NKG Working Group of Geodynamics and Earth Observation

# The Impact of the Baltic Sea Loading on GNSS Station Coordinate Time Series in the territory of Latvia

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The objective 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 coordinate time series and tide gauge data.

## Contents

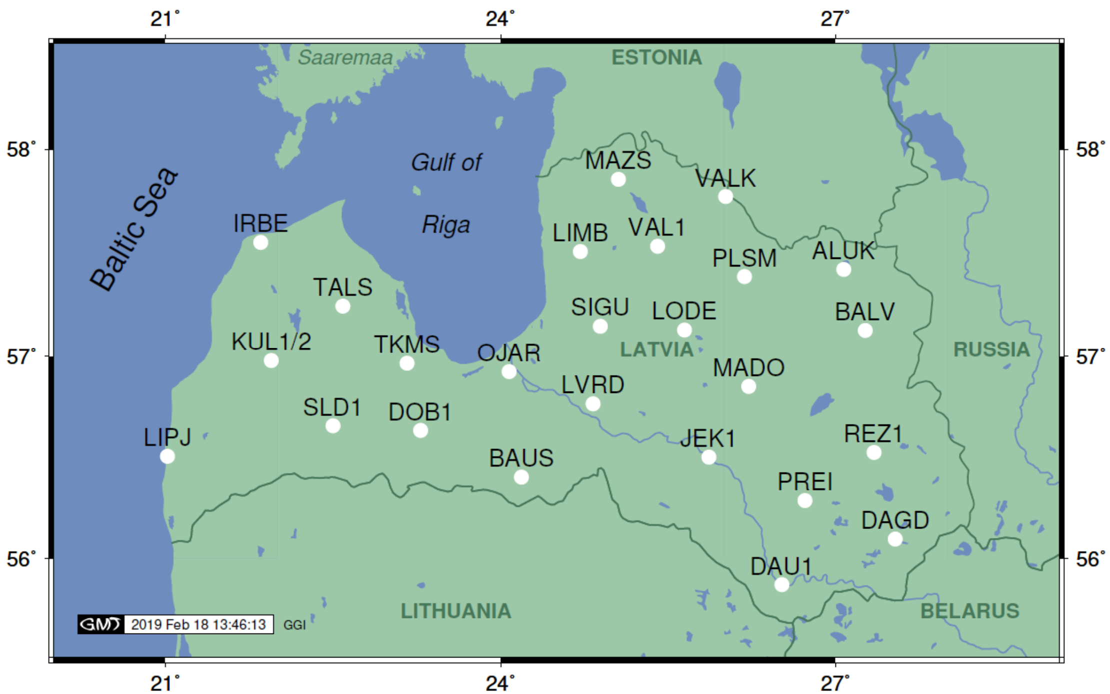
- GNSS data processing strategy;
- Latvian GNSS station cumulative and annual horizontal velocities (2012-2018);
- Description of the water level variations of the Baltic Sea at the Latvian coast;
- Correlations between GNSS time series in North, East and Up components and sea level data;
- Conclusions.

# Latvian GNSS stations

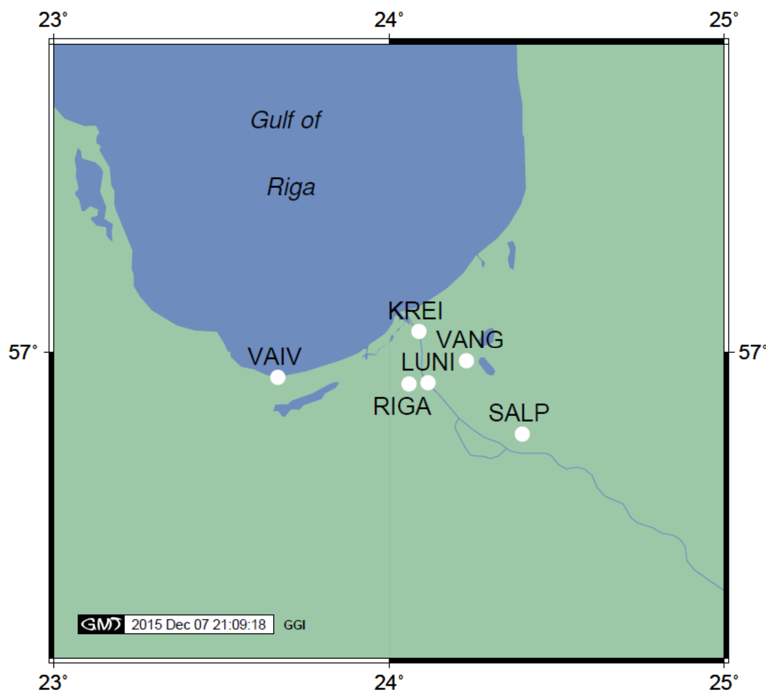
- EUPOS®-Riga and LatPos, which have been operating since 2006, serve primarily as geodetic reference networks established for surveying and navigation purposes in the territory of Latvia.

LatPos station DAU1

LatPos station IRBE



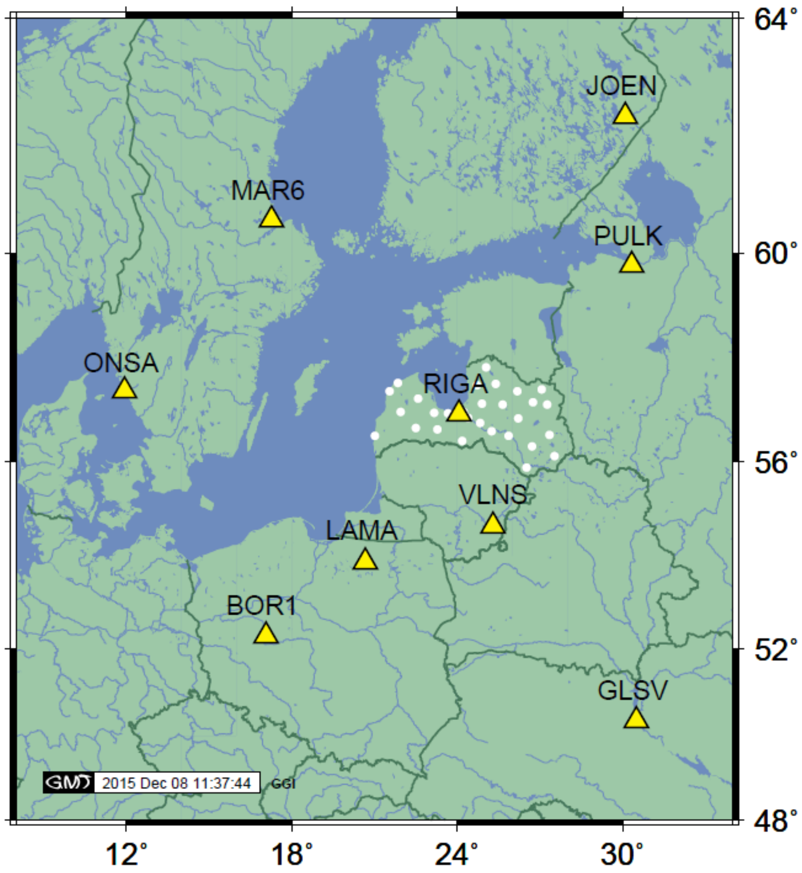

LatPos network with 25 continuously operating GNSS stations




EUPOS®-Riga and IGS/EPN station RIGA

# GNSS data processing

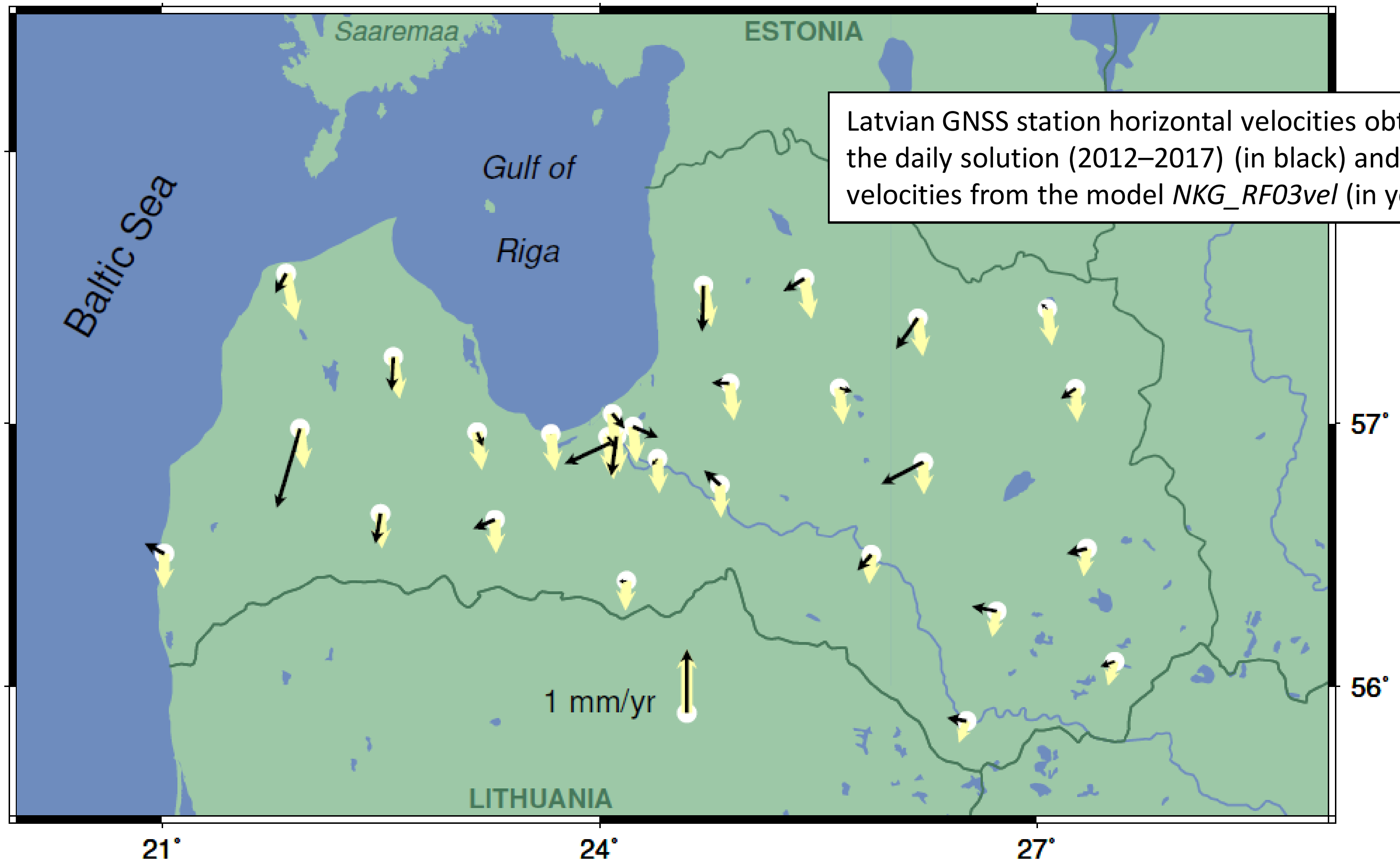
- Observation period (7 years): 2012-2018
- Daily coordinate time series computed using Bernese GNSS software v5.2 in a double-difference (DD) mode
- Combined processing of GPS and GLONASS observations since 2015
- 9 fiducial stations from EPN/IGS
- Elevation cutoff angle: 3°
- Station positions corrected for the effect of solid Earth tides (IERS2010) and the ocean tidal loading (FES2004 ocean tide model); without corrections of the atmospheric tidal loading
- Coordinates obtained in IGb08 and IGS14, transformed to ETRF2000 using one-step transformation with 14 transformation parameters according to *Boucher and Altamimi (2011)*




Latvian GNSS stations (white dots) and fiducial stations (yellow triangles) from EPN/IGS networks: BOR1, GLSV, JOEN, LAMA, MAR6, ONSA, PULK, RIGA, VLNS

# Latvian GNSS station cumulative horizontal velocities

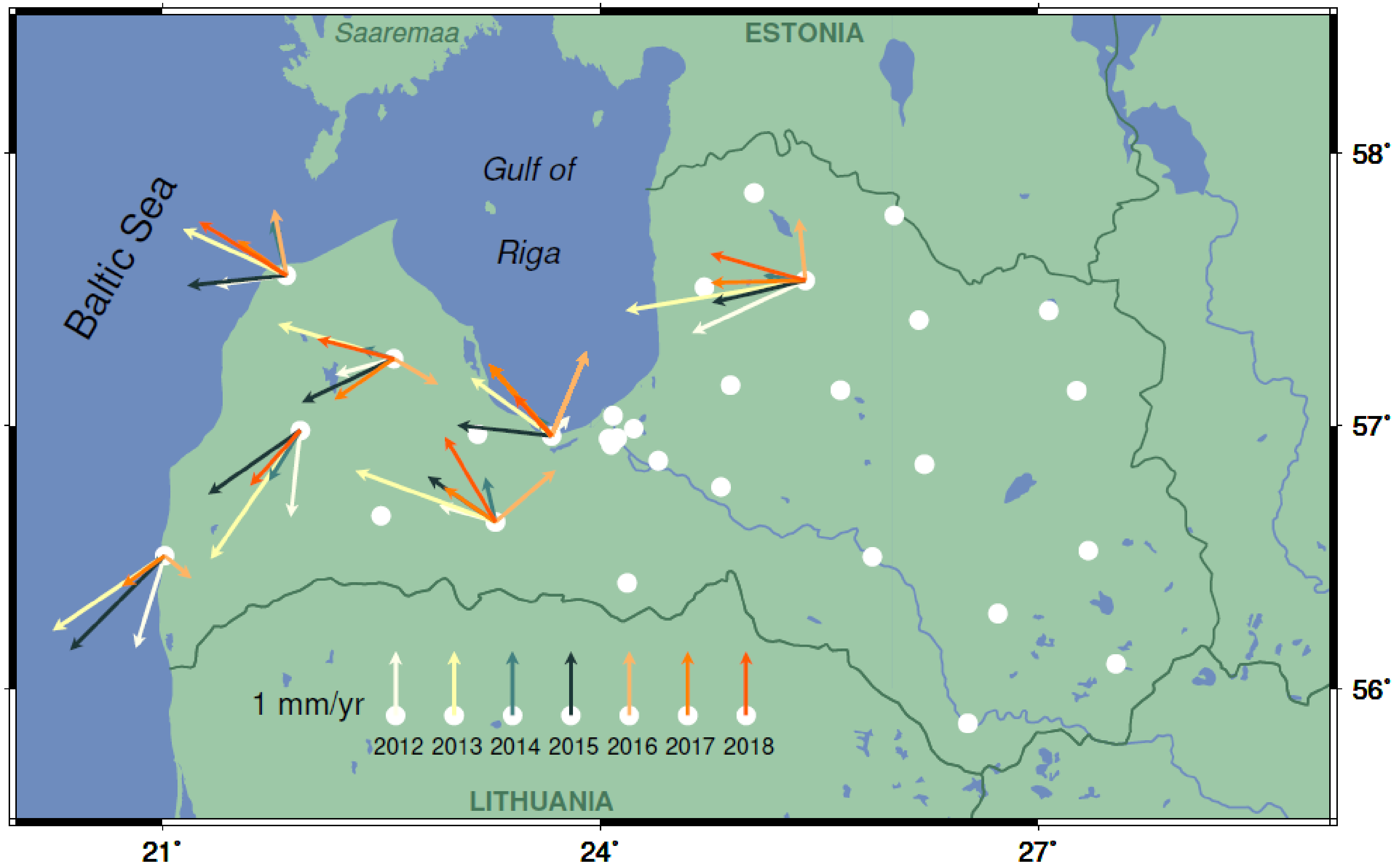
- Time series analysis performed using Tsview software
- Standard settings for the analysis: outlier rejection by criterion of 3-sigma
- Editing of the data affected by snow




Latvian GNSS station horizontal velocities obtained from the daily solution (2012–2017) (in black) and horizontal velocities from the model *NKG_RF03vel* (in yellow)

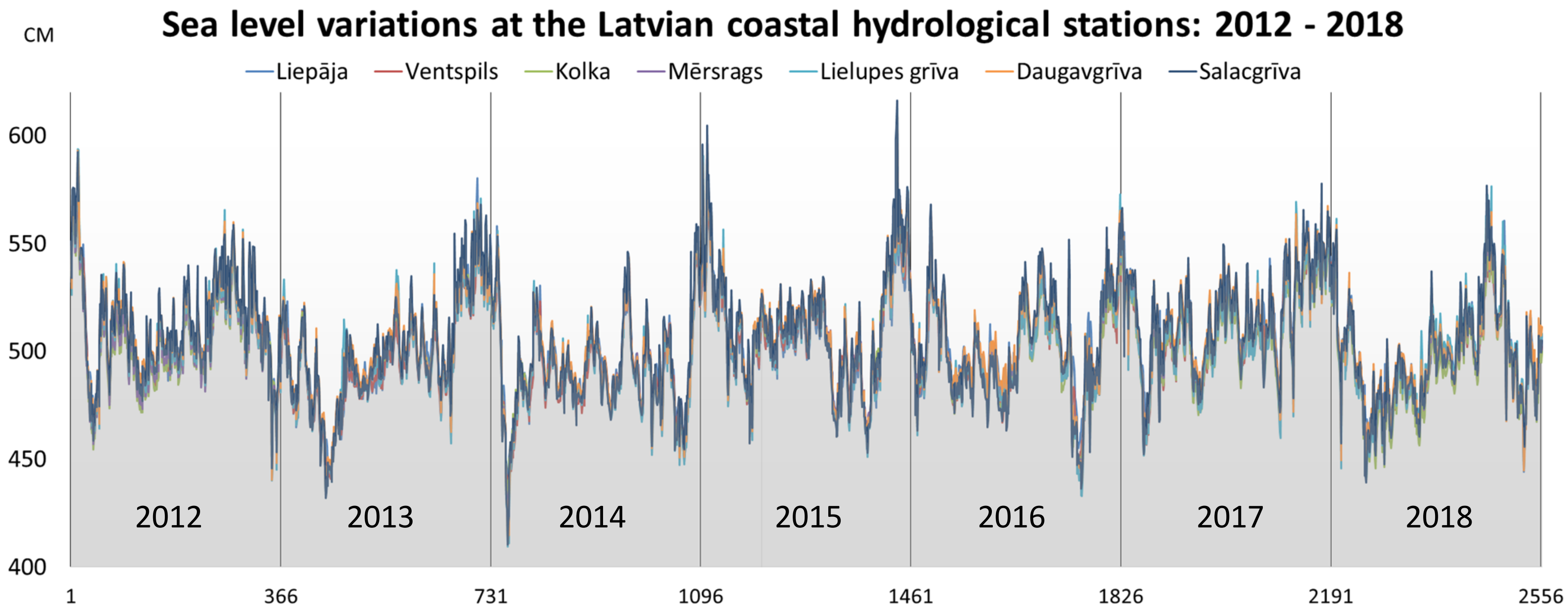
# Latvian GNSS station annual horizontal velocities

- Time series analysis performed using Tsview software
- Outlier rejection by criterion of 3-sigma; editing of the data affected by snow
- Without removing of annual and semi-annual trends for the annual velocities



# Sea level variations at the Latvian coast

- Observation period: 2012-2018
- Data (daily mean values of hourly records) of 7 tide gauges
- The water level data are given above the gauge zero datum

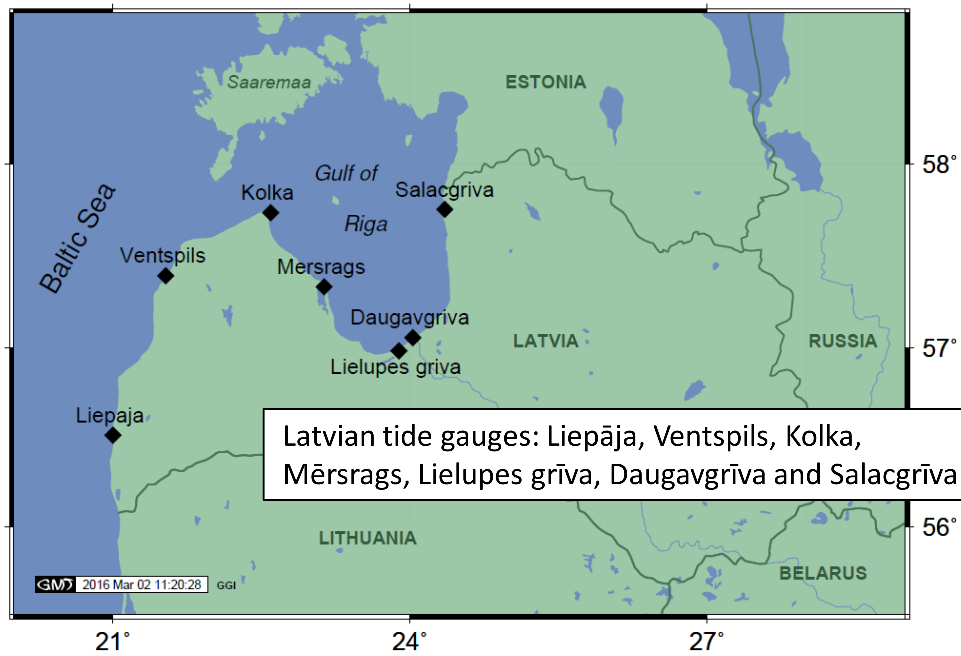

- ➢ The time series has a distinct increase in the amplitude during the winter season: the reason – winds (this effect was pointed out by *Ekman* (*1998*))

# Correlation

| GNSS station | VAL1 | | |
|---|---|---|---|
| **2013** | **N** | **E** | **Up** |
| Liepāja | 0.10 | -0.64 | 0.26 |
| Ventspils | 0.09 | -0.63 | 0.26 |
| Kolka | 0.05 | -0.63 | 0.27 |
| Mērsrags | 0.04 | -0.63 | 0.27 |
| Lielupes grīva | 0.03 | -0.60 | 0.25 |
| Daugavgrīva | 0.03 | -0.62 | 0.26 |
| Salacgrīva | 0.02 | -0.63 | 0.28 |
| **MAX \|corr_k\|** | **0.10** | **-0.64** | **0.28** |
| Stockholm | 0.15 | -0.60 | 0.22 |

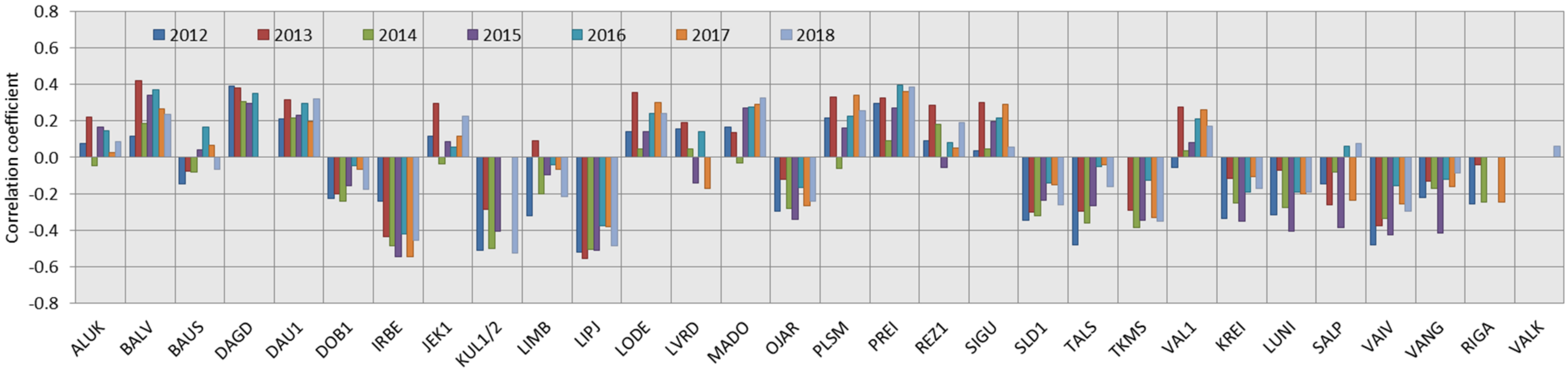
$P_N(|r| \geq |0.20|) \leq 0.05$ % N > 300
The correlations have a less than 0.05 % probability of occurring randomly

| **MAX \|corr_k\|** | **0.10** | **-0.64** | **0.28** |
|---|---|---|---|
| Probability (%) | 5.7 | < 0.05 | < 0.05 |

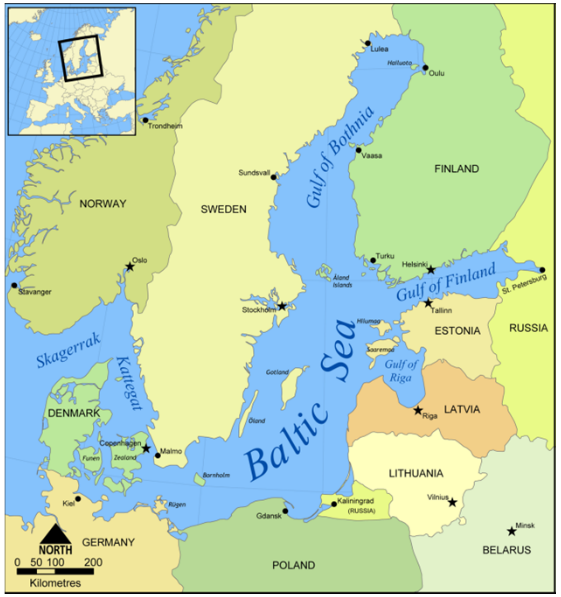


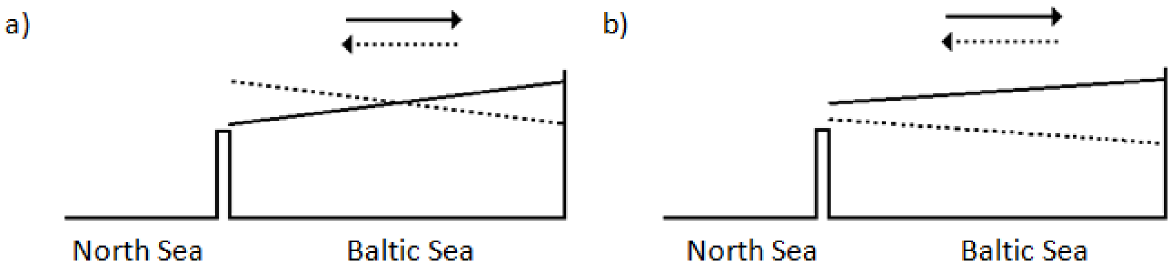

Latvian tide gauges: Liepāja, Ventspils, Kolka, Mērsrags, Lielupes grīva, Daugavgrīva and Salacgrīva

**Correlation: Up component**



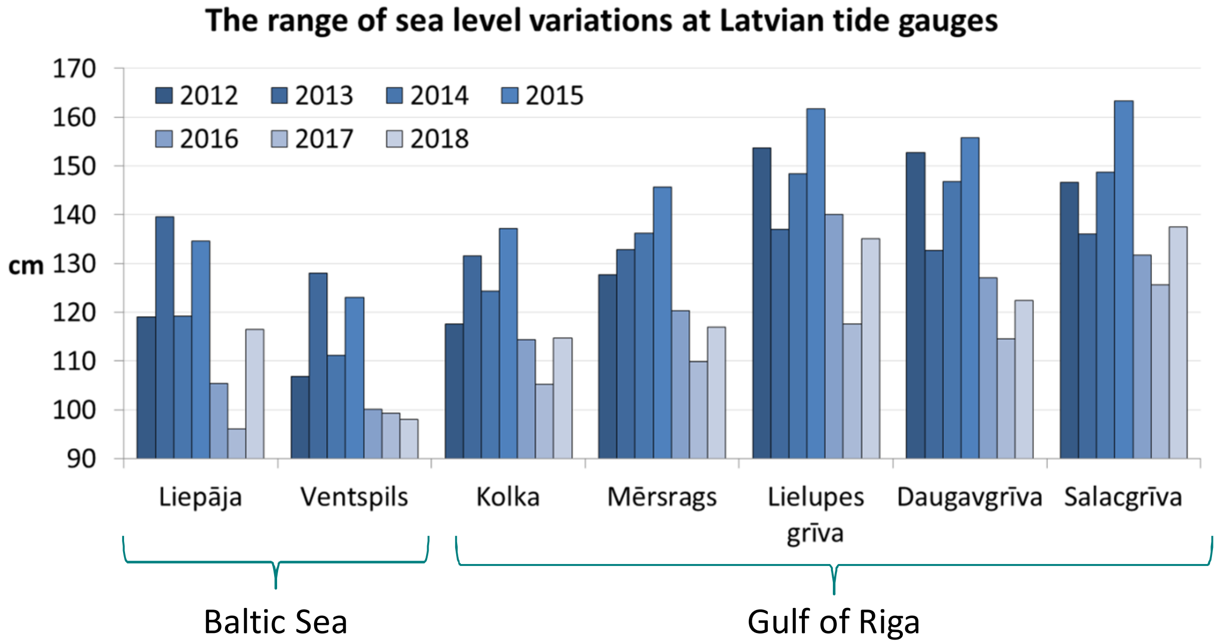
# Dynamics of the sea level at the Latvian coast

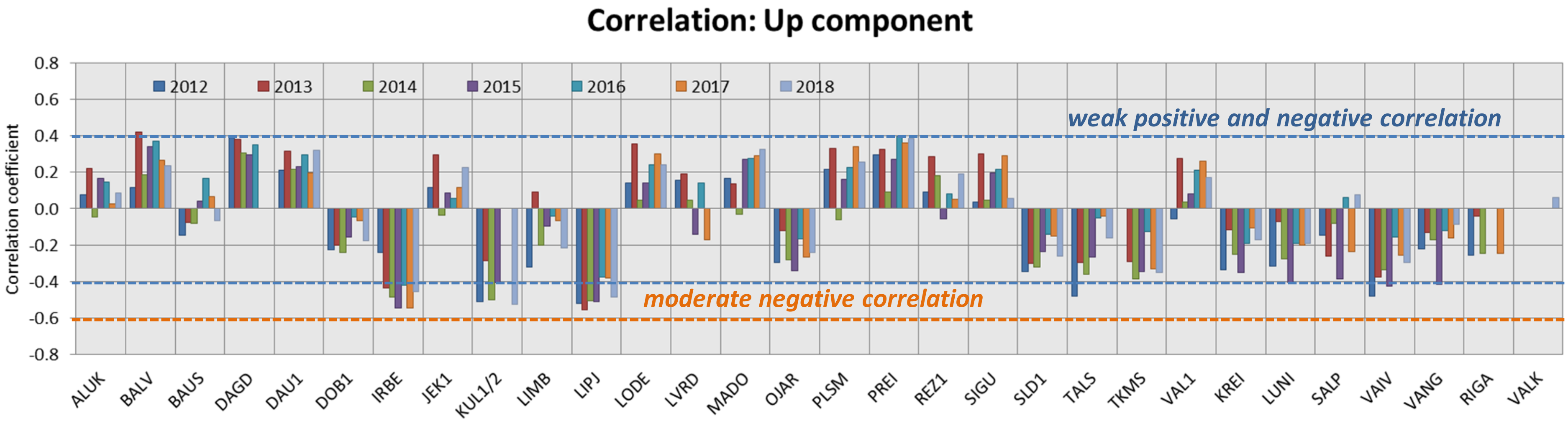


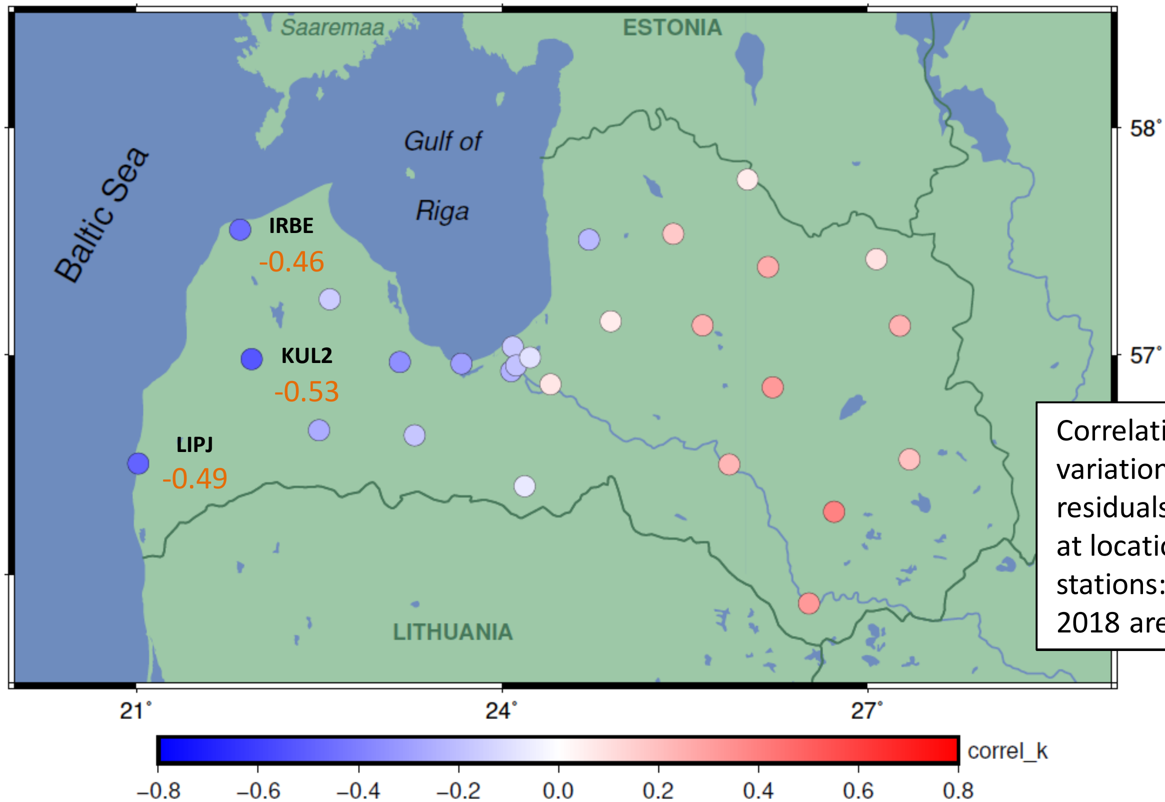




The short-term effect on the Baltic Sea level caused by a temporary wind (a) and the long-term effect caused by a persistent wind (b): continuous line – south-west wind and dashed line – north-east wind (*Ekman 2009*)

➢ The short-term variations (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*).

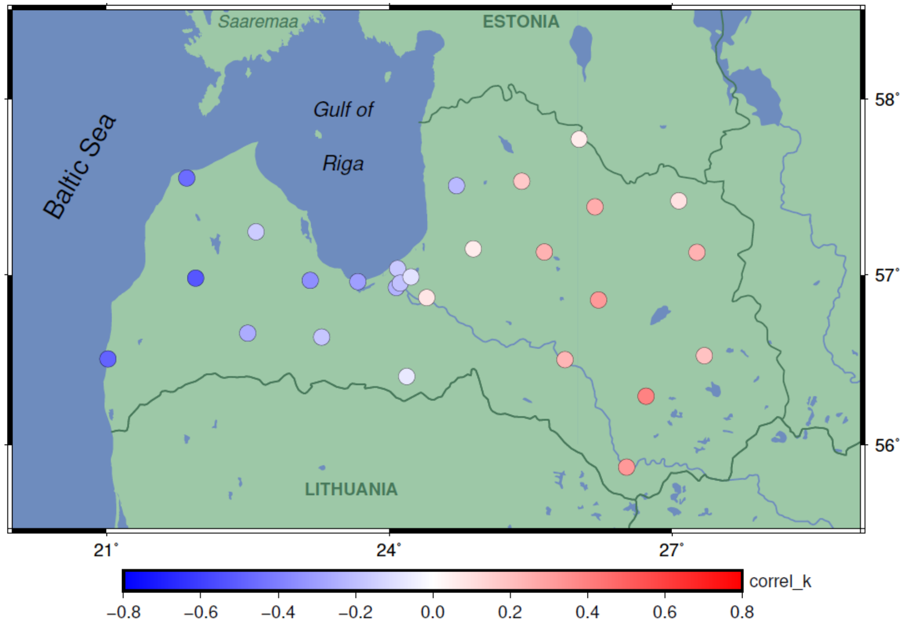


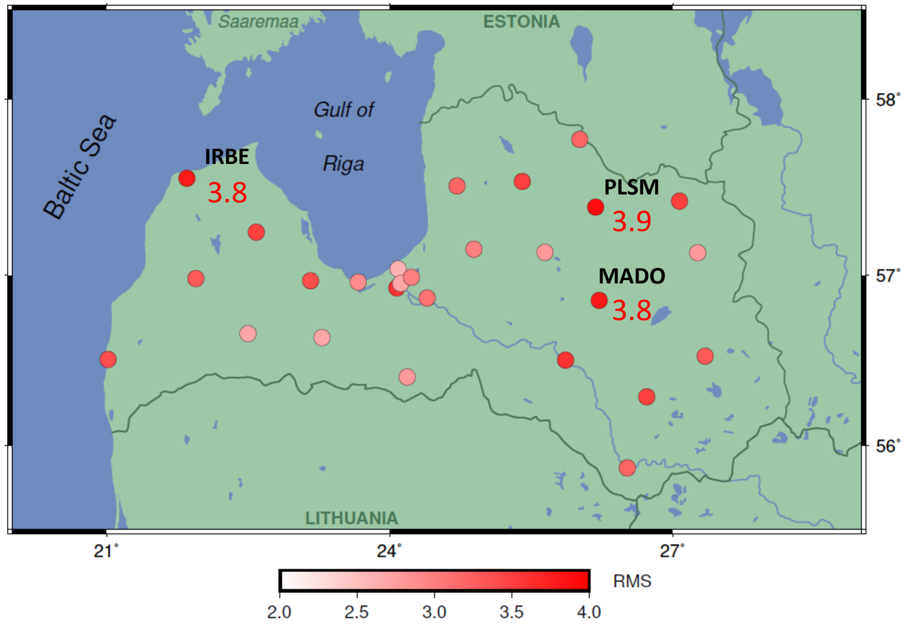



Correlation between sea level variations and coordinate residuals of the GNSS_DD solution at locations of the Latvian GNSS stations: observations of the year 2018 are used

# Correlation in Up component and RMS of GNSS position residuals (2018)

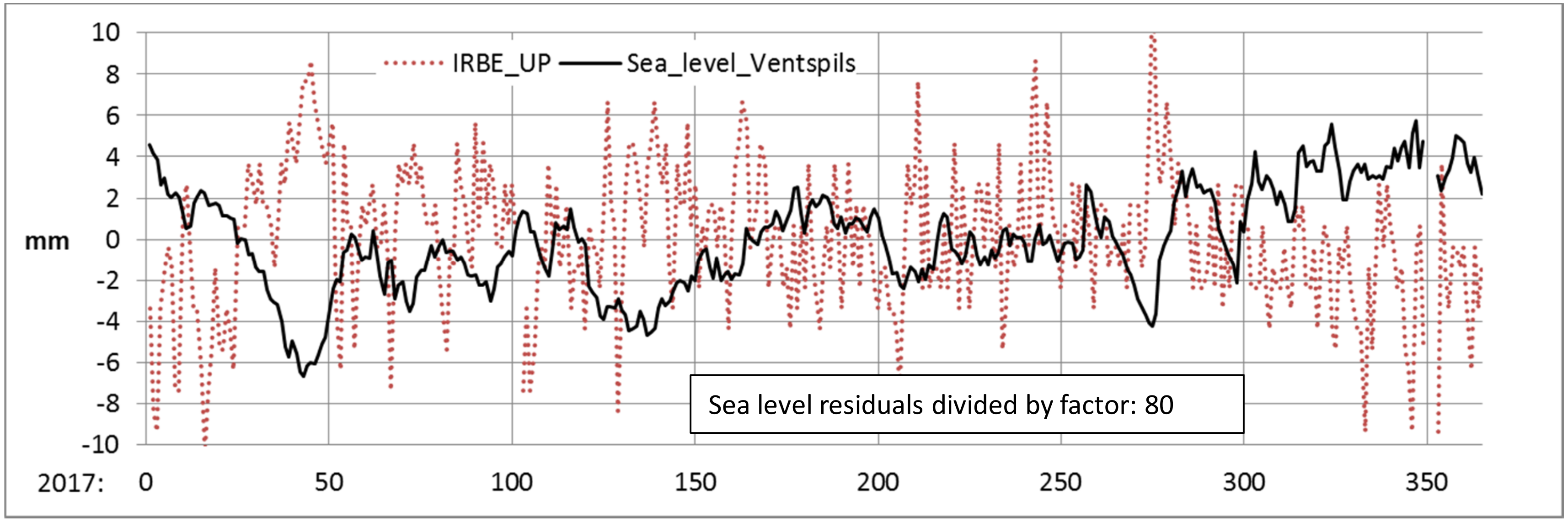


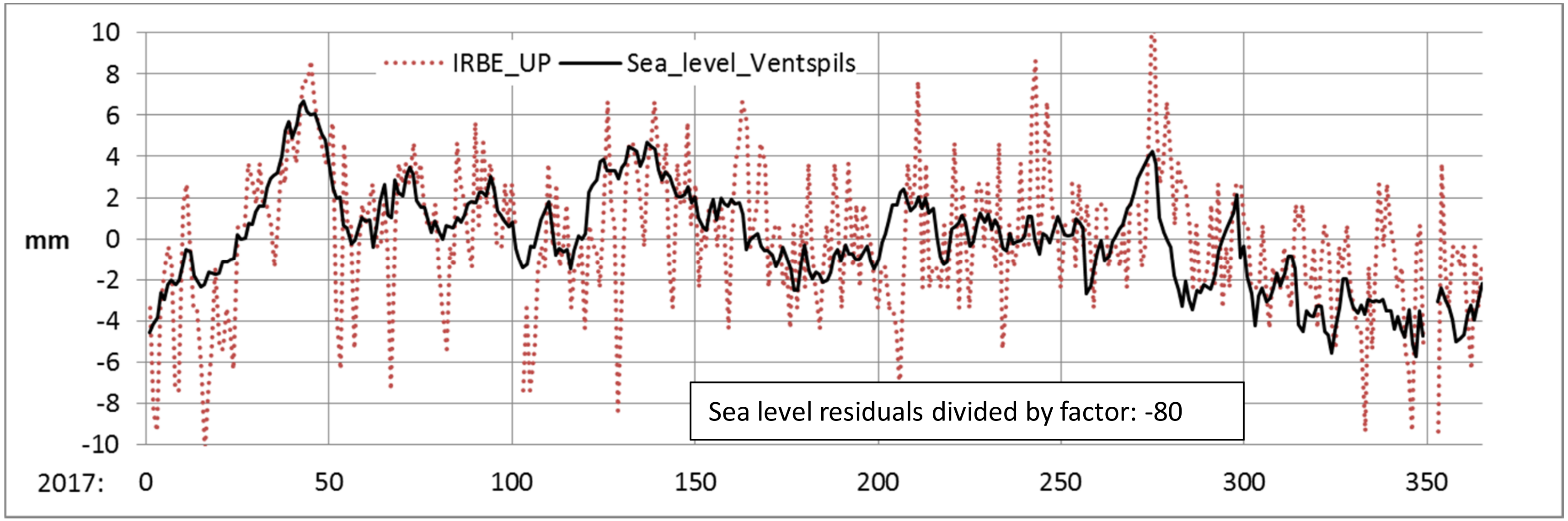



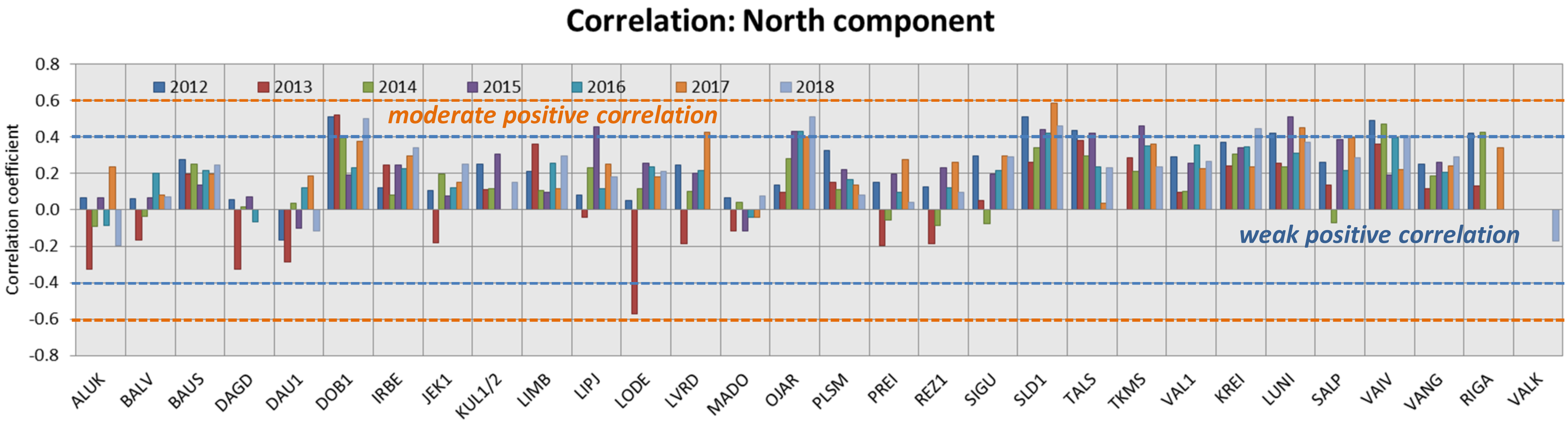

Correlation between sea level variations and coordinate residuals of the GNSS_DD solution at locations of the Latvian GNSS stations: observations of the year 2018 are used

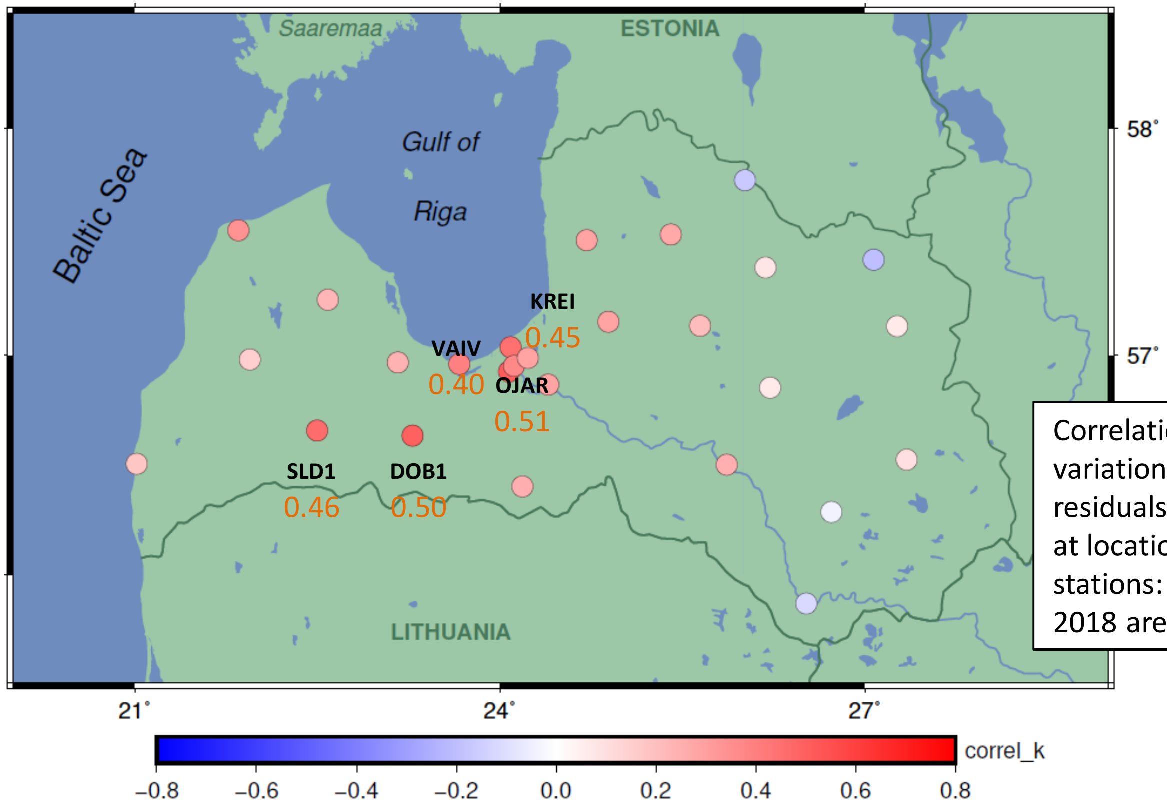
RMS (mm) variability of GNSS position residuals in Up component (2018)

# Moderate negative correlation (-0.53) at IRBE in Up component (2017)



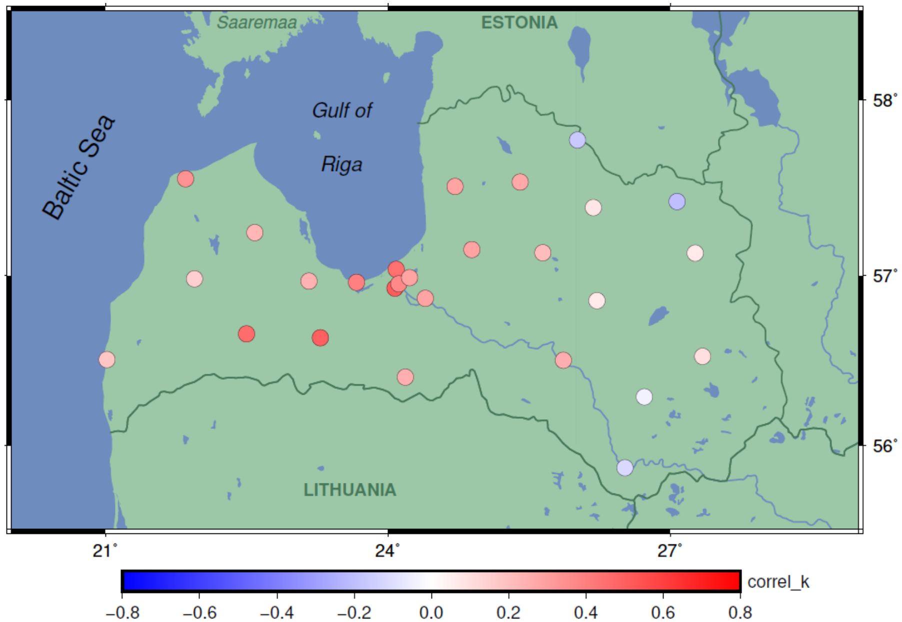



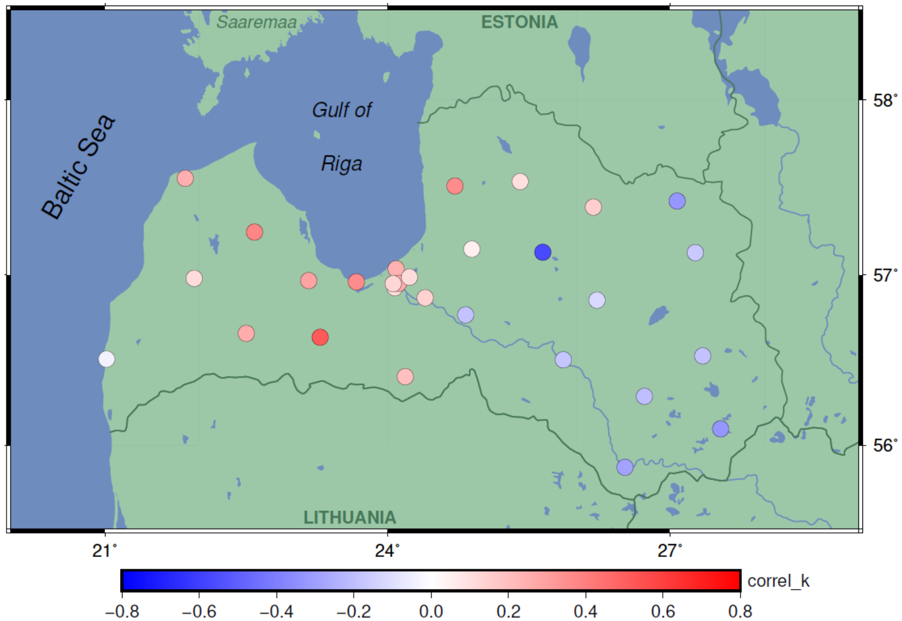



Correlation between sea level variations and coordinate residuals of the GNSS_DD solution at locations of the Latvian GNSS stations: observations of the year 2018 are used

# Correlation in North component (2018 vs 2013)

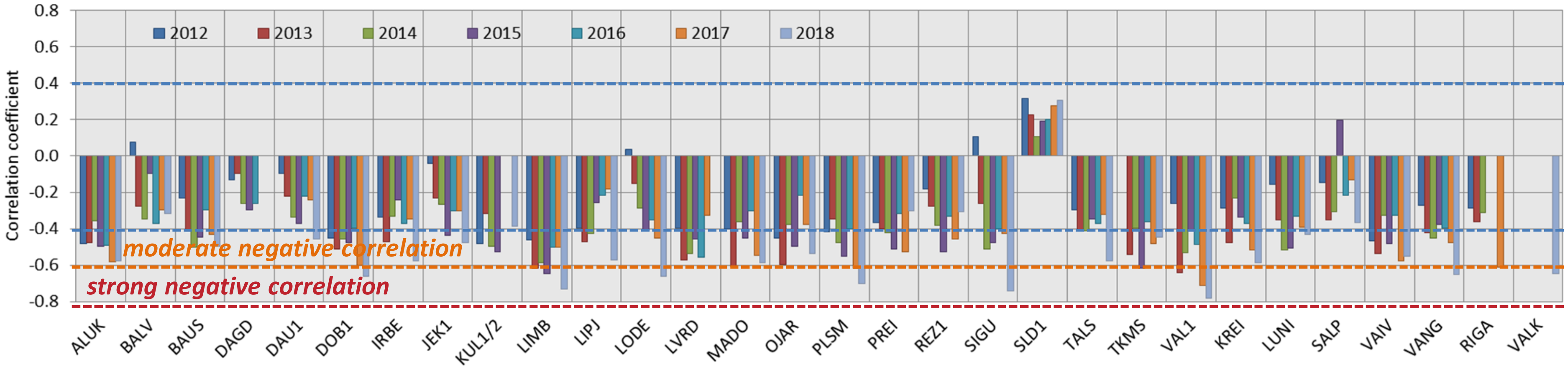


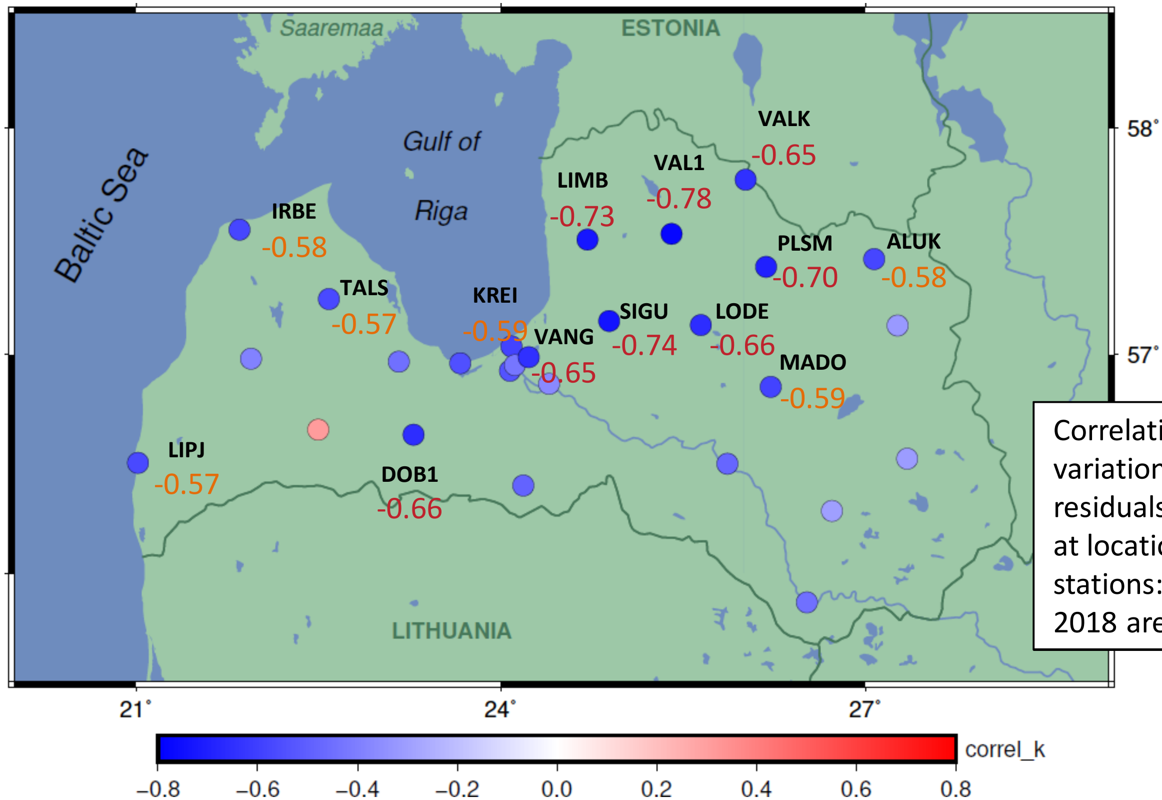




Correlation between sea level variations and coordinate residuals of the GNSS_DD solution at locations of the Latvian GNSS stations: observations of the year **2018** are used

Correlation between sea level variations and coordinate residuals of the GNSS_DD solution at locations of the Latvian GNSS stations: observations of the year **2013** are used

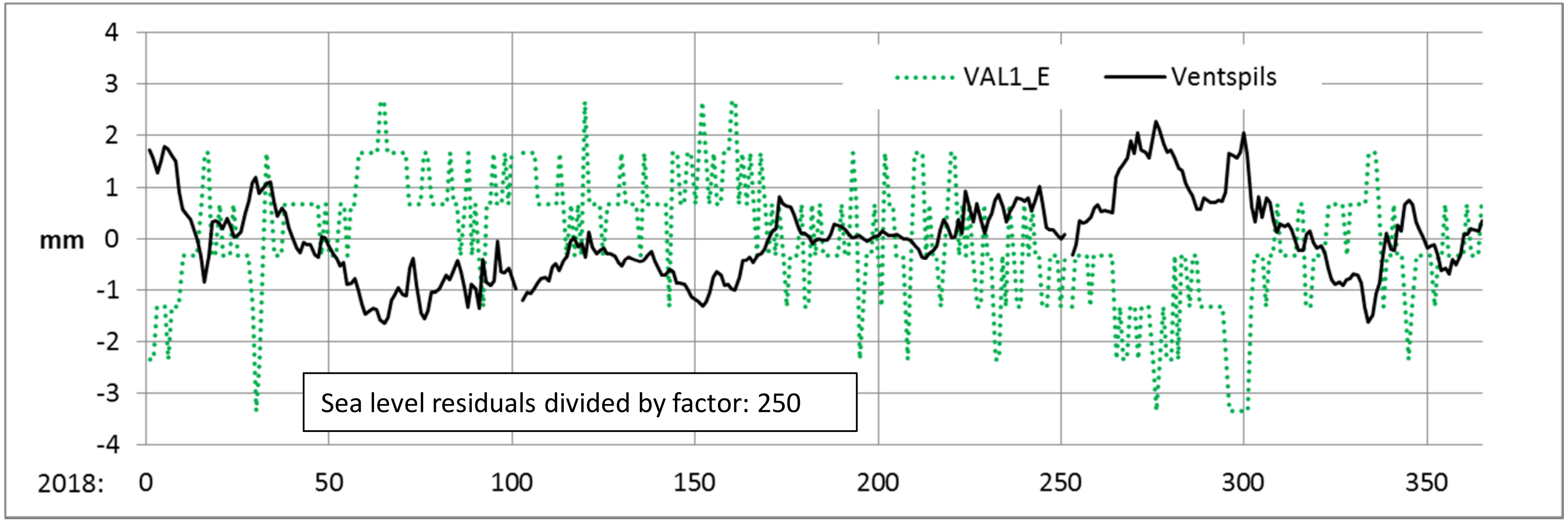
# Correlation: East component

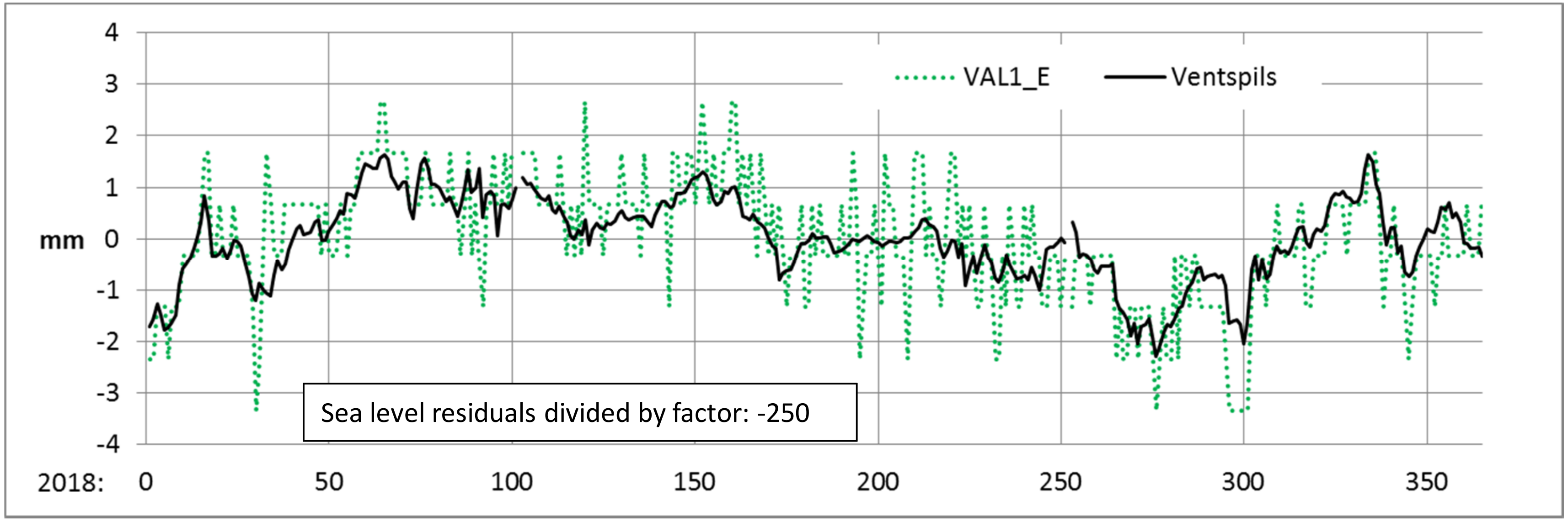



Correlation between sea level variations and coordinate residuals of the GNSS_DD solution at locations of the Latvian GNSS stations: observations of the year 2018 are used

# Strong negative correlation (-0.78) at VAL1 in East component (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 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 coefficient -0.78 at VAL1 in 2018.

- Correlations are changing from year to year, but even weak correlations at sites display regionally related results.

# Thank You!

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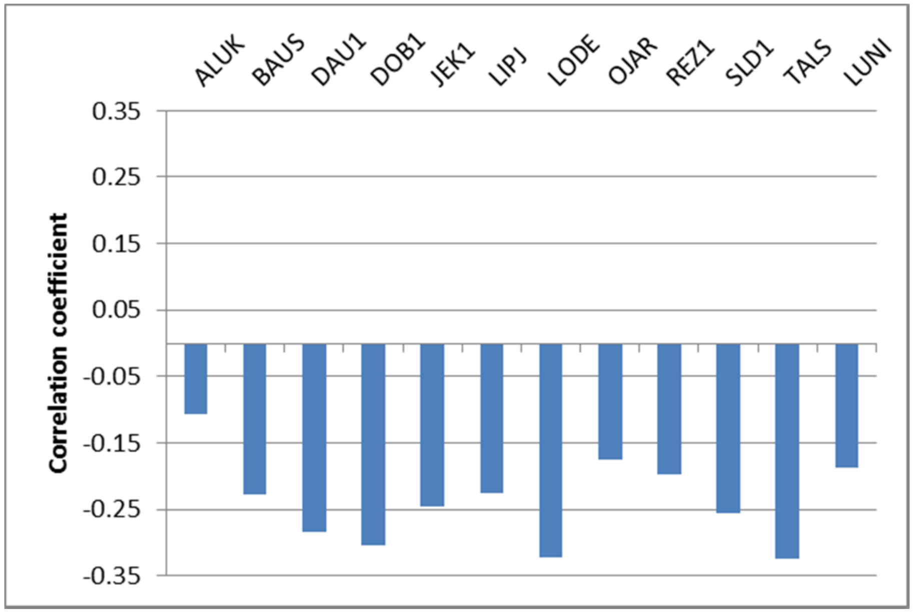
# Atmospheric loading

- Correlation between GNSS position residuals in Up component and atmospheric pressure data at each site: weak negative correlation (in 2018)




| GNSS station | Correlation (Up) | Probability of occurring randomly (%) |
|---|---|---|
| ALUK | -0.11 | 8.06 |
| BAUS | -0.23 | 0.00 |
| DAU1 | -0.28 | 0.00 |
| DOB1 | -0.30 | 0.00 |
| JEK1 | -0.25 | 0.00 |
| LIPJ | -0.23 | 0.02 |
| LODE | -0.32 | 0.00 |
| OJAR | -0.17 | 0.09 |
| REZ1 | -0.20 | 0.03 |
| SLD1 | -0.26 | 0.00 |
| TALS | -0.32 | 0.00 |
| LUNI | -0.19 | 0.04 |

# Latvian GNSS station horizontal velocity values with uncertainties (2012-2017)

| Station name | Velocity, mm/yr (North) ETRF2000 | Uncertainty of vel., mm/yr *RealSigma* | Velocity, mm/yr (East) ETRF2000 | Uncertainty of vel., mm/yr *RealSigma* |
|---|---|---|---|---|
| ALUK | 0.08 | 0.09 | -0.10 | 0.05 |
| BALV | -0.16 | 0.06 | -0.23 | 0.09 |
| BAUS | -0.01 | 0.05 | -0.12 | 0.08 |
| DAGD | -0.08 | 0.12 | -0.22 | 0.07 |
| DAU1 | 0.05 | 0.06 | -0.31 | 0.03 |
| DOB1 | -0.14 | 0.02 | -0.34 | 0.04 |
| IRBE | -0.31 | 0.06 | -0.17 | 0.06 |
| JEK1 | -0.25 | 0.08 | -0.22 | 0.05 |
| KREI | -0.23 | 0.06 | 0.19 | 0.13 |
| KUL1 | -1.24 | 0.04 | -0.36 | 0.07 |
| LIMB | -0.72 | 0.11 | -0.02 | 0.05 |
| LIPJ | 0.16 | 0.09 | -0.31 | 0.04 |
| LODE | -0.06 | 0.12 | 0.20 | 0.05 |
| LUNI | -0.62 | 0.07 | -0.08 | 0.19 |
| LVRD | 0.23 | 0.09 | -0.25 | 0.10 |
| MADO | -0.34 | 0.07 | -0.66 | 0.07 |
| MAZS | -2.69 | 0.25 | 0.33 | 0.07 |
| OJAR | -0.33 | 0.19 | -0.72 | 0.23 |
| PLSM | -0.48 | 0.06 | -0.34 | 0.05 |
| PREI | 0.08 | 0.07 | -0.39 | 0.08 |
| REZ1 | -0.08 | 0.11 | -0.32 | 0.05 |
| RIGA | -0.19 | 0.06 | 0.15 | 0.09 |
| SALP | -0.11 | 0.11 | -0.09 | 0.05 |
| SIGU | 0.01 | 0.04 | -0.28 | 0.04 |
| SLD1 | -0.47 | 0.11 | -0.08 | 0.30 |
| TALS | -0.53 | 0.08 | -0.03 | 0.06 |
| TKMS | -0.23 | 0.10 | 0.09 | 0.06 |
| VAIV | 0.00 | 0.07 | 0.01 | 0.11 |
| VAL1 | -0.20 | 0.03 | -0.33 | 0.04 |
| VANG | -0.17 | 0.06 | 0.40 | 0.07 |