Hydrological balance in the large Russian river basins from GRACE satellites

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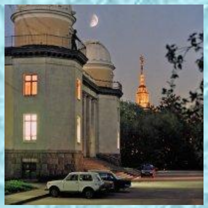
Lomonosov Moscow State University



29 September 2016
Moscow

NASA missions of remote sensing of the Earth

Huge amount of data is available for the scientific community (including hydrological)

Its analysis requires international collaboration

Satellite data on hydrology is contained in

Passive (SSM/I) and active (ERS) microwave radar measurements

Optical and near-infrared imaging (AVHRR)

Altimetry data (Jason)

Ground moisture data (SMOS)

Atmospheric vapor and precipitation profiles

Gravity measurements (GRACE, GOCE)

Mass changes (hydrological) depend on

River and lake levels

Subsurface water and biomass

Snow cover

Precipitation

Gravity field studies are useful for

Hydrology, meteorology, climatology, geodynamics.

The climate change, for example, influence the river hydrological balance, permafrost, rivers discharge into ocean, sea level, water and ice balance of the Arctic, etc.

Mass redistribution influence the rotation of the Earth.

The full set of geodetic and geodynamical problems is involved.

Their study is also important for rational resources management, construction work, flood prediction, agriculture and so on.

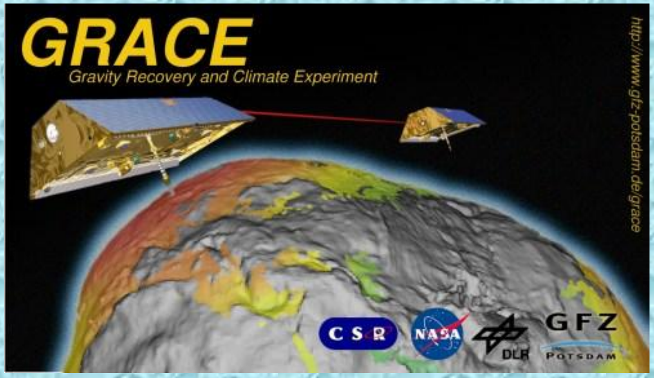
Gravity space missions

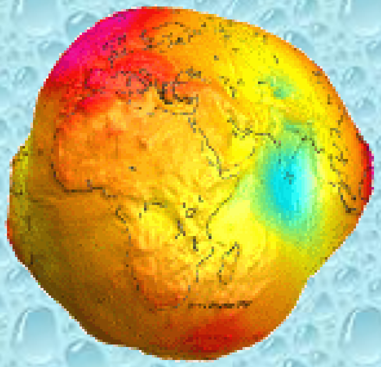
CHAMP – launched by GFZ in July, 2000 to an orbit of ~ 450 km altitude. For gravity and magnetic field research. The data span is ~ 8 years.

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.

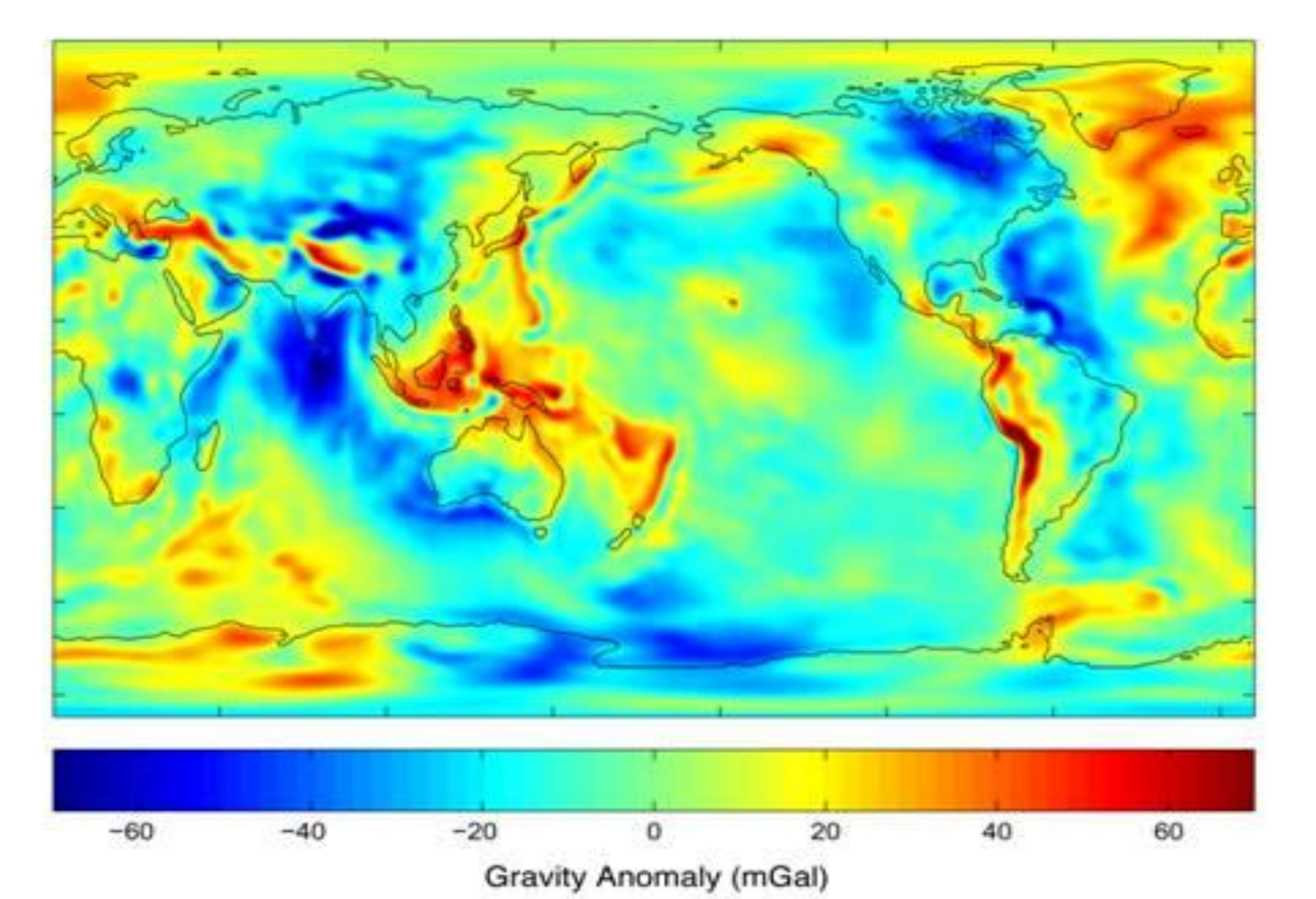
The basic measurement is the distance between the satellites and its rate, changing under the influence of the accelerations caused by the flight over the mass sources. Mission extended to 2017. Battery capacity now is 10 times lower than at the beginning.

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 November 2013 by falling down into the ocean.





Earth gravity field model GRACE (GGM03s)



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

GRACE data preprocessing

We uses monthly JPL Level-2 RL05 files with coefficients of spherical decomposition up to order and degree 60 since 01.2003 till 06.2016. Tidal and atmospheric effects were removed by JPL during the stage of the first level processing.

16 files (06.03, 01.11, 06.11, 05.12, 10.12, 03.13, 08.13, 09.13, 02.14, 07.14, 12.14, 05.15, 06.15, 10.15, 11.15, 04.16) were linearly interpolated (*N*=154 files totally). Some data in the last months is not delivered because of accumulator problems onboard.

C_{20} values from SLR are used.

12-yeae average field is subtracted.

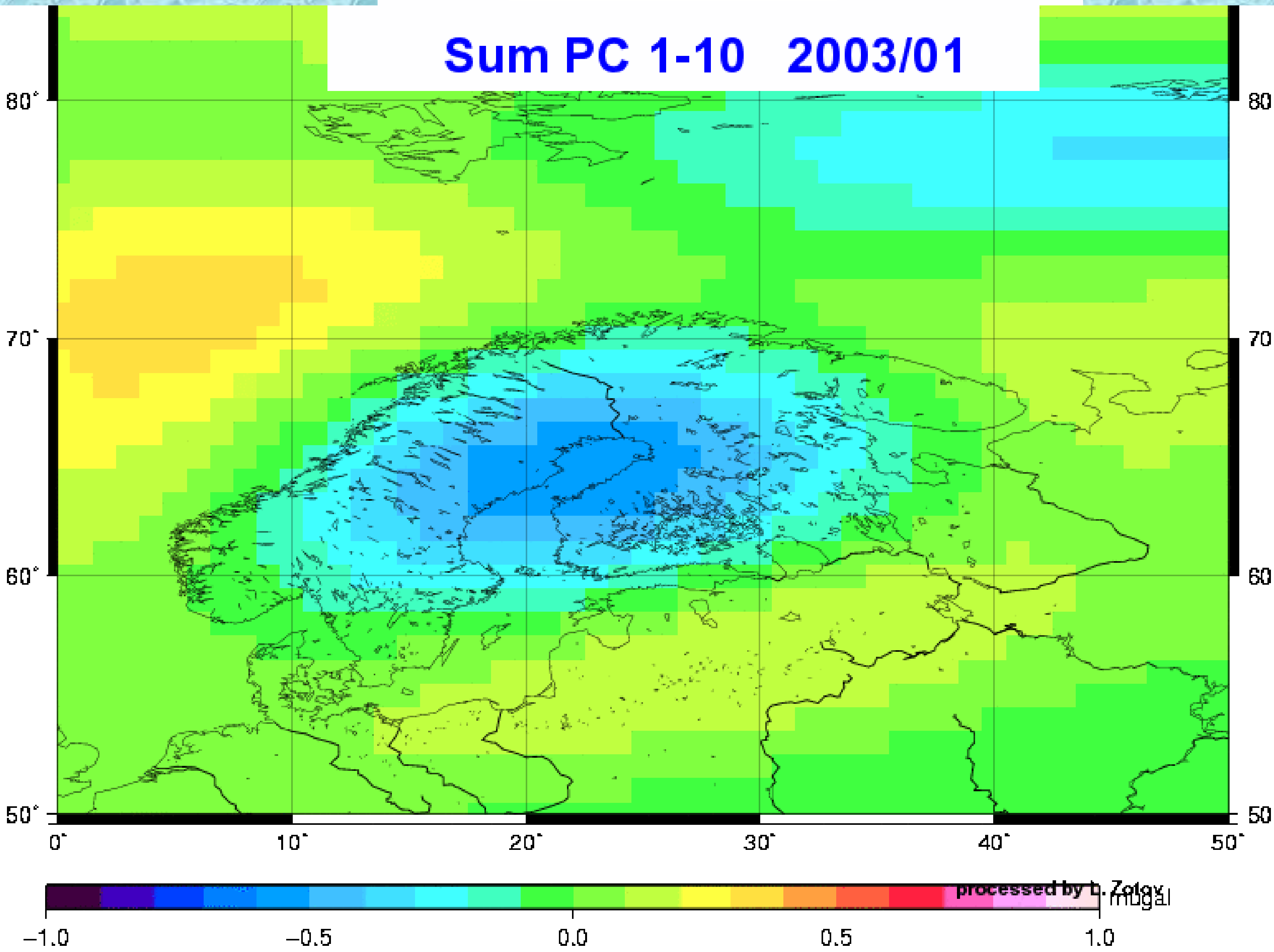
GIA effect is removed according to Paulson 2007 model.

The results are converted into Equivalent Water Height levels (EWH, cm), the animated maps are constructed with GMT.

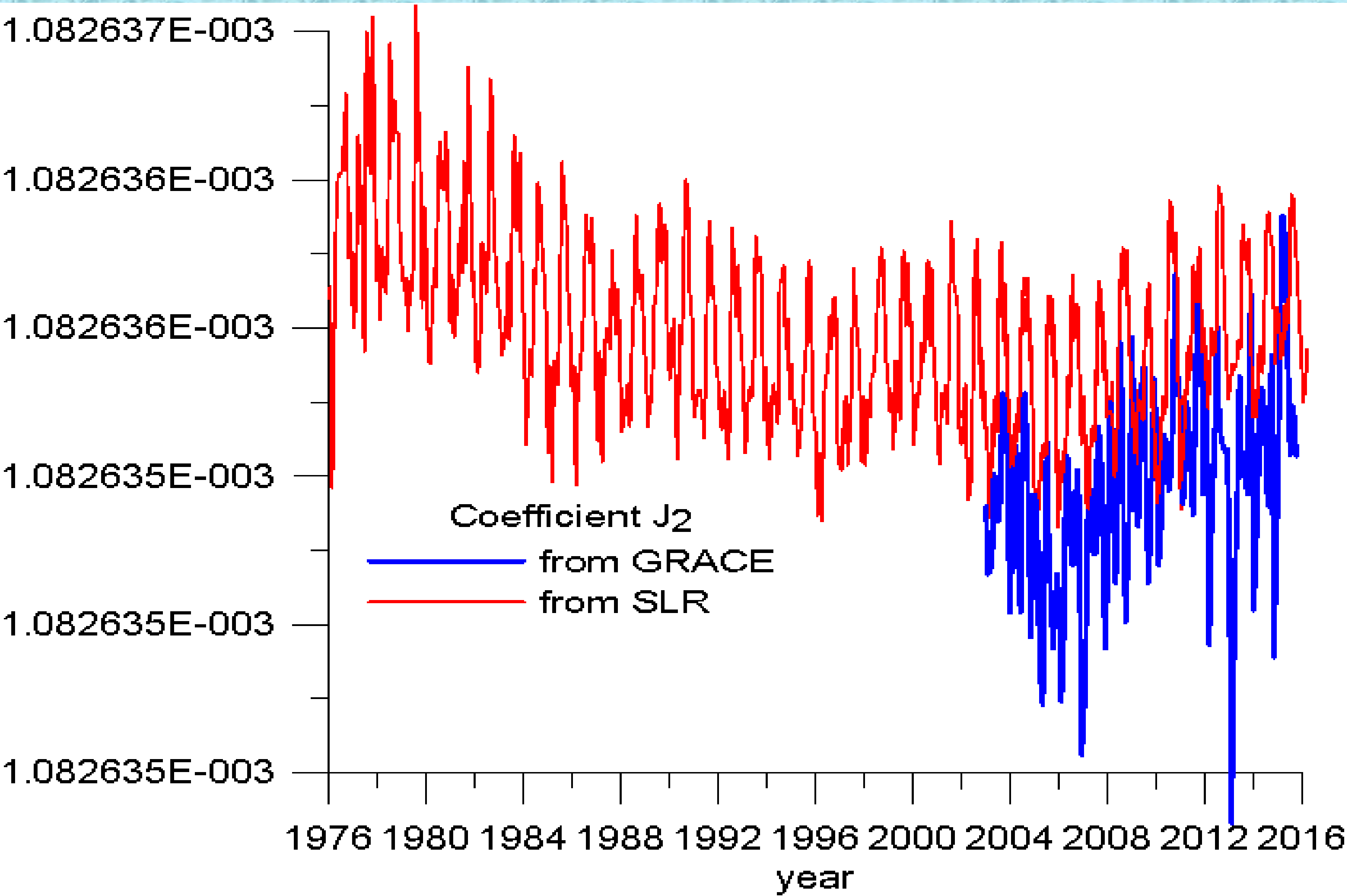
$$\Delta h(\varphi,\lambda,t) = \frac{a\rho_{ave}}{3\rho_w}\sum_{n=2}^{60}\sum_{m=0}^{n}\frac{2n+1}{1+k_n}W_n(\Delta C_{nm}(t)\cos m\lambda + \Delta S_{nm}(t)\sin m\lambda)P_n^m(\sin\varphi),$$

Glacial isostatic adjustment GIA modeling

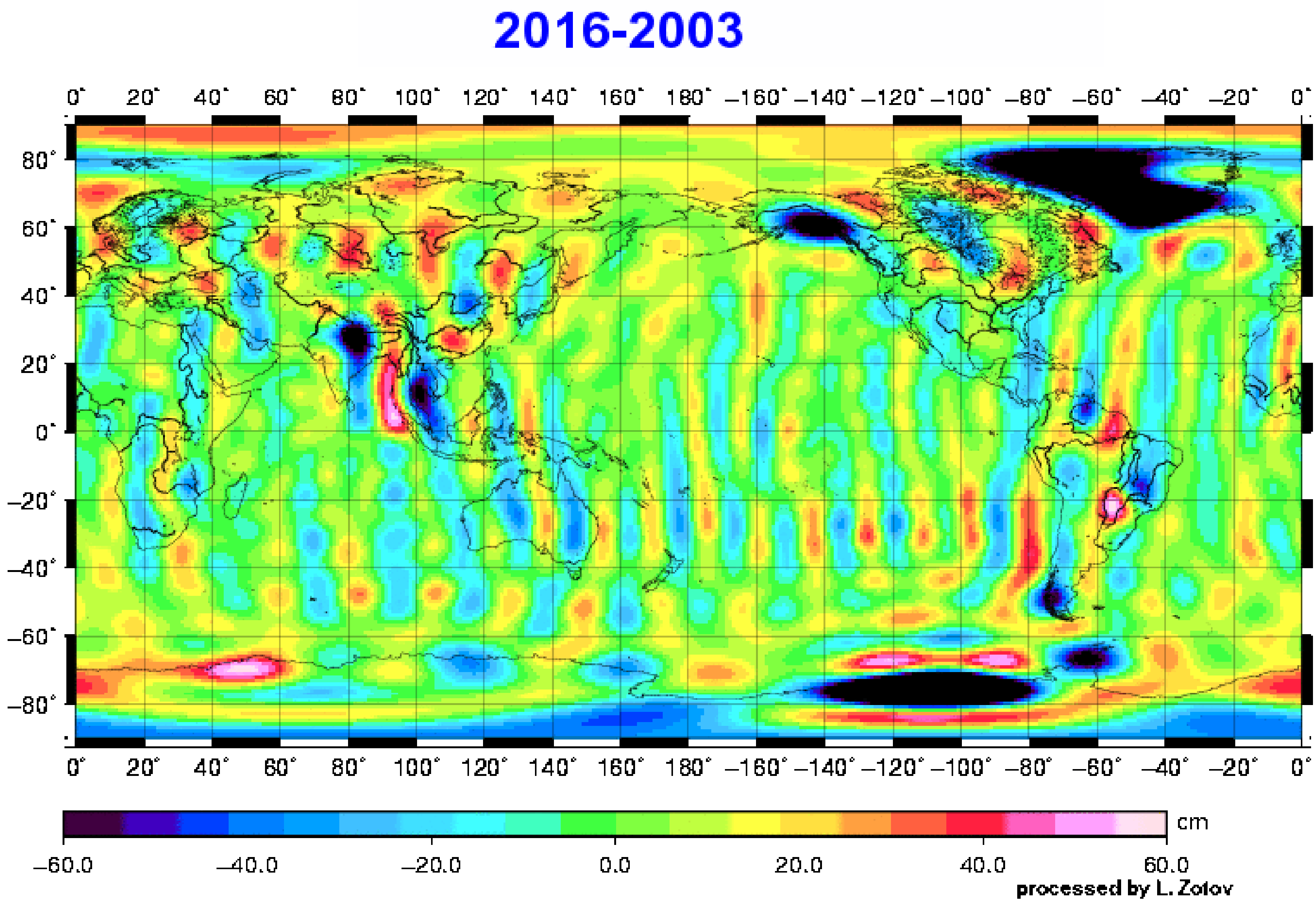
Over Scandinavia



Variations in J_2 from SLR and GRACE



Initial data GRACE JPL RL05 Level 2



Equivalent Water Height (EWH)

Multichannel Singular Spectrum Analysis

1) Lag parameter *L* selection

SSA- generalization of PCA

Multichannel signal

$$x = (x_1, x_2, \dots, x_N)$$

Embedded into block matrix X

2) SVD — singular value decomposition of the matrix is performed

$$X = USV^T$$

3) For each singular number s_i the matrices are reconstructed

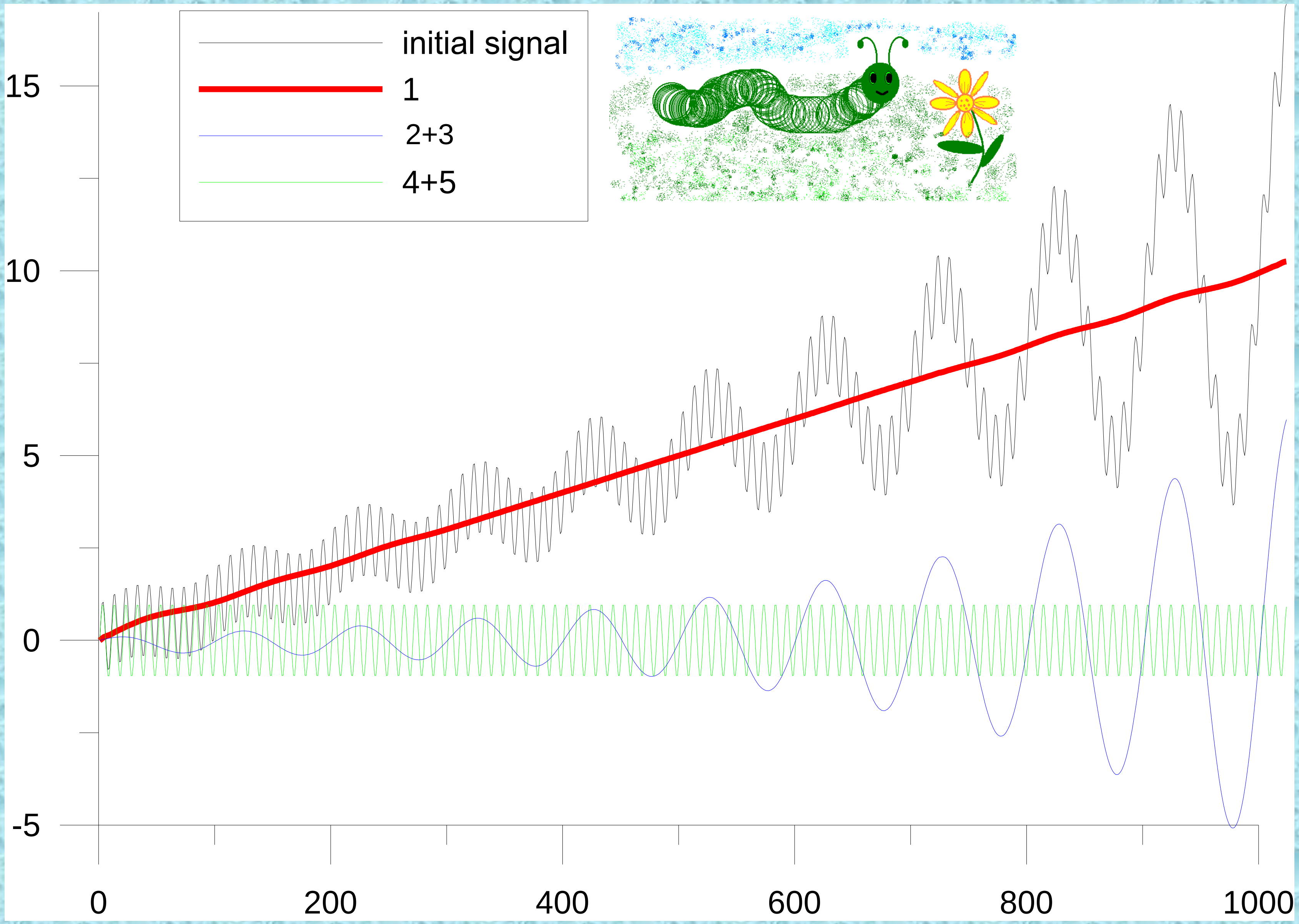
$$X^i = s_i u_i v_i^T ,$$

and signal for every component is obtained by Hankelization

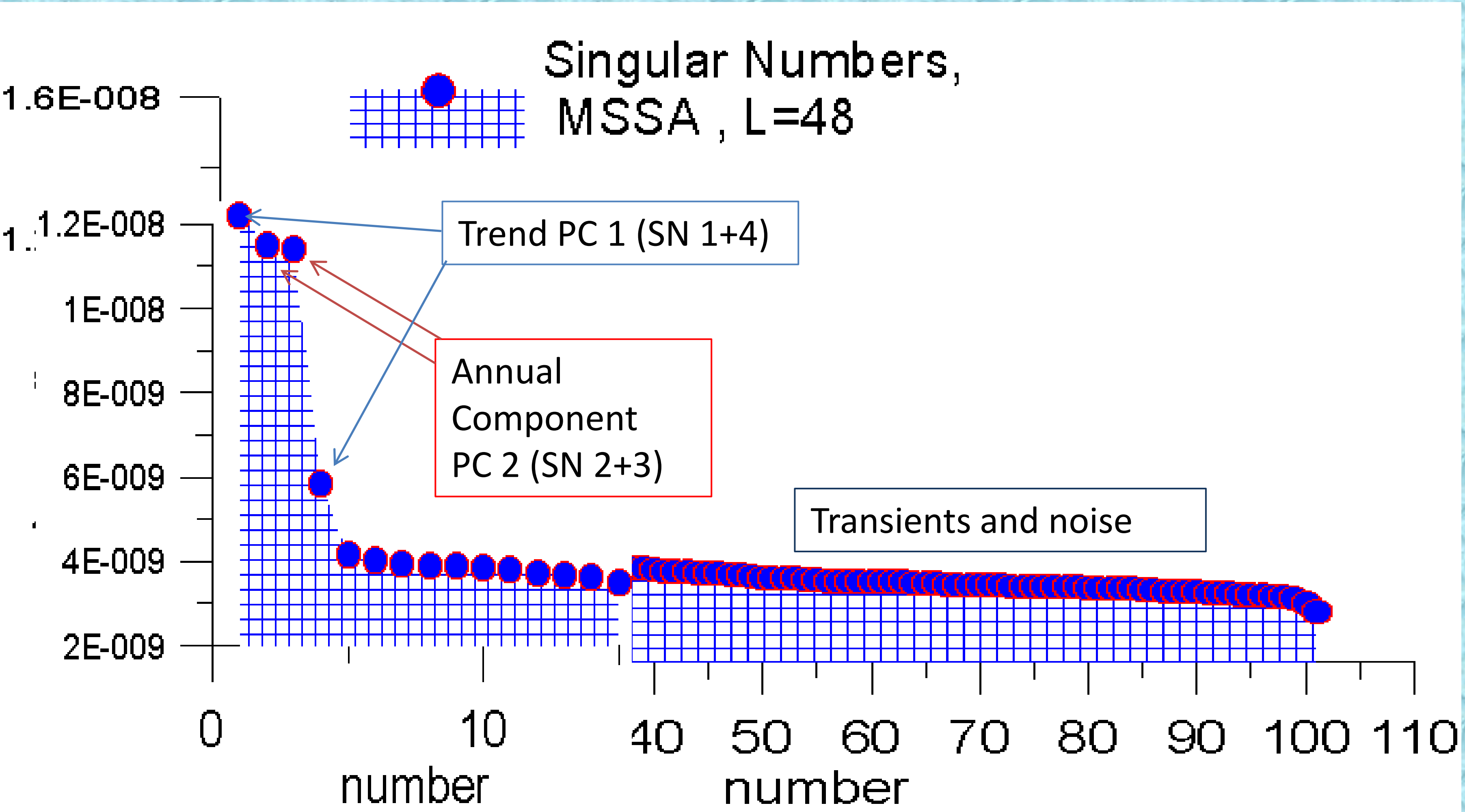
4) Similar signals are grouped into Principal Components (PCs)

PC1, PC2, PC3…

1D SSA example – “caterpillar”



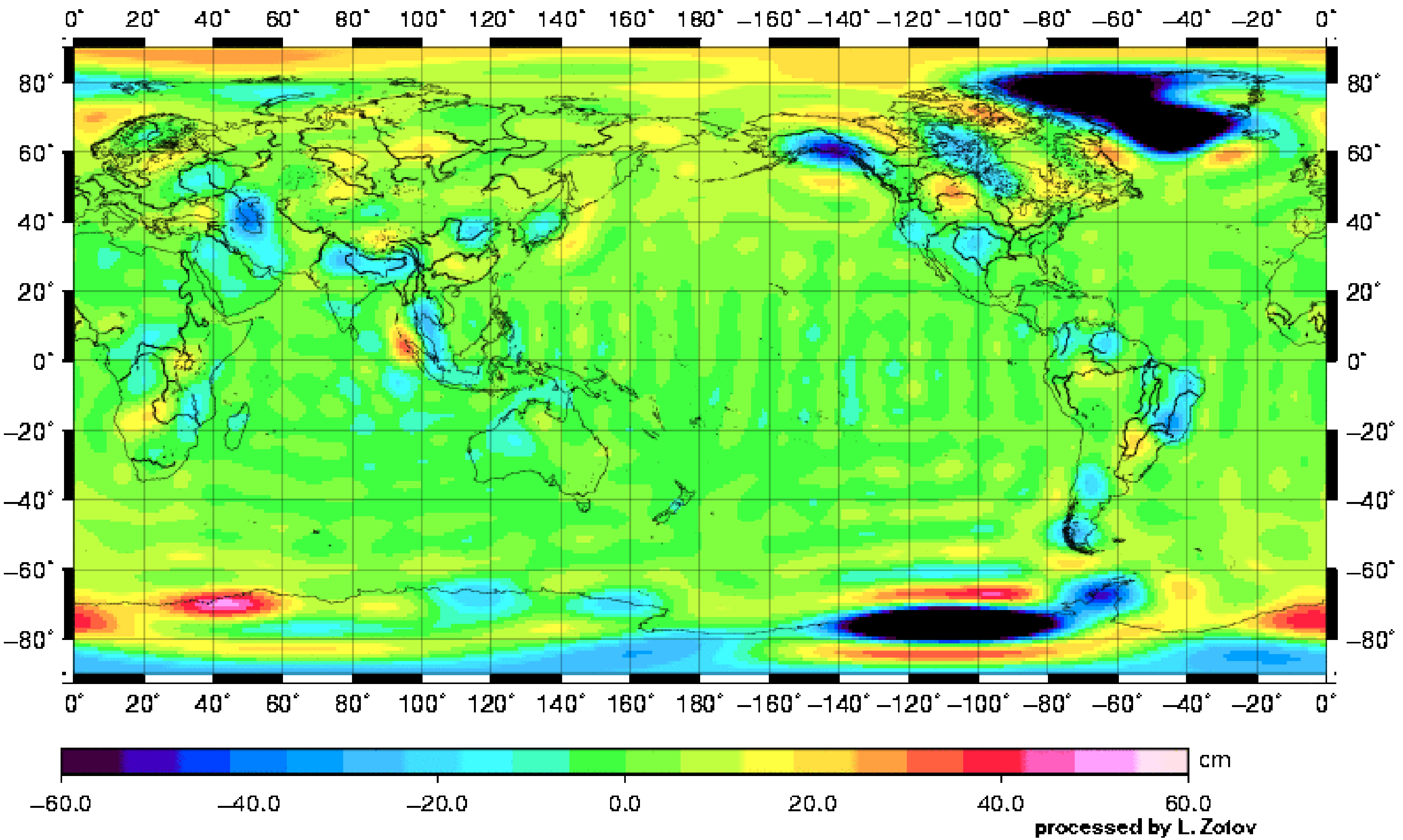
GRACE data MSSA – singular numbers L=48 months (4 years)



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.

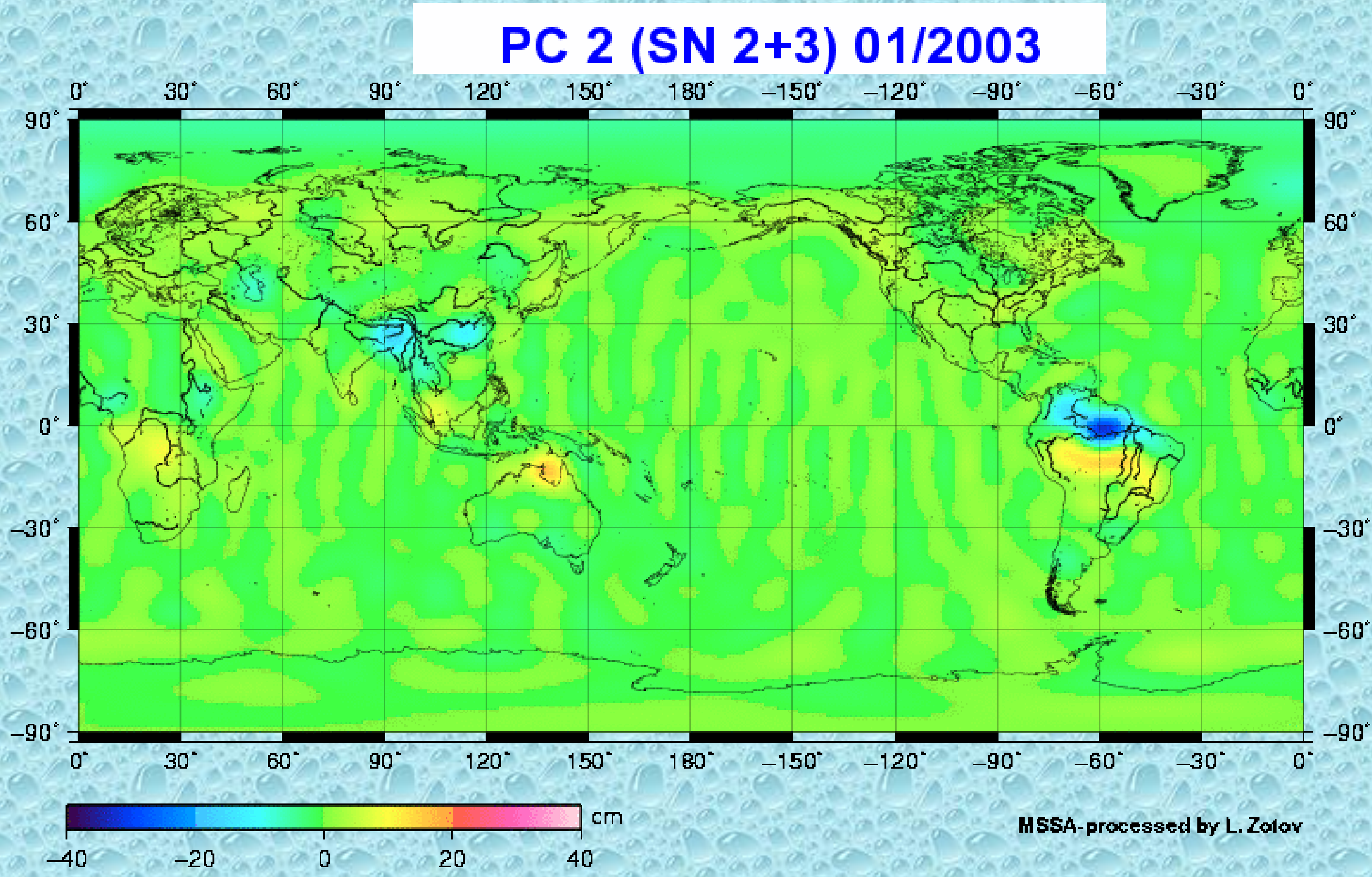
Trend - PC 1

2016-2003



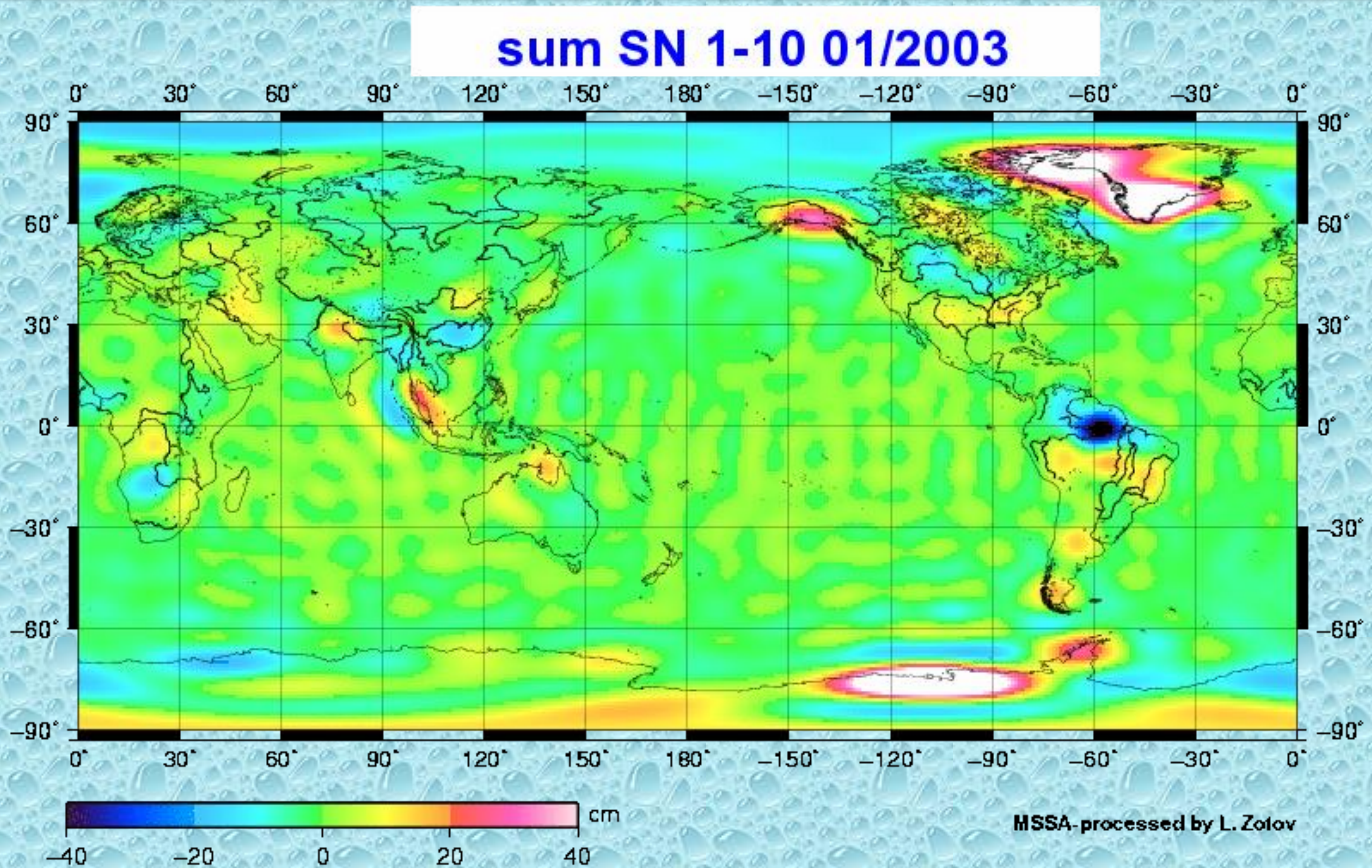
MCCA, L=48 months

Annual component – PC 2



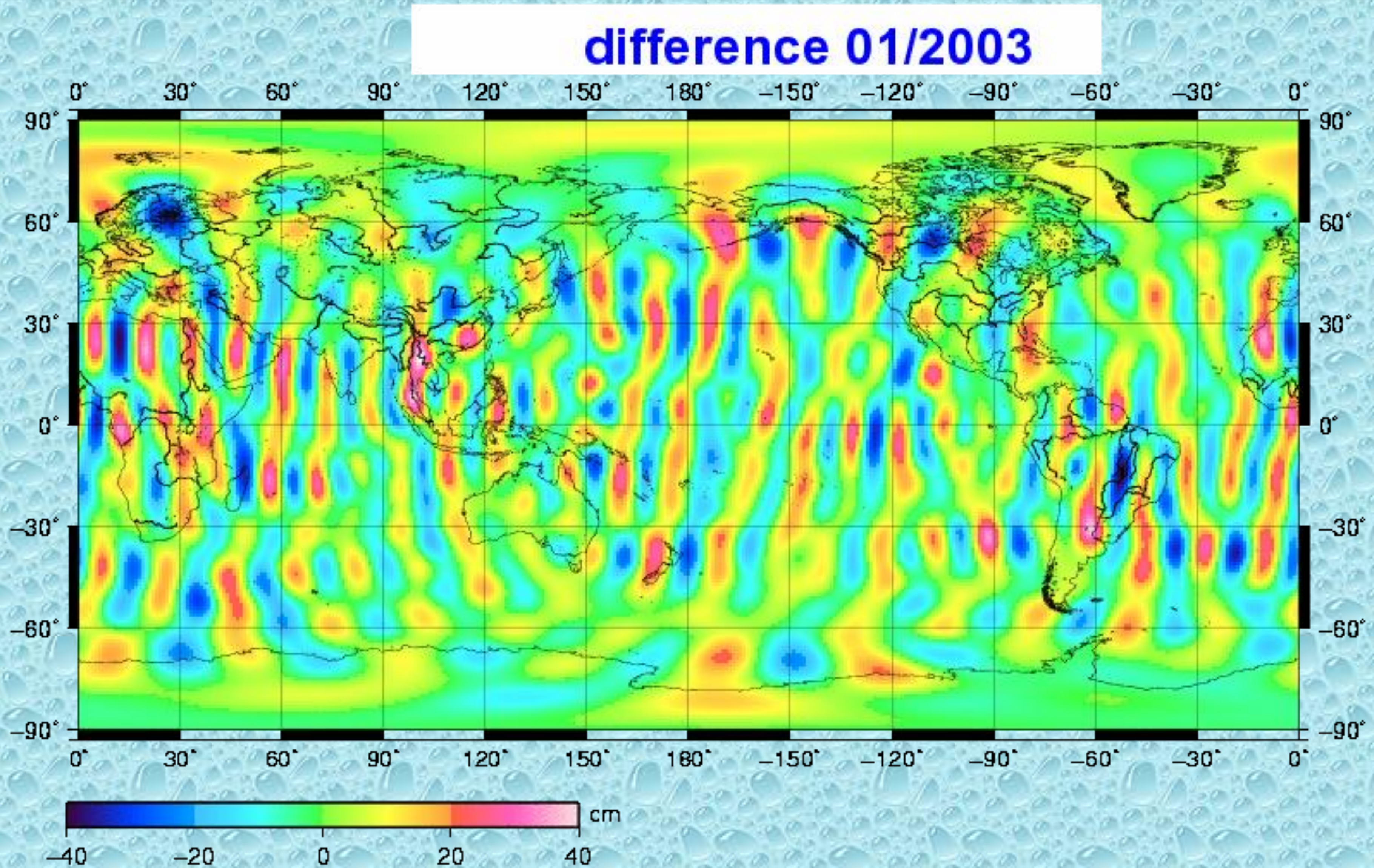
MCCA, L=48 months

Sum of first 10 singular numbers



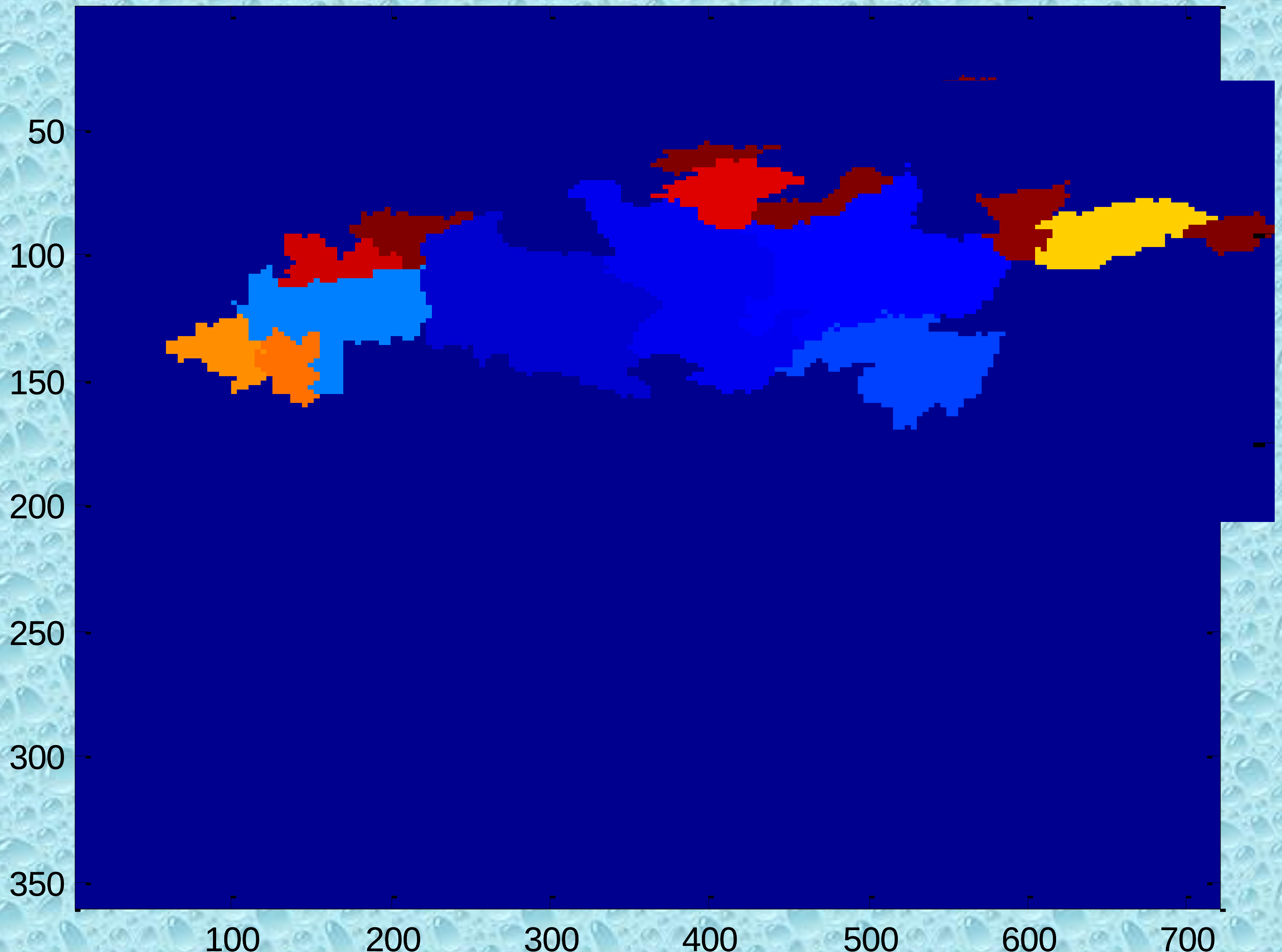
MCCA, L=48 months

Remaining components, Sum of SNs >10

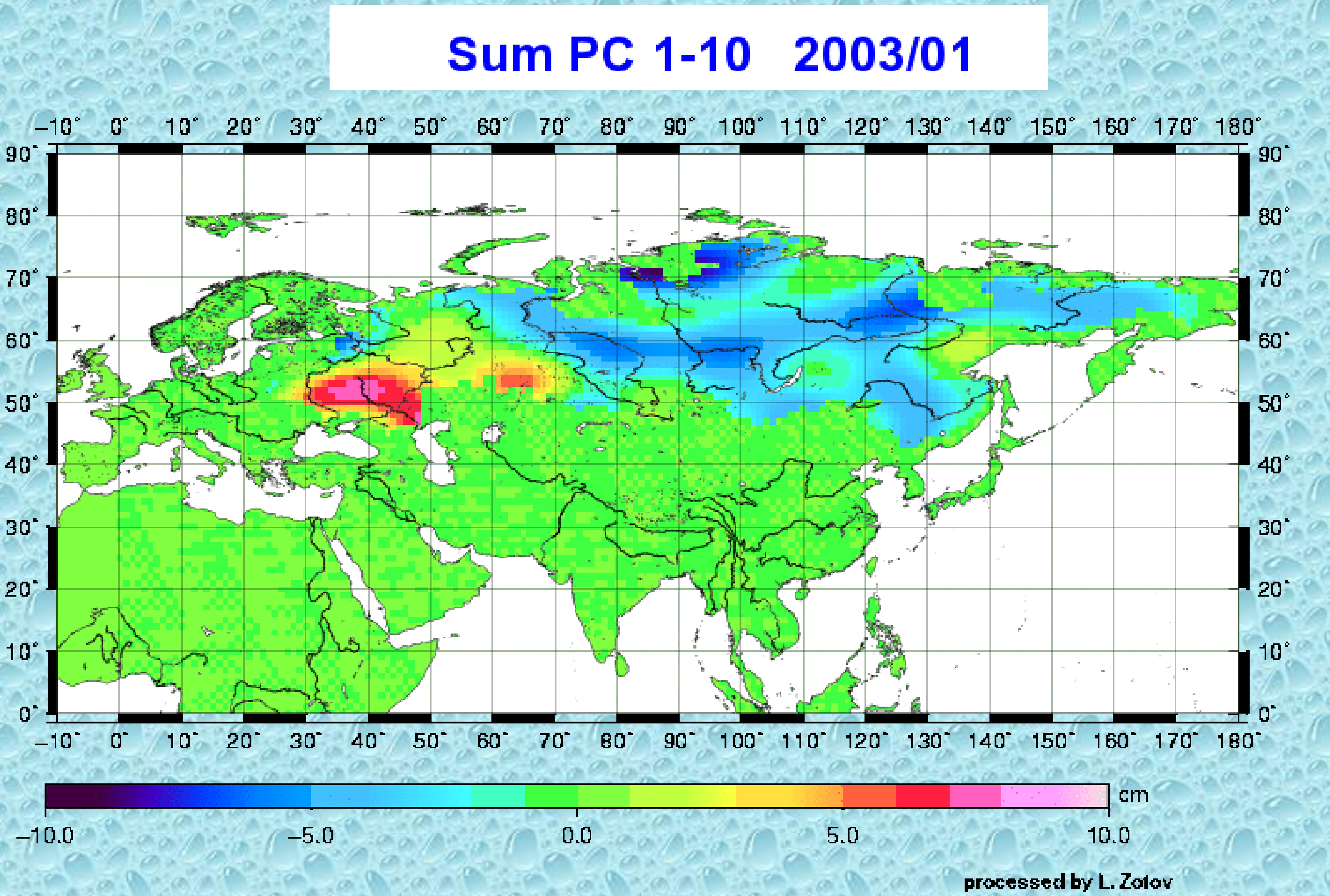


MCCA, L=48 months

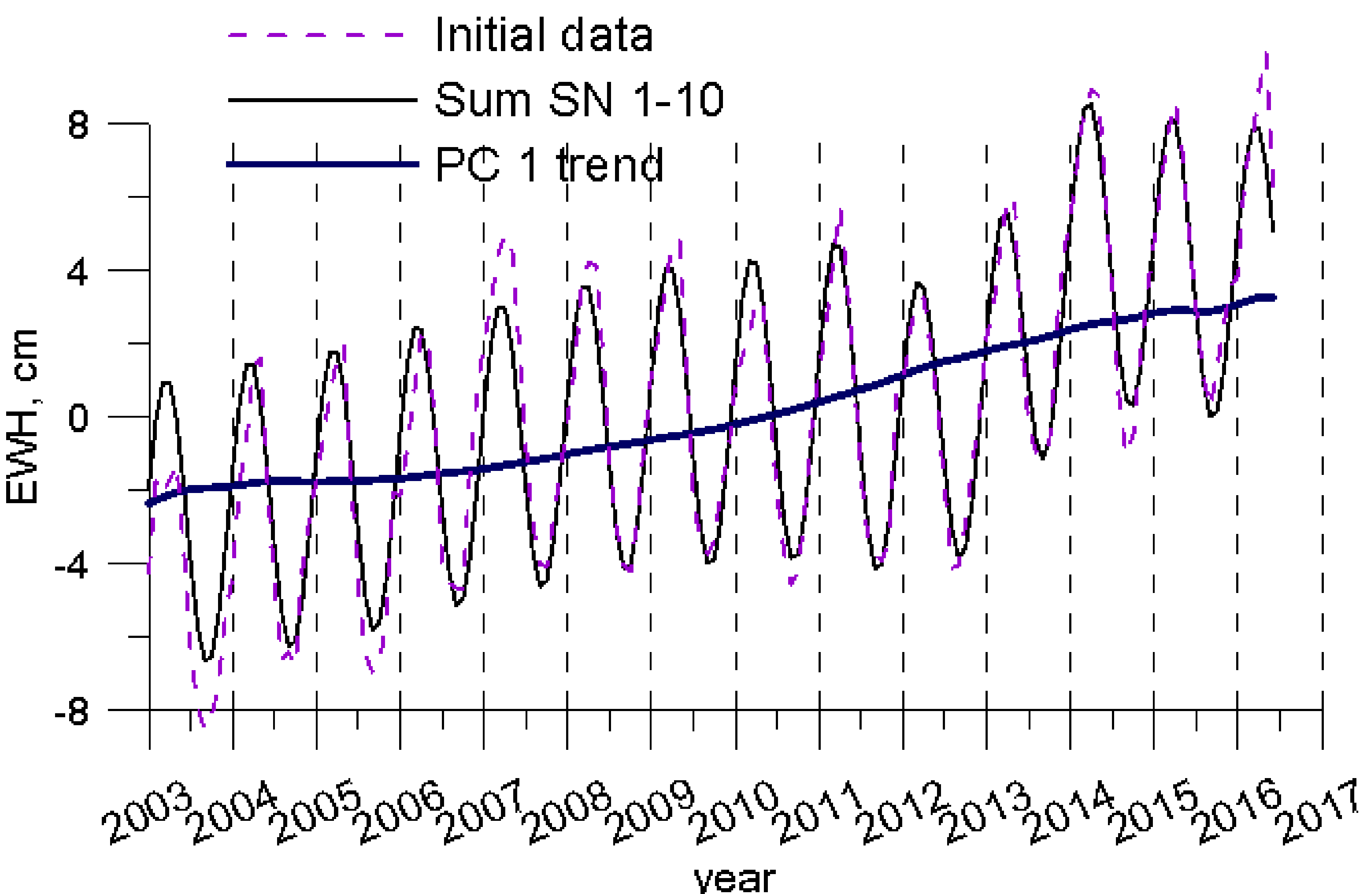
Simulated Topological Networks (STN-30p) database Used to extract 15 big Russian river basins



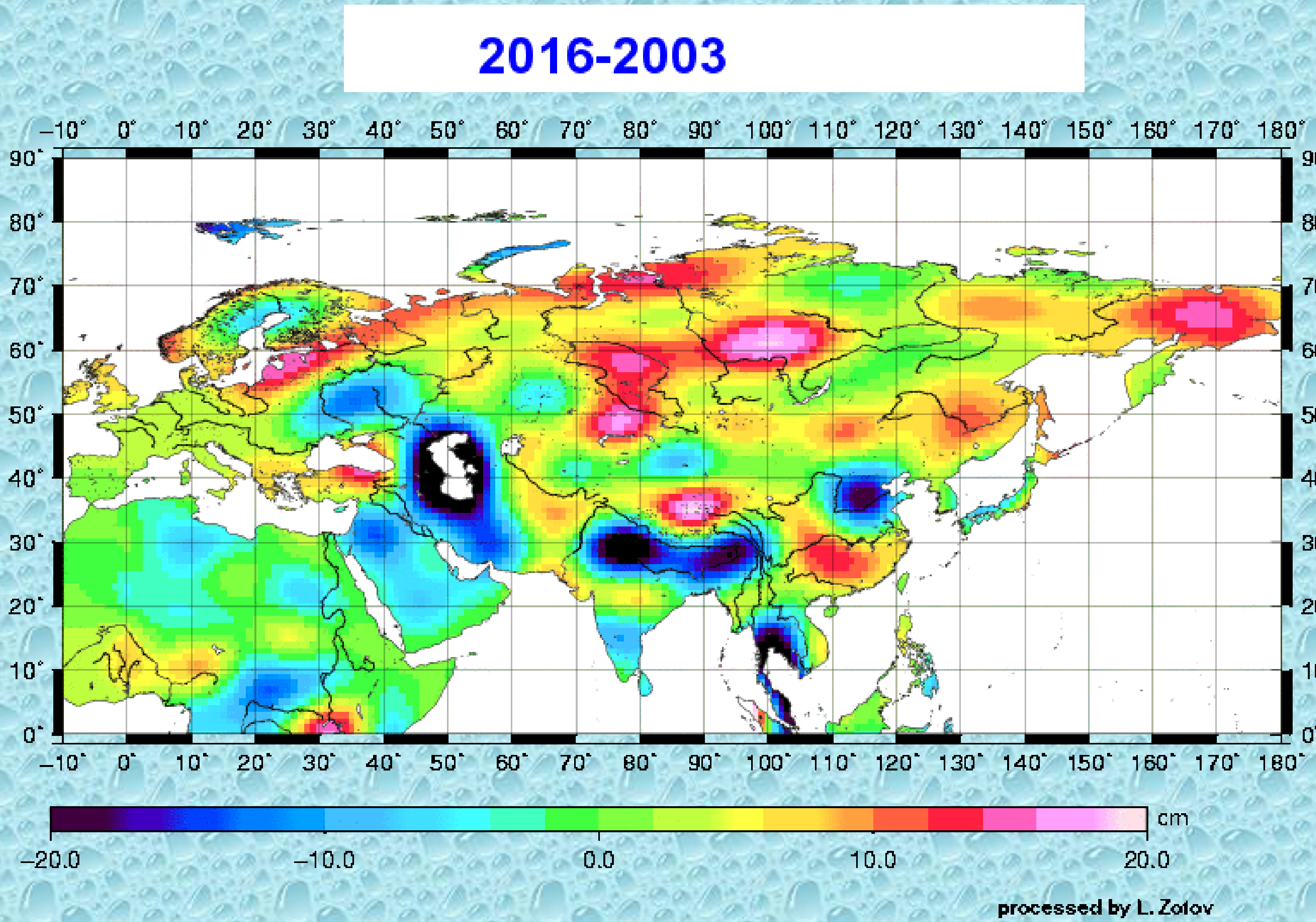
Changes over 15 large Russian rivers



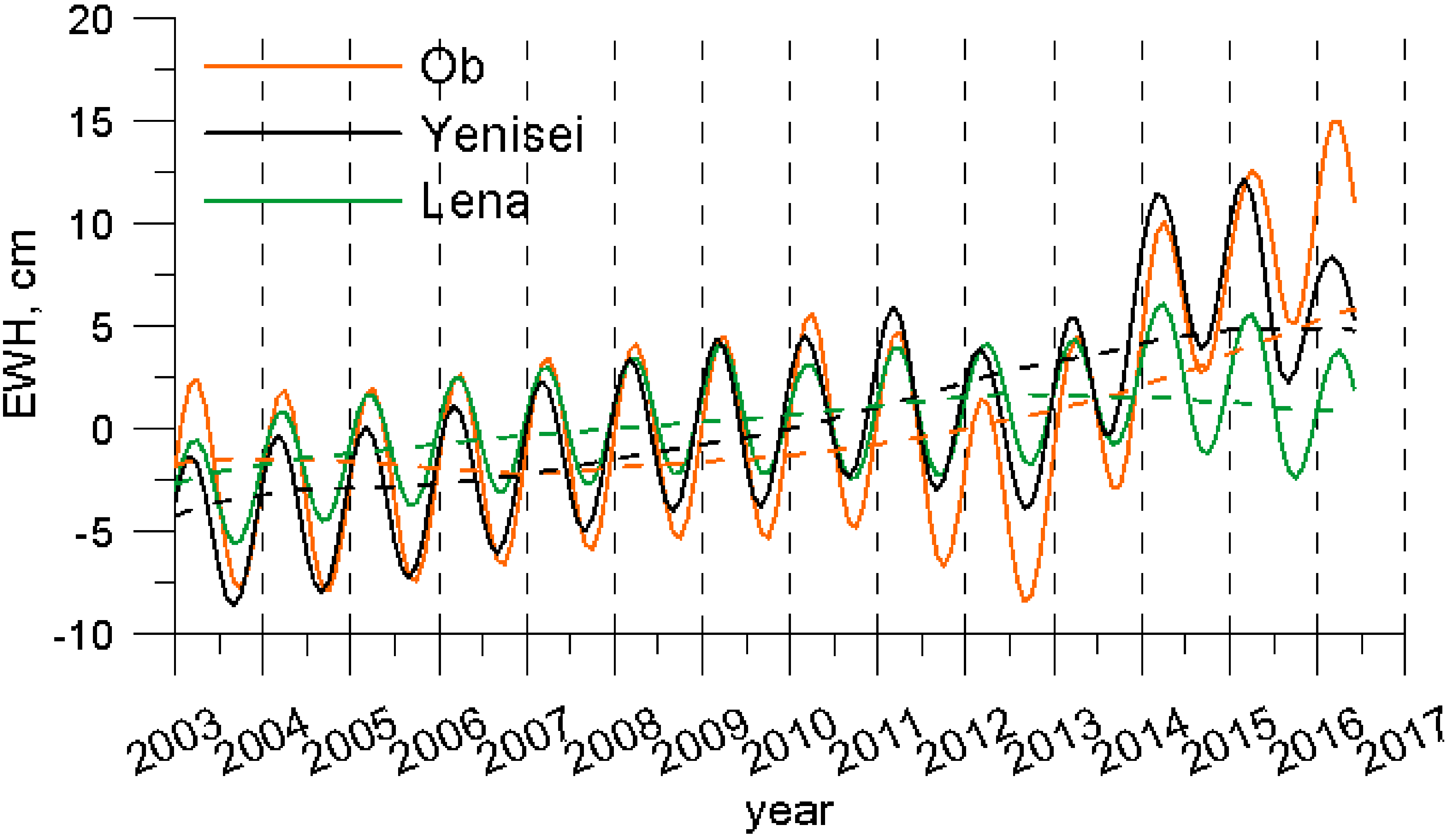
Mass anomaly (averaged field)
In the basins of 15 large rivers or Russia



The difference between 2016 and 2003 trend (PC 1)

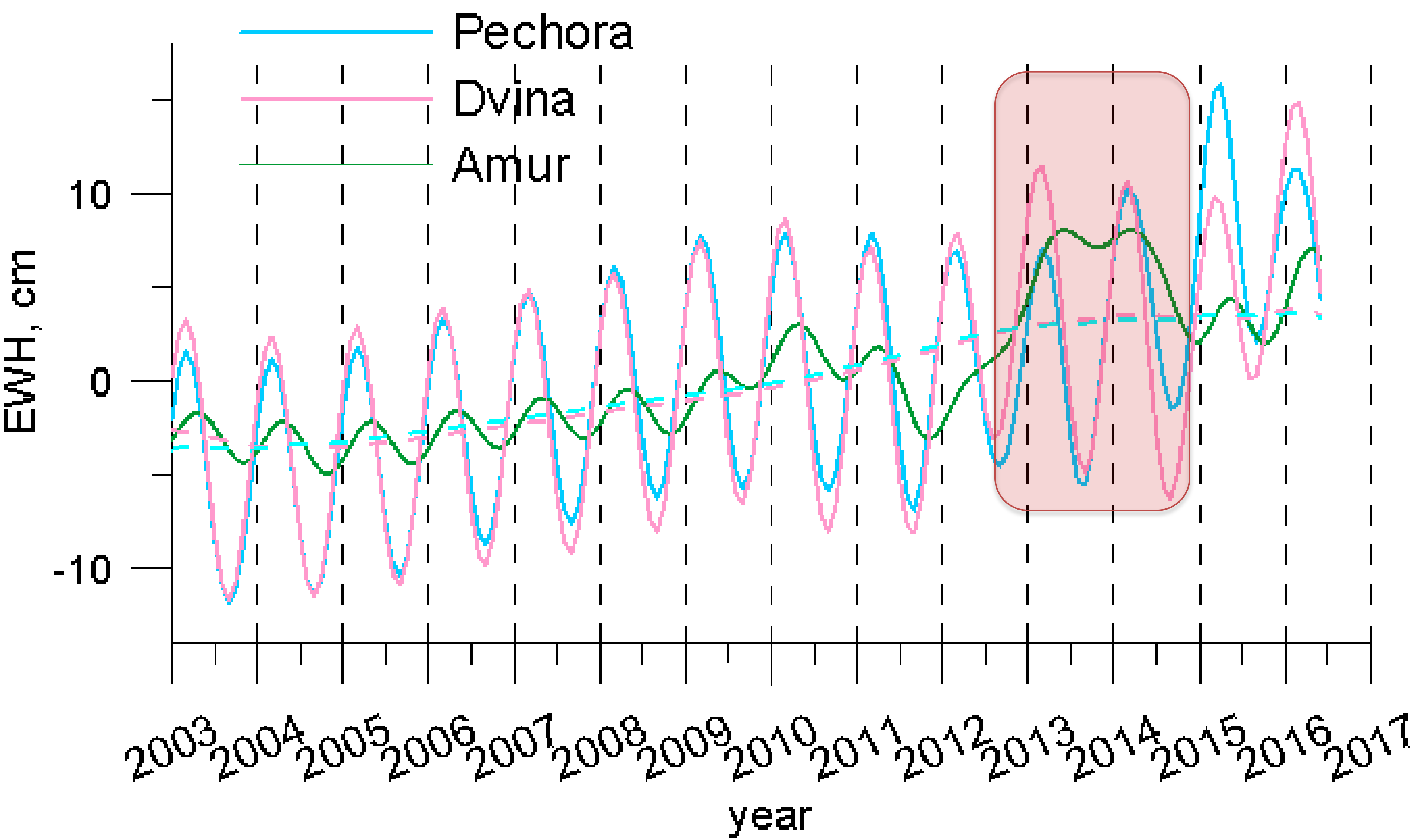


Changes in the Siberia river basins



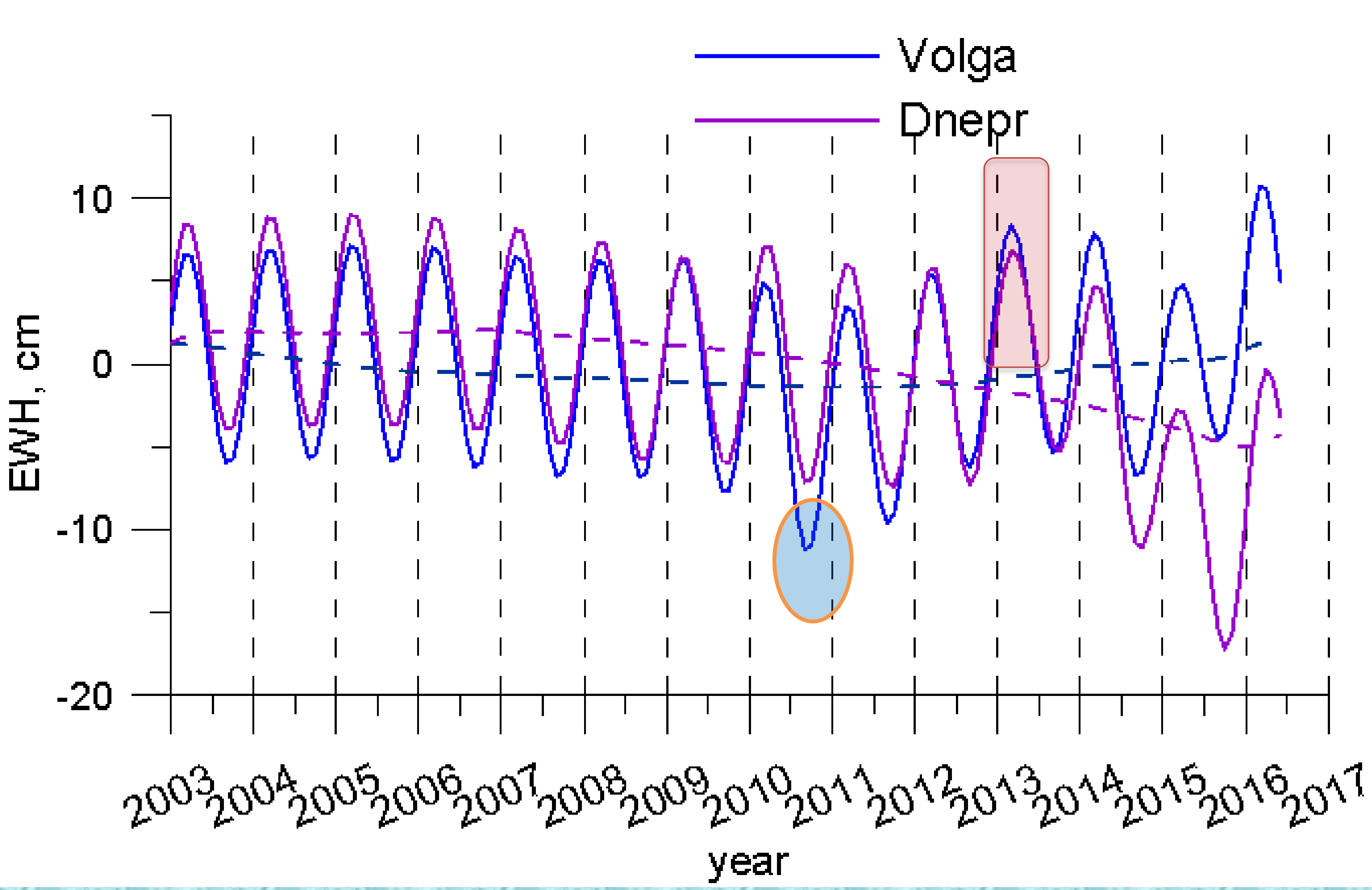
EWH scale – equivalent water height

Mass changes
In Amur and northern river basins

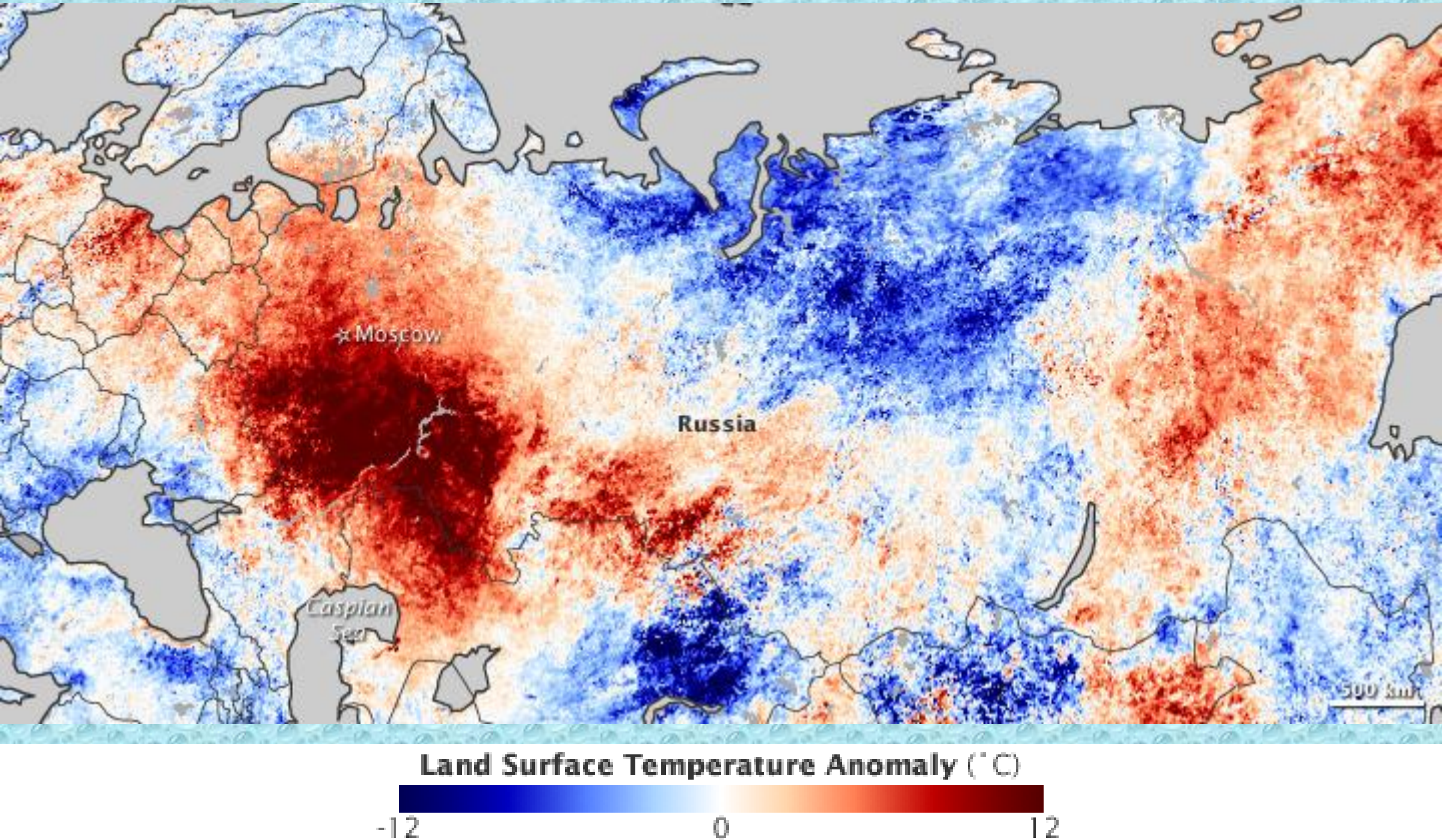


Amur flood

Changes in the basins of the European river basins

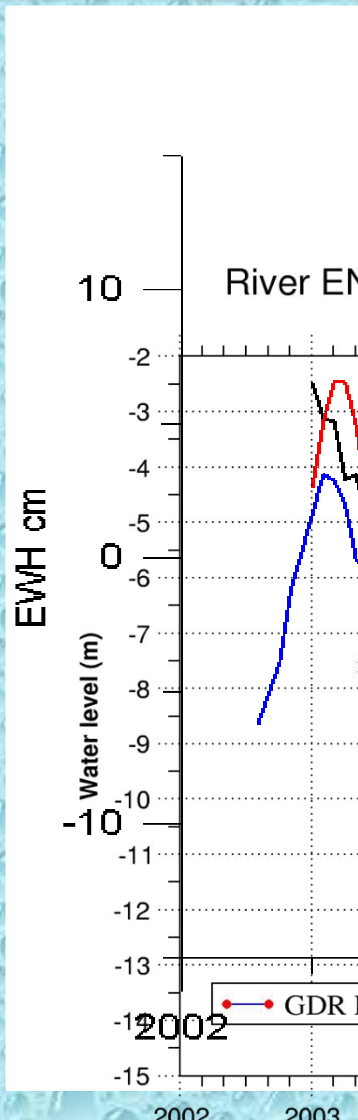


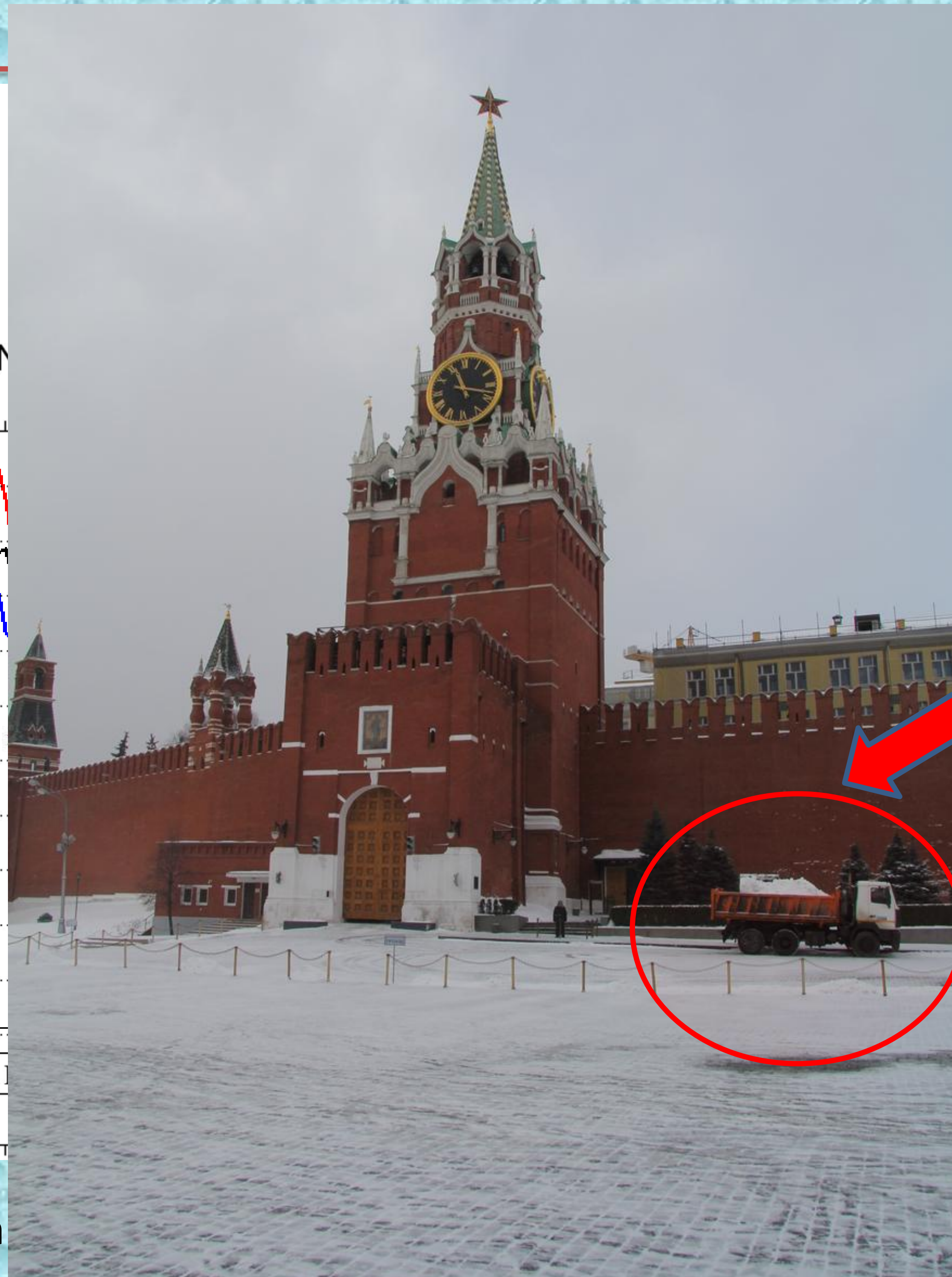
Anomalous heat wave in Moscow, Russia 20-27 July 2010
Compared to average over 2000-2008, MODIS, Terra

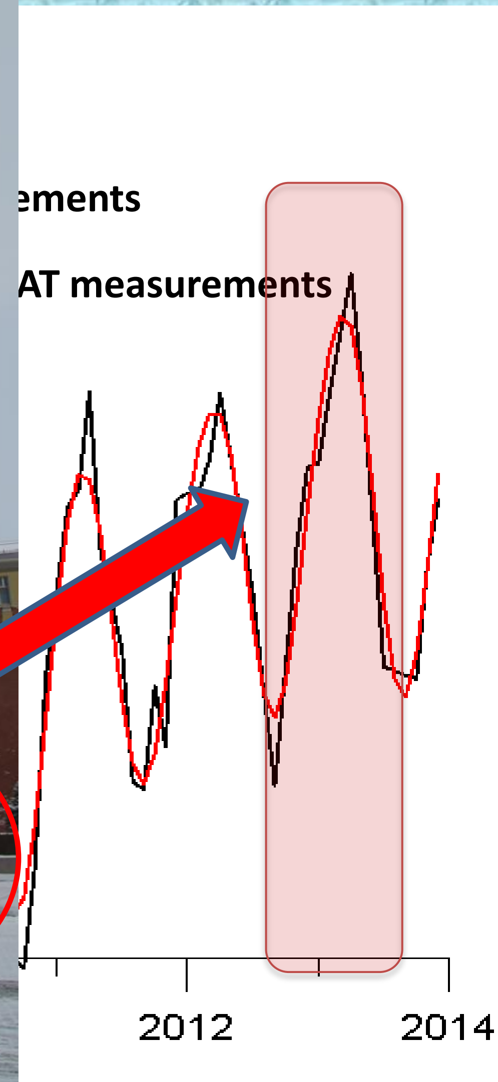



Moscow heat wave 2010

Comparison with data from hydrological web
CYcle de l’eau et de la Matière dans les bassins vErsaNTs (CYMENT)





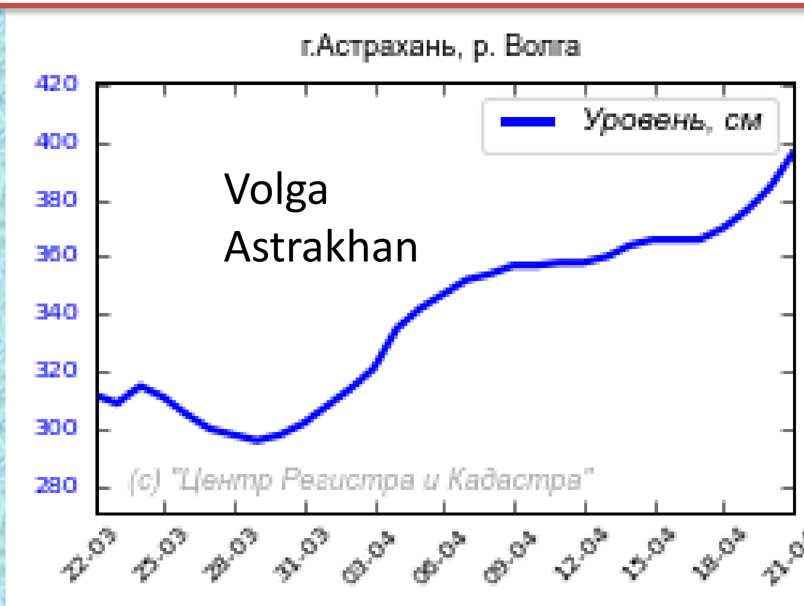


CYMENT data from roweb/

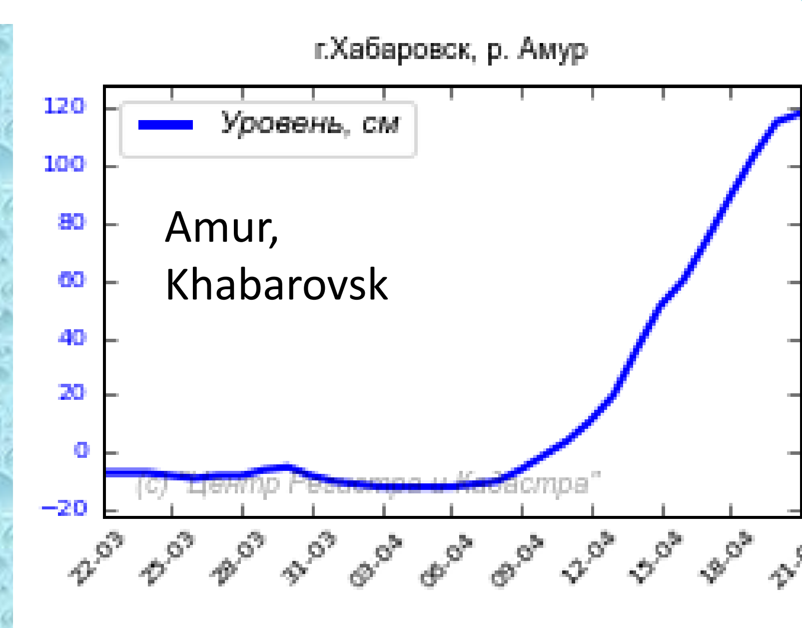
ЦЕНТР регистра и кадастра

Информационное обеспечение оперативного управления водными ресурсами и противопаводковыми мероприятиями для бассейнов рек России 2013

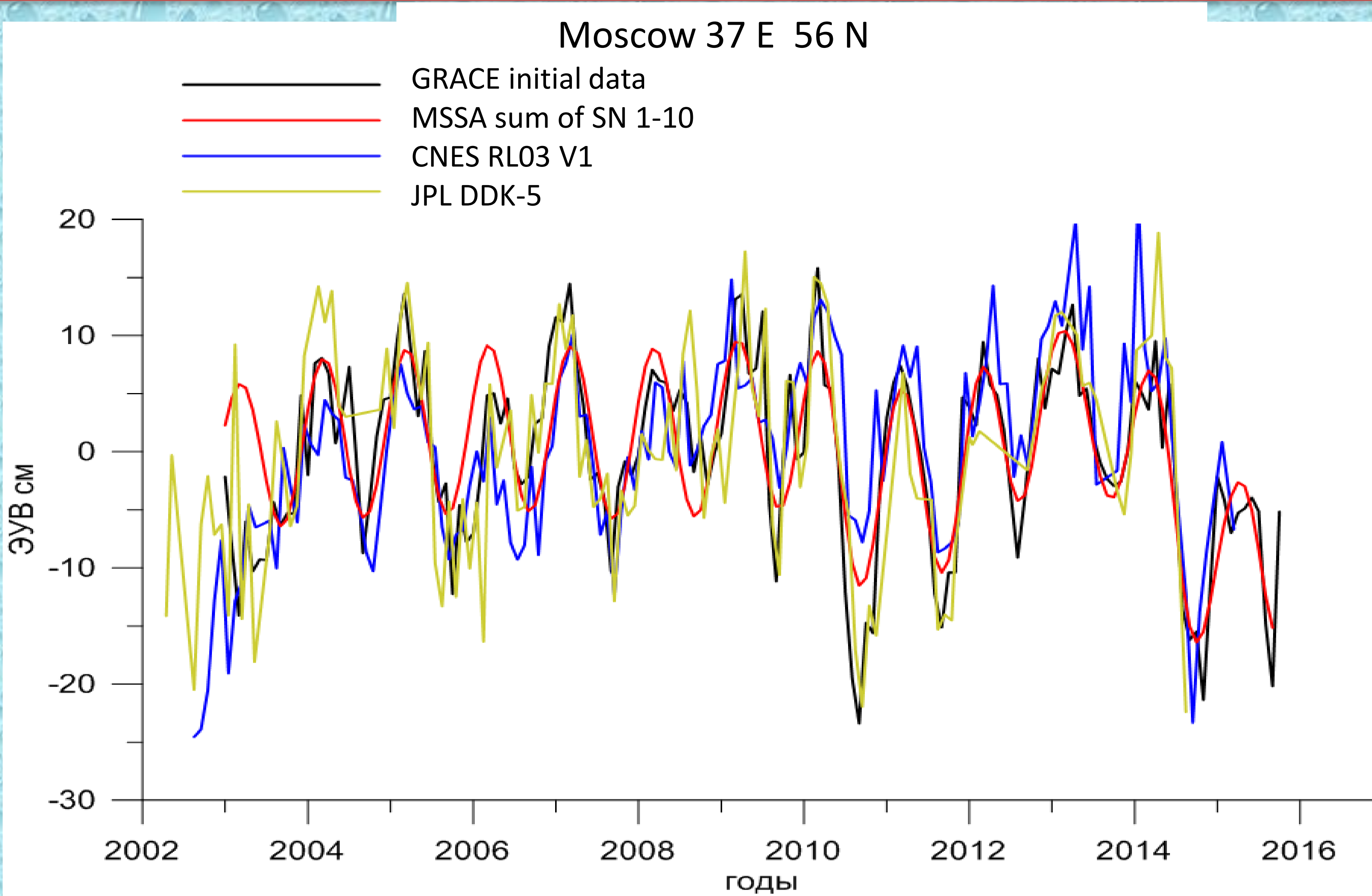
cm



cm

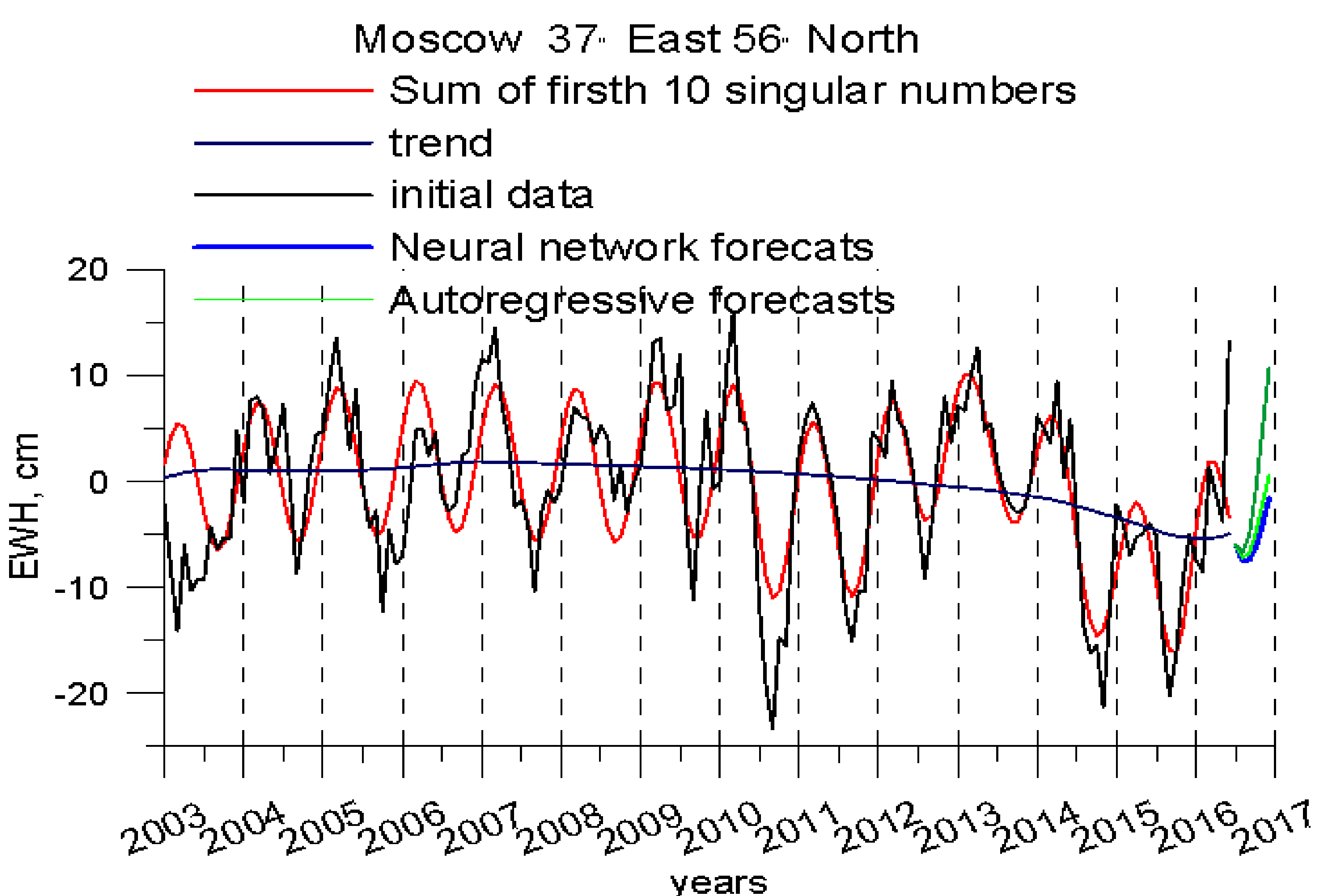


Comparison with CNES/GRGS RL 03 for Moscow



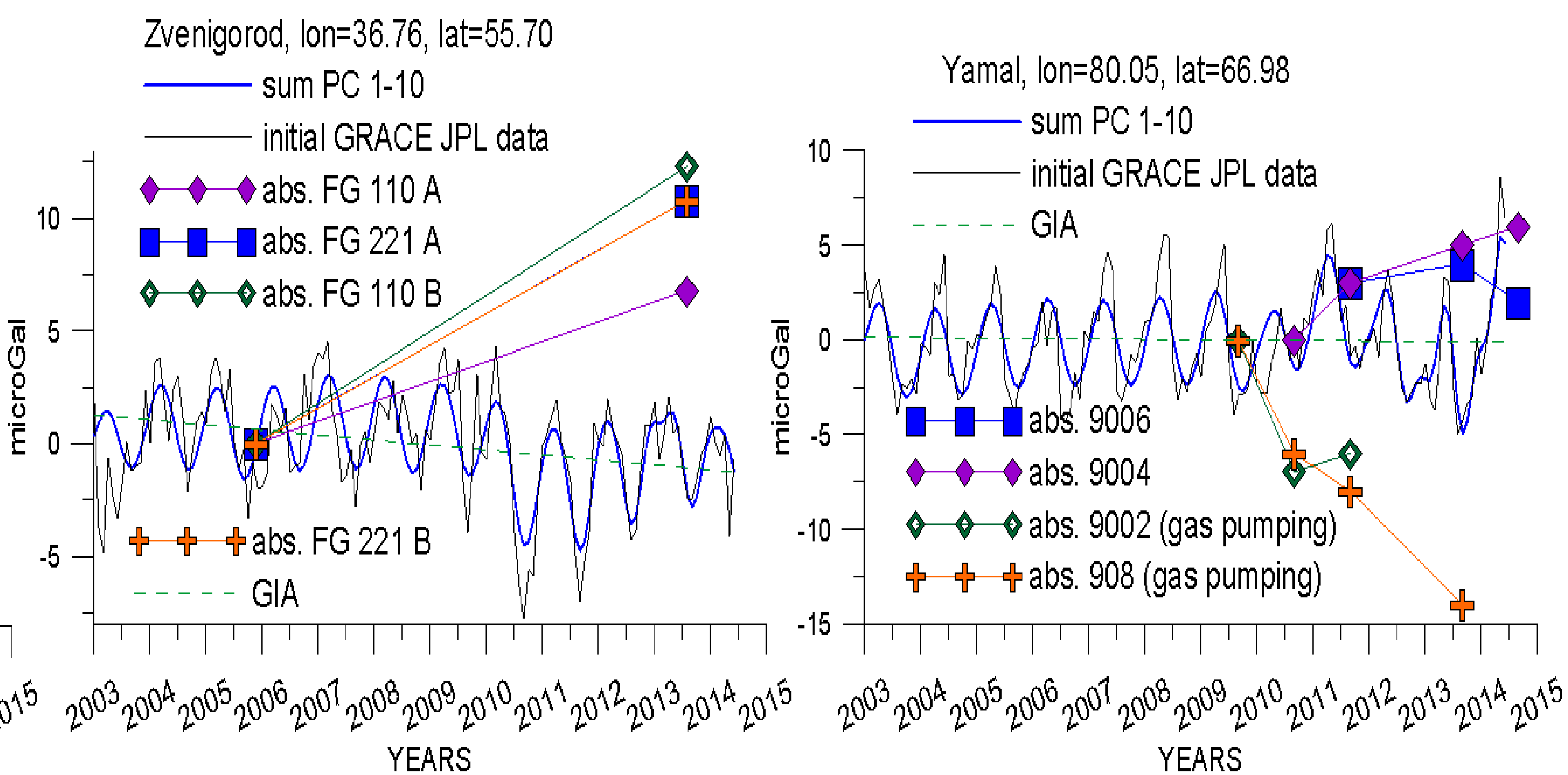
CNES and JPL plots from http://www.thegraceplotter.com/

Difficulty of prediction



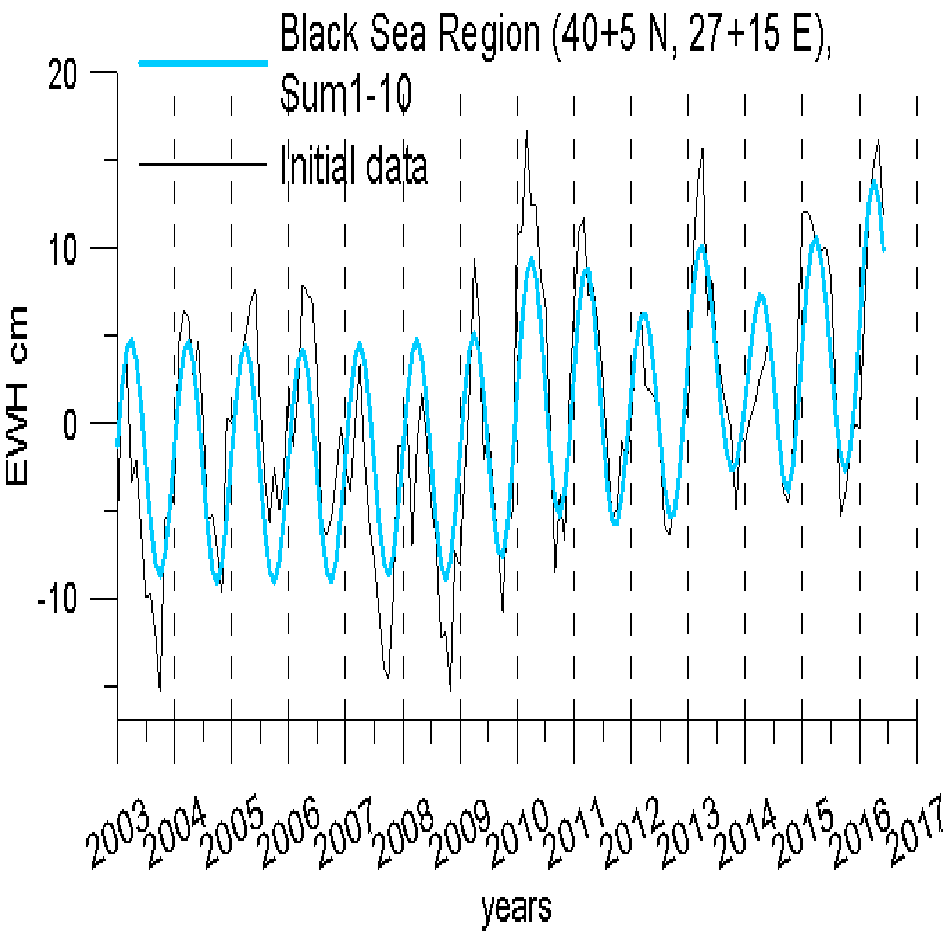
Gravity changes over Russia from GRACE and absolute gravimetry

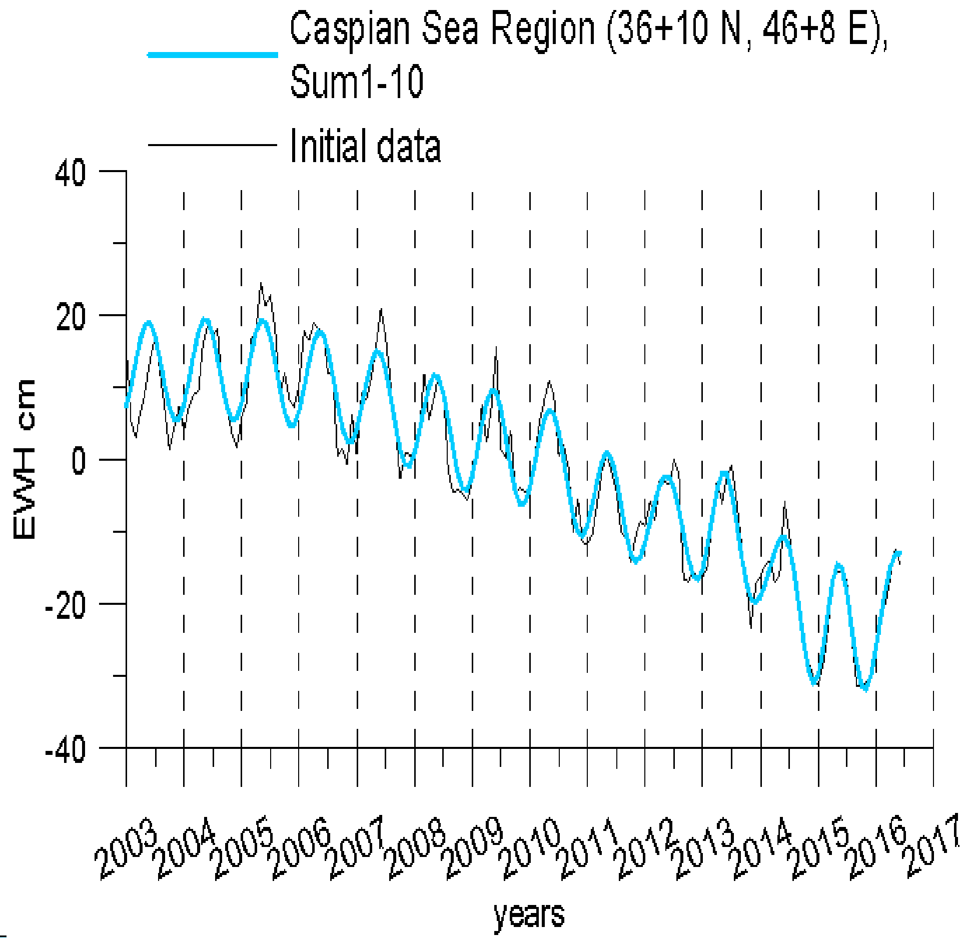
Leonid Zotov[1,5] (*wolftempus@gmail.com*), Viktor Yushkin[1,2], Jaakko Makinen[3], Mirjam Bilker-Koivula[3], Roman Sermyagin[2] and Natalya Frolova[4]



GRACE Science Team Meeting 2014 Sep 29 to Oct 1, 2014

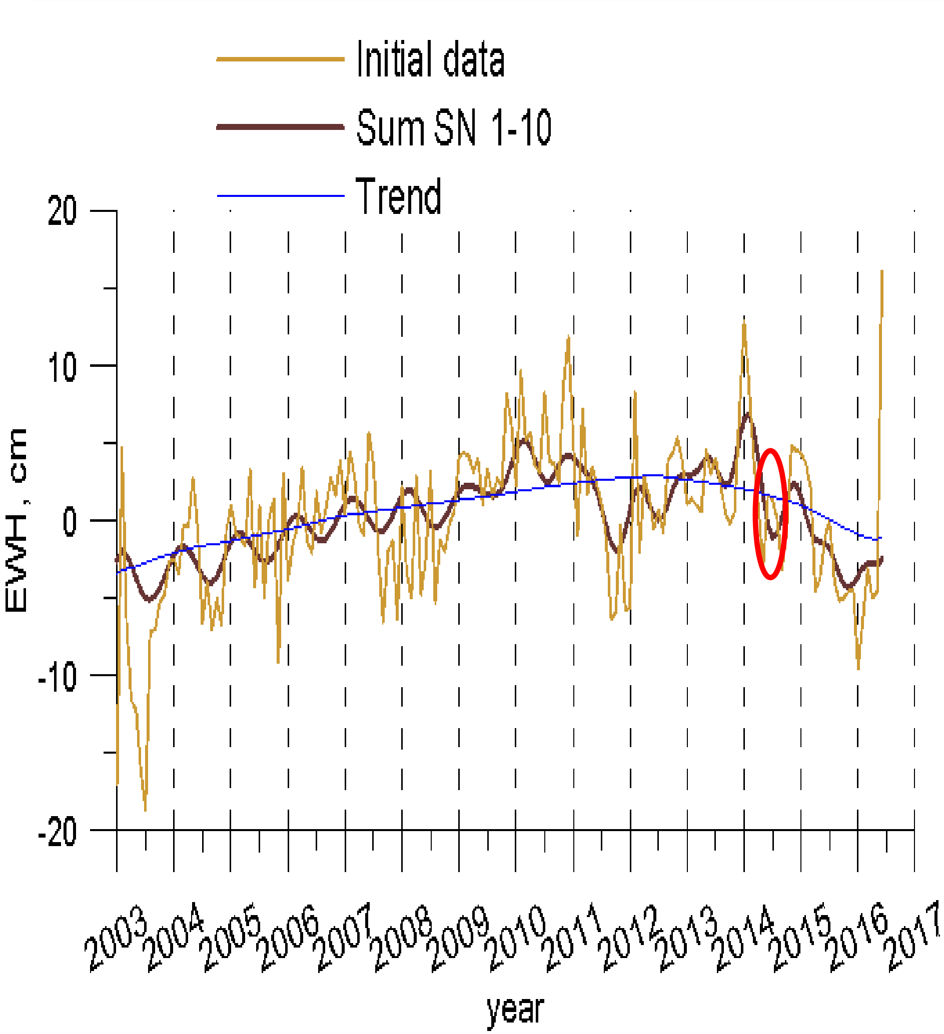
Black Sea and Caspian Sea levels, and OBP from GRACE

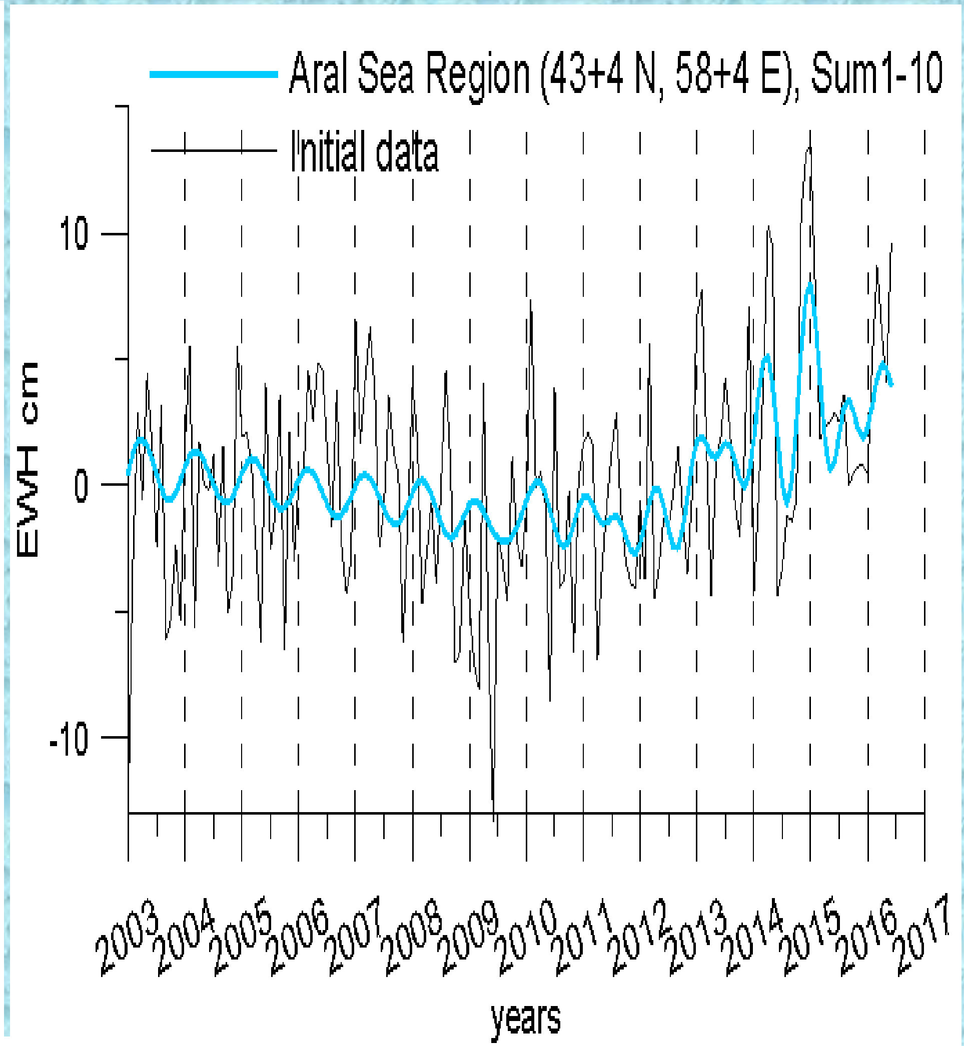




Initial and MSSA-processed GRACE data (with land hydrology)

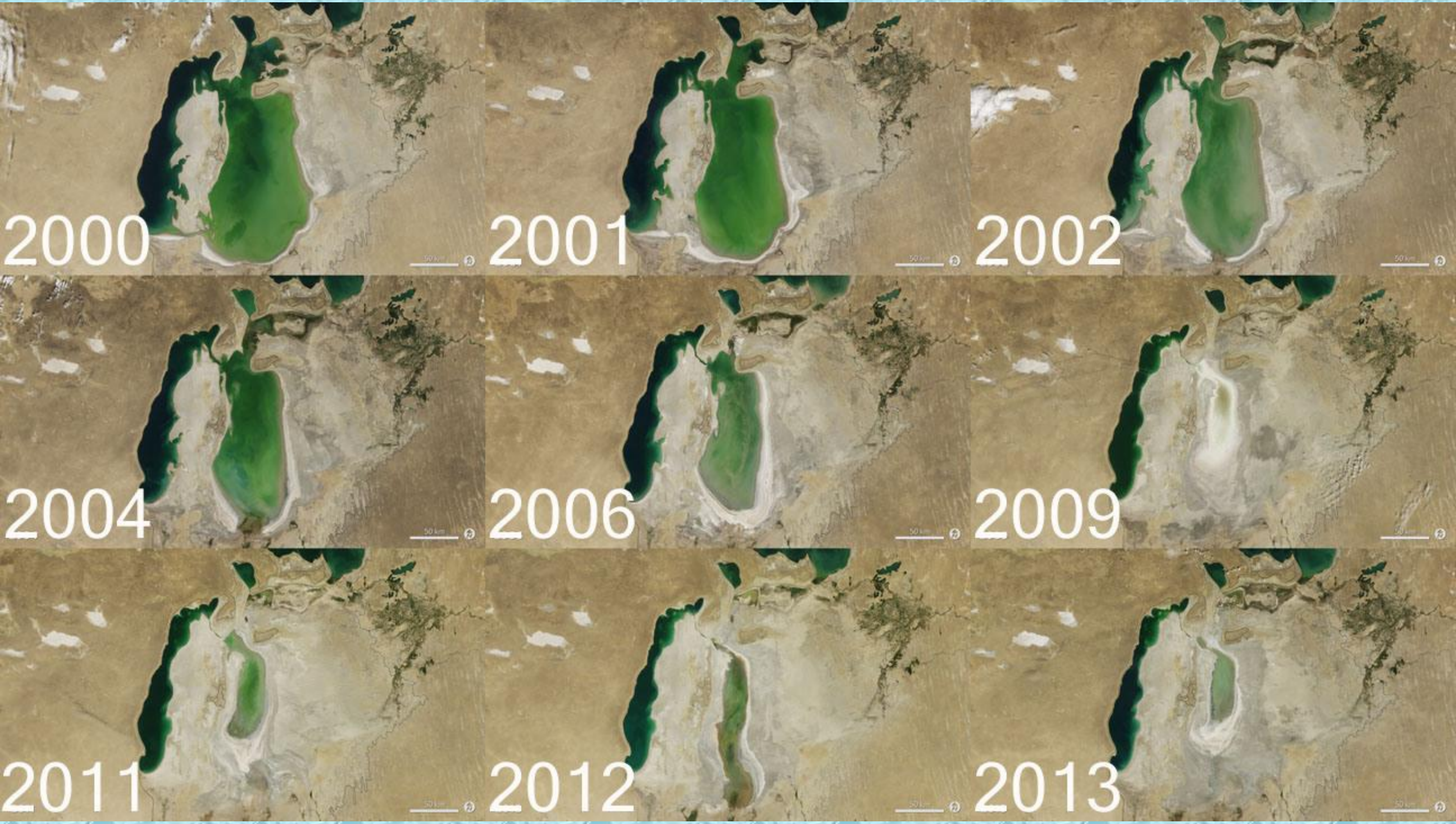
Baikal lake draft and Aral sea



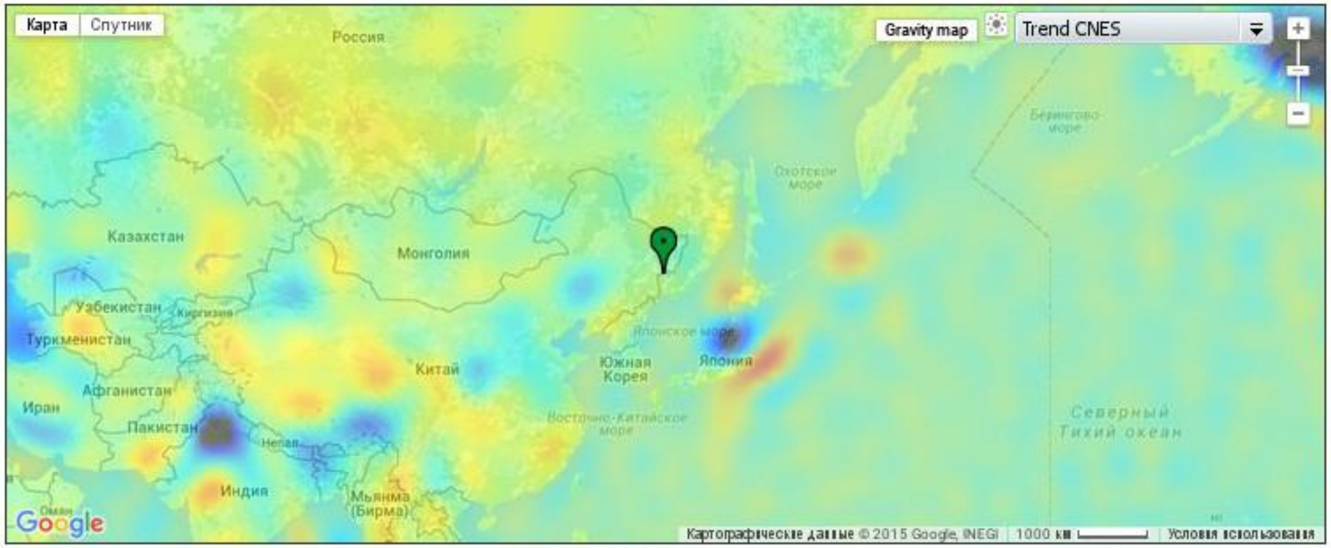


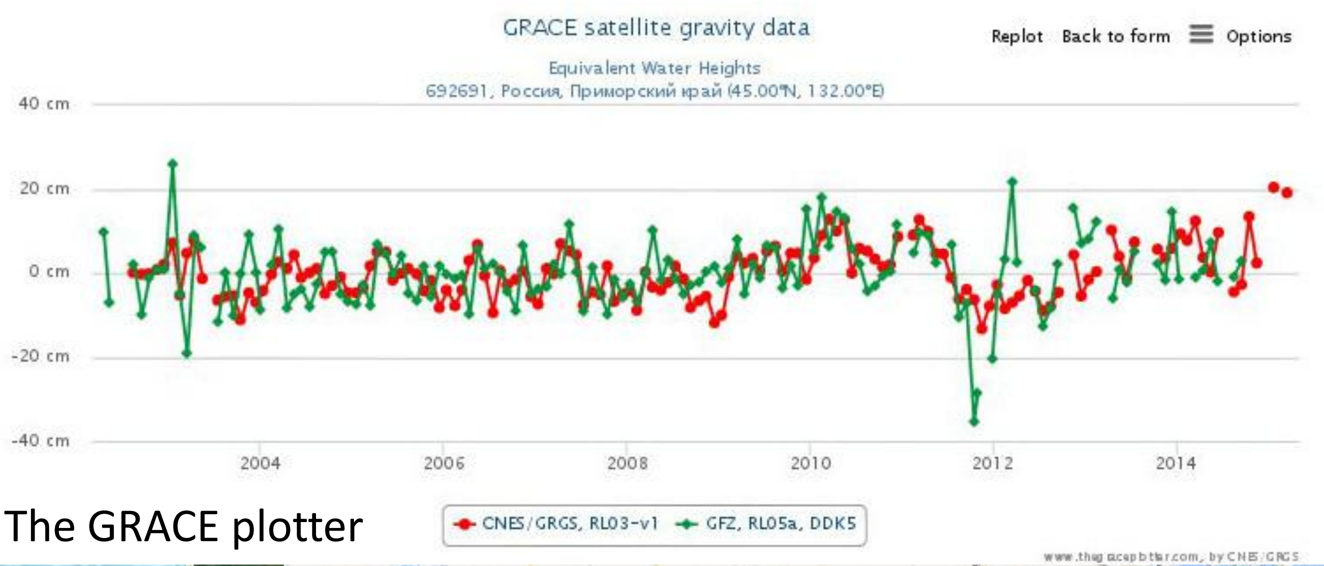
"Приток воды в озеро Байкал в июне составил 71% от нормы; в июле – 60% от нормы. Ожидается, что в августе он составит 37-60% от нормы, в сентябре – 35-66%; в целом в третьем квартале – 42-67%", - говорится в сообщении министерства.

Aral Sea

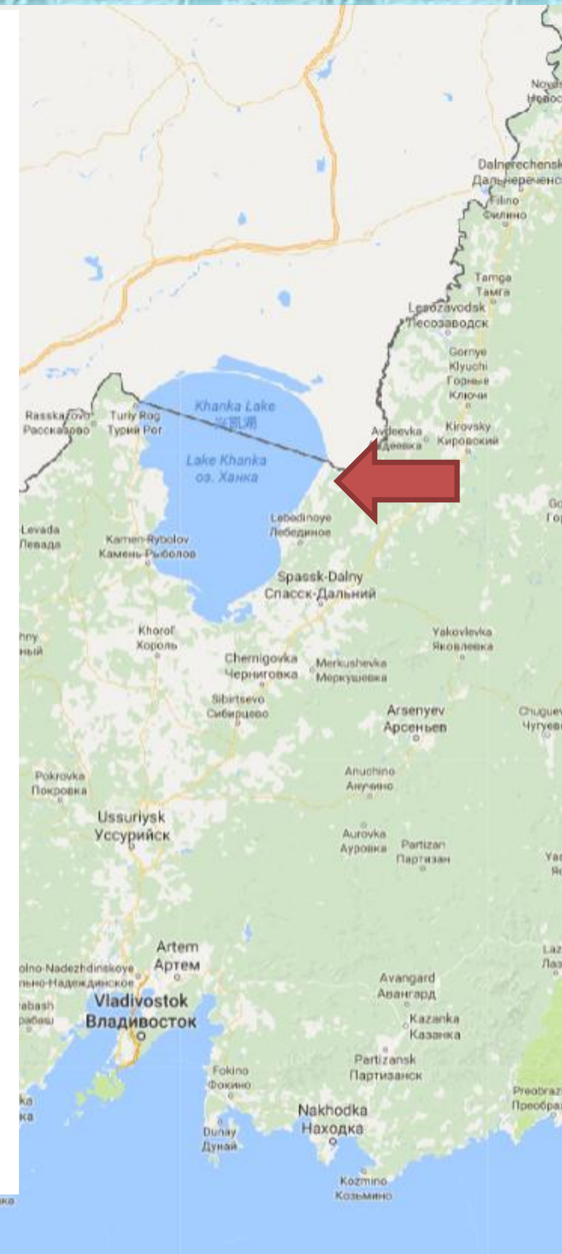


Khanka lake 兴凯湖

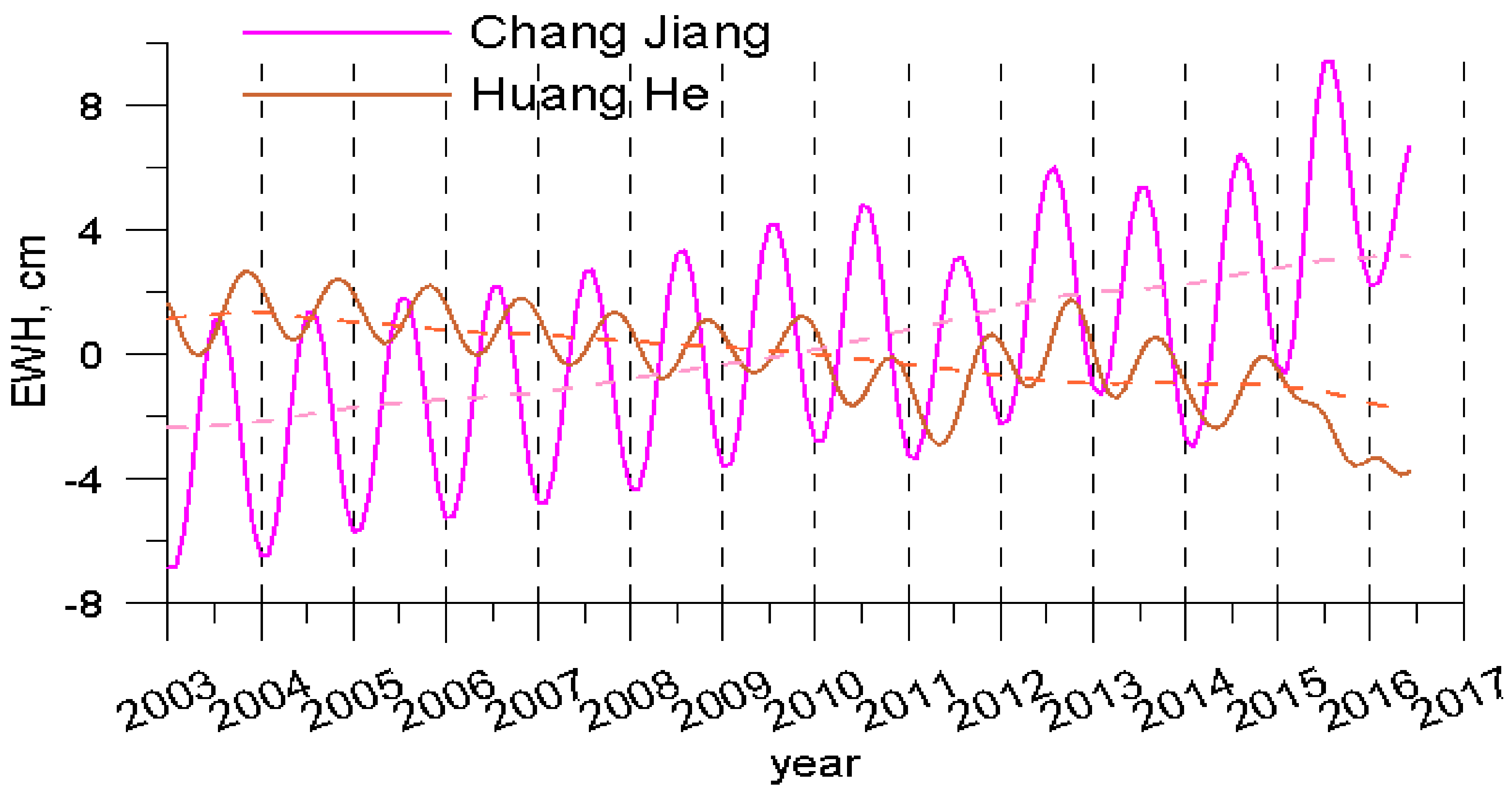




The GRACE plotter



Mass changes in the basins of large rivers of China



Global Land Data Assimilation System (GLDAS)

http://ldas.gsfc.nasa.gov/gldas/GLDASgoals.php

LDAS Land Data Assimilation Systems

Home | NLDAS | **GLDAS** | Resources | FAQ

General Information
- GLDAS News
- GLDAS Concept/Goals
- GLDAS Specifications
- GLDAS Participants

Parameters

Forcing Data

Model Output

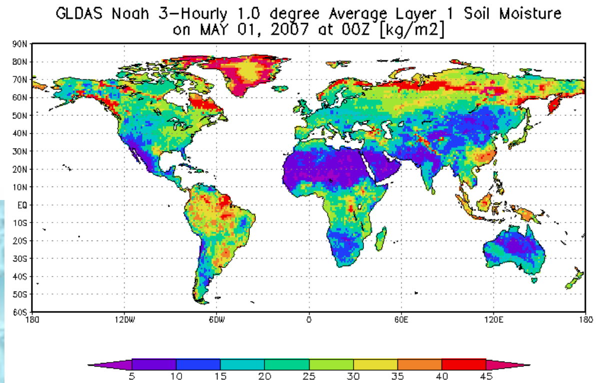
Presentations

Publications

GLDAS: Project Goals

The goal of the Global Land Data Assimilation System (GLDAS) is to ingest satellite- and ground-based observational data products, using advanced land surface modeling and data assimilation techniques, in order to generate optimal fields of land surface states and fluxes (Rodell et al., 2004a). The software, which has been streamlined and parallelized by the Land Information System (LIS) sister project, drives multiple, offline (not coupled to the atmosphere) land surface models, integrates a huge quantity of observation based data, executes globally at high resolutions (2.5-degrees to 1 km), and is capable of producing results in near-real time. A vegetation-based tiling approach is used to simulate sub-grid scale variability, with a 1-km global vegetation dataset as its basis. Soil and elevation parameters are based on high resolution global datasets. Observation-based precipitation and downward radiation products and the best available analyses from atmospheric data assimilation systems are employed to force the models. Intercomparison and validation of these products is being performed with the aim of identifying an optimal forcing scheme. Data assimilation techniques for incorporating satellite based hydrological products, including snow cover and water equivalent, soil moisture, surface temperature, and leaf area index, are now being implemented as part of a follow-on project funded by the NASA Energy and Water Cycle Study (NEWS) Initiative. The high-quality, global land surface fields provided by GLDAS support several current and proposed weather and climate prediction, water resources applications, and water cycle investigations. The project has resulted in a massive archive of modeled and observed, global, surface meteorological data, parameter maps, and output which includes 1-degree and 0.25-degree resolution 1979-present simulations of the Noah, CLM, VIC, and Mosaic land surface models.

Responsible NASA Official: Matthew Rodell
NLDAS Technical Contact: David Mocko
GLDAS Technical Contact: Hiroko Kato Beaudoing
Webmaster: Susannah Pearce



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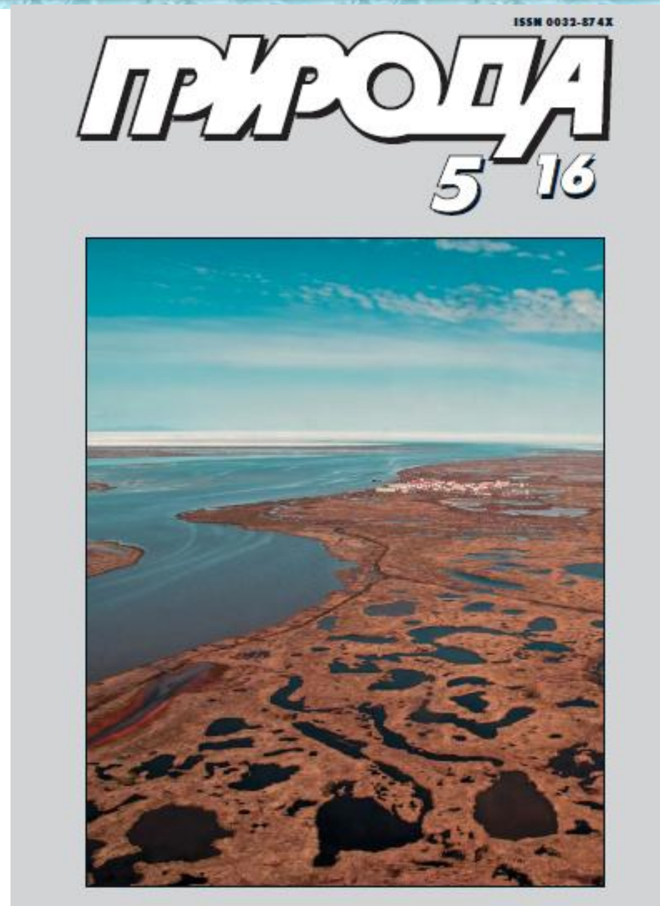
ECOMAG –
Hydrological model used in the Russian institute of water problems

Mass trends PC 1 in hydrology basins of large Russian rivers

Леонид Валентинович Зотов, кандидат физико-математических наук, доцент Московского института электроники и математики Национального исследовательского университета «Высшая школа экономики», старший научный сотрудник Государственного астрономического института имени П.К.Штернберга МГУ имени М.В.Ломоносова. Область научных интересов — вращение Земли, гравитационное поле, климатические изменения.

Наталья Леонидовна Фролова, профессор, доктор географических наук, заведующая кафедрой гидрологии суши географического факультета Московского государственного университета имени М.В.Ломоносова. Занимается изучением стока рек, дистанционными методами исследования Земли, горной гидрологией.

С.К.Шам (C.K.Shum), профессор отделения геодезии Школы наук о Земле Университета штата Огайо (г.Колумбус, США). Один из авторов отчета IPCC по климату 2007 г. Специалист в области климатических изменений, спутниковой геодезии, геодинамики, исследований системы моря, данных GRACE.



3 **Зотов Л.В., Фролова Н.Л., Шам С.К.**

Гравитационные аномалии в бассейнах крупных рек России

Спутниковая система GRACE, действующая на орбите Земли с 2002 г., позволяет изучать гравитационные аномалии и их временные вариации, обусловленные процессами массопереноса в оболочках Земли. На основе анализа гравитационных отклонений, зарегистрированных с помощью спутников GRACE, удалось оценить изменчивость влагозапаса бассейнов 15 крупнейших рек России за последние 13 лет.

Conclusions

- GRACE gravity information allows to study mass redistribution in the Earth systems, including the hydrological changes
- Multichannel Singular Spectrum Analysis is a useful method for satellite data processing
- Data, averaged in the large river basins clearly show anomalies related to floods and drafts
- The climatologically trend over Russian territory show the increase of mass in Lena and Irtysh basins, what can be related to permafrost degradation over 12 years. The negative anomaly over Caspian sea could be related to its level decrease as a result of Volga river discharge decrease.
- GRACE data can be also used for oceanography and non-steric sea level rise estimation
- USA and China are actively competing for the launch of GRACE Follow-on mission. GRACE satellites have been working 3 times longer than there expected period and should be replaced in 2017. The GRACE-FO mission will be sufficiently better laser range measurements will be 100 times more precise). Russian space agency is also interested in space gravity missions.

The attendance at the conference is supported by NRU HSE and Dr. Wenbin Shen


Thank you for attention!