MSSA Analysis Of Seasonal Loading-Induced Deformation From GNSS Time Series

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27th IUGG General Assembly – July 8 – 18 2019 – Montreal, Canada
Session G06 – **poster G06p-320**

1. Introduction and study objectives

- Loading crustal deformations induced by ocean, atmosphere and continental water mass redistributions can be monitored by space geodesy (e.g. GNSS and GRACE)
- Usually surface waters (rivers, lakes) are not included in hydrological loading models considering only snow and soil-moisture
- Huge discrepancies between GNSS observations and models arise around large rivers such as the Amazon where nearly half of the vertical signal cannot be explained by the combination of loading models
- In this study, Multi Singular Spectrum Analysis (MSSA) and Taylor Diagram Analysis are used together to compare GNSS observations and loading models to numerically evaluate the part of crustal deformation not yet explained by the loading models
- Studied area is located in South America (*Figure 1*) where the hydrological effects are among the largest in the world mainly due to the river level variations

2. Data and models

For the loading models please refer to the EOST loading service (http://loading.u-strasbg.fr)

Models

- **ATMOSPHERE** – *ECMWF surface pressure fields* → ATMMO
- **Non-tidal OCEAN** – *barotropic oceanic response to pressure and winds using TUGO-m model* → ATMMO
- **CONTINETAL WATER STORAGE** – *soil-moisture and snow* → GLDAS, MERRA
- **Large RIVER contribution (Amazon, Orenoque, Parana)** → GLDAS river, MERRA river

Observations

- **GPS** – *NGL daily solution (Blewitt et al., 2018)*
- **GRACE** – *mascon solution (corrected from ocean and atmosphere)*

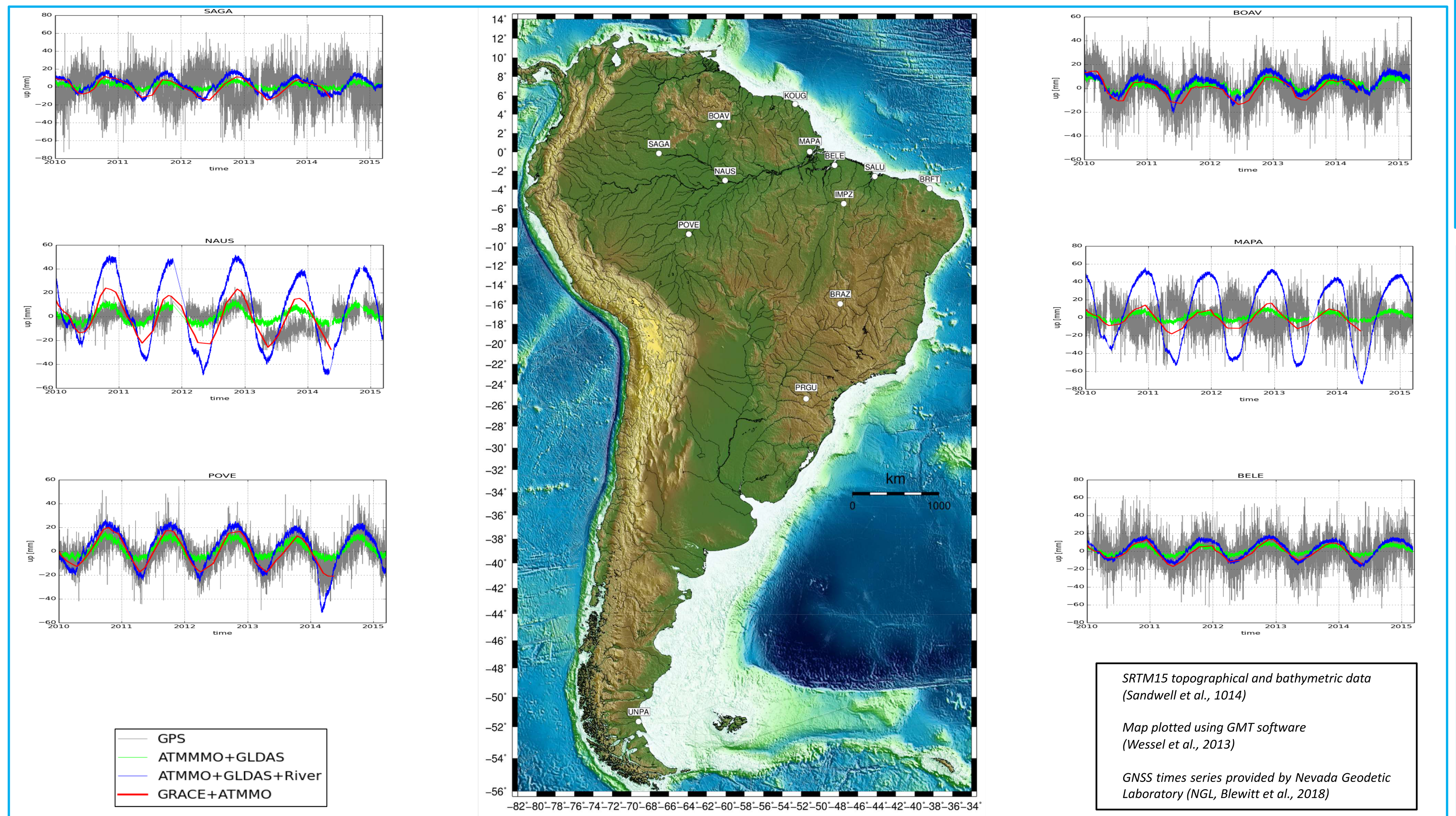

Figure 1: Network of GNSS stations and vertical time series examples

3. Multi Singular Spectrum Analysis (MSSA)

- Singular Spectrum Analysis (SSA) is a statistical method that allows to decompose time series of scalar quantities into oscillatory components and noises. Multi Singular Spectrum Analysis (MSSA) does the same for time series of vector quantities.
- *Figure 2* shows an example of such a decomposition on the East, North and Up components of the position vector of POVE GNSS station (cf Fig. 1)

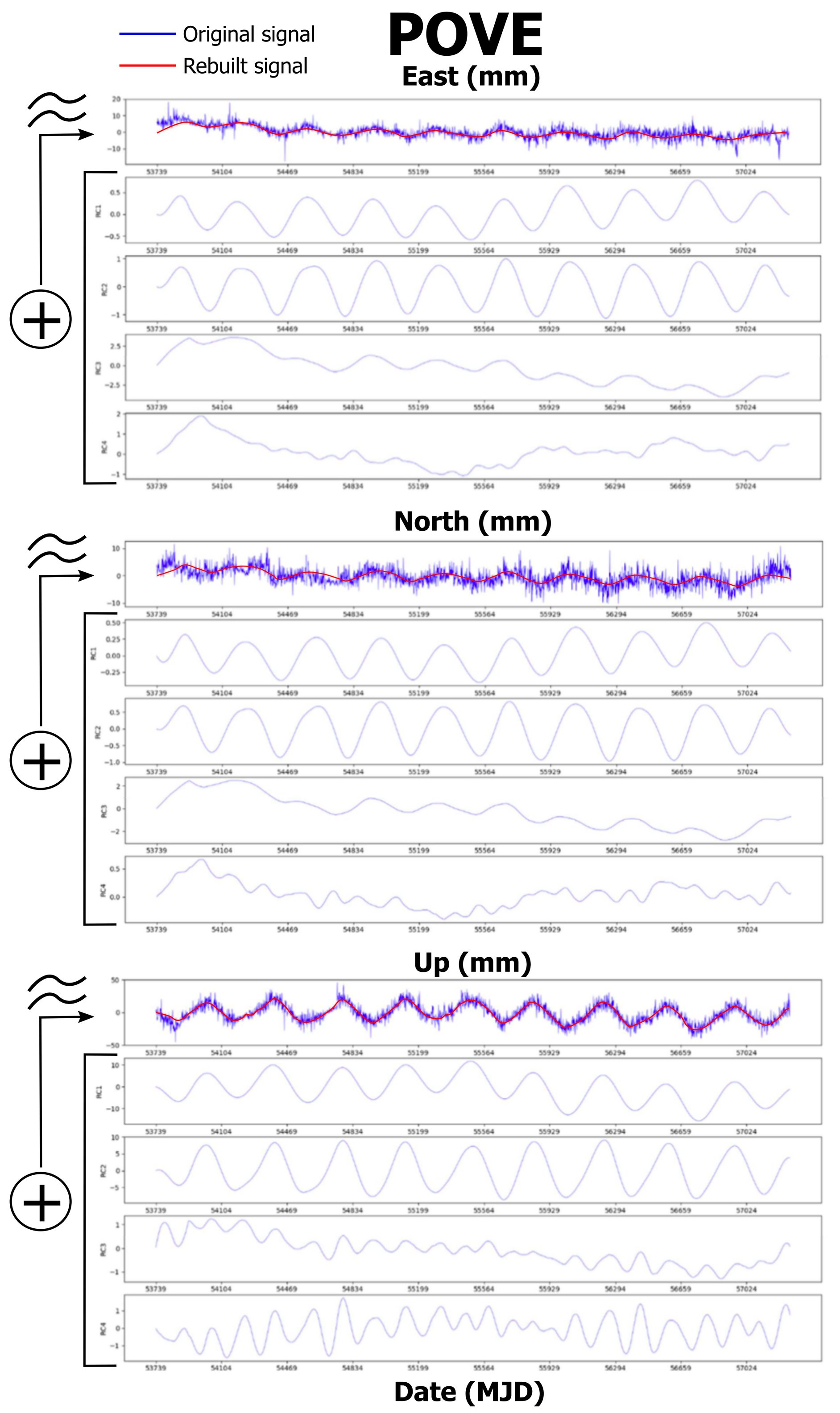

Figure 2: MSSA applied to GNSS-determined position of POVE station

- In this study, MSSA has been systematically applied to GNSS observations and loading models
- The principal components (PC) provided by MSSA have been projected back onto the eigenvectors basis to reconstruct the time series (RC) of East, North Up position vector components
- The analysis time window M has been set to 183 days (ie 6 months)
- Comparisons have been only carried out for the oscillatory components of same frequency
- Following MSSA, PCs of same frequency have been simply summed together

References

1. Claessen and Groth (CERES-ERTI; ENS Paris), 2018
2. Ghil et al. Rev Geophys, 2002

The useful guide to SSA and MSSA written by Claessen and Groth is available from http://environnement.ens.fr/IMG/file/DavidPDF/SSA_beginners_guide_v9.pdf

4. Analysis using Taylor Diagram

- Taylor Diagrams (*Figures 3 & 4*) were first used for climate model analysis (Taylor, JGR, 2001)
- A given time series of observations (*Reference*) can be compared to one another provided either by a model or observations (*Test*); each time series corresponds to one unique point in the Taylor diagram (cf Fig. 4)
- Standard deviations of both times series are determined using one of the dotted semicircles centered at the origin (in blue in Fig. 3)
- The correlation coefficient between time series "Test" and "Reference" can be determined from one of the radial graduations (in red in Fig. 3) plotted on the external semicircle
- The corresponding centered Root Mean Square difference is given by one semicircle (in green in Fig. 3) from a second set of dashed semicircles

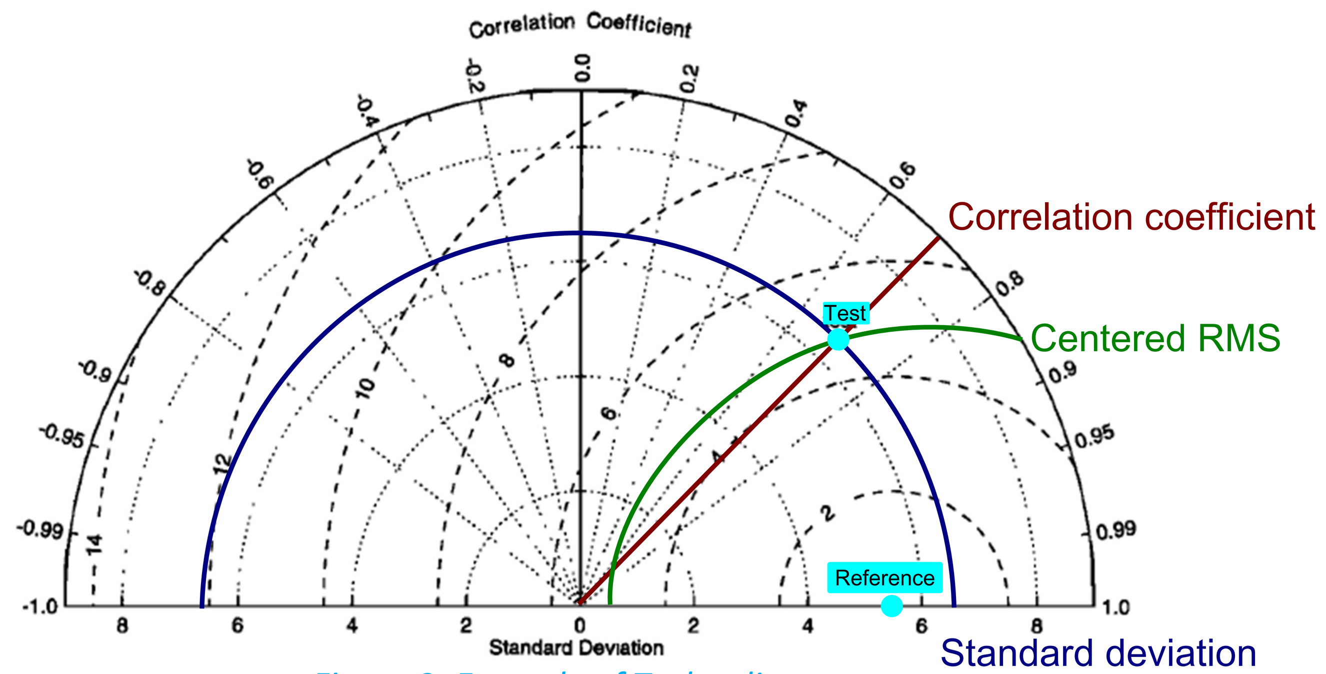

Figure 3: Example of Taylor diagram

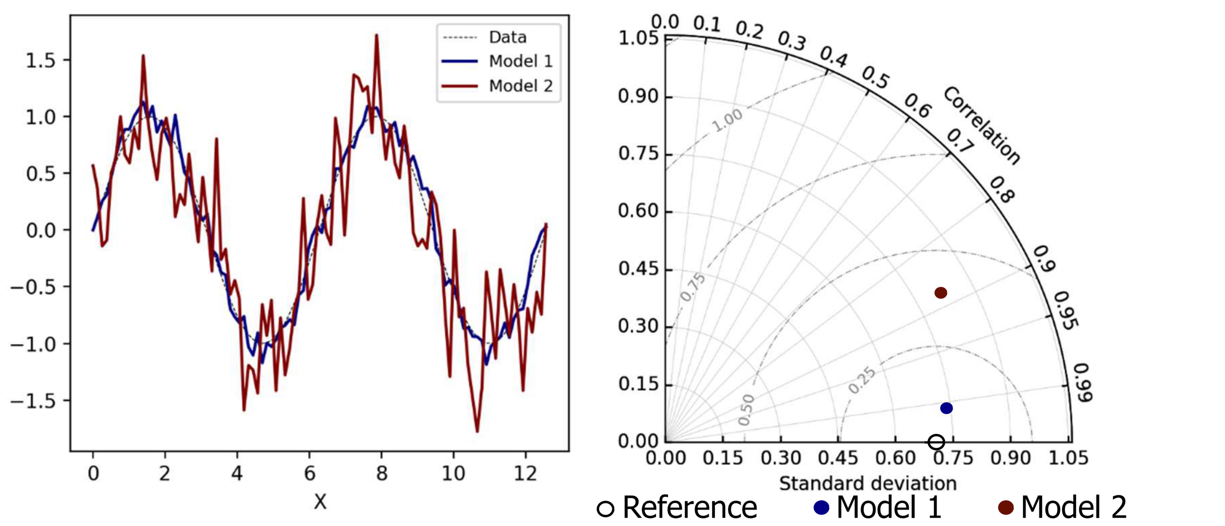

Figure 4: Analysis of simulated time series models

5. First promising results

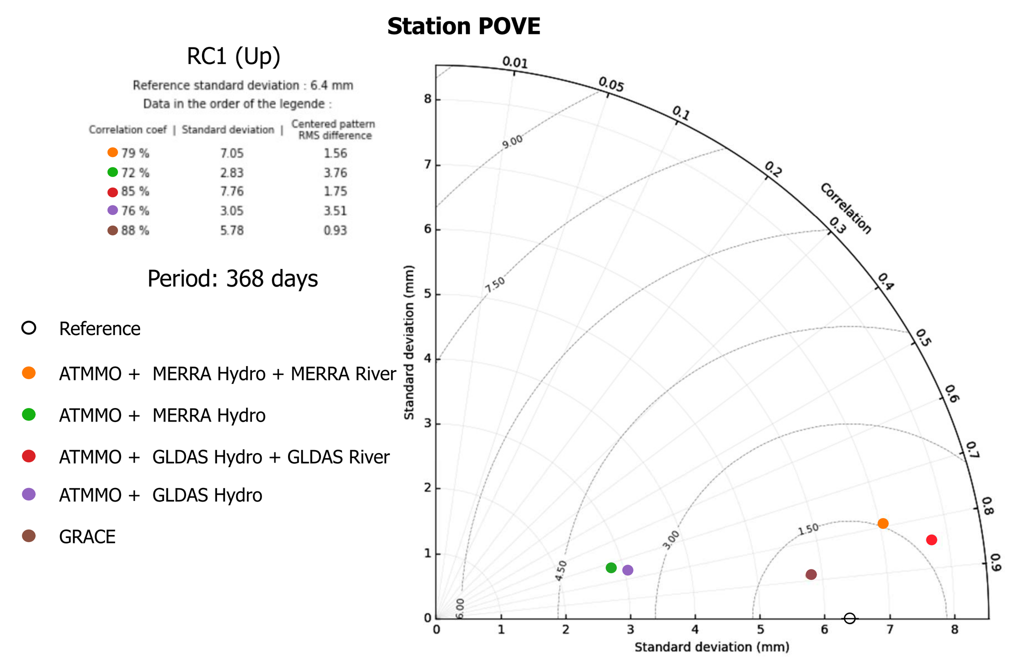

Figure 5: Station located in the Amazon basin (tropical climate)

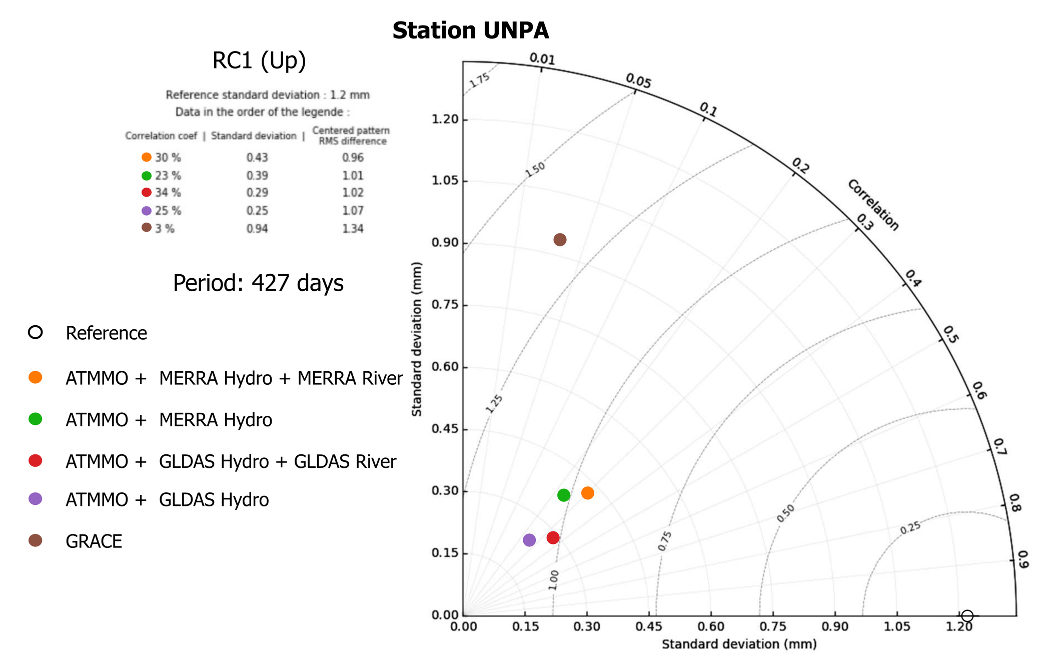

Figure 6: Station located in mountainous region (arid climate)

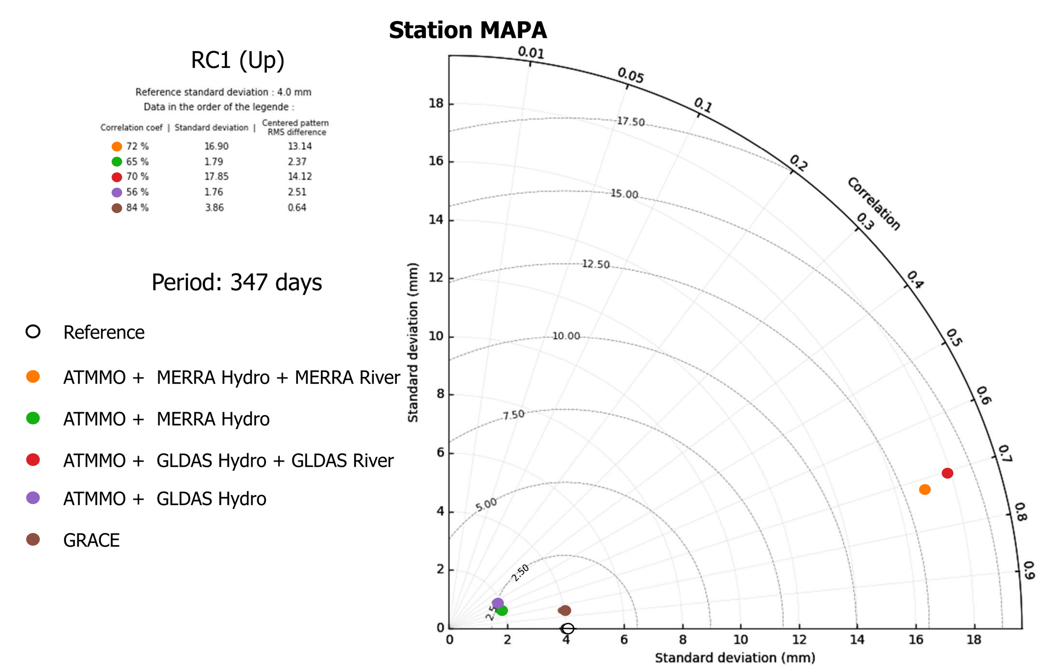

Figure 7: Station located in coastal region (tropical climate)

6. Conclusion and prospects

- These results are preliminary and only concern the vertical component and the first RC for the moment. Our method for estimating RC period still needs to be refined
- The case of POVE (*Figure 5*) clearly suggests that the annual vertical displacement is best explained by models that account for rivers (better correlation MERRA: 72 % -> 79 %; GLDAS: 76% -> 85 %; lesser RMS differences MERRA: 3.8 mm -> 1.6 mm; GLDAS: 3.5 mm -> 1.8 mm)
- The UNPA case (*Figure 6*) indicates that despite a very low correlation between GNSS observations and loading models at annual period (< 30 %), the RMS differences remains moderate (< 1.3 mm)
- The case of MAPA (*Figure 7*) is typical of an overestimation of the annual vertical movement by models including rivers (MERRA: 2.4 mm -> 13 mm; GLDAS: 2.5 mm -> 14 mm)
- Such analyses have now to be carried out for the 3D position vector components (East, North, Up) of large number of GNSS sites (*Figure 8*) at different periods (few hours to seasonal) in order to confirm the results and to infer geophysical interpretations.

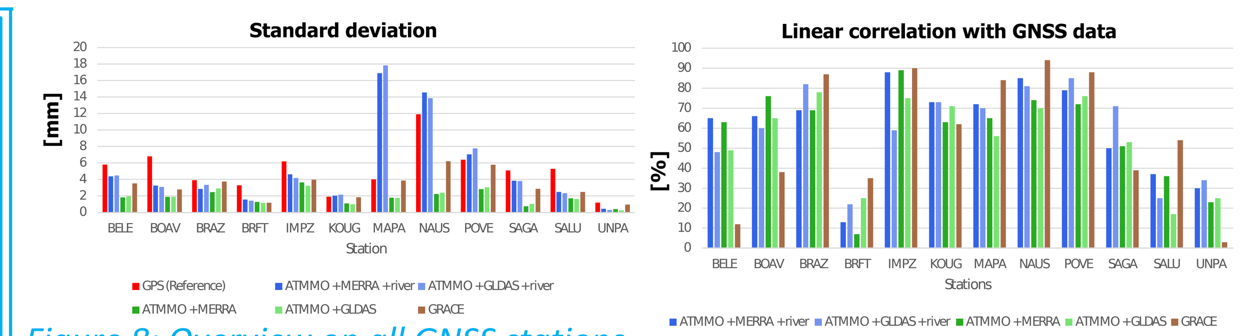

Figure 8: Overview on all GNSS stations