Gravity changes over Russia from GRACE and absolute gravimetry

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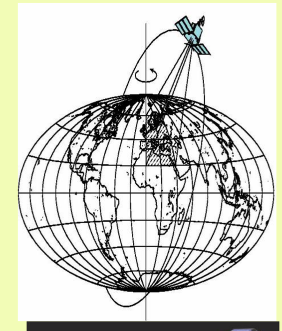
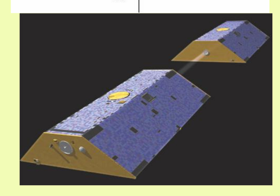




Abstract: Gravity Recovery and Climate Experiment (GRACE) satellites, launched 17.03.2002 from Plesetsk, provide a set of monthly Earth's gravity field observations. They present a big interest for hydrological studies. Gravity data reflect changes, related to the groundwater redistribution, ice melting, and precipitation accumulation. However, de-stripping/filtering is required to use the GRACE data products. We apply Multichannel Singular Spectrum Analysis (MSSA, or extended EOF) technique to filter GRACE data and separate the principal components (PCs) of different periods.

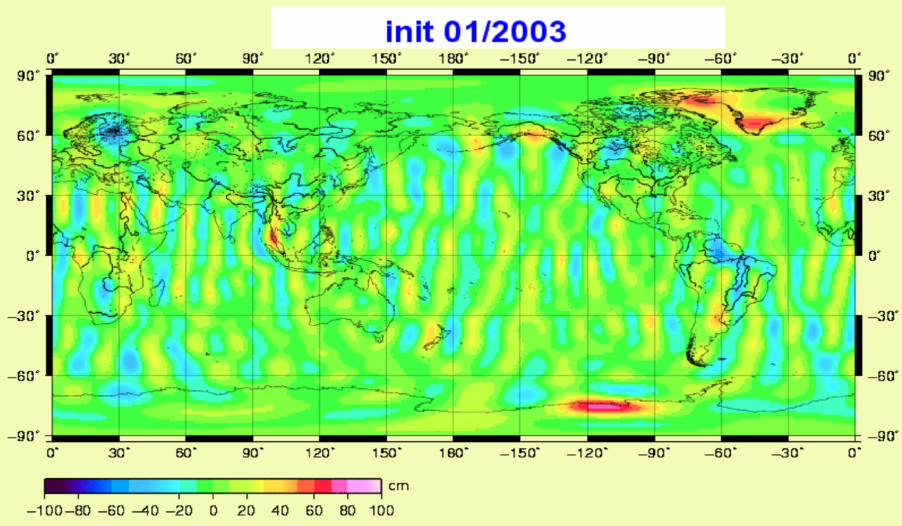
We performed data averaging over the large river basins of Russia. Winter 2012-2013 was the most snowy winter in Russia since 1960s. Melting of this snow induced large floods and river levels increase. The exceptional maxima are seen in the curves obtained from GRACE. Next spring and summer 2014 were much less snowy.

Long-periodic climate-related changes were separated into PC 2. Gravity field increase in Siberia, Black sea, and decrease around Caspian sea are seen.

We compare GRACE results with measurements made by absolute gravimeters in several regions of Russia. Local trends in the gravity field were found to be similar.

Data: We used JPL Level-2 RL05 monthly GRACE spherical harmonic data since 01.2003 till 06.2014 with coefficients complete to degree 60. Nine files (06/03, 01/11, 06/11, 05/12 10/12, 03/13, 08.13, 09.13, 02.14) were linearly interpolated (overall N=138 files). C_{20} coefficients were replaced by SLR-derived. Average field over 10 years was subtracted. GIA effect according to Paulson 2007 model was removed. Results are represented in form of equivalent water height (EWH) level (cm) maps.

Fig 1. → Vertical "stripes" manifest as high-frequency correlated errors dominates each of the monthly temporal gravity field solutions. Initial data contains mostly stripes, and illustrates constant (geographically-correlated) spatial behavior. MSSA can be used for de-striping.



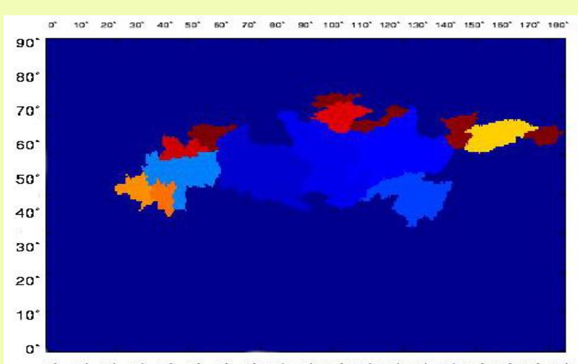
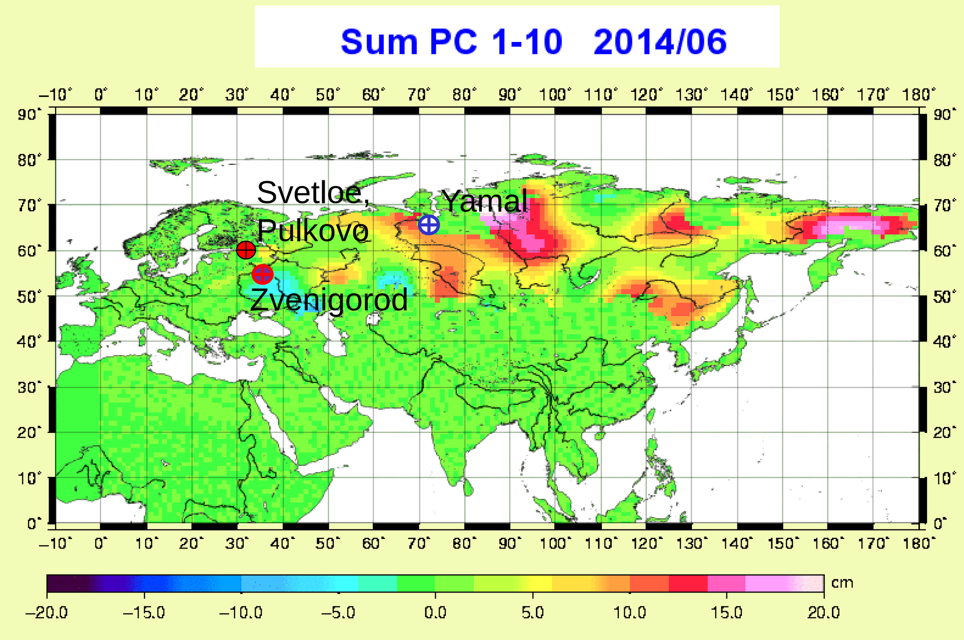
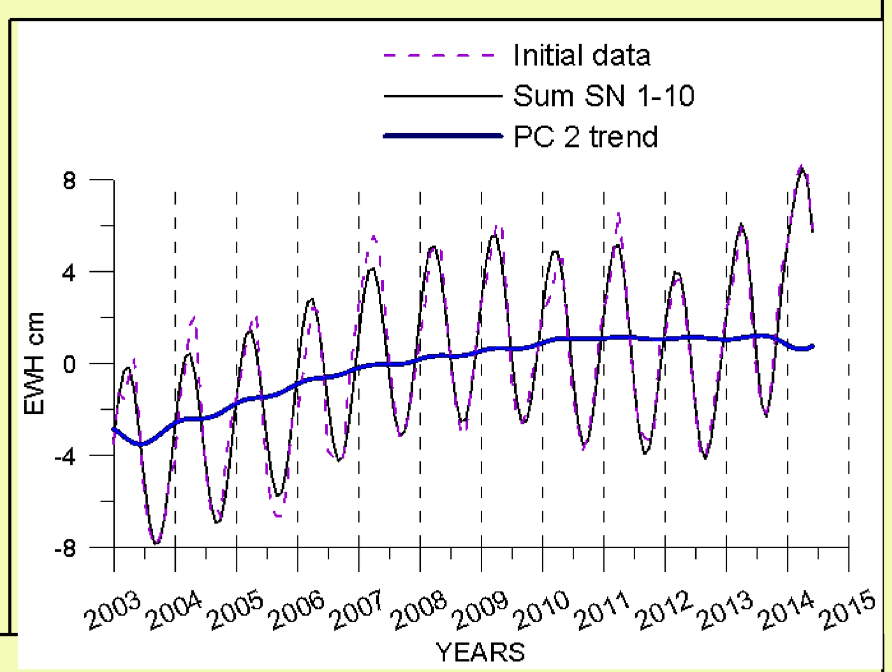


Fig 2. ← Sum of MSSA PCs 1-10 (L=48) represent main signal variability (energy). Stripes are mostly removed (they go to larger PCs). Simulated Topological Networks (STN-30p) database is used to constrain the region of study to the basins of 15 large Russian rivers (left).
↓ The map for 06.2014 is presented (below).





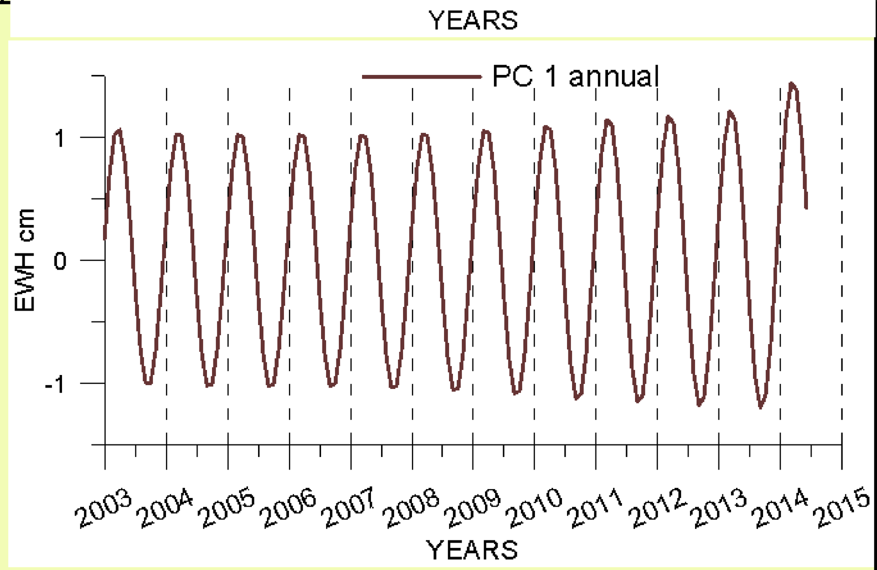


Fig 3. → Top: Results of averaging over the basins of large Russian rivers. Black curve is sum of SNs 1-10. Purple curve - initial data (sum of all SNs). Trend (PC 2) is shown in blue. It increases until 2009, then reaches a plateau.

→Bottom: Average for the annual oscillation captured by PC 1 demonstrates amplitude increase since 2009.

MSSA Method: Multichannel Singular Spectrum Analysis (MSSA), also called Extended EOF, is a generalization of Singular Spectrum Analysis (SSA) for the multidimensional (multichannel) time series. SSA, in its turn, is a Principal Component Analysis, generalized for the time series in such way, that instead of the simple correlation matrix, the trajectory matrix is analyzed. It is obtained through the time series embedding into the L-dimensional space. Parameter L is called lag or "caterpillar" length. When $L=1$, SSA becomes PCA. In every point ij on the map we have time series $A_{ij}(t_k)$ of length N. The trajectory matrix for every X_{Aij} should be build and incorporated into large block matrix X as follows:

$$X_{A_{ij}} = \begin{pmatrix} A_{ij}(t_0) & A_{ij}(t_1) & \ldots & A_{ij}(t_{K-1}) \\ A_{ij}(t_1) & A_{ij}(t_2) & \ldots & A_{ij}(t_K) \\ \ldots & \ldots & \ldots & \ldots \\ A_{ij}(t_{L-1}) & A_{ij}(t_L) & \ldots & A_{ij}(t_{N-1}) \end{pmatrix} \qquad X = [X_{A_{1,1}}, X_{A_{2,1}}, X_{A_{1,2}} \ldots, X_{A_{ij}}, \ldots, X_{A_{P-1,Q}}, X_{A_{P,Q}}]^T$$

$K=N-L+1$ SVD: PC-i matrix:

$$X = USV^T \qquad X^i = s_i u_i v_i^T$$

Then Singular Value Decomposition (SVD) should be applied to X. As a result, a sequence of singular numbers (SN) s_i standing along the diagonal of matrix S in order of decreasing values and the corresponding eigenvectors u_i, v_i are obtained. The Principal Components (PCs) can be reconstructed from them, knowing the structure of the matrix X^i. Some of SNs may be related to one and the same PC and represent similar behavior. Than SN-components should be grouped together and reconstructed as one PC. As a result, the set of PCs with decreasing amplitudes representing different modes of time series variability are obtained.

MSSA is more flexible for recognition of trend, modulated oscillations of different periods, denoising of multidimensional time series, then simple EOF. Different channels "help" each other to capture spatio-temporal correlation patterns. We applied MSSA in frequency domain to the matrix of Stokes coefficients. Lag parameter was selected to be $L=48$ (4 years).

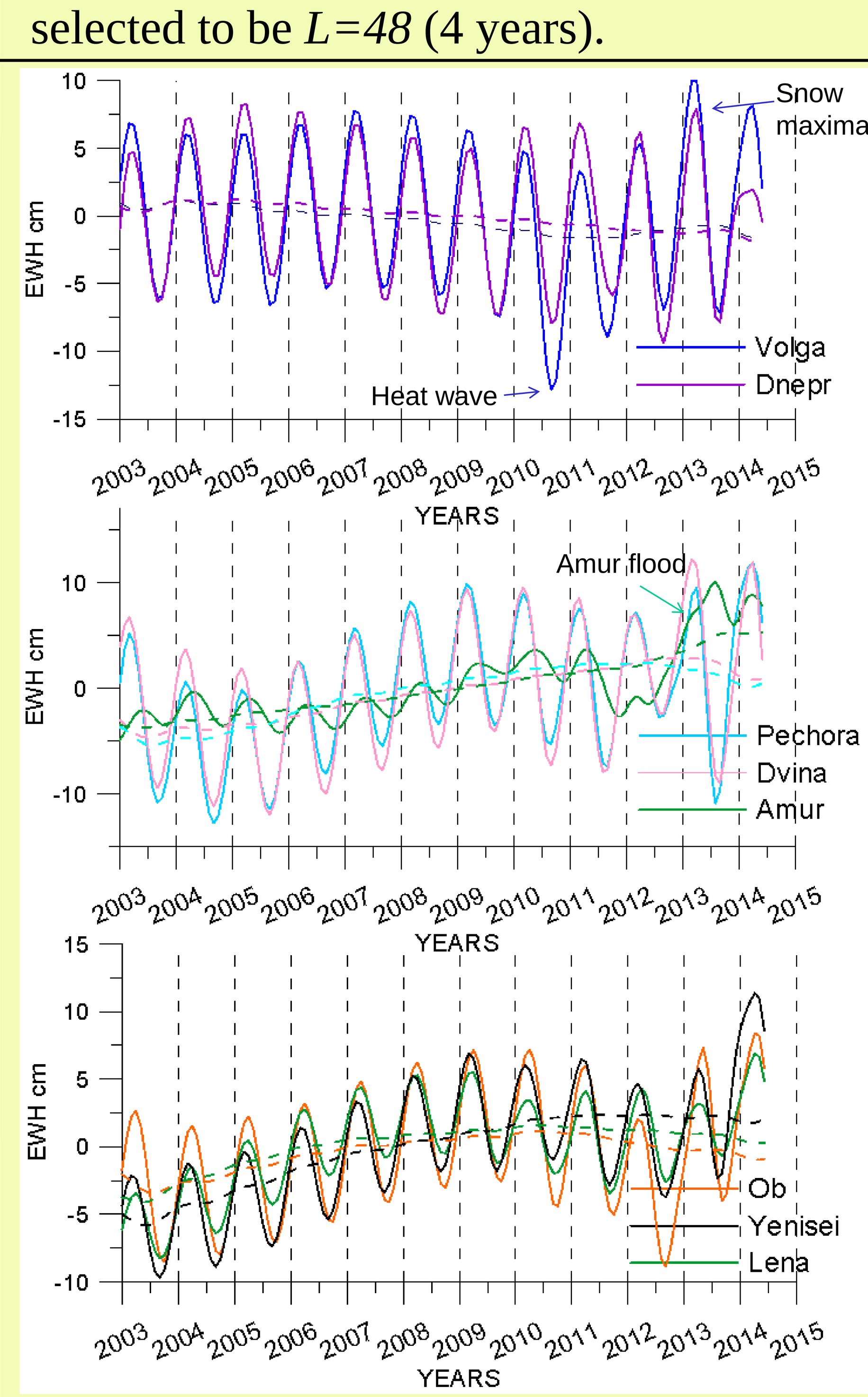


Fig 4.↓ Singular numbers for MSSA with parameter $L=48$

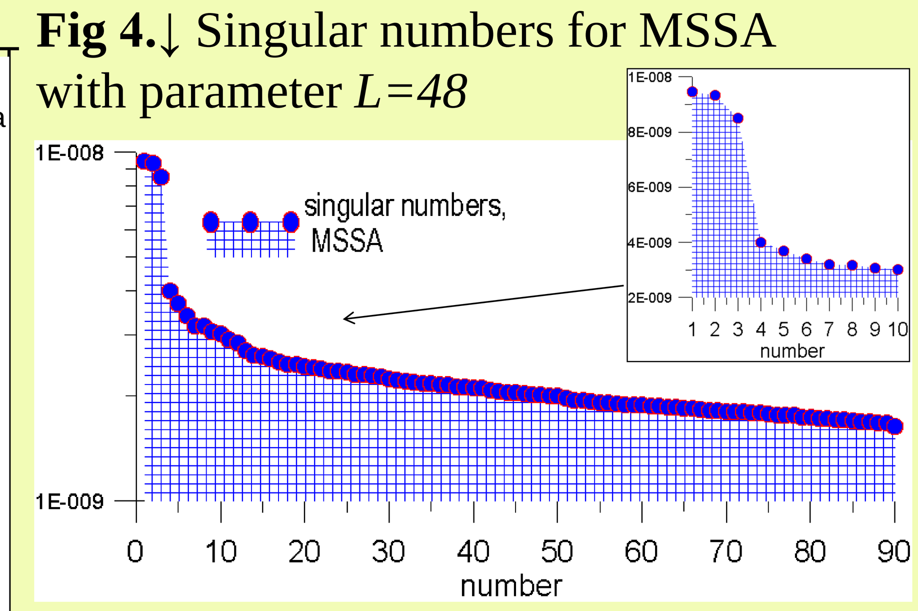


Fig 5.↓ Difference between 2014 and 2003 for the trend component (PC 2).

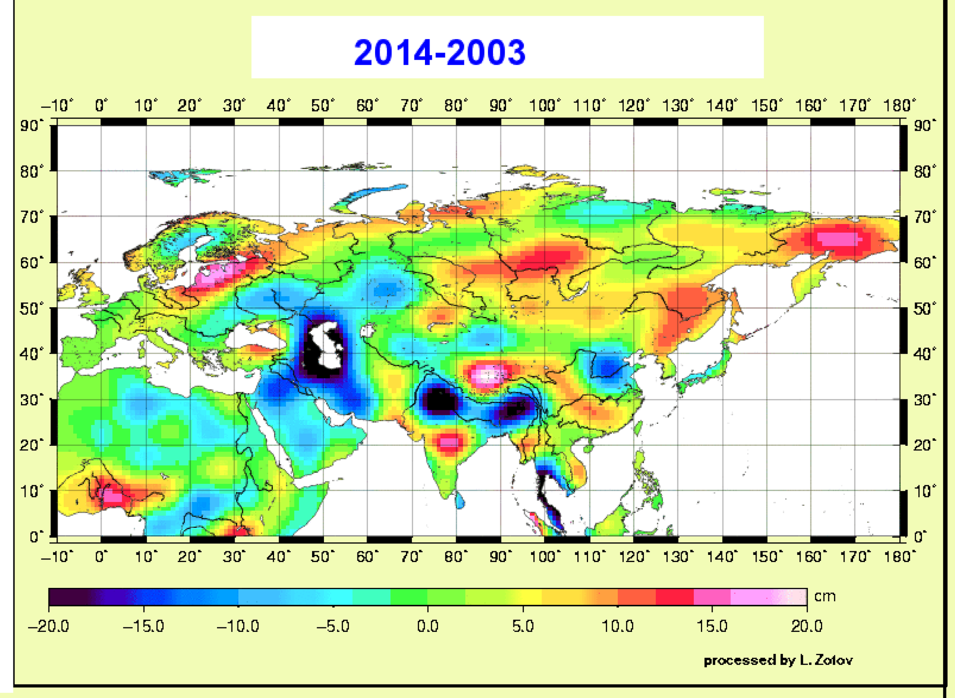
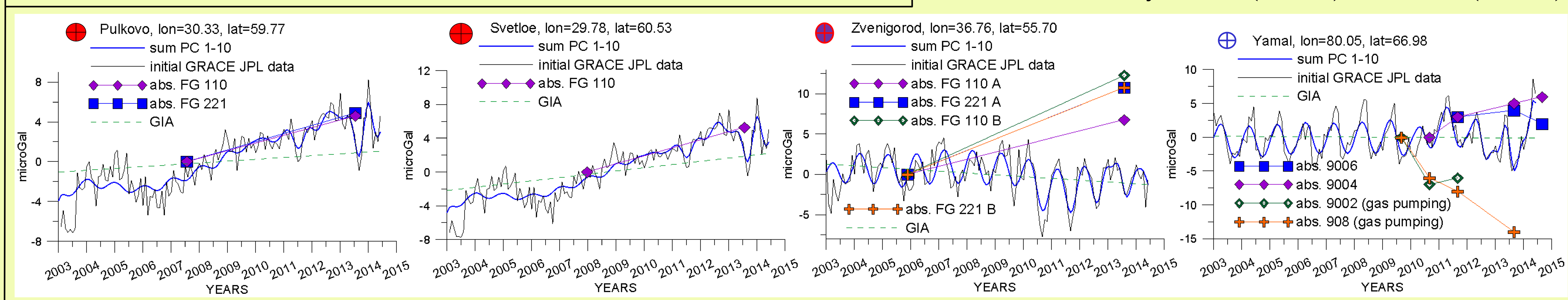


Fig 6. ↑ Sum of PCs 1-10 for particular rivers basins. Different trends' behavior for European and Siberian rivers is seen together with grate maxima in summer 2013. Minimum in summer 2010 for Volga river corresponds to the heat wave.

Fig 7. ↓Comparison of initial GRACE data, MSSA sum SN 1-10 (with GIA), and measurements made by Russian (FG 110) and Finnish (FG 221) absolute gravimeters (FG-5) at several sites (Pulkovo, Svetloe, Zvenigorod A and B). Measurements at Yamal were made by GABL-M gravimetr at the deposit site where gas is pumped out (9002, 908) and outside the deposit site (9006, 9004).



References:

1. L.V. Zotov, C.K. Shum, N.L. Frolova Gravity changes over Russian rivers basins from GRACE, chapter in "Planetary Exploration and Science: Recent Results and Advances", Springer, 2014.
2. J. Mäkinen1, R.A. Sermyagin, I.A. Oshchepkov , A.V. Basmanov, A.V. Pozdnyakov, V.D. Yushkin, Yu.F. Stus, D.A. Nosov , Finnish Geodetic Institute, Masala, Finland (FGI) Russian-Finnish Comparison of five absolute gravimeters at four different sites in 2013, IGFS-2014.
3. Frappart, F., et al.: Interannual variations of the terrestrial water storage in the Lower Ob' Basin from a multisatellite approach, Hydrol. Earth Syst. Sci., 14, 2443-2453, 2010.
4. Golyandina N. et al., Analysis of time series structure: SSA and related techniques, Chapman & Hall, 2001

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Conclusion: GRACE data is very useful for hydrological and climatological studies, especially over large territory, not completely covered by the meteorological and hydrological networks, like Russia. MSSA is a promising method for GRACE data processing, de-striping, filtering, and Principal Components (PCs) separation.

After averaging over 15 large Russian rivers basins annual component shows amplitude increase since 2009 (Fig. 3). Trend component grows until 2009, then reaches a plateau. It is mostly dominated by Siberian rivers. Map for the trend (Fig. 5) show gravity field increase in Siberia, at Back sea and decrease over Caspian sea since 2003.

Comparison with absolute gravimetry shows agreement in the trends, though low-spatial resolution of satellite gravimetry does not allow to capture small-scale features.