Observing seismic signatures of slow slip events with unsupervised learning

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Observation of slow-slip events
Geodetic data and associated seismicity

Low-frequency earthquakes
Guerrero, Mexico

Slow-slip events and low-frequency earthquakes swarms

- Slow-slip events visible in GPS signal
- Are intermittent
- Occur with slow earthquakes (LFE, tremors)

Initial workflow

Slow-slip events and associated seismicity


Seismograms

Detection

Explicit

Catalog (LFE, tremors)

Decomposition

Arbitrary

Displacement

Definition of a tremor signal?
Decomposition threshold?
Initial workflow

Slow-slip events and associated seismicity

- Seismograms
- Detection: Explicit
- Catalog (LFE, tremors)
- Decomposition: Arbitrary
- Displacement

Definition of a tremor signal? Decomposition threshold?

Proposed workflow

AI-based analysis of seismic & geodetic data

Seismograms

Clustering: Data-driven

Regression: Data-driven

Displacement

Unsupervised detection of associated seismic signals

- Seydoux et al. (in prep)
- Husker et al. (G& 2012, GRL 2019)
Proposed workflow

Al-based analysis of seismic & geodetic data

Seismograms

Clustering Data-driven

Clusters

Regression Data-driven

Displacement

Unsupervised detection of associated seismic signals

Clustering strategy

Continuous seismograms (3C)

Basic waveform features

Relevant features

Deep scattering network features (Physics-driven)

Relevant features extraction with ICA

Hierarchical clustering

Cluster sequence

Seydoux et al. (in prep)
**Proposed workflow**

AI-based analysis of seismic & geodetic data

- **Seismograms**
- **Clustering** Data-driven
- **Clusters**
- **Regression** Data-driven
- **Displacement**

**Unsupervised** detection of associated seismic signals

**Regression strategy**

Linear regression illustration

- **Seismic cluster sequence**
  - $A\hat{x} = y$
  - Per-cluster displacement

- **Surface displacement**
  - 0.5 mm in a day

- **Surface velocity (cm/day)**
  - Day 1
  - Day 2

*Seydoux et al. (in prep)*
**Application**

Geodetic and seismic data in Guerrero, Mexico

Seydoux et al. (in prep)

Analysis of 2.5 years of continuous data

[Map and graphs showing geodetic and seismic data in Guerrero, Mexico]
Clusters of seismic signals
From 2.5-years of continuous 3C seismic data

Visual inspection of seismic signal clusters
- Electronic glitches and data gaps
- High waveform similarities
- Anthroponic noise
- Tremor episodes
- Long-duration emergent signals
- Distant earthquakes
- Local earthquakes
- Short-duration pulse-like events
Displacement regression results
From 2.5-years of seismic clusters

- **Dendrogram**
- **Detection rate**
- **Hourly**

GPS signal prediction from the **cluster sequence**

- 82% accuracy of prediction
- Automatic selection of the clusters contribution

Seydoux et al. (in prep)
Conclusions

• We cluster 2.5 years of seismic data with an unsupervised deep-learning method

• We find seismic signals that occur preferentially during slow-slip events

• We predict the horizontal displacement from the cluster sequence of seismic signals

Perspectives

• Cross-validate meta-parameters

• Interpret the displacement contribution of each cluster

• Apply to geodetic and seismic arrays and to longer time series