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Sternberg Astronomical Institute

Commission for Water Sustainability

IGU UGI

BINM SB RAS

Evaluation of water balance in large Russian river catchments with the help of the satellite system of the earth’s gravity field measurement (GRACE)

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V.Yu. Grigoriev, A.A.Sazonov,
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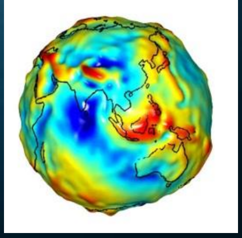
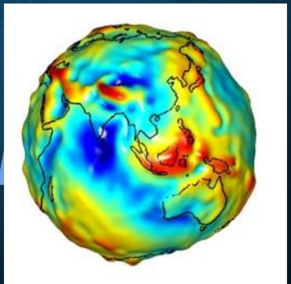
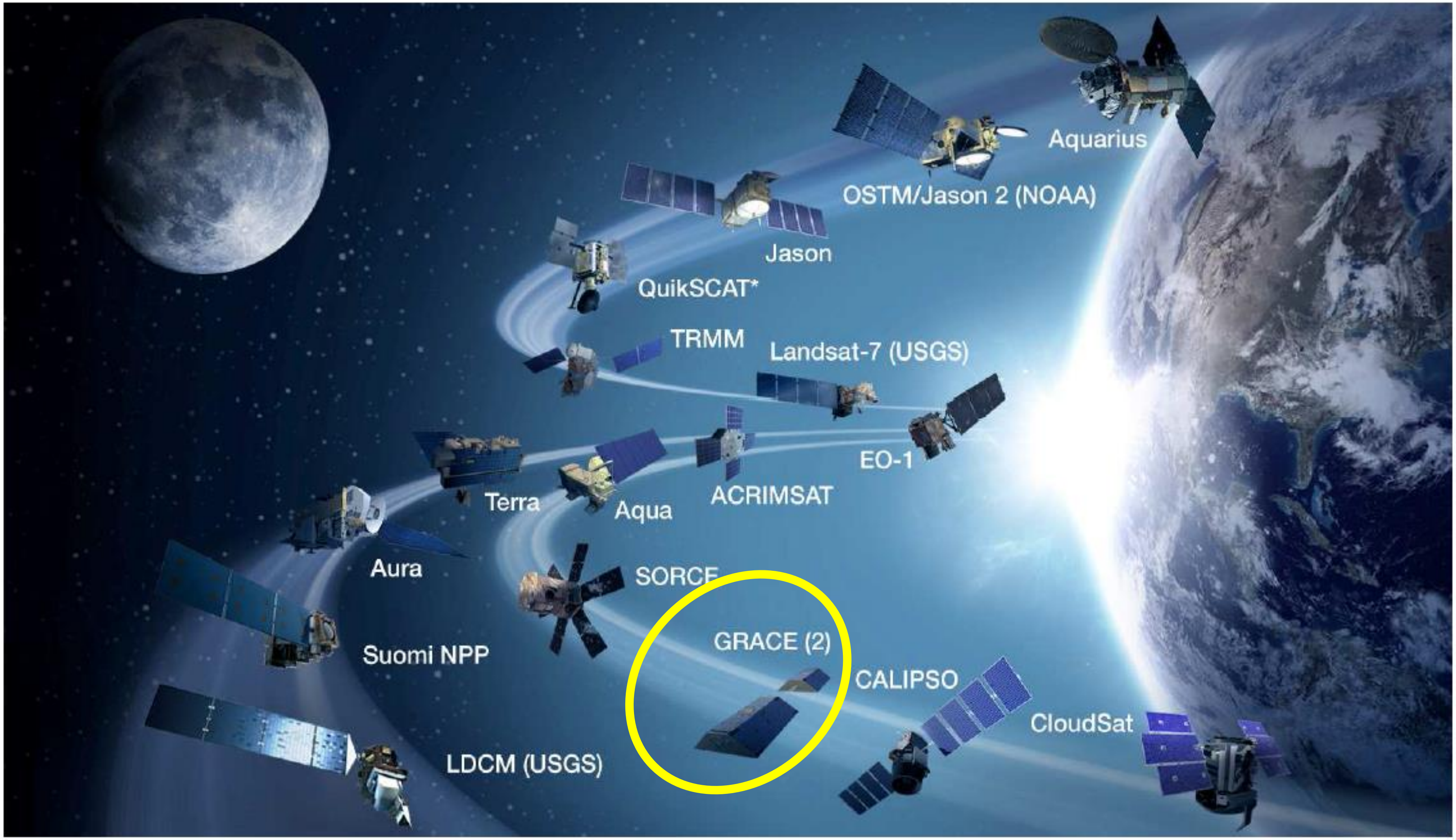


1. GRACE-derived assessment of terrestrial water storage (TWS)



NASA Earth observing missions



GRACE (Gravity Recovery and Climate Experiment)
twin satellites mission was launched on 17.03.2002 from Plesetsk cosmodrome.

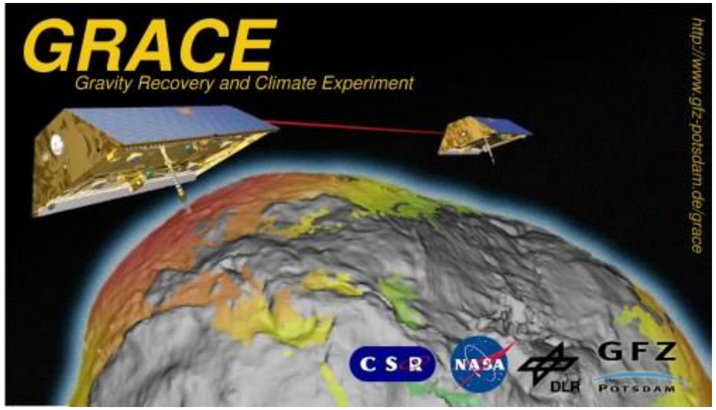
Gravity space missions

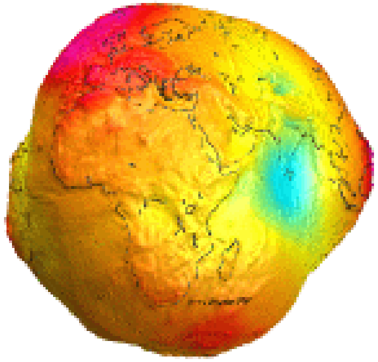
CHAMP – launched by GFZ in July, 2000 to an orbit of ~ 450 km altitude. For gravity and magnetic field research. The data span is ~ 8 years.

GRACE - Gravity Recovery and Climate Experiment. Two twin satellites, developed by NASA/DLR, launched from Plesetsk cosmodrome on March, 17th, 2002.

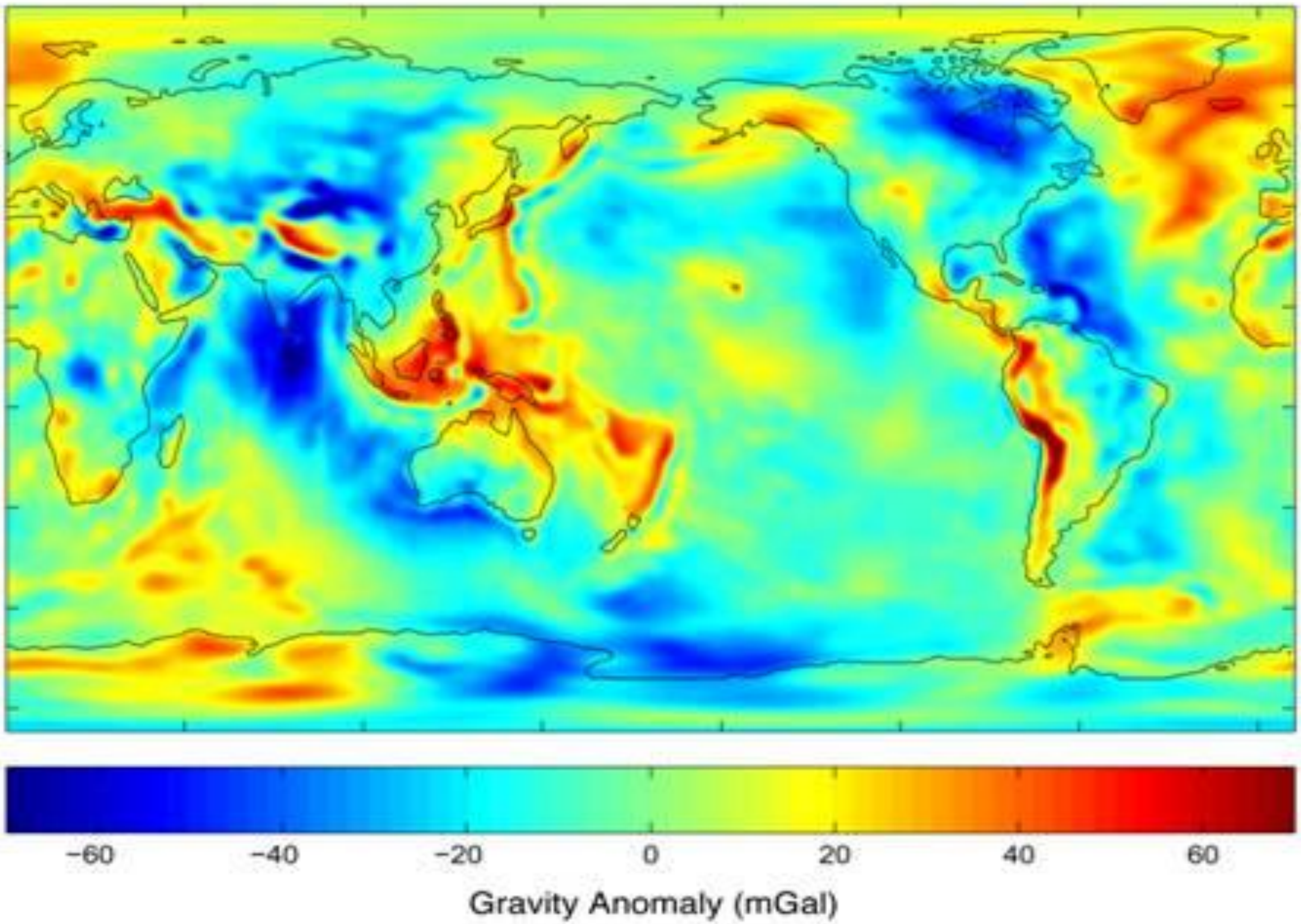
Satellites are separated from each other by ~220 km. Follow one another on a polar orbit at ~500 km altitude, covering the Earth in ~30 days. Spatial resolution is ≈ 300 km. The basic measurement is the distance between the satellites and its rate, changing under the influence of the accelerations caused by the flight over the mass sources.
Mission extended to 2017. Battery capacity now is 10 times lower than at the beginning.

GOCE - launched in March, 2009 to an orbit of ~260 km altitude. High-accuracy model of the gravitational field was obtained by means of high-accuracy gradiometery with ~1 mGal accuracy and heights of geoid error ~1-2 cm at a 100 km spatial resolution, and better then 1 mm accuracy for higher spatial frequencies. Mission finished 11 march 2013 by falling down into the ocean.





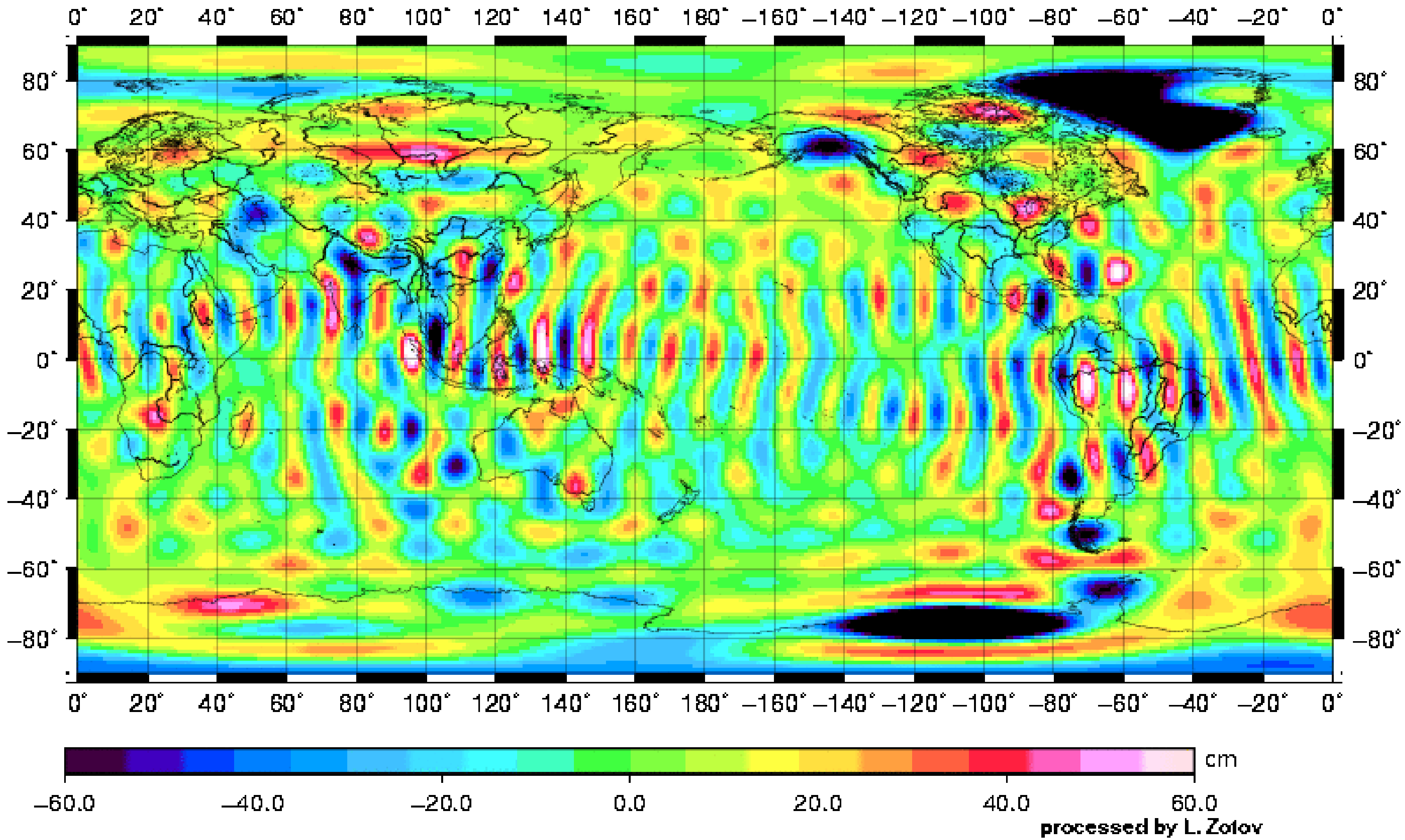
Earth gravity field model GRACE (GGM03s)



$$V(\varphi,\lambda,r)=\frac{GM}{r}\sum_{n=0}^{\infty}\sum_{m=0}^{n}\left(\frac{a}{r}\right)^{n}\left(C_{nm}\cos m\lambda+S_{nm}\sin m\lambda\right)P_{n}^{m}(\sin\varphi)$$

Initial data GRACE JPL RL05 Level 2

2015-2003



Results are represented in equivalent water height (EWH) level (cm)

Multichannel Singular Spectrum Analysis MSSA

1) The delay parameter *L* is chosen.

SSA is a generalization of EOF (PCA)

Multivariate signal $x = (x_1, x_2, ..., x_N)$

Incorporated into block trajectory matrix *Z*

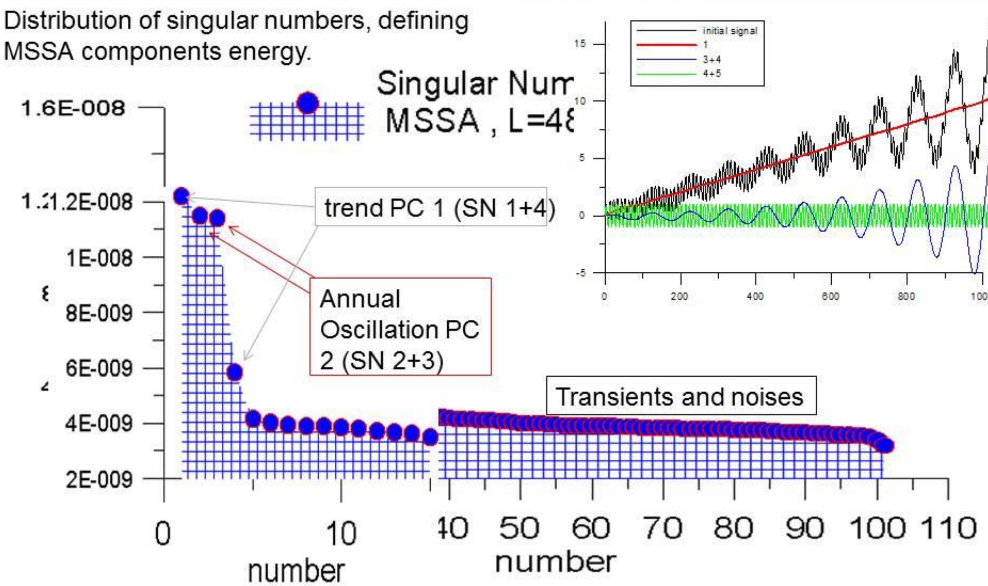
2) SVD — singular value decomposition is performed

$$X = USV^T$$

3) Matrices for every singular number s_i are reconstructed

$$X^i = s_i u_i v_i^T ,$$

signal for each component is obtained by Hankelization.



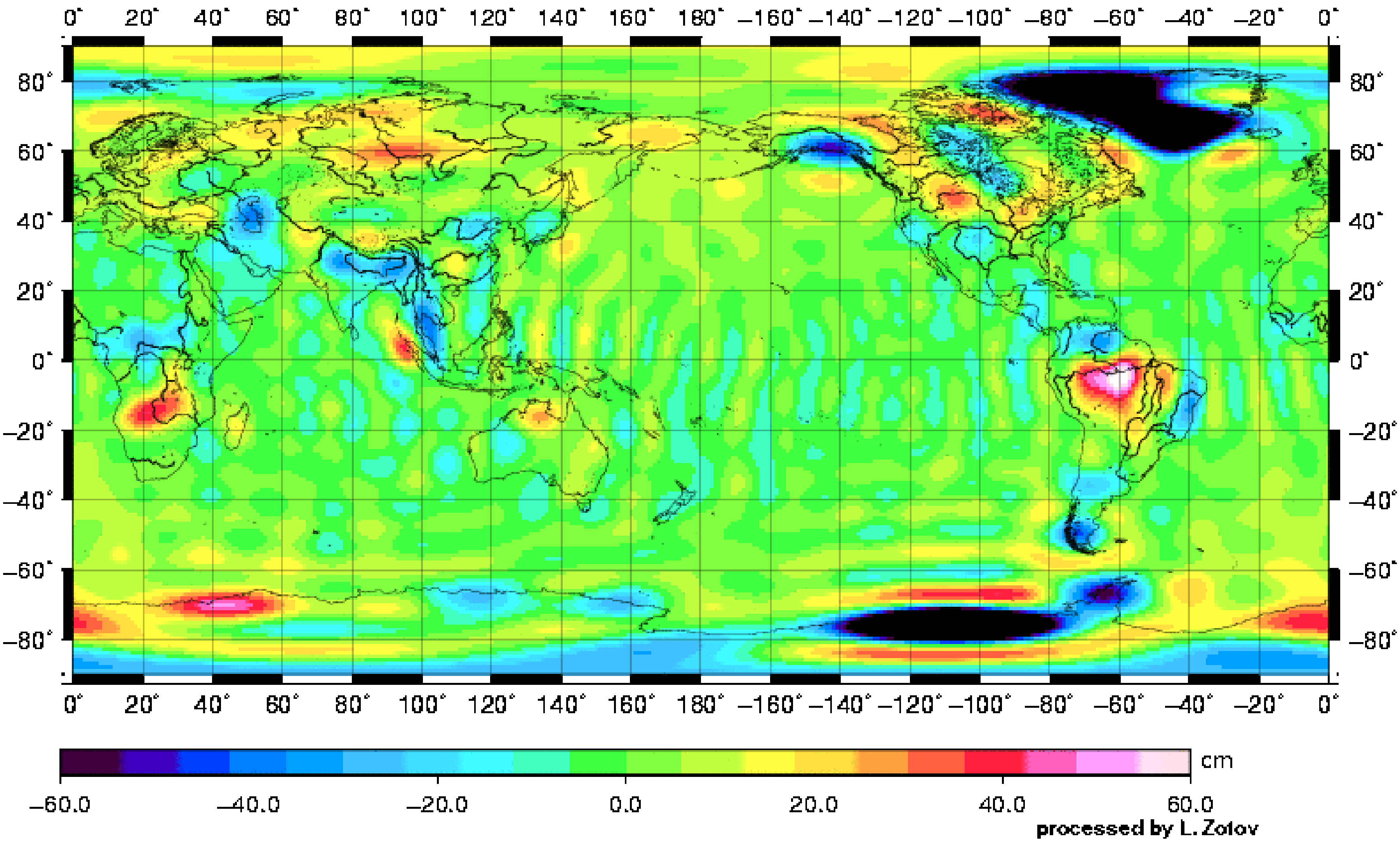
L. Zotov, C.K. Shum. Singular spectrum analysis of GRACE observations, American Institute of Physics Proceedings, of the 9th Gamow summer school, 2009, Odessa, Ukraine.

4) Similar signals are grouped into Principal Components (PCs)

PC1, PC2, PC3…

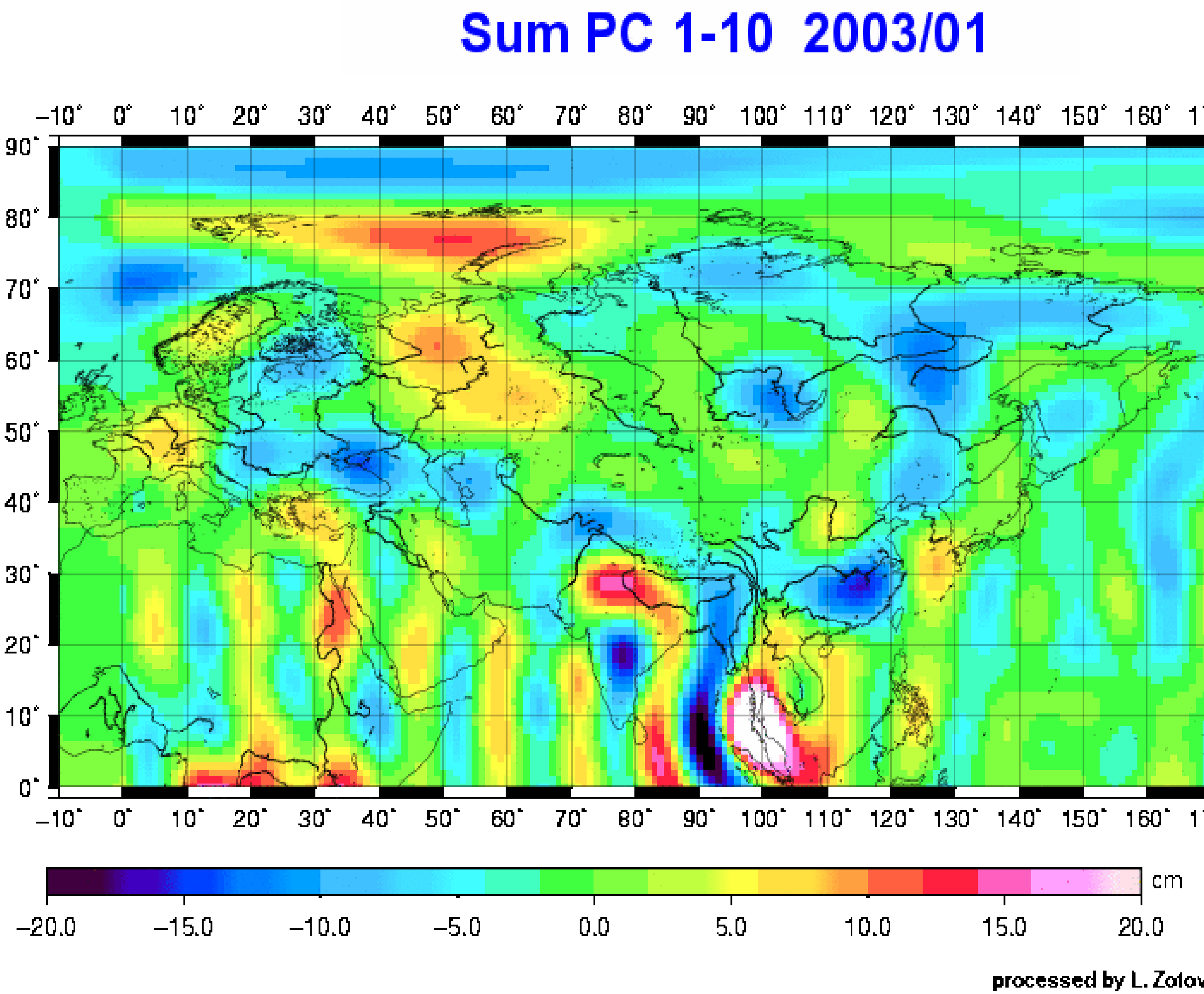
Trend - PC 1

2015-2003



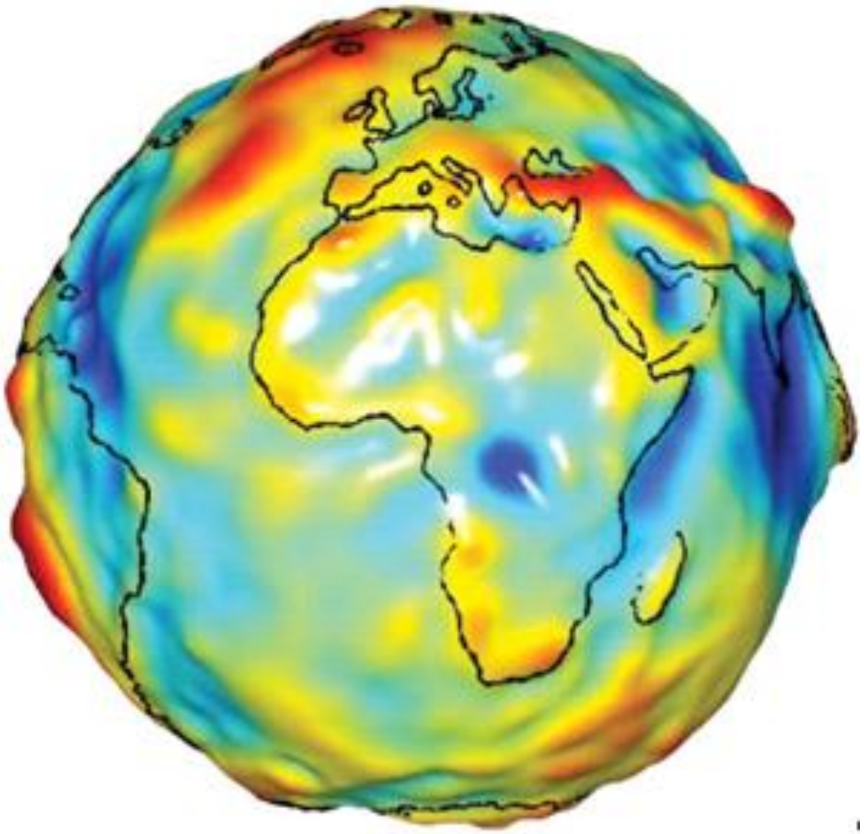
MCCA, L=48 месяцев

Sum of first 10 PCs over Eurasia



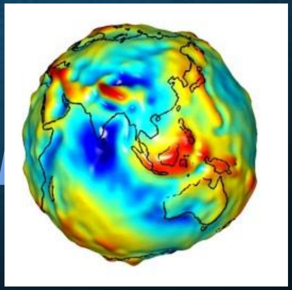
Карты аномалий гравитационного поля Земли для каждого месяца в период с января 2003 г. по февраль 2013 г. с разрешением по широте и долготе в 1 градус

Gravity field studies

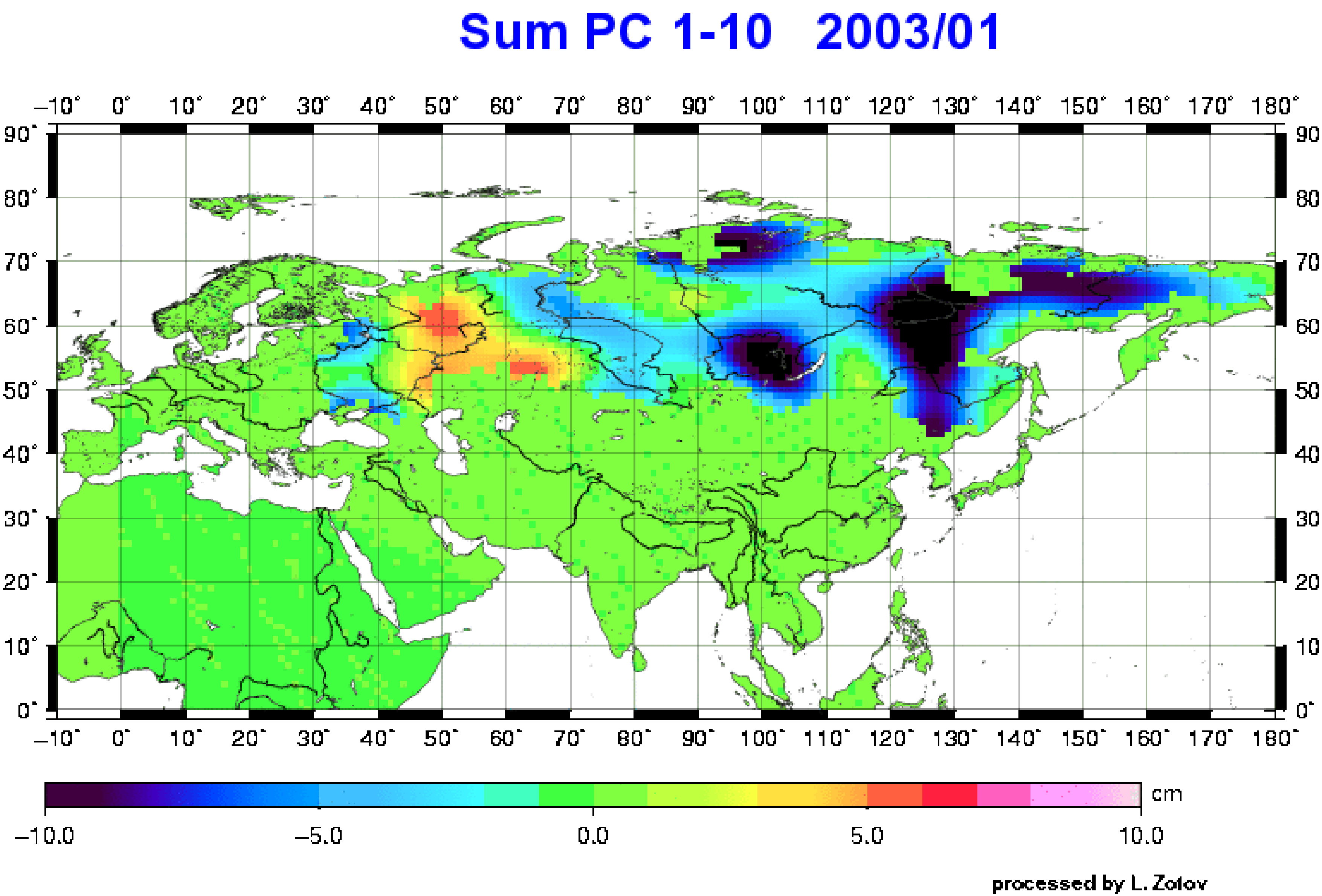


- *Hydrological, meteorological, climatological research.*
- *Flood forecast.*
- *Climate Change influence on river's water balance, permafrost, water discharge to the ocean, sea level, water and ice regime of Arctic study.*
- *Mass redistributions influence on Earth rotation estimation.*
- *The whole set of geodetic and geodynamical questions, whose study could be important for rational natural resources management, water management, construction, etc.*

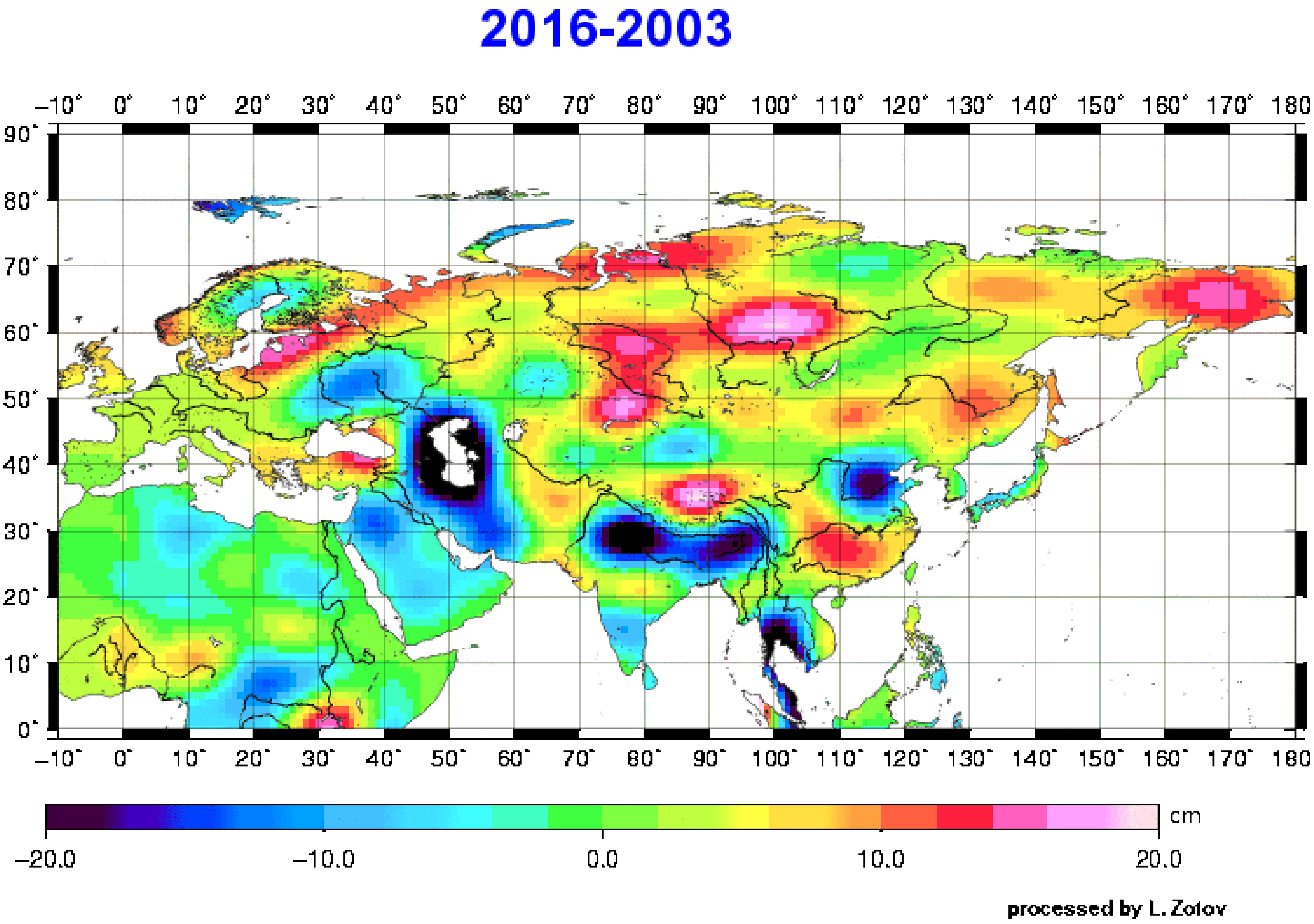
2. GRACE-derived gravity anomalies assessed for large river basins of Russia



Changes in the basins of 15 large Russian rivers

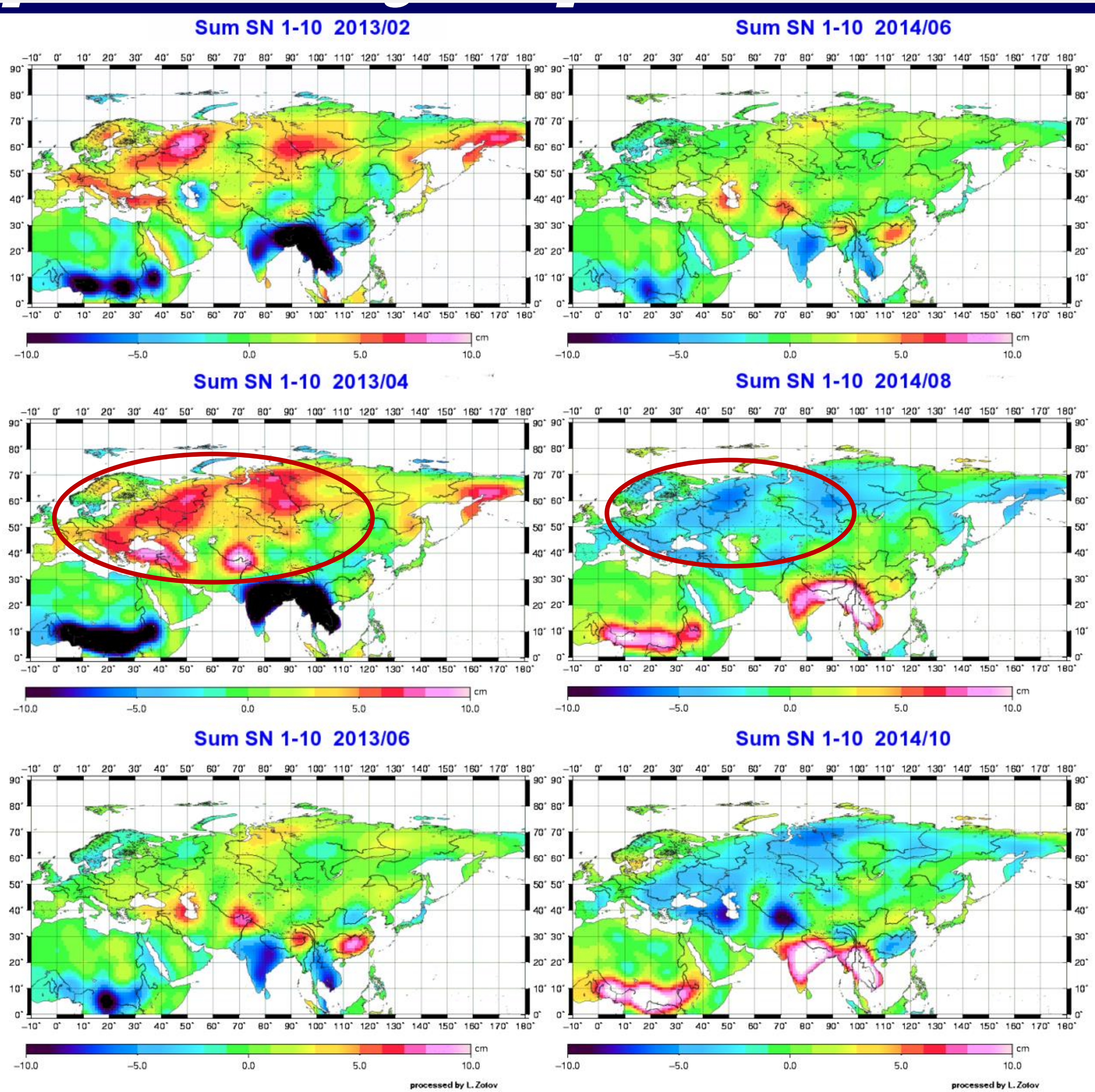


Difference between 2016 and 2003 for trend

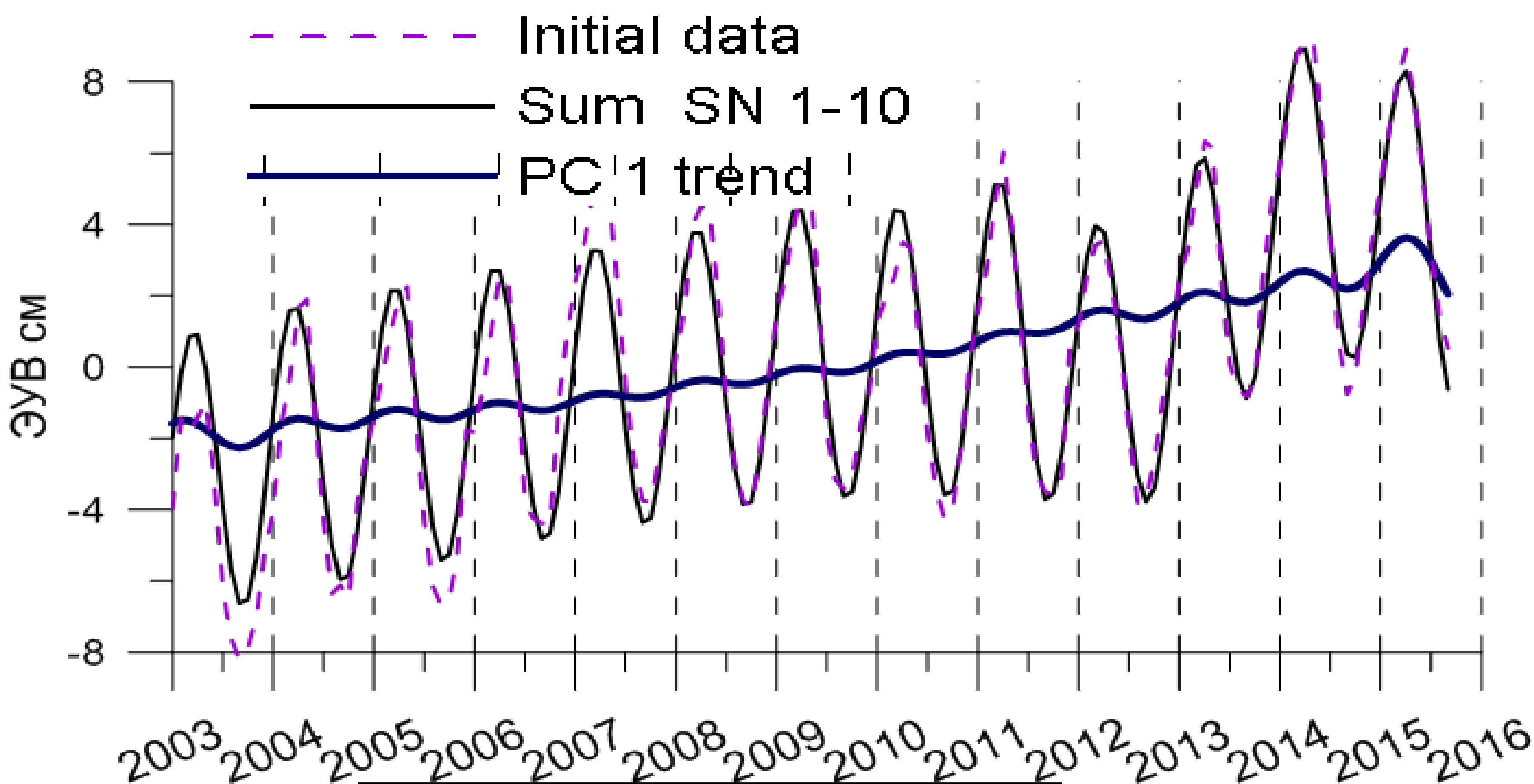


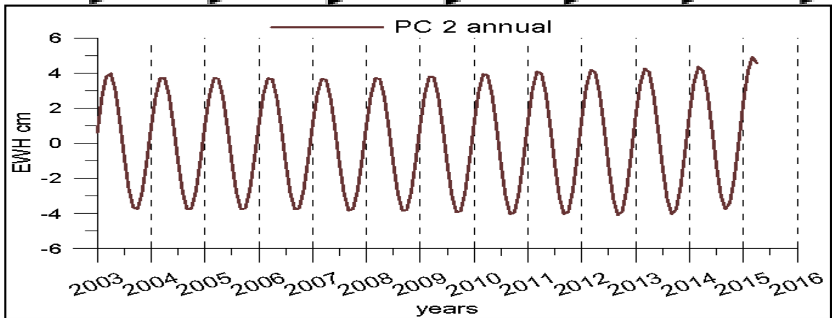
The differences for the annual PC 1 between monthly maps and average maps

Spring 2013 can be characterized by the extremely large snow accumulation occurred in Russia

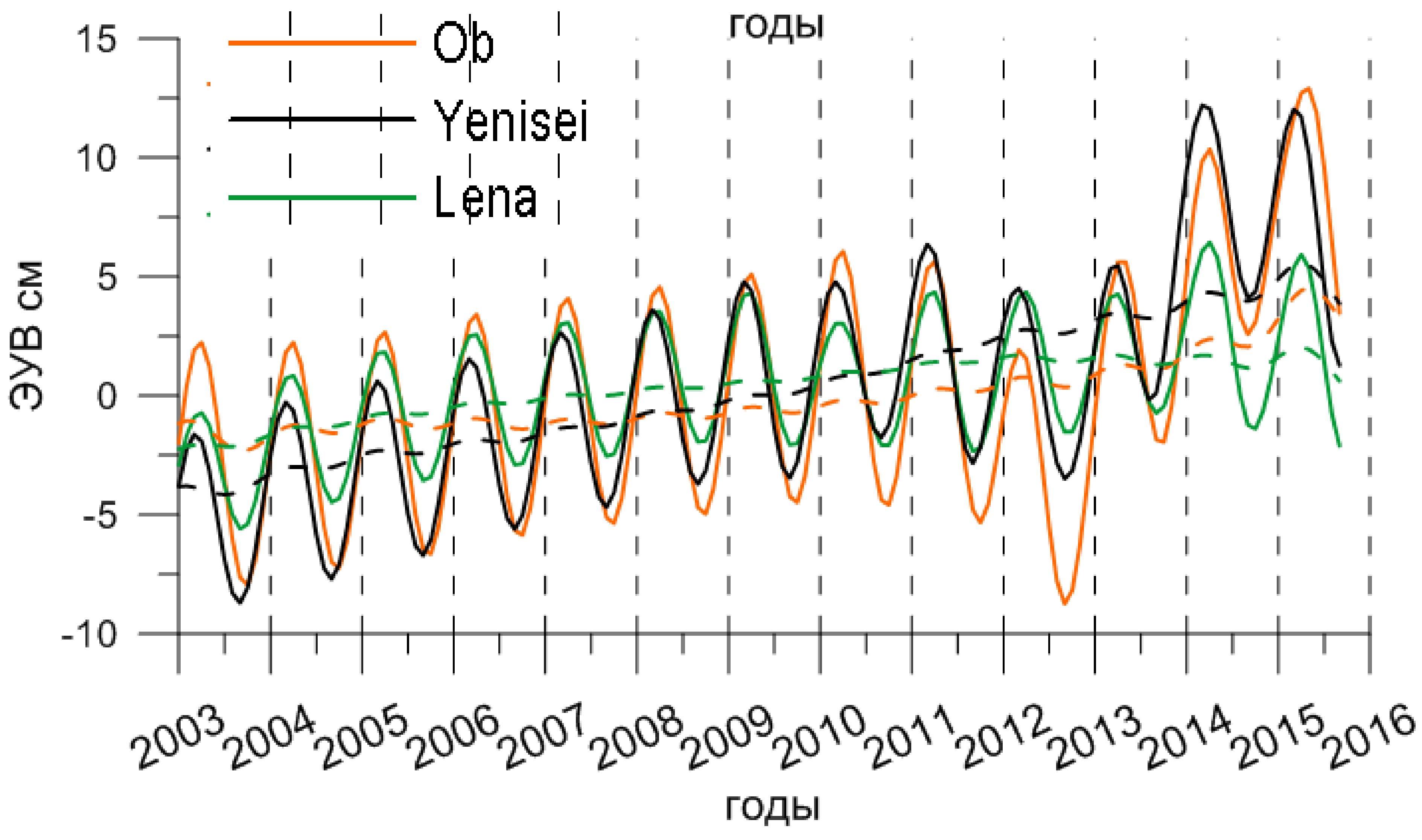


Average mass changes in the basins of 15 large Russian rivers for the sum of SN 1-10

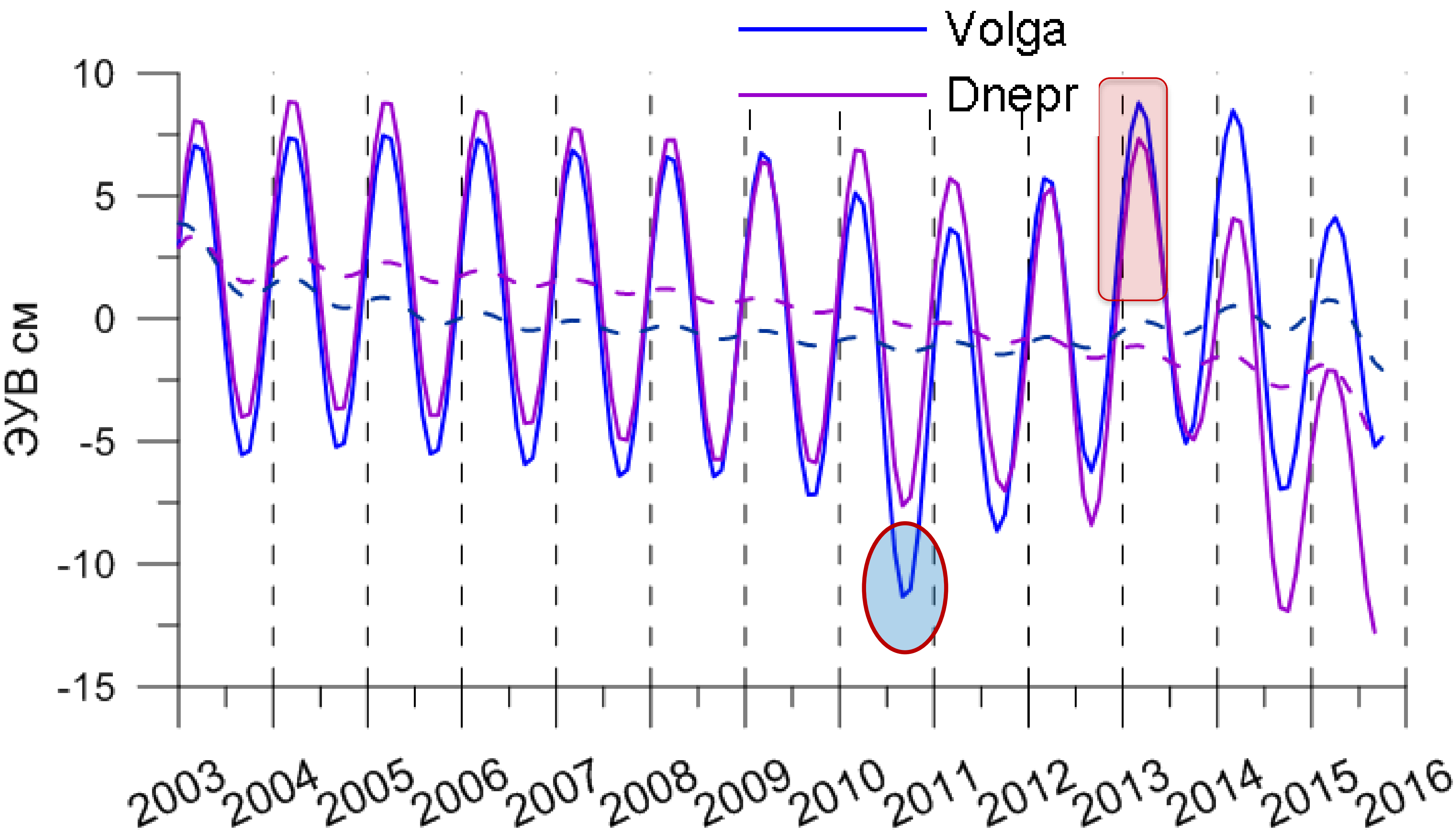




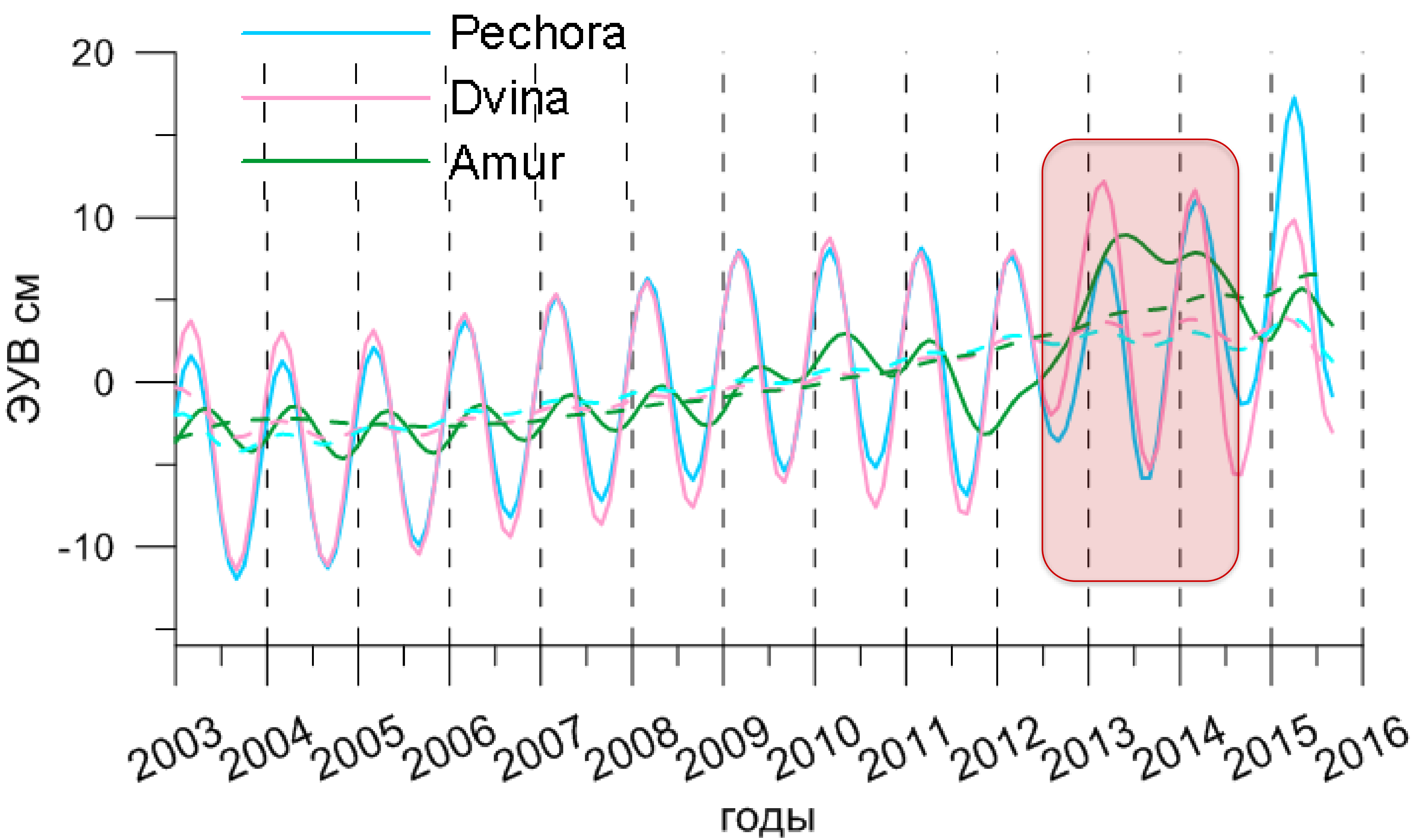
Gravity changes in the basins of large rivers of Siberia



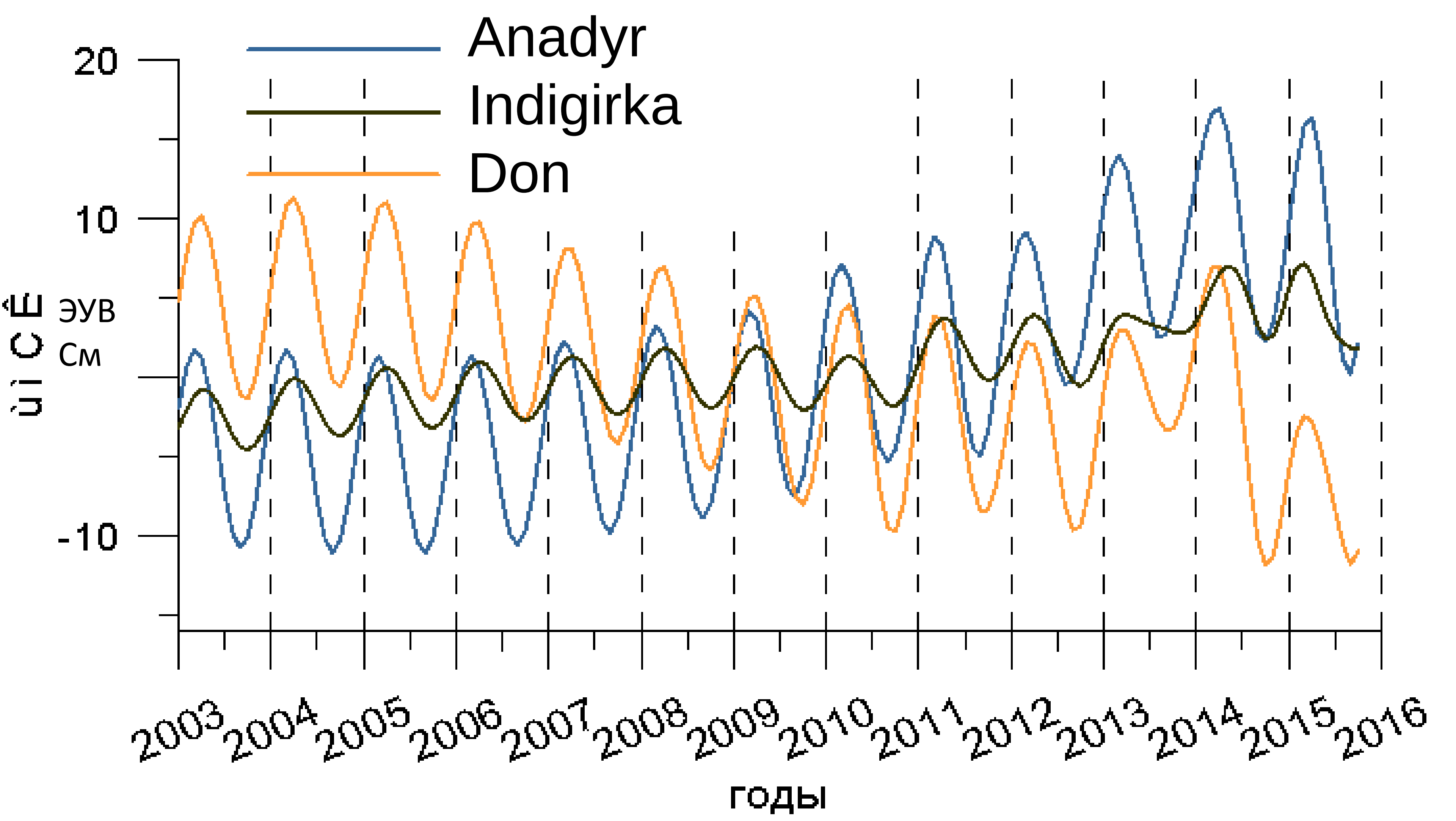
Average mass changes in the basins of European Russian rivers



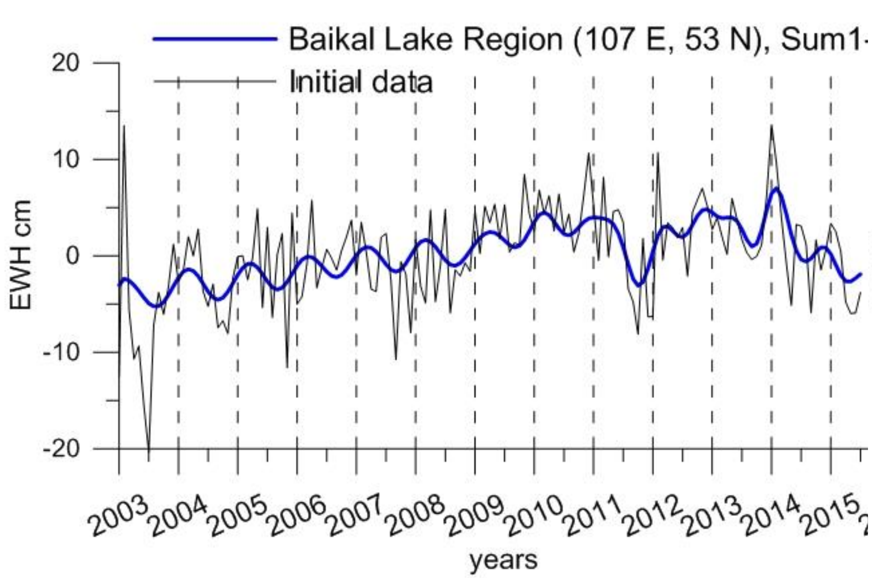
Gravity changes in the basins of large rivers of Russian North and Far East

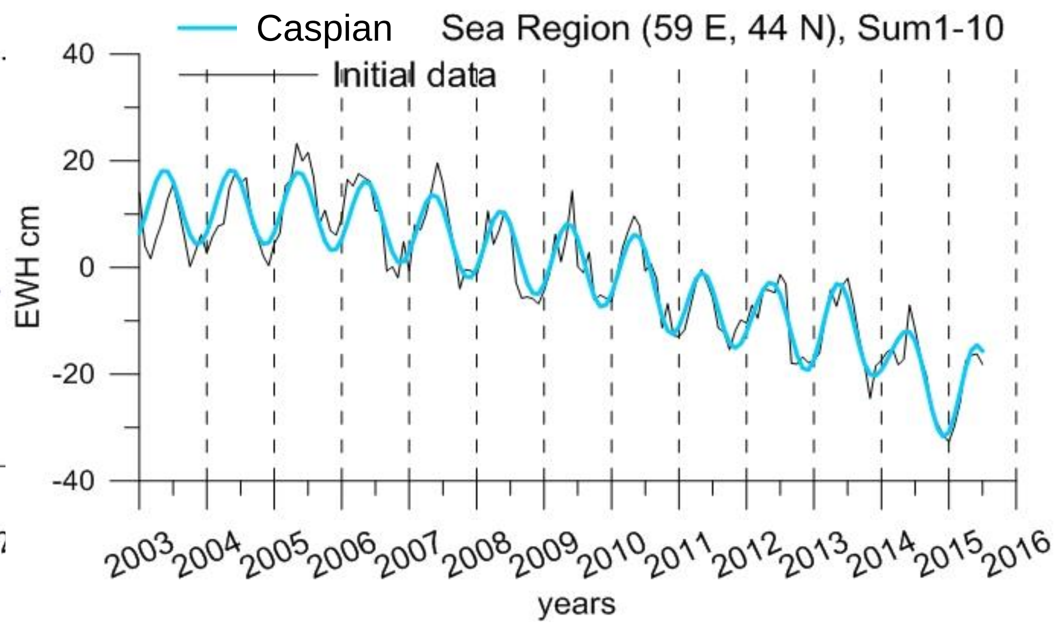


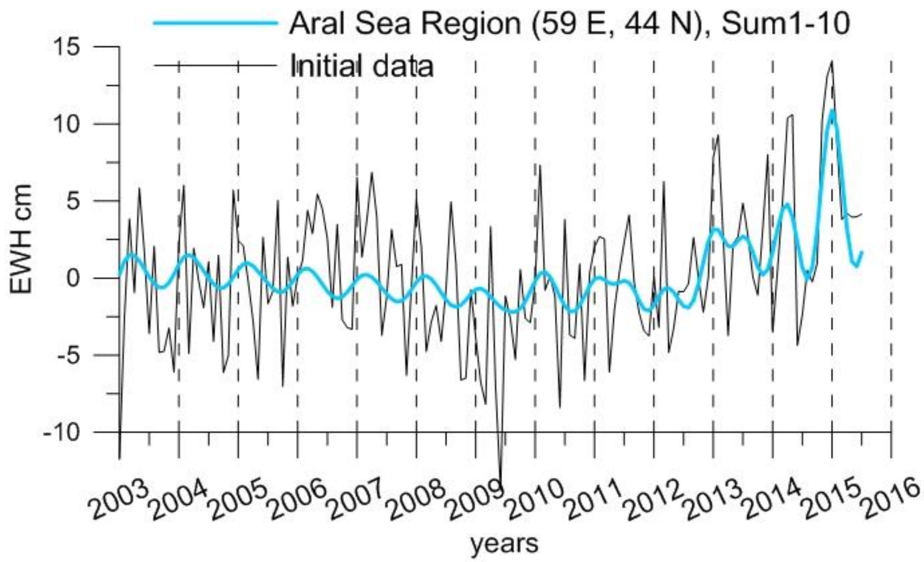
Gravity changes in the basins of large rivers of Siberian and European rivers

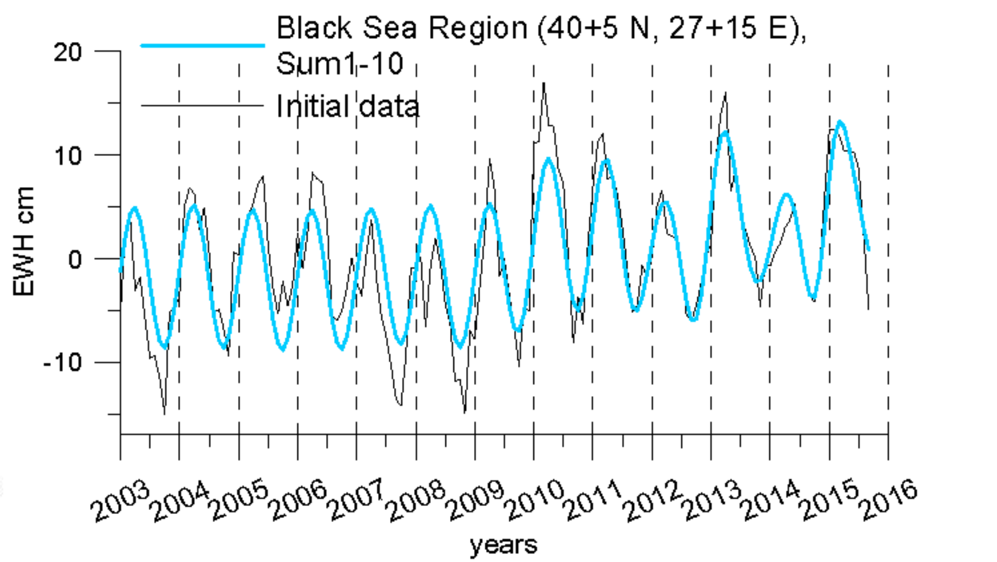


Gravity changes in the basins of Baikal, Aral and Caspian Sea

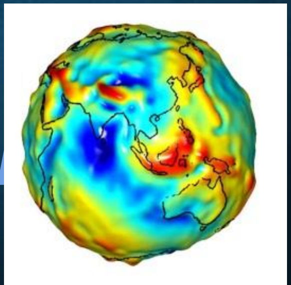








3. Application of the satellite system of the earth’s gravity field measurement (GRACE) for the evaluation of water balance characteristics



Mass balance equation

$$\Delta TWS = \Delta SW + \Delta(P-E) + \Delta SN + \Delta TSS - \Delta R,$$

where **ΔTWS – measured by GRACE**

ΔSW – changes in lakes and swamps

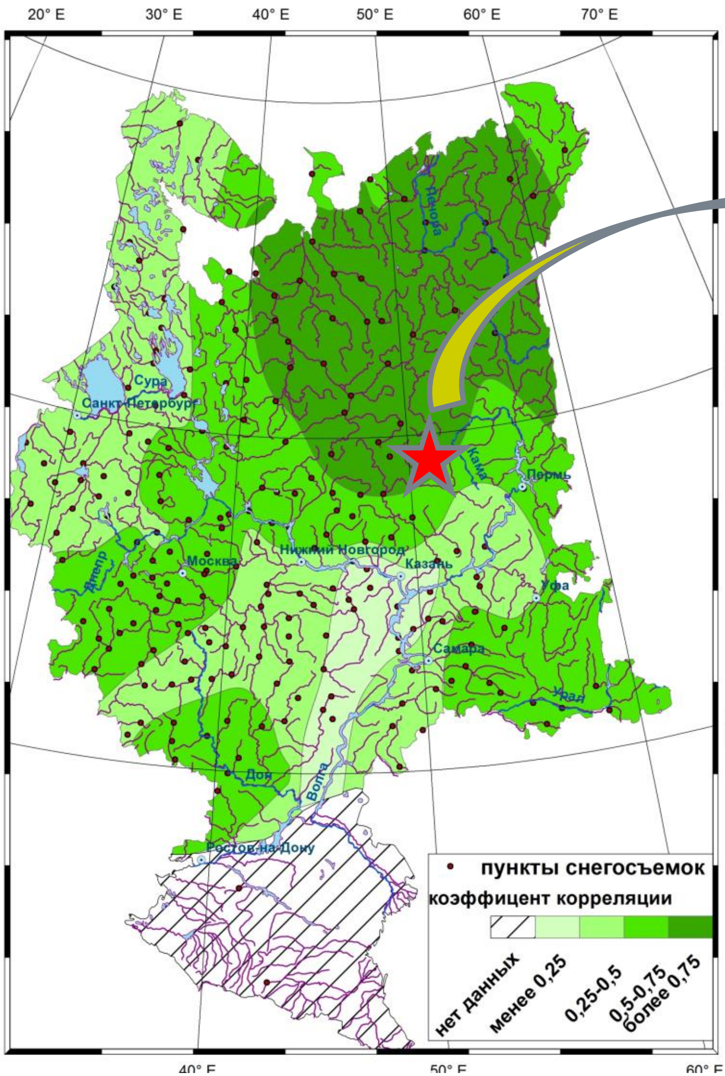
Δ(P-E) – changes of precipitation–evaporation difference

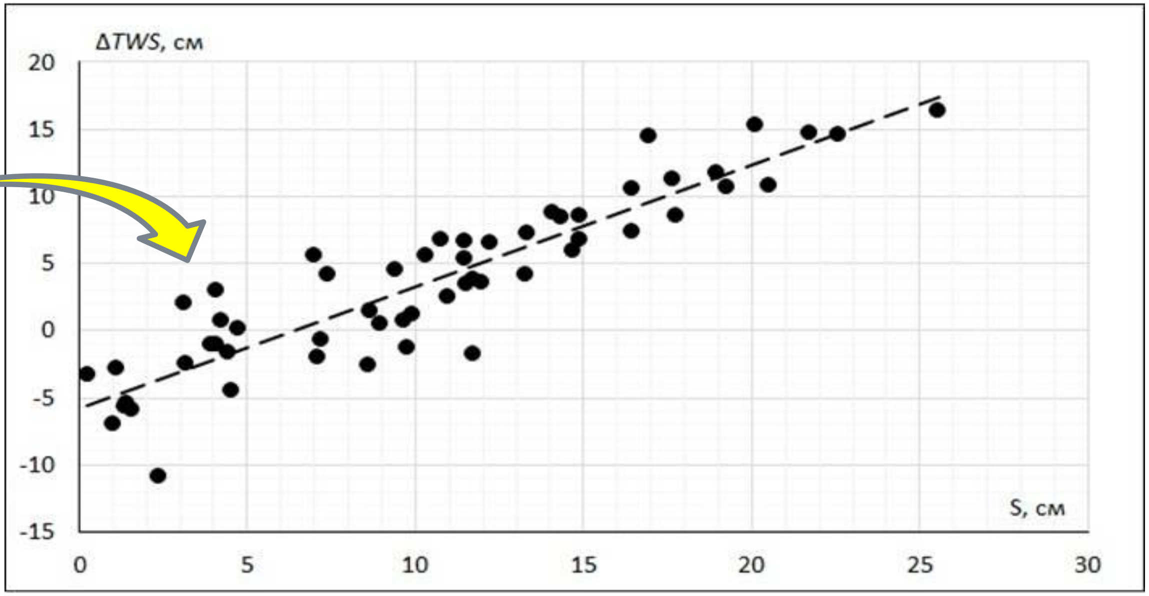
ΔSN – snow cover storage changes

ΔTSS – ground water storage changes

ΔR – river discharge changes

Possibility of GRACE data use for assessment of characteristics of snow cover





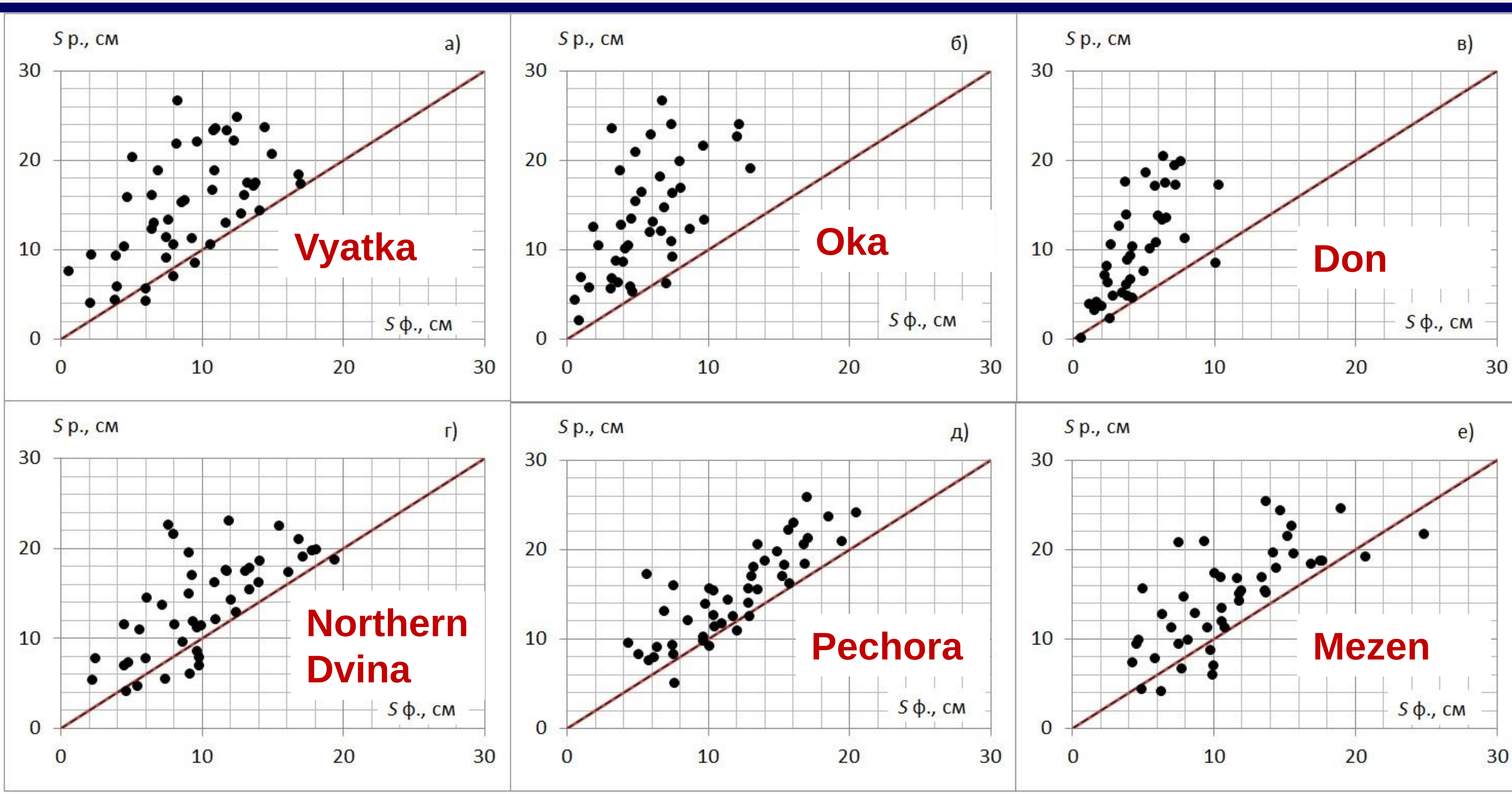
Correlation of ΔTWS and S (snow cover for stations of European Russia - meteo.ru) for marked station.

Материалы по снегомерным съёмкам взяты по 229 пунктов с 2002 по 2011 г.

Zotov, Frolova et al., 2016

$\Delta TWS = \Delta SN$ snow cover storage changes for November - April

Correlation of calculated and measured values of snow cover (cm) for different river basins



а) р. Вятка – г. Вятские Поляны; б) р. Ока – г. Муром; в) р. Дон – ст.Раздорская; г) р. Северная Двина – с. Абрамково; д) р. Печора – с. Оксино; е) р. Мезень – д. Малонисогорская

Correlation of ΔTWS and runoff

ΔTWS = ΔSW+ Δ(P-E) + ΔSN + ΔTSS - ΔR,

ΔTWS – measured by GRACE

ΔTSS – ground water storage changes

ΔSN – snow cover storage changes

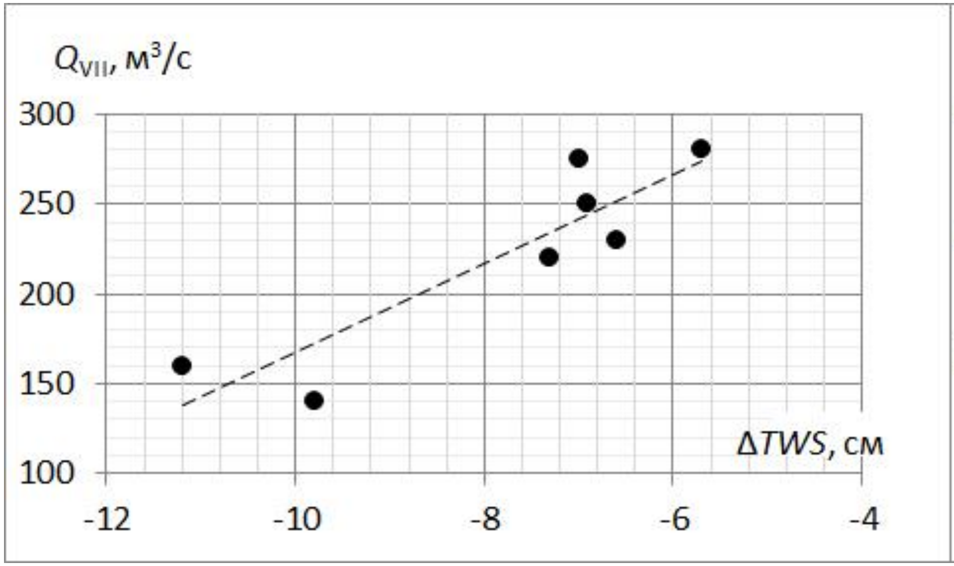
ΔSW – changes in lakes and swamps

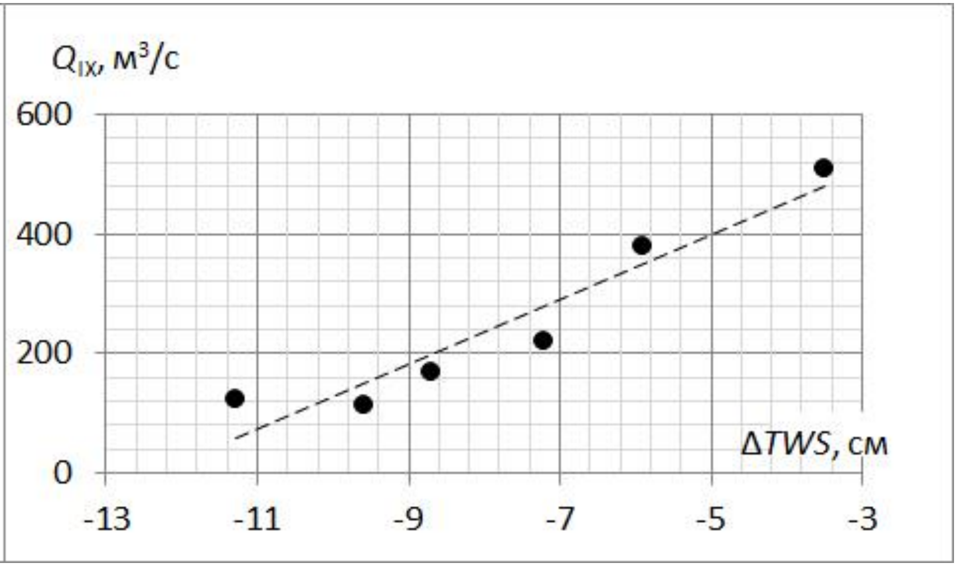
Δ(P-E) – changes of precipitation–evaporation difference

ΔR – **river discharge changes**

In these periods of year change of Water Terrestrial Storage obtained from GRACE can be explained the changes in channel network and respectively of ΔR.

Runoff of Pechora basin

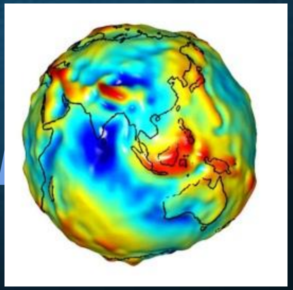




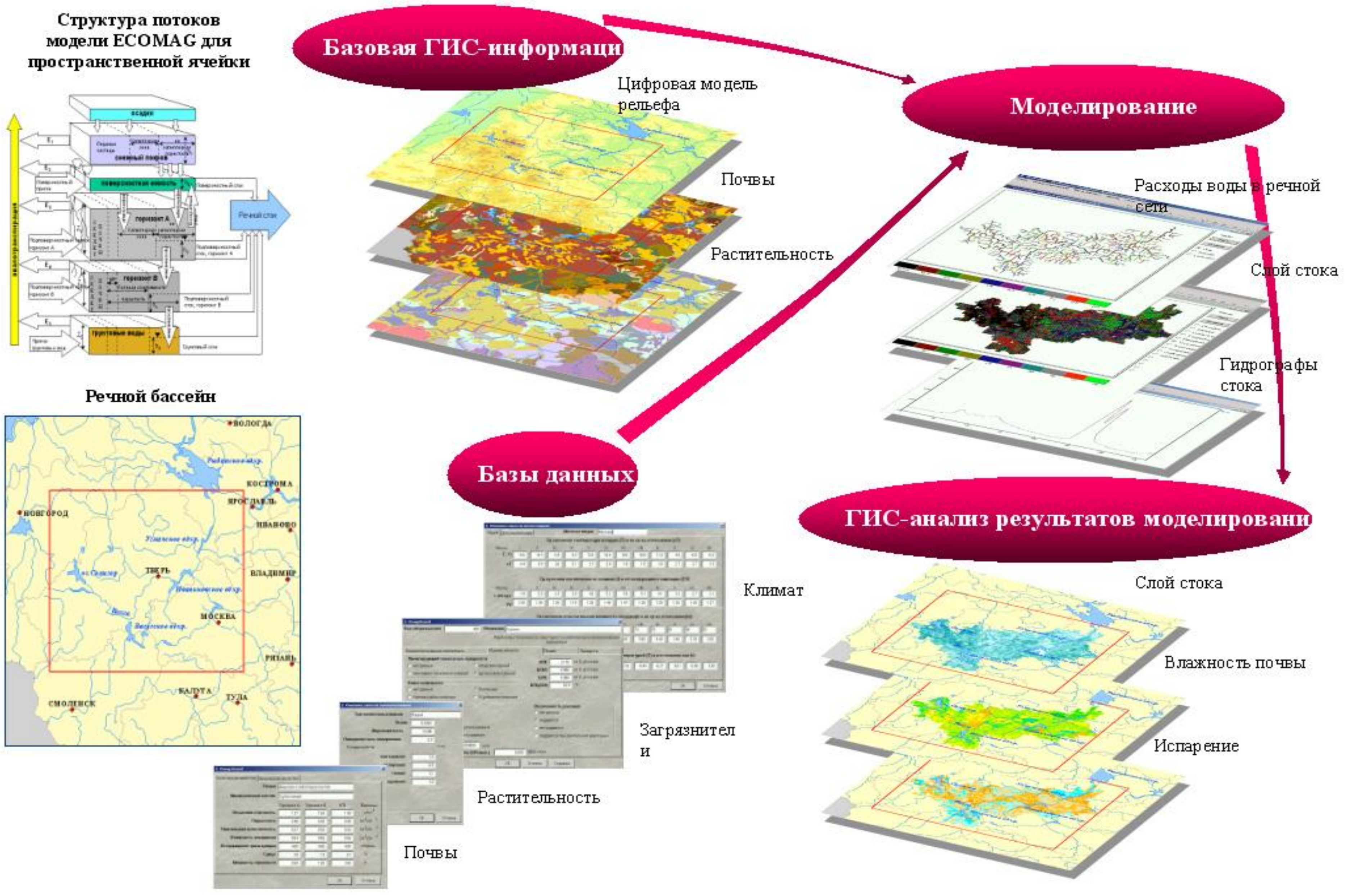
July

September

4. Comparison of monthly TWS retrieval from GRACE data with TWS-estimates obtained by the hydrological model

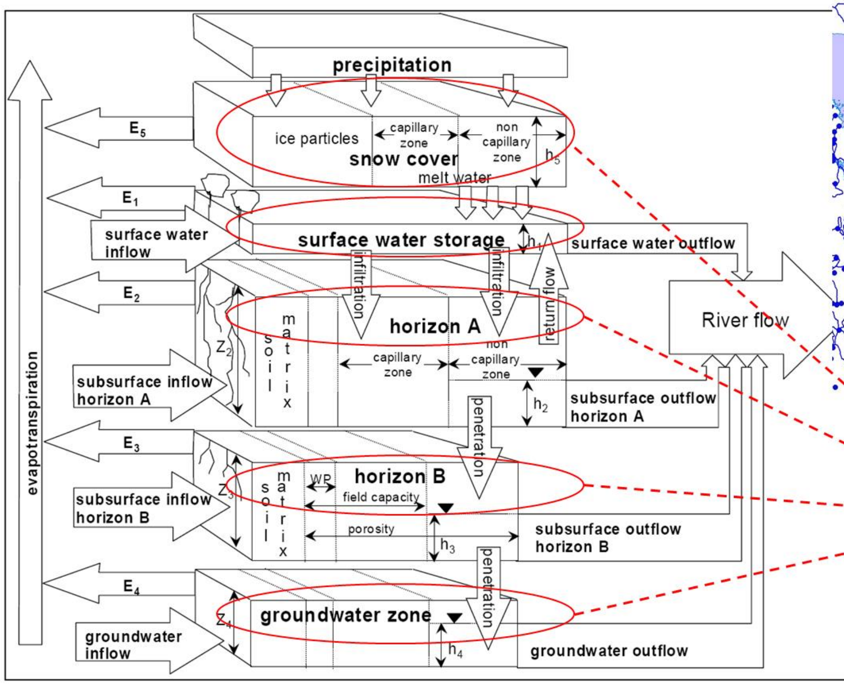


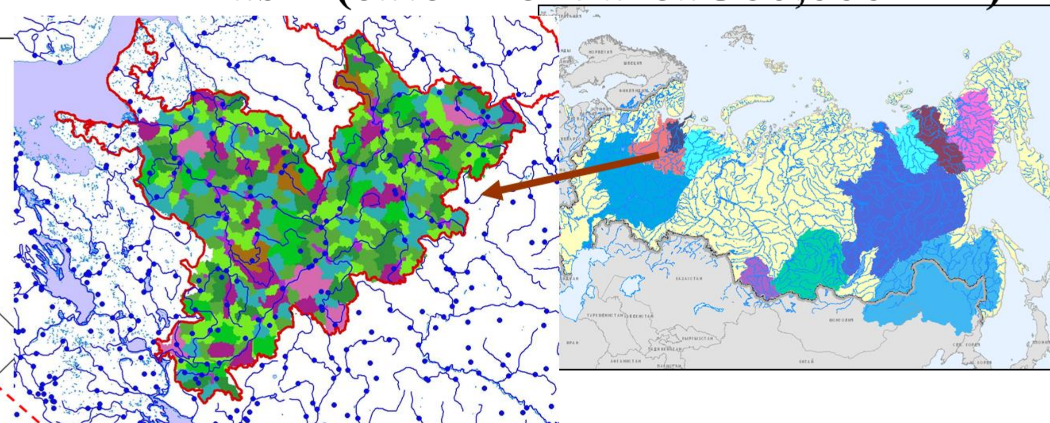
ECOMAG hydrological model



ECOMAG (Ecological Model for Applied Geophysics) (Motovilov et al., 1999)

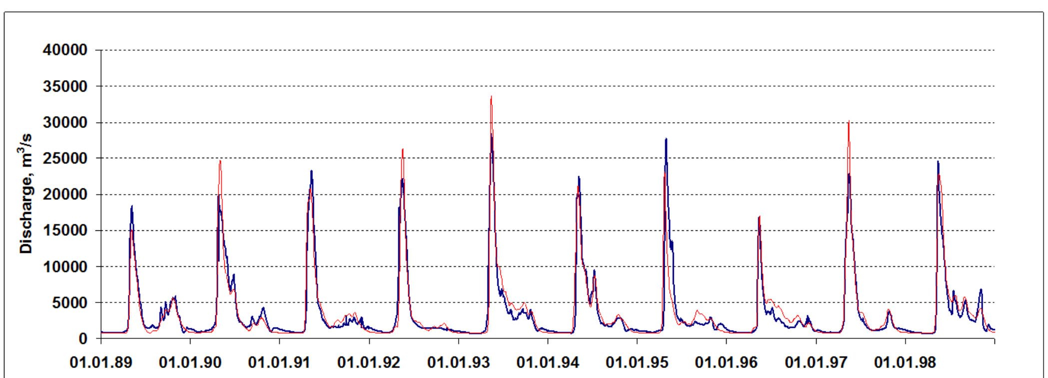
Case Study: Northern Dvina River Basin (catchment area 360,000 km²)



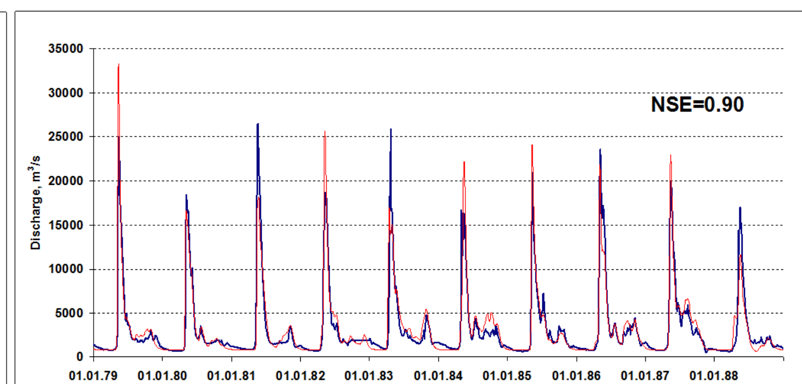


Basin TWS (= sum of all surface water, soil moisture, snow water, and groundwater) is simulated by ECOMAG with daily time step

Calibration: 1989-1998

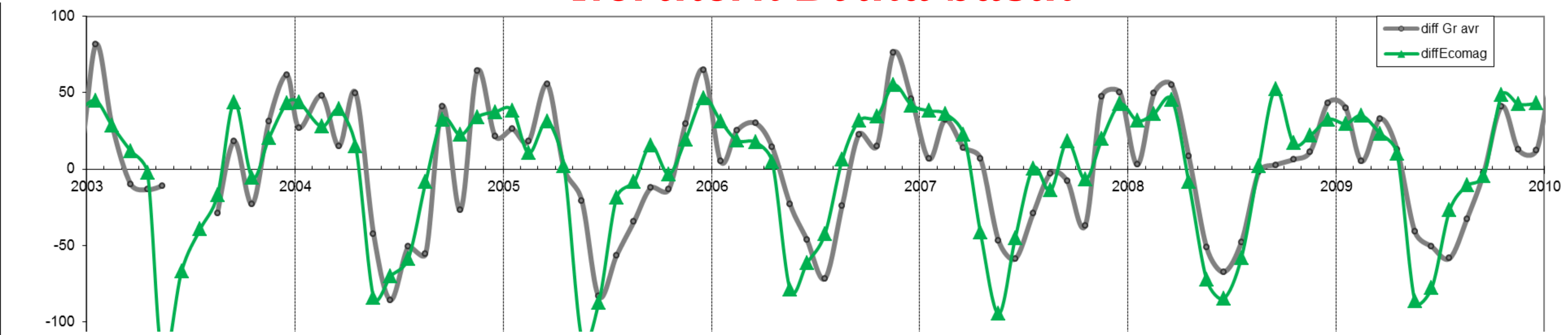


Validation: 1979-1988



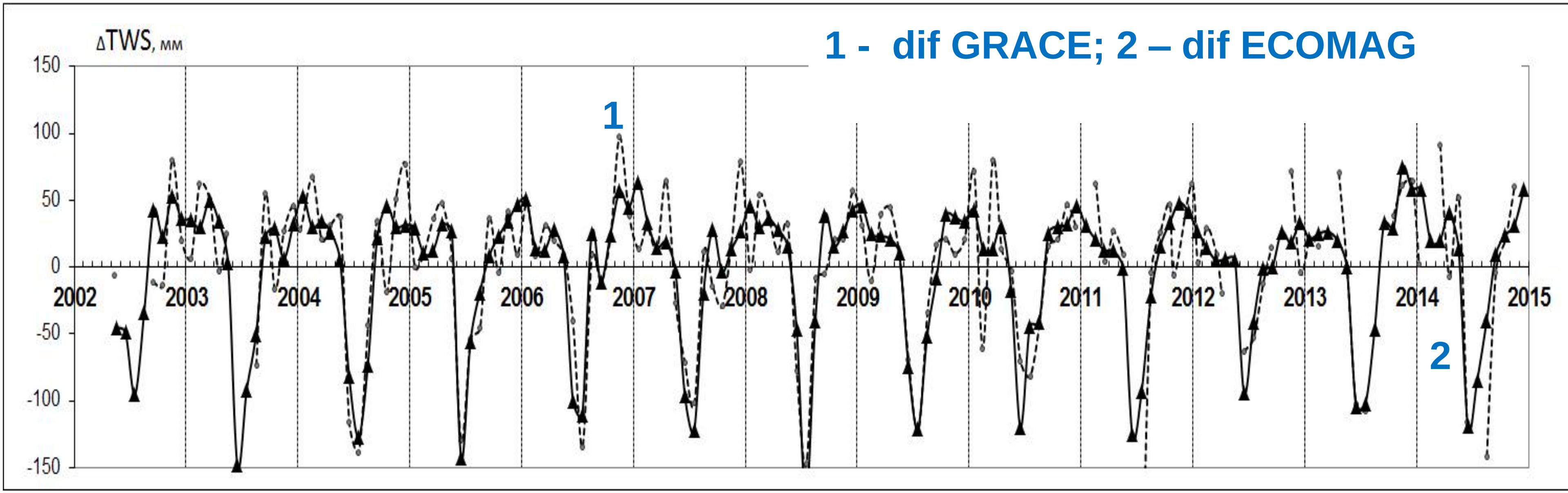
Comparison of monthly TWS retrieval from GRACE data (2002-2010) with TWS-estimates obtained by the ECOMAG model

Northern Dvina basin

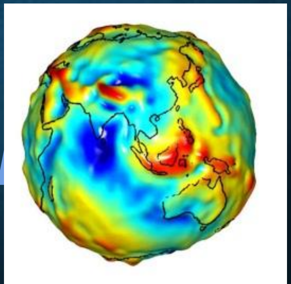


Basin TWS (= sum of all surface water, soil moisture, snow water, and groundwater) is simulated by ECOMAG with daily time step

Pechora basin



5. Conclusions



- **Data of space gravitation measurements are extremely useful in a hydrology. GRACE is the technology available for near-real-time, global monitoring of TWS. GRACE provides an unprecedented opportunity to improve quantification, understanding, and simulation of TWS variability. To improve the TWS-estimates, it is reasonable to combine the simulated TWS with independent observations provided by the GRACE gravity data.**

- **Multichannel Singular Spectrum Analysis is a promising method for GRACE data processing, de-striping, filtering, and Principal Components (PCs) separation.**

- **GRACE Data can be used for assessment of change of water resources of large river basins and territories under the influence of climatic and anthropogenic factors.**

- **Remote information is well agreed with data of hydrological models and measurements for big river basins for the separate periods of time.**


Many thanks for your attention!