Gravity changes over Russian rivers basins from GRACE

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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
- Snow cover
- Water stored in soil and in biomass
- 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 gradiometry 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)

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

$$\Delta h(\varphi, \lambda, t) = \frac{a \rho_{ave}}{3 \rho_w} \sum_{n=2}^{60} \sum_{m=0}^{n} \frac{2n + 1}{1 + k_n} W_n(\Delta C_{nm}(t) \cos m\lambda + \Delta S_{nm}(t) \sin m\lambda) \lambda^m (\sin \varphi),$$
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 $A_{ij}$ ($C_{ij}$ or $S_{ij}$). Trajectory matrixes for all the components are embedded into the large block matrix $X$

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

$$K = N - L + 1$$

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

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

$$X = USV^T$$

3) Principal 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

![Diagram showing initial signal and components 1, 2+3, and 4+5.](image-url)

- **Initial Signal**
- **1**
- **2+3**
- **4+5**
MSSA of GRACE data – singular numbers
L=48 months (4 years)

Annual cycle – PC 1

PC 1 (SN 1+2) 01/2003

MCC, L=48 months
Trend - PC 2

PC 2 (SN 3+4) 01/2003

MCCCA, L=48 months

MSSA-processed by L. Zolov
Sum of first 10 SNs

MSSA with L=36 months
Remaining components, sum SNs >10

difference 01/2003

MCCA, L=48 months
Sum of first 10 PCs over Eurasia

Sum PC 1-10 2003/01

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

Sum PC 1-10  2014/01

processed by L. Zotov
Mass anomaly (averaged field) in the basins of 15 large Russian rivers

- forecast
- Sum PC 1-10
- PC 2 - trend
- initial data

EWH cm


YEARS
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
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.
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)
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
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

![Graph](image-url)
Comparison with data from hydrological web

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

VOLGA basin

- GRACE initial JPL data
- MSSA PC 1-10
- CYMENT data
- Gravity measurements

River ENV025VOLGAE282 lon=45.196190 lat=48.468110

ENVISAT measurements

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

Will the heat repeats in 2014?
River’s level changes from the Cadastr Center of Russia
Mass balance equation

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

where \( \Delta \text{TWS} \) – measured by GRACE
\( \Delta \text{SW} \) – changes in lakes and swamps
\( \Delta (P-E) \) – changes of precipitation–evaporation difference
\( \Delta \text{SN} \) – snow cover storage changes
\( \Delta \text{TSS} \) – ground water storage changes
\( \Delta \text{R} \) – river discharge changes
Ob river

Catchment area: 2990 000 km²
River length 3650 km
Mostly snow supply
• Presence of no-discharge areas
• Many lakes and swamps
• Several climatic zones

\[ \Delta \text{TWS} = \Delta \text{SW} + \Delta (P-E) + \Delta \text{SN} + \Delta \text{TSS} - \Delta R \]
2-D MSSA of data from IPCC Fifth Assessment report
“CLIMATE CHANGE-2013”

Zotov, Bizouard, EGU2014-5683
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 warming trend. Continuation of study based on balance equation is required.

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Merci pour votre attention!