Generating realistic synthetic GNSS station position time series to evaluate automatic discontinuity detectors

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1 - Introduction:

Trajectory modeling of **GNSS station position time series** plays a central role in the establishment of terrestrial reference frames and in a wide range of geophysical studies. Unfortunately, trajectory modeling is complicated by the presence of unrecorded discontinuities in the time series, e.g., outliers, mean offsets (jumps), and changes in velocity (to name a few). With the increasing number and longevity of GNSS stations, traditional **manual trajectory modeling** of position time series by an experienced operator becomes increasingly **time-consuming and even impossible** for large datasets. For this reason, **automatic discontinuity detection** approaches are increasingly appealing for many geodetic and geophysical applications. However, a central concern with automatic modeling approaches is their **reliability**. While past studies suggest that automatic approaches are less reliable than human experts, this situation may change with advances in artificial intelligence. To address current performance assessment issues, this study presents efforts to develop an **improved benchmark** for **discontinuity detection algorithms**.

2 - Common problems with discontinuity detector validation:

The problems with *real* station position time series:

- Real, high-quality station position time series trajectories are **rare**.
- Manual trajectory models are not necessarily an ideal validation dataset for discontinuity detectors because (1) they **miss small discontinuities** and (2) they are subject to the **operators' modeling choices**.

The problems with *synthetic* station position time series:

- Synthetic position time series used for benchmarks are often **limited in scope** and **not fully realistic.**
- They are often limited to **one discontinuity type** (usually offsets).
- They often neglect outliers, velocity changes, post-seismic signals, transients, missing data ...
- Synthetic position time series do usually not have a spatial structure: this does not allow testing the capacity of detectors to exploit the existence of common mode components for improved detection.

3 - Proposed solution:

" A simulator of realistic spatiotemporally correlated station position time series whose properties are derived from real and reliable datasets. "

-> Multiple benefits!

- ✔ **More realistic synthetic series:** more realistic performance assessment.
- ✔ **Unlimited number of series:** exhaustive detector performance and uncertainty assessment.
- ✔ **Spatially correlated series:** assessment of approaches that exploit spatial correlations for improved discontinuity detection.
- ✔ **Fully adaptable generator:** explore and identify the strengths and weaknesses of different algorithms.
- ✔ Allow the development of **new machine learning approaches**.
- ✔ Towards an updated version of Gazeaux et al. (2013)'s benchmark?

4 - How to generate more realistic synthetic station position time series?

1. **Generate trajectories whose data structure properties mimic a real and reliable dataset in terms of:**

- Time series length
- Length of data segments and data gaps
- Offset amplitudes and occurrence frequencies
- Velocity change amplitudes and occurrence frequencies
- Outlier amplitudes, occurrence frequencies, and cluster sizes
- Post-seismic signal properties
- Transients

→ Study of the IGS repro3 station position time series trajectories.

2. **Generate station position noise that mimics real datasets in terms of:**

- Variance(s)
- Temporal correlation (reproduce the white and flicker noise observed in the station position time series)
- Spatial correlation (correlation between different stations of a network).

→Employ the white and flicker noise spatial correlation model developed by Rebischung and Gobron (2024) and Gobron et al., (2026, submitted).

5 - The IGS repro3 station position time series and trajectory models:

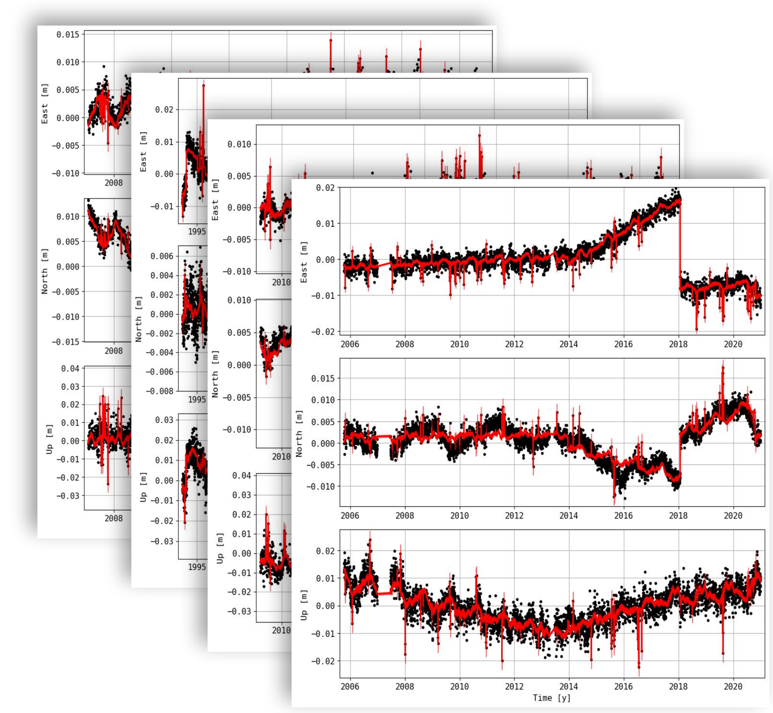

Fig 1: Example of IGS repro3 station position time series (black) and trajectory models (red) used in this study to characterize the properties of « normal » station position time series.

6 - Modeling the properties of IGS repro3 station position time series with probability density functions:

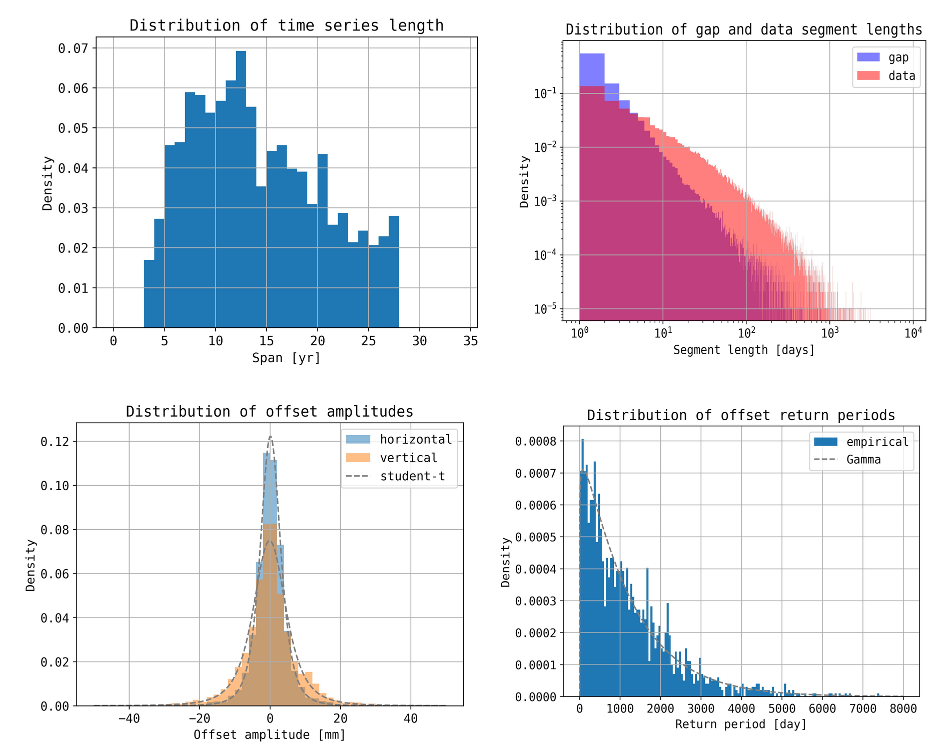

Fig 2: Examples of empirical distributions of certain properties of the IGS repro3 station position time series, and of analytical models of these distributions.

7 - Simulate synthetic station position noise using a newly developed white noise and flicker noise spatial correlation model (Gobron et al., 2026, submitted):

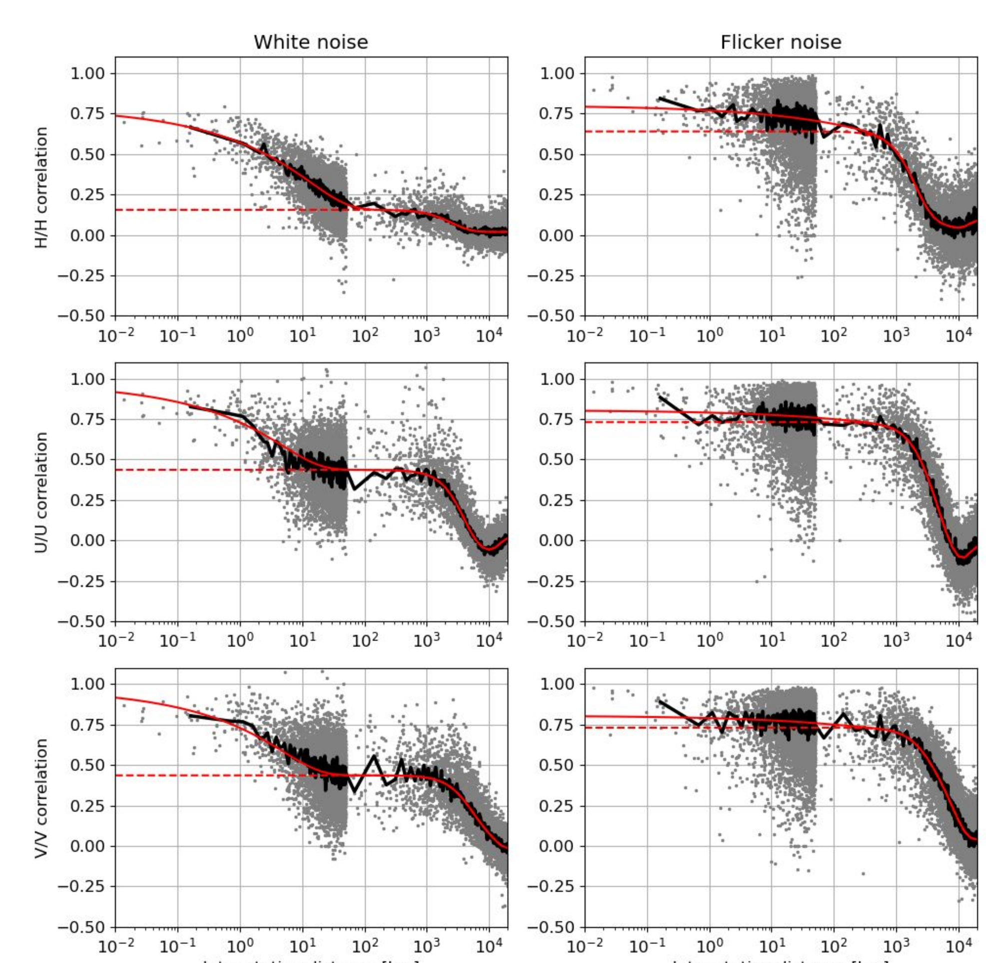

Fig 3: Empirical spatial correlation estimates of white and flicker noise expressed as functions of inter-station distance. Grey dots: empirical pairwise correlation estimates derived using variance component estimation for 12,591 selected station pairs. Black line: median correlations calculated within predefined classes of inter-station distances. Red solid line: multi-scale spatio-temporal correlation model used in this work (Gobron et al., 2026, submitted to JGR: Solid Earth). Red dashed line: large-scale spatio-temporal correlation model presented in Rebischung and Gobron (2024).

8 - Example of two randomly generated synthetic station position time series:

With this approach, it is very easy to simulate multiple cross-correlated 3D station position time series. As an illustration, we present two randomly generated cross-correlated time series of vertical station positions.

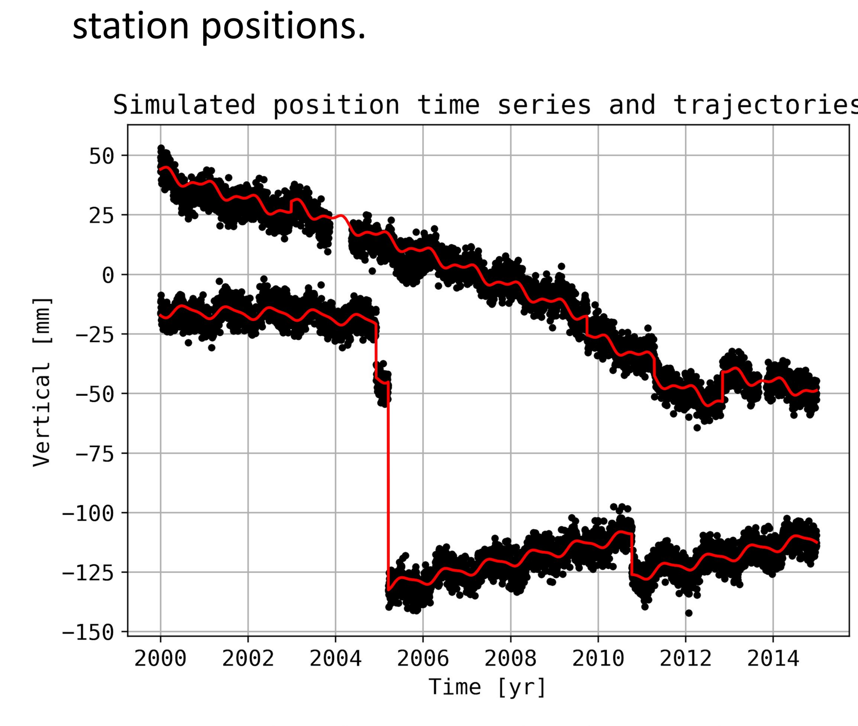

Fig 4: Example of two simulated vertical station position time series.

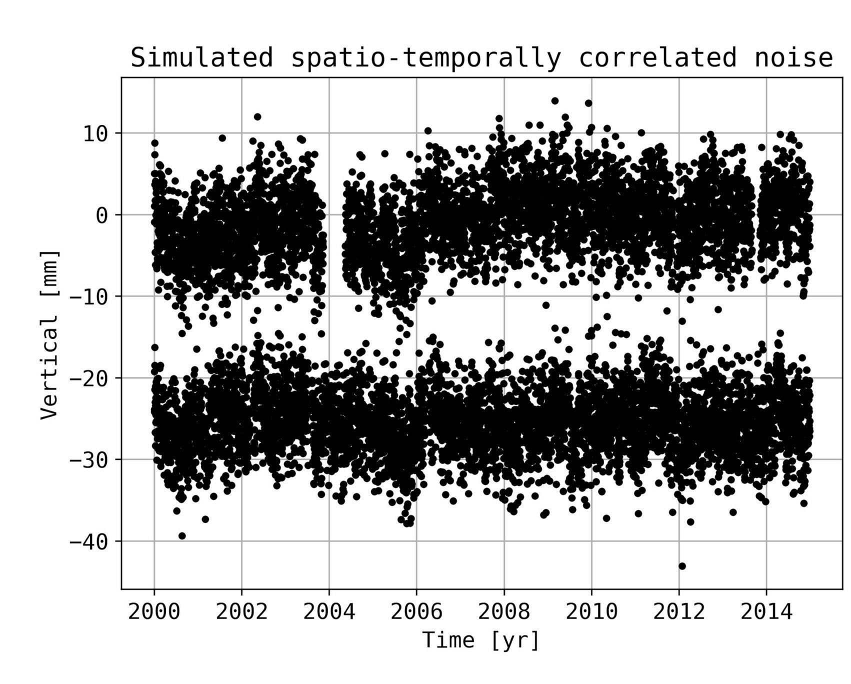

Fig 5: Example of the simulated noise for the two vertical station position time series presented in Fig 4.

9 - Conclusion & perspectives:

- We are building an **improved benchmark** for automatic **discontinuity detectors**.
- We are able to generate networks of 3D synthetic station position time series with realistic **gaps**, **offsets**, **velocity changes**, and **spatiotemporally correlated noise**.
- Work in progress to add realistic outliers, post-seismic signals, and transients.
- **Interested in testing your discontinuity detection algorithm? Please contact us at gobron@ipgp.fr.**

10 - References:

- Gazeaux, J., Williams, S., King, M., Bos, M., Dach, R., Deo, M., ... & Webb, F. H. (2013). Detecting offsets in GPS time series: First results from the detection of offsets in GPS experiment. Journal of Geophysical Research: Solid Earth, 118(5), 2397-2407.
- Rebischung, P., & Gobron, K. (2024). Modeling random isotropic vector fields on the sphere: theory and application to the noise in GNSS station position time series. Journal of Geodesy, 98(9).

11 - Acknowledgment:

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