
Influence of **non-tidal atmospheric and oceanic loading** deformation on the **stochastic properties** of over 10,000 GNSS **vertical land motion** time series

Kevin Gobron^{1,2,3}, Paul Rebischung⁴, Olivier de Viron¹, Michel Van Camp², Alain Demoulin³

kevin.gobron@ksb-orb.be

¹La Rochelle Université, LIENSs, La Rochelle, France

²Royal Observatory of Belgium, Uccle, Belgium

³University of Liège, Department of Physical Geography and Quaternary, Liège, Belgium

⁴Université de Paris, Institut de Physique du Globe de Paris, CNRS, IGN, Paris, France

*** Link to the recorded presentation:**

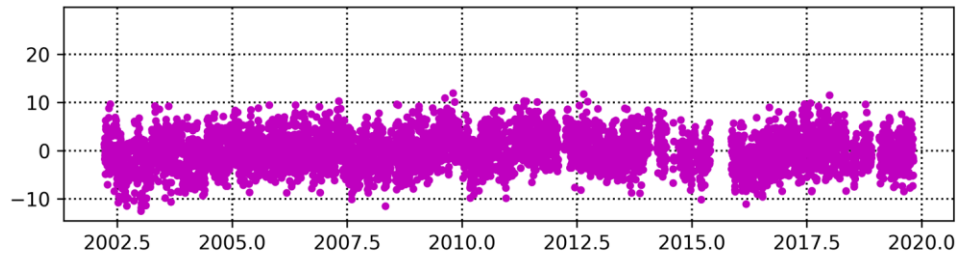
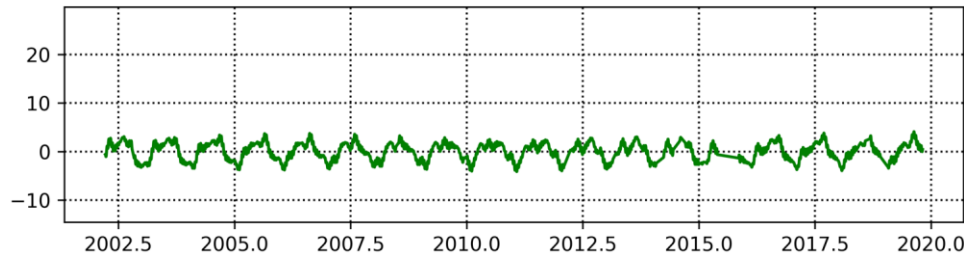
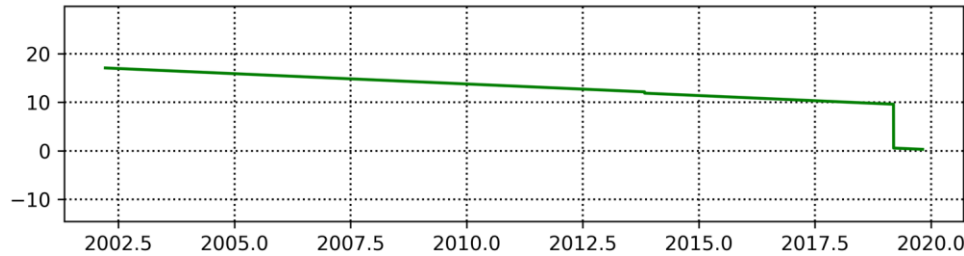
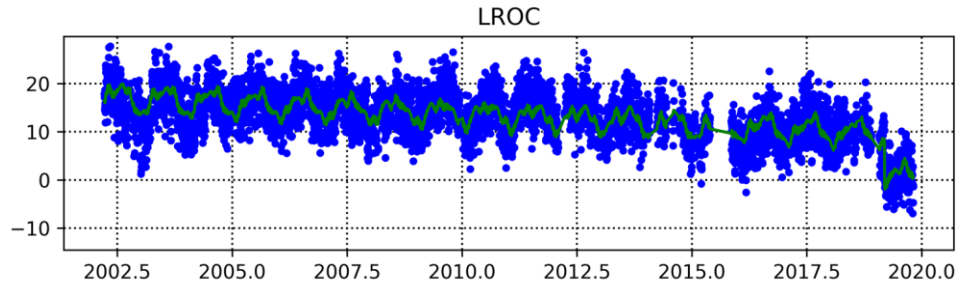
<https://youtu.be/G3mT2mNW1Lg>

*** Link to an animation of the influence of NTAOL deformations on VLM residuals:**

<https://youtu.be/ZkqNepHUjgk>

What do we mean by stochastic properties?

Trajectory modelling of GNSS position time series



Observations

=

Trends
& Discontinuities

+

Periodic
Oscillations

+

Residuals
Stochastic variability
(Noise)

Functional model
Deterministic properties

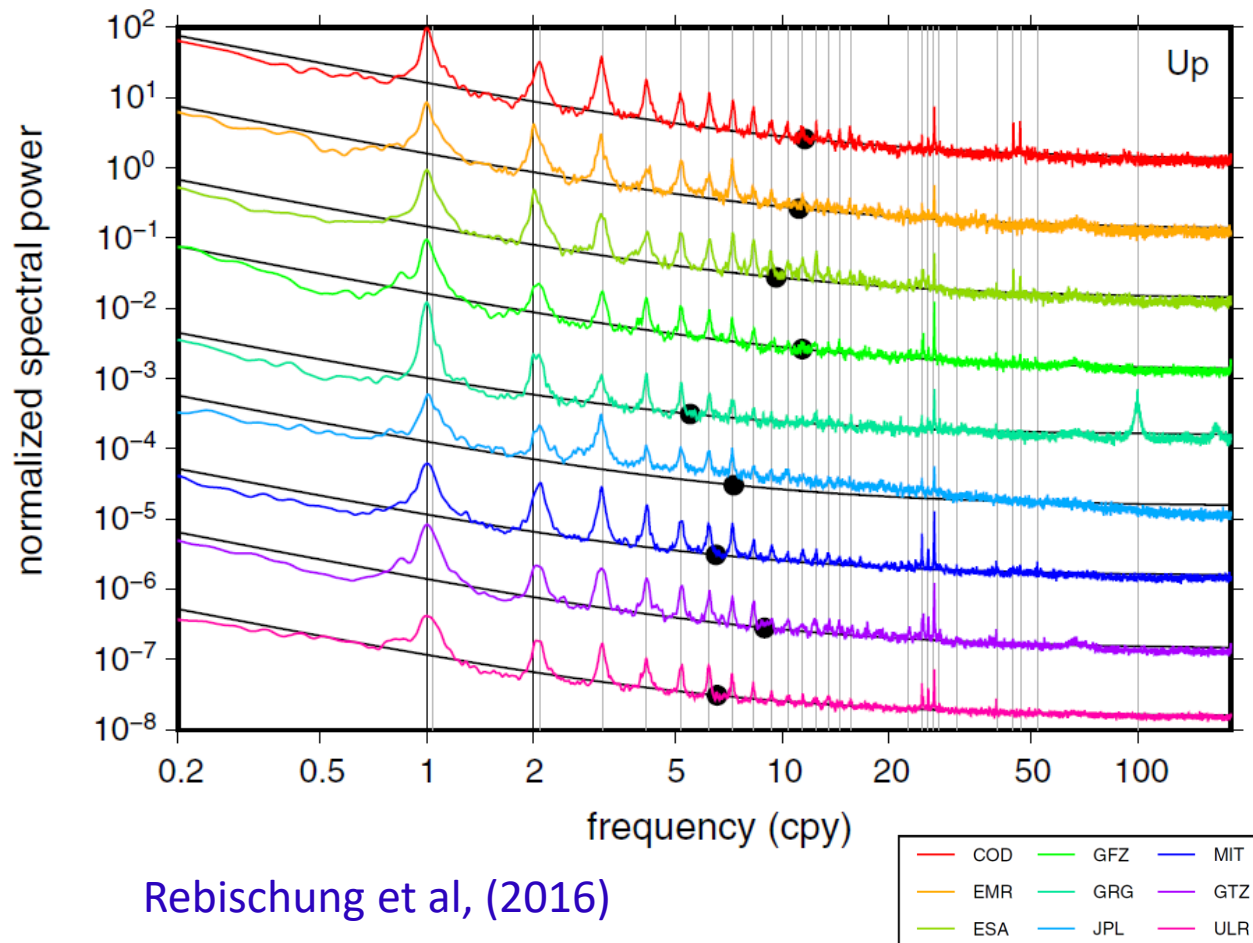
Uncertainty

Stochastic model
Stochastic properties

Power-law processes

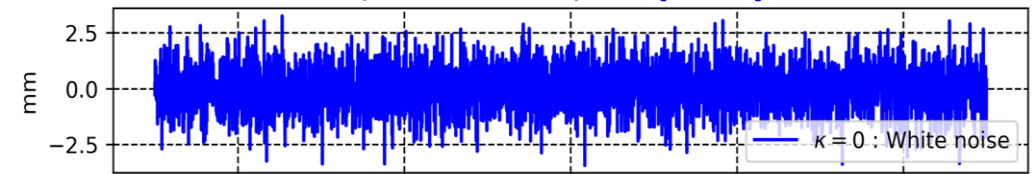
What choice for the stochastic model?

Average power-spectrum

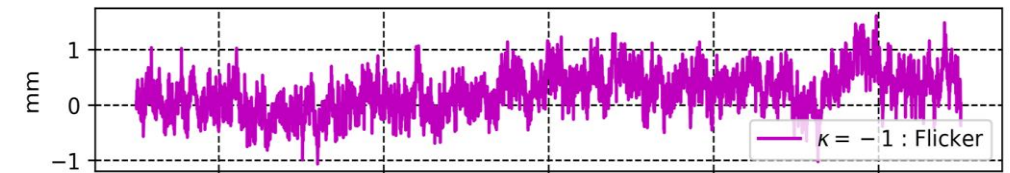


WN+PL model

White noise (WN)



+ Power-law process (PL)



- Unknown WN amplitude
- Unknown PL amplitude
- Unknown PL spectral index κ

Power-law processes

Problem: velocity uncertainties in the presence of power-law correlation

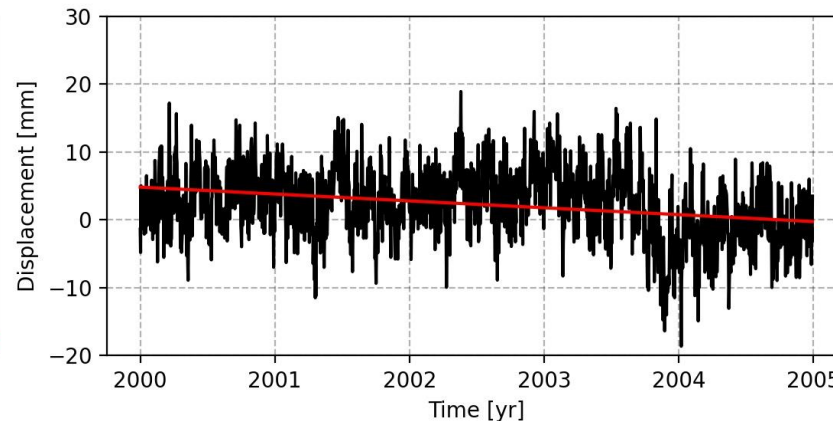
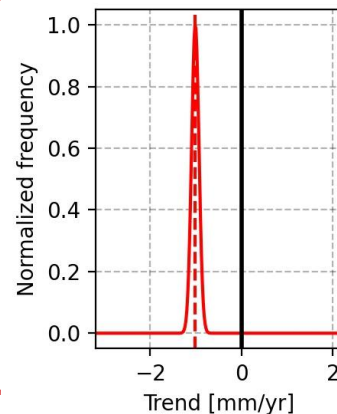
Example: simulated time series with **no velocity** and a **pure power-law process**

Incorrectly assuming white noise:

Velocity estimate (1) :

$-1.0 \pm 0.08 \text{ mm/yr}$

Significant subsidence?

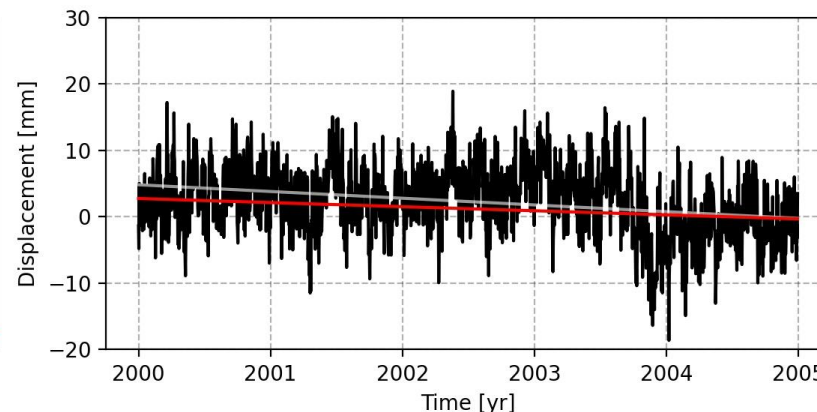
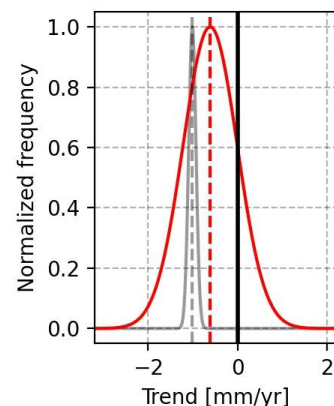


Correctly assuming power-law process:

Velocity estimate (2) :

$-0.61 \pm 0.60 \text{ mm/yr}$

- Uncertainty **7 x larger** !
- No significant **subsidence**



Power-law
RMSE: 5 mm
Spectral index : -0.8

Problematic & Strategy

Research questions

- Origin of **power-law** correlation? **Artifact** or **deformation**?
- Can we reduce **power-law process** influence?
- Is Non-Tidal Atmospheric Oceanic Loading (**NTAOL**) a source of such **time-correlation**?
- To what extent is NTAOL deformation a source of **spatial correlation**?

Strategy

- Diagnosis of the spatial variability of **white noise amplitude**, **power-law amplitude** and **spectral index**
- Diagnosis of the **spatial correlation**
- Influence of **NTAOL deformations** on both the **spatial variability** & **spatial correlation**
- Do this for over **10 000 stations** to provide a complete description

Data & method

NGL's GNSS position time series

- 10,125 stations – Observations prior to 2018
- Median cumulative span: **8 years**
- **PPP processing** – GipsyX software – **JPL Repro3.0 orbit and clock products**
- **IGS14 reference frame**
- **VMF1 mapping function**
- **1st and 2nd order ionospheric corrections**

NTAOL deformation time series

- Earth System Modelling team at GFZ Potsdam (**ESMGFZ**).
- **ECMWF** and **MPIOM** pressure models
- **ak135** earth model

Processing strategy

Statistical modelling & estimation

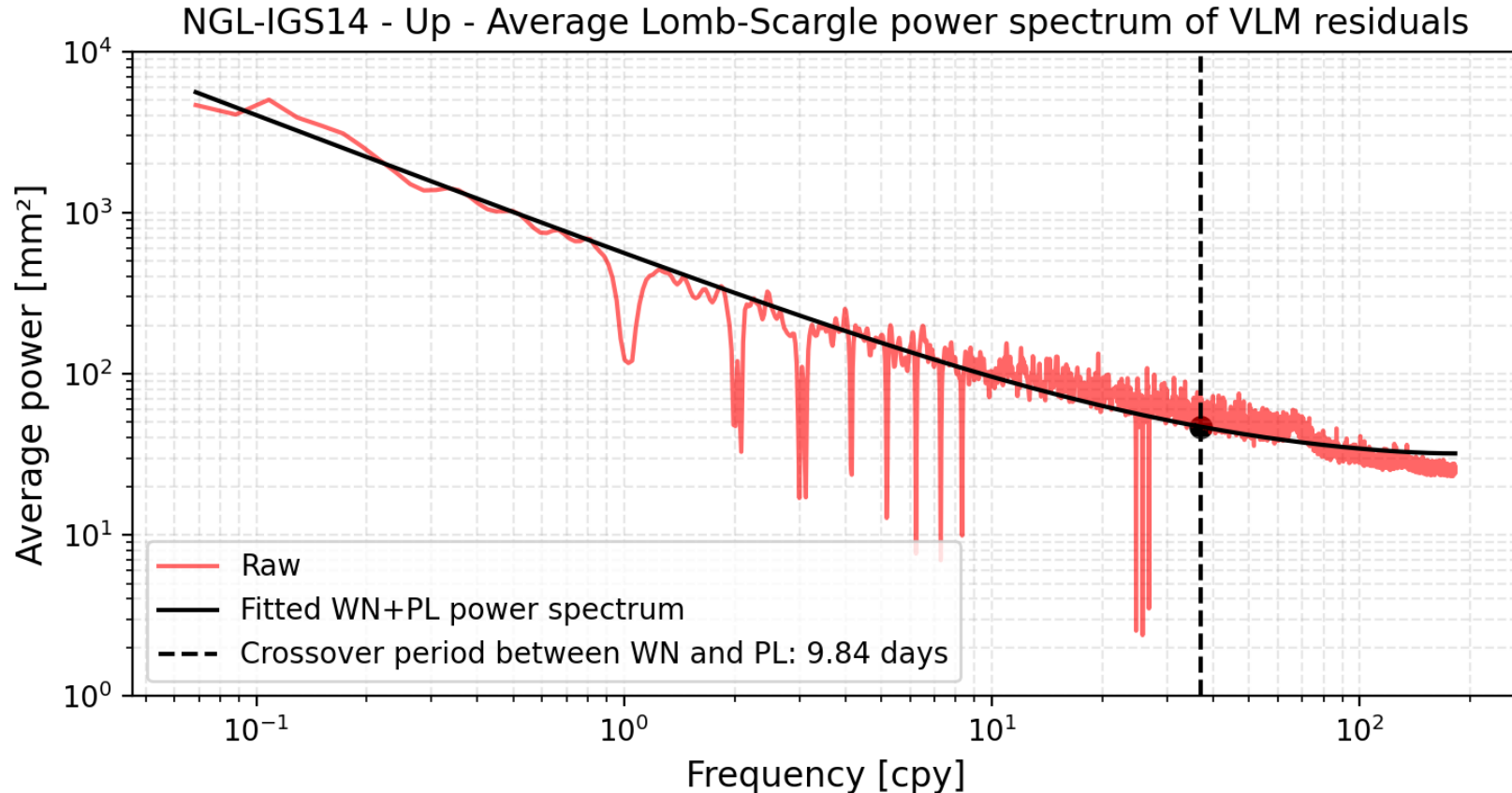
- **Linear functional model**: trend + seasonals + draconitics + steps + velocity changes + outliers
- NGL's master step database considered by default
- + **Multivariate detection** of discontinuities (Amiri-Simkooei, 2018)
- **WN+PL stochastic model**
- **WN and PL amplitudes** estimated using the LS-VCE method
- **Spectral index (k)** estimated by testing 30 stochastic models with $k = -0.30, -0.35, \dots, -1.80$
- Best spectral index maximises the **restricted likelihood (REML)** criterion
- **Spatial correlation** based on the **Pearson correlation** coefficient between residual time series



Diagnosis of the stochastic variability prior to NTAOL corrections

Power-spectrum of the stochastic variability

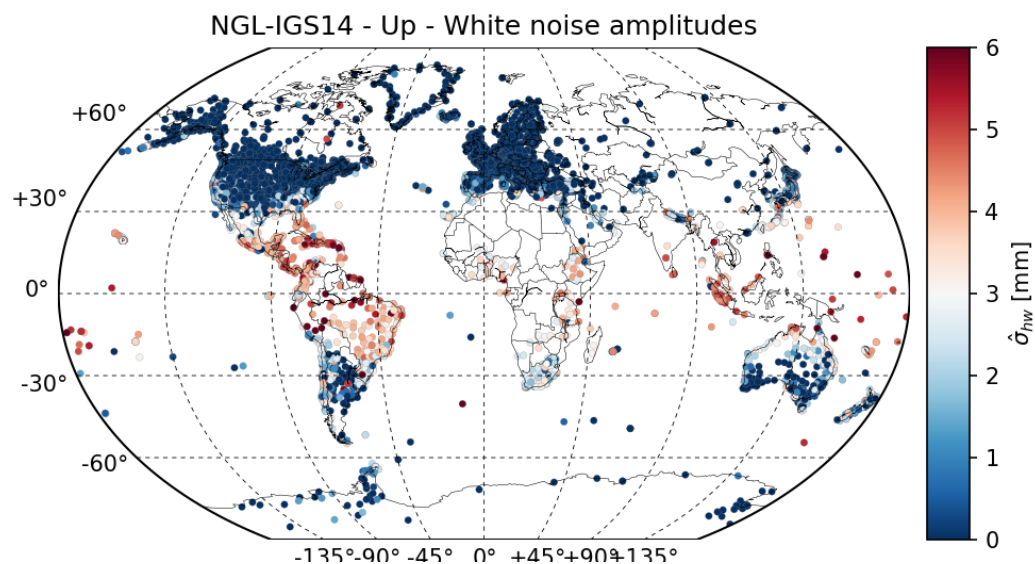
Average power-spectrum of the residuals



- **White noise + Power-law** is a good approximation

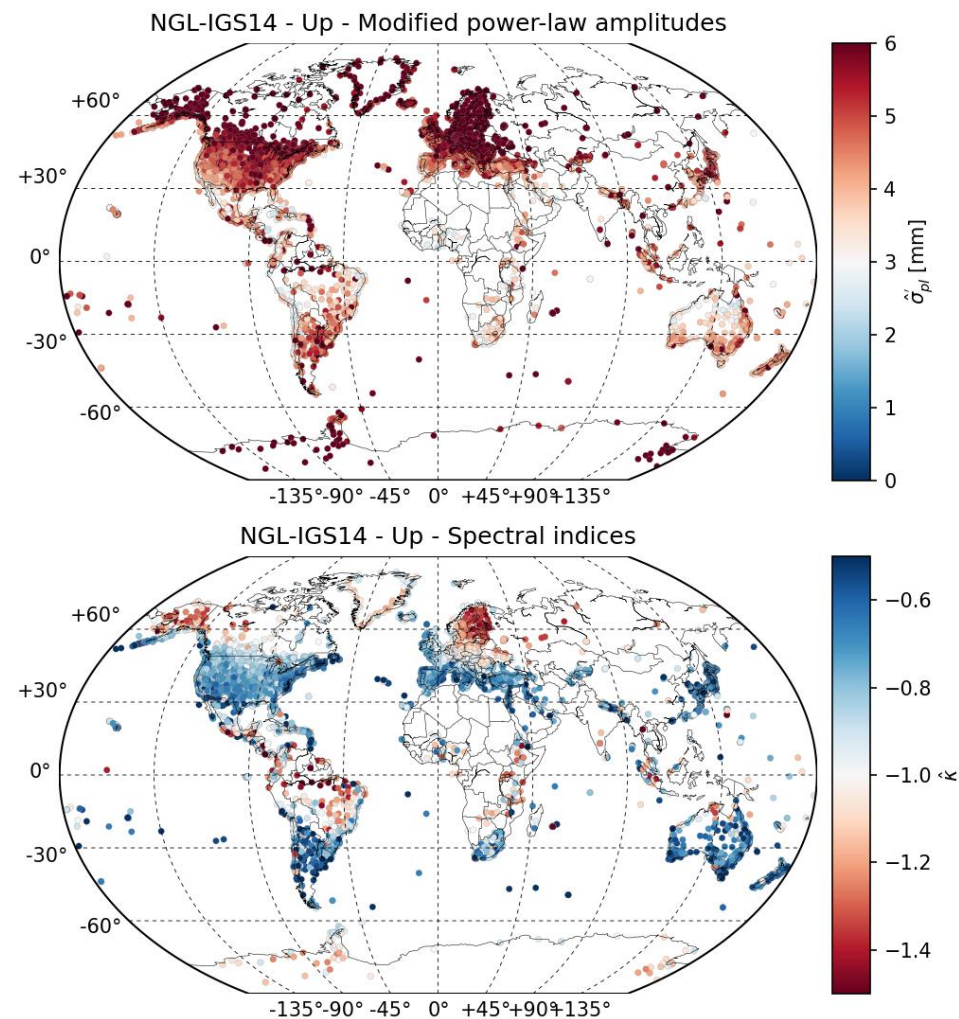
Spatial variability of stochastic parameters

White noise



- Mostly a **latitude dependence** of all stochastic parameters

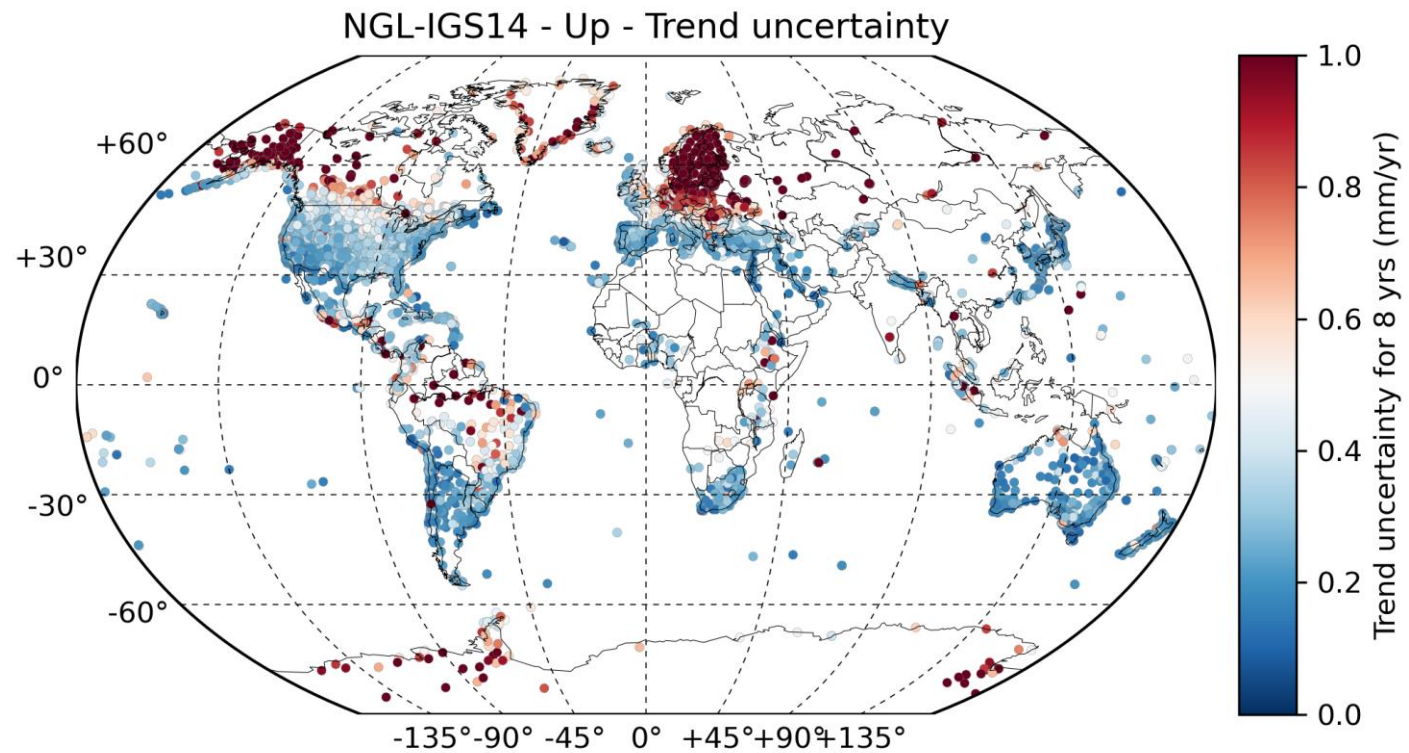
Power-law process



Spatial variability of velocity uncertainty

Velocity uncertainty

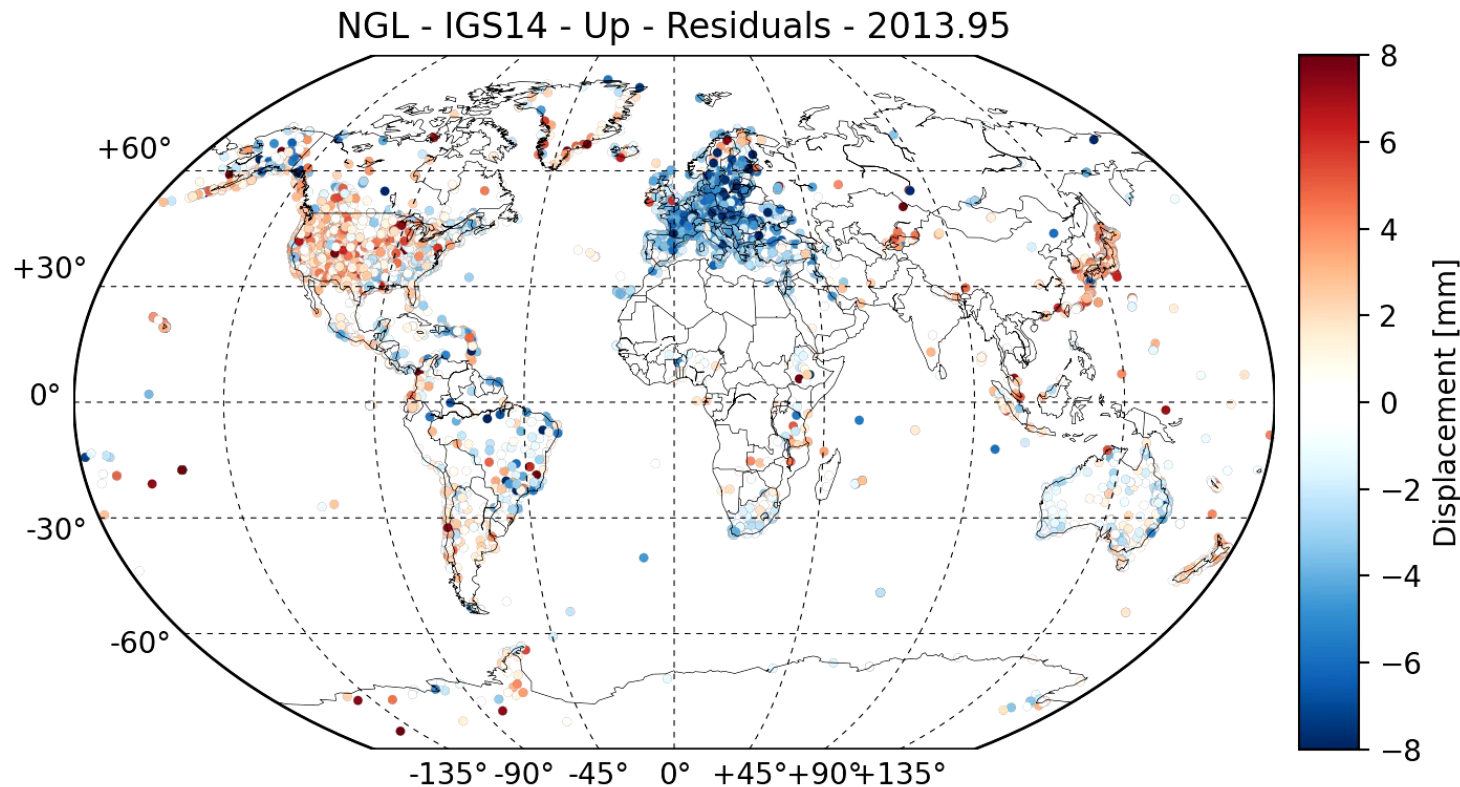
Expected velocity uncertainty for a continuous daily time series of 8 years assuming no periodic nor nonlinear motions.



Spatial correlation

Study of the spatial correlation

Weekly average of the residuals

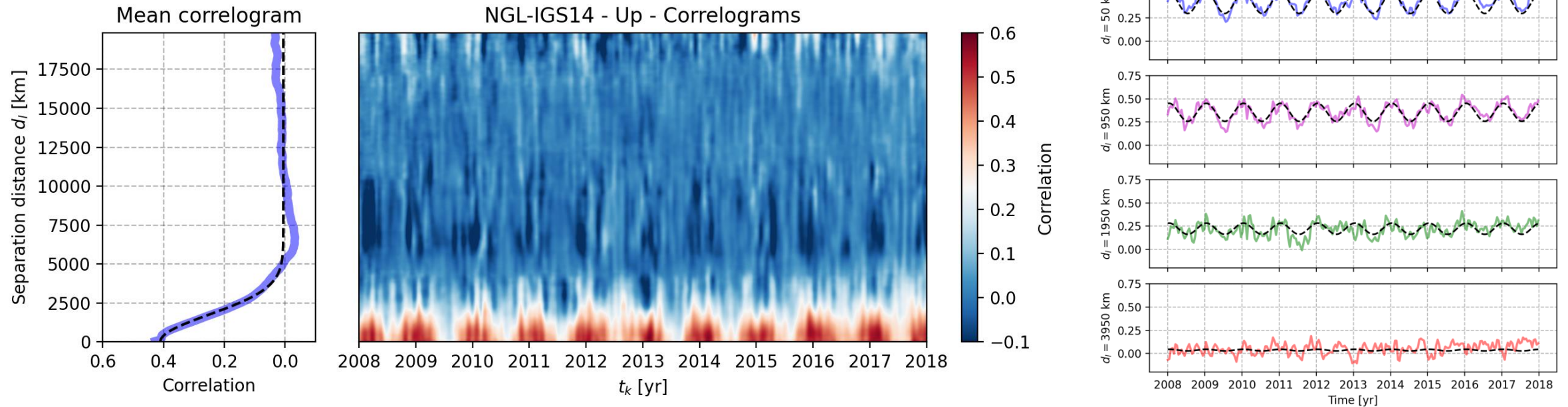


- Clear spatial correlation
- Temporal variability?

Spatial correlation

Study of the spatial correlation and its seasonality

Spatial correlation over monthly windows for 10 years



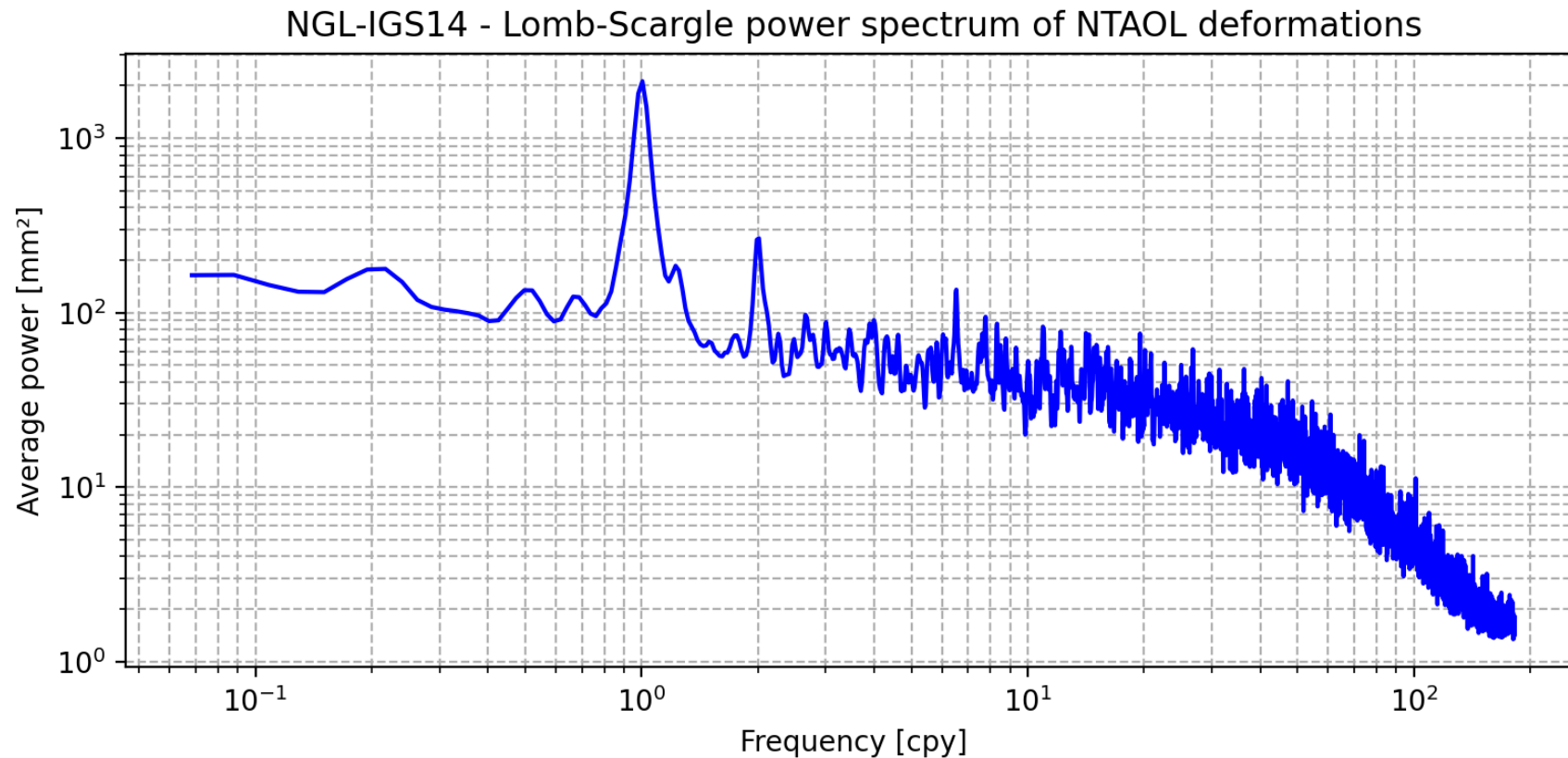
Well approximated by a seasonal gaussian correlation:

- Minimum of correlation (short distances) : **+ 0.30 – July**
- Maximum of correlation (short distances) : **+ 0.53 – January**

Influence of NTAOL deformations

Average power-spectrum of NTAOL deformations

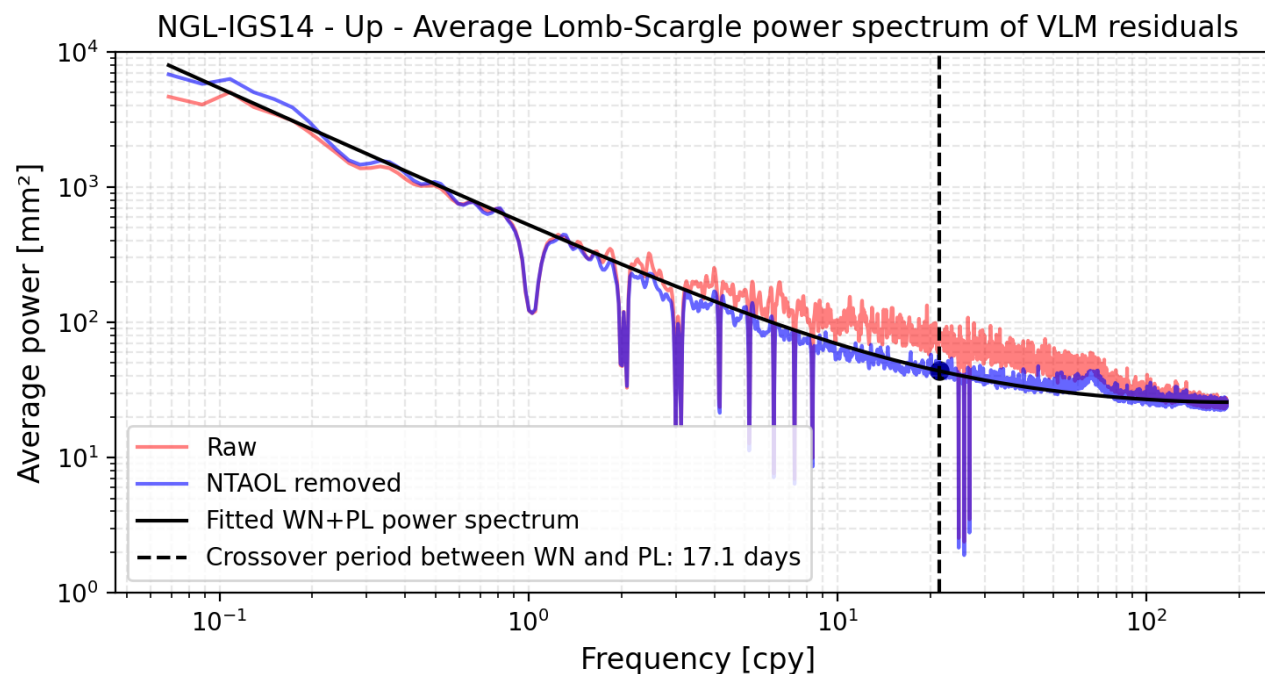
Average power-spectrum of predicted NTAOL deformations



- Not a combination of white noise and power-law processes
- Rather a Fractionally Integrated Generalized Gauss Markov (FIGGM) process

Influence of NTAOL deformations on stochastic parameters

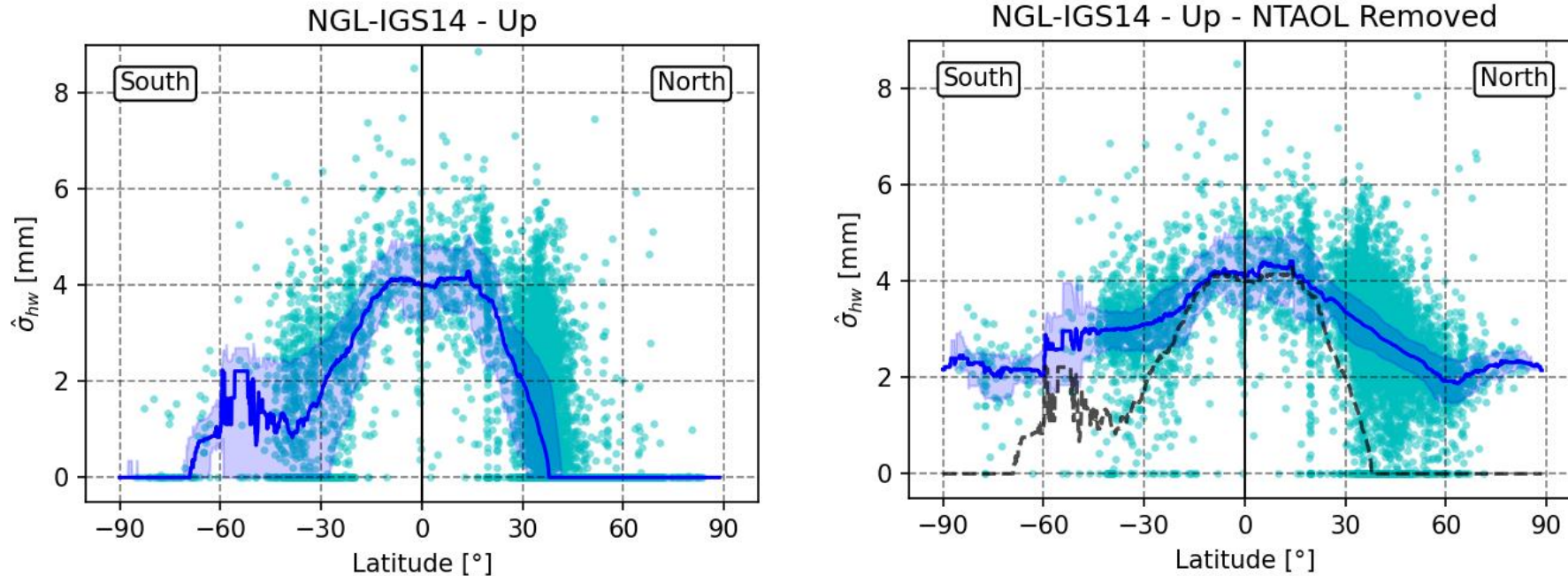
Change in power-spectrum



- Influence of NTAOL deformations maximum at **sub-annual periods**
- **WN+PL model** is even more appropriate after NTAOL corrections than before

Influence of NTAOL deformations on stochastic parameters

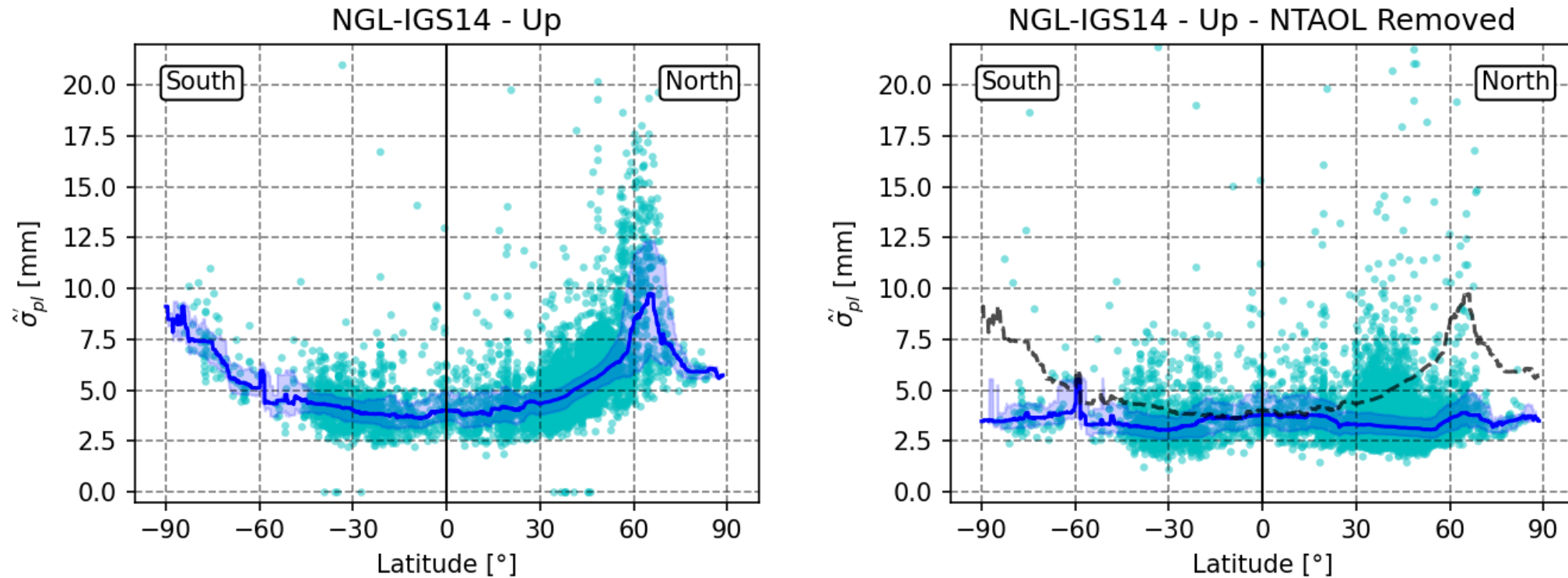
Influence on white noise amplitudes



- White noise **often undetected before** NTAOL corrections
- White noise **detected at all latitudes after** NTAOL corrections
- The **equatorial bulge** remains present

Influence of NTAOL deformations on stochastic parameters

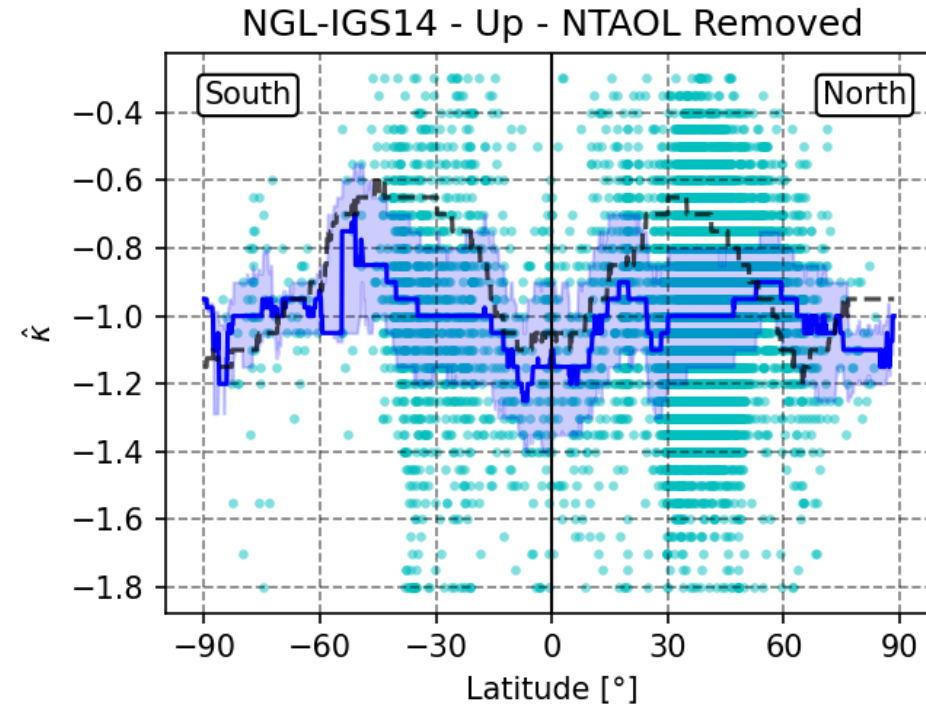
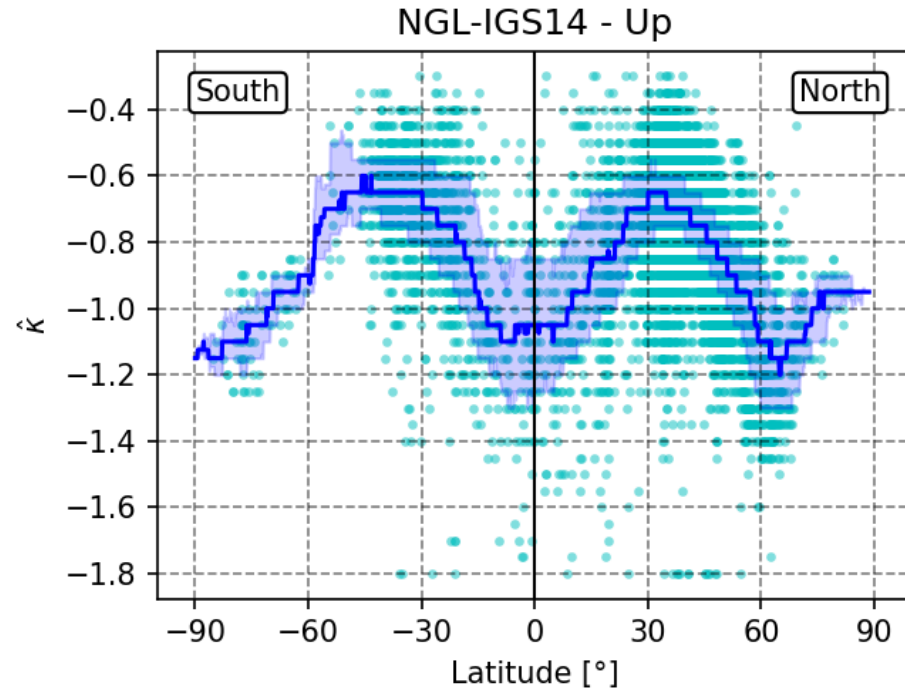
Impact on modified power-law amplitudes



- **Dramatic decrease** in amplitude at high latitudes
- Power-law processes are **not removed**: about 3.5 mm amplitude at all latitudes

Influence of NTAOL deformations on stochastic parameters

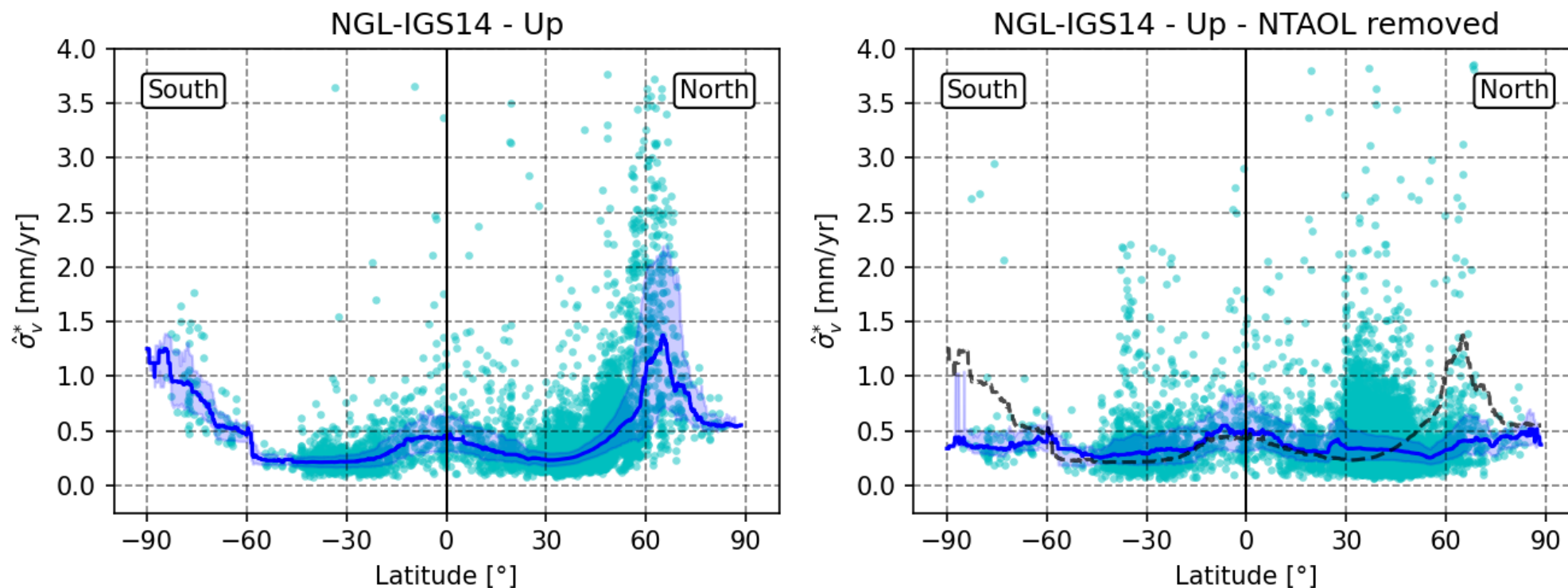
Impact on spectral indices



- On average **closer to flicker noise** process after NTAOL corrections
- Increase in scatter (latitude representation not appropriate anymore)

Influence of NTAOL deformations on stochastic parameters

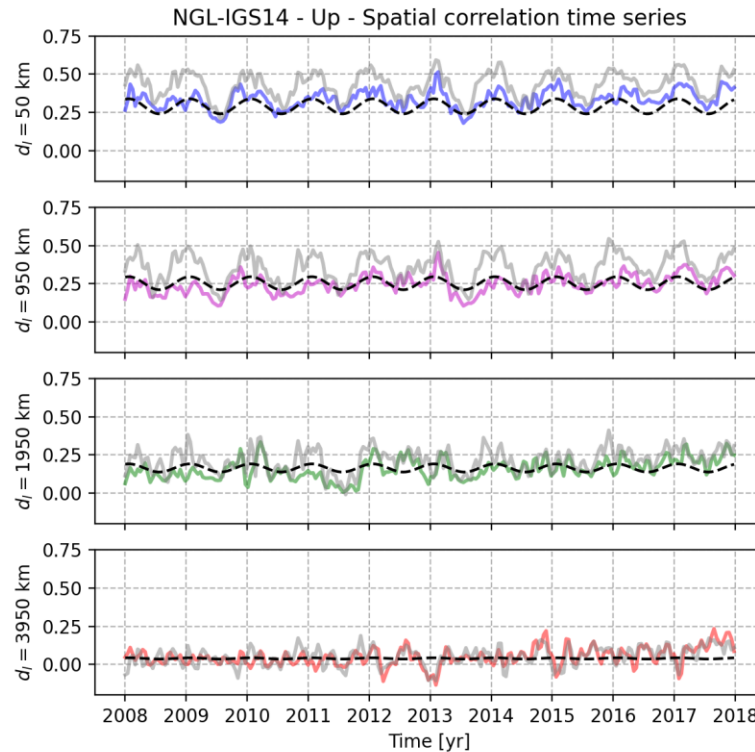
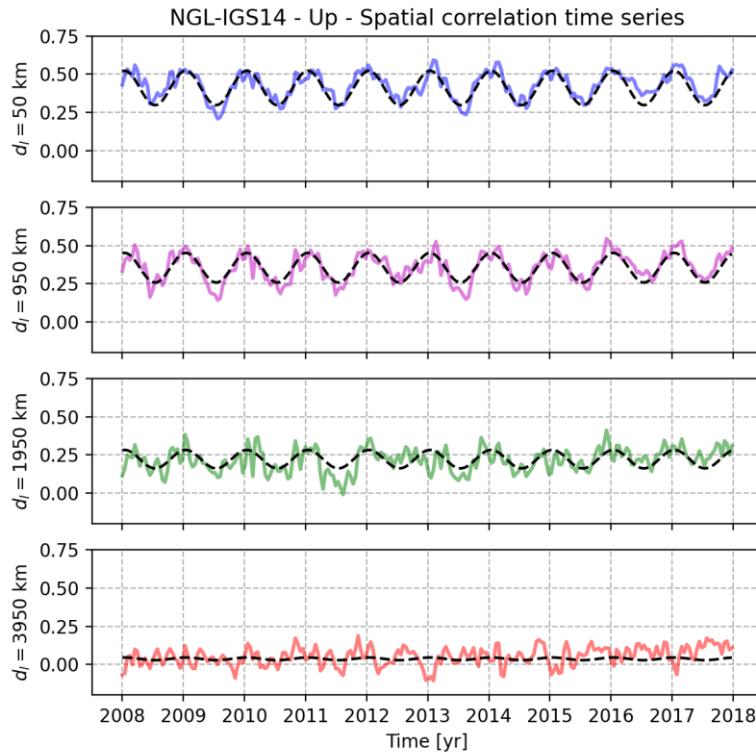
Impact on velocity uncertainties



- The median reduction at high latitude **reaches -70.8%**
- Only **37.8% of the stations** show a **reduction** of velocity uncertainty due to changes in spectral indices at mid-latitudes

Study of the influence of non-tidal loading deformations

Impact on spatial correlations



- Colour: estimates
- Grey: estimates before NTAOL corrections
- Black: Seasonal gaussian correlation model

- Reduction of the average correlation (-29.3%) & seasonality (-54.4%) at short separation distances.

Conclusions & perspectives

Study of the influence of non-tidal loading deformations

Contributions

- **Global scale** description of stochastic parameter's variability
- **Latitude dependence** of white noise amplitudes, power-law amplitudes, and spectral indices.
- **Seasonal variability** of the **spatial correlation**

- White noise often undetected at high latitudes **due to NTAOL**.
- Latitude dependence of power-law amplitudes **due to NTAOL**.
- NTAOL corrections have a dramatic influence on **velocity uncertainties**.

- The spatial correlation is **partly explained by NTAOL**

Study of the influence of non-tidal loading deformations

Perspectives

- White noise amplitudes **equatorial bulge**?
- Cause of remaining **power-law** at all latitudes?
- Origin of residual **spatial variability** & **spatial correlation**?
- Influence of **hydrological loading** deformations?

Thank you !