Gravity changes over Russian rivers basins from GRACE

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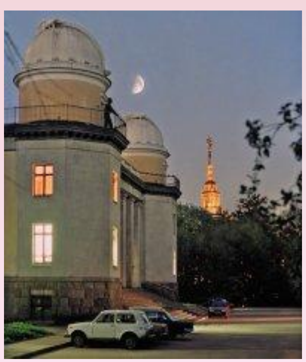
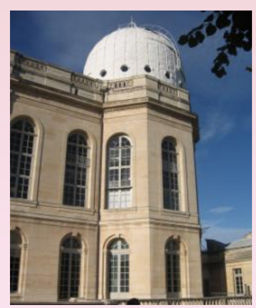




20 May 2014
CNES, Toulouse, France

Satellites give hydrological data, which present in

Passive (SSM/I) and active (ERS) microwave radars data

Visual light and near infrared (AVHRR) images

Altimetry data (JASON, Envisat, ERS)

Soil moisture data (SMOS)

Atmospheric precipitation and humidity profiles

Gravity measurements (GRACE, GOCE)

Hydrological mass changes are related to

Levels of rivers and lakes

Water stored in soil and in biomass

Snow cover

Precipitation

Gravity field studies can be useful for

Hydrological, meteorological, climatological research.
For example, Climate Change influence river's water balance, permafrost, changes water discharge to the ocean, sea level, water and ice regime of Arctica.
Mass redistributions influence Earth rotation.
The whole set of geodetic and geodynamical questions is involved.
Their study could be important for rational natural resources management, construction, etc.

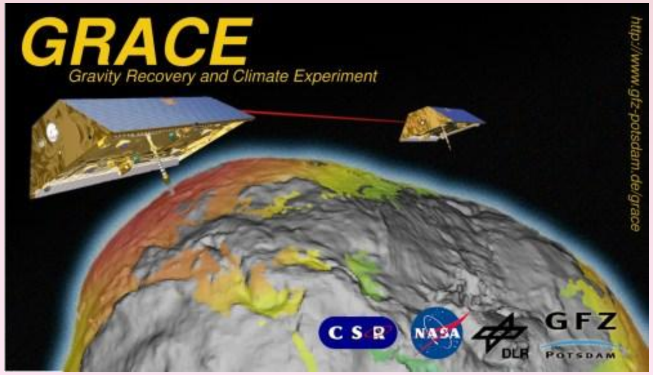
Gravity space missions

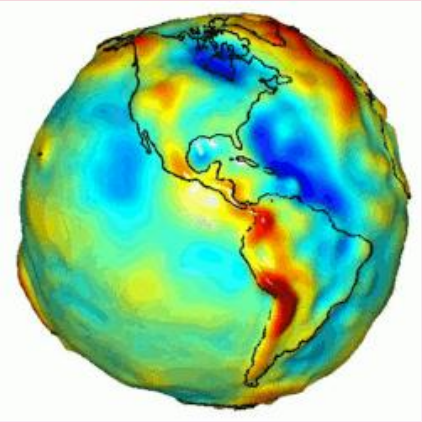
CHAMP – launched by GFZ in July, 2000 to an orbit of ~ 450 km altitude. For gravity and magnetic field research. The data span is ~ 8 years.

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.

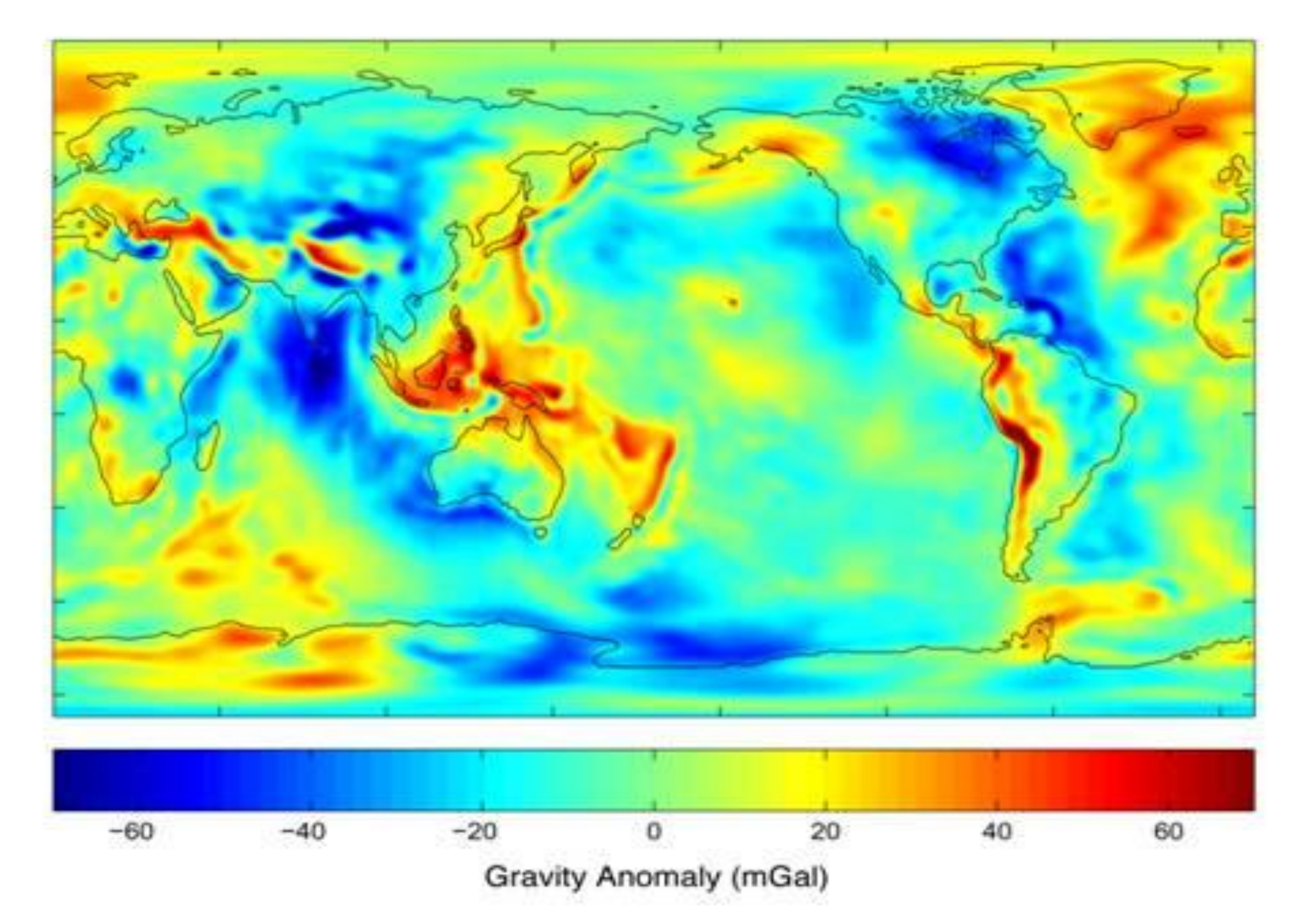
The basic measurement is the distance between the satellites and its rate, changing under the influence of the accelerations caused by the flight over the mass sources. Mission extended to 2017.

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.





GRACE Earth's gravity field model (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 used JPL Level-2 RL05 monthly GRACE spherical harmonic data since 01.2003 till 12.2013 with coefficients complete to degree and order 60.

Accumulator power shortage and economy caused absance of data for some months. Only January (01.01-17.01) L2 file is delivered in 2014.

Eight files (06.03, 01.11, 06.11, 05.12, 10.12, 03.13, 08.13, 09.13) were linearly interpolated (overall *N*=132 files used).

C_{20} coefficients were replaced by SLR-derived.

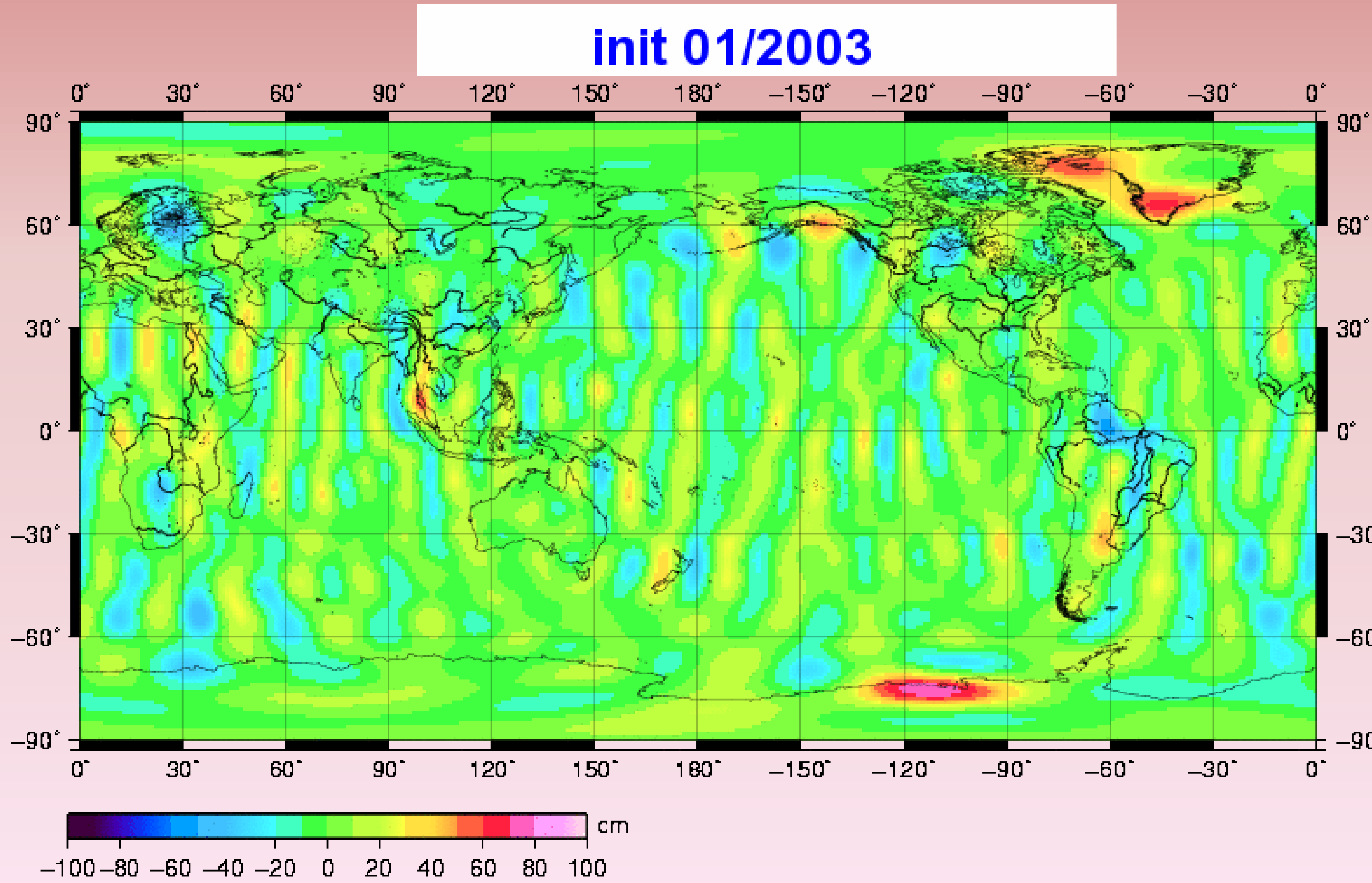
Average field over 10 years was subtracted.

GIA effect was removed according to Paulson 2007 model.

Results are represented in equivalent water height (EWH) level

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

Initial data GRACE JPL RL05 Level 2



Equivalent Water Height (EWH)

Multichannel Singular Spectrum Analysis is a generalization of the principal components analysis (PCA)

1) The delay parameter *L* is chosen. For each component of a multidimensional time series the trajectory matrix is constructed. In our case - the channel (component) are Stokes coefficients *Aij* (*Cij* or *Sij*). Trajectory matrixes for all the components are embedded into the large block matrix *X*

$$X_{A_{ij}} = \begin{pmatrix} A_{ij}(t_0) & A_{ij}(t_1) & \dots & A_{ij}(t_{K-1}) \\ A_{ij}(t_1) & A_{ij}(t_2) & \dots & A_{ij}(t_K) \\ \dots & \dots & \dots & \dots \\ A_{ij}(t_{L-1}) & A_{ij}(t_L) & \dots & A_{ij}(t_{N-1}) \end{pmatrix}$$

$$K = N - L + 1$$

$$X = [X_{A_{1,1}}, X_{A_{2,1}}, X_{A_{1,2}} \dots, X_{A_{ij}}, \dots, X_{A_{P-1,Q}}, X_{A_{P,Q}}]^T$$

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

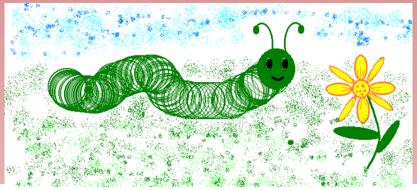
$$X = USV^T$$

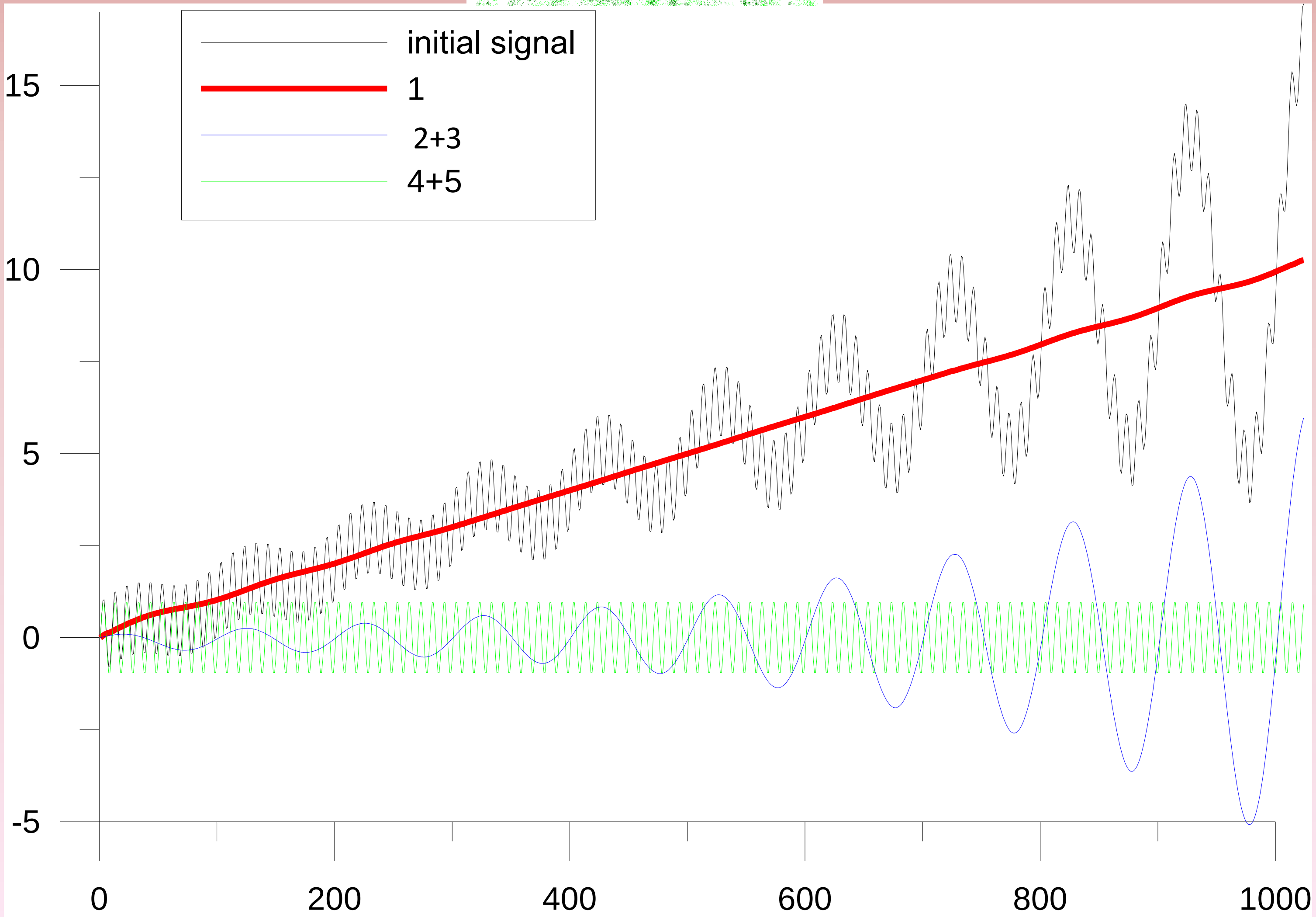
3) Principal components (PC) correspond to every singular number s_i. The components with similar properties are grouped and their matrixes are obtained by multiplying of s_i by the first and the second singular basis vectors u_i,v_i

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

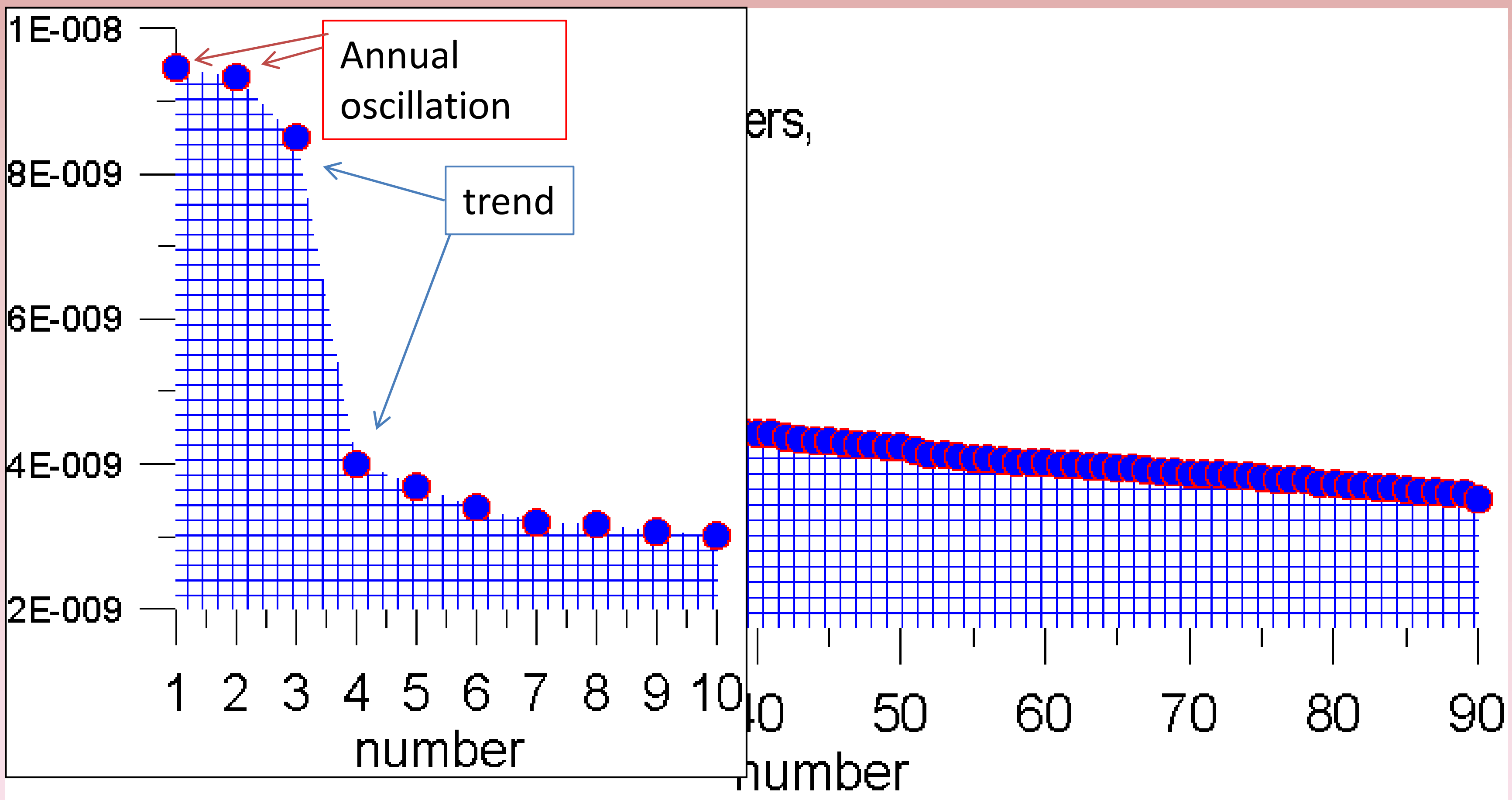
4) Signal in each channel is reconstructed from the X^i matrixes for each PC by averaging along the side diagonals (operation of Hankelization).

1D Caterpillar – SSA method



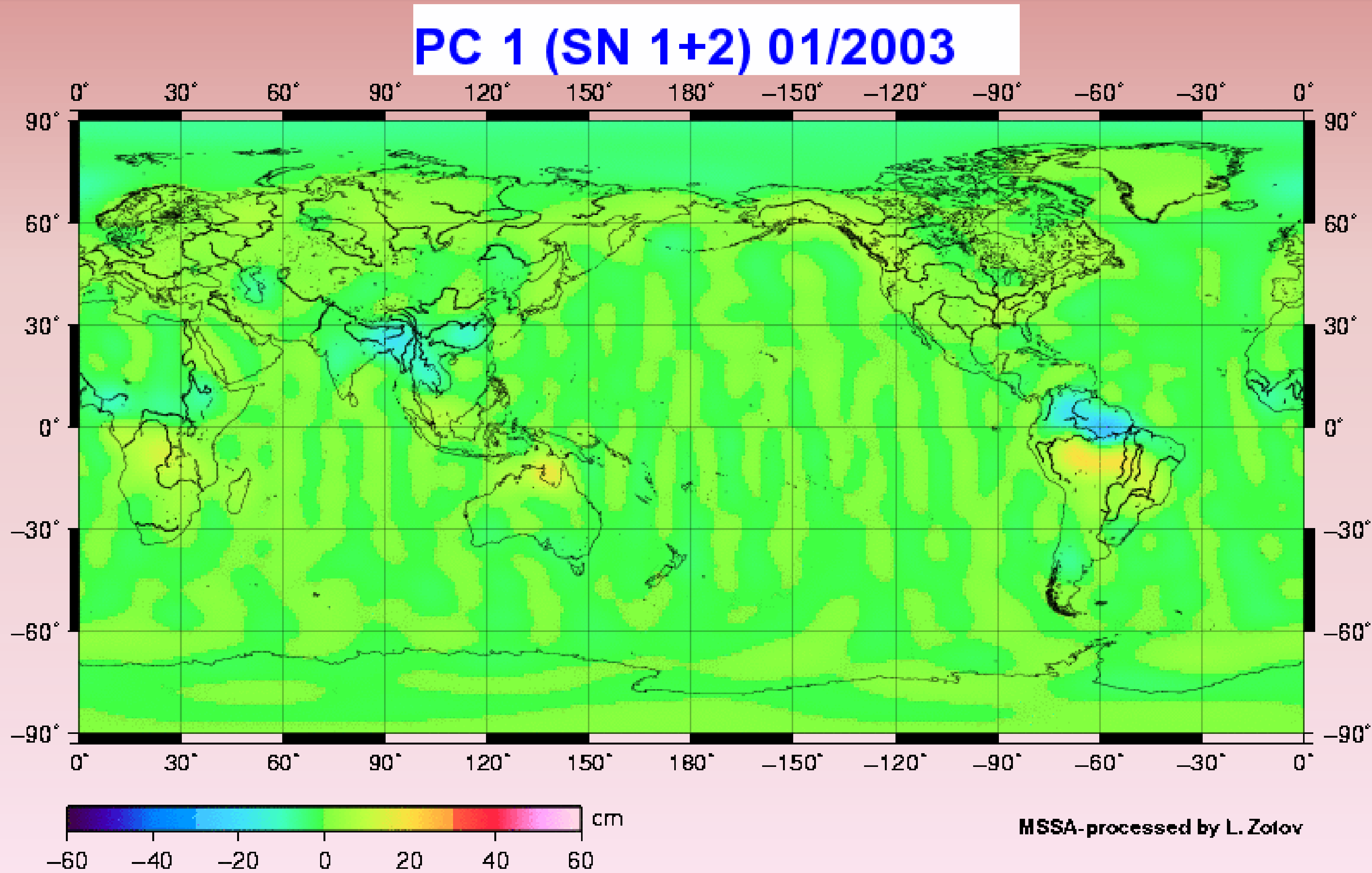


MSSA of GRACE data – singular numbers L=48 months (4 years)



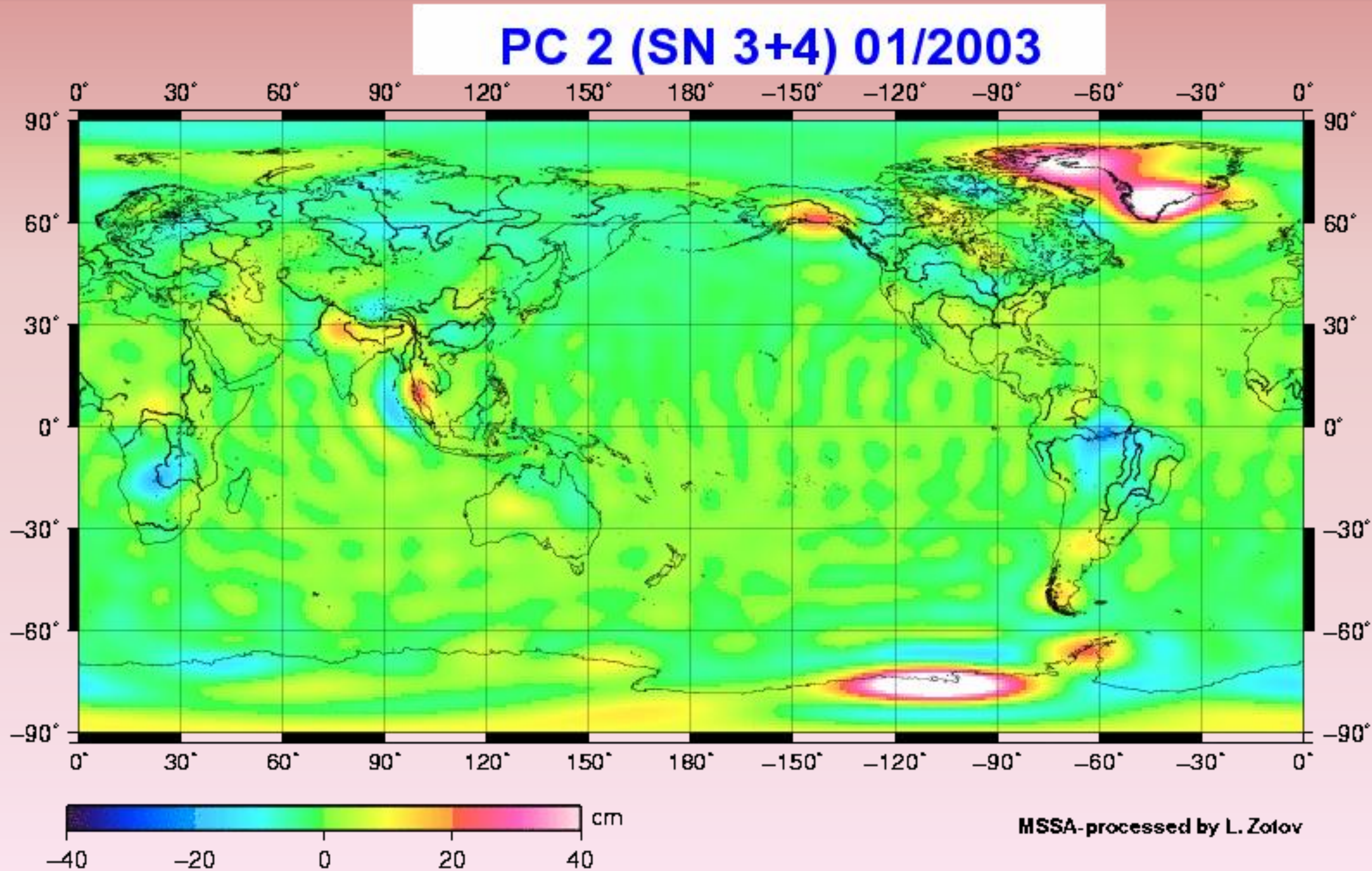
L. Zotov, C.K. Shum. Singular spectrum analysis of GRACE observations, American Institute of Physics Proceedings, of the 9th Gamow summer school, 2009, Odessa, Ukraine.

Annual cycle – PC 1



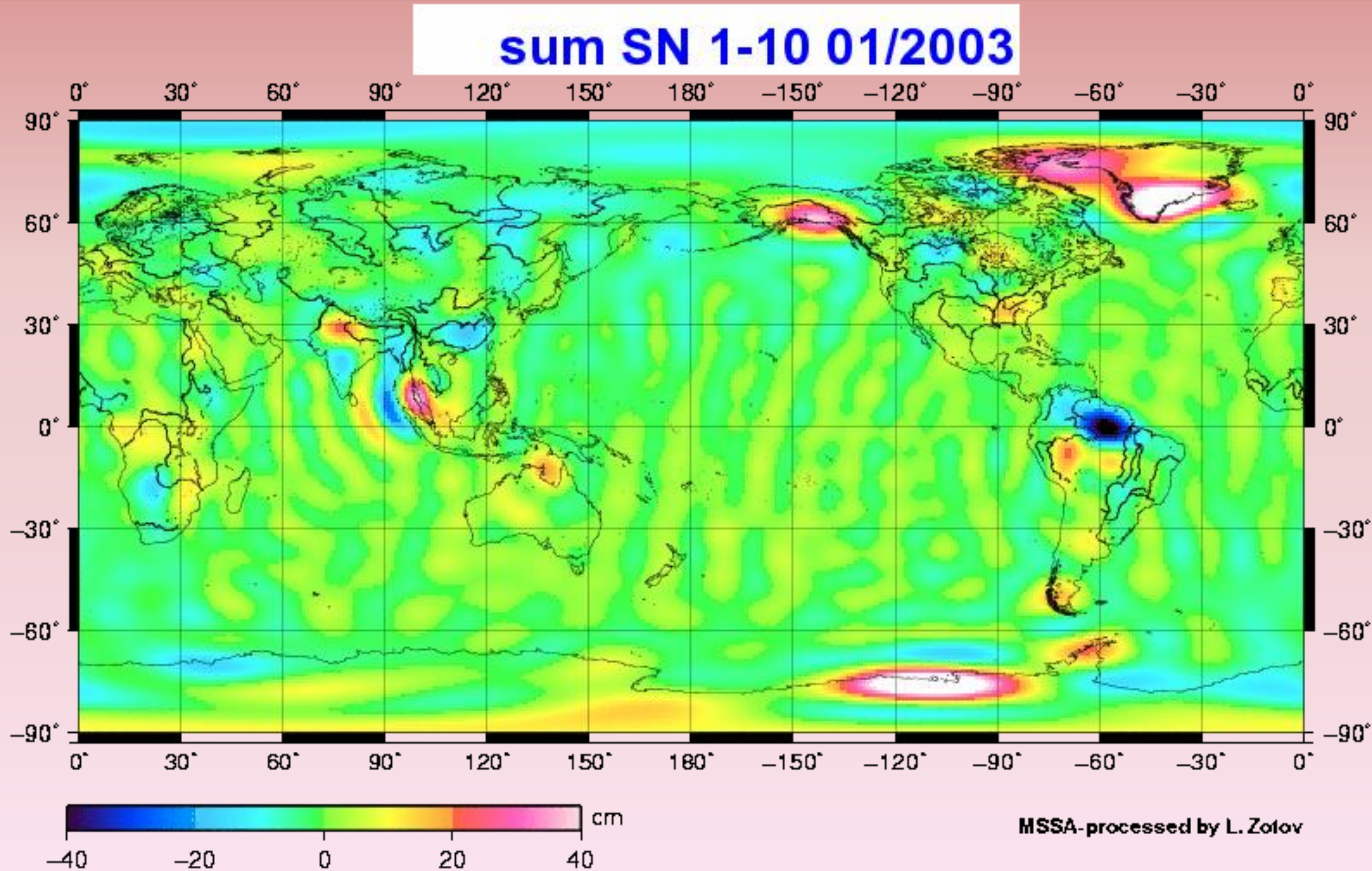
MCCA, L=48 months

Trend - PC 2



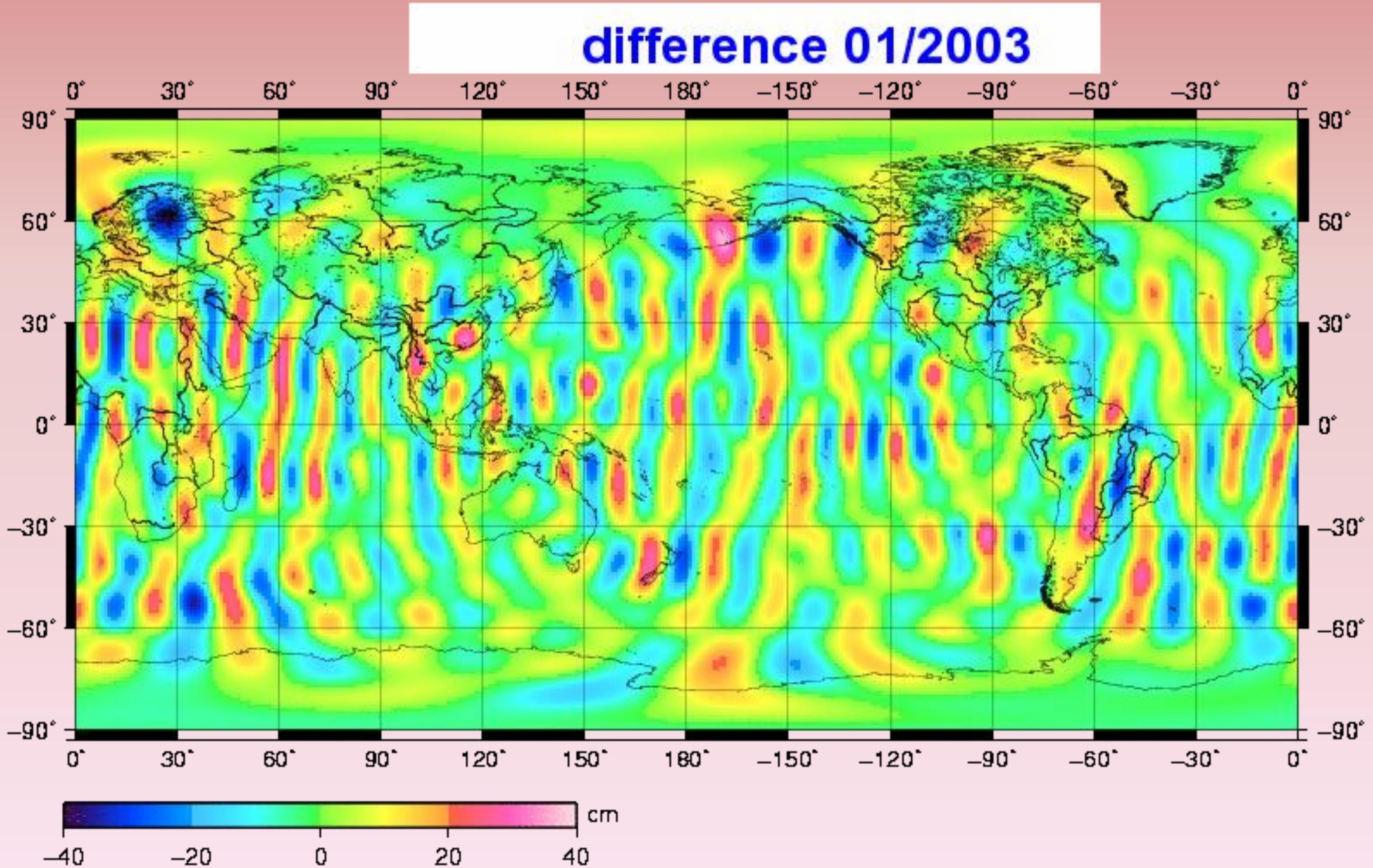
MCCA, L=48 months

Sum of first 10 SNs



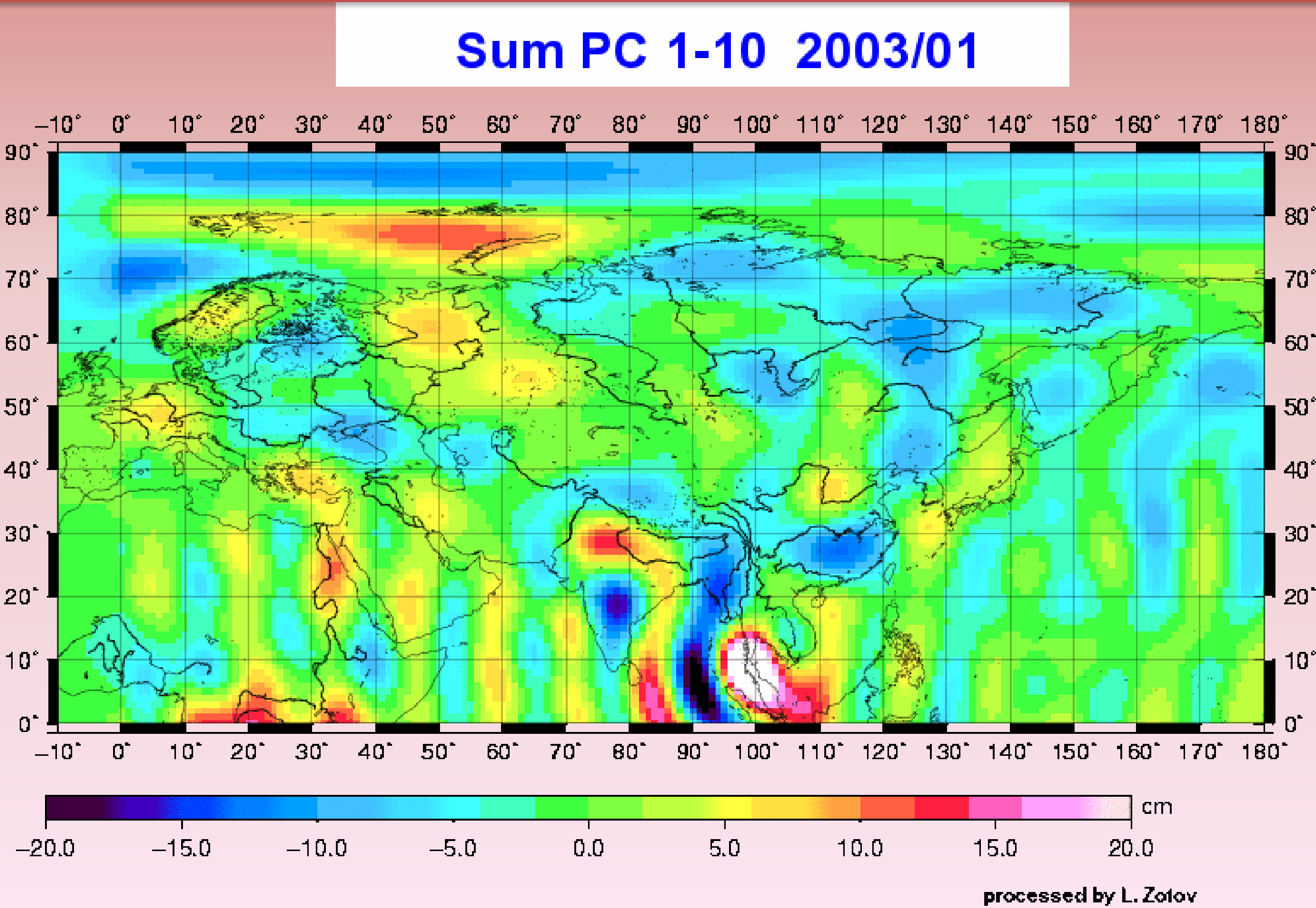
MSSA with L=36 months

Remaining components, sum SNs >10



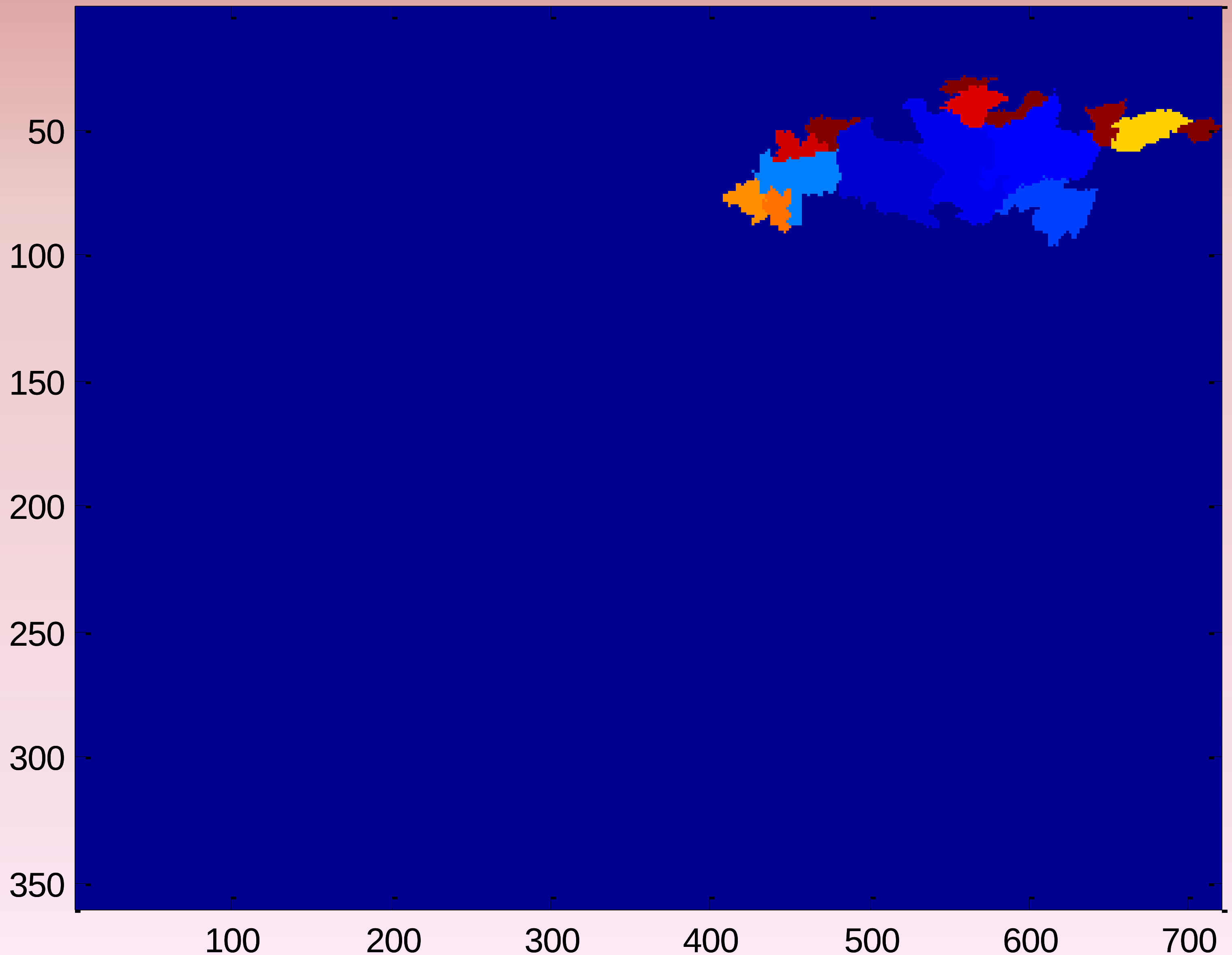
MCCA, L=48 months

Sum of first 10 PCs over Eurasia

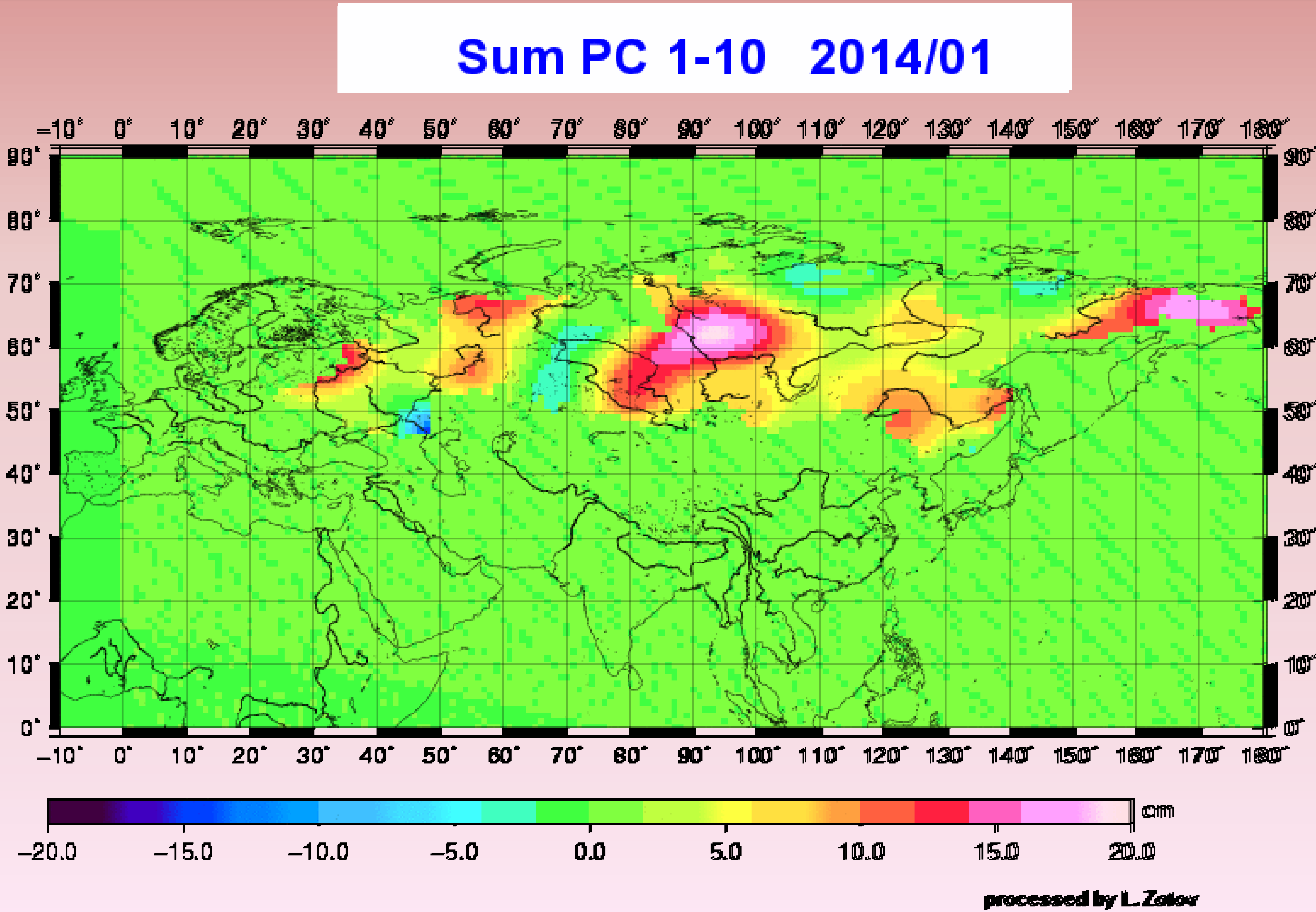


MCCA, L=48 months

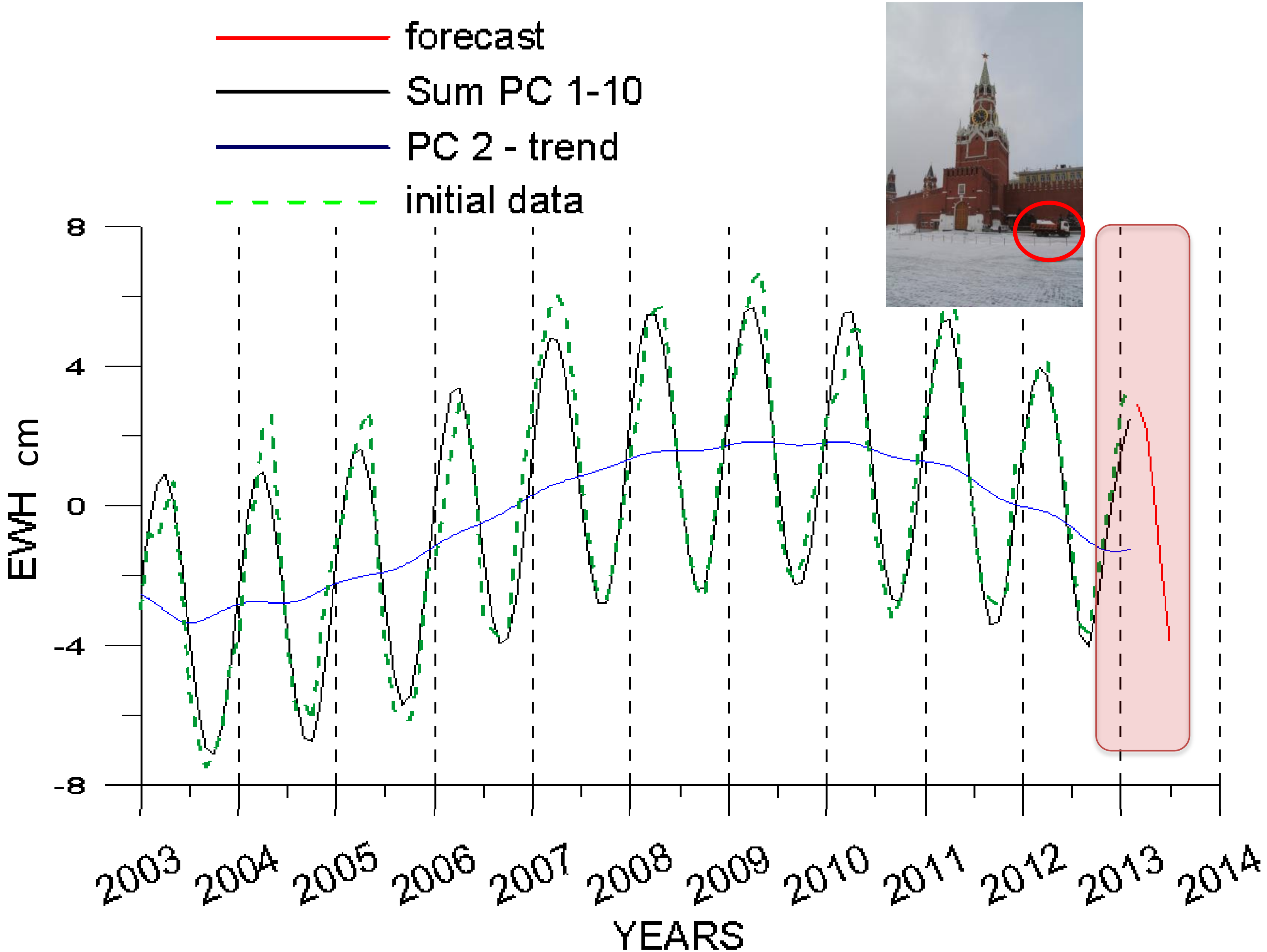
Simulated Topological Networks (STN-30p) database
is used to constrain the region to the basins of 15 large Russian rivers



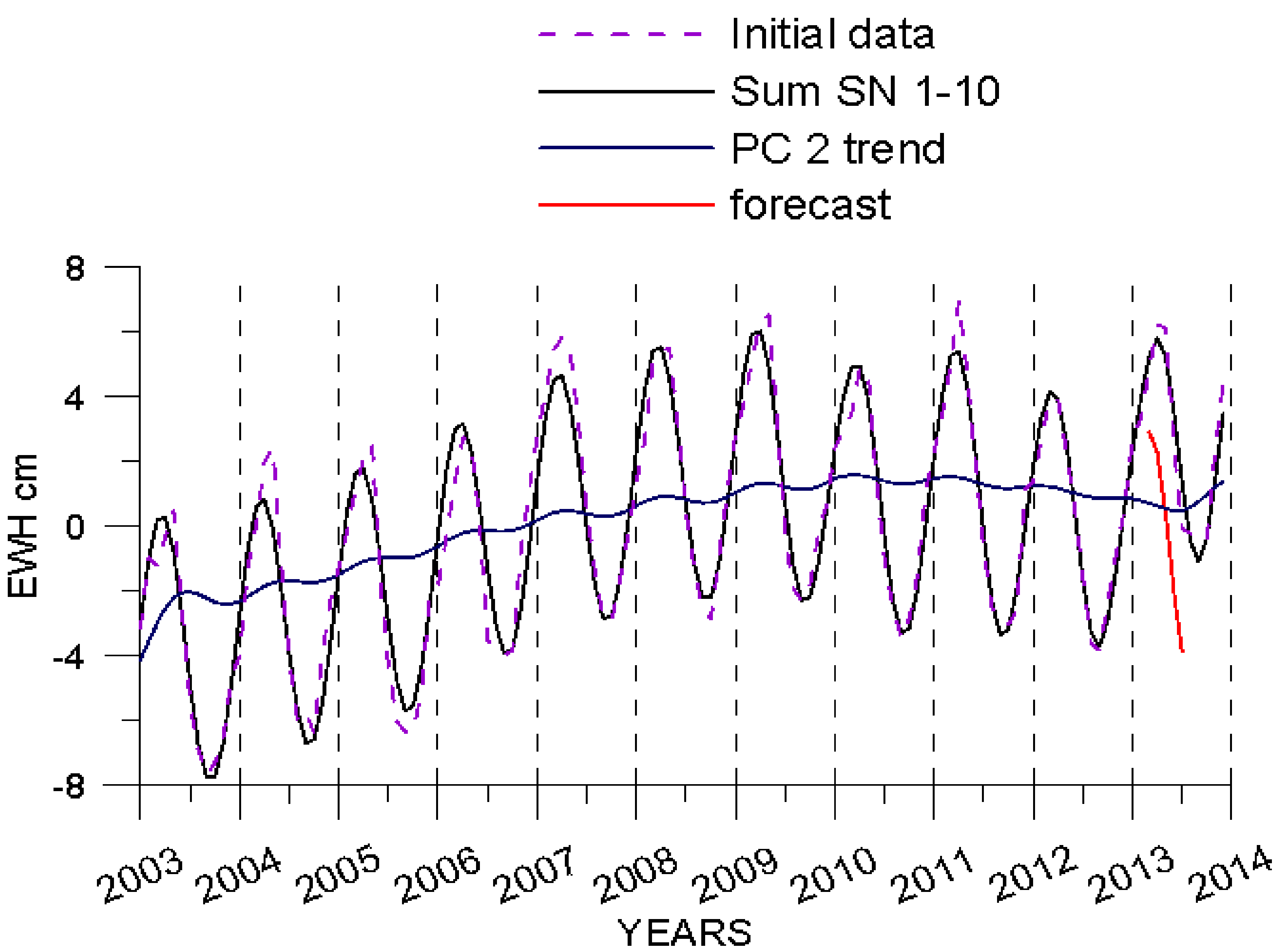
Changes in the basins of 15 large Russian rivers



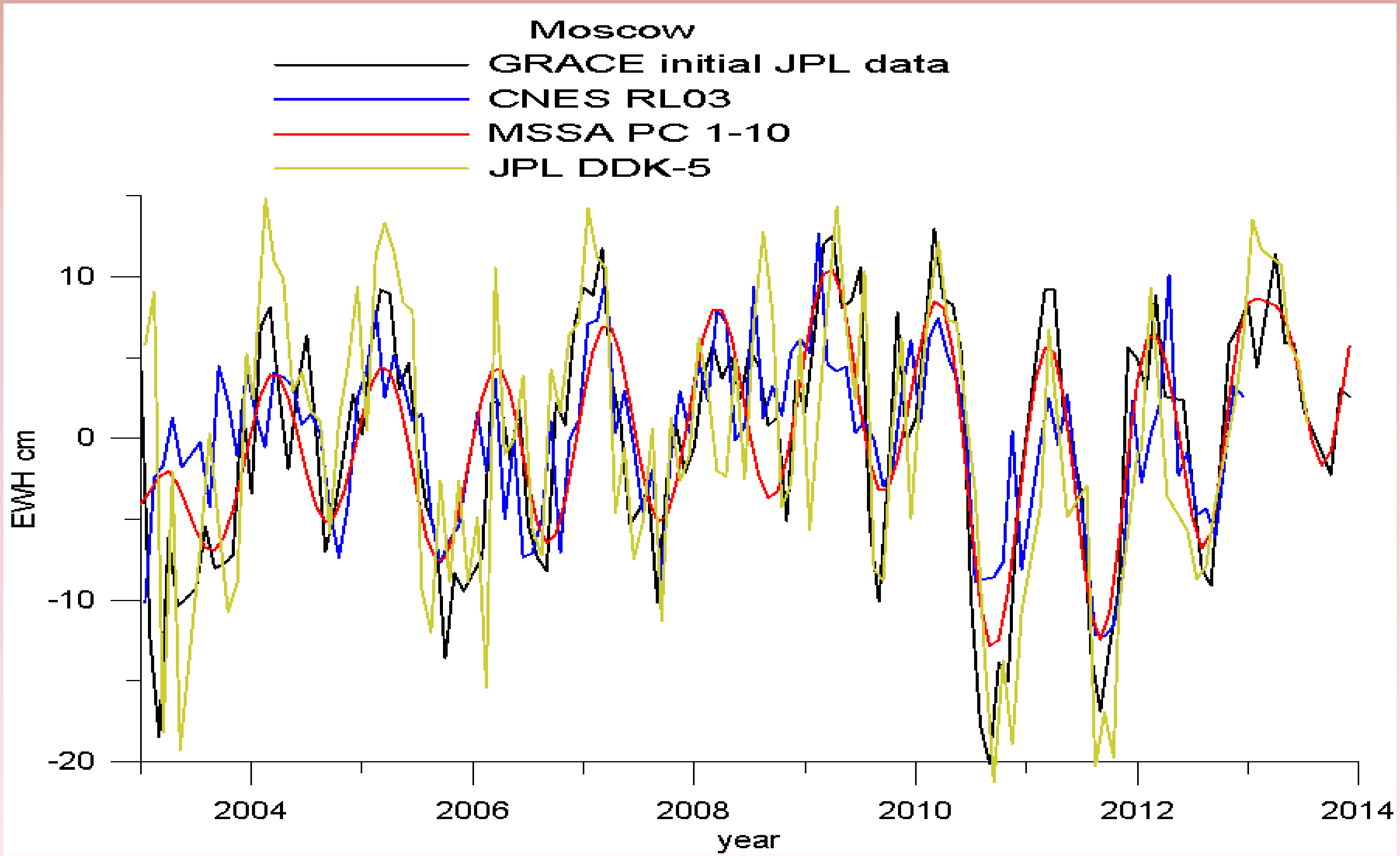
Mass anomaly (averaged field) in the basins of 15 large Russian rivers



Mass anomaly (averaged field) in the basins of 15 large Russian rivers

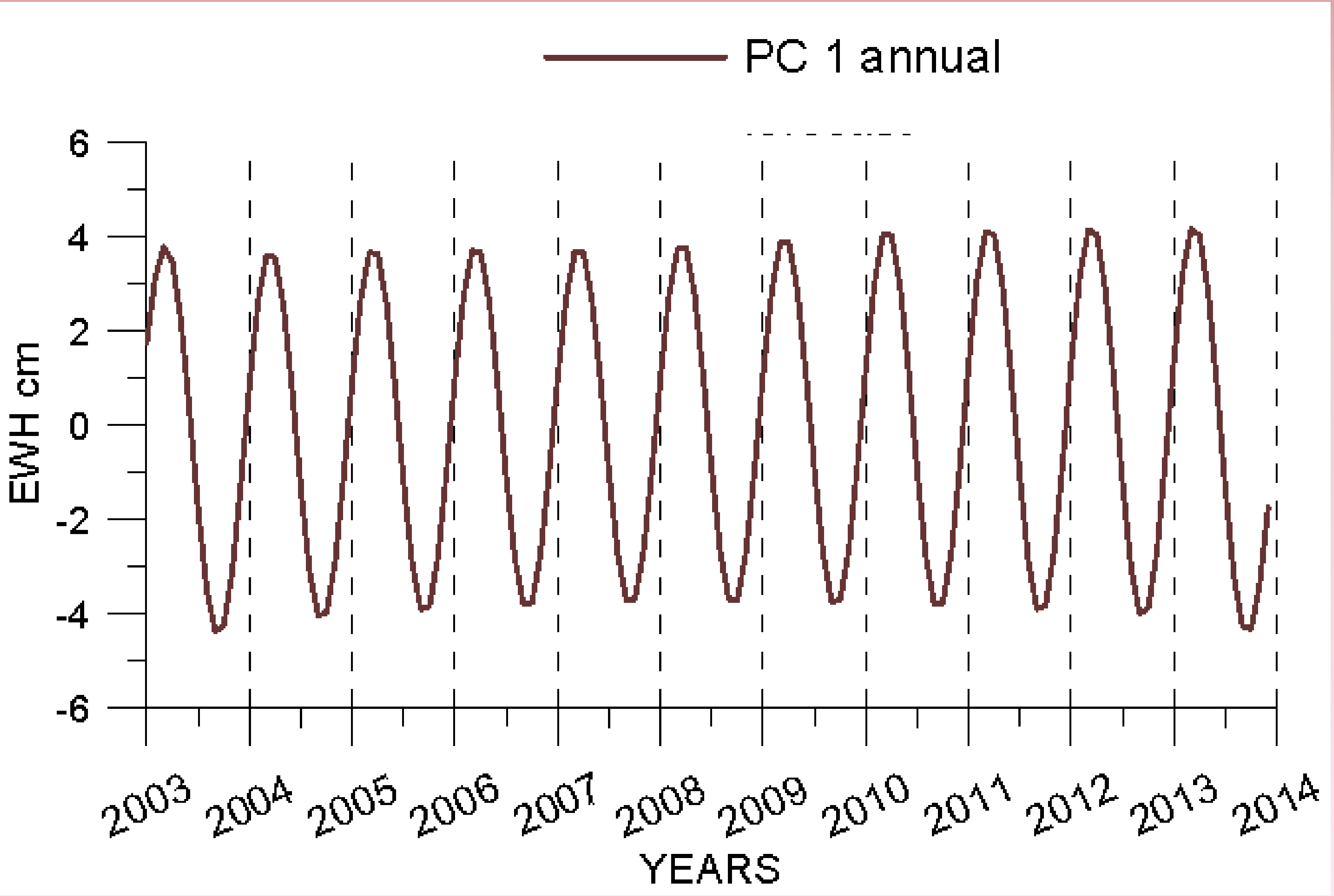


Comparison with CNES/GRGS RL 03 for Moscow

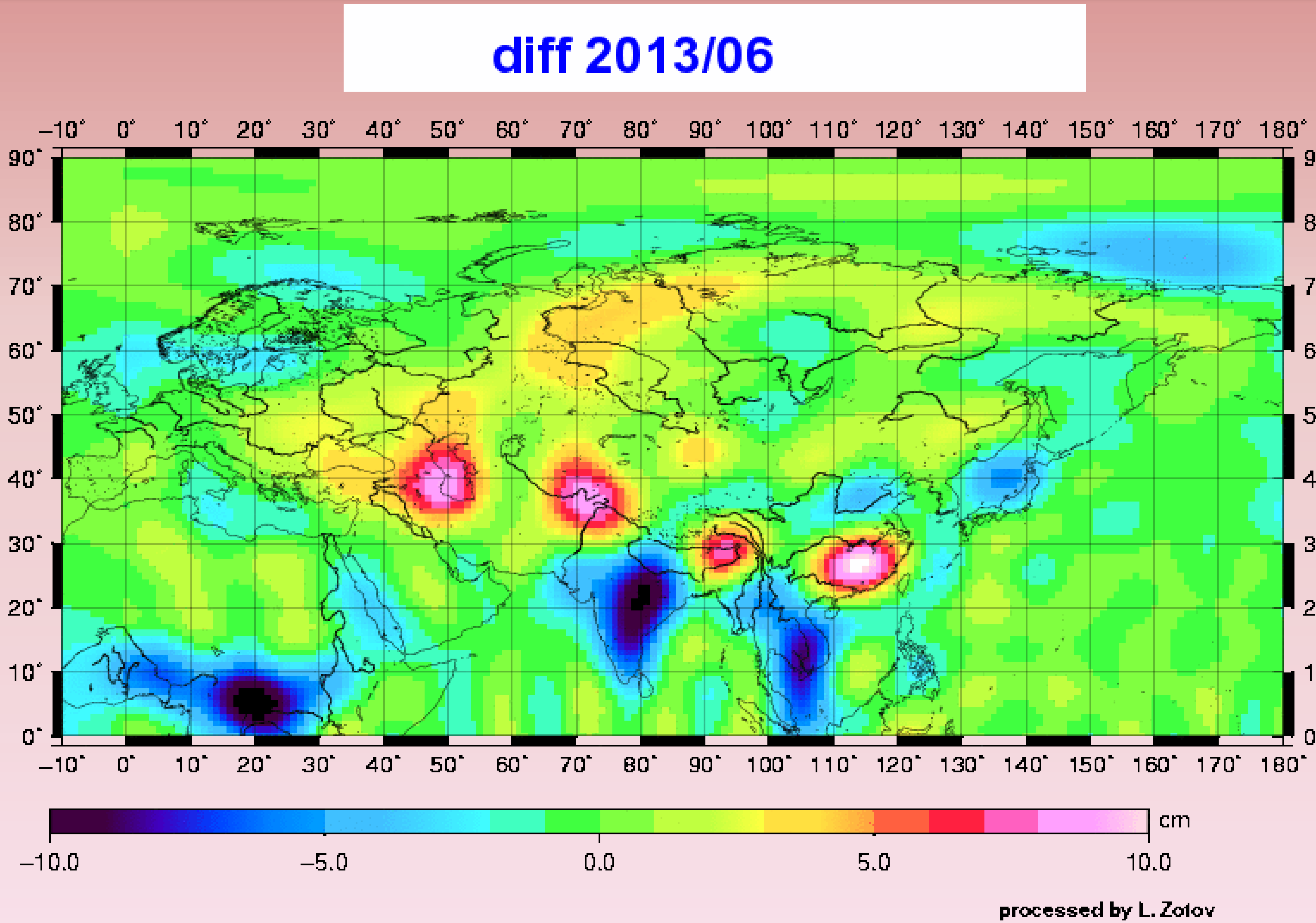


CNES and JPL data from http://www.thegraceplotter.com/

Averaged annual cycle over the basins of 15 large Russian rivers



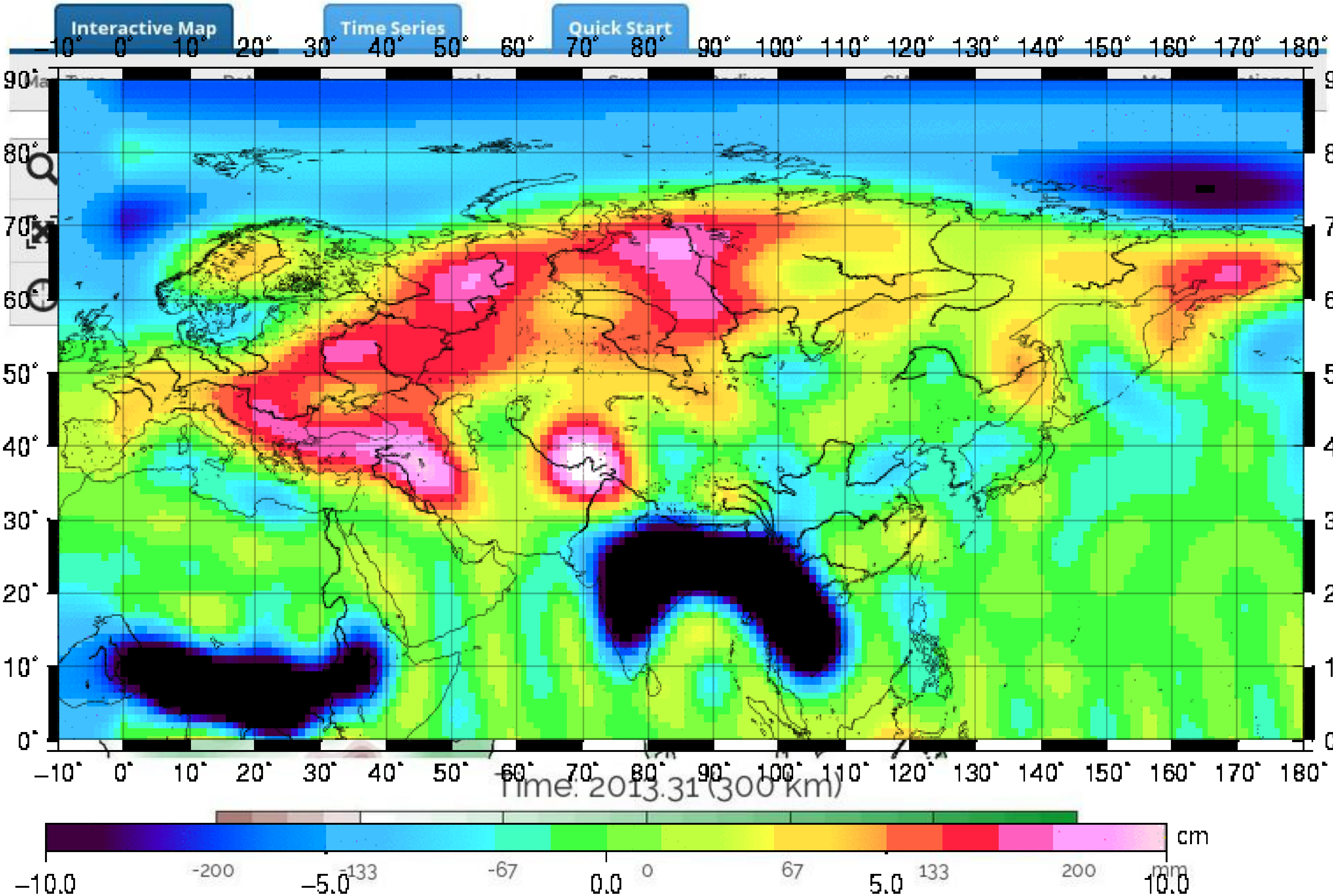
Annual cycle anomalies for March-June



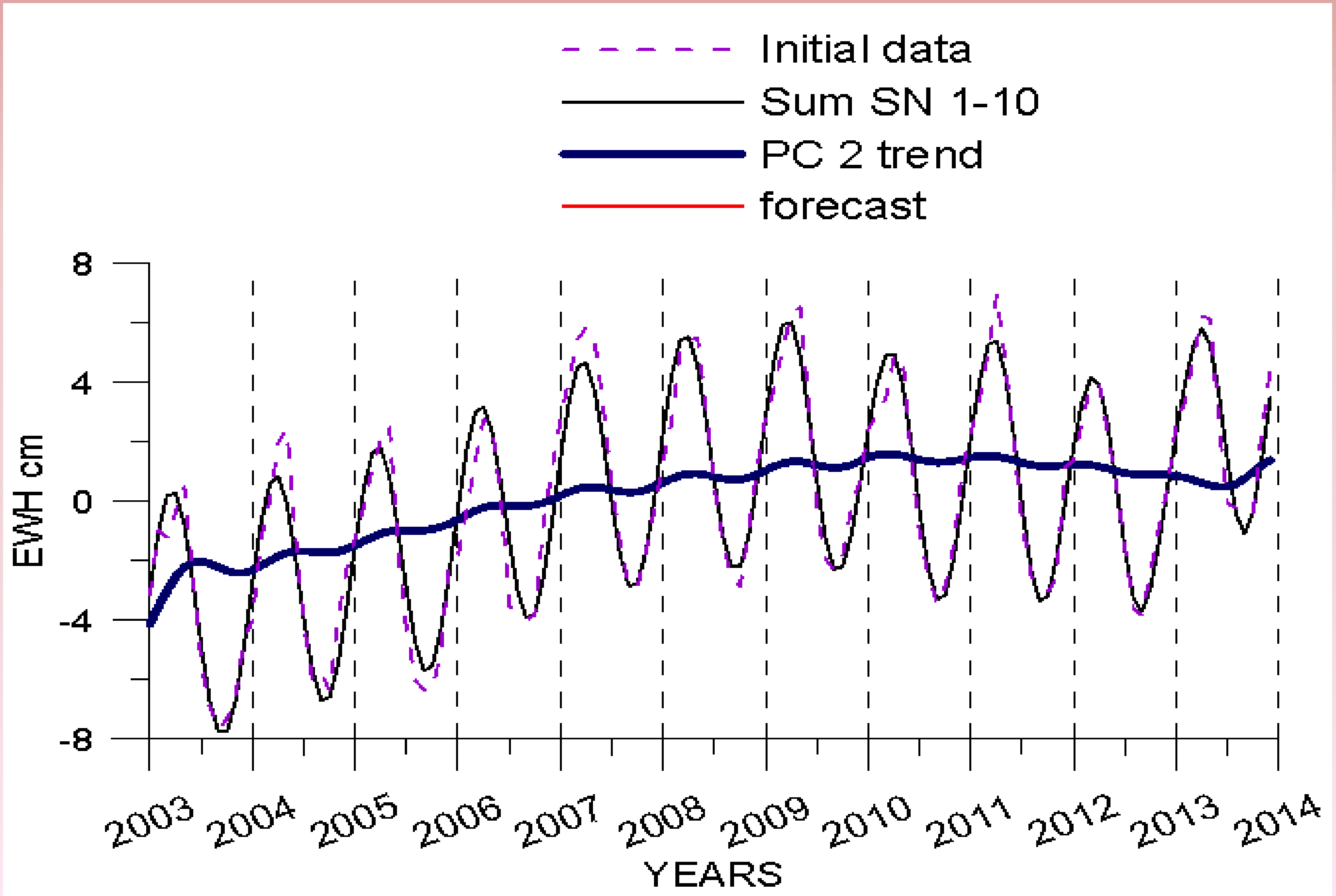
The differences for the annual PC 1 between monthly (March-June 2013) maps and average maps over 9 years (2003-2012) for the corresponding months. Positive anomalies in spring 2013 over Russia depicts anomalous snow accumulation.

\\ CU GRACE Data Portal

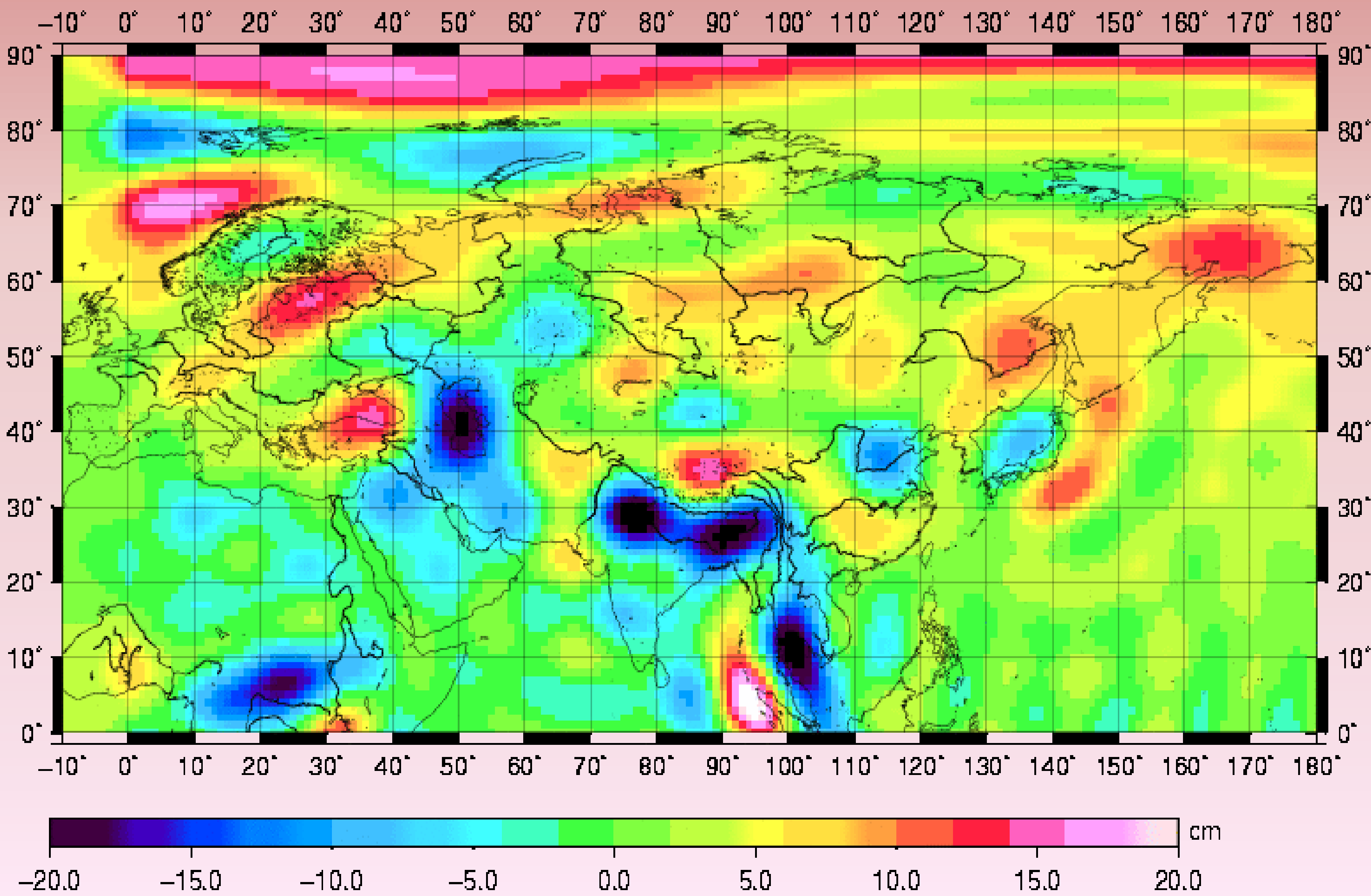
300 km gaussian smoothing, GIA subtracted,
Map from http://geoid.colorado.edu/grace/dataportal.html



Averaged trend over the basins of 15 large Russian rivers

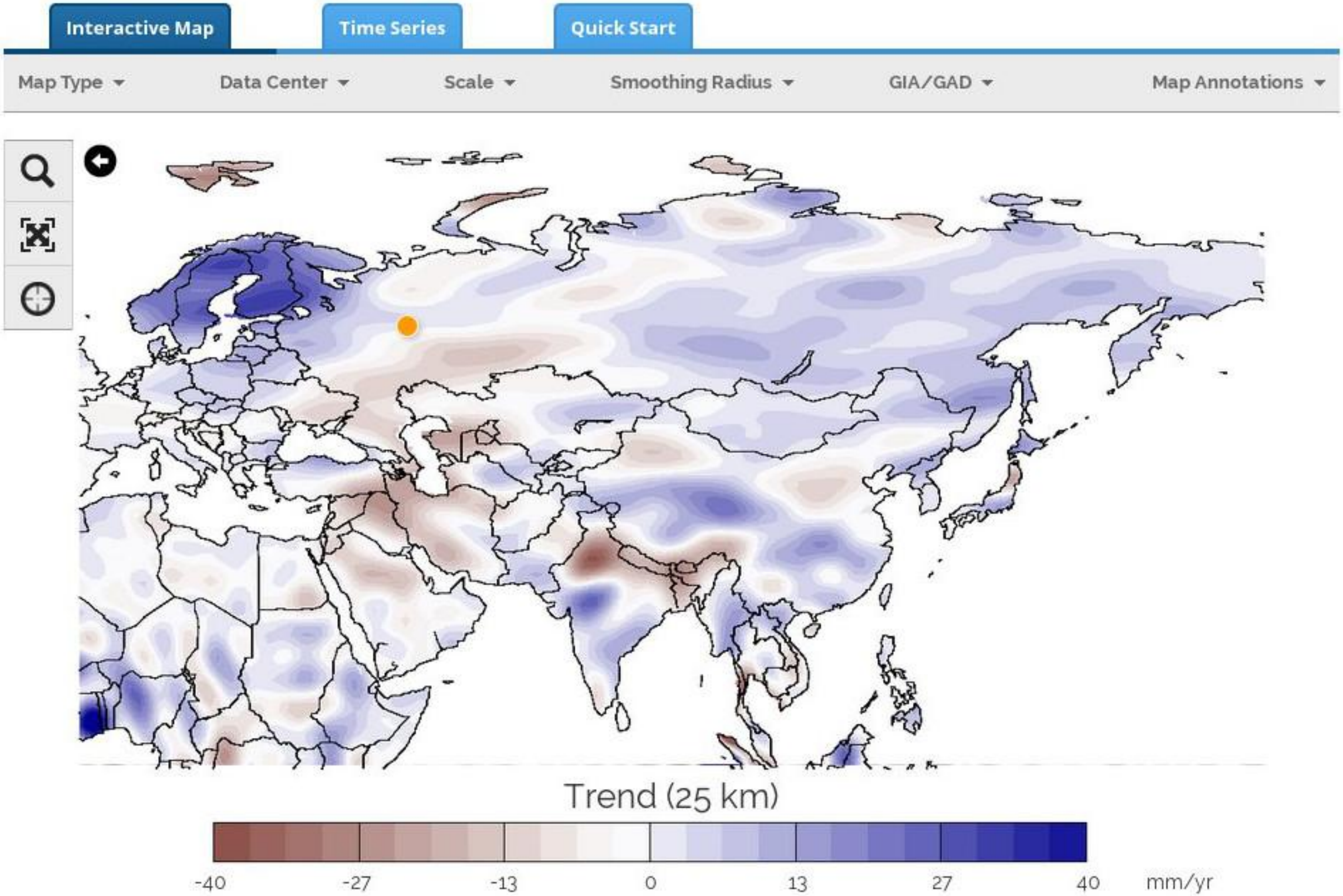


Difference between 2013 and 2003 for trend (PC 2)

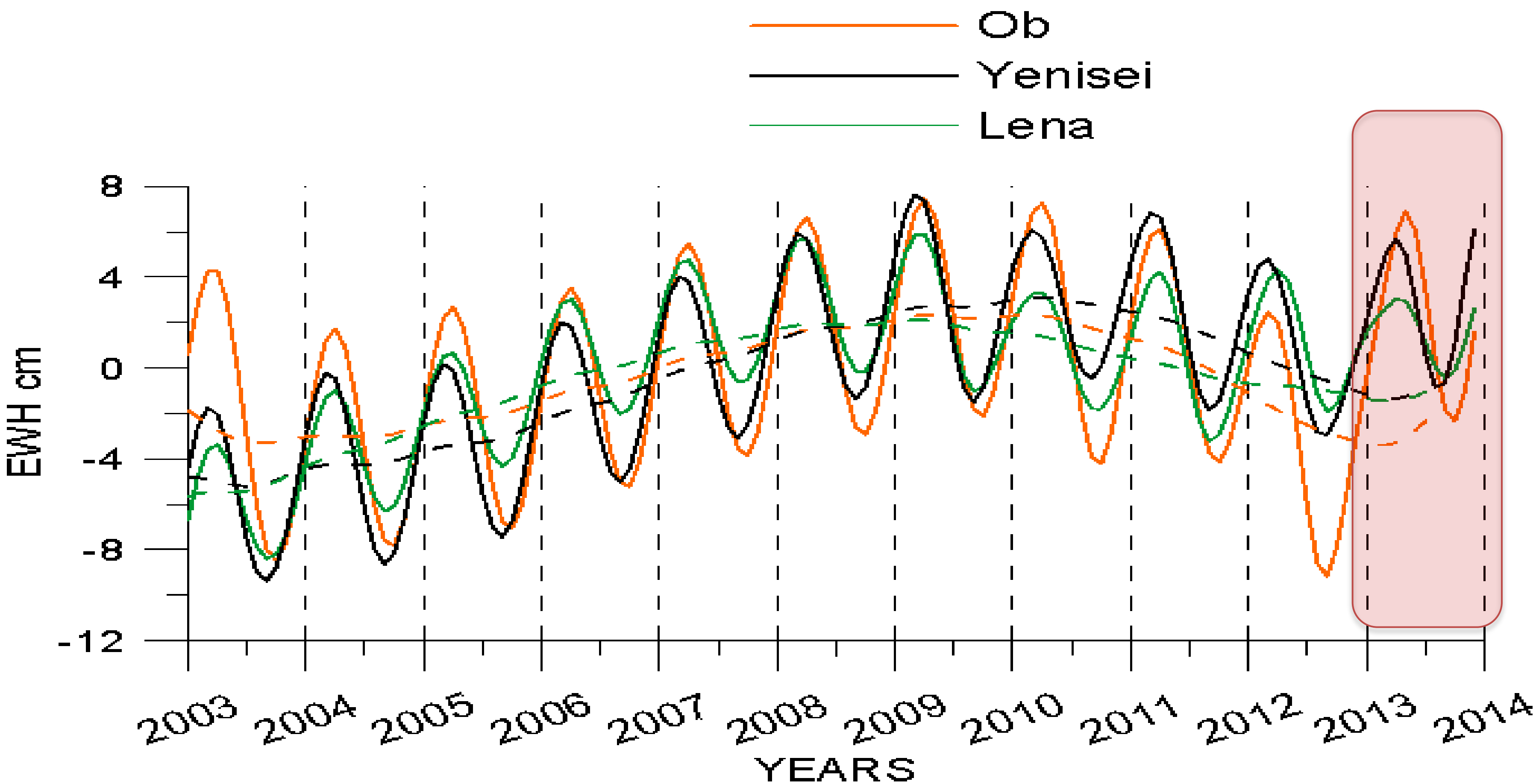


\\ CU GRACE Data Portal

25 km gaussian filter, GIA subtracted,
map from http://geoid.colorado.edu/grace/dataportal.html



Gravity changes in the basins of large rivers of Siberia

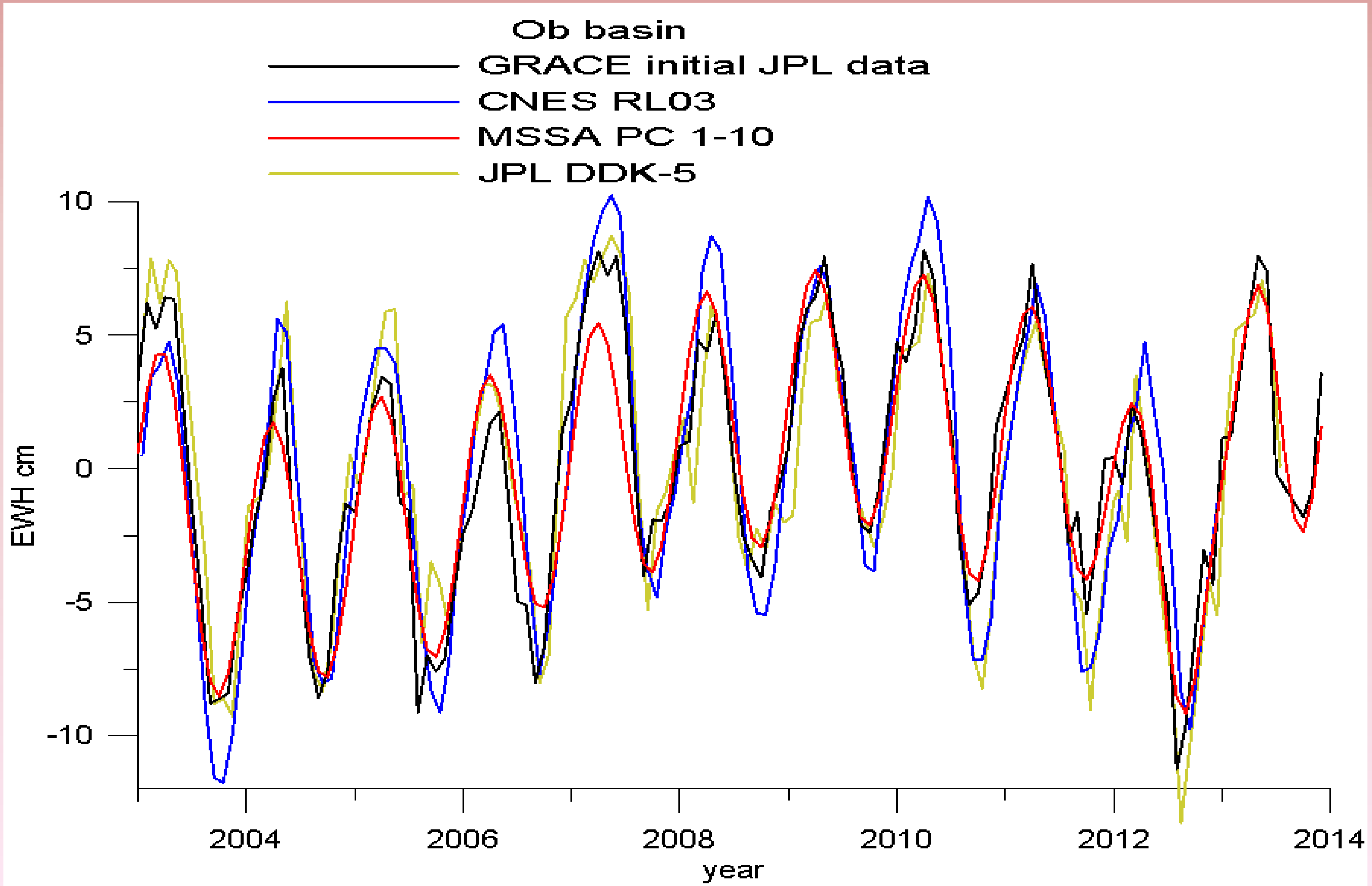


See also:

F. Frappart et al., Interannual variations of the terrestrial water storage in the Lower Ob' Basin from a multisatellite approach, Hydrology and Earth System Sciences 14, 2010

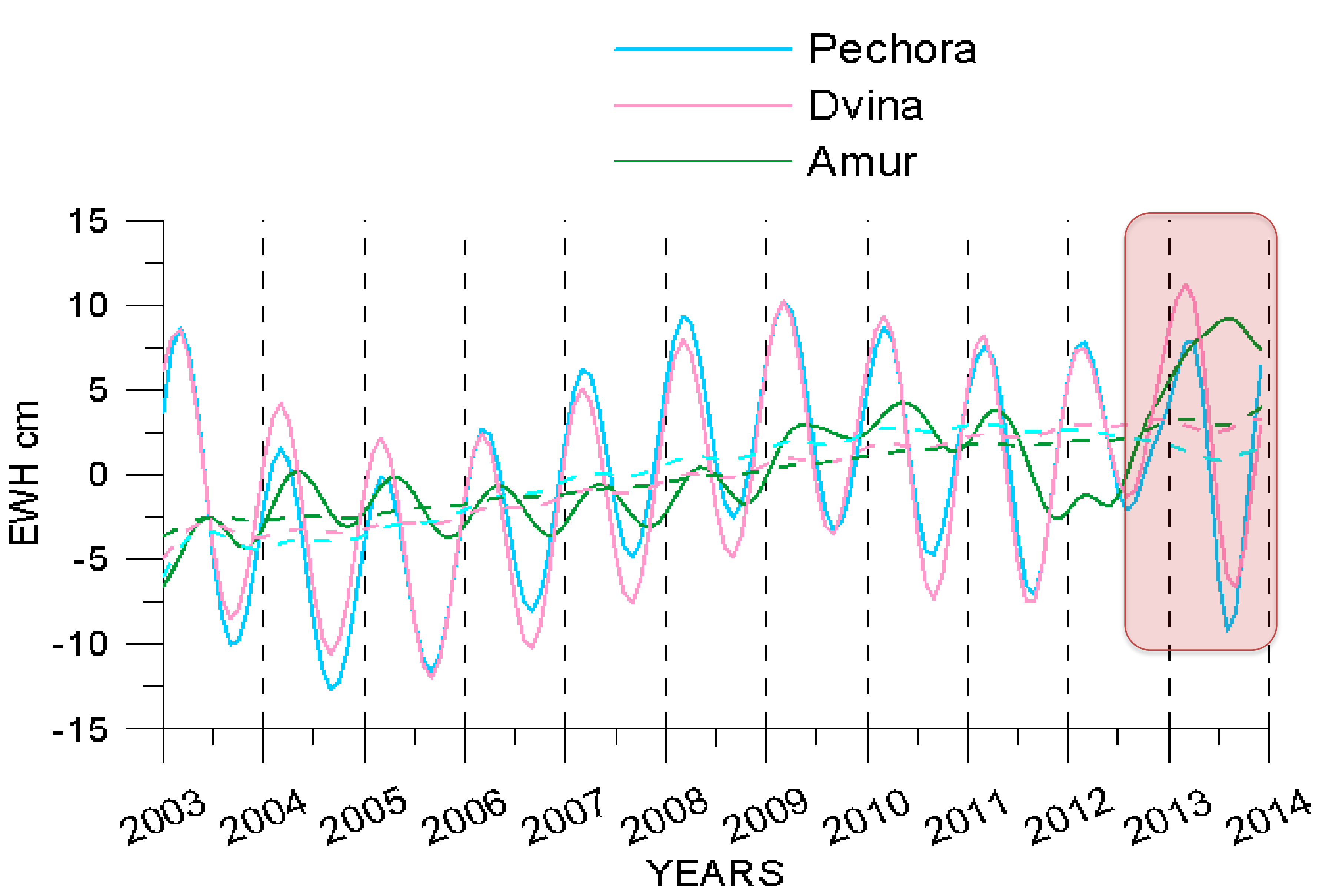
Sibylle Vey · Holger Steffen · Jürgen Müller · Julia Boike , Inter-annual water mass variations from GRACE in central Siberia, J Geod (2013) 87:287–299 DOI 10.1007/s00190-012-0597-9

Comparison with CNES/GRGS RL 03 for Ob basin



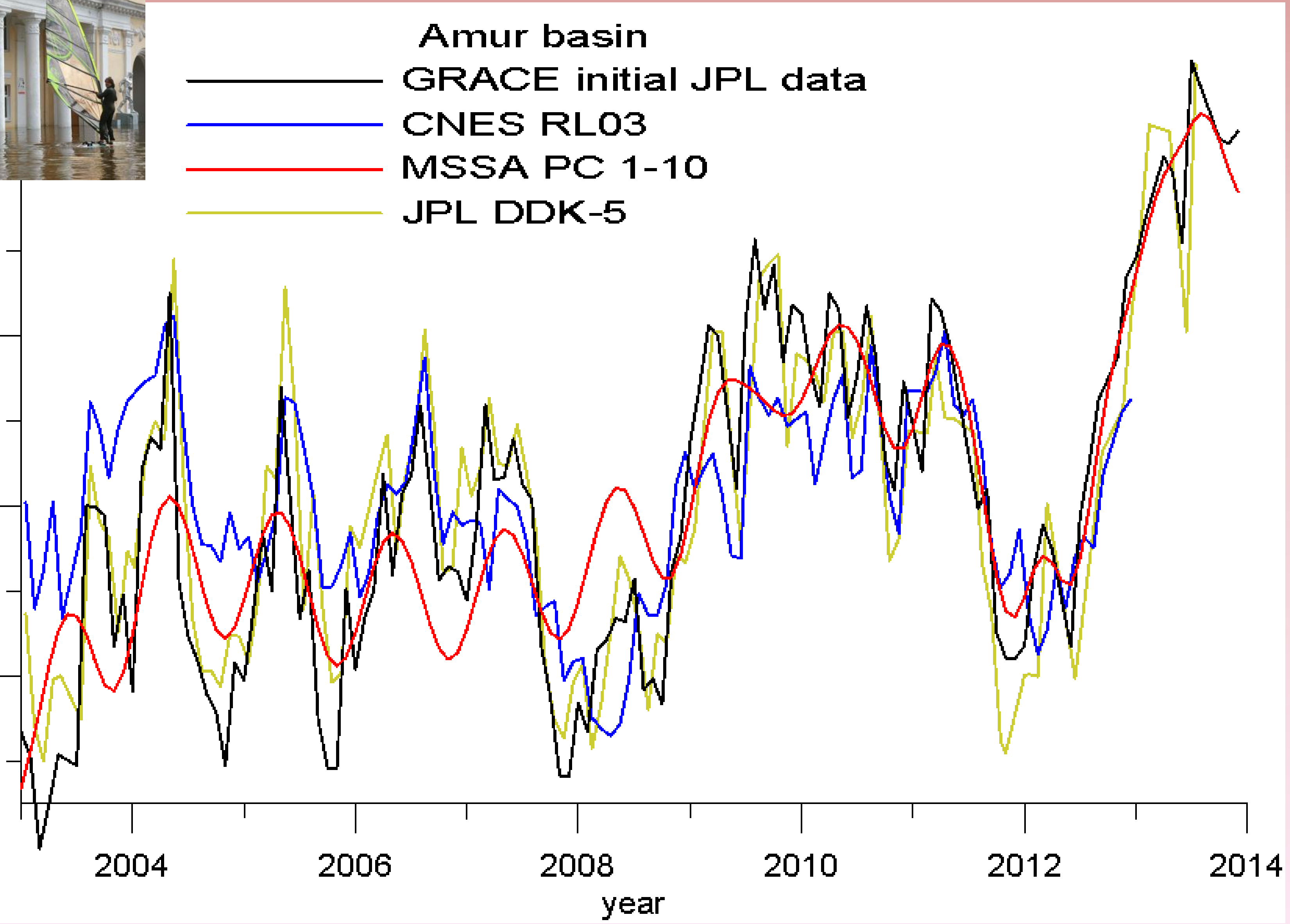
CNES and JPL plots from http://www.thegraceplotter.com/

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



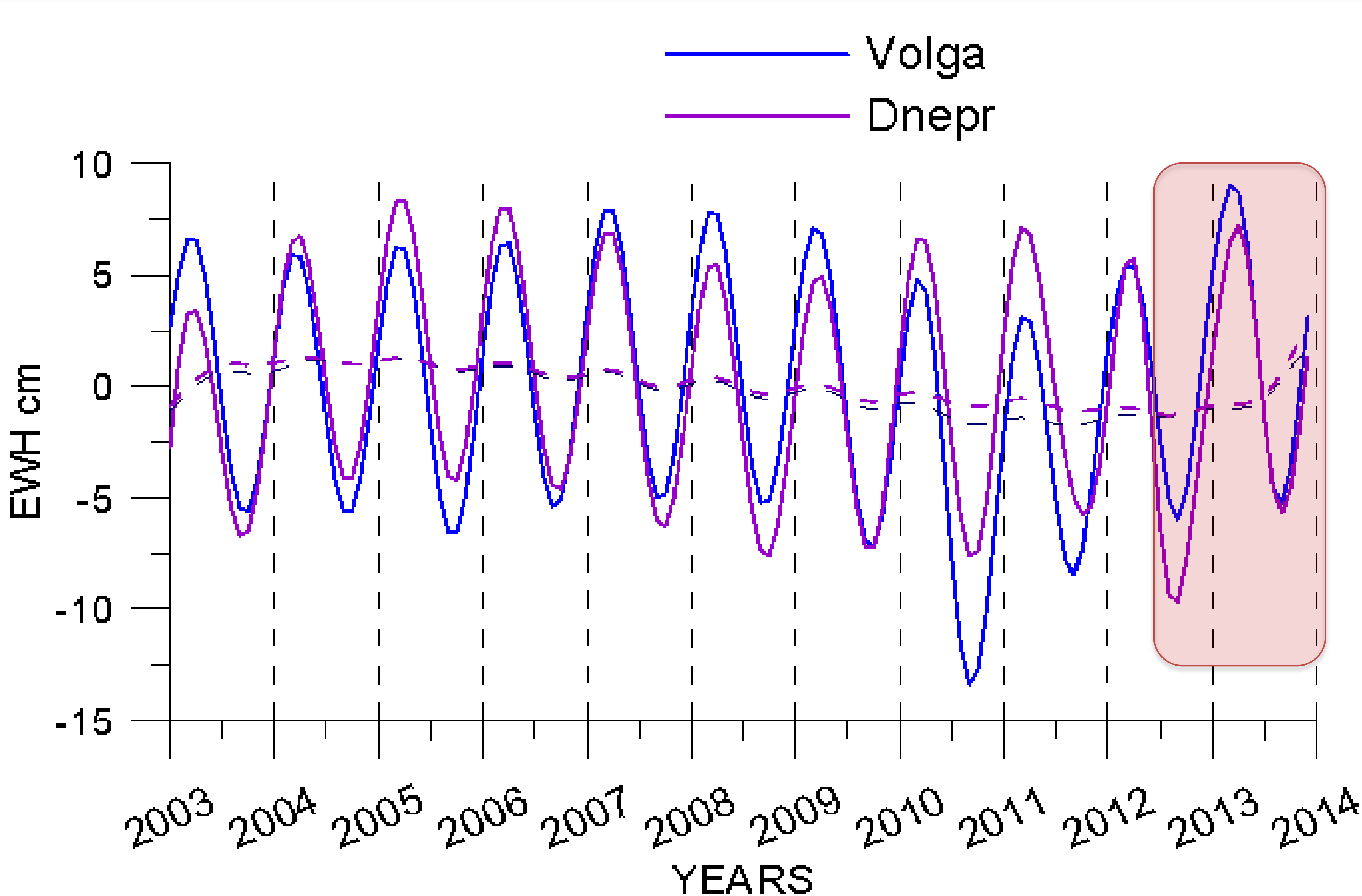
Comparison with CNES/GRGS RL 03 data

For Amur river basin



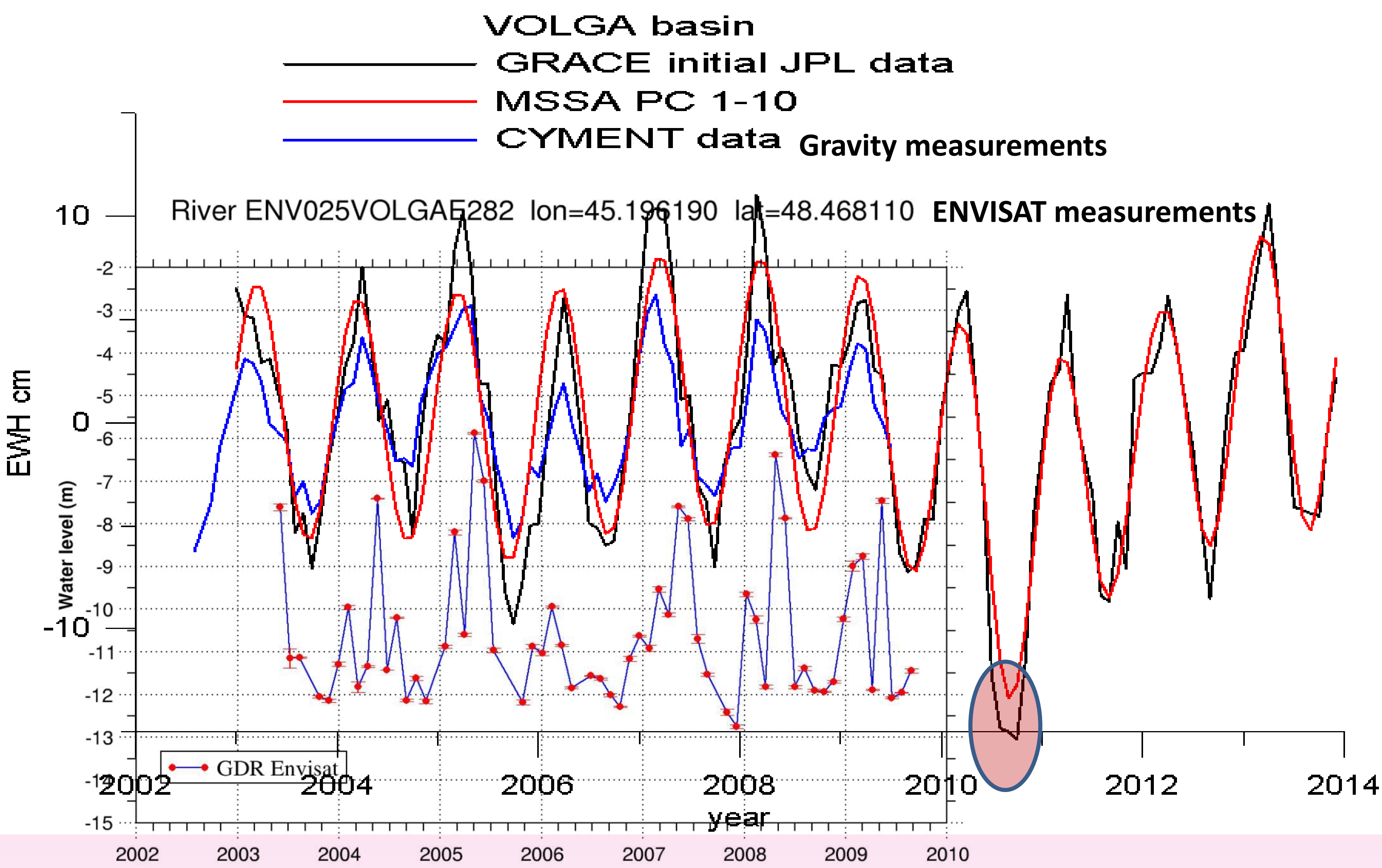
CNES and JPL data from http://www.thegraceplotter.com/

Gravity changes in the basins of large rivers of European part



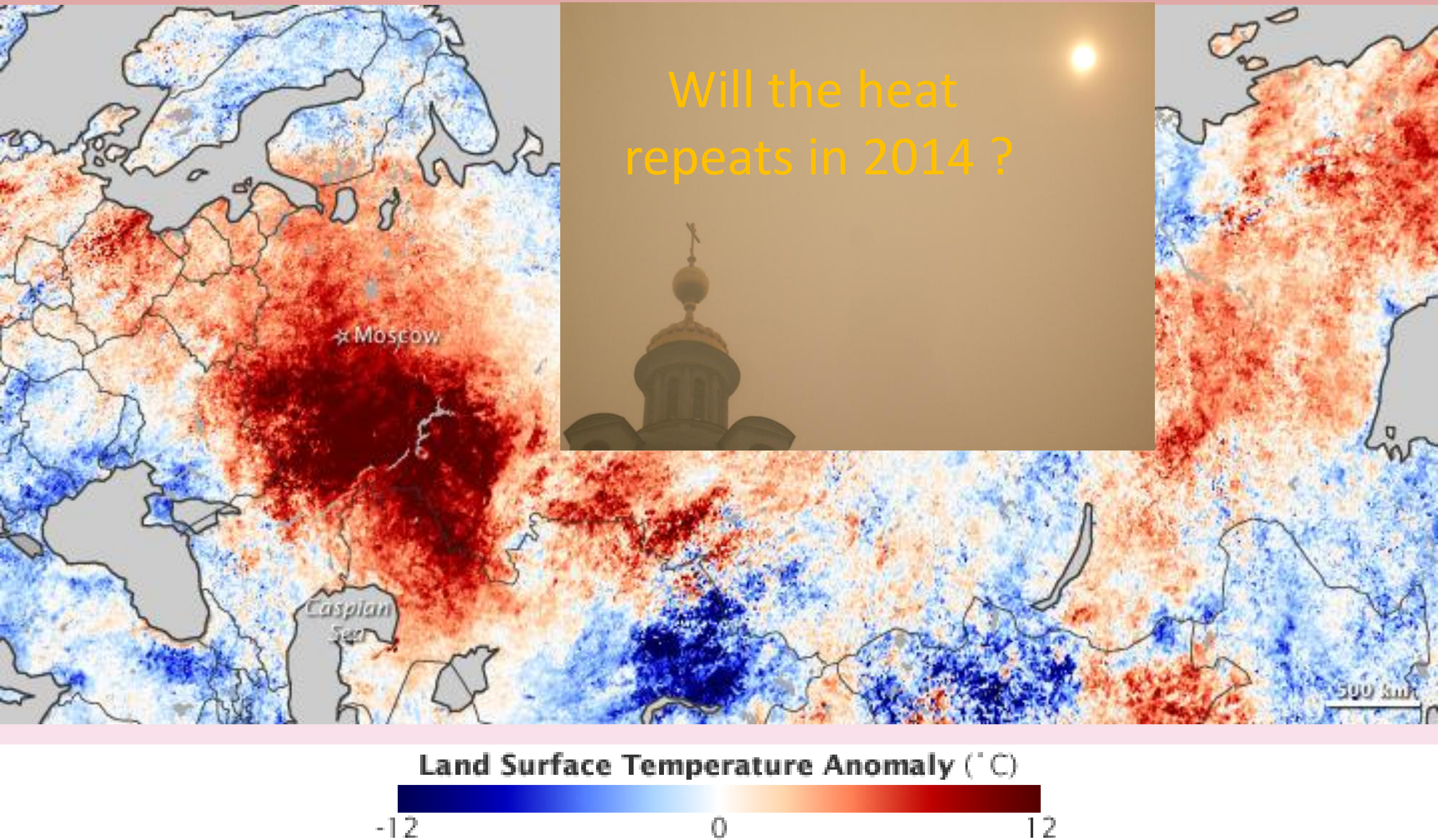
Comparison with data from hydrological web

CYcle de l’eau et de la Matière dans les bassins vErsaNTs (CYMENT) for Volga basin



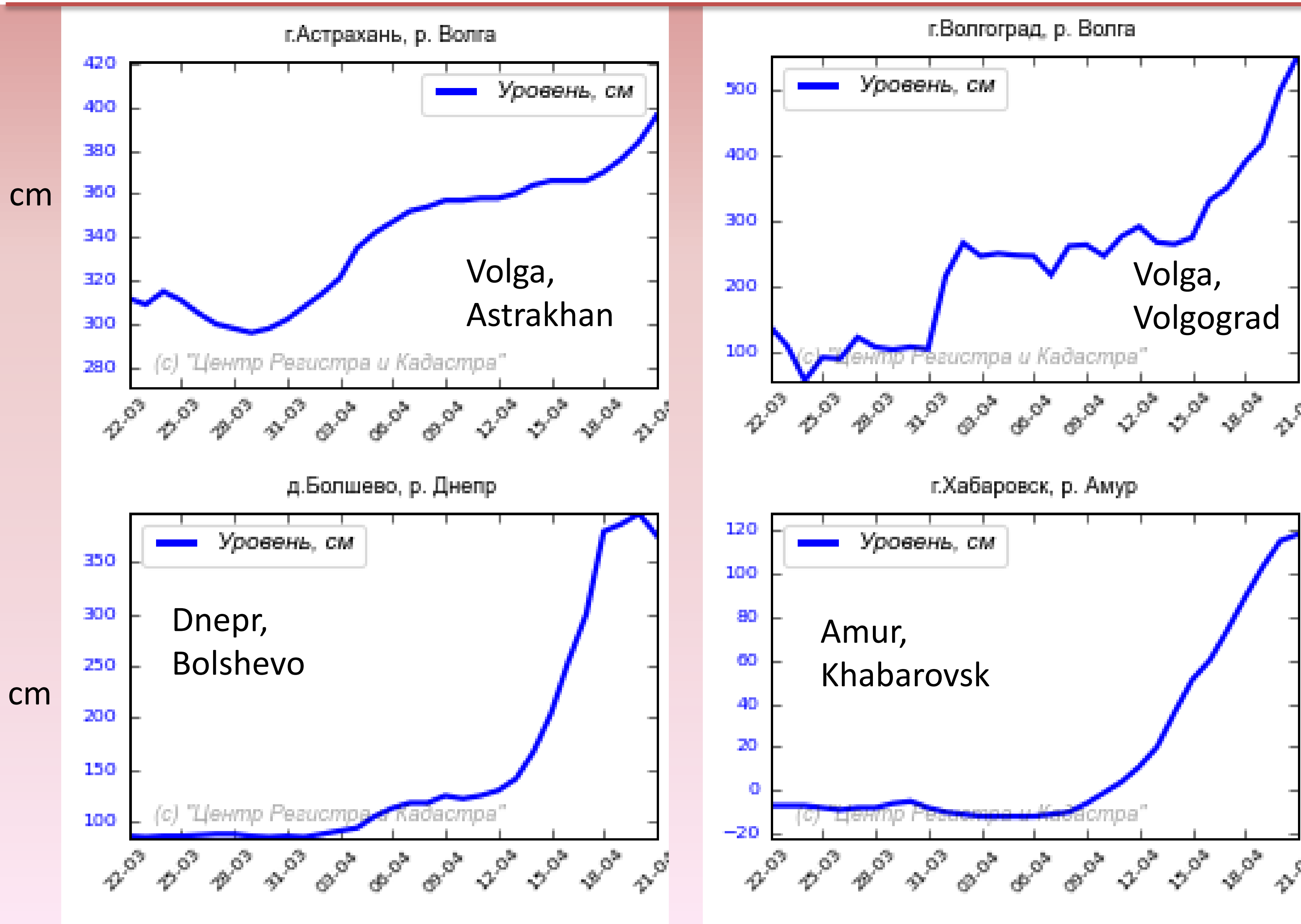
CYMENT data from http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/

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



ЦЕНТР регистра и кадастра

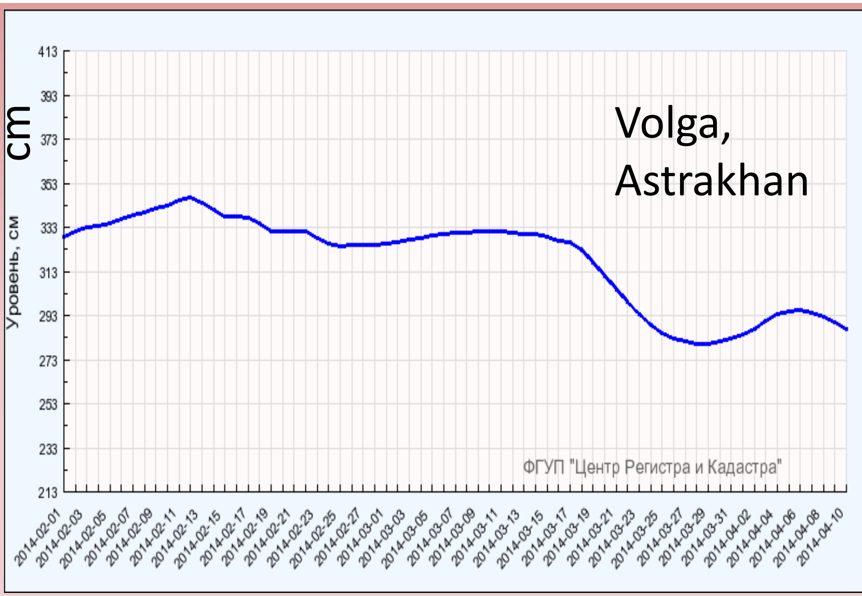
Информационное обеспечение оперативного управления водными ресурсами и противопаводковыми мероприятиями для бассейнов рек России 2013

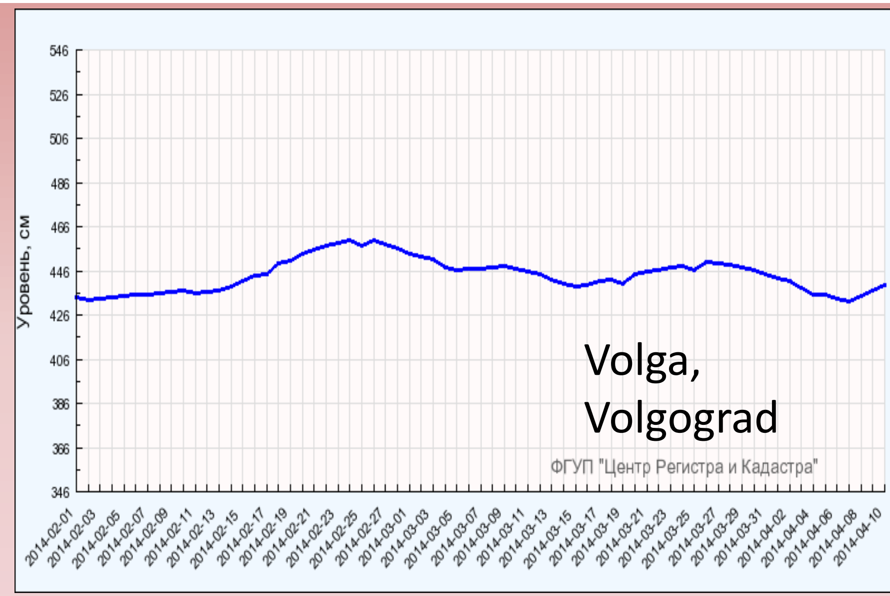


River’s level changes from the Cadastr Center of Russia

ЦЕНТР регистра и кадастра

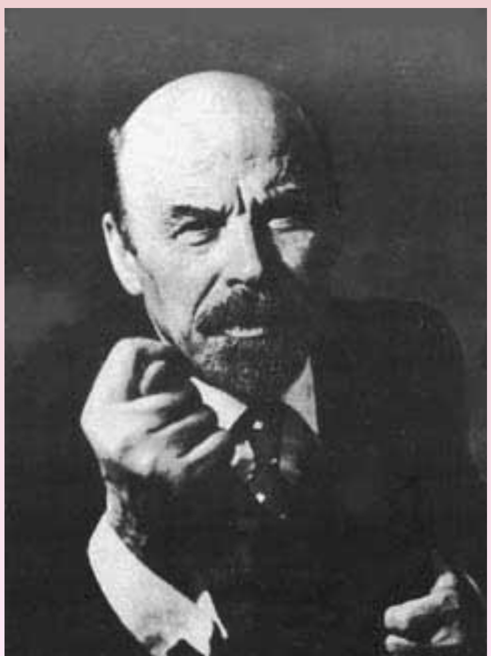
Информационное обеспечение оперативного управления водными ресурсами и противопаводковыми мероприятиями для бассейнов рек России 2014

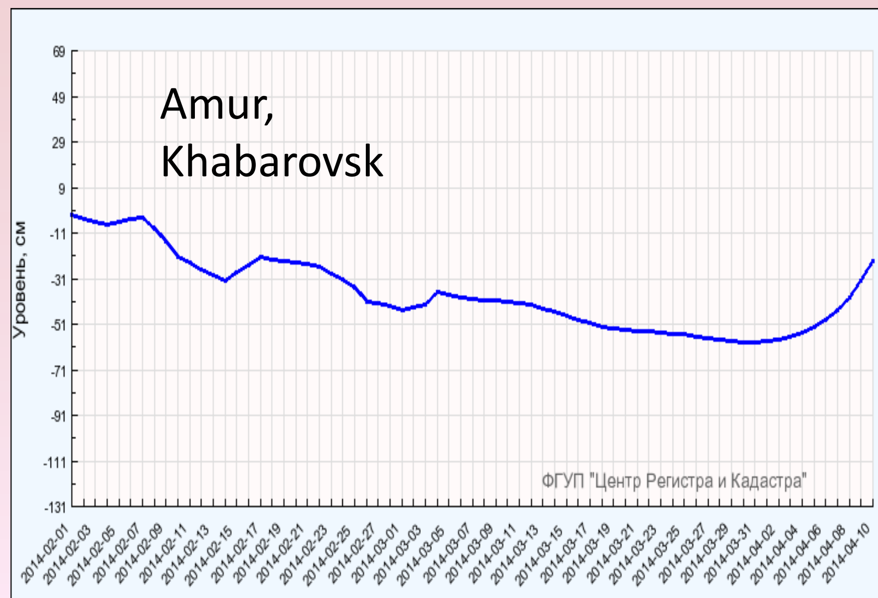




Dnepr,
Bolshevo

Vous n'aures auncune donnees (pas de gaz sans argent)





Mass balance equation

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

where ΔTWS – measured by GRACE

ΔSW – changes in lakes and swamps

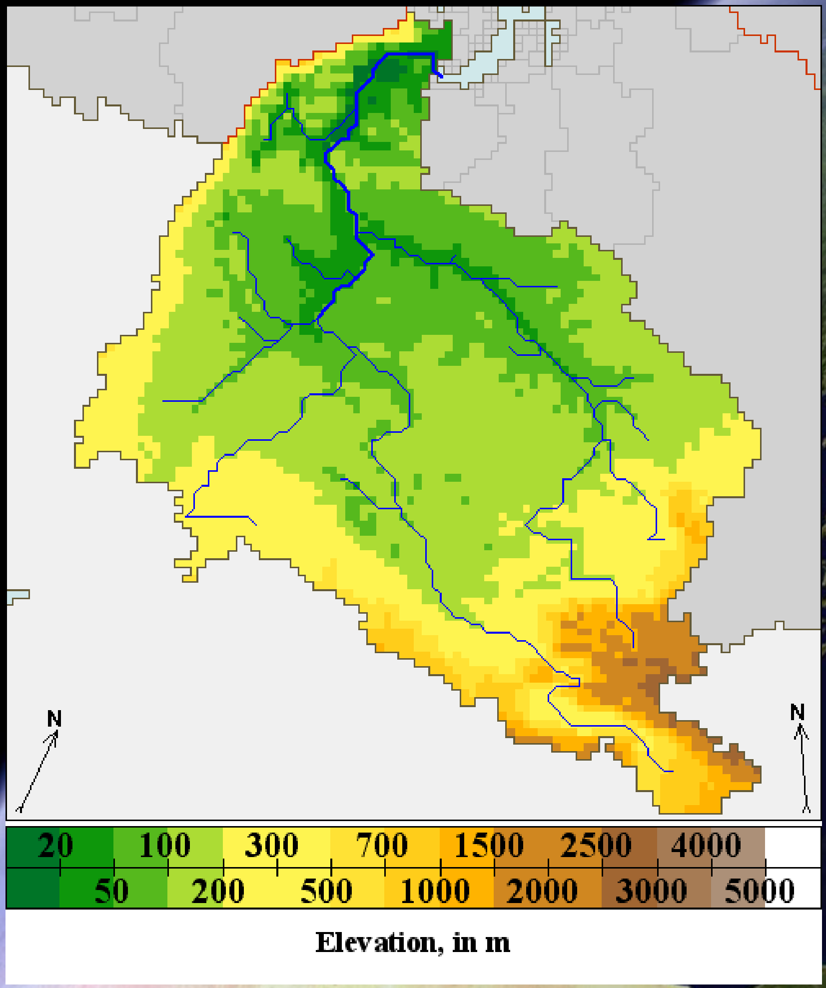
Δ(P-E) – changes of precipitation–evaporation difference

ΔSN – snow cover storage changes

ΔTSS – ground water storage changes

ΔR – river discharge changes

Ob river



Catchment area: 2990 000 km^2

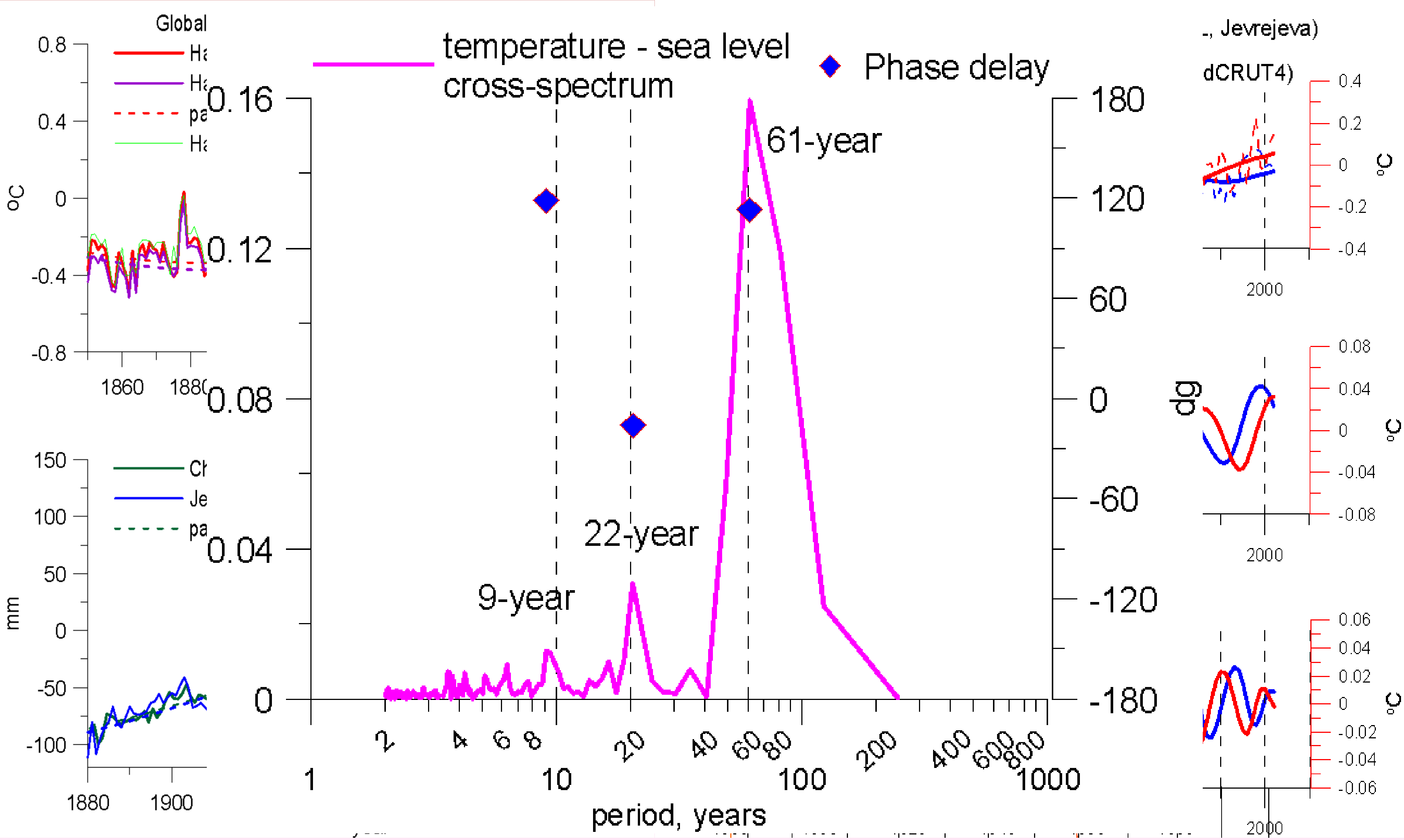
River length 3650 km

Mostly snow supply

- Presence of no-discharge areas
- Many lakes and swamps
- Several climatic zones

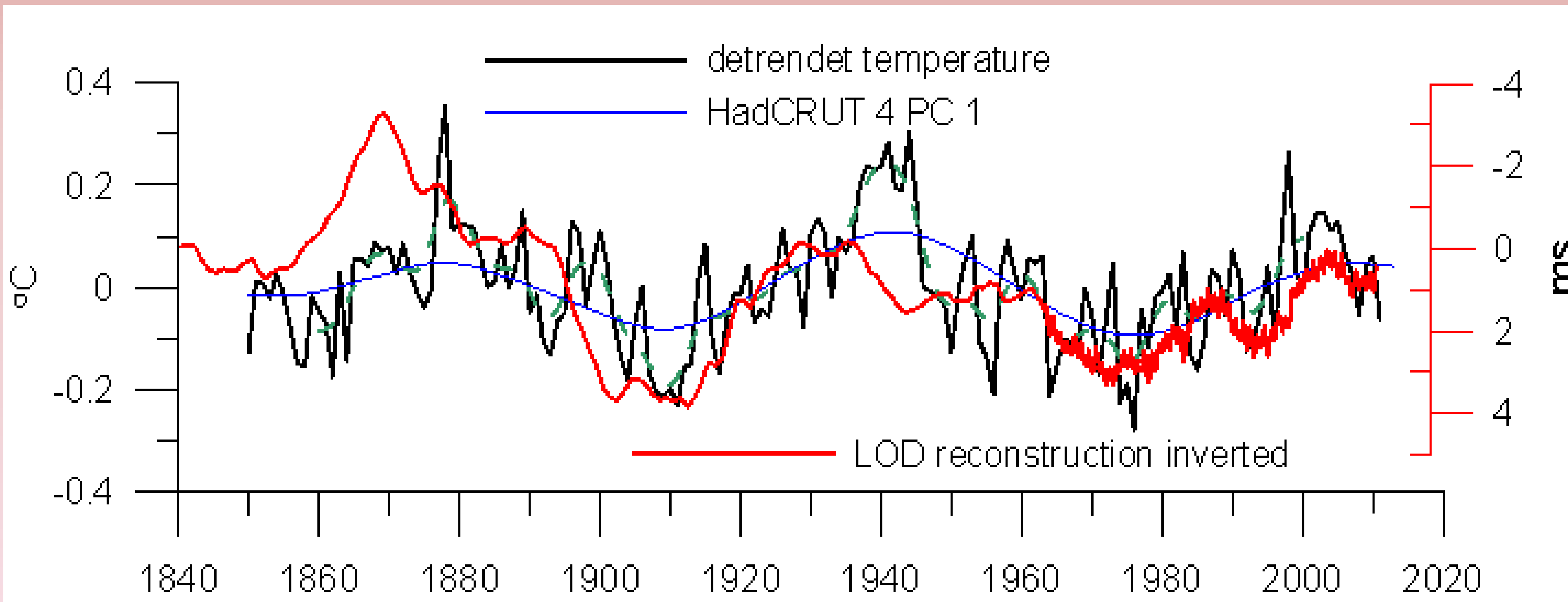
$$\Delta TWS = \Delta SW + \Delta(P-E) + + \Delta SN + \Delta TSS - \Delta R$$

2-D MSSA of data from IPCC Fifth Assessment report "CLIMATE CHANGE-2013"



Zotov, Bizouard, EGU2014-5683

HadCRUT4 after trend subtraction and Length of Day LOD



years

Correlation
0.43-0.55

Are Earth rotation and Climate Change related?

This question already posed in K. Lambeck (1980) monograph.

Conclusions

- Multichannel Singular Spectrum Analysis is a promising method for GRACE data processing, de-striping, filtering, and Principal Components (PCs) separation
- Average curves from GRACE demonstrate anomalous maxima related to unprecedented snow accumulation occurred by spring 2013 over majority of Russian territory, what caused intensive spring floods, with 2% provision for some rivers (once in 50 years)
- In spring 2014 snow accumulation over European Russia found to be anomalously small, dry conditions can cause fires in summer
- Trend component increases since 2003, has maximum in 2009-2010, following by the decrease. It is dominated by Siberian basins
- Maps for the trend show gravity field increase at Lena and Irtysh rivers sources (most probably related to permafrost degradation) and decrease over Caspian sea since 2003
- Some arguments say about possible decrease on Global worming trend. Continuation of study based on balance equation is required.

Acknowledgements: This talk is sponsored by Paris Observatory. Thanks to Jean Dickey and Oliver de Viron for consultations and help with rivers basins retrieval.

Photo by Irina Repina