Gravity changes over Russian rivers basins from GRACE

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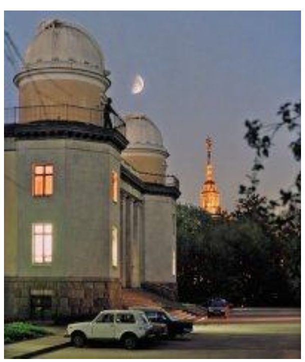
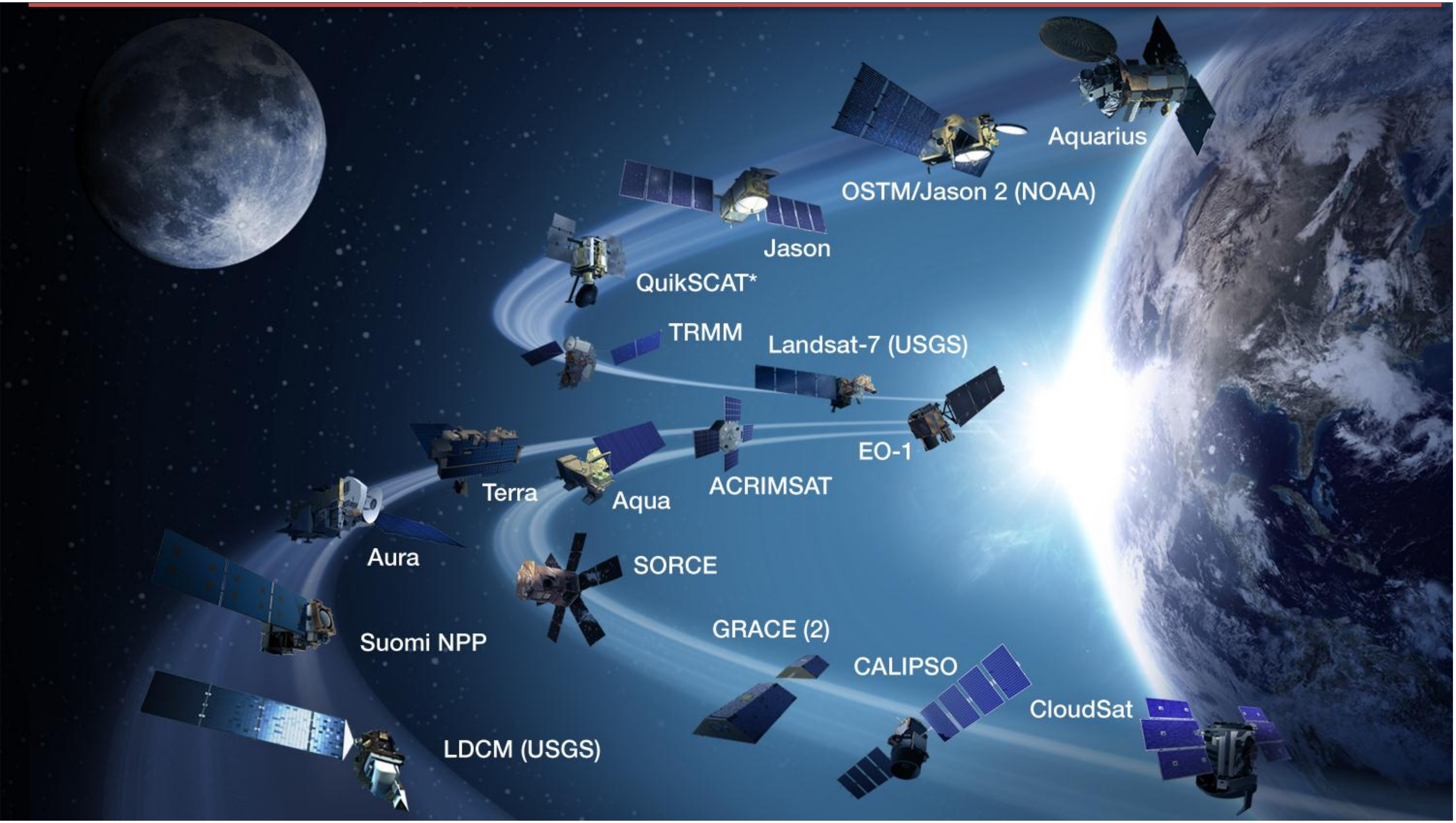


23-26 October 2013
GSTM, Austin, Texas

NASA Earth satellites missions



Huge amount of data is provided for scientific community (including the data upon the hydrology)
Its analysis requires international collaboration

Data preprocessing

We used JPL Level-2 RL05 monthly GRACE spherical harmonic data since 01.2003 till 06.2013 with coefficients complete to degree 60.

Six files (06.03, 01.11, 06.11, 05.12, 10.12, 03.13) were linearly interpolated (overall N=126 files used).

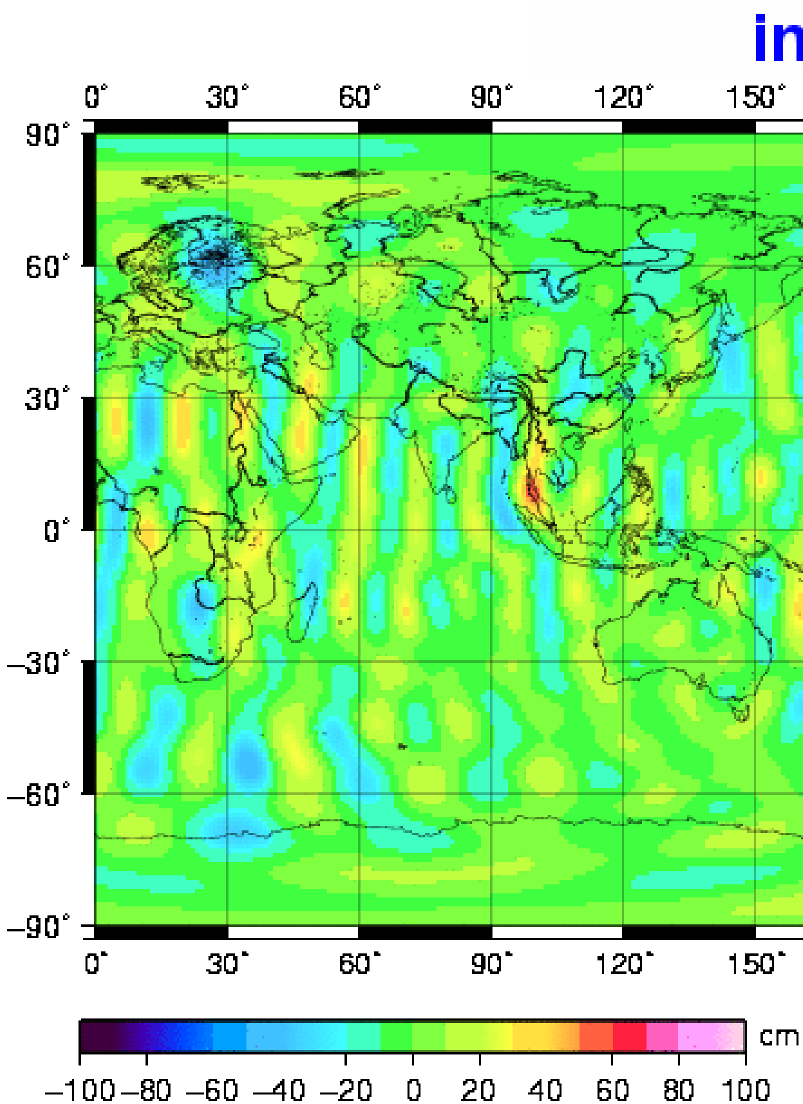
C_{20} coefficients were replaced by SLR-derived.

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) animated maps.

Initial data GRACE JPL RL05 Level 2



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

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

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

$$K = N - L + 1$$

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

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

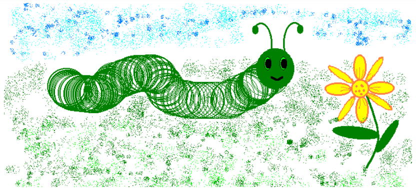
$$X = USV^T$$

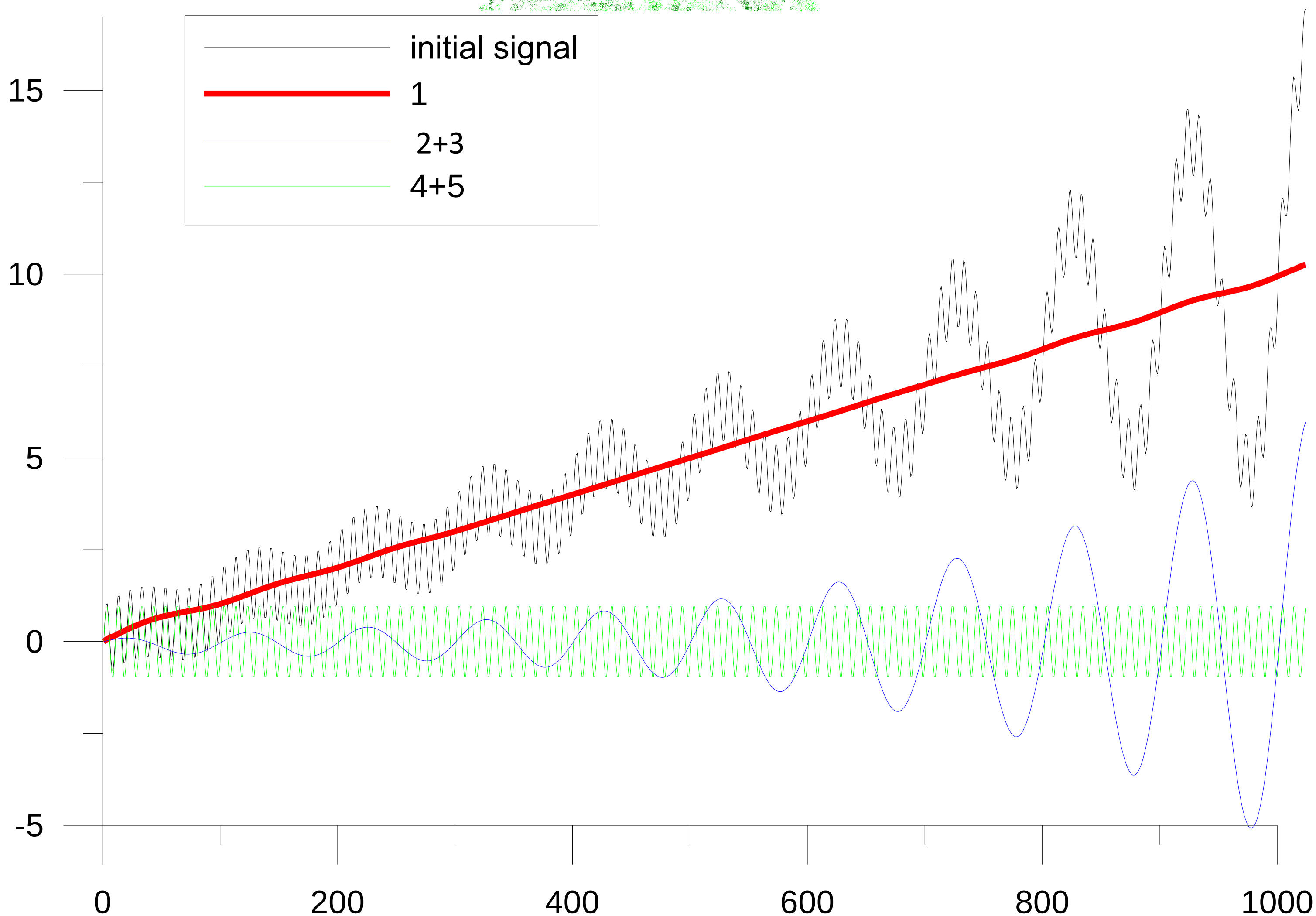
3) Principal component (PC) corresponds to every singular number s_i. The components with similar properties are grouped and their matrixes are obtained by multiplying of s_i by the first and the second singular basis vectors u_i,v_i

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

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





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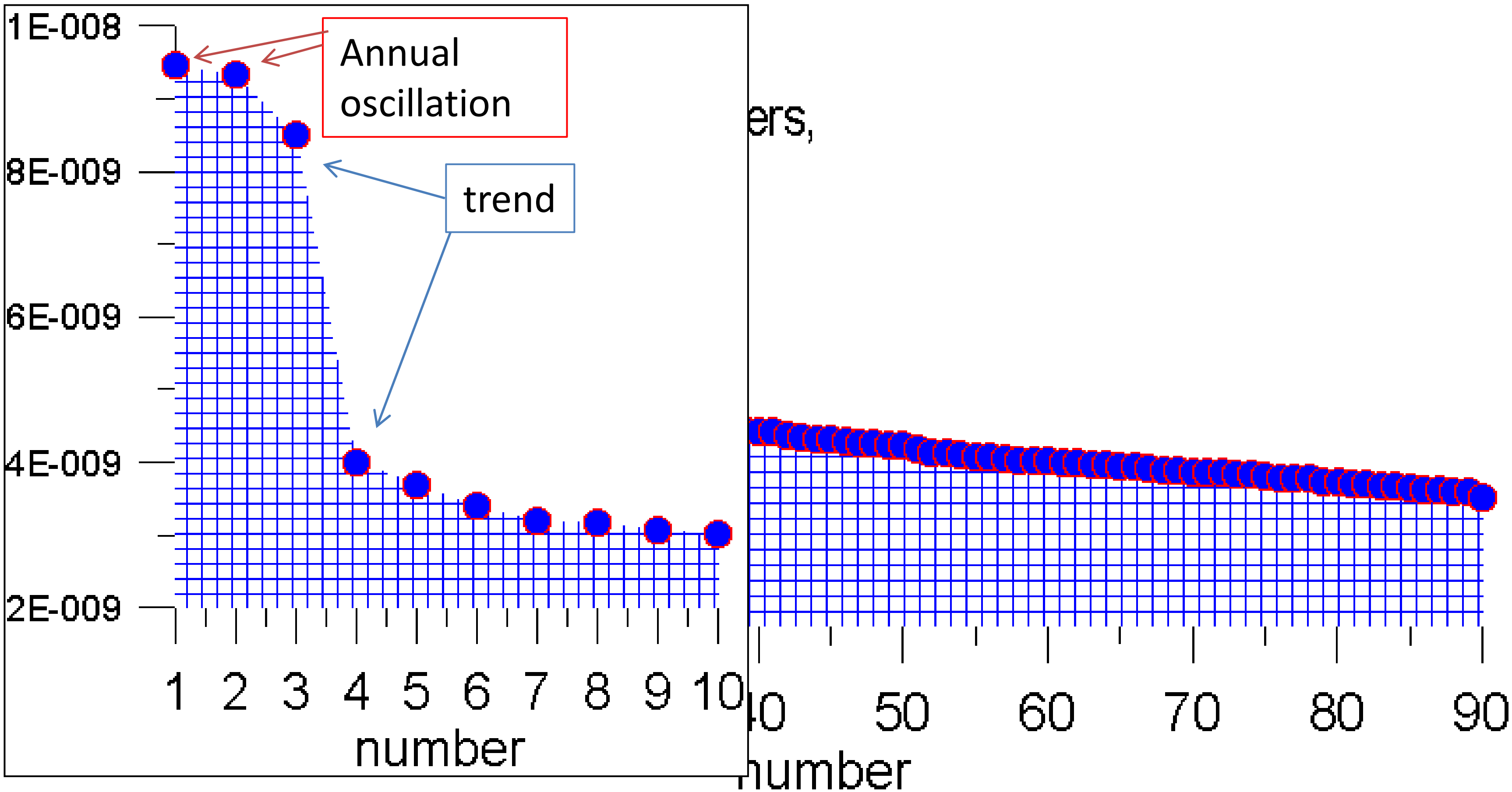
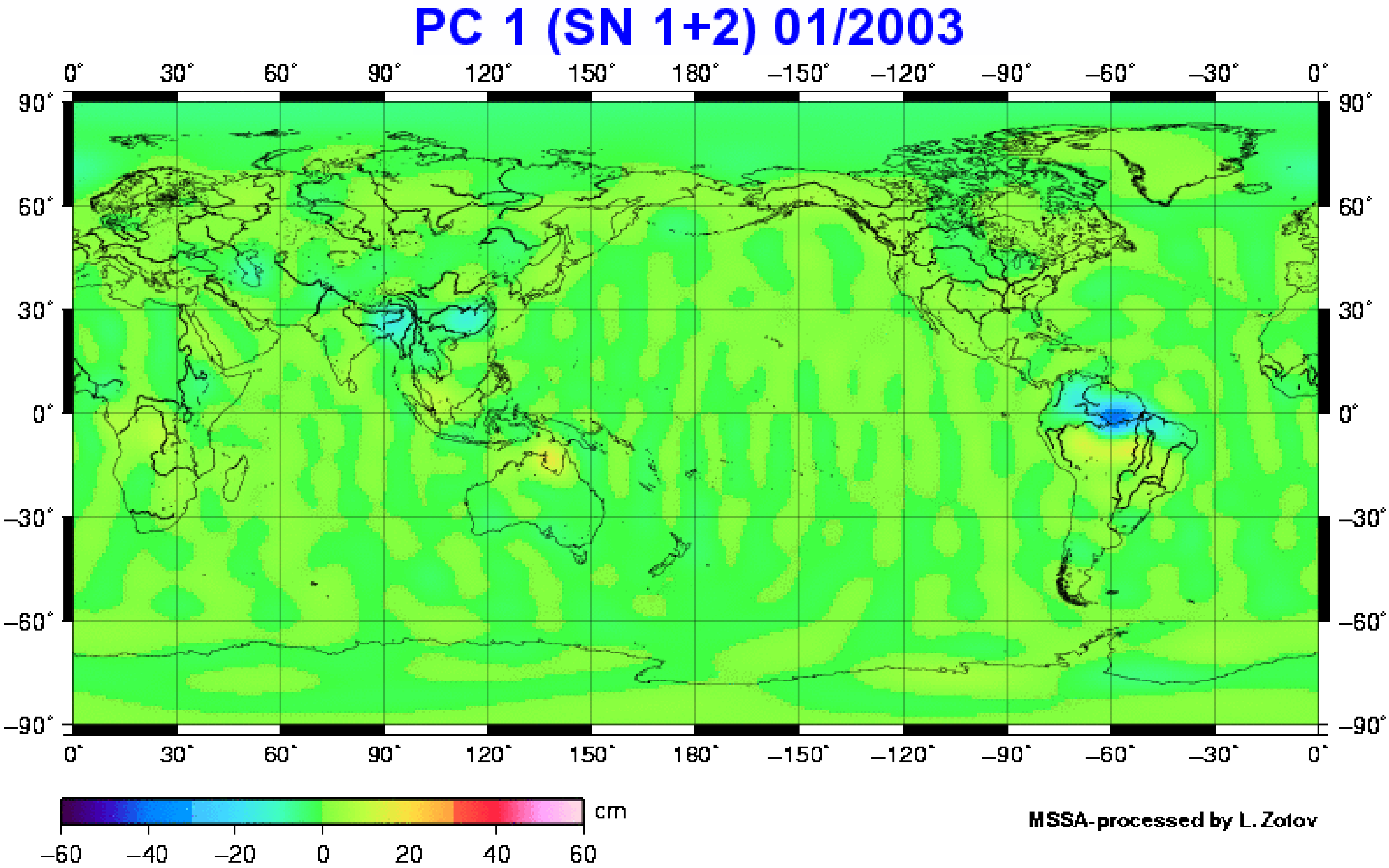
MSSA of GRACE data – singular numbers
L=36 months (3 years)



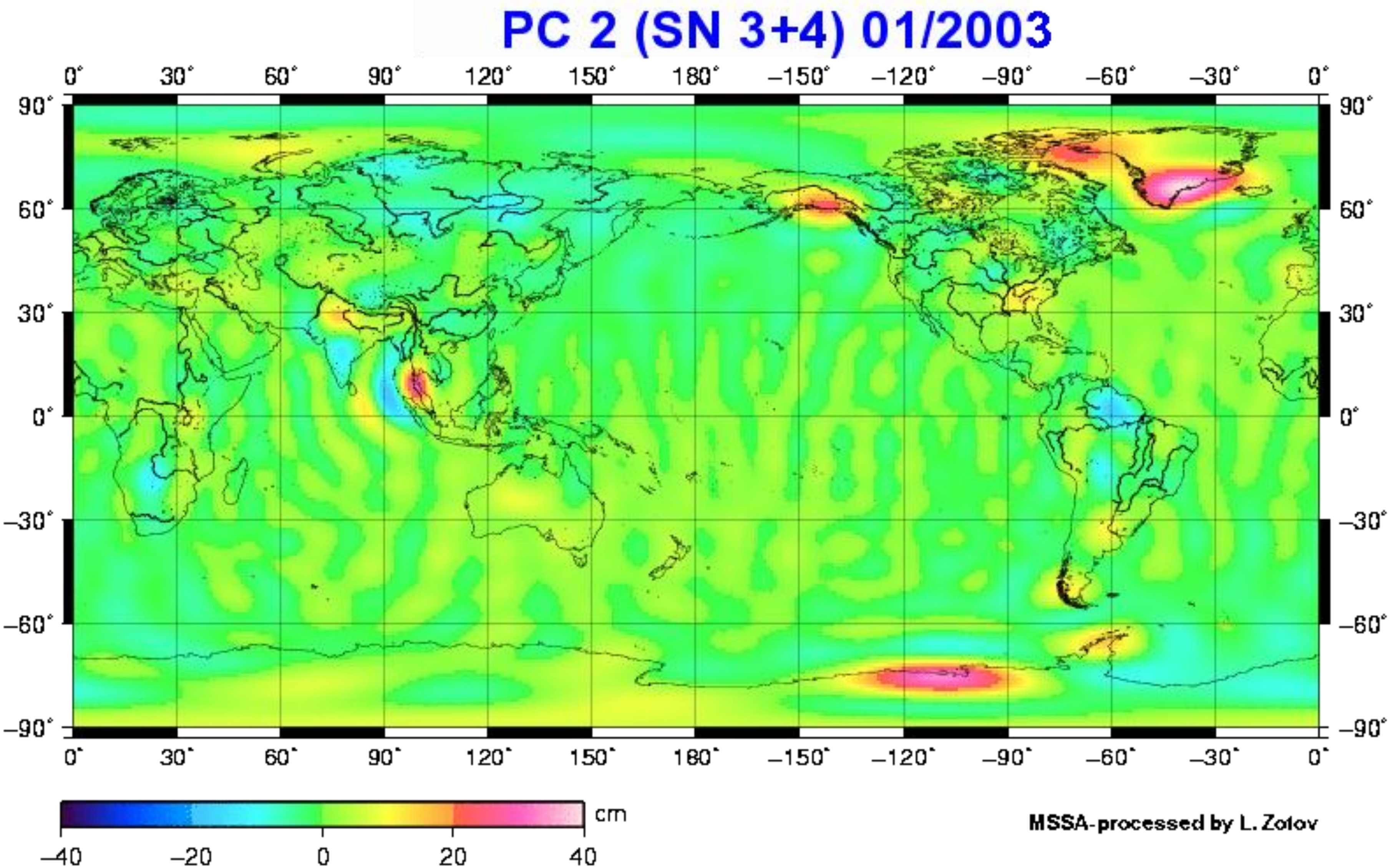
L. Zotov, C.K. Shum. Singular spectrum analysis of GRACE observations, American Institute of Physics Proceedings, of the 9th Gamow summer school, 2009, Odessa, Ukraine.

Annual cycle - PC 1



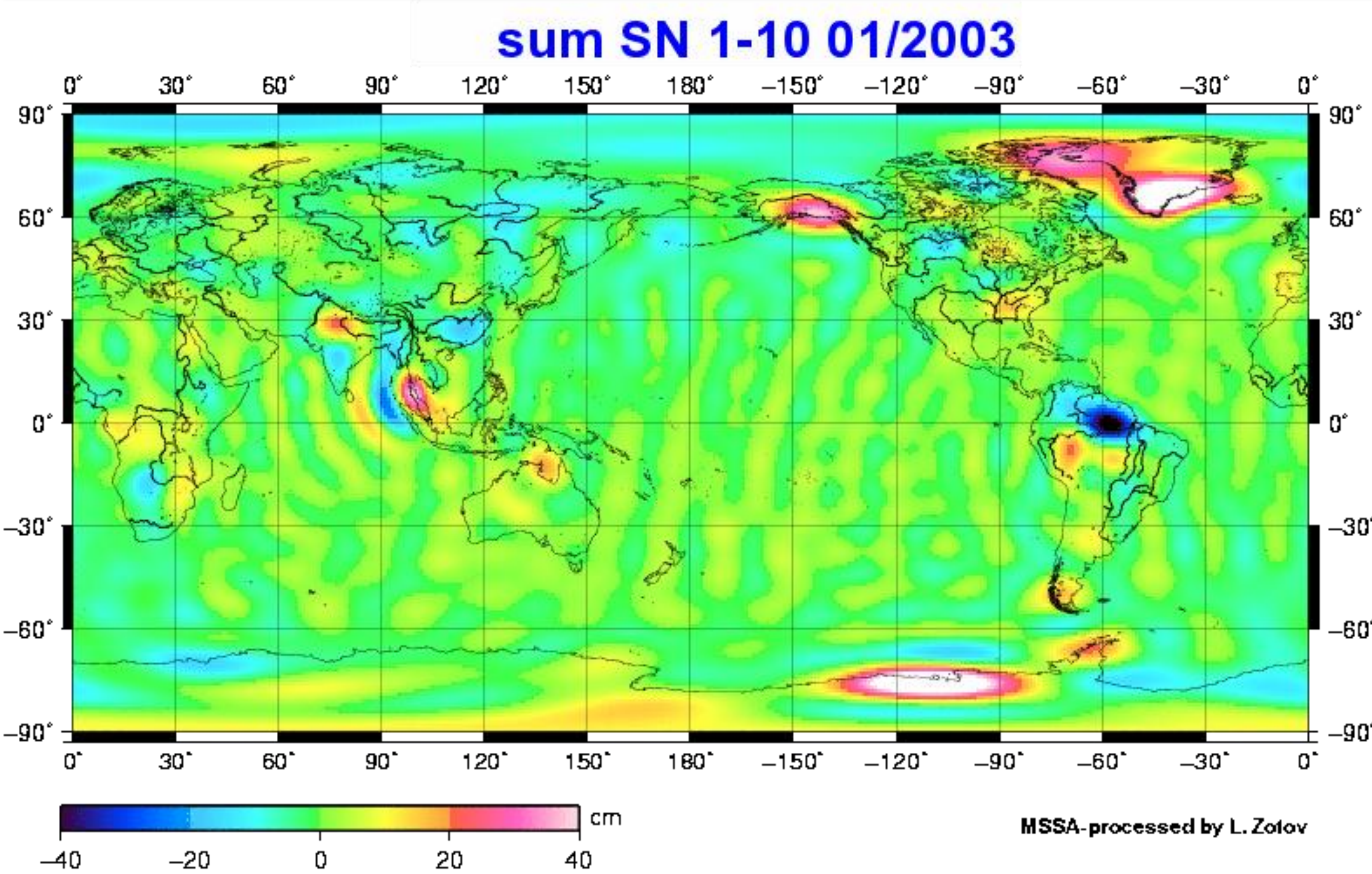
MSSA with L=36 months

Trend - PC 2



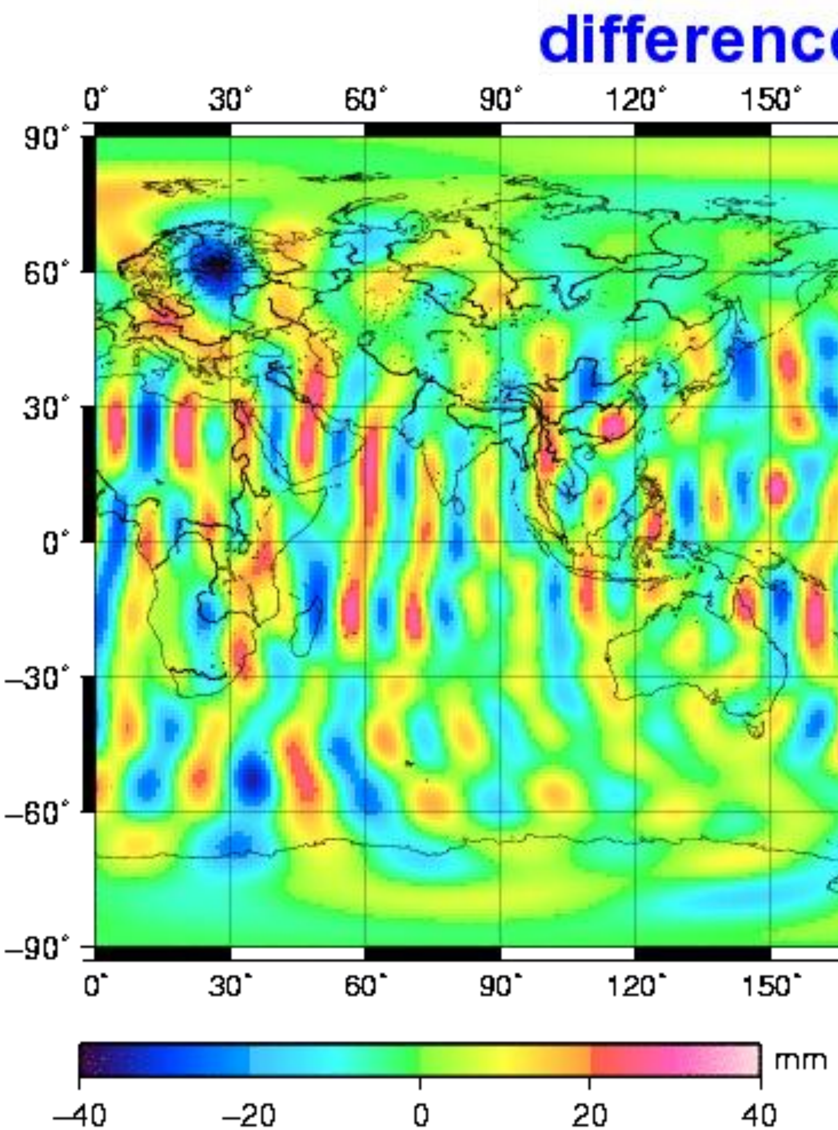
MSSA with L=36 months

Sum of first 10 SNs



MSSA with L=36 months

Remaining part sum SNs >10



MSSA with L=36 months

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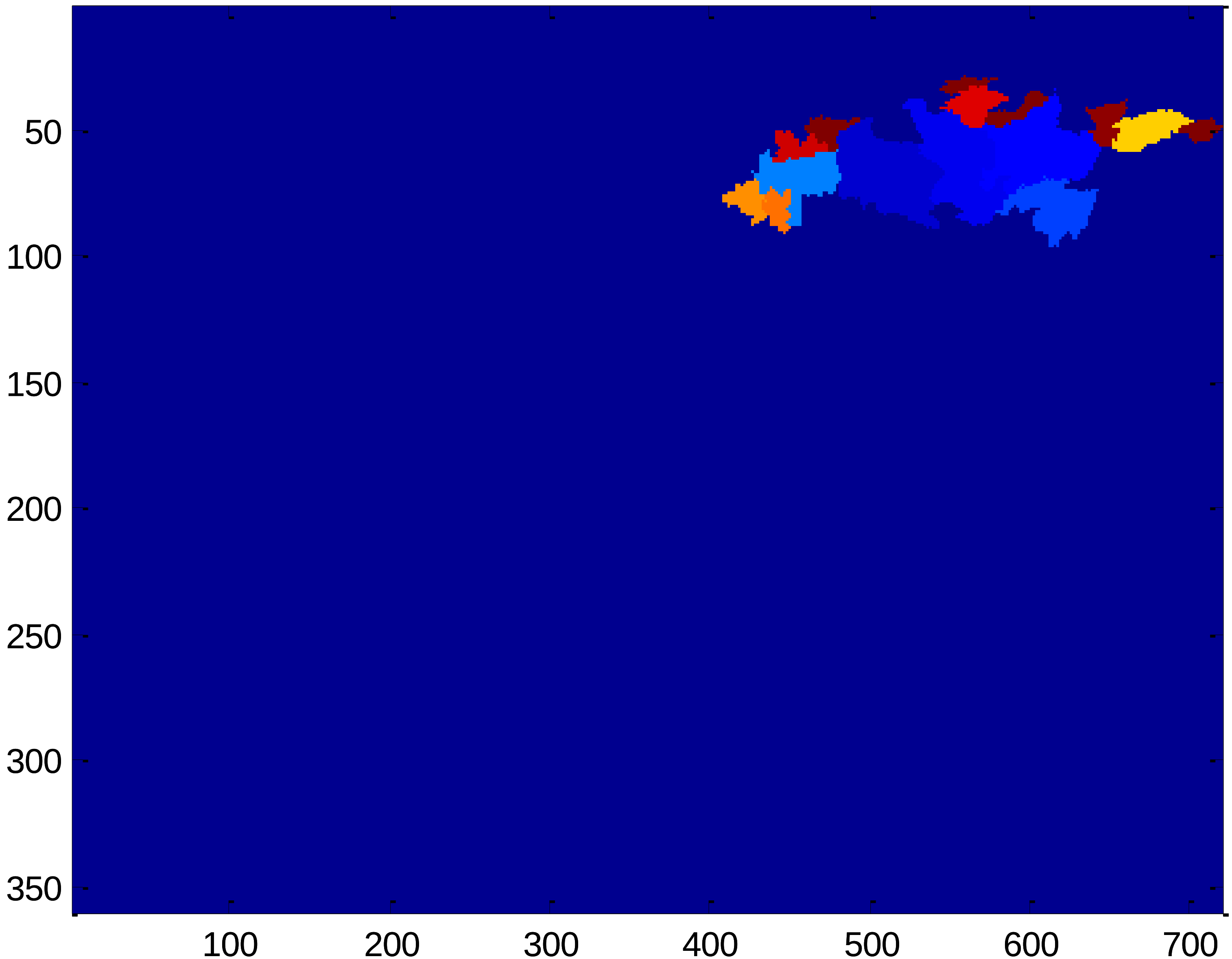
Simulated Topological Networks (STN-30p) database
is used to constrain the region to the basins of 15 large Russian rivers



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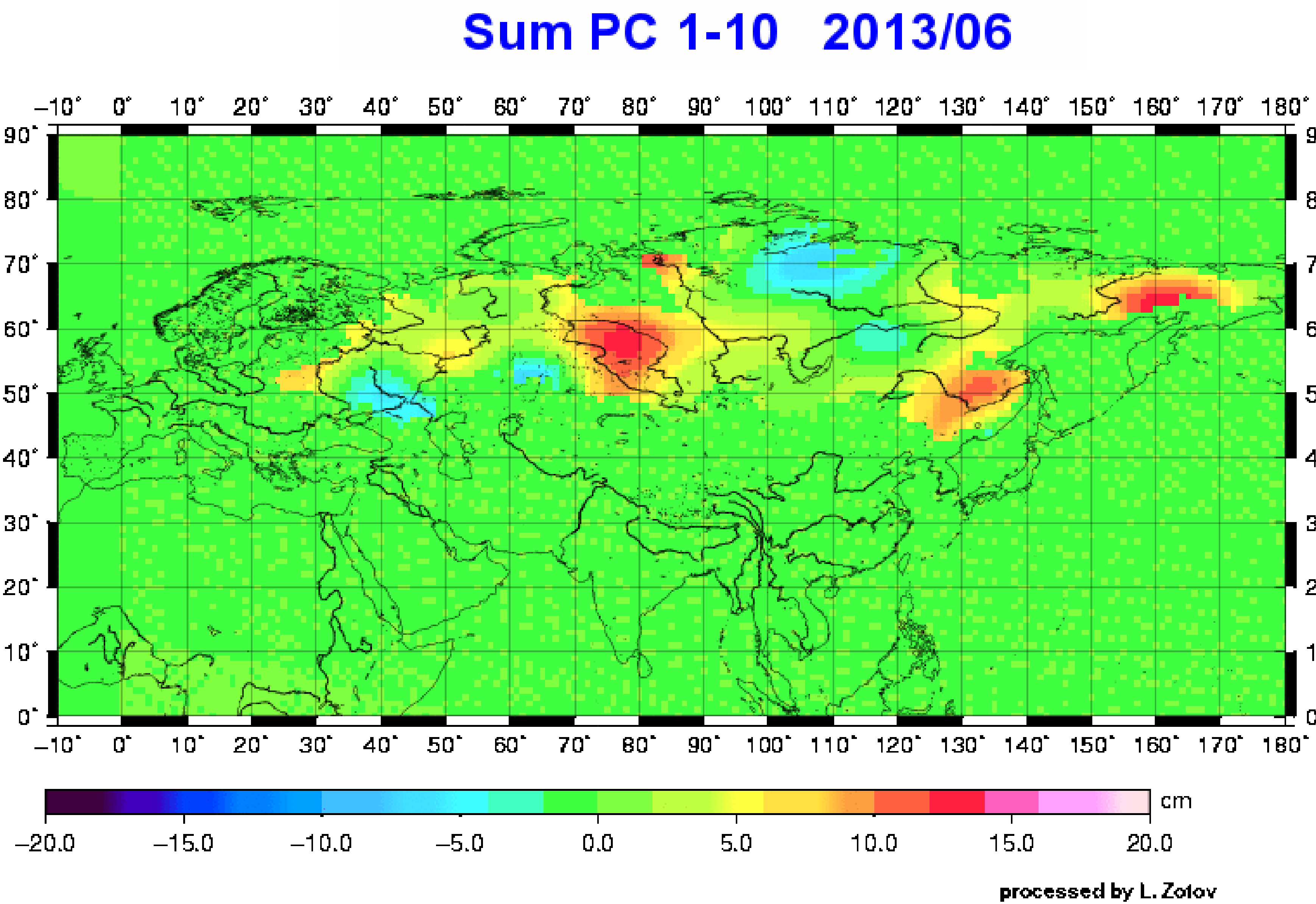
Changes in the basins of 15 large Russian rivers



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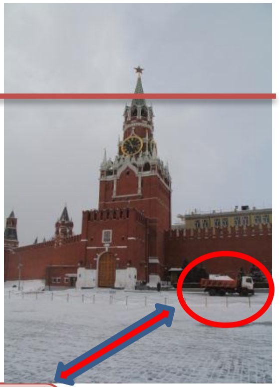
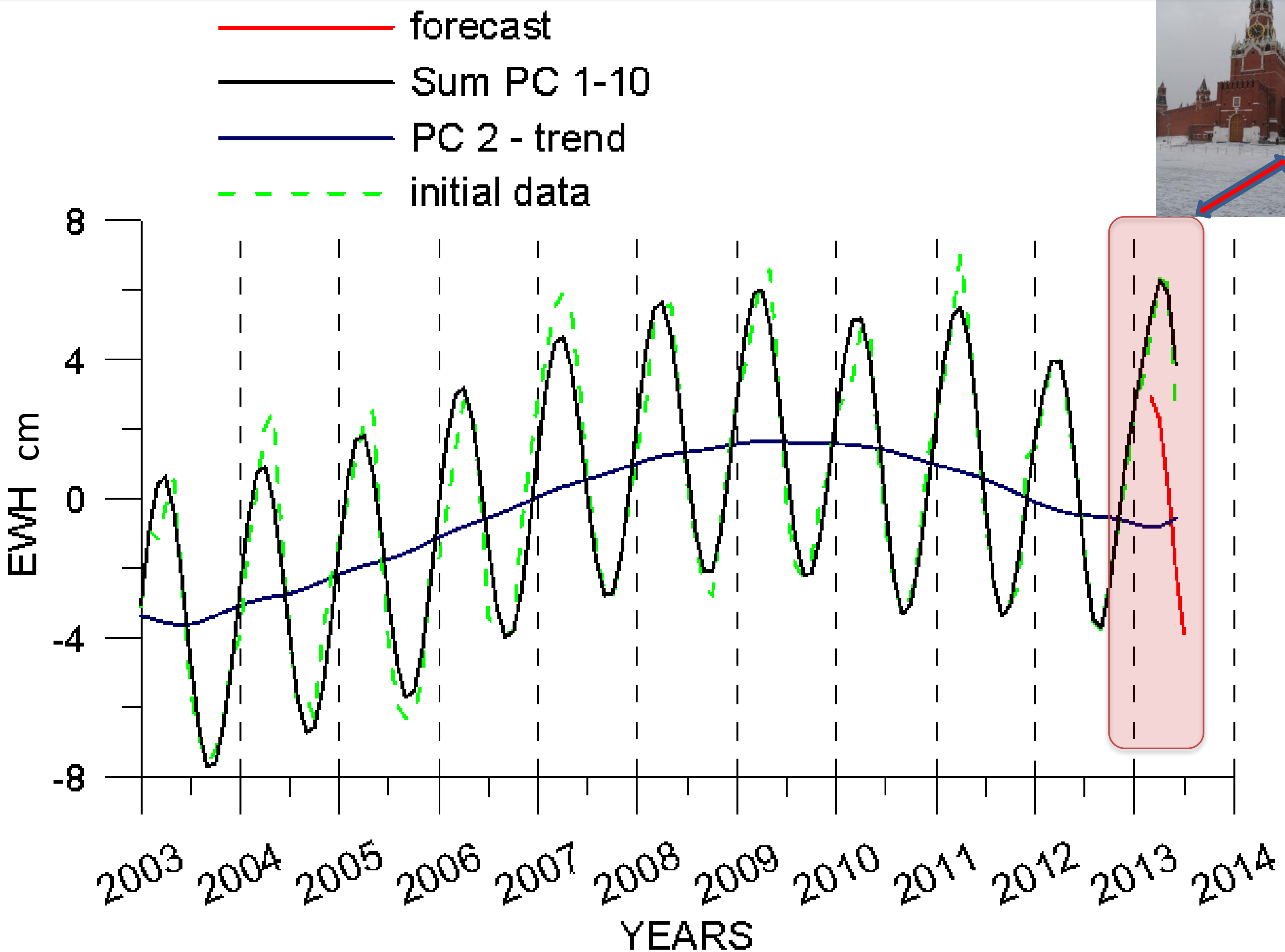
Average
over the basins of 15 large Russian rivers





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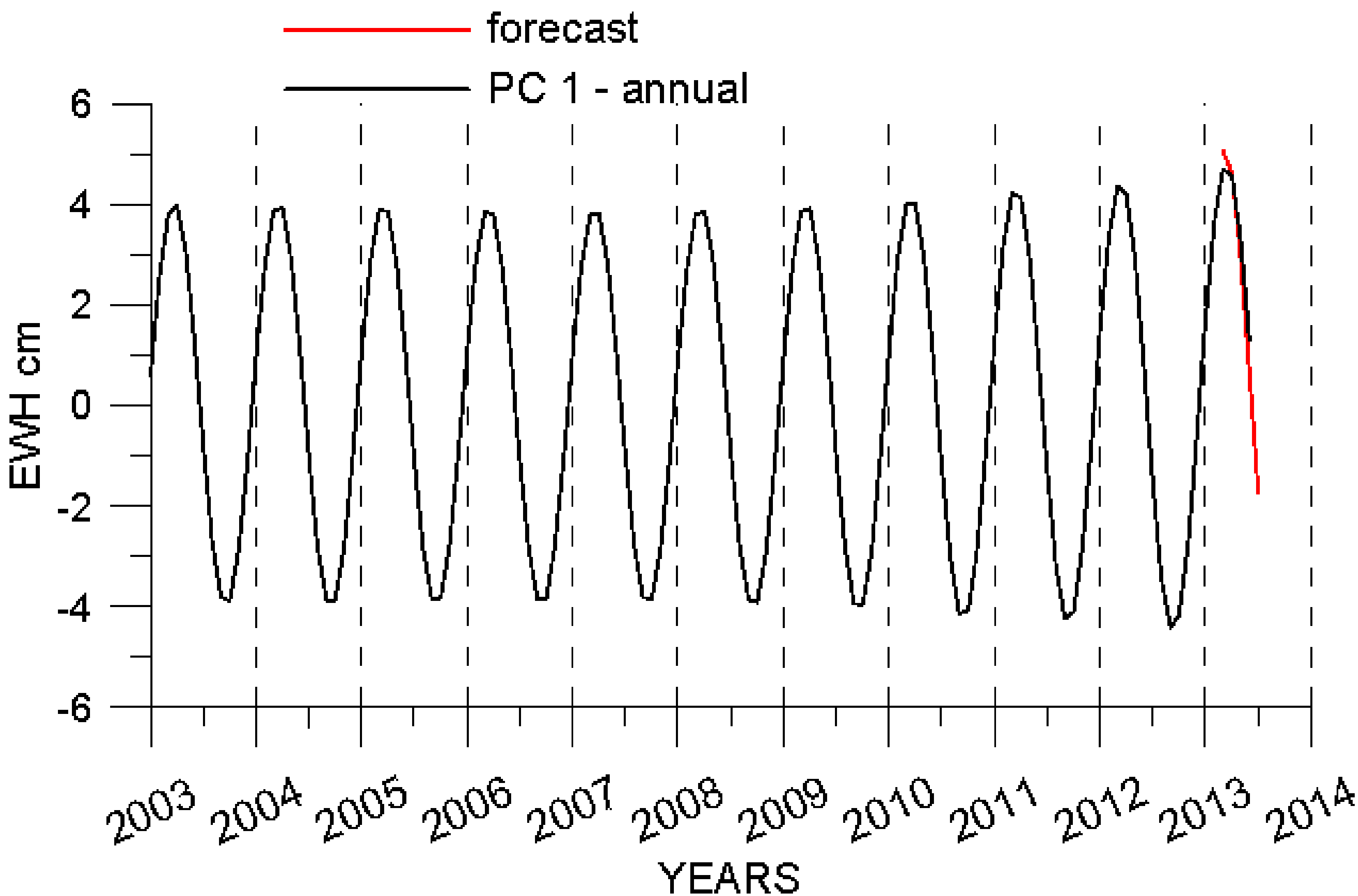
Averaged annual cycle
over the basins of 15 large Russian rivers



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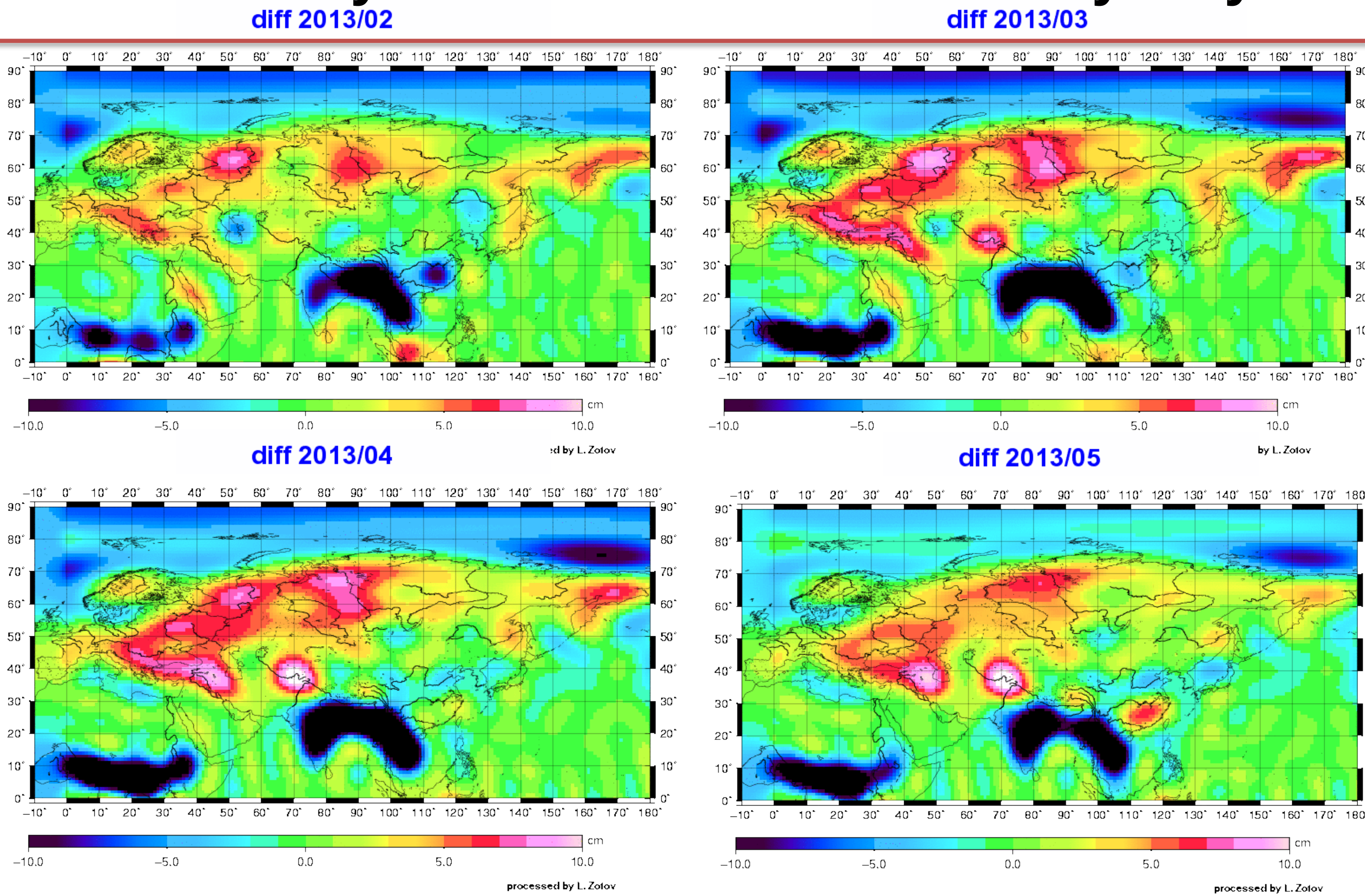
Annual cycle anomalies for February-May



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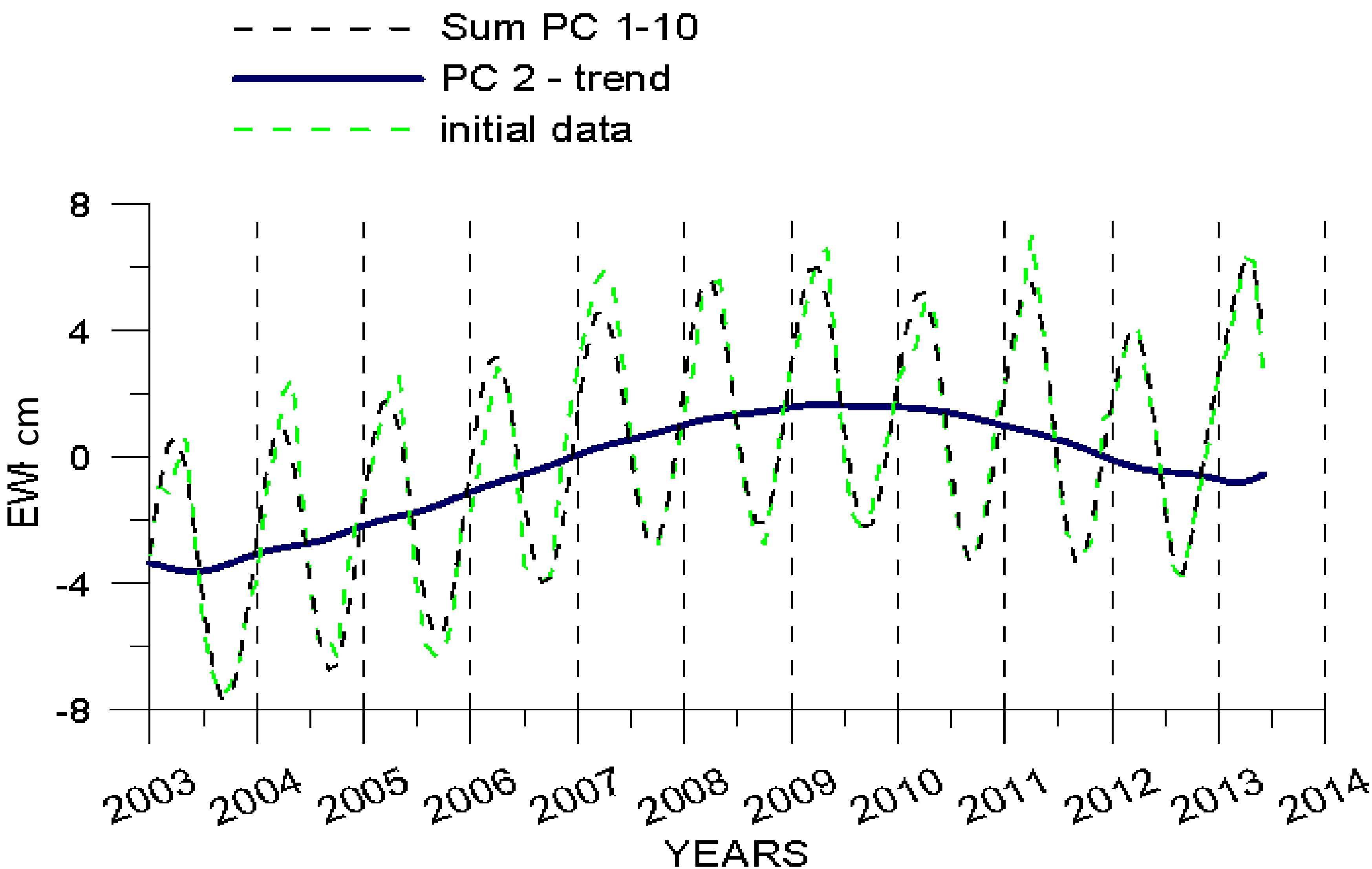
The differences for the annual PC 1 between monthly (March-June 2013) maps and average maps over 9 years (2003-2012) for the corresponding months. Positive anomalies in spring 2013 over Russia depicts anomalous snow accumulation

Averaged trend
over the basins of 15 large Russian rivers



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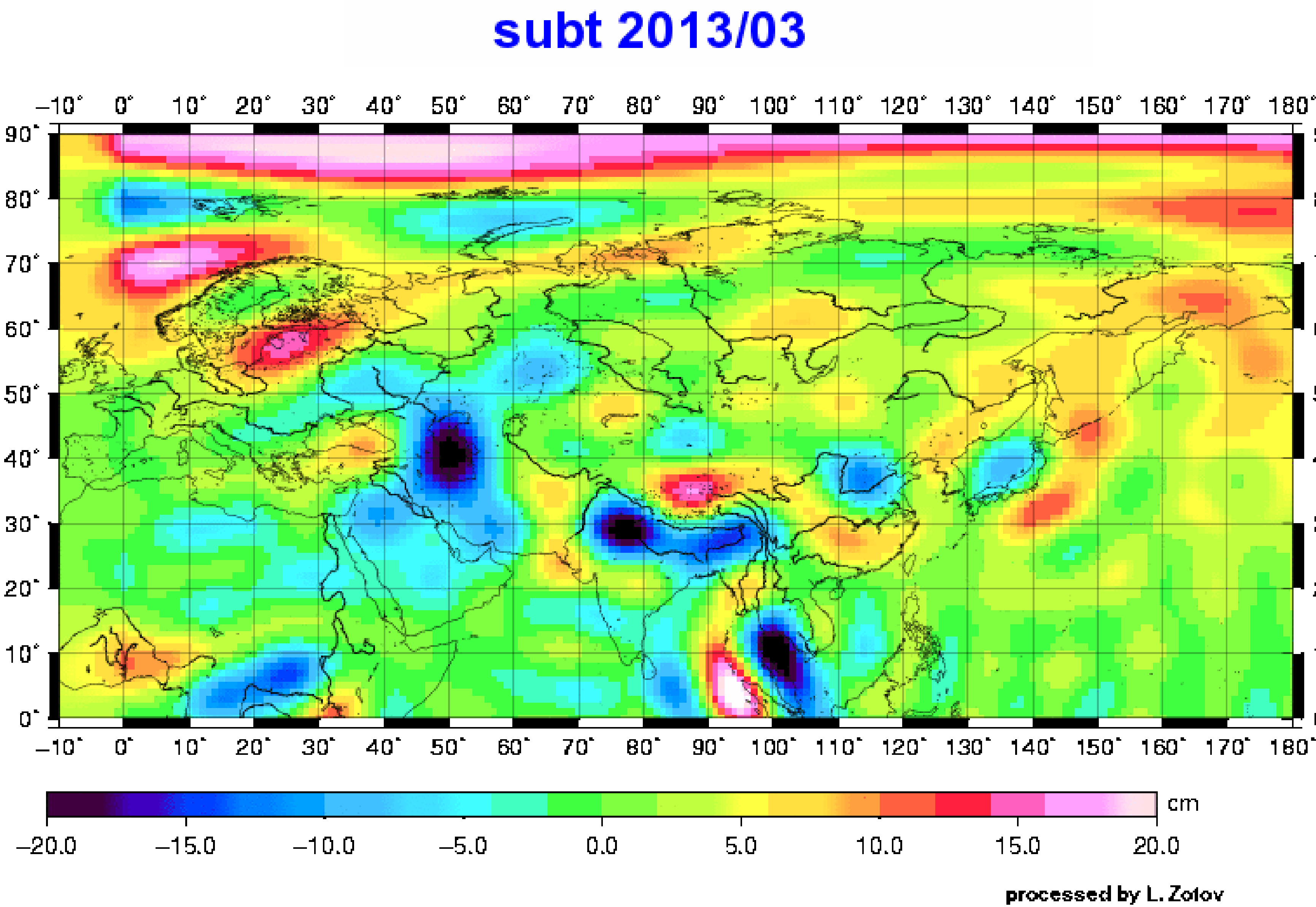
Difference between 2013 and 2003 for trend (PC 2)



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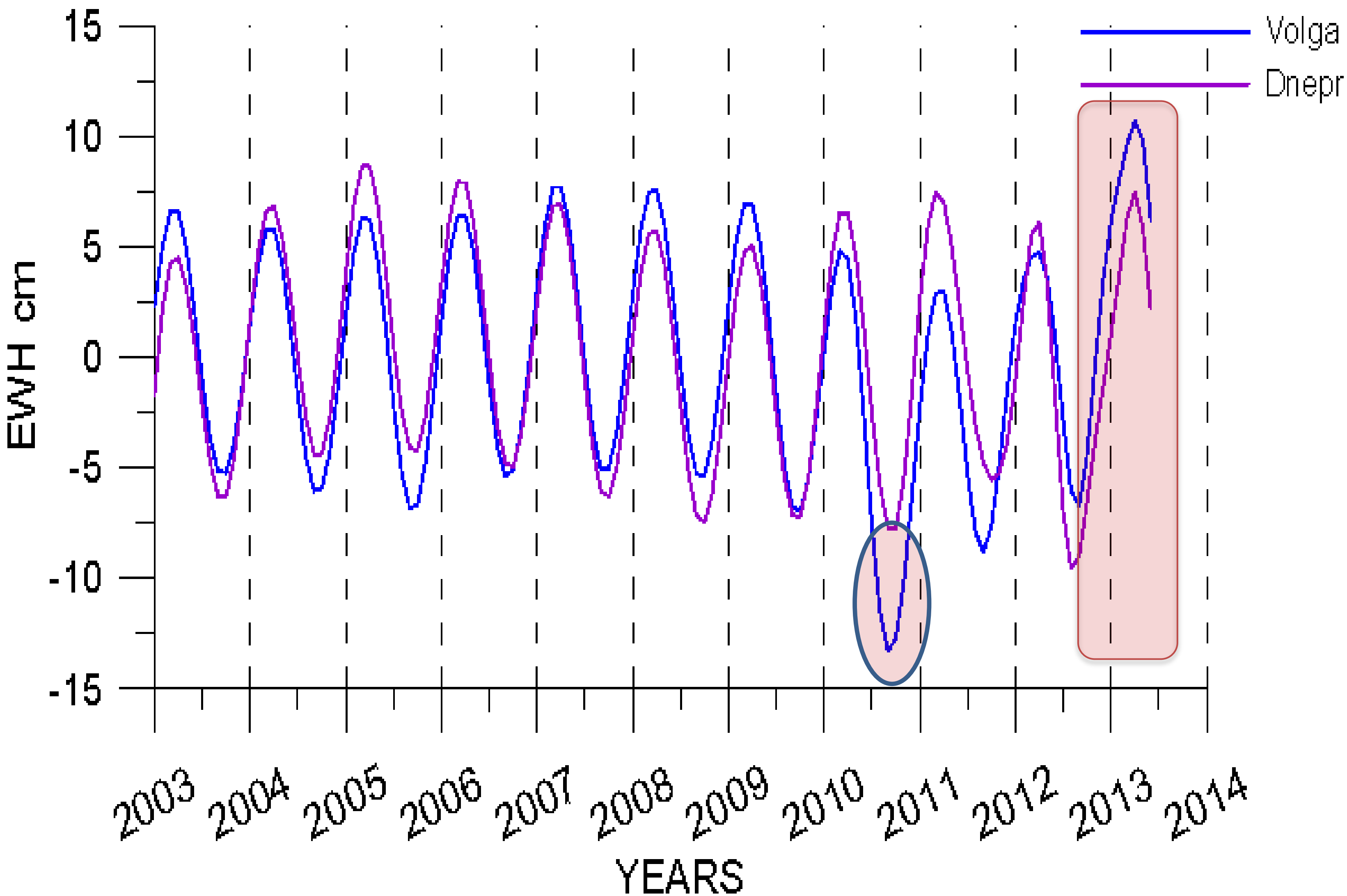
Gravity changes in the basins of large rivers of European part



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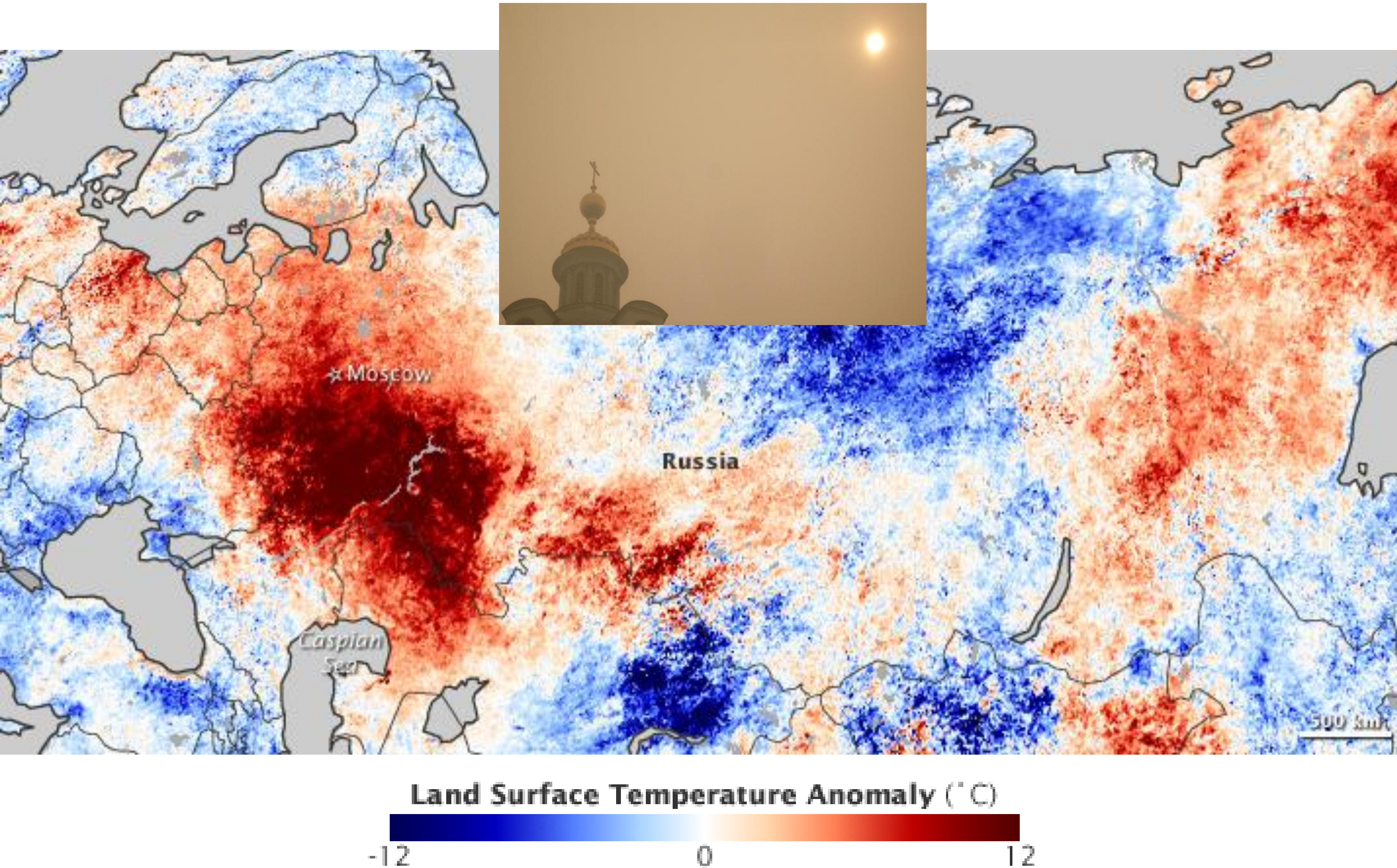
Anomalous heat wave in Moscow, Russia 20-27 July 2010
Compared to average over 2000-2008, MODIS, Terra



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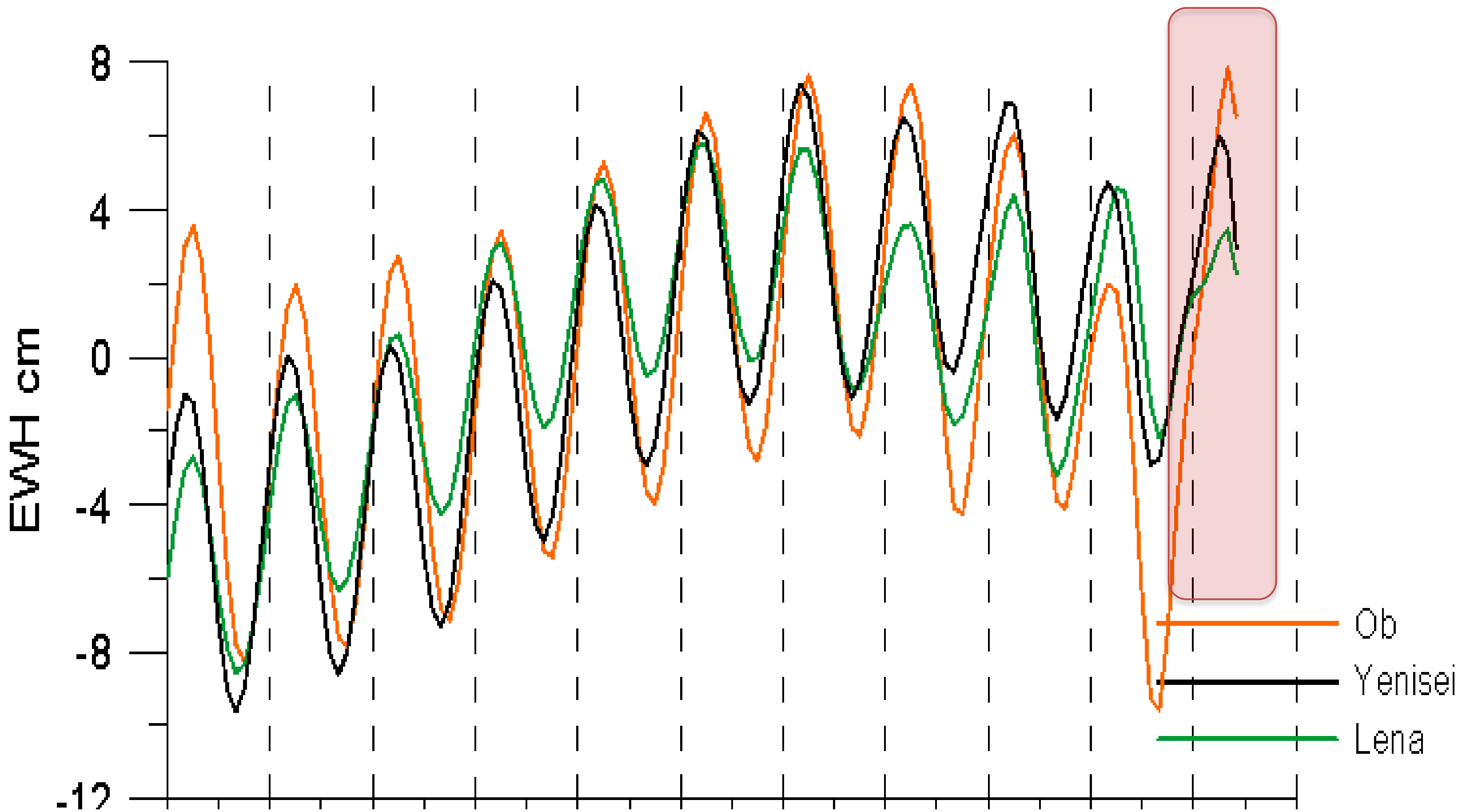
Gravity changes in the basins of large rivers of Siberia

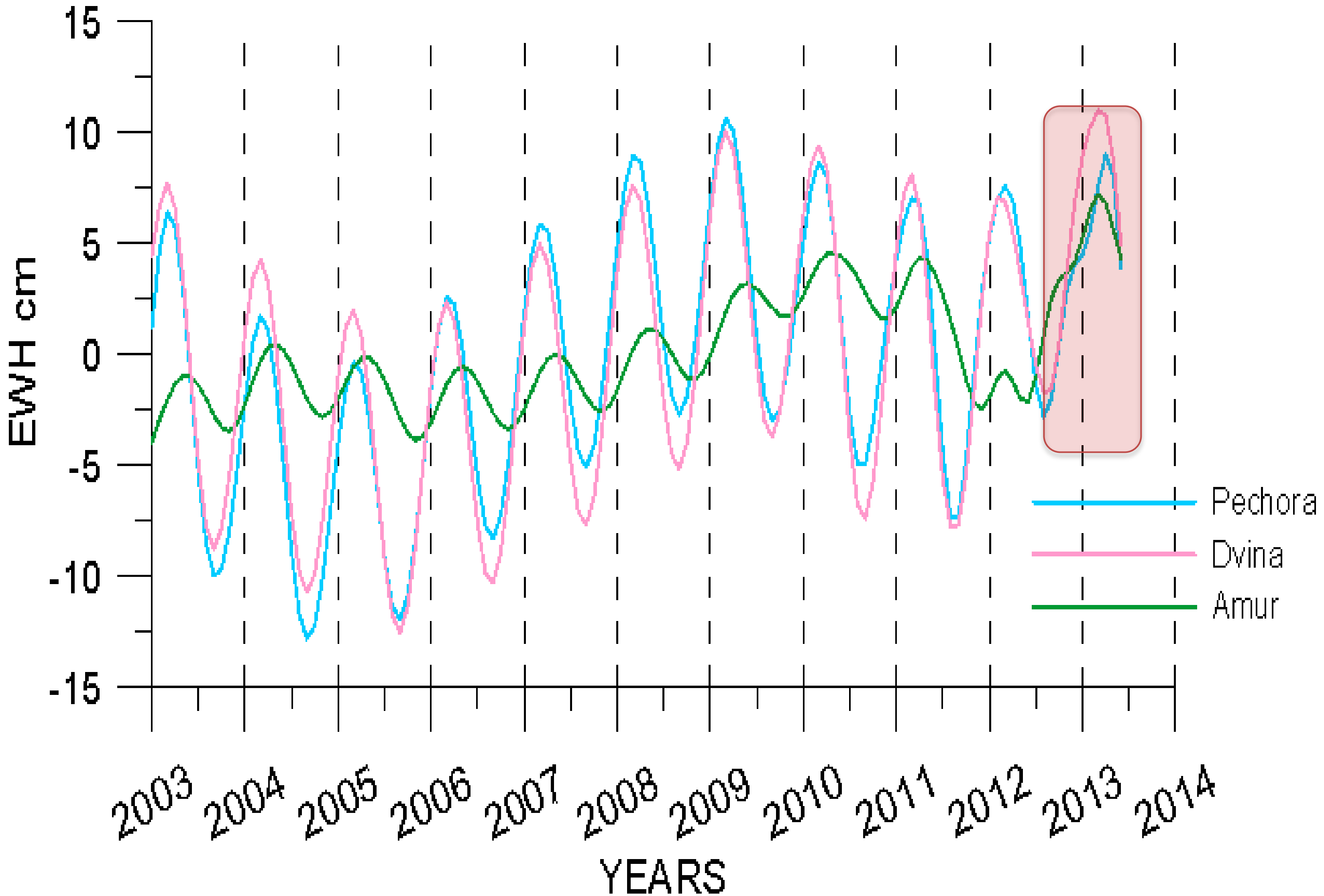


See also:

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

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



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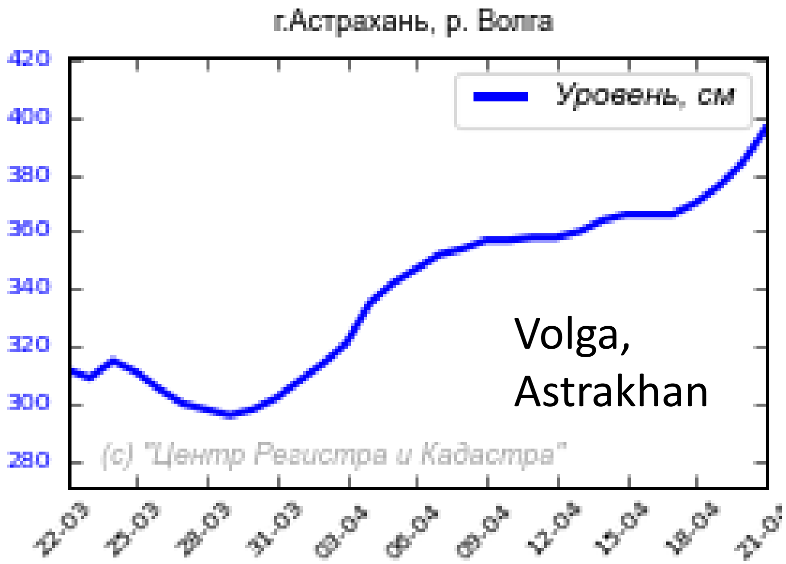
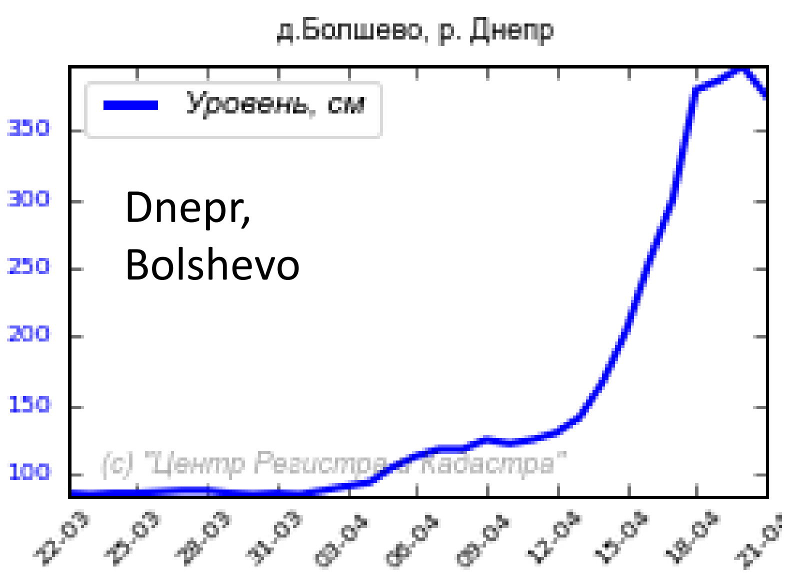
River levels changes in April 2013

cm



cm



Mass balance equation

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

where ΔTWS – measured by GRACE

ΔTSS – ground water storage changes

ΔSN – snow cover storage changes

ΔSW – changes in lakes and swamps

$\Delta(P-E)$ – changes of precipitation–evaporation difference

ΔR – river discharge changes

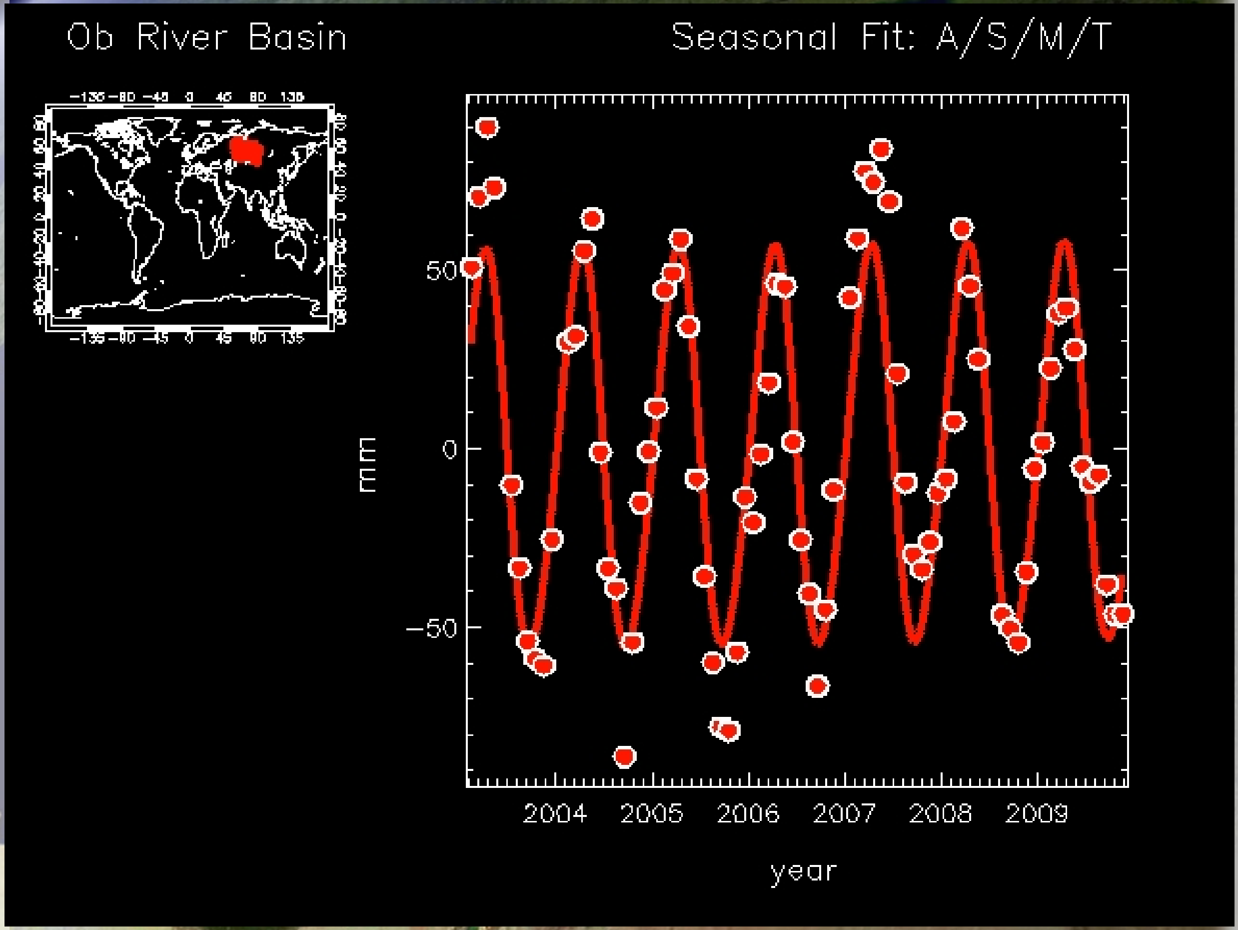
Data structure

Models and data used:

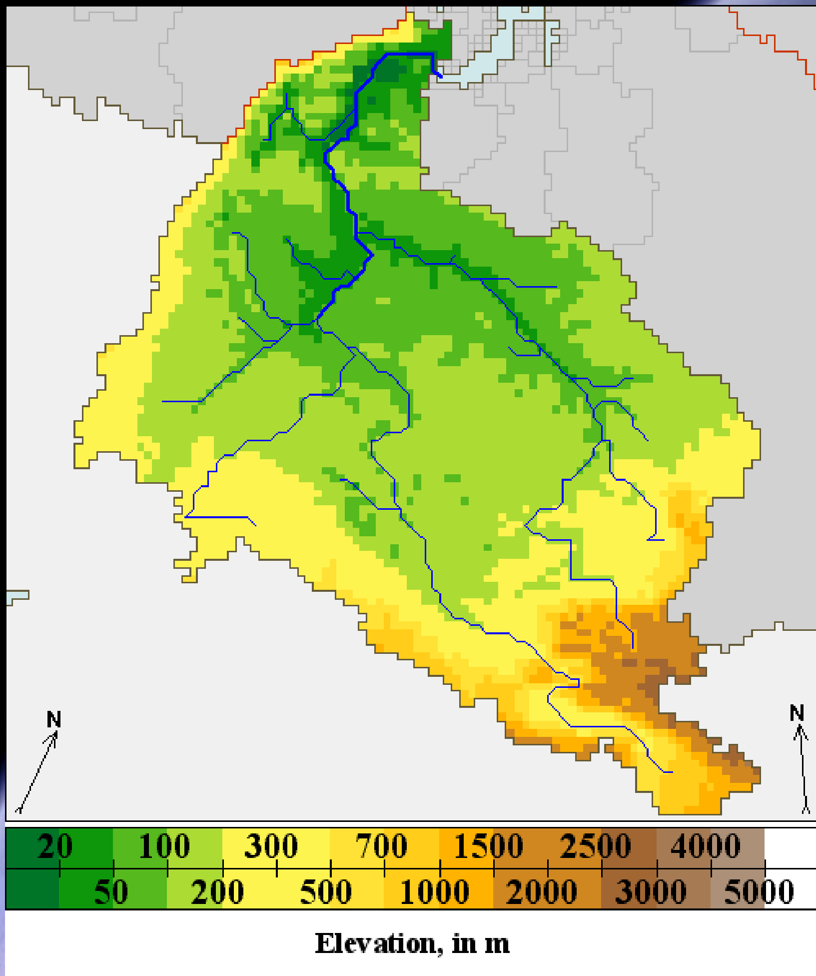
- **GLDAS VIC**
- **NCEP-NCAR**
- **ERA Interim**
- **ArcticRims data**
- **GRACE data**

Components required:

- **Liquid precipitation**
- **Evaporation**
- **Snow storage**
- **Rivers discharge**
- **Ground water (0-2 m)**



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

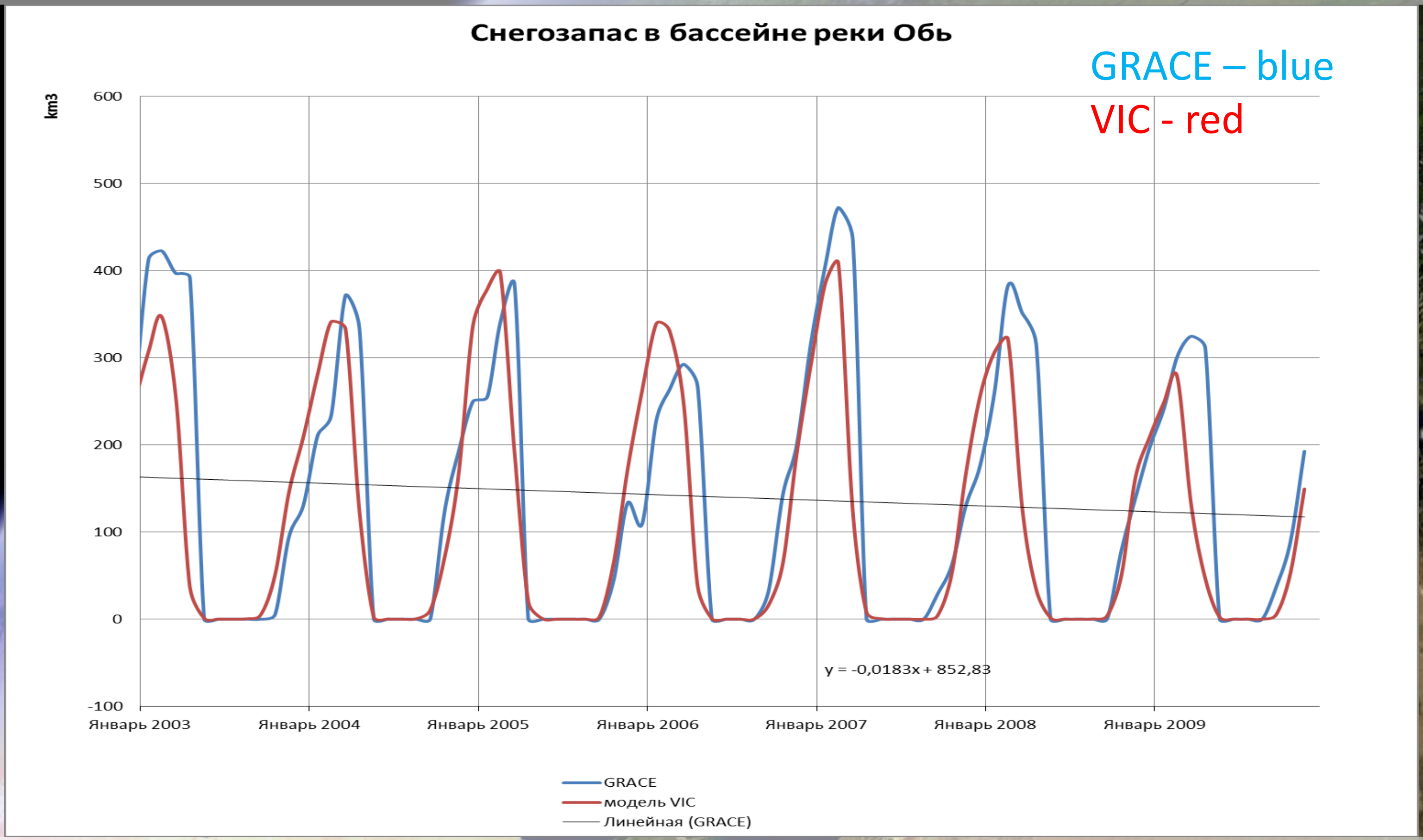
$$\Delta TWS = \Delta SW + \Delta(P\text{-}E) +$$
$$+\Delta SN + \Delta TSS - \Delta R$$

Changes of water storage in lakes and swamps

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

Snow storage calculation for OB

$$\Delta TWS = \Delta SN$$



Supposed:

1. **In winter ground water changes are small ($\Delta TSS = 0$)**
2. **$\Delta(P-E) = 0$**
3. **$\Delta SW=0$**

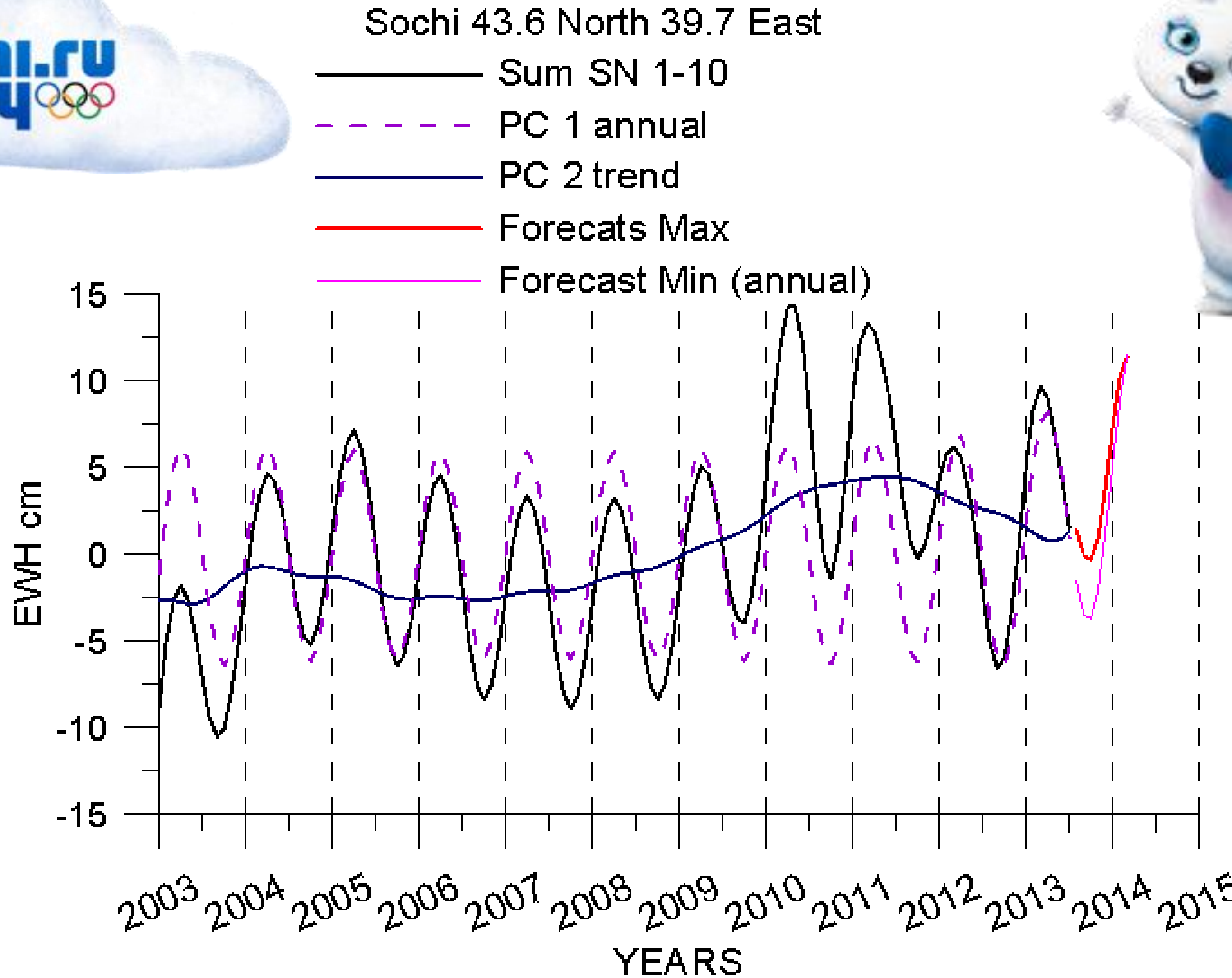
Conclusions

- 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)
- Average plots from GRACE show different behavior of European and Siberian rivers
- Trend component shows increase since 2003, maximum in 2009, following by the decrease. Map for the trend show gravity field increase at Lena and Irtysh rivers sources (probably related to permafrost degradation) and decrease over Caspian sea since 2003

Acknowledgements: This work is sponsored by RFBR grant N 12-02-31184, by Paris Observatory, and IAG travel grant. **Thanks to Jean Dickey for help with rivers basins.**

Thanks to Earth's gravity field changes
we learn much about Earth's system

Welcome to Sochi in March 2014!



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