FAMOS, 2015

The simulations of the Lena River estuary dynamics

B-15

V. Fofonova[1,2], S. Danilov[1], A. Androsov[1], Y. K. Ying[3], S. Tomety[1], E. N. Golubeva[4], K. H. Wiltshire[2]
AWI, [1]Bremerhaven, [2]Sylt ; [3]FAU, Erlangen; [4]ICMMG SB RAS, Novosibirsk

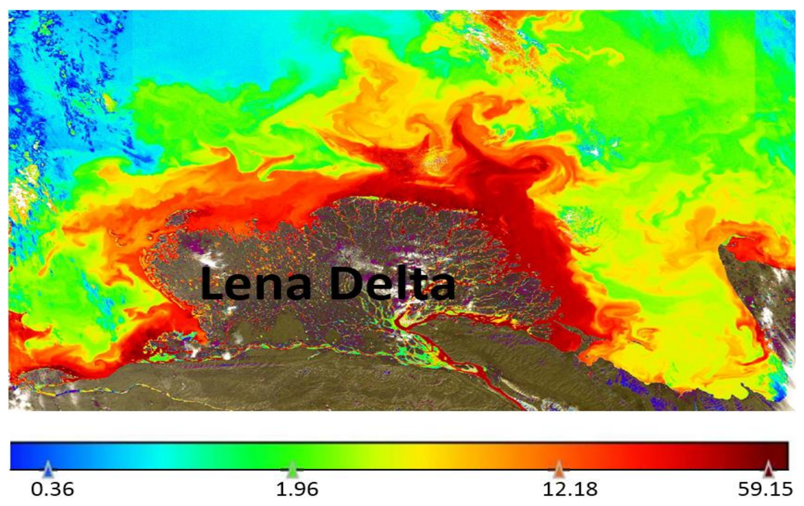
ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

Introduction

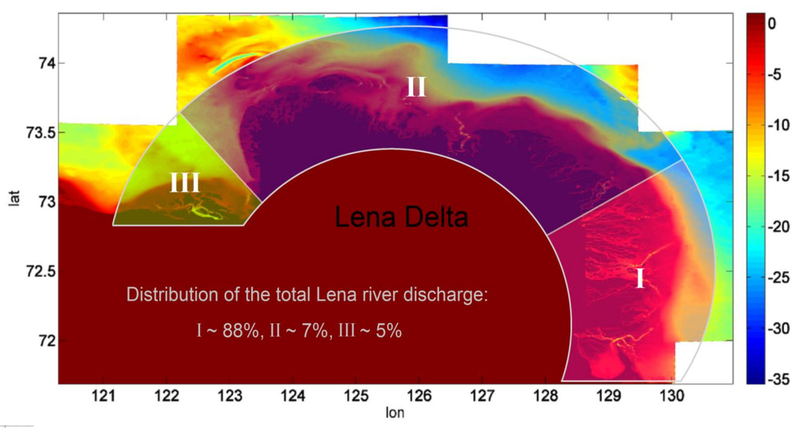
The Lena River is one of the largest rivers in the Arctic and has the largest delta. The mean annual runoff volume of the Lena River from 1935 to 2014 was about 539 km^3. Water mass characteristics at the Lena River basin outlet are particularly important for dynamics of the Laptev Sea and the Arctic Ocean as a whole. Observational data available for the Lena River suggest an on-going change in climate and biological factors over the last 50 years. Given the large territory of the Lena Delta, the direct measurements are by far insufficient, calling for a modeling approach. However, mostly all models, which include the Laptev Sea shelf zone, do not resolve the Lena Delta and as a consequence lose information about Lena river stream changes using input data with insufficient quality.

At the current stage we are working on the hydrodynamics model for the Lena Delta region. In frame of the current work available hydrological information for the Lena River lower reaches was collected, analyzed and used for the model verification.

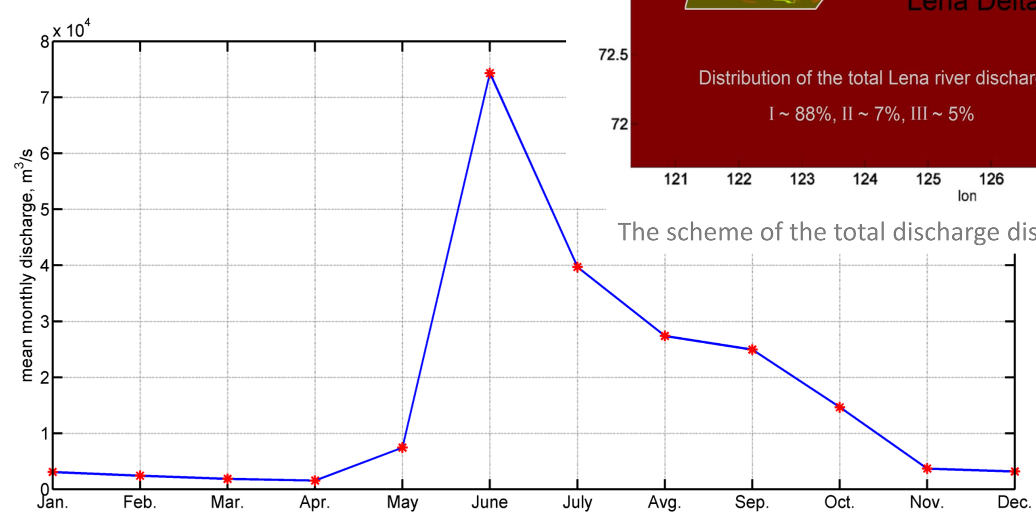
The developed hydrodynamics model provides first necessary step for the further modeling efforts in the area. It also gives an input for the larger scale models resolving hydrodynamics of more than twenty main Lena River freshwater channels with a turning on wetting/drying option



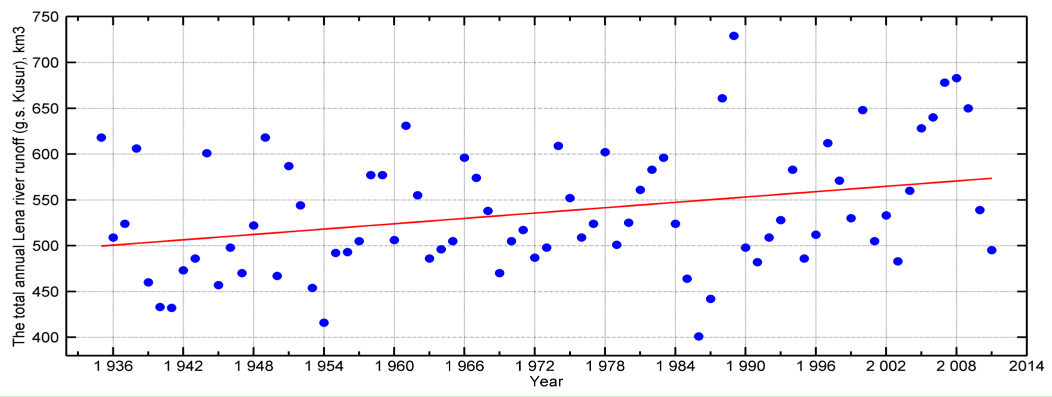
Total Suspended Matter (TSM), g m^{-3}, late summer, 2011. The image is provided by G. Heim; Envisat-MERIS.



The scheme of the total discharge distribution



The mean monthly discharge for the period from 1935 to 2011 (Kusur Station).



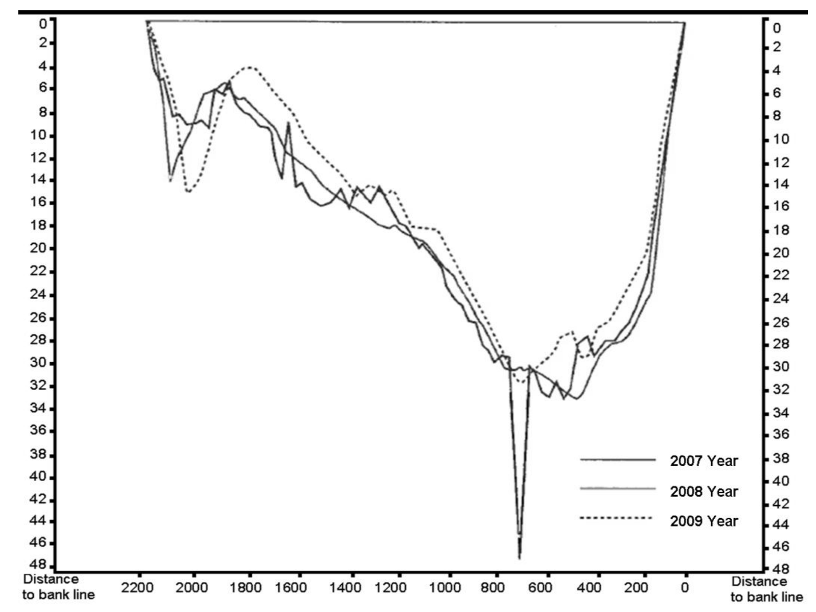
The total annual runoff. Regression line is showed in red. Theoretical slope of the line is significantly different from 0 with 99.6% probability.

Main Difficulties

1) Subflow processes
2) Chains of the permanent and gostly islands within the channels. Where are the solid boundaries?

The mean discharge rate for the Lena River for the period from 1935 to 2011, measured at main-stream Kusur station, [m^3/sec], and the mean water level for the period from 2002 to 2011 (zero level corresponds to station level mark), [mm].

Month	June	July	August	September
Mean discharge rate	74003	39578	27356	24926
Mean water level	1446.633	999.7667	780.4667	822.1



The Lena River bed profile, area of GS Stolb, main channel, August, [m]. The picture is taken from Bolshiyanov et al., 2013.

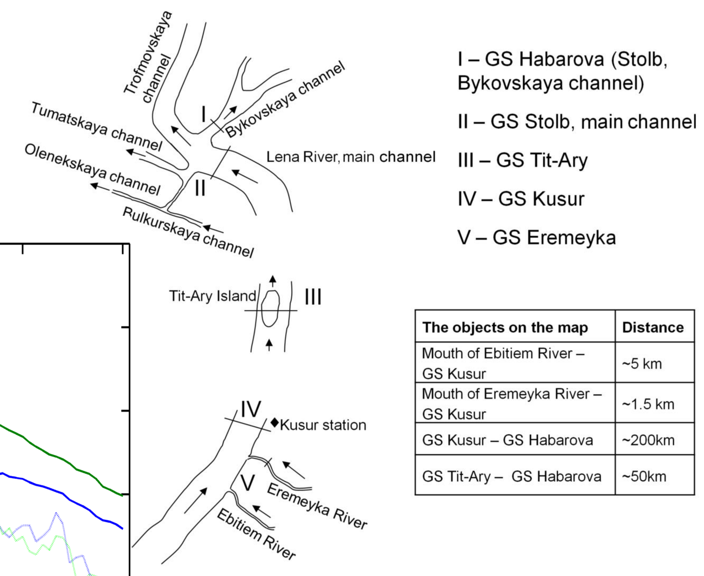
According to numerous recent estimates, the Lena River supplies its delta with 20.7 to 21.4 mln t of suspended material, as measured at Kusur GS (Holmes et al., 2002; Hasholt et al., 2005). Following the inter-annual variability of the river flow, the annual suspended sediment varies from 16.6 to 26.2 mln t (Korotaev, 2012).

3) Counting of heat fluxes from the river bed (thickness of the active layer and its geomorphologic characteristics are unknown)

The climate of central Yakutia allows around 8.0 m of bed material (silty sands) to be frozen during the wintertime (Tananaev, 2013). Given estimates should be reduced to about 2.5 m for the Lena Delta region due to generally coarser alluvium and higher winter temperatures. In high-energy environments, adjacent to the midstream, with normally coarser bed material grain sizes, the frozen state of the alluvium cannot be retained throughout the summer season due to lesser ice content and higher bed mobility. In this case, seasonal freeze is replaced by seasonal thaw, which penetrates the bedforms to a depth of 1.6 to 2 m.

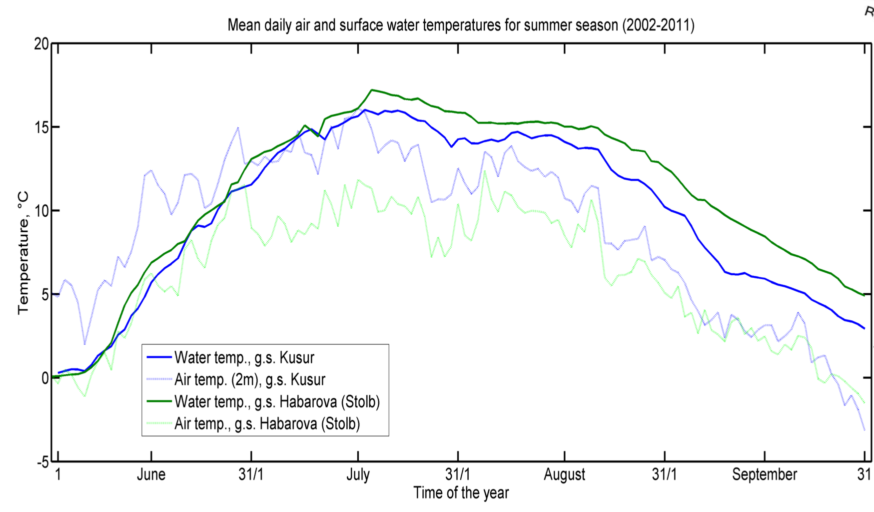
4) Lack of channels topography data
5) Complex geomorphological structure of the delta region

The Lena Delta is subdivided into three geomorphological types of the terraced floodplains (Bolshiyanov et al. 2013).



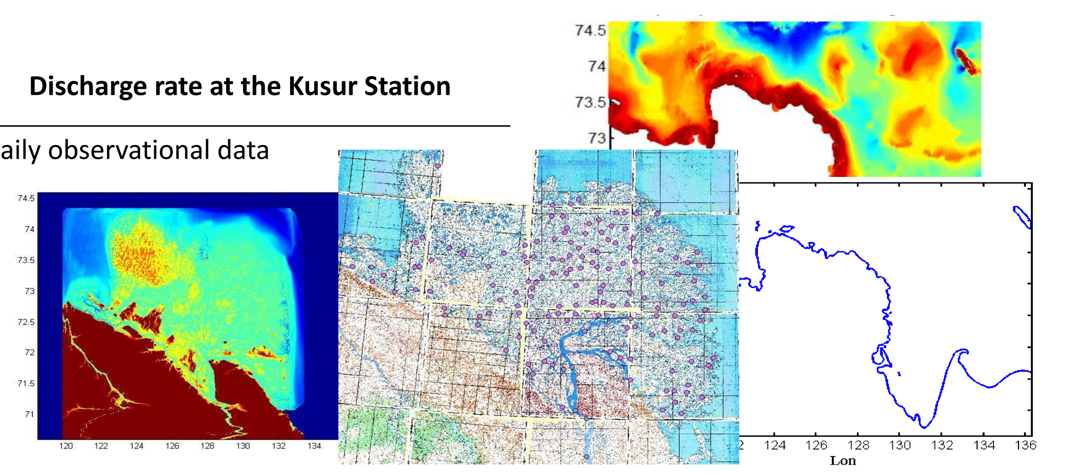
The eastern part of delta represents the first youngest terrace (first terrace is 1-12m a.s.l), the north-western part of the delta, which is formed mainly by sandy islands, represent the major part of second terrace (20-30m a.s.l). The third and oldest terrace (30-55m a.s.l) is composed by ice complex rock and partly occupies the area of Olenekskaya channel and area between Trofimovskaya and Bykowskaya channels.

6) Water temperature anomaly in the delta head area



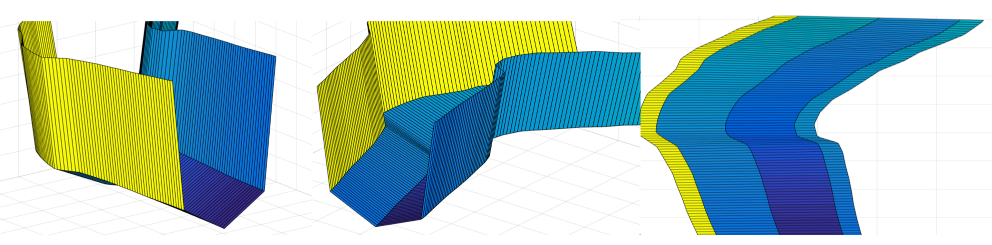
Model setup

Bathymetry&topo data	Tidal elevation at the open boundary	Discharge rate at the Kusur Station
Digitized Soviet maps Latest observations GEBCO, NOAA coastline database Digital elevation model,~100m, Shuttle Radar Topography Mission http://doi.pangaea.de/10.1594/PANGAEA.779748	Amplitudes and phases of the main components (M2, S2, K1, O1) are taken from Fofonova et al., 2014 numerical solution for the Laptev Sea shelf	Daily observational data



Construction of the digitized relief matrix

The channels bathymetry profiles were generated based on topography data, information about maximum and mean depth for the cross area, discharge rates (main channels) and velocity regimes.

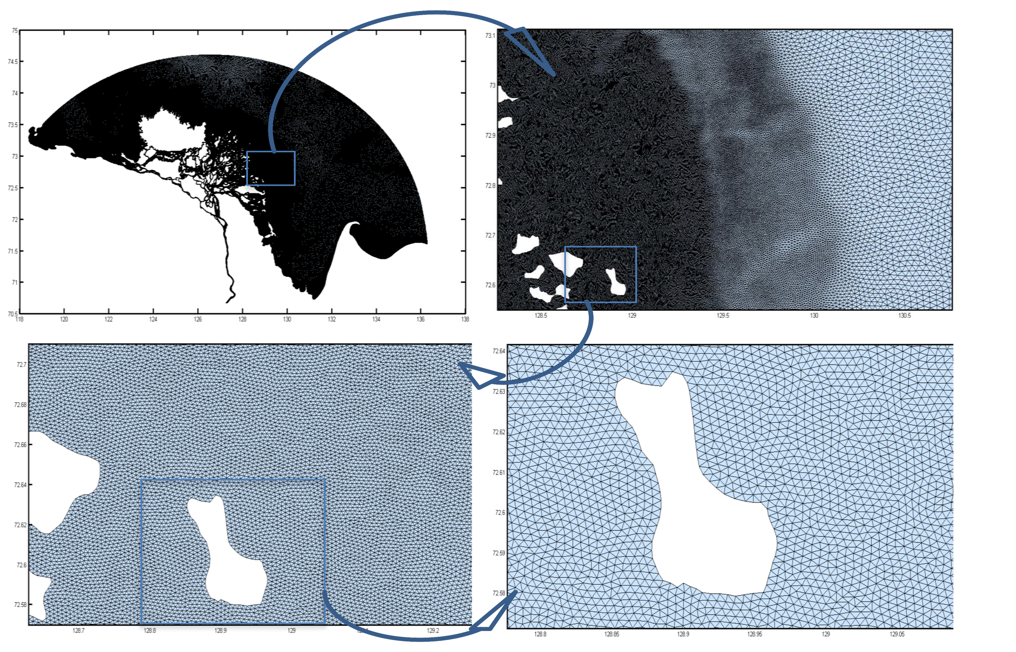


Reconstructed bathymetry profile (3D and 2D plots)

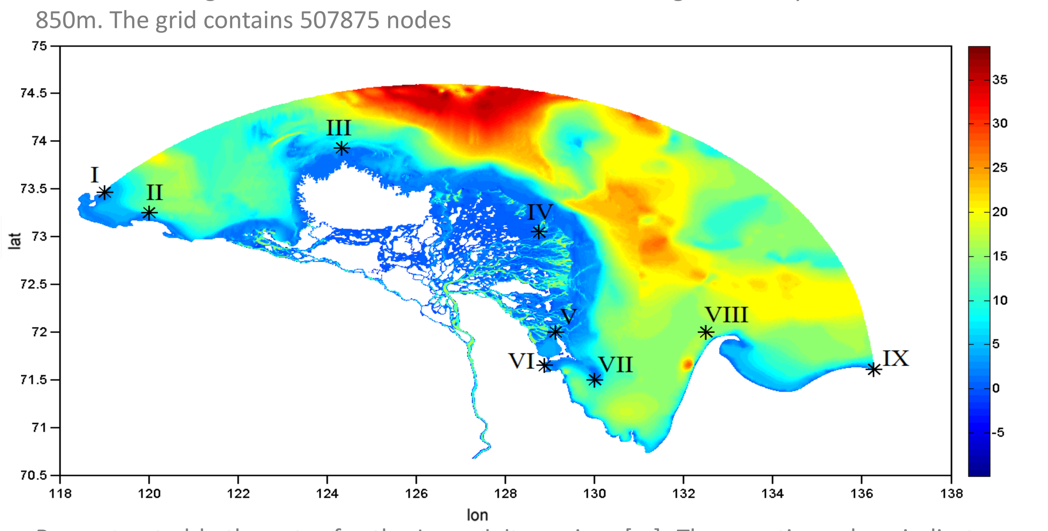
Numerical tools

To simulate the barotropic task the numerical model based on Discontinues Galerkin approach was used.

Domain under consideration



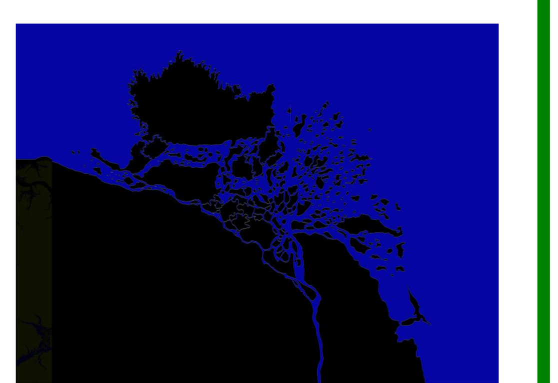
The unstructed grid for the considered domain. Element edge sizes vary from 30m to 850m. The grid contains 507875 nodes



Reconstructed bathymetry for the Lena delta region, [m]. The negative values indicate the topography data above see level, the asterisks show the location of the stations used for validation of the tidal dynamics

Solid boundary construction

Solid boundary includes more than 350 islands with a 'stable' border. More than 50 channels and subchannels are resolved. On the basis of topographic and elevation data the flooded area has been detected and solid boundaries have been constructed in a way to catch the dynamics during high water.

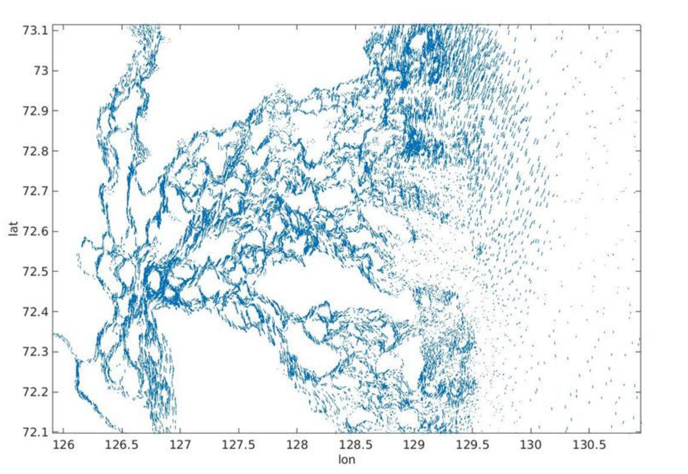


Preliminary results

error <15% from the observed value in all main freshwater channels, where the data were available.

Low water season results

Channel name	Mean velocity, m/s	
	Within channel	Mouth area
Olenekskaya	0.4	0.3
Tumatskaya	0.7	0.1
Bykovskaya	0.5	0.3
Trofimovskaya	0.4	0.1



Summary

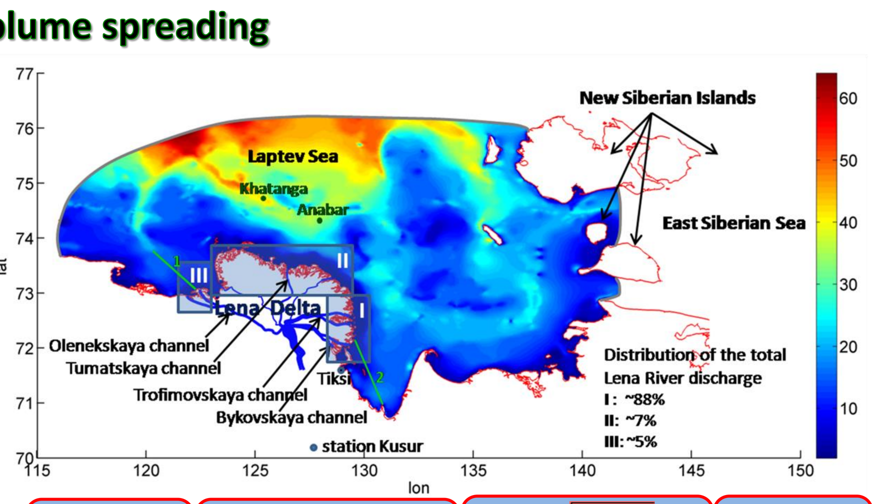
- Particular attention was paid to the collecting and analyzing of the available bathymetry, hydrodynamics and morphology data for the considered area
- The bathymetry generator was constructed in order to fill the gaps in observational data
- To resolve carefully the dynamics in the region high quality mesh was generated and applied
- The barotropic, but multilayer, simulations for the Lena Delta region were setup and analyzed, including analysis of velocity regimes in the different freshwater channels during the low water season

Outlook

Two the most interesting tasks for the nearest future are detailed analysis of tidal wave transformation and tides-river competition in the mouth area of the Lena River.

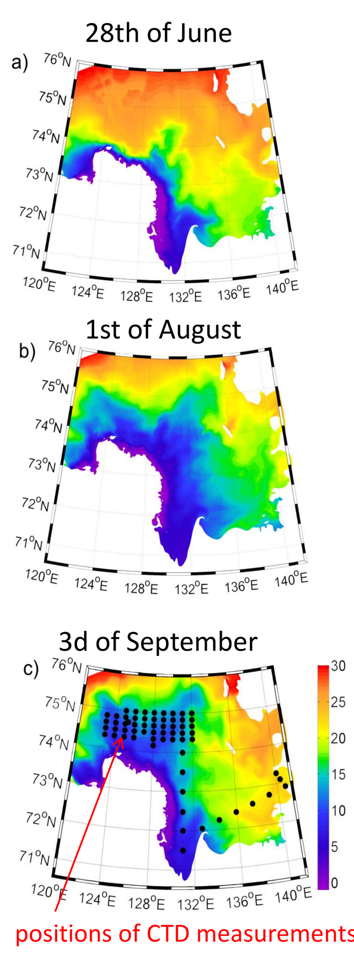
Simulation of the Lena River plume spreading

The Lena River freshwater plume spreading is a key process defining the dynamics of the Laptev Sea region in the summer. It influences stability of the water column and modifies vertical mixing. Atmospheric winds and tidal mixing can be considered as main driving factors (Fofonova et. al, 2015).

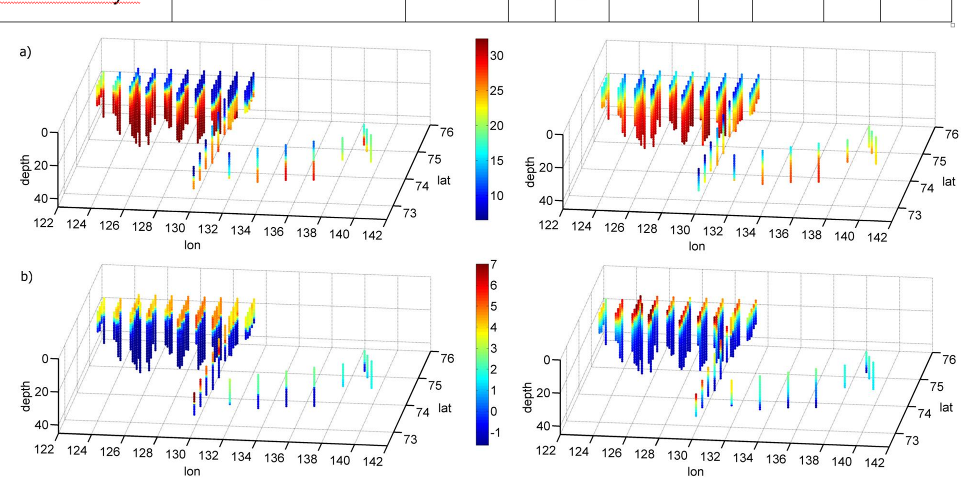


$$K = L_a \cdot \frac{f}{\sqrt{g'h}} \qquad u_{dis} = \frac{1}{K}(2g_r' Q f)^{1/4} \qquad u_{wind} = \sqrt{\frac{\rho_{air}}{\rho_{bl}}\frac{C_{10}}{C_{Da}}}U \qquad W_s = \frac{u_{wind}}{u_{dis}}$$

Name	Mean average Q from May to September 1977-2008, $m^3 s^{-1}$	f (mouth area), $10^{-4} s^{-1}$	K	L_a, km	u_{dis}, $cm\ s^{-1}$	W_s	t_{tilt}, days	W_s	t_{tilt}, hours
						u_{wind} = 11 (|U|=4 $m\ s^{-1}$)		u_{wind} = 21 (|U|=8 $m\ s^{-1}$)	
Trofimovskaya + Bykovskaya	29,395 (20,357+9038)	1.39	~11	~90	~12	~0.9	~4	~1.7	~24
Olenekskaya	2601	1.395	~4	~20	~16	~0.7	~1/3	~1.3	~2
Tumatskaya	2535	1.4	~4	~20	~16	~0.7	~1/3	~1.3	~2



The simulated surface salinity, in practical scale.



The simulated (right panels) versus observed (left panels) temperature (b), [°C], and salinity (a), in practical scale, for September 2008

Main freshwater channels produce large-scale buoyant outflows which can be easily shifted to the wind driven state due to their large Kelvin number ● Buoyancy-driven plume propagation speed is on average between 10 and 20 cm/s depending on the channel ● Winds with a magnitude more then 6 m/s can shift the plume to a wind-driven state and reverse the buoyant outflows from all main freshwater channels ● Persistent westward winds can cause significant plume propagation from the Trofimovskaya and Bykovskaya channels to the north toward the continental slope area ●Plume from Olenekskaya and Tumatskaya channels can be modified much faster than the width of the plume from Trofimovskaya and Bykovskaya channels ● Downweling favorable winds (associated with a cyclonic atmospheric circulation) strengthen the down-shelf buoyancy-driven flows from all main channels ● Tides in the area contribute to mixing by adding up to 0.015 m^2/s to the vertical diffusivity in some areas, but their role remains relatively minor east of the Lena Delta (except for its vicinity) ● The residual circulation associated with tides significantly contributes to the eastward plume propagation along the northern part of the delta, where it reaches about 2 cm/s.

References
Bolshiyanov D., Makarov A., Schneider W., and Stof G., 2013. Origination and development of the Lena River Delta. St. Petersburg: AARI, 268 p., in Russian.
Fofonova V., Androsov A. , Danilov S. , Janout M. , Sofina E. and Wiltshire K. H., 2014. Semidiurnal tides in the Laptev Sea Shelf zone in the summer season , Continental Shelf Research, 73 , pp. 119-132 . doi: 10.1016/j.csr.2013.11.010
Fofonova V., Danilov S., Androsov A., Janout M., Bauer M., Overduin P., Itkin P. and Wiltshire K. H., 2015. Impact of wind and tides on the Lena River freshwater plume dynamics in the summer season, Ocean Dynamics. doi: 10.1007/s10236-015-0847-5
Hasholt B., Bobrovitskaya N. N., Bogen J., McNamara J., Mernild S., Milburn D., and Walling D. E., 2005. Sediment transport to the Arctic Ocean and adjoining cold oceans. 15th International Northern Research Basins Symposium and Workshop. Luleå to Kvikkjokk, Sweden, pp. 41–67.
Holmes R. M., McClelland J. W., Peterson B. J., Shiklomanov I. A., Shiklomanov A. I., Zhulidov A. V., Gordeev V. V. and Bobrovitskaya N. N., 2002. A circumpolar perspective on fluvial sediment flux to the Arctic Ocean, Global Biogeochem. Cycl., 16(4), p. 1098. doi:10.1029/2001GB001849
Korotaev V. N., 2012. Essays on the geomorphology of estuarine and coastline systems. Moscow, Moscow State University Publ., 540 p., in Russian.
Tananaev N. I. and Anisimova L. A., 2013. Evaluating the annual runoff of traction load on the rivers in the north of Siberia and the Far East, Geogr. and Nat. Resour., 34(1), pp. 79–87.