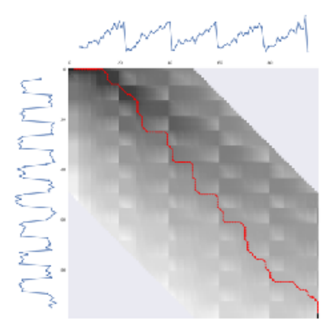




We produce our synthetic test data for agglomerative clustering by making 3 copies of each original signal, add random noise and then shuffle the 15 time series, randomly.

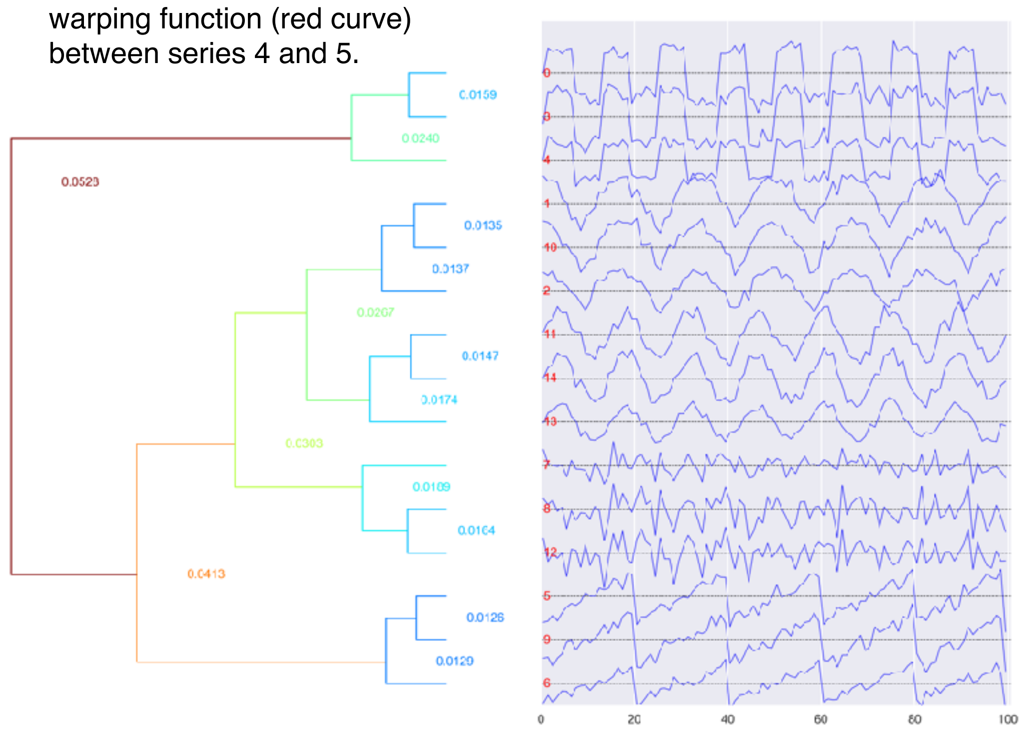


Time alignment of series 4 and 5 time series (DTW warping path - yellow lines).



DTW cost matrix and the warping function (red curve) between series 4 and 5.

DTW distance metric (normalized) and warping function for time series 4 (sign function) and time series 5 (sawtooth function). We use the distance metric to find the similarity between clusters in agglomerative clustering.



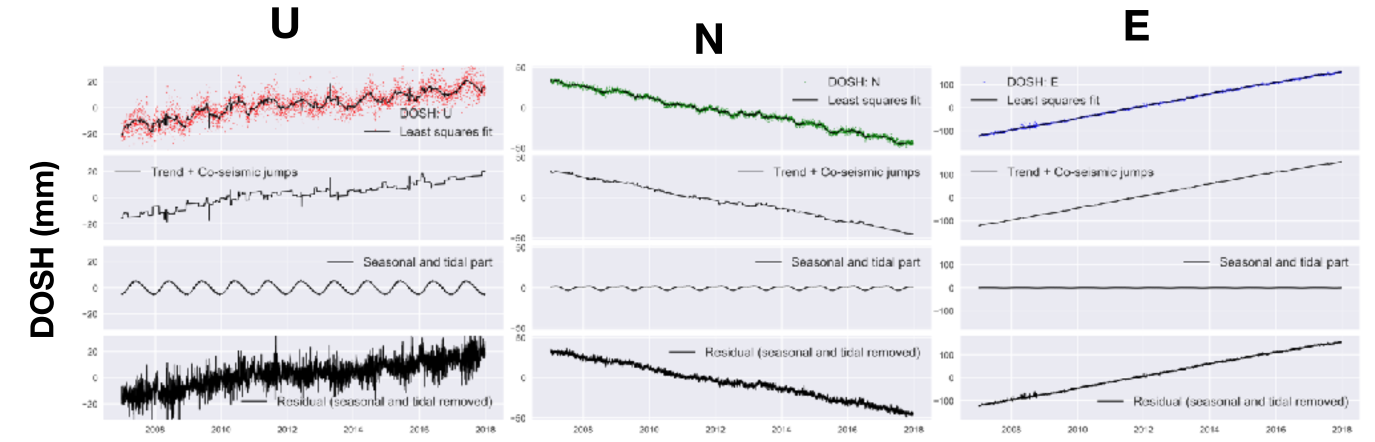
Steps for Agglomerative Clustering:

1. Begin with m (m = 15) clusters.
2. Search for most similar pair of clusters by calculating the distance metric of DTW algorithm.
3. Repeat step 2 till the number of clusters left is 0.

DATA & RESULTS

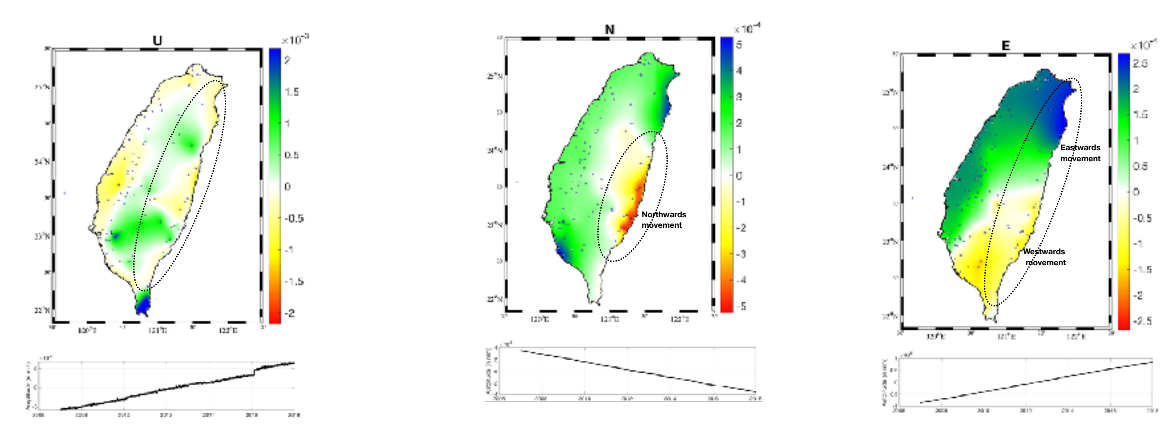
Least-squares modeling

to remove the seasonality, tides and common-mode error



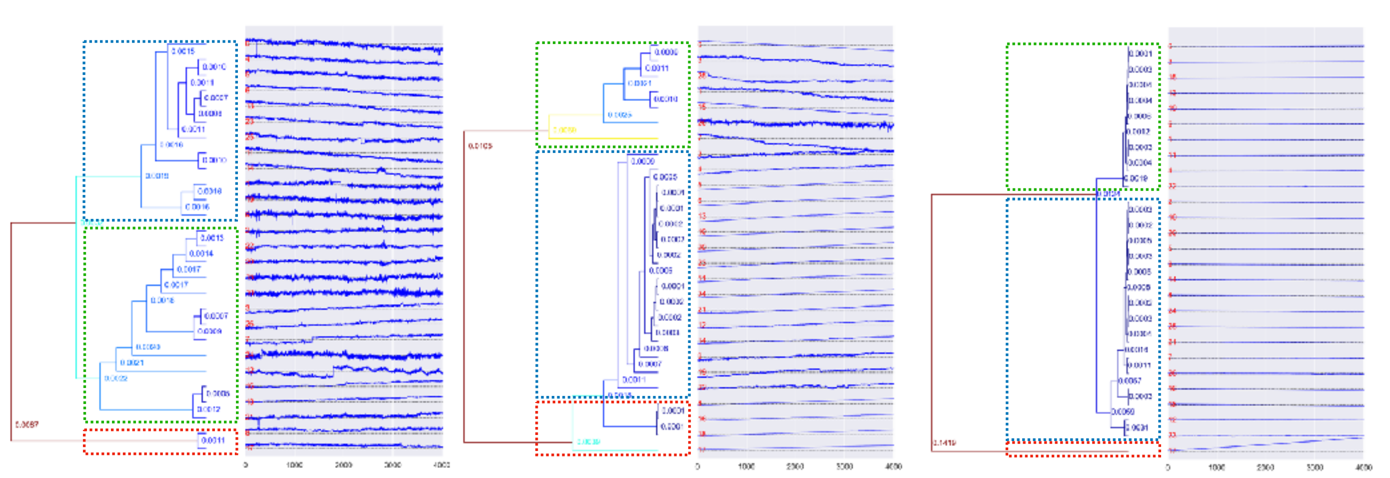
Empirical Orthogonal Functions

after removing seasonality, tides and common-mode error for 101 stations all over Taiwan gives overall picture of the tectonics on the Eastern coast

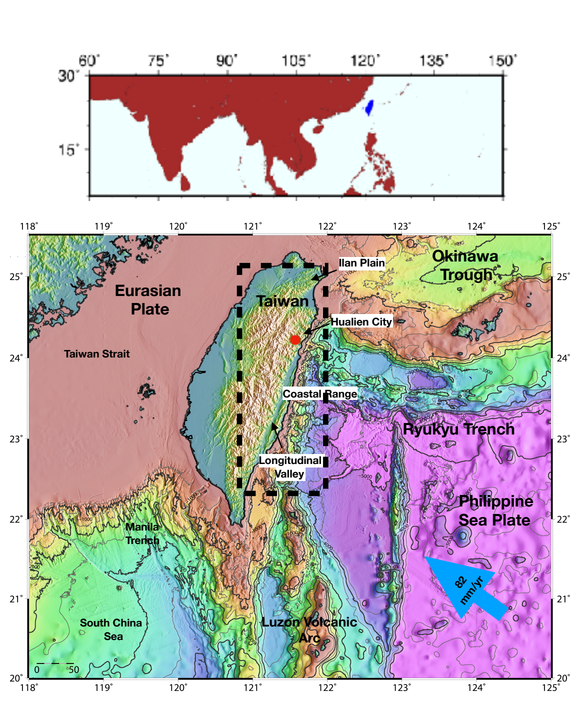


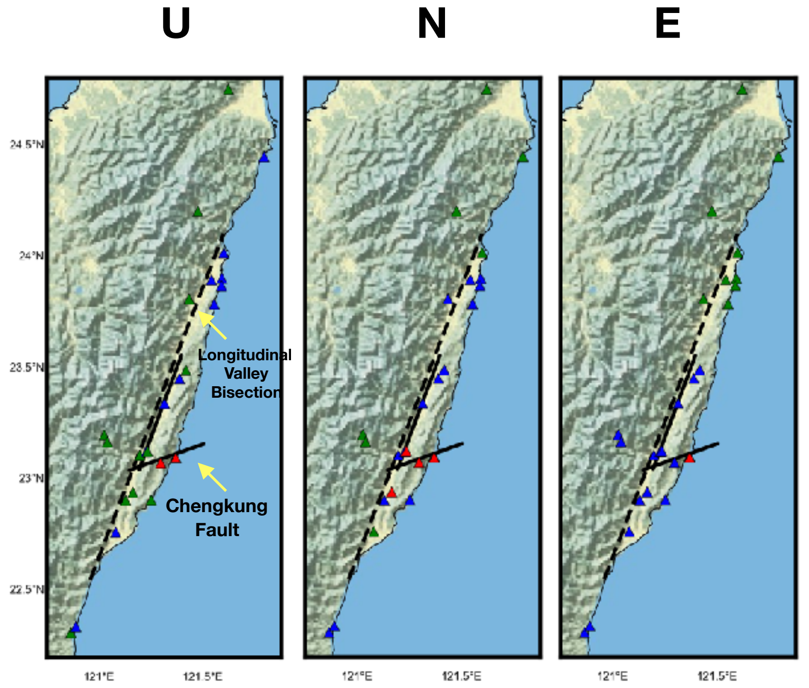
Agglomerative Clustering

gives dendrogram of DTW distance metrics



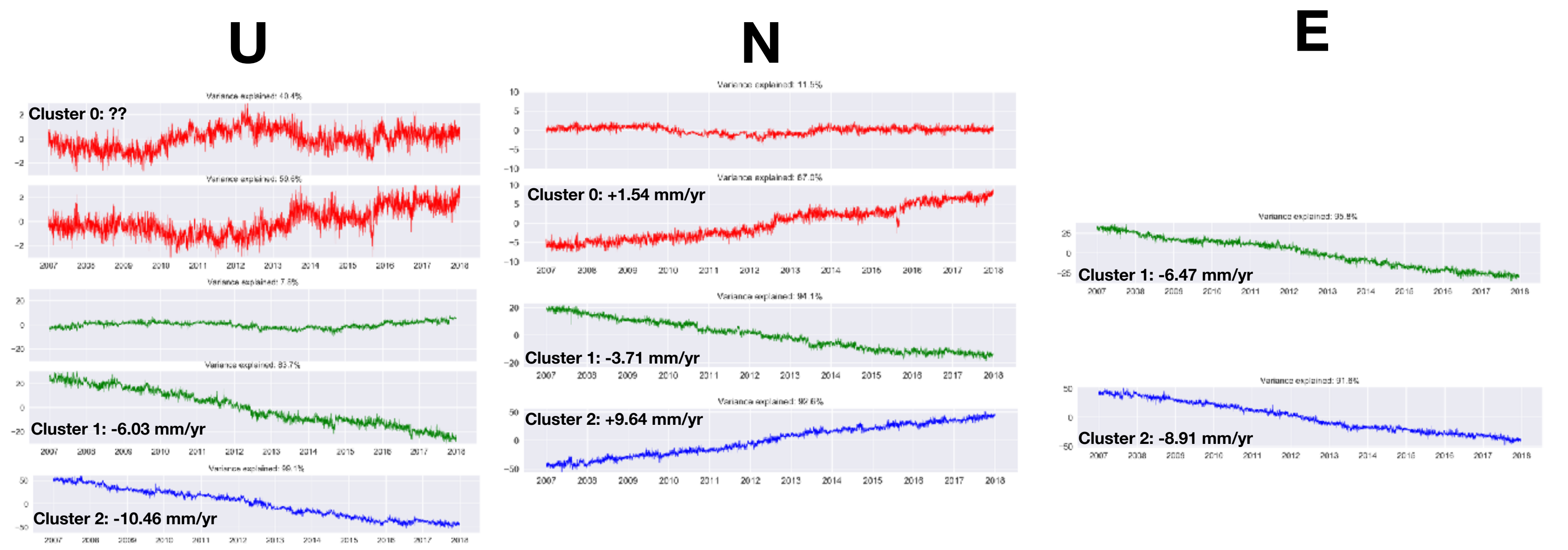
Clusters





Principal Component Decomposition (PCA)

for each cluster to obtain PCs that explain maximal variability



Cluster 0 — Cluster 1 — Cluster 2

CONCLUSIONS

- The results of the study is predominantly data analysis based on well established DTW and Agglomerative clustering algorithm from Machine Learning.
- Synthetic tests are first performed to understand the strength and weaknesses of DTW algorithm.
  - DTW is more robust than the commonly used windowed time-lagged cross correlation (WTLCC) in high SNR and non-homogenous media[4].
  - DTW algorithm has good time resolution when identifying small differences in the waveforms.
- Agglomerative Clustering algorithm categorized the east coast tectonics of Taiwan into 3 geographical clusters based on pairwise DTW distance metrics:
  - On the Chengkung Fault (related to 2003 M_w6.8 Chengkung Earthquake)
  - Inside Longitudinal Valley
  - Others
- Principal Component Analysis of all time series in each cluster to obtain the pattern with highest variance (energy):
  - Cluster 1 & 2 subsiding but cluster 2 is subsiding faster than cluster 1. Cluster 0 shows complex behavior.
  - Stations inside LV is moving northwards with rate as high as 9.64 mm/yr.
  - Cluster 1 and 2 moving westwards but not enough stations in the cluster 0 to delineate its movement pattern.

FUTURE WORKS

- Inspect the available data for seismic, strainmeter, creepmeter, gravity and tide-gauge to have better understanding of the tectonics.

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