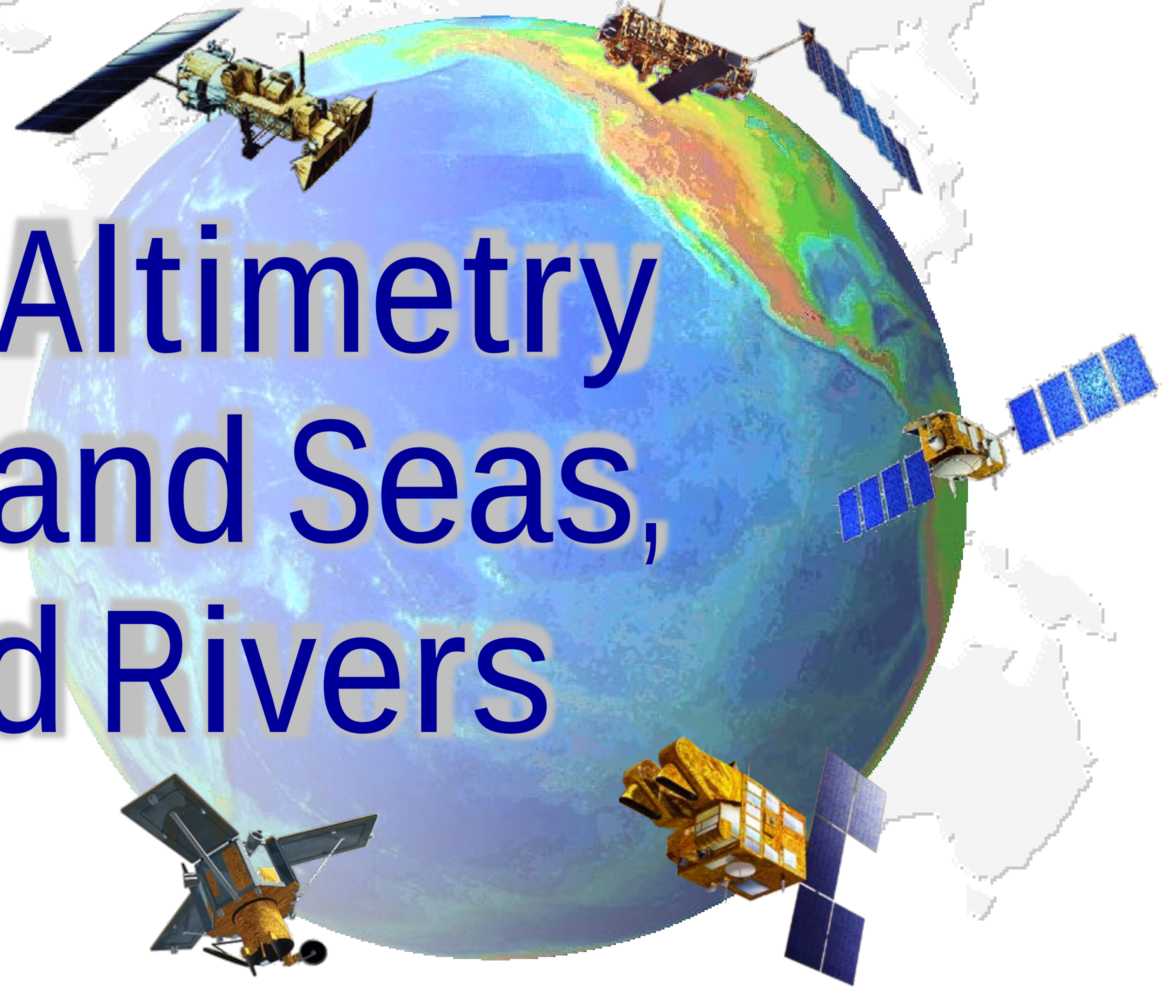
Sergey A. Lebedev

Geophysical Center,
Russian Academy of Sciences

Space Research Institute,
Russian Academy of Sciences



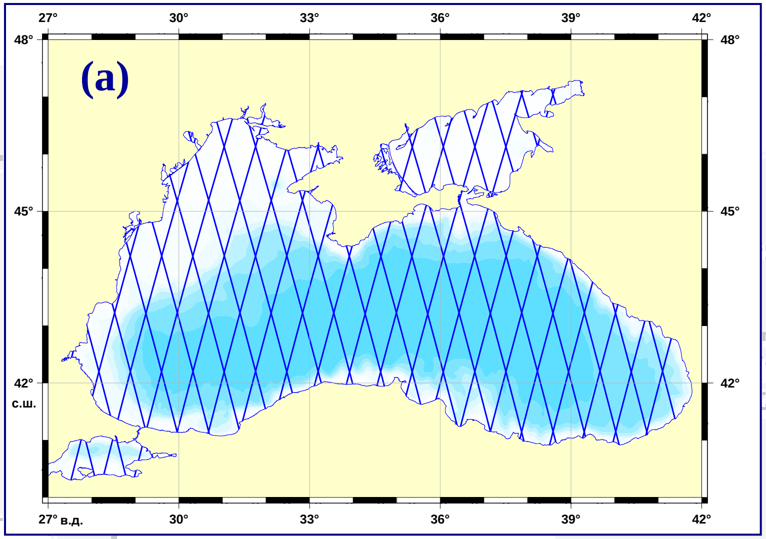
Satellite Altimetry of the Inland Seas, Lakes and Rivers

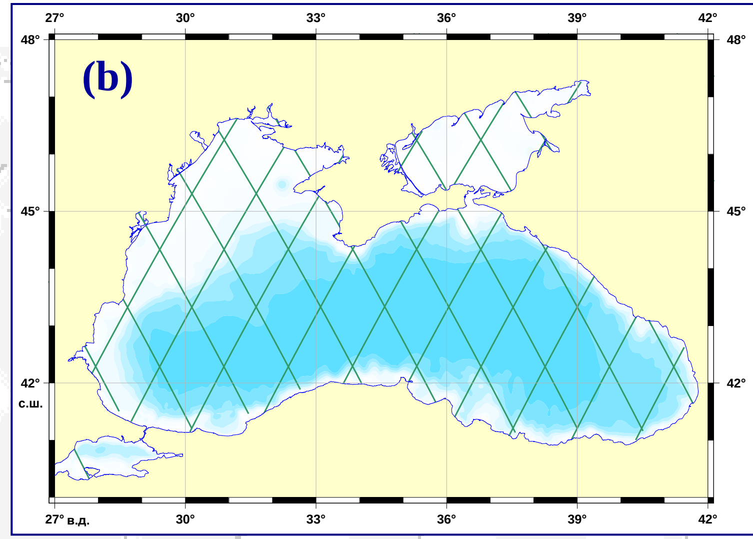
Joint COSPAR and WMO Capacity Building Workshop
«Satellite remote sensing, water cycle and climate change»

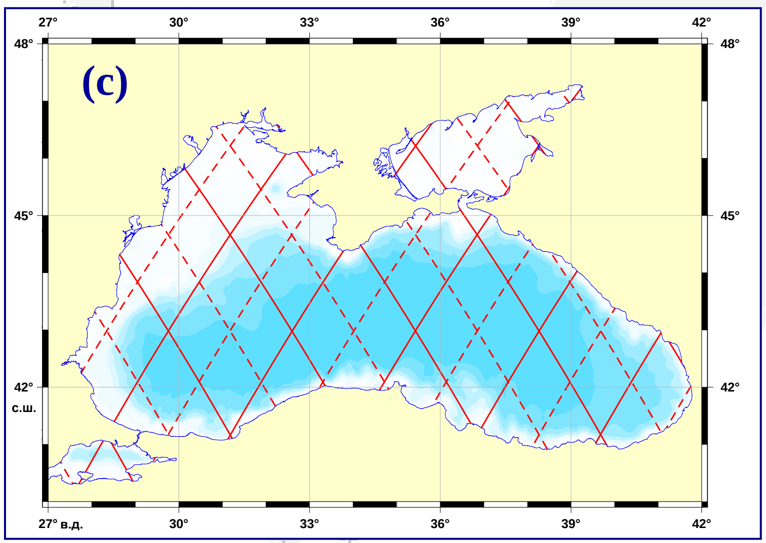
20 July — 1 August 2014,
Tver, Russian Federation

Tver State University.

The Black and Azov Seas







Groundtracks on the Black and Azov Seas for the following satellites:

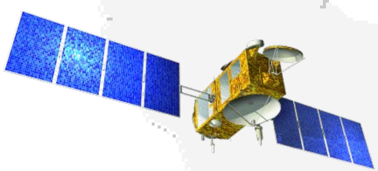
(a) **ERS-1/2 and ENVISAT with a repeat period of 35 days**

(b) **GEOSAT and GFO-1 with a repeat period of 17 days**

(c) **TOPEX / Poseidon and Jason-1/2 with a repeat period of 10 days (the dashed line shows the position of the satellites tracks after the satellites maneuver).**

Altimetry Data

Satellite
TOPEX/Poseidon



Satellite
Jason-1/2

For investigation of interannual variability of the Black and Azov Seas Level the measurements of TOPEX/Poseidon (T/P) and Jason-1/2 (J1/2) satellites along tracks were used because:

- **The orbital repeat period (~9.916 days) is close to characteristic temporal scale of the basic hydrological and hydrodynamic phenomena.**
- **The altimetry data coverage for the Black and Azov Seas allows to take into account all hydrological and hydrodynamic features.**
- **The T/P data represent the longest time-series of satellite altimetry measurements (September 1992 – August 2002) with the possibility of the data extension by J1 data along the same tracks (August 2002 – February 2009) and J2 (July 2008 – present time).**

Processing of Satellite Altimetry Data

Processing of the T/P and J1/2 satellite data was done using the software of Integrated Satellite Altimetry Data Base (ISADB) elaborated in Geophysical Center RAS as follows:

- **The "dry" troposphere correction was calculated by model ECMWF (European Centre for Medium-Range Weather Forecasts) data.**

$$dh_{dry} = 2,277 \cdot P_{surf} \left(1 + 0,0026 \,\mathrm{Cos}\left(2\varphi \right) \right)$$

- **The wet troposphere correction was calculated by Microwave Radiometer data.**

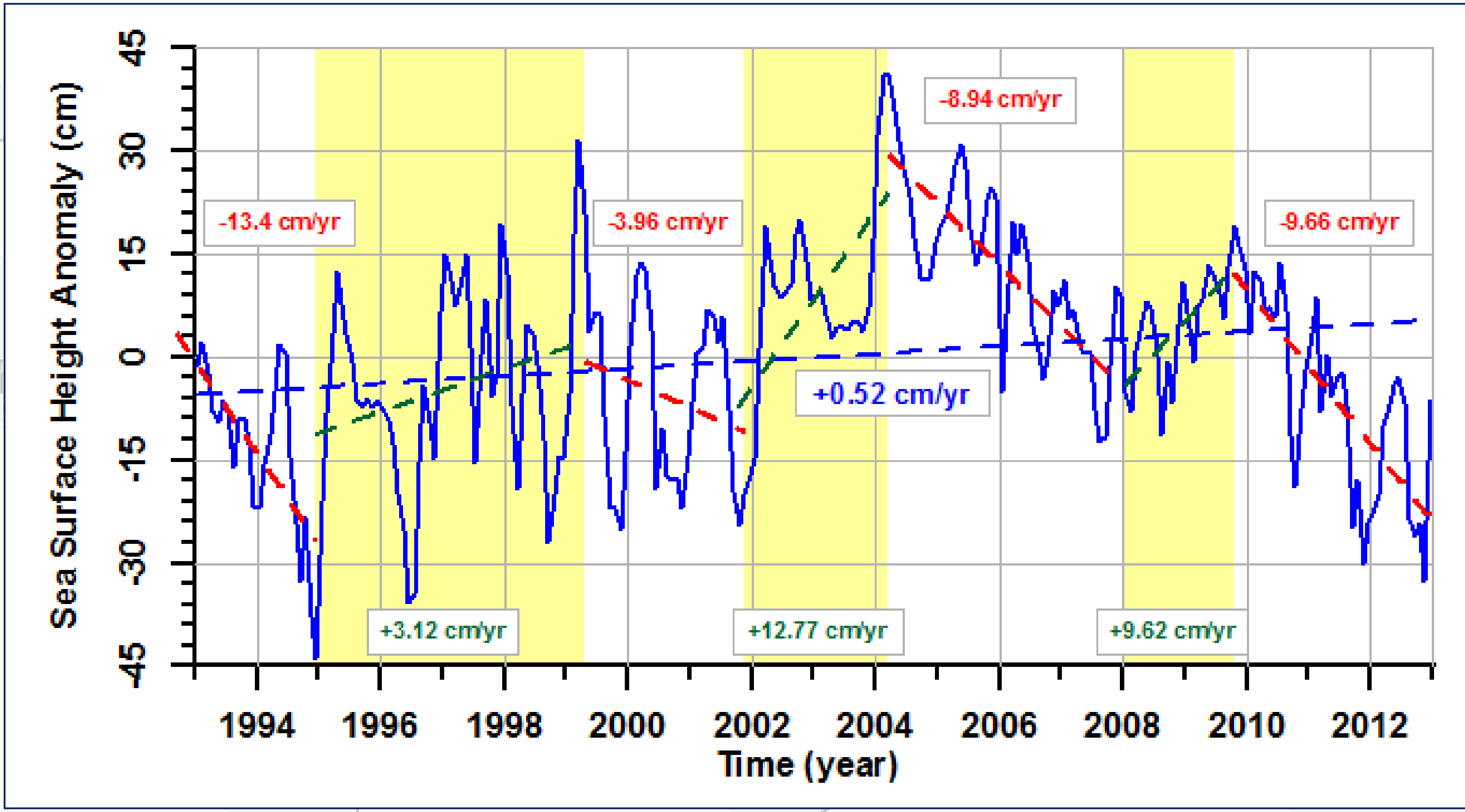
$$h_{wet} = \beta_0 + \sum_{i=1}^{N} \beta_i \ln\left(280 - T_{Bi}\right)$$

- **Dual-frequency ionosphere correction was used for correction altimetric measurements of sea surface height.**

- **Sea state bias was calculated by model and/or *in-situ* measurements of wave height.**

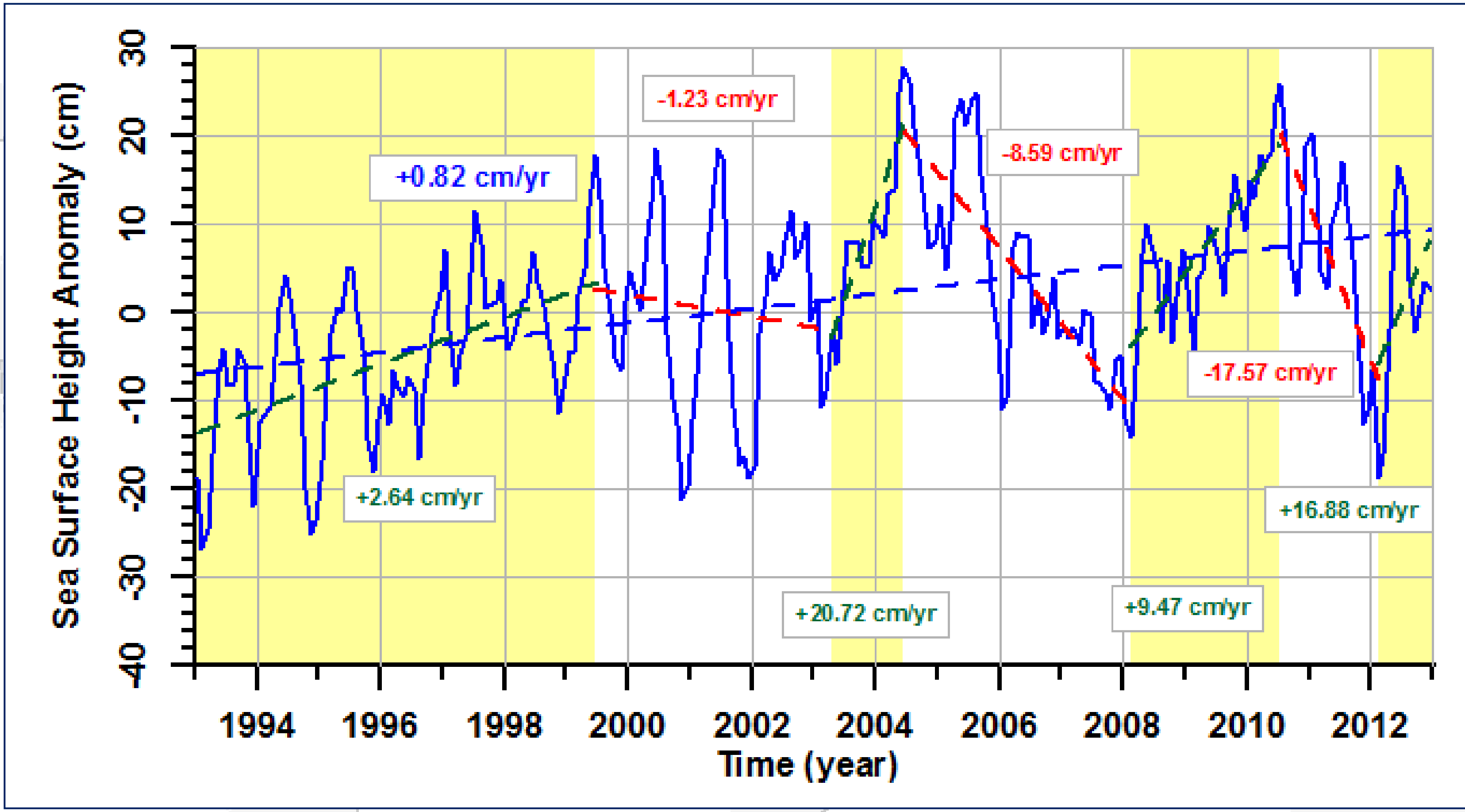
$$dh_{emb} = F_1\left(h_{swh}, U_{10}\right) \approx F_1\left(h_{swh}, \sigma^0\right)$$

Temporal Variability of the Azov Sea Level



Temporal variability of the Azov Sea surface height anomalies from January 1993 to December 2012 based on the T/P and J1/2 satellite altimetry data (blue line). Interannual linear trends are shown by dotted lines. Periods of raising are shown by yellow color areas.

Temporal Variability of the Black Sea Level



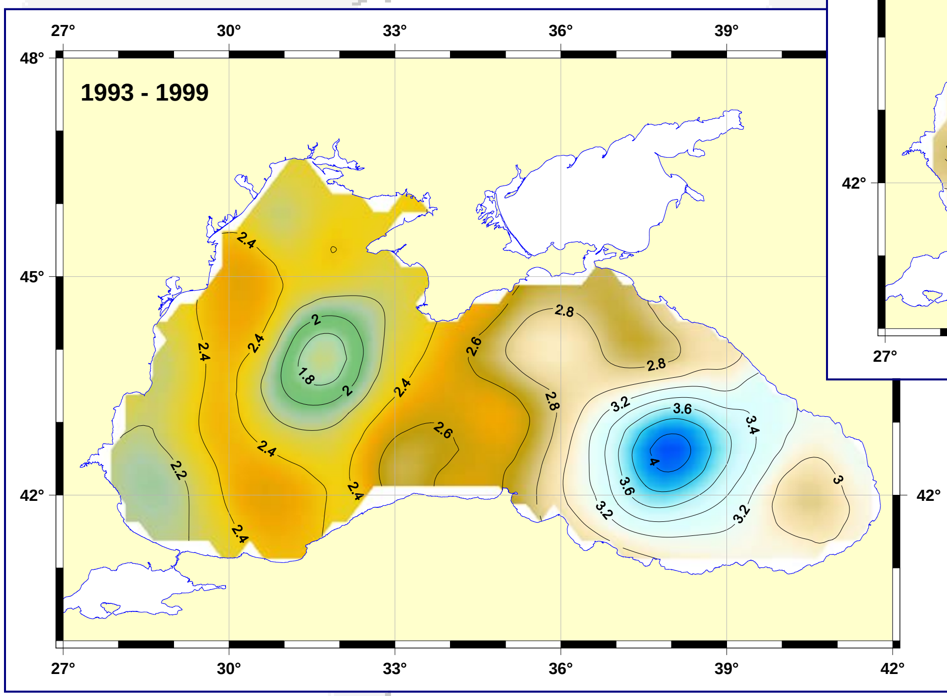
Temporal variability of the Black Sea surface height anomalies from January 1993 to December 2012 based on the T/P and J1/2 satellite altimetry data (blue line). Interannual linear trends are shown by dotted lines. Periods of raising are shown by yellow color areas.

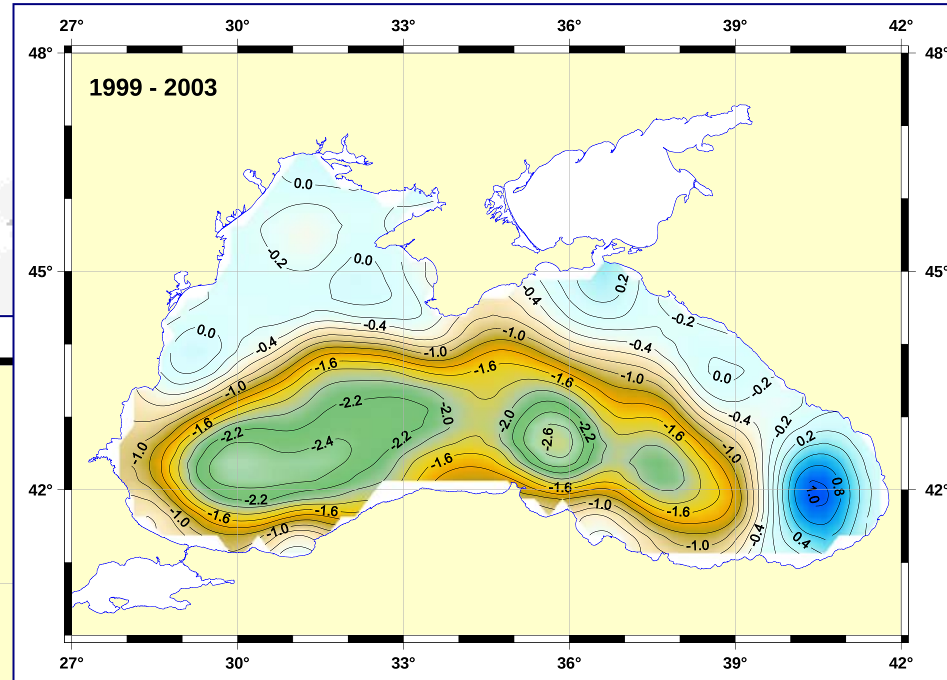
Joint COSPAR and WMO Capacity Building Workshop
«Satellite remote sensing, water cycle and climate change»

20 July — 1 August 2014,
Tver, Russian Federation

Tver State University.

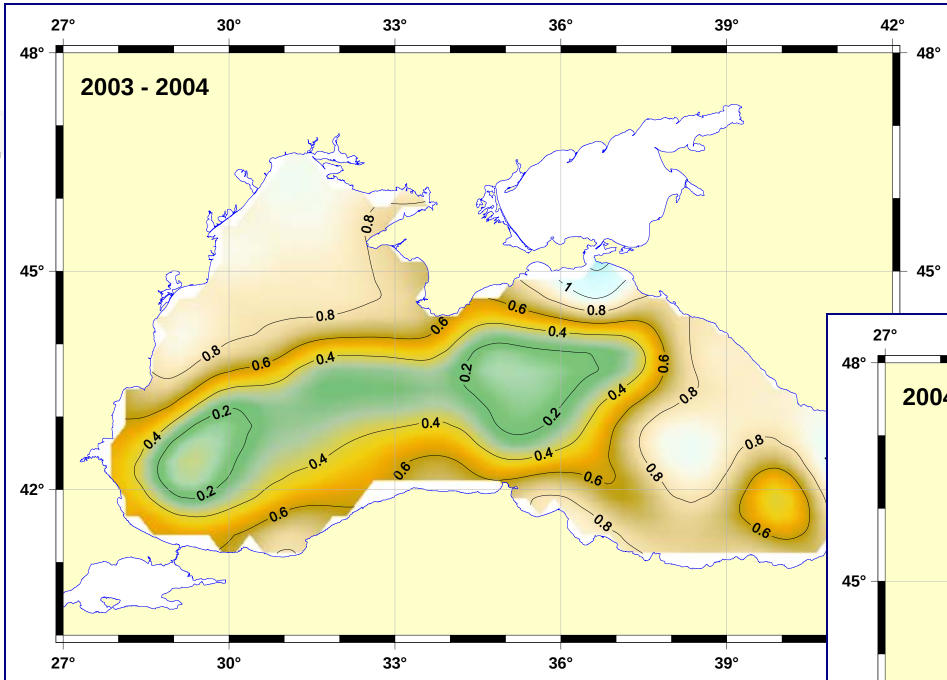
Space-Time Variability of the Black Sea Level

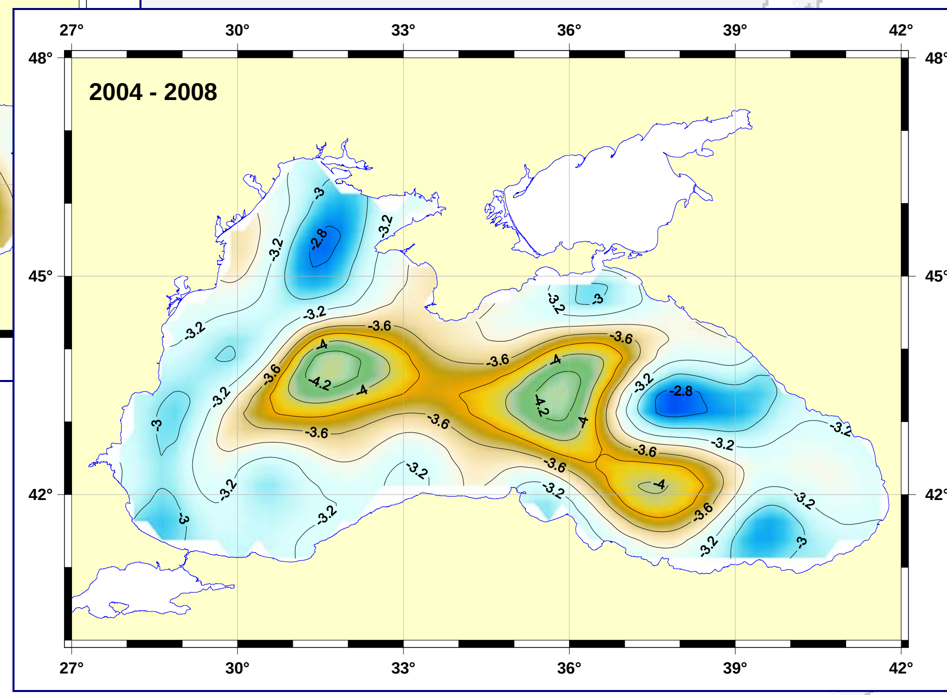




Spatial variability of the interannual rate of change of the Black Sea level anomalies (cm/yr) based on satellite altimetry data for different time intervals 1993–1999 (rise) and 1999–2003 (drop)

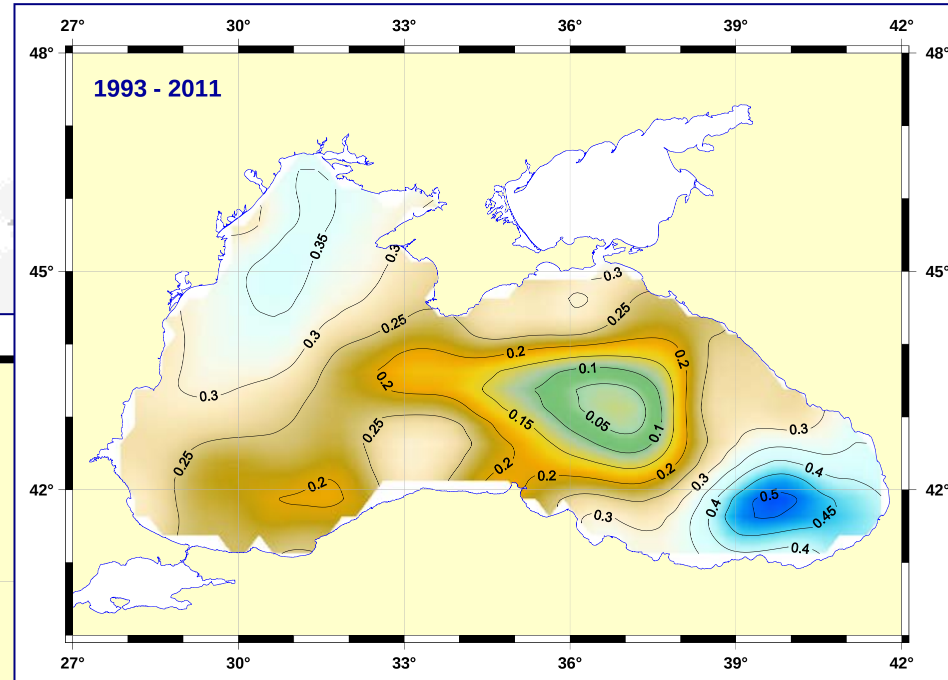
Space-Time Variability of the Black Sea Level

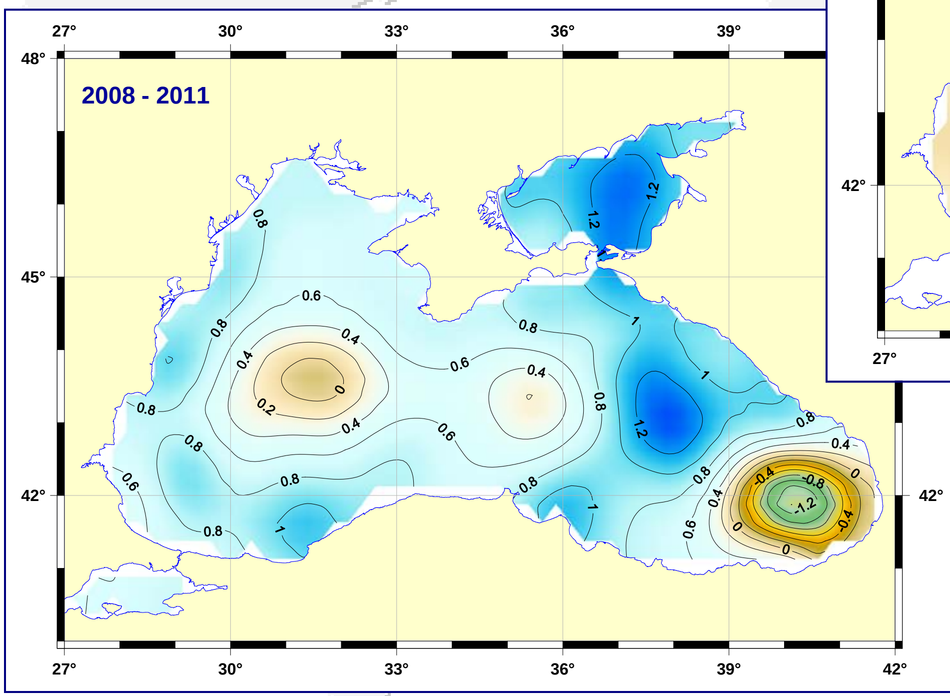




Spatial variability of the interannual rate of change of the Black Sea level anomalies (cm/yr) based on satellite altimetry data for different time intervals 2003–2004 (rise) and 2004–2008 (drop)

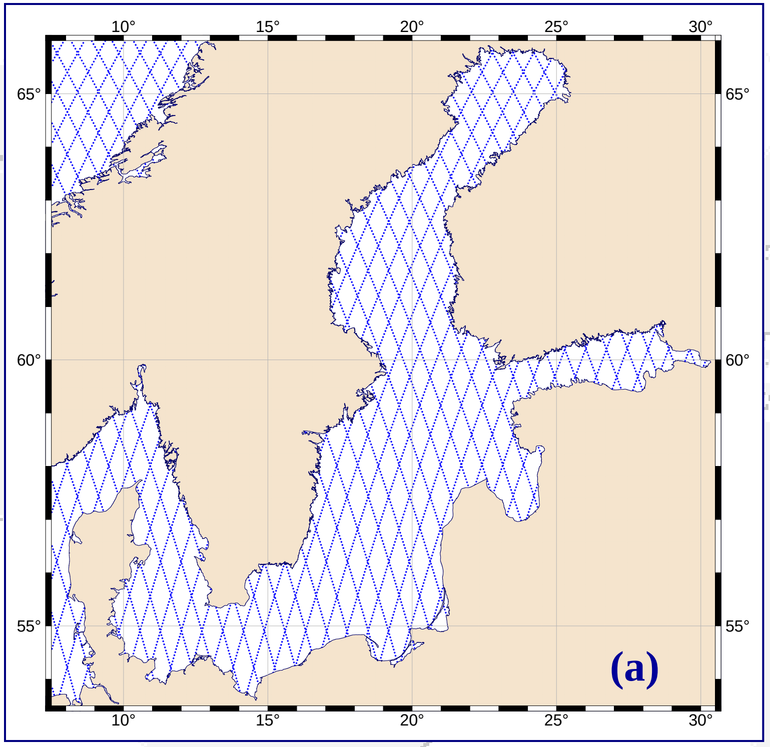
Space-Time Variability of the Black Sea Level

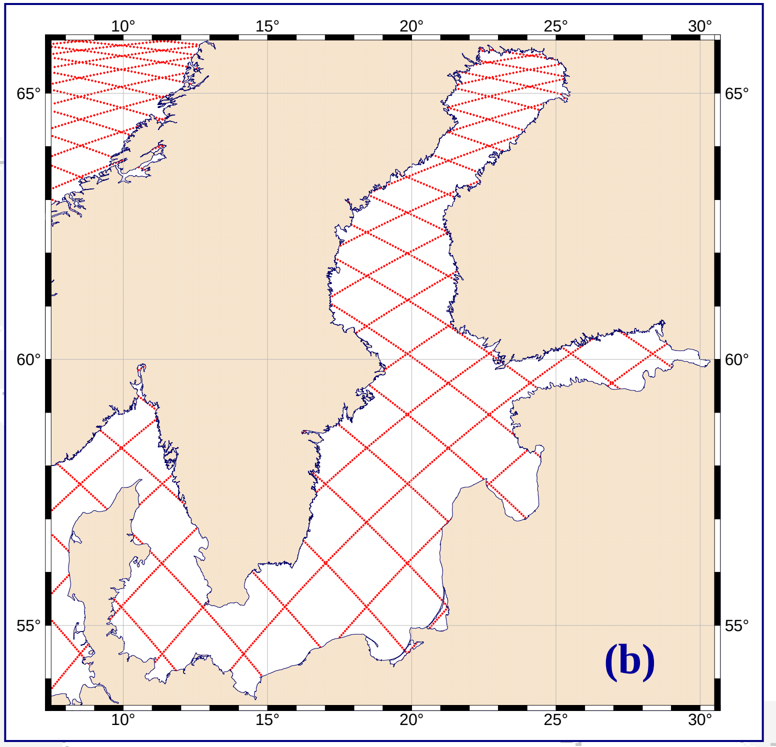




Spatial variability of the interannual rate of change of the Black Sea level anomalies (cm/yr) based on satellite altimetry data for different time intervals 2008–2011 (rise) and 1993–2011 (rise)

The Baltic Sea



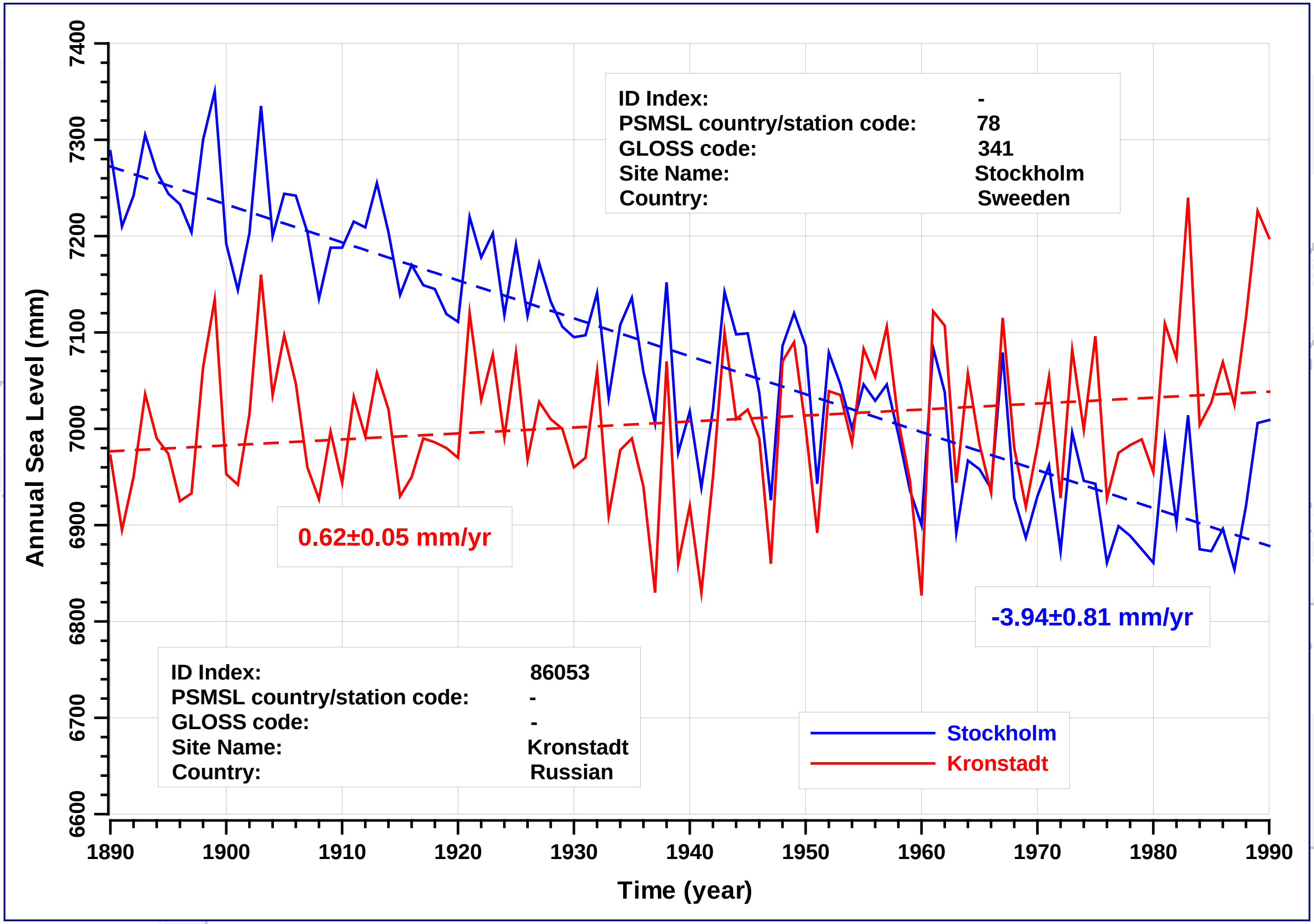


Groundtracks on the Baltic Sea for the following satellites:

(a) ERS-1/2 and ENVISAT with a repeat period of 35 days

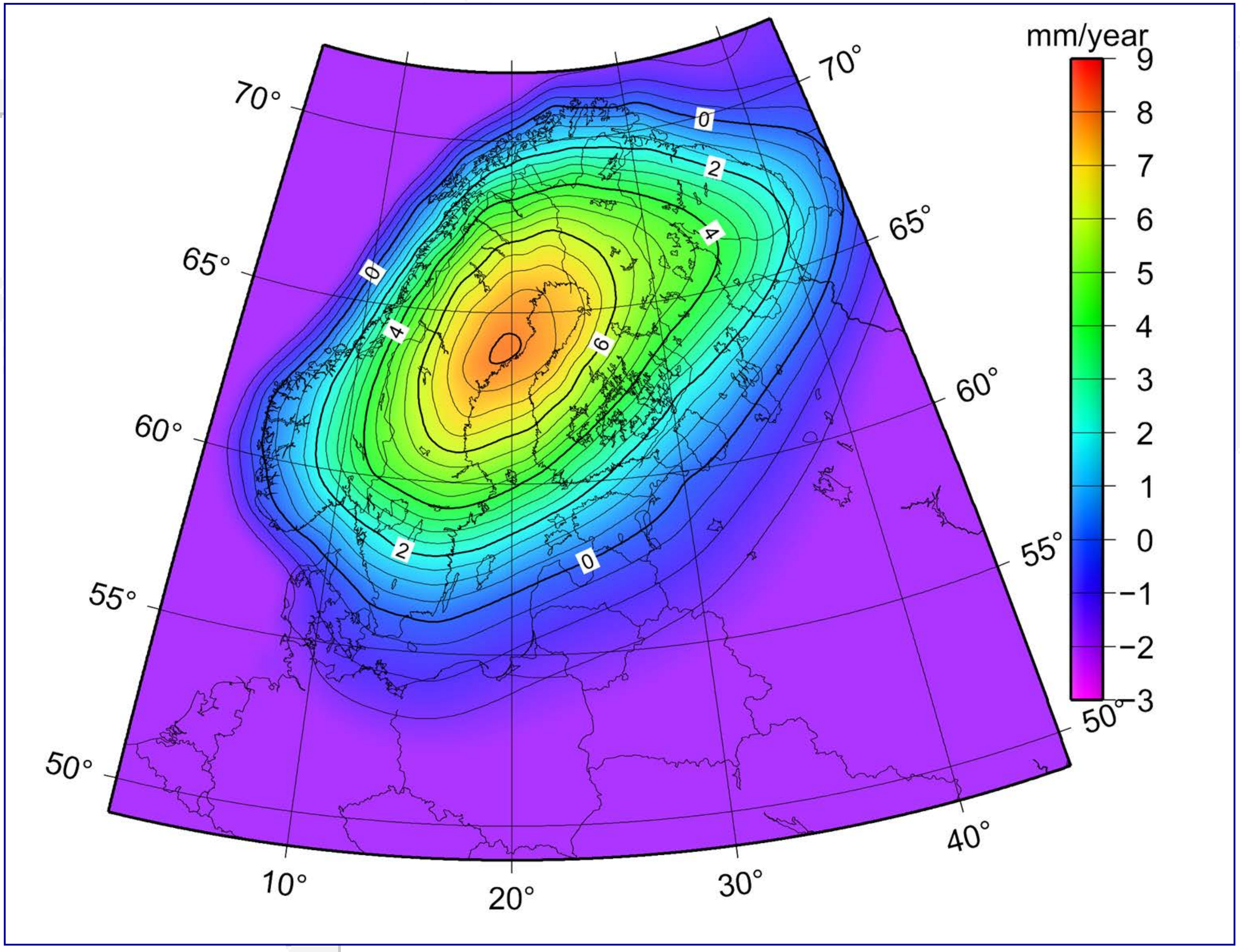
(b) TOPEX / Poseidon and Jason-1/2 with a repeat period of 10 days.

The Baltic Sea Level Variability (Tide Gauges)



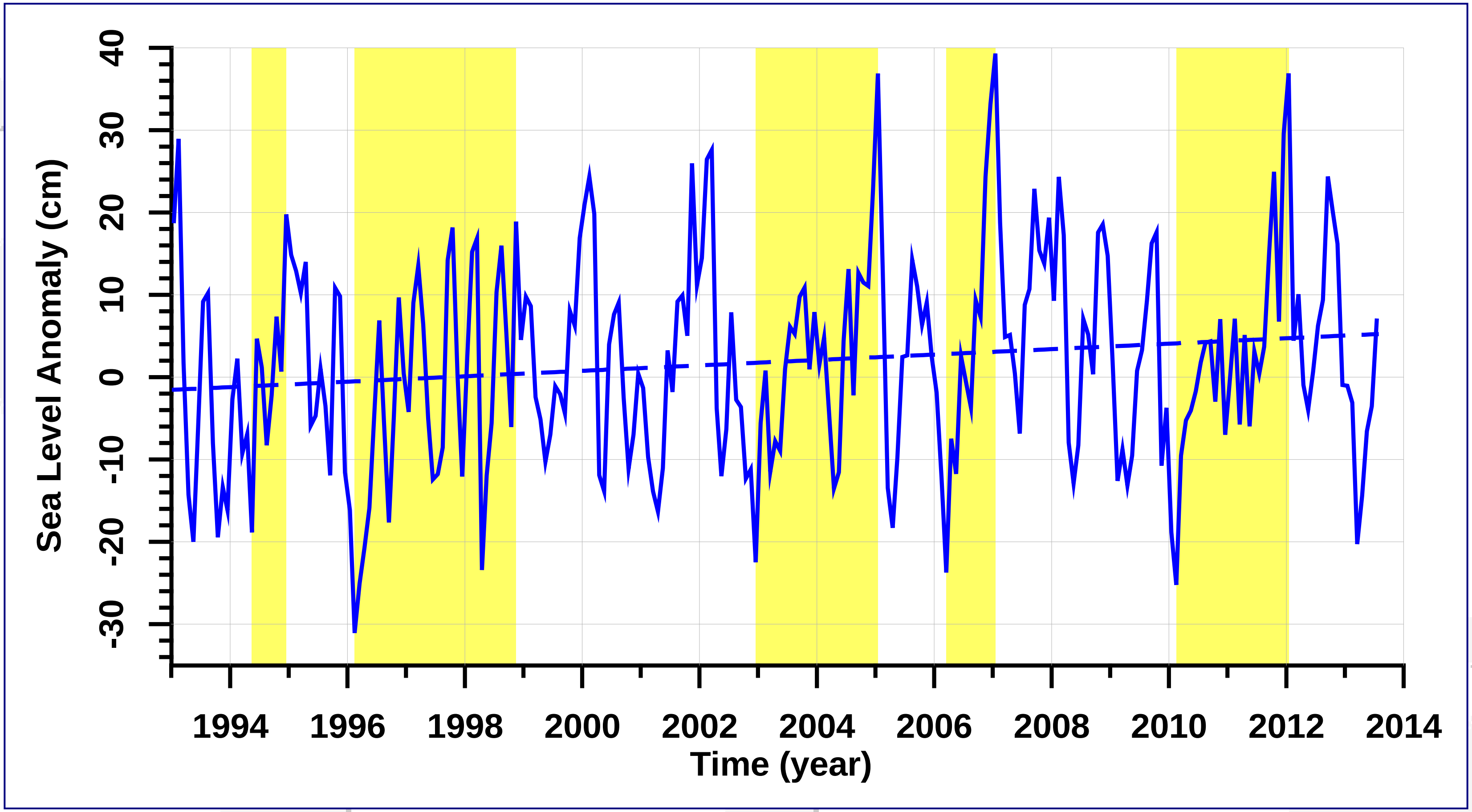
Comparison of the interannual sea level variability of tide gauges data between Stockholm (Sweden) and Kronstadt (Russia).

Fennoscandian Land Uplift



Fennoscandian land uplift (mm/year) model NKG2005LU relative to RH 2000 LU. The model is based on tide gauges, GPS observations, and geophysical models (*Ågren and Svensson, 2007*)

Temporal Variability of the Baltic Sea Level

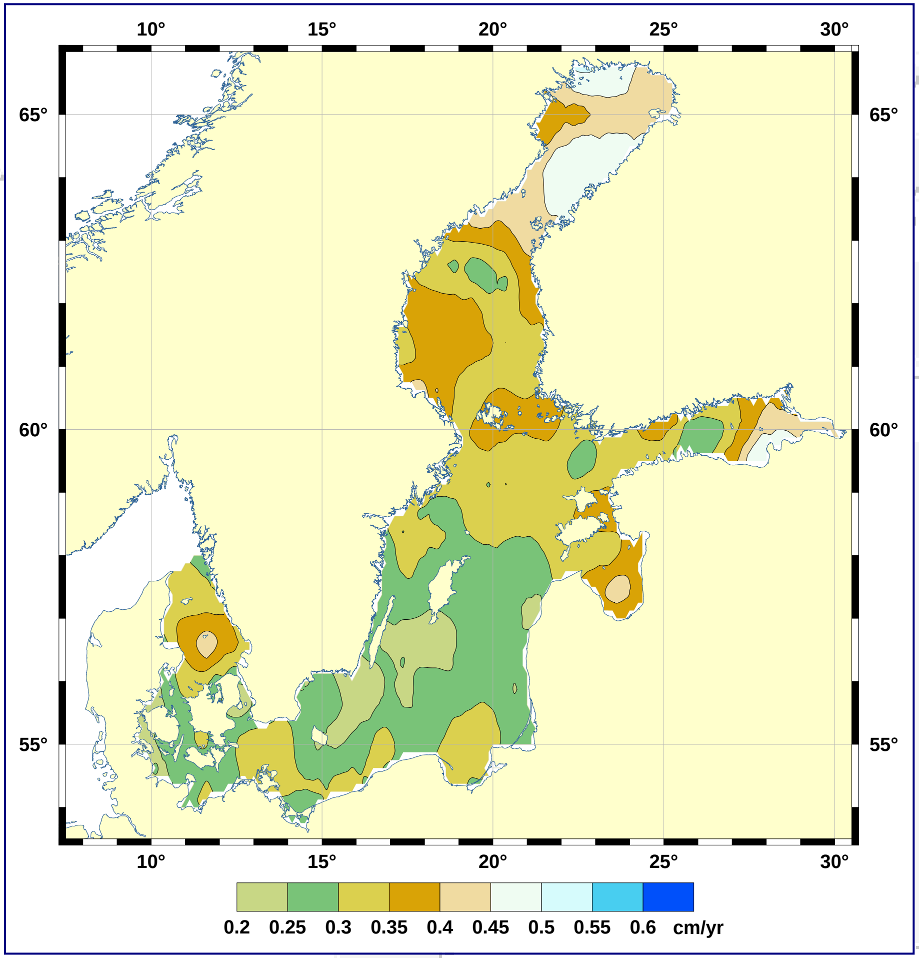


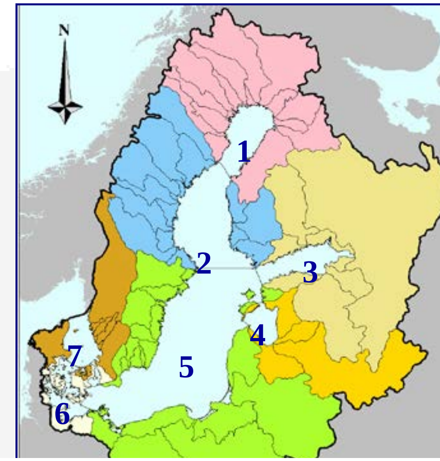
Temporal variability of the Baltic SLA from January 1993 to December 2013 based on to satellite altimetry T/P and J1/2 data (blue line) and interannual linear trends are shown by black dotted lines. Rise periods are showed on yellow color area.

Joint COSPAR and WMO Capacity Building Workshop
«Satellite remote sensing, water cycle and climate change»

20 July — 1 August 2014,
Tver, Russian Federation
Tver State University.

Space-Time Variability of the Baltic Sea Level

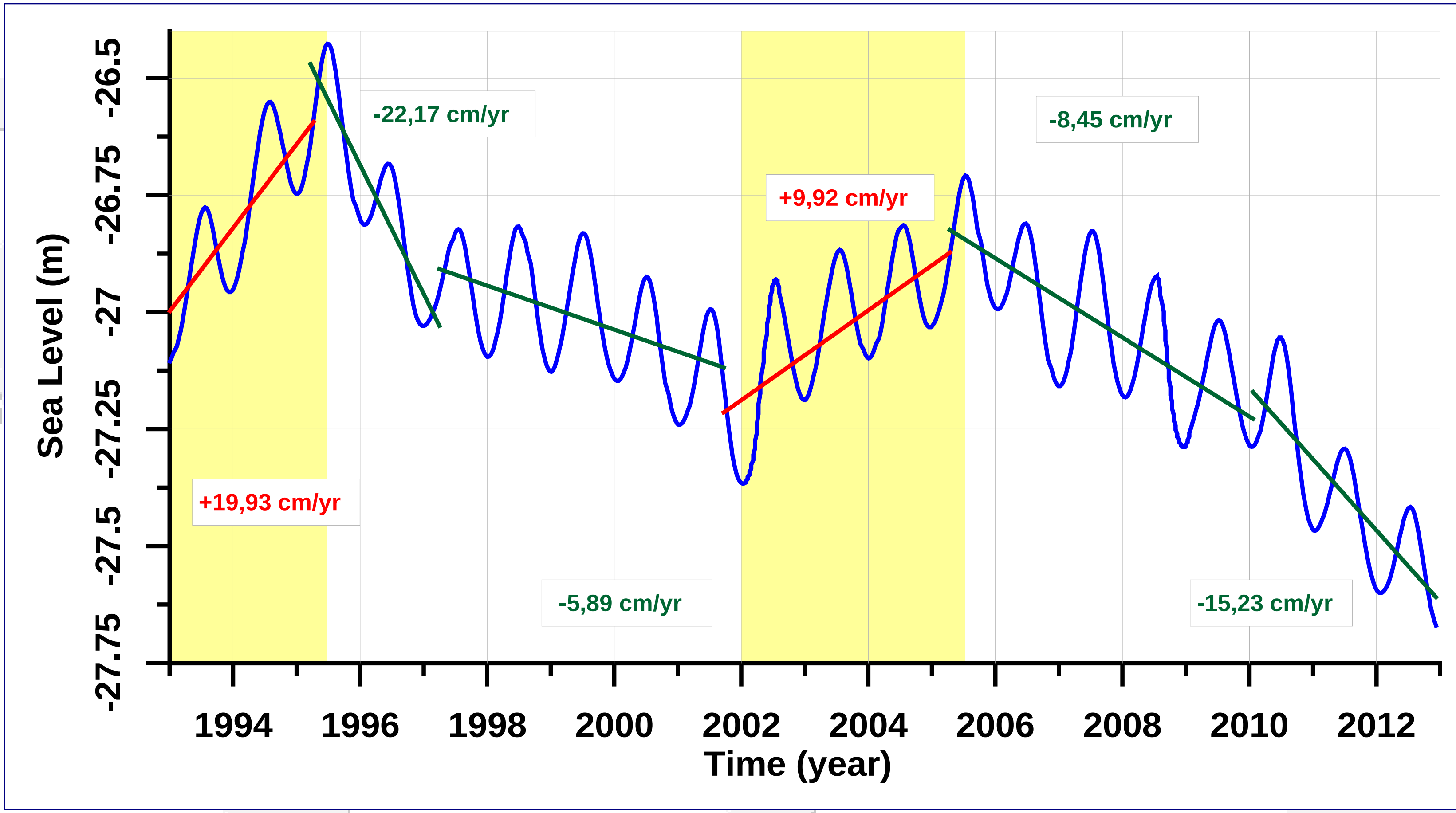




Interannual trend of the Baltic Sea level (cm/yr).

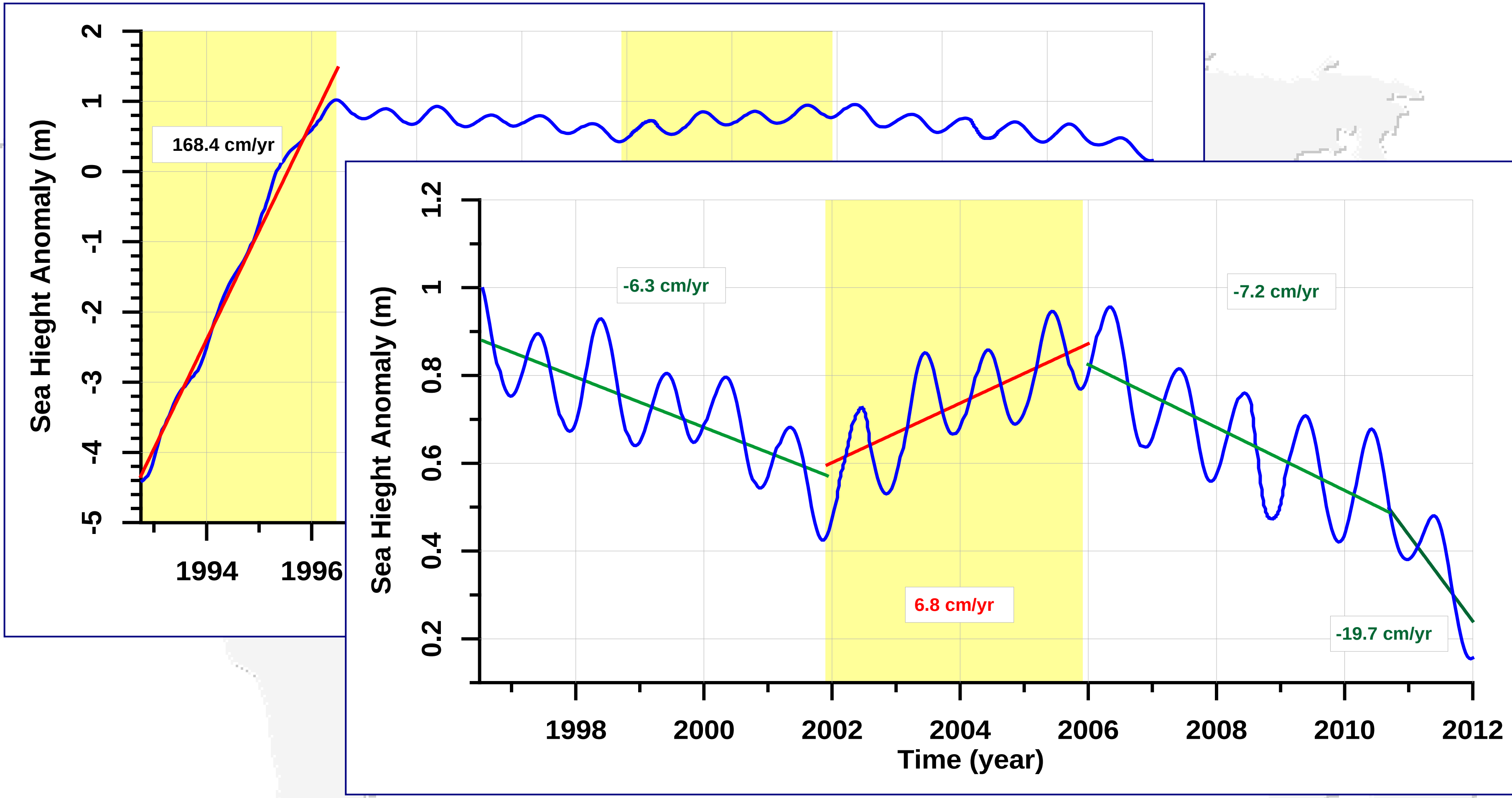
Area	Mean	Minimum	Maximum
Bothnian Bay	0.44±0.03	0.35	0.51
Bothnian Sea	0.35±0.03	0.28	0.42
Gulf of Finland	0.35±0.06	0.26	0.49
Gulf of Riga	0.37±0.03	0.32	0.43
Baltic Proper	0.28±0.02	0.23	0.38
Belt Sea	0.28±0.02	0.21	0.31
Kattegat	0.32±0.05	0.23	0.43

Temporal Variability of the Caspian Sea Level



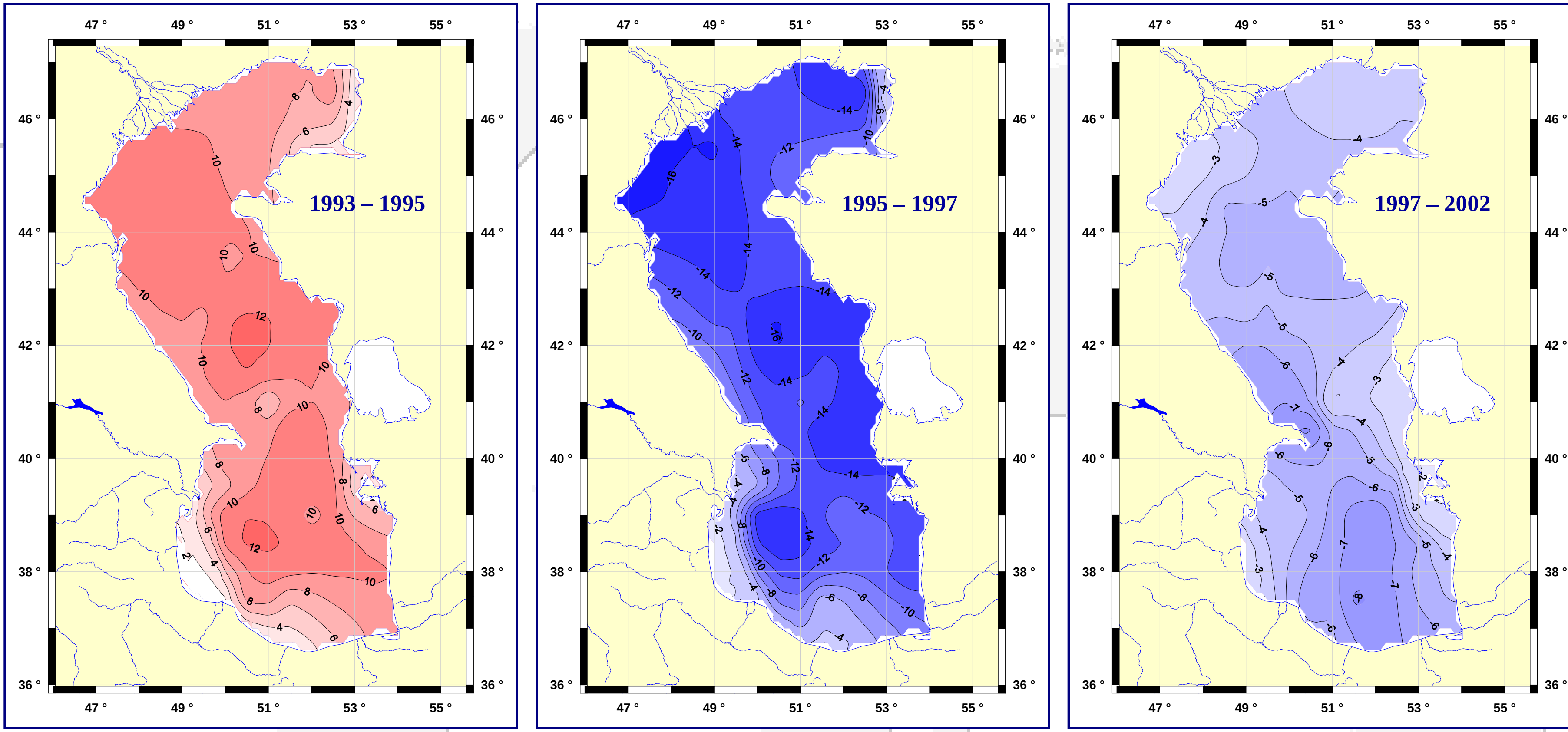
Temporal variability of the Caspian Seas level from January 1993 to December 2013 based on to satellite altimetry T/P and J1/2 data (blue line) and interannual linear trends are shown by black dotted lines. Rise periods are showed on yellow color area.

Temporal Variability of the Kara-Bogaz-Gol Bay Level



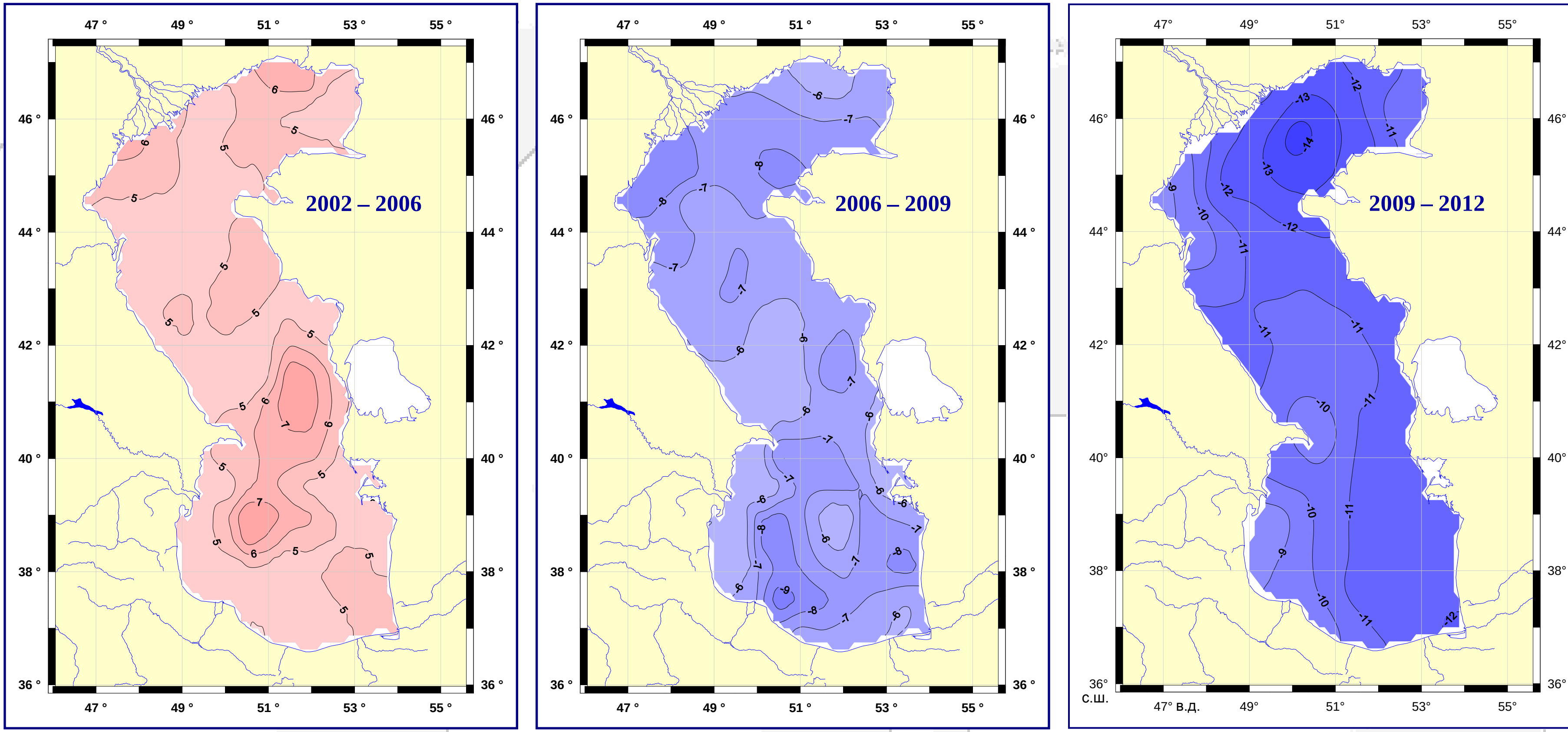
Temporal variability of the Kara-Bogaz-Gol Bay level from January 1993 to December 2013 based on to satellite altimetry T/P and J1/2 data (blue line) and interannual linear trends are shown by black dotted lines. Rise periods are showed on yellow color area.

Space-Time Variability of the Caspian Sea Level



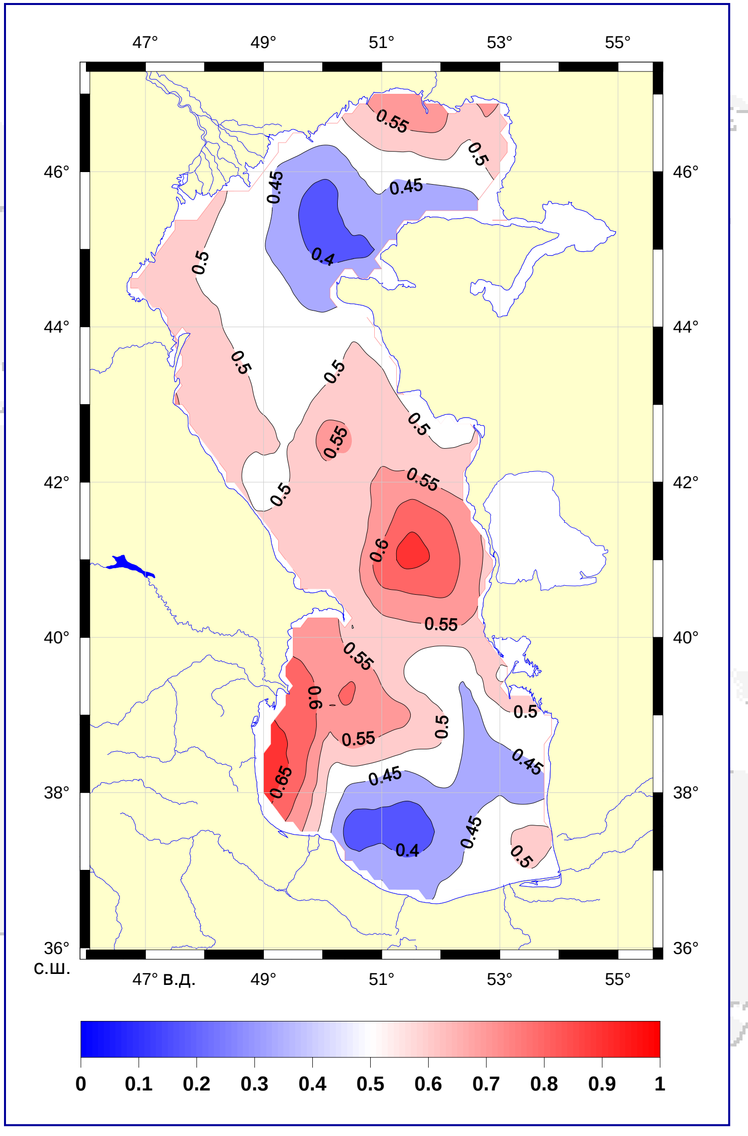
Spatial variability of the interannual rate of change of the Black Sea level anomalies (cm/yr) based on satellite altimetry data for different time intervals 1993–1995 (strong rise), 1995–1997 (strong drop) and 1997–2002 (slow drop).

Space-Time Variability of the Caspian Sea Level



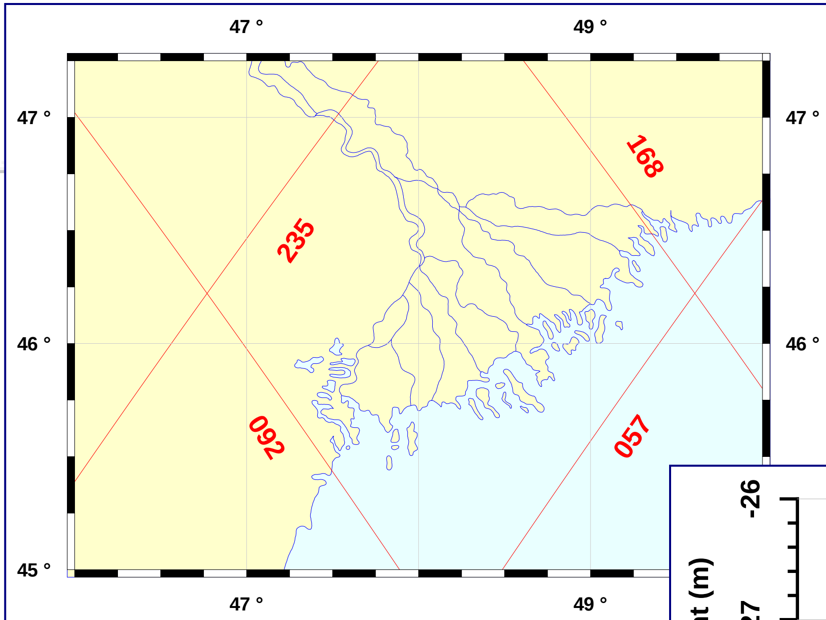
Spatial variability of the interannual rate of change of the Black Sea level anomalies (cm/yr) based on satellite altimetry data for different time intervals 2002–2006 (slow rise), 2006–2009 (slow drop) and 2009–2022 (srong drop).

Space-Time Variability of the Caspian Sea Level



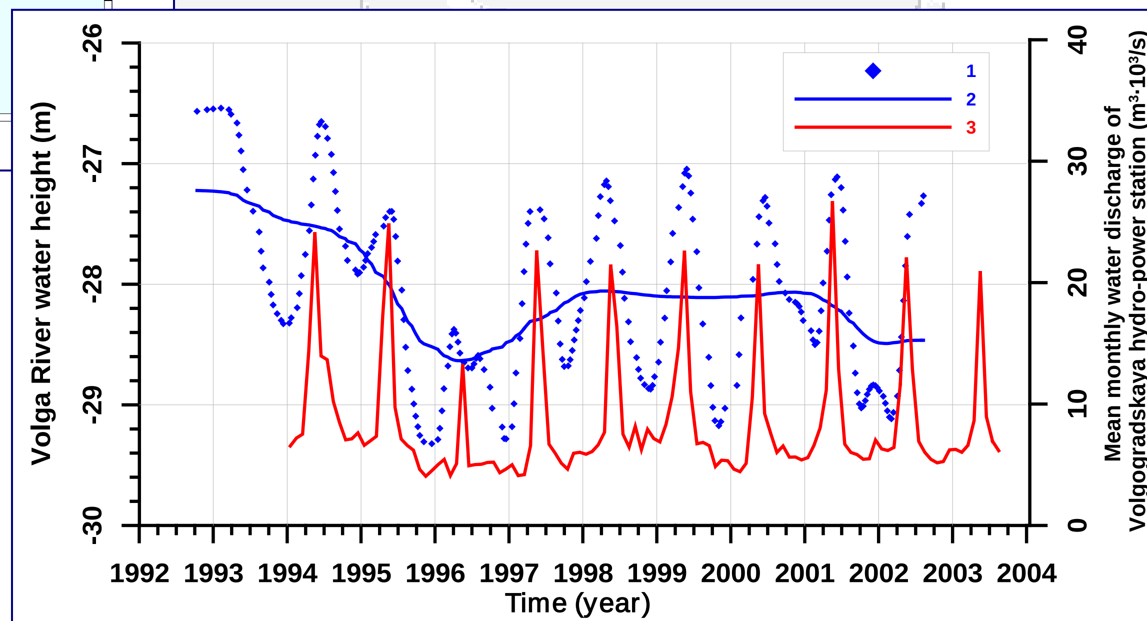
Normalized rate of change of the Caspian Sea by the altimetry satellites T / P and J1 / 2 from January 1993 to December 2012

The Volga River Water Height Variability



Ground tracks of T/P and J1/2 in the Volga River delta.

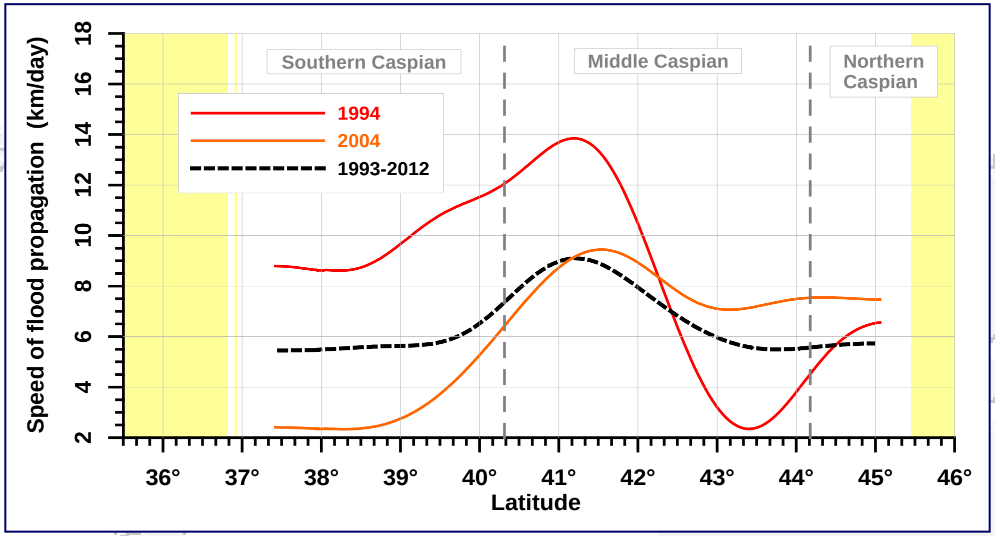
10-days (1) and interannual (2) variability of Volga water height (m) (October 1992 – August 2003) by T/P satellite altimetry data along 235 ascending pass and variability of monthly mean water discharge (3) at Volgogradskaya hydro-power station ($m^3 \cdot 10^3/s$).



Joint COSPAR and WMO Capacity Building Workshop
«Satellite remote sensing, water cycle and climate change»

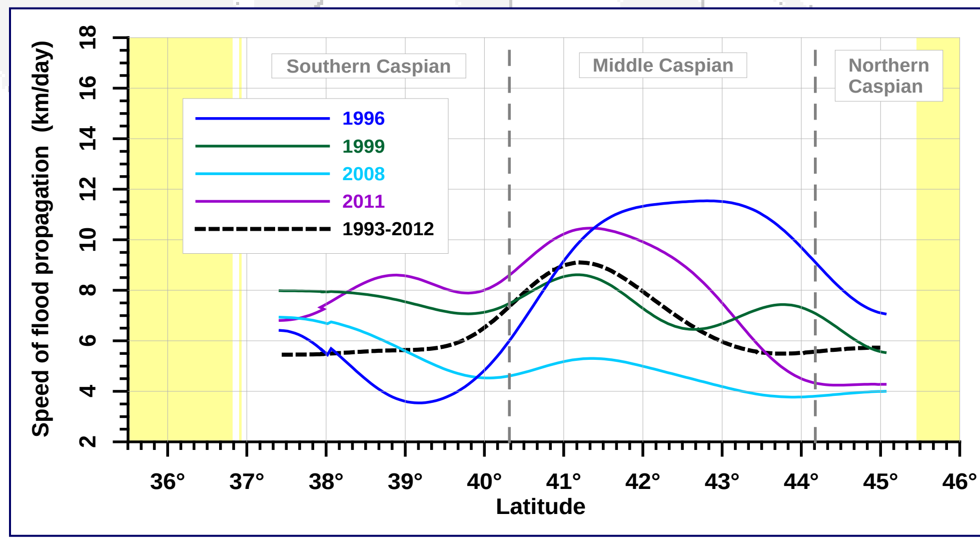
20 July — 1 August 2014,
Tver, Russian Federation
Tver State University.

River Volga Flood Propagation on the Caspian Sea area

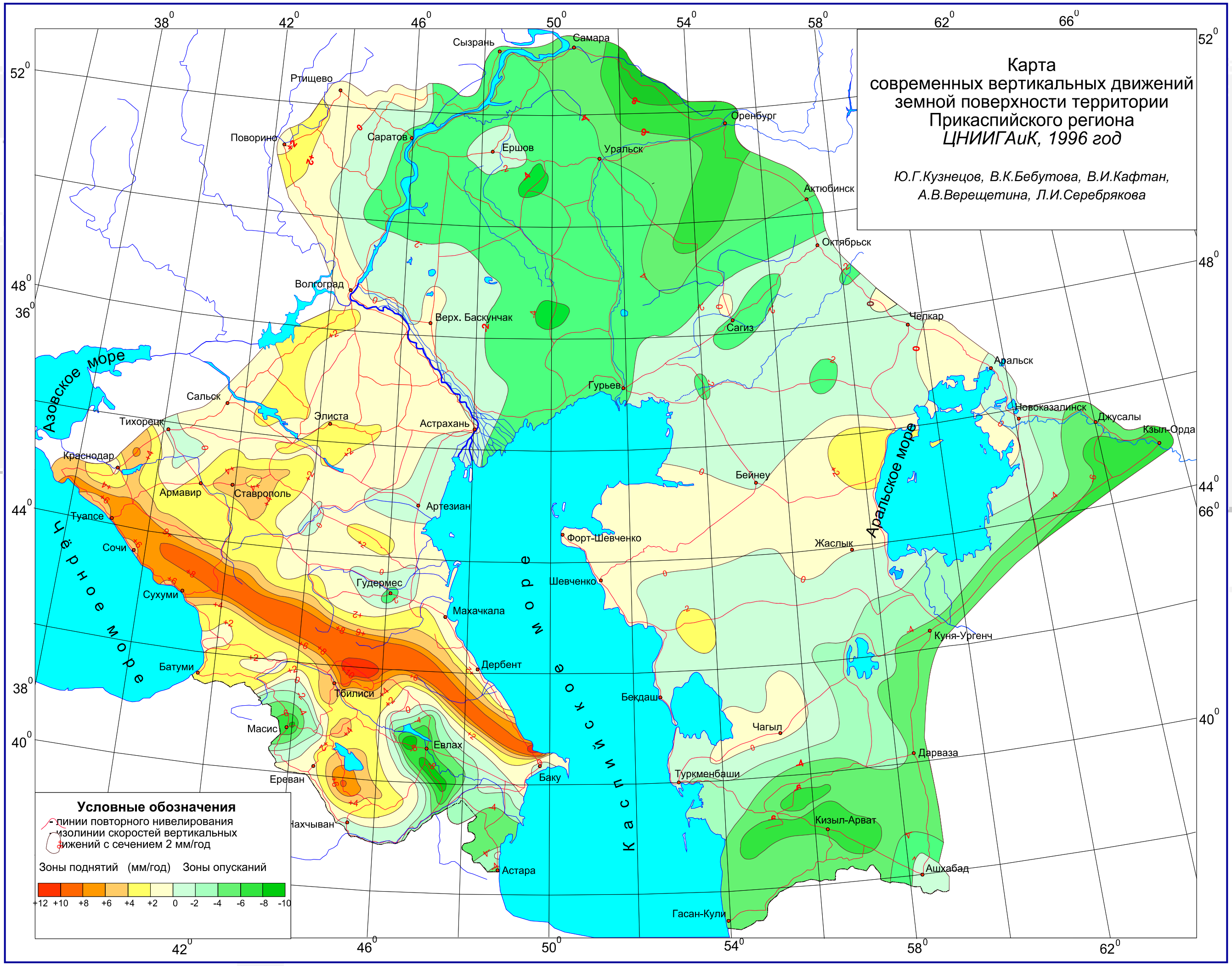


Variability speed gradient of the Volga River flood propagation (km/day) according to altimetry along the track 092 of T/P and J1/2 satellites into period of the Caspian Sea level rise. Yellow highlighted areas of land. Dashed lines indicate the boundaries between the Northern, the Middle and the Southern Caspian.

Variability speed gradient of the Volga River flood propagation (km/day) according to altimetry along the track 092 of T/P and J1/2 satellites into period of the Caspian Sea level drop. Yellow highlighted areas of land. Dashed lines indicate the boundaries between the Northern, the Middle and the Southern Caspian.



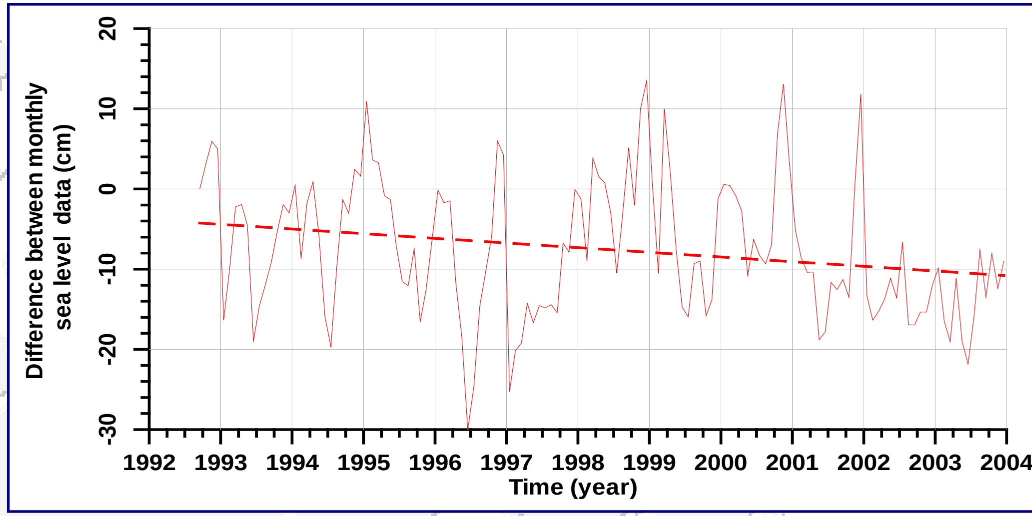
Uplift of the Earth's Crust



Map of recent uplift of the earth's crust in the Caspian region.

Estimated Value of Uplift of the Earth's Crust

Value of the Earth’s crust uplift was estimated basing on the difference between monthly (and/or annual) sea level gauge measurements and sea level derived from satellite altimetry data since October 1992 till December 2005. numerator is monthly data, denominator is annual data

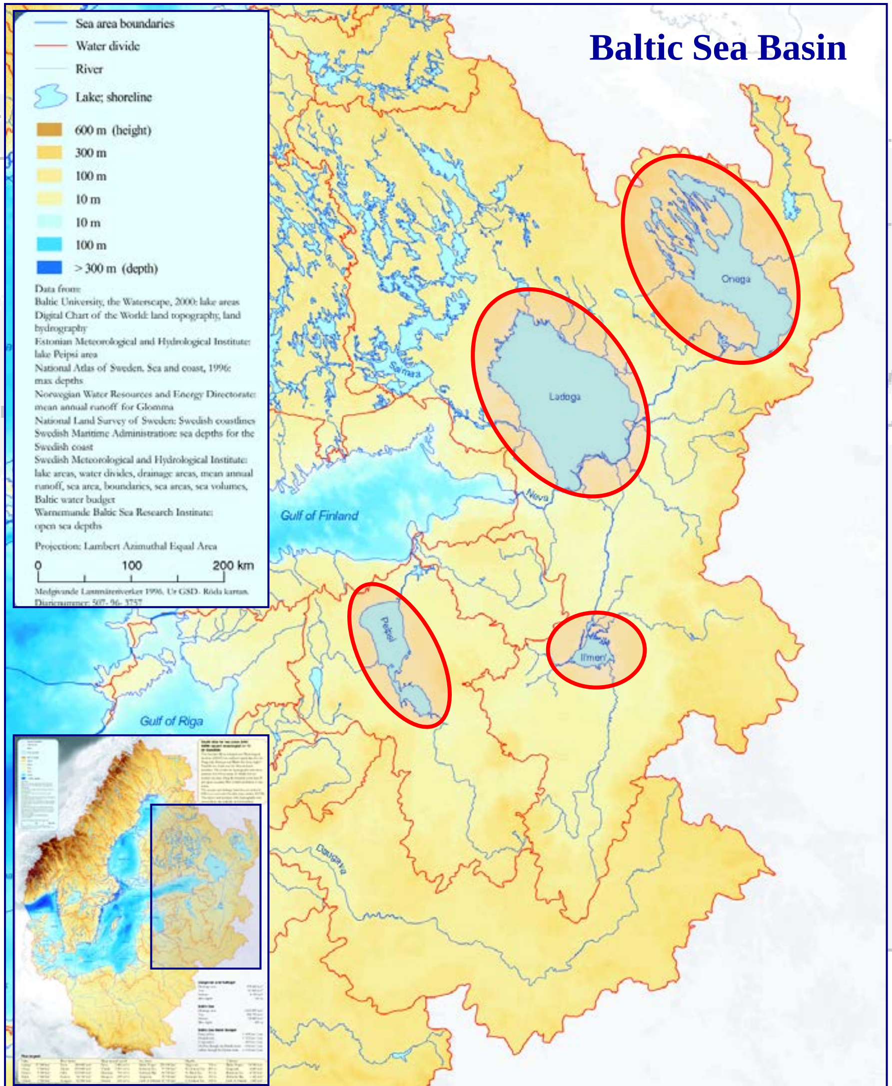


Temporal difference between monthly Makhachkala sea level gauges and results of processing of satellite altimetry data.

	Level gauges	Earth’s crust uplift *(cm/yr)*
Middle Part	Makhachkala	<u>-0,449</u> / -0,455
	Fort Shevchenko	<u>-0,459</u> / -0,446
Southern Part	Turkmenbashi	<u>-0,459</u> / -0,446
	Baku	<u>-0,614</u> / -0,605

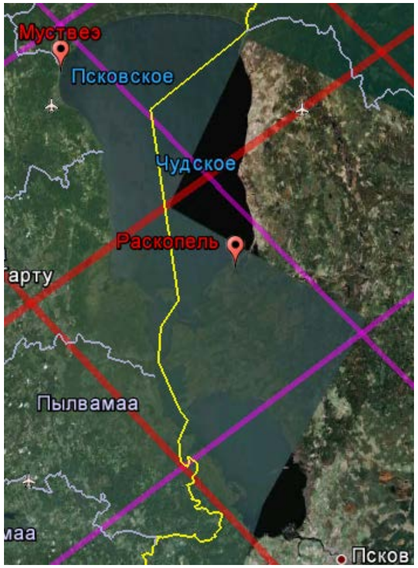
Estimated value of the Earth’s crust uplift (cm/year) by sea level gauge measurements and sea level derived from satellite altimetry data since October 1992 till December 2005.

Lakes Level in Northwest Russia

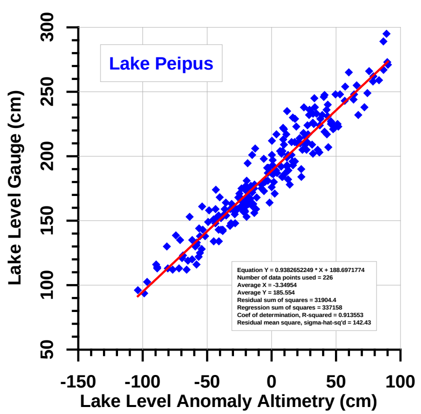


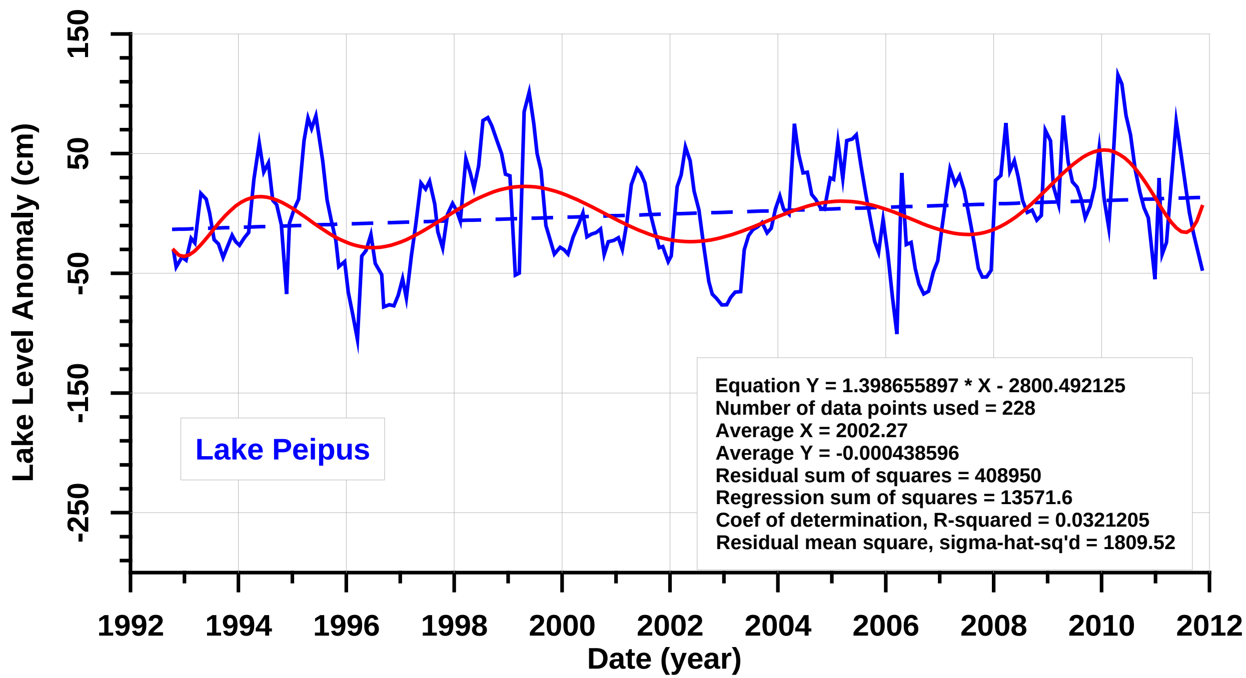
The Northwestern lake region of Russia covers the territory of the Kola Peninsula, Karelia, Leningrad, Pskov, Novgorod, Tver, and Vologda Oblasts. In addition to small and medium-sized lakes, the Northwestern region has large lakes such as Ladoga, Onega, Il'men', Peipus or Chudsko-Pskovskoye (shared with Estonia) and others. All lakes belongs to the Baltic Sea watershed and are linked with the Gulf of Finland via Neva and Narva rivers.

Temporal Variability of the Lake Peipus Level



Position of T/P and J1/2 satellites groundtracks before (red line) and after (purple line) the maneuver in the water area Lake Peipus. Red points are showed level gauges Mustvee and Raskopel. Yellow line show state boundary between Russian Federation and Estonia.





Joint COSPAR and WMO Capacity Building Workshop
«Satellite remote sensing, water cycle and climate change»

20 July — 1 August 2014,
Tver, Russian Federation

Tver State University.

Спасибо за внимание

Thank you for your attention

Helpful Information

On site of A.M. Obukhov Institute of Atmospheric Physics of Russian Academy of Sciences (http://www.ifaran.ru/science/dissertations/Lebedev_2014.html), is a doctoral and abstract thesis “Satellite Atimetry Caspian Sea“ (in russian) of Sergey A. Lebedev.