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# Study on common seasonal signals in GPS time series and environmental loadings using Multichannel Singular Spectrum Analysis

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Seasonal oscillations in the GPS position time series can arise from real geophysical effects and numerical artefacts. According to Dong et al. (2002) environmental loading effects can account for approximately 40% of the total variance of the annual signals in GPS time series, however using generally acknowledged methods (e.g. Least Squares Estimation, Wavelet Decomposition, Singular Spectrum Analysis) to model seasonal signals we are not able to separate real from spurious signals (effects of mismodelling aliased into annual period as well as draconitic). Therefore, we propose to use Multichannel Singular Spectrum Analysis (MSSA) to determine seasonal oscillations (with annual and semi-annual periods) from GPS position time series and environmental loading displacement models. The MSSA approach is an extension of the classical Karhunen-Loève method and it is a special case of SSA for multivariate time series. The main advantage of MSSA is the possibility to extract common seasonal signals for stations from selected area and to investigate the causality between a set of time series as well.

In this research, we explored the ability of MSSA application to separate real geophysical effects from spurious effects in GPS time series. For this purpose, we used GPS position changes and environmental loading models. We analysed the topocentric time series from 250 selected stations located worldwide, delivered from Network Solution obtained by the International GNSS Service (IGS) as a contribution to the latest realization of the International Terrestrial Reference System (namely ITRF2014, Rebishung et al., 2016). We also researched atmospheric, hydrological and non-tidal oceanic loading models provided by the EOST/IPGS Loading Service in the Centre-of-Figure (CF) reference frame. The analysed displacements were estimated from ERA-Interim (surface pressure), MERRA-land (soil moisture and snow) as well as ECCO2 ocean bottom pressure. We used Multichannel Singular Spectrum Analysis to determine common seasonal signals in two case studies with adopted a 3-years lag-window as the optimal window size. We also inferred the statistical significance of oscillations through the Monte Carlo MSSA method (Allen and Robertson, 1996).

In the first case study, we investigated the common spatio-temporal seasonal signals for all stations. For this purpose, we divided selected stations with respect to the continents. For instance, for stations located in Europe, seasonal oscillations accounts for approximately 45% of the GPS-derived data variance. Much higher variance of seasonal signals is explained by hydrological loadings of about 92%, while the non-tidal oceanic loading accounted for 31% of total variance.

In the second case study, we analysed the capability of the MSSA method to establish a causality between several time series. Each of estimated Principal Component represents pattern of the common signal for all analysed data. For ZIMM station (Zimmerwald, Switzerland), the 1st, 2nd and 9th, 10th Principal Components, which accounts for 35% of the variance, corresponds to the annual and semi-annual signals. In this part, we applied the non-parametric MSSA approach to extract the common seasonal signals for GPS time series and environmental loadings for each of the 250 stations with clear statement, that some part of seasonal signal reflects the real geophysical effects.

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