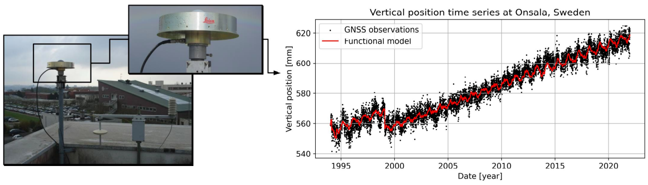
Toward a realistic spatio-temporal description of GNSS station position time series

Kevin Gobron[1] (gobron@ipgp.fr), **Paul Rebischung**[1,2], **Zuheir Altamimi**[1,2]
[1] Université Paris Cité, Institut de Physique du Globe de Paris, CNRS, IGN, Paris, France [2]Univ Gustave Eiffel, ENSG, IGN

One of the missions of **geodesy** is to accurately measure the Earth's geometric shape and its evolution with time. To fulfil this mission, geodesists often rely on Global Navigation Satellite Systems (GNSS), such as the **American Global Positioning System (GPS)** or the **European global satellite navigation system**, named **GALILEO.** These GNSS constellations allow estimating daily position time series of thousands of globally distributed GNSS antennas, with a precision of a few millimeters. At this level of precision, one can measure a wide range of **deformation induced by geophysical processes** (plate tectonics, vertical land motion, co- and post-seismic displacements, seasonal loading, …). This makes GNSS extremely useful for wide range of scientific applications, from seismology to sea-level change monitoring. In addition, GNSS position time series are fundamental to the realization of the **International Terrestrial Reference Frame (ITRF)**, which is this most stable reference available to express positions and velocities at the surface of the Earth.

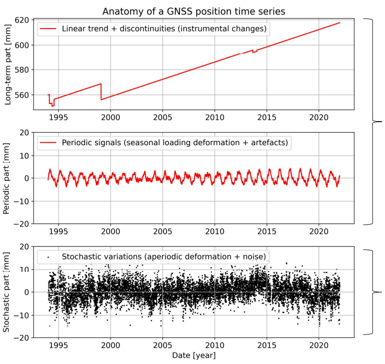
What are GNSS station position time series?

Example of GNSS station (left) and a position time series (right)



What's going on with this GNSS station in Sweden ? This station is moving upward at about 1 cm/year because of the Glacial Isostatic Adjustment (GIA) affecting Northern Europe.

For interpretation, position time series are split into different parts



Deterministic = predictable

Deterministic variations are predictable and easy to model with mathematical functions. They usually represent the deformation of interest (for instance, long-term deformation rate, co-seismic slip, or seasonal loading deformation).

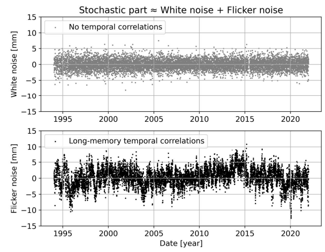
However, these deformations are only estimated from the position time series and are therefore contaminated by noise.

Unpredictable = source of uncertainty!

Stochastic variations are unpredictable and must be modelled using *stochastic processes* to obtain *realistic uncertainties* on the measured deformation.

The problem of temporally and spatially correlated stochastic variations

✓ **Temporal correlations:** well-known and routinely modelled



Temporal correlation = White noise + Flicker noise

White noise: temporally uncorrelated noise. Assumed to be caused by instrumental errors and atmospheric perturbations.

Flicker noise: temporally correlated noise. The temporal correlations are responsible of 90% of the uncertainty on the estimated long-term deformation. Its origins remain unknown and need to be investigated. However, it is now accounted for realistic uncertainty assessment.

❑ **Spatial correlations:** poorly known and never modelled …

Investigating spatial correlations and their impact on scientific applications is crucial because **most studies use a network of spatially distributed stations but neglect a possible spatial dependence of positioning errors**. A better understanding of spatial correlations is needed to develop a realistic spatial and temporal correlation model.

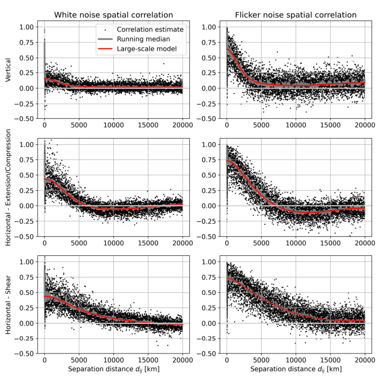
Key questions investigated in this work

- ❑ What are the spatial correlations of white and flicker noises?
- ❑ Are the white and flicker noise spatial correlations similar?
- ❑ Can we provide a mathematical model for both spatial and temporal correlations?
- ❑ What is the impact of these spatio-temporal correlations on geodetic and geophysical applications?

Global-scale spatio-temporal correlations diagnosis

Using the position time series provided by the Nevada Geodetic Laboratory, we quantified, for the first time, white and flicker noise spatial correlations separately at the global scale.

Spatial correlations as function of the distance between stations



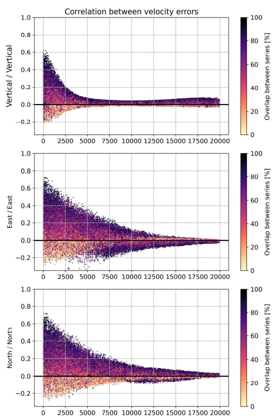
Important observations

- ✓ Large-scale white and flicker noise spatial correlations in all directions
- ✓ Difference between white and flicker noise spatial correlations. This suggests different noise sources.
- ✓ Flicker noise shows higher spatial correlations. This implies that most of the flicker noise results from large-scale processes.

Improved deformation uncertainty assessment

With the developed spatio-temporal correlation model, we quantified how spatial correlations of the noise propagate to the spatial correlation of velocity errors.

Spatial correlations between velocity errors



Important remarks

- ✓ Significant and large-scale spatial correlations between velocity errors.
- ✓ Non-trivial spatial correlations propagation (it does not only depend on the distance).
- ✓ It depends also significantly on the overlap between position time series (represented in colors in the figure on the left).

Which stochastic model for these spatial and temporal correlations?

- Large-scale white and flicker noise spatial correlations approximately follow a **Matérn-like isotropic vector spatial stochastic process on the sphere** (red solid line on the figure above).
- This model allows us to perform **error propagation** and therefore to improve uncertainty assessment.

Major geoscientific implications

- The assessment of the covariance between velocity errors will **improve how we compute the likelihood of geophysical models**, and therefore, improve our understanding of **deformation mechanisms**.
- This covariance assessment will also allow a better uncertainty assessment for the parameters of interest and is an important step toward the **realistic assessment of ITRF uncertainties**.

Perspectives

- A publication of these results will soon be submitted to **Journal of Geodesy**
- **We will then prove the benefits of spatial correlation modelling for Bayesian deformation inversion**. A study of deformation inversion around the San Andreas fault is in progress.
- **We will also investigate the possible origin of large-scale flicker noise**. Investigations about the influence of solar radiation pressure errors are in progress.