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The Impact of the Baltic Sea Loading on GNSS Station Coordinate Time Series: the Case of Latvia

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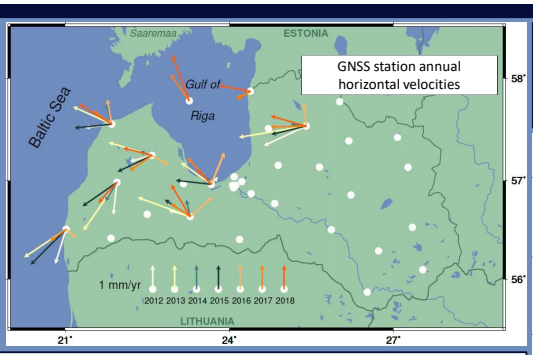
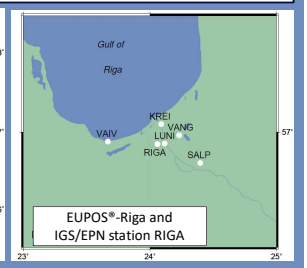
Introduction

The objective of this study is to discover the geodynamic processes of the Earth's crust in the territory of Latvia, occurred due to the effect of the Baltic Sea non-tidal loading, by way of using GNSS permanent station daily coordinate time series and tide gauge data to find correlations between two data sets for the period from 2012 up to 2018.

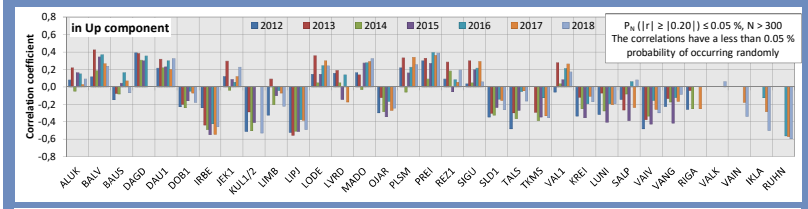


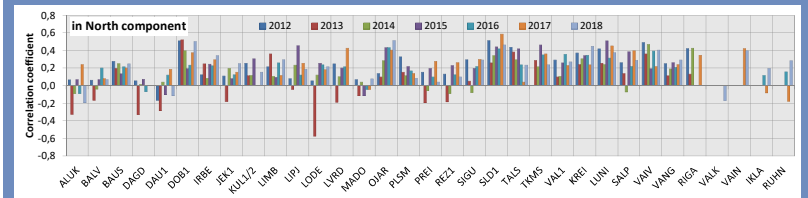
The detailed models and algorithms for eliminating the influence of ocean and atmospheric tidal loading effects on GNSS station positions are given in the IERS Conventions, and mostly ensured through the scientific post-processing software packages. Correction for non-tidal ocean loading still needs further investigation, especially in the case of the Baltic region, which is unique with the postglacial land uplift of Fennoscandia and the Baltic Sea itself. The Baltic Sea exhibits a number of remarkable phenomena. One of them is the sea level variations due to winds, complicated by the shape of gulfs and islands. In the case of tidal variations of the Baltic Sea the range is in the order of centimetres only, but under mentioned influence, the range of sea level variations can reach 3 m on the coasts of gulfs.

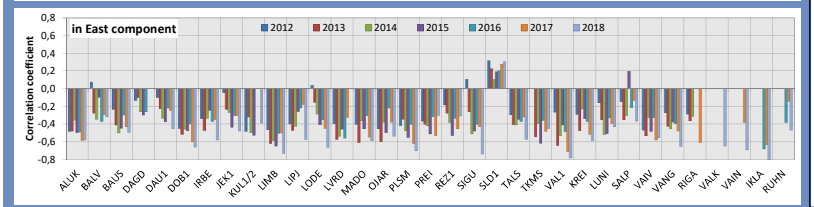
For this study observations of 31 Latvian and 2 Estonian GNSS stations were used. Stations belong to the LatPos, EUPOS®-Riga, EPN and EstPos networks. Station daily coordinate time series computed using Bernese GNSS software v5.2 in a double-difference mode with 9 fiducial stations from EPN/IGS.



The short-term variations (a) of the Baltic Sea (less than one month) are mainly internally driven variations, with maximum amplitudes in the far north and the far south, and a nodal line close to Stockholm in the middle. Thus short-term sea level variations are nearly eliminated at this site (Ekman 2009), and the long-term variations (b) have mean values.
Concerning the Gulf of Riga, the range of sea level variations runs up to 1.50 m and higher.

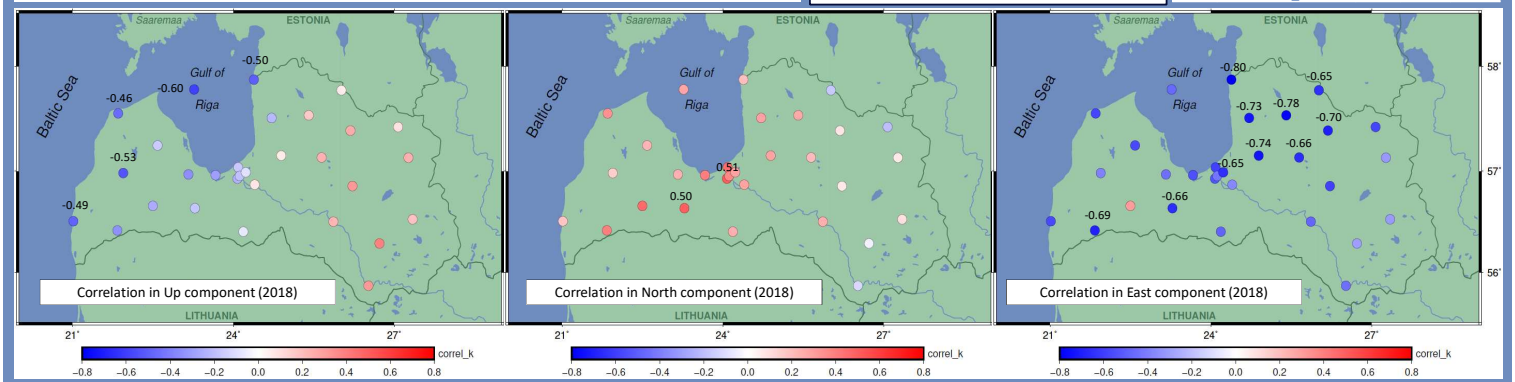


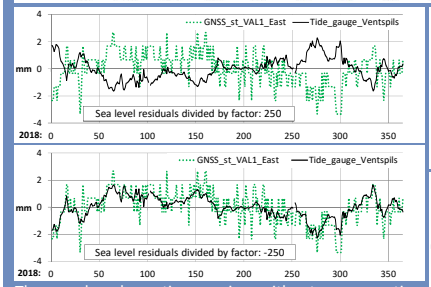


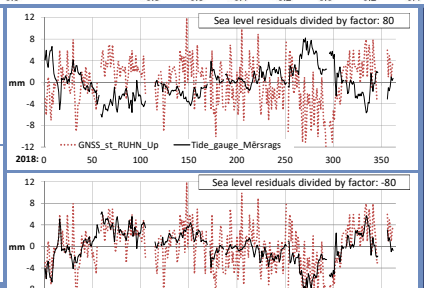


For each year (2012-2018) and each GNSS station (33) correlation coefficients were obtained, using station position residuals in North, East and Up components and sea level data of 7 tide gauges. To visualize results, the maximum values were used. The results have a high probability of being statistically significant, as number of data pairs in any case is higher than 300.
The table (right) presents comparison for the data of 2012 with the 3D displacements computed using SPOTL program NLOADF and kindly provided by Nordman *et al.* (2015). The table shows practically the same correlation coefficients for the East and Up components and good agreement for the North component for the results of study and modelled deformation previously.

Station	Correlation with	North	East	Up
LIPJ	Tide_gauge_Liepāja	0.08	-0.40	-0.50
	loadd_3D	0.02	0.43	0.51
TALS	Tide_gauge_Ventspils	0.44	-0.29	-0.47
	loadd_3D	0.41	0.27	0.48
OJAR	Tide_gauge_Mērsrags	0.12	-0.44	-0.29
	loadd_3D	0.11	0.45	0.30
BALV	Tide_gauge_Liepāja	0.05	0.06	0.12
	loadd_3D	-0.02	-0.06	-0.07
DAU1	Tide_gauge_Liepāja	-0.10	-0.10	0.21
	loadd_3D	-0.18	0.11	-0.18
IRBE	Tide_gauge_Ventspils	0.12	-0.34	-0.21
	loadd_3D	0.15	0.35	0.21
LVRD	Tide_gauge_Liepāja	0.25	-0.34	0.14
	loadd_3D	0.21	0.34	-0.14
MADO	Tide_gauge_Liepāja	0.07	-0.40	0.16
	loadd_3D	-0.01	0.43	-0.14
PLSM	Tide_gauge_Liepāja	0.33	-0.42	0.19
	loadd_3D	0.34	0.39	-0.19
REZ1	Tide_gauge_Liepāja	0.13	-0.16	0.09
	loadd_3D	0.09	0.15	-0.08







The graphs show time series with strong negative correlation (-0.78) at VAL1 in East comp. and moderate negative correlation (-0.60) at RUHN in Up comp. (2018).

Conclusions

- The correlation between Latvian GNSS station coordinate time series and sea level variations (2012-2018) is well observable in North, East and Up components.
- Both negative and positive correlations are observable in the Up component. Sites located closer to the open sea display the highest negative correlations of all.
- The maximum correlation coefficient in Up component: -0.60 at RUHN in 2018.
- The correlation is most prominent in the East component – it is observable for the most stations with highest values during 7-year observation period, and with maximum correlation coefficients -0.78 at VAL1 and -0.80 at IKLA in 2018.
- In the case of North component, positive weak and moderate correlations are observable with outstanding values for the 2013, when negative correlation appears.
- Correlations are changing from year to year, but even weak correlations at sites display regionally related results.