Détection et caractérisation des glissements lents dans les zones de subduction par intelligence artificielle appliquée aux données GNSS

Giuseppe Costantino¹, Sophie Giffard-Roisin¹, Mathilde Radiguet¹, Mauro Dalla Mura²,³, David Marsan¹, Anne Socquet¹

¹Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, IRD, Univ. Gustave Eiffel, ISTerre, 38000 Grenoble, France
²Univ. Grenoble Alpes, CNRS, Grenoble INP, GIPSA-Lab, 38000 Grenoble, France
³Institut Universitaire de France (IUF), France
Slow slip events?

- No seismic wave radiation
- Duration of days to months

Help better understand the role of aseismic slip in earthquake cycle → insights into the fault mechanics

Dragert et al., 2001

Courtesy of L. Marill
Slow slip events are hard to detect

Slow slip events are hidden in the noise of GNSS time series...

Slow slip events have been observed worldwide, yet catalogues are still sparse and incomplete

Simplified after Jolivet, Frank, 2020, AGU Advances

Bletery and Nocquet, 2023, Science
Detecting slow slip events through denoising

Systematic SSE detection still hindered by the noise in GNSS time series

Denoising as intermediate step

GNSS time series → Denoising → Clean GNSS time series → Detection + Characterization

Denoising as an intermediate step produces a clean GNSS time series, which is then used for detection and characterization of slow slip events.
Objective

Multi-station spatiotemporal denoising method based on deep learning

Area of study: Cascadia (North America)

No major earthquakes affecting the GNSS time series
Correlation between slow slip events and tremors: validation
SSE catalogue\(^1\) : further comparisons

\(^1\) Michel et al., 2019, *Nature*

Rogers and Dragert, 2003, *Science*
Proposed approach

Generation of a **realistic synthetic** database

Training of deep learning models

Test on synthetic data

Test on real data
Synthetic data generation

Realistic noise + SSE template → Synthetic SSE
SSEgenerator: generation of realistic noise

Non-post-processed GNSS time series → Principal Component Analysis

Preserves the spatial variability

Improved
Iteratively adjust the amplitudes to match the original ones
Better statistical similarity

Fourier phase randomization

Preserves the temporal coherency

FFT⁻¹

PCA⁻¹

Artificial time series

Real GNSS time series

Artificial GNSS time series

Costantino et al., 2023, Nat. Comms. Env., accepted

1 Schreiber, 2000, Physica
SSEgenerator: generation of synthetic slow slip events

Model of the **elastic ground response** associate with an earthquake of given physical parameters

Physical parameters → Okada → Modeled displacement

(fault position, orientation and size, amount of slip)

Different nuances of SNR (magnitude) and event durations
Randomly generated physical parameters (fault position and orientation, amount of slip)

1 Okada, 1985, BSSA

Costantino et al., 2023, *Nat. Comms. Env.*, accepted
One template per event is **not enough**

e.g., slow slip events can propagate in space and time

- **No signal**
  - Zero displacement: SSEdenoiser can better understand what noise look like

- **Up to three signals**
  - More realistic signals, better modeling slow slip propagation

Costantino et al., in prep.
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**Zero displacement**: SSEdenoiser can better understand what noise look like

More realistic signals, better modeling slow slip propagation

Costantino et al., in prep.
SSEdenoiser – high level architecture

Costantino et al., in prep.
Denoising of real data in Cascadia

Costantino et al., in prep.
Denoising of real data in Cascadia

Costantino et al., in prep.

SSEdenoiser
Denoising of real data in Cascadia

Costantino et al., in prep.
Denoising of real data in Cascadia

Costantino et al., in prep.
Denoising of real data in Cascadia

Costantino et al., in prep.
Validation against tremors in Cascadia

Costantino et al., in prep.
Validation against tremors in Cascadia

Costantino et al., in prep.
Detection and characterization on denoised time series
Merci pour votre attention !