Ice-jam floods modeling in frameworks of intelligent system for river monitoring

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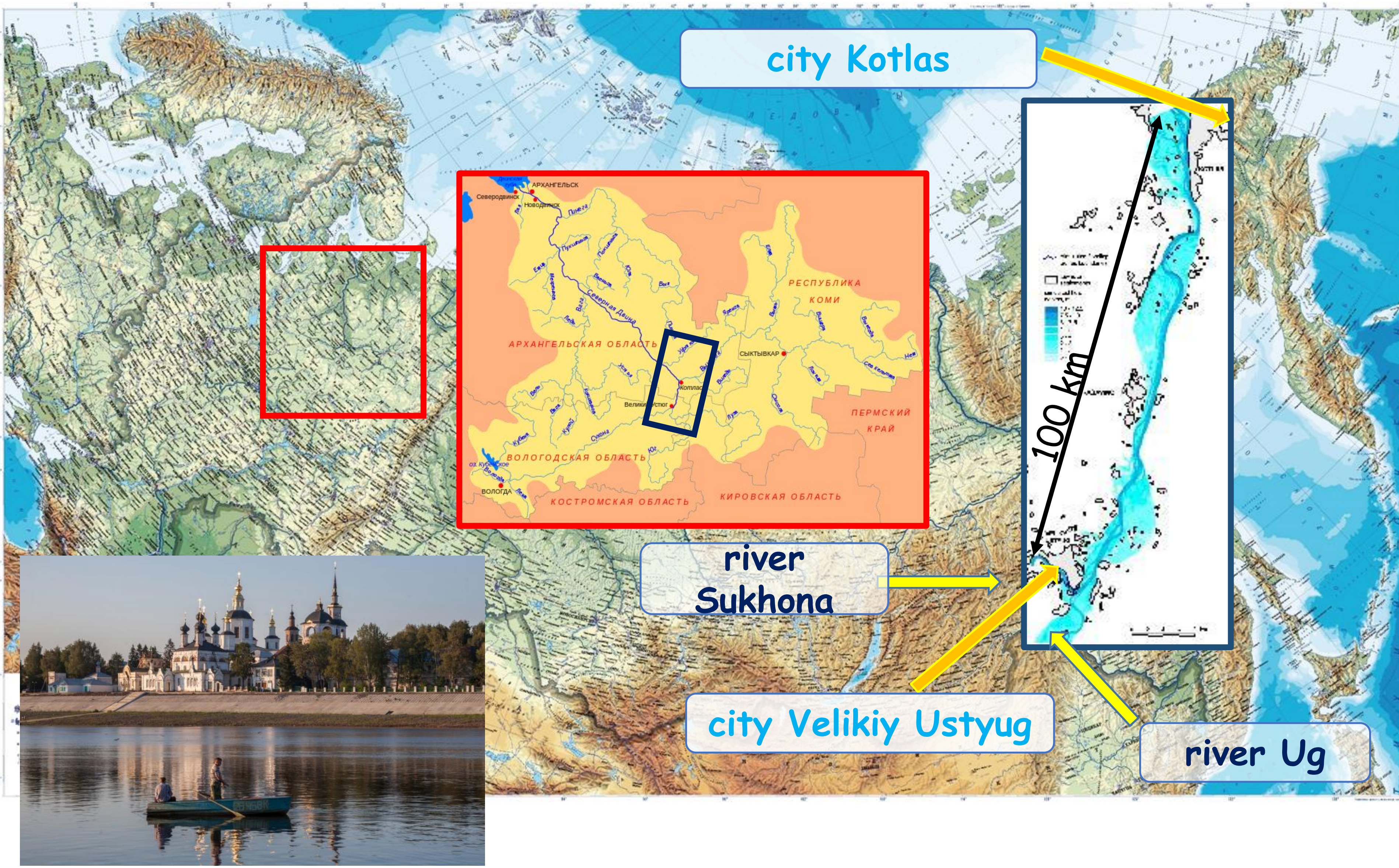
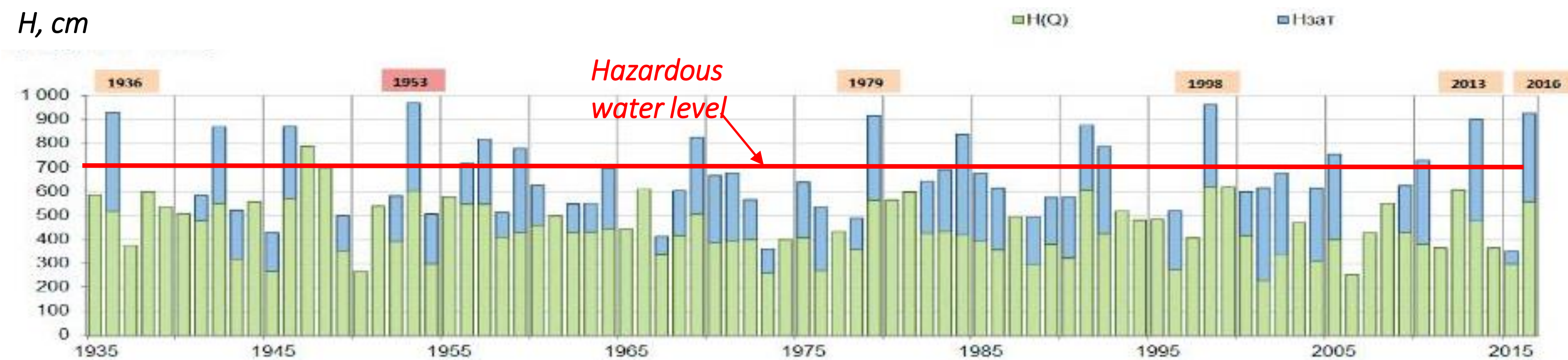
Study area

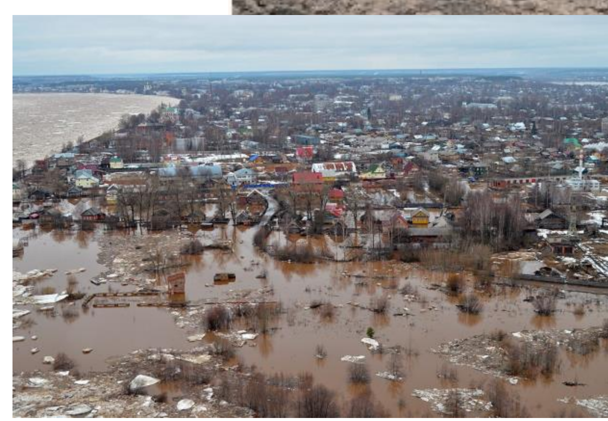


city Velikiy Ustyug

Motivation

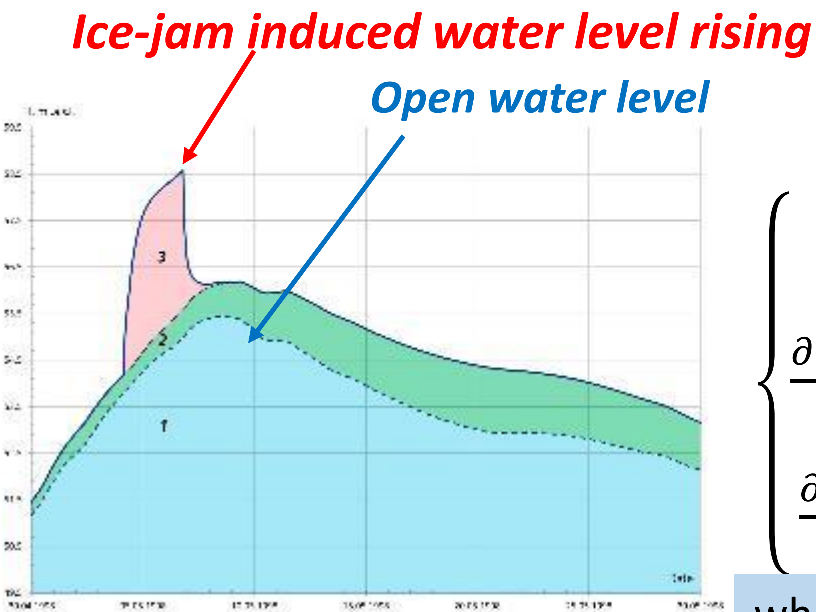


Ice jams formation frequency – 62%
Disastrous floods – 1936, 1953, 1979, 1998, 2013, 2016



Velikiy Ustyug is an ancient Russian city founded in 13th century. Nowadays the urban areas have spread from terraces to river floodplains, which, together with the location of the city at the junction of large rivers and the high frequency of ice-jamming, predetermines a high danger of flooding.

Modeling of flooding in the river reaches with ice-jam formation



STREAM_2D and STREAM_2D CUDA two-dimensional model with ice-module (Aleksyuk, Belikov et. al.)

$$\begin{cases} \dfrac{\partial h}{\partial t} + \dfrac{\partial (hu)}{\partial x} + \dfrac{\partial (hv)}{\partial y} = 0, \\ \dfrac{\partial (hu)}{\partial t} + \dfrac{\partial \left(hu^2 + \frac{1}{2} g h^2\right)}{\partial x} + \dfrac{\partial (huv)}{\partial y} = -gh \dfrac{\partial b'}{\partial x} + \dfrac{\tau_1^b + \tau_1^i}{\rho}, \\ \dfrac{\partial (hv)}{\partial t} + \dfrac{\partial (huv)}{\partial x} + \dfrac{\partial \left(hv^2 + \frac{1}{2} g h^2\right)}{\partial x} = -gh \dfrac{\partial b'}{\partial y} + \dfrac{\tau_2^b + \tau_2^i}{\rho}. \end{cases}$$

where (x, y) and t are the Cartesian coordinates and time;

$u(x, y, t)$, $v(x, y, t)$ depth-averaged fluid velocity components

$h(x, y, t)$ - the flow depth;

$b' = b + \rho_i H/\rho$, where b denotes the bed level;

ρ and ρ_i represent water and ice density,

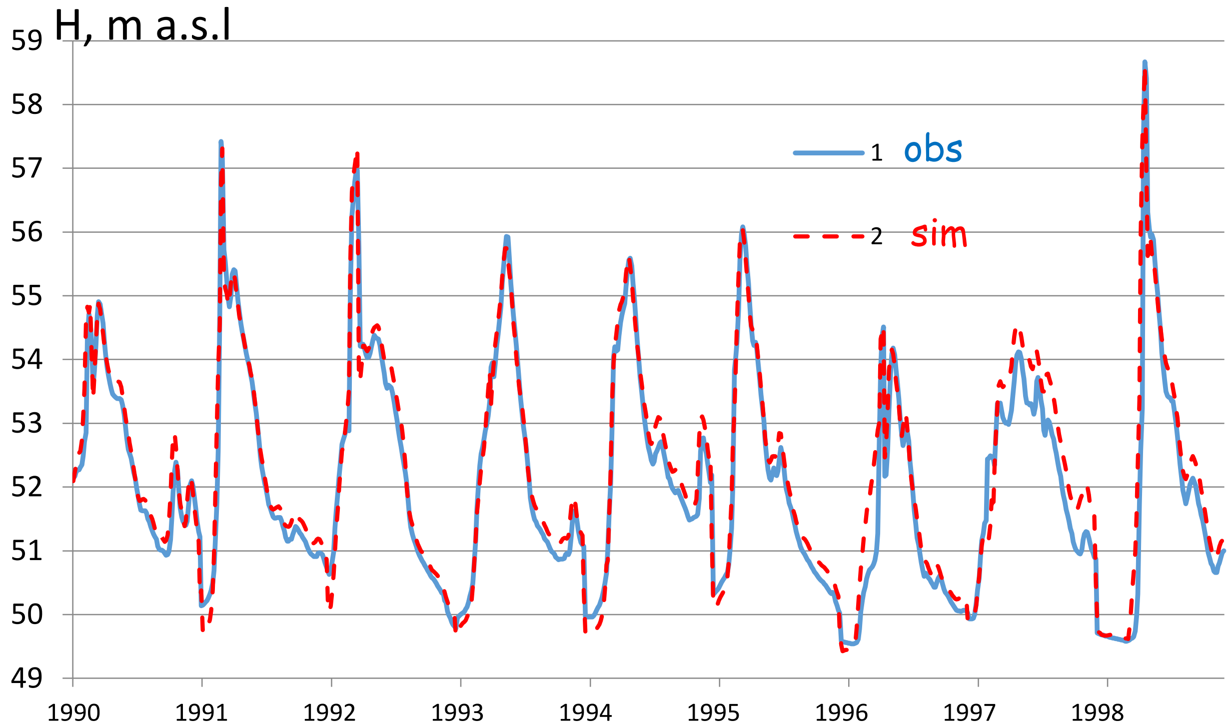
H - ice thickness;

vectors (τ_1^b, τ_2^b) and (τ_1^i, τ_2^i) - the bed and ice surface shear stresses,

g - is the gravitational acceleration.

Hydrodynamic modeling taking into account ice jams

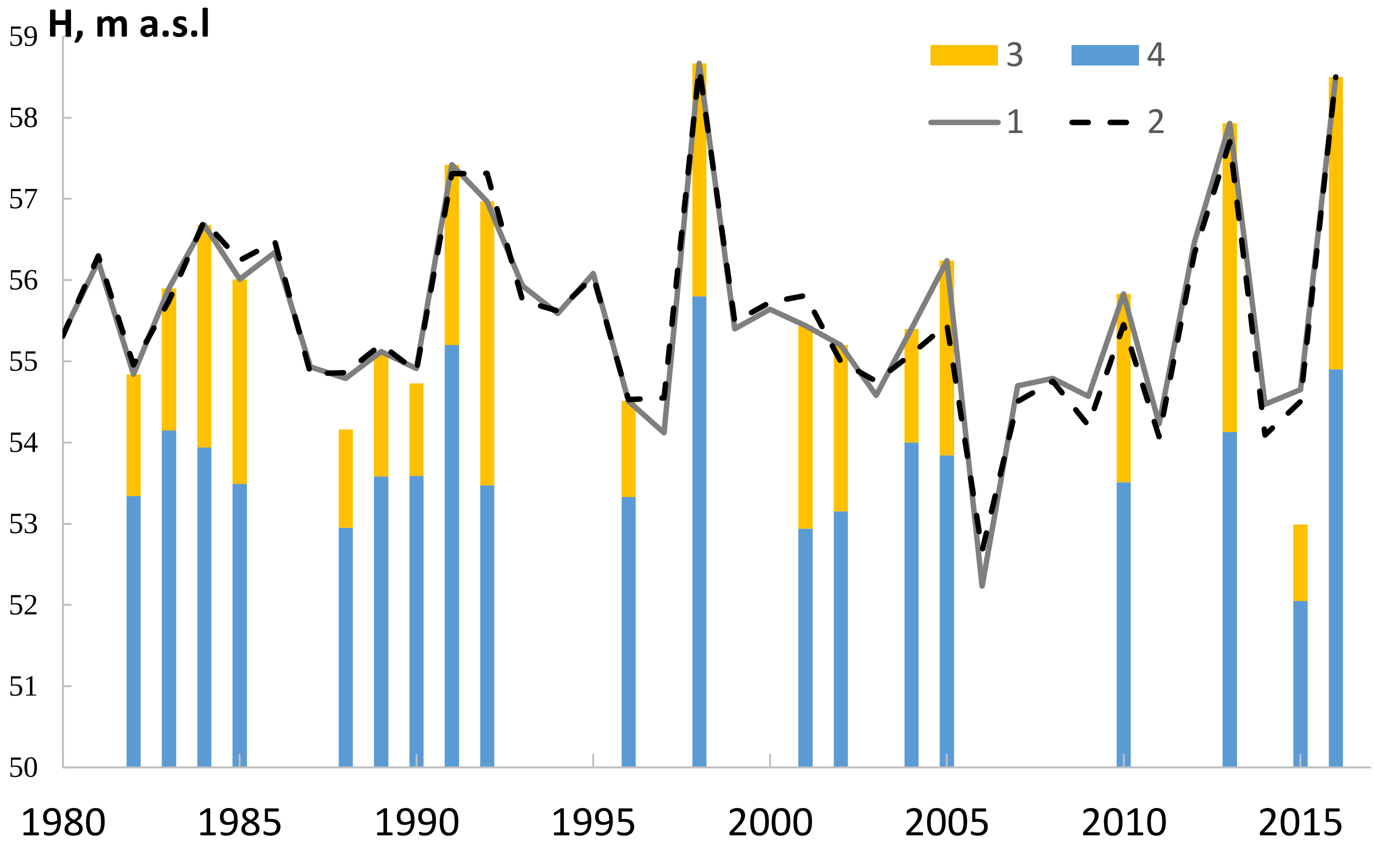
Daily observed (1) and simulated (2) water levels (*H*) at the gauge Velikiy Ustyug (only periods of each year from April, 1 till June, 30).



Efficiency criteria (NSE) received for comparison of observed and simulated daily water levels at the gauge station Velikiy Ustyug

Period	Years	Days with ice-jams formation	All
Calibration	1980–1998	0.72	0.94
Verification	1999–2016	0.79	0.91

Maximum water levels in the years with ice-jam formation



Comparison of maximum year observed (1) and simulated (2) water levels at the gauge Veliky Ustug for the period 1980–2016 years;
additional ice-jam induced water level rising (3);
open water levels in the years with ice-jam formation (4).

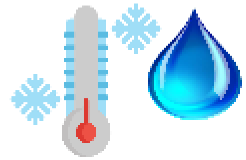
Parameters of ice module, received for different heights of ice-jam induced water level rising near city Velikiy Ustyug

№	Type of ice-jam	Ice-jam induced water level rise, m	Ice roughness coefficient, n_i	Ice thickness parameter, m
1	Small	<1.5	0.045	1
2	Medium	1.5–2.5	0.045	1.5
3	Congestion	2.5–3.5	0.075	2
4	Catastrophic	>3.5	0.100	2

Models chain

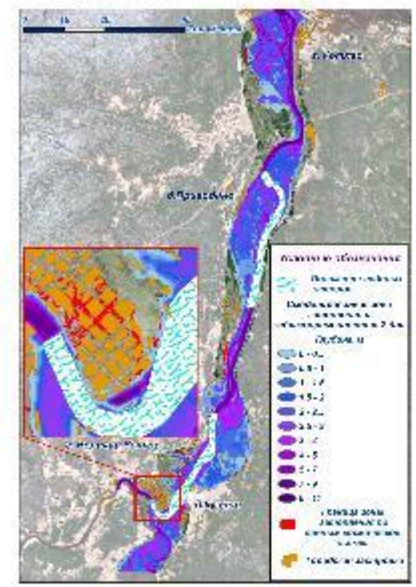
Mesoscale atmospheric model COSMO-Ru

- Precipitation,
- air temperature, deficit of air moisture



Runoff formation model ECOMAG

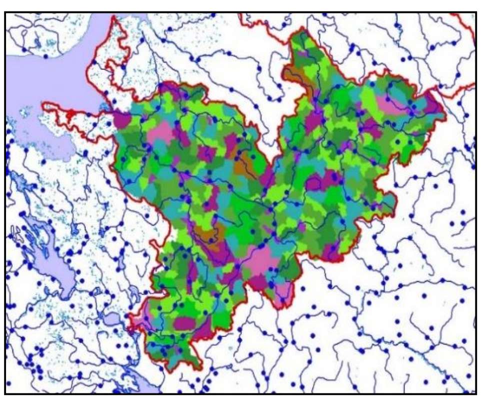
- River discharges



1 - 3 day advance flooding forecast

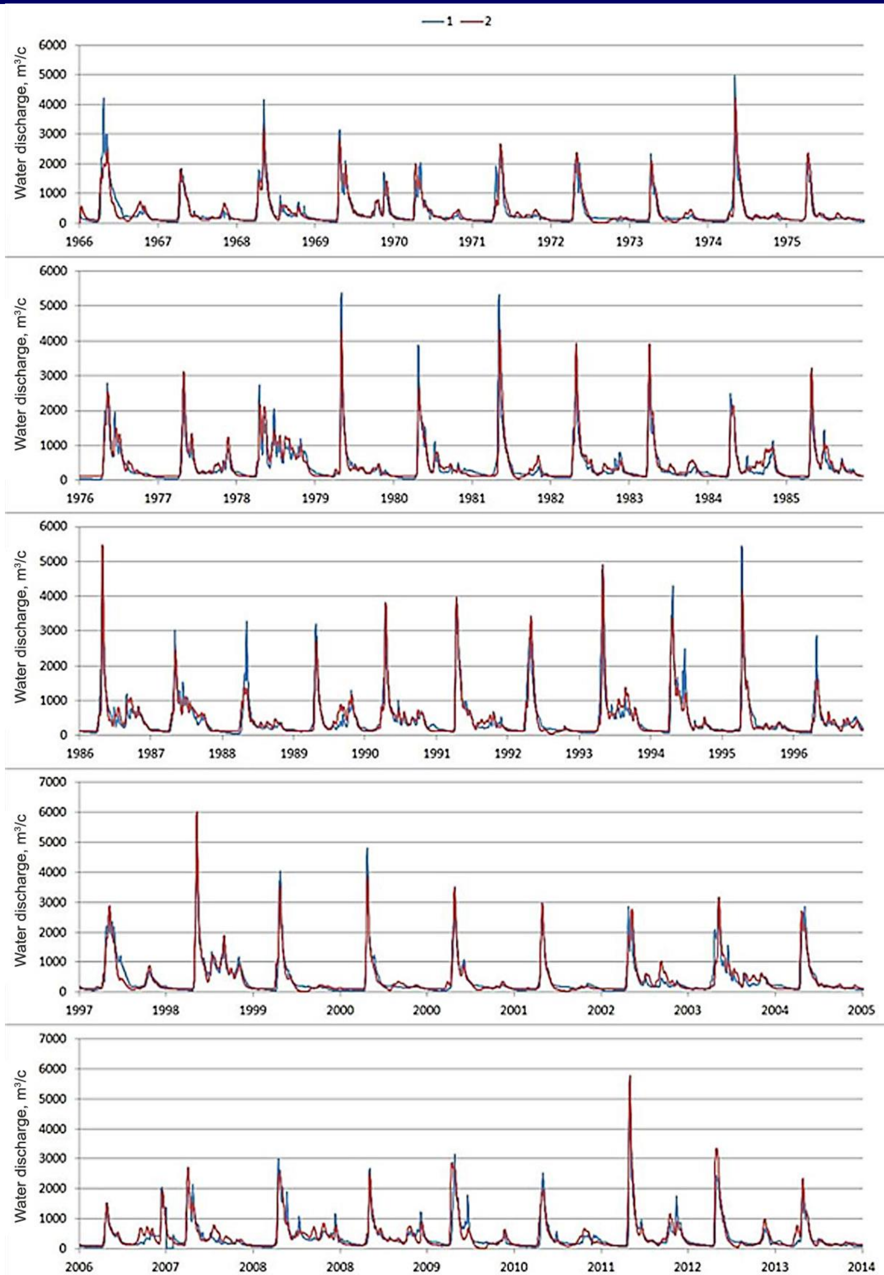
Two-dimensional hydrodynamic model STREAM_2D

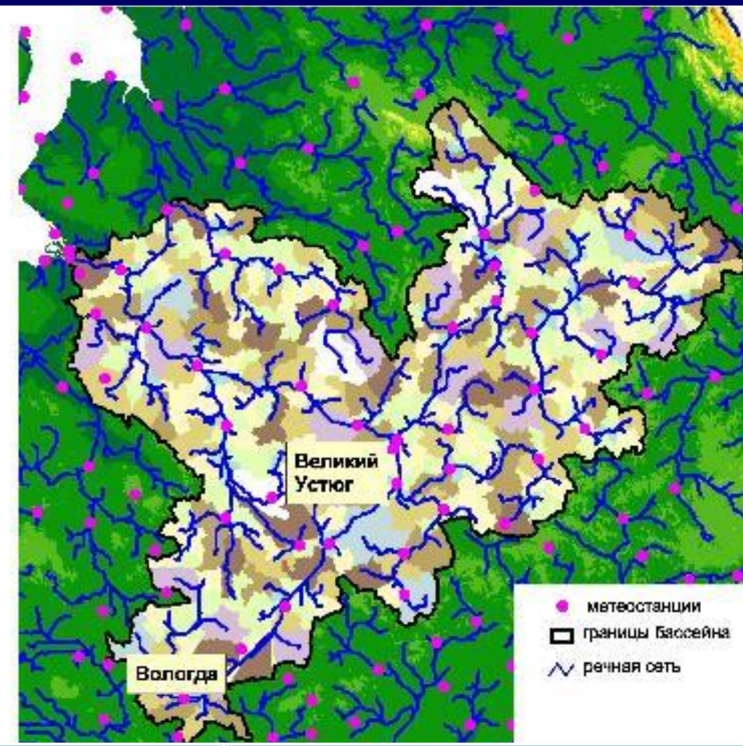
- Water levels, flooding depths,
- boundaries of flooding,
- flow velocities



Northern Dvina River basin

Runoff formation modeling using ECOMAG software on the base of observed meteorology

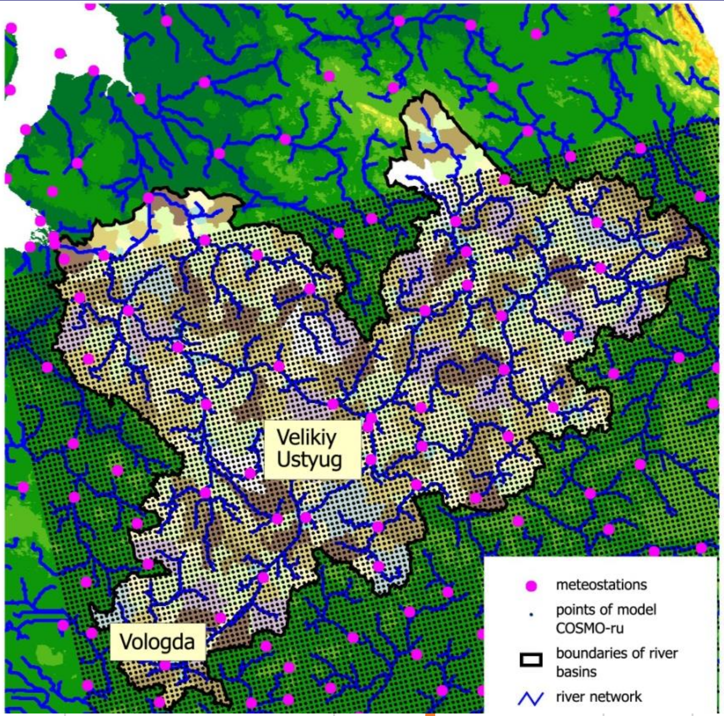


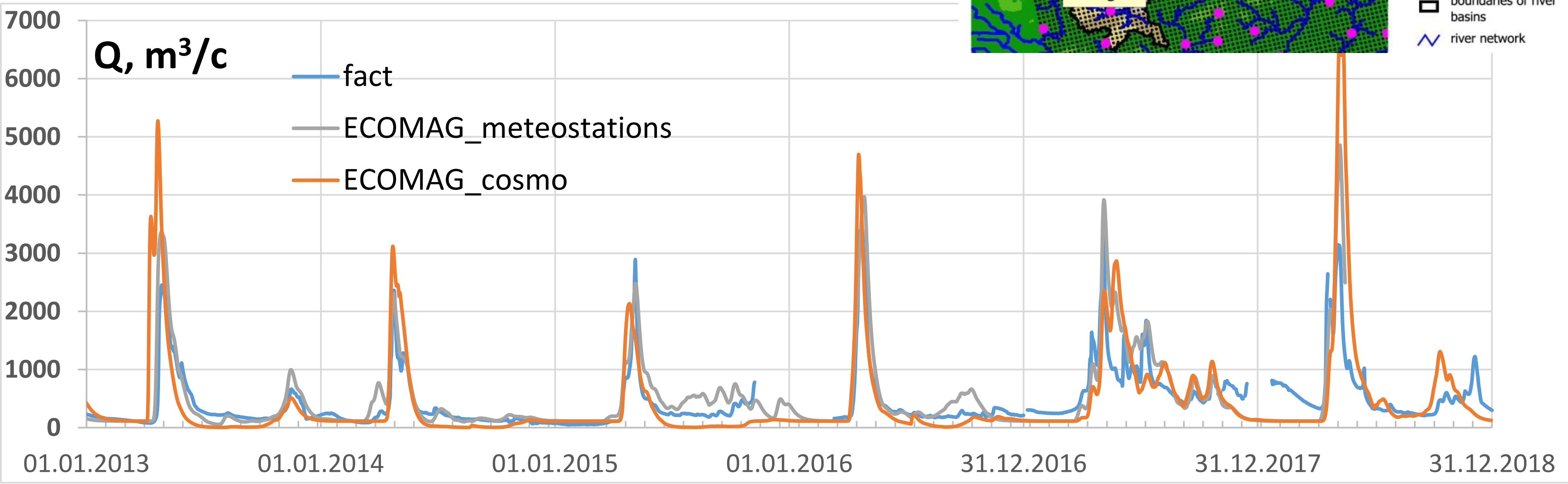


Period	NSE, daily discharges	
	r. Sukhona – Kalikino	r. Ug –Gavrino (closed in 1989)
1969 – 1984 (calibration)	0.83	0.84
1985 – 2014 (verification)	0.81	0.79

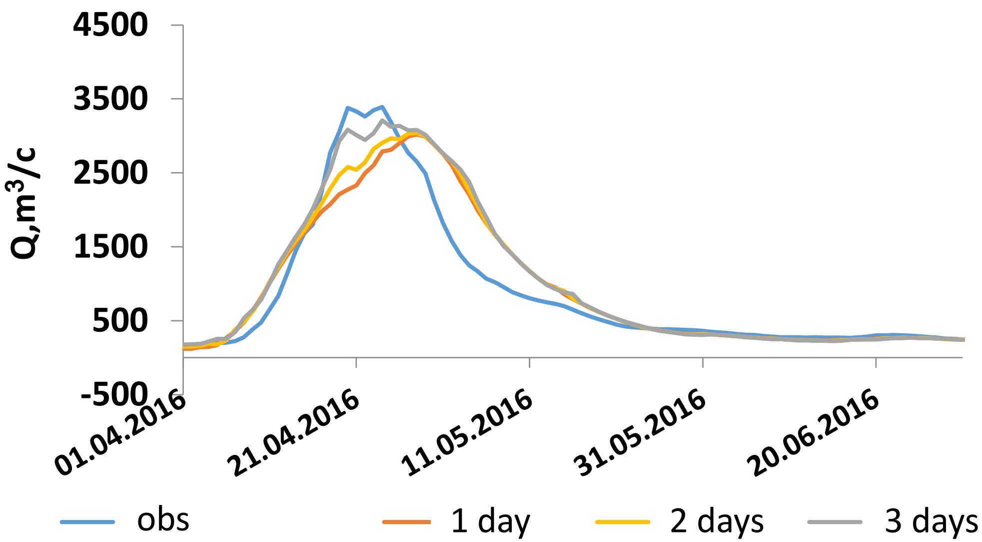
Data of the regional meteorological model COSMO-RU as the base for runoff forecasting in the North river basin

Daily discharges of Sukhona river –gauge Kalikino: observed (1), simulated on the base ECOMAG using observed meteorology (2), simulated on the base ECOMAG using forcing data of COSMO-ru (3)





Forecast of discharges and water levels for the flood 2016 with different advance time

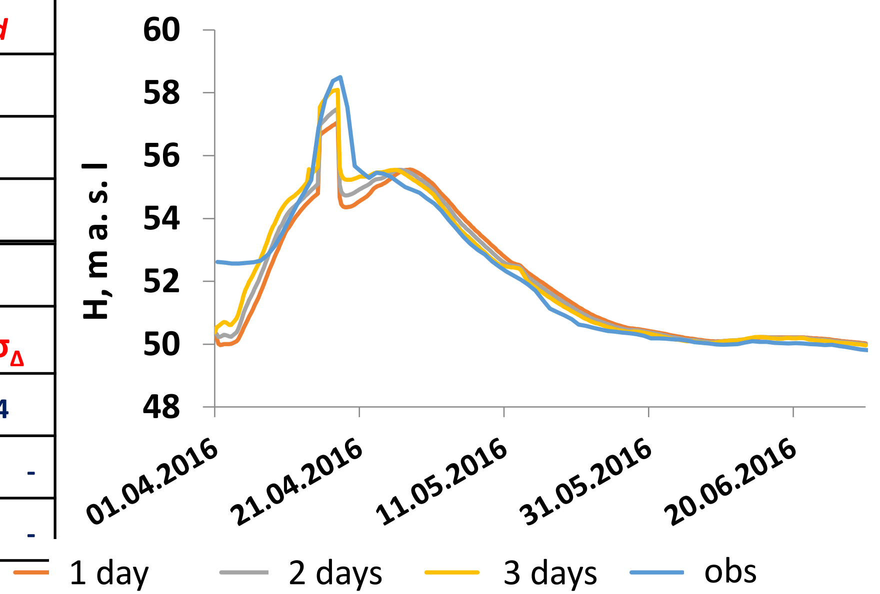


δ	NSE
1 day	0,84
2 days	0,86
3 days	0,87

δ	Q, m^3/c				
	S	σ_Δ	S/σ_Δ	S_Δ	S_Δ/σ_Δ
1 day	389	133	2,93	105	0,79
2 days	365	256	1,42	172	0,67
3 days	345	374	0,92	200	0,54

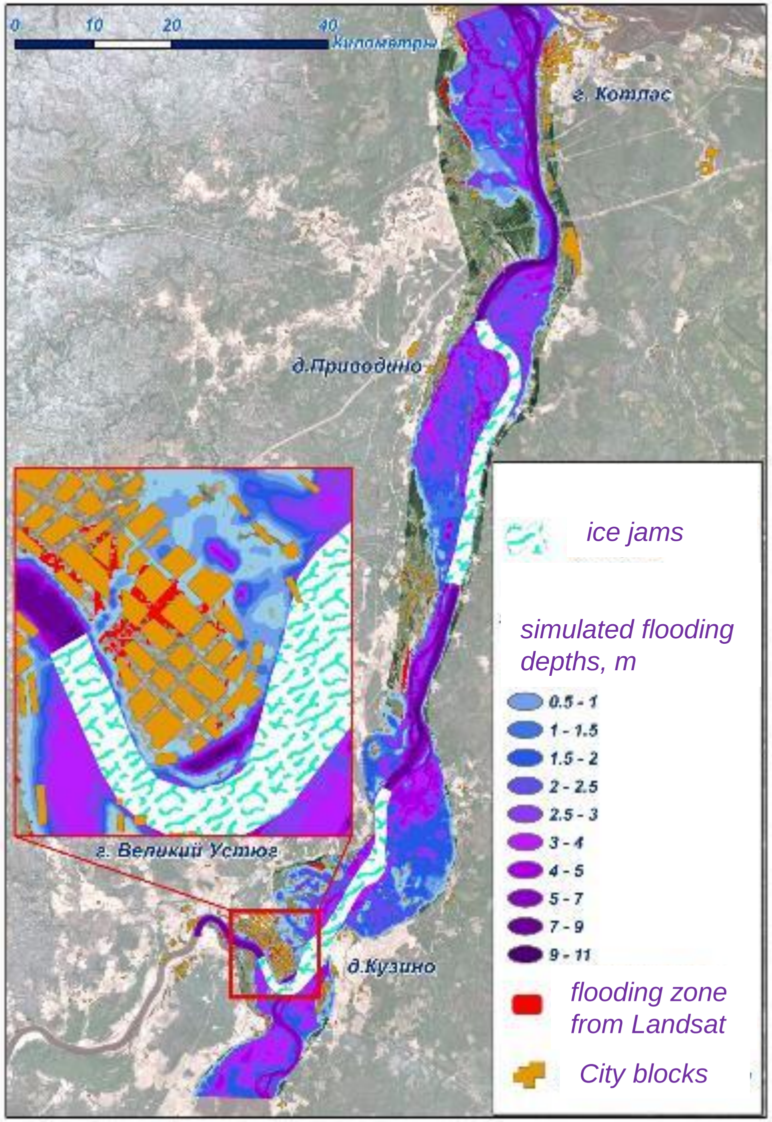
δ	NSE	
	All period	*Open water period*
1 day	0,86	0,84
2 days	0,90	0,89
3 days	0,92	0,90

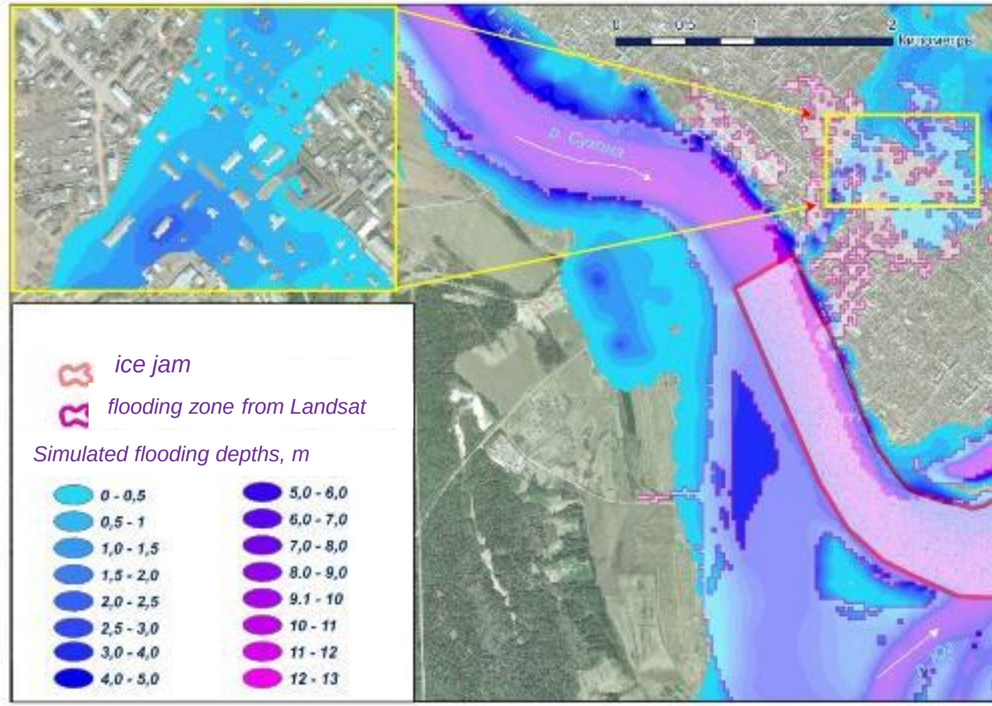
δ	H, m a.s.l.				
	S	σ_Δ	S/σ_Δ	S_Δ	S_Δ/σ_Δ
1 day	0,67	0,36	1,86	0,41	1,14
2 days	0,52	0,65	0,81	-	-
3 days	0,39	0,88	0,44	-	-



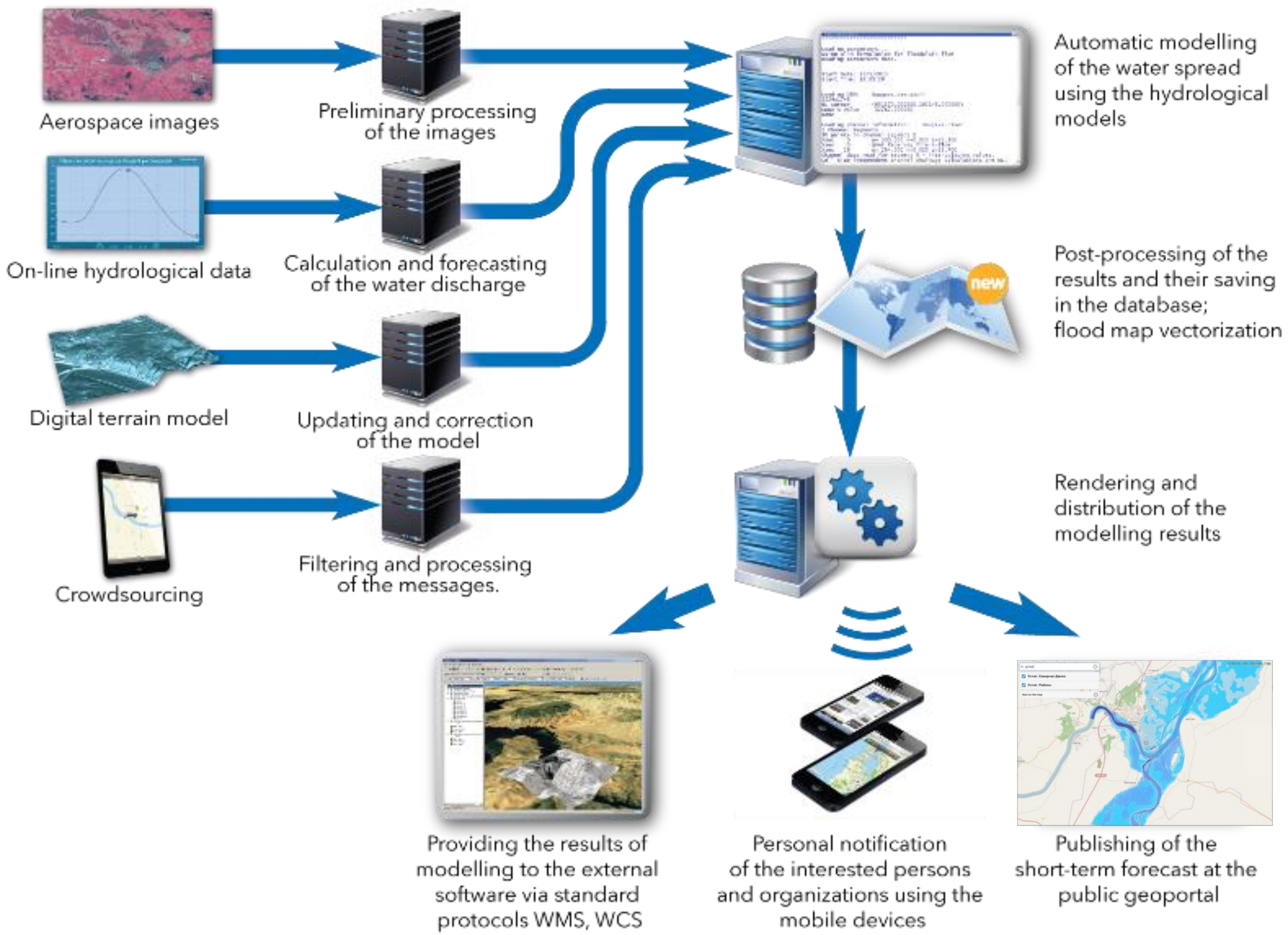
Flooding zone forecast

Maximum flooding in the year 2016





Flood operational forecasting system



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WATER RESOURCES AND THE REGIME OF WATER BODIES

Modeling Ice-Jam Floods in the Frameworks of an Intelligent System for River Monitoring

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Abstract—The article presents the results of adaptation and application of two-dimensional hydrodynamic model STREAM_2D to reproduce the characteristics of ice-jam-induced floods in the vicinity of the city of Velikiy Ustyug (the Northern Dvina river basin, Vologda region, Russia). The additional hydraulic resistance due to ice roughness and the decrease in the flow cross-section area due to ice-caused congestion were taken into account for modeling of ice-jam-induced water level variations. The corresponding model parameters were estimated on the basis of numerical experiments and flood modeling for the period from 1980 to 2016, which includes more than 32 significant cases of ice-jamming. Grouping of model parameters by the height of the ice-jam-induced water level rises could be useful for the application of the developed model in the framework of an intelligent information system of river flood monitoring.

Keywords: hydrodynamics, river ice, ice-jams, 2D-modeling, flooding, STREAM_2D, Northern Dvina, Velikiy Ustyug

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INTRODUCTION

The development of intelligent information systems for monitoring hydrological phenomena is one of the most relevant and promising directions for enhancing both the possibility of flood forecasting, and the awareness of the population allowing the prevention of devastating losses of human lives. Increasingly, mathematical models that are configured to use operational data of hydrometeorological observations, such as Mike Flood Watch [30], Delft FEWS Flood Early Warning Systems [19], are used as the computational core of such systems. The systems such as Flood Early Warning Systems, European Flood Awareness System (EFAS) [29] cover large regions, often containing a number of states. Similar systems being developed in Russia are more local and focused on solving specific practical problems, such as monitoring and predicting of rain floods in Far East region [13], the propagation of flood waves along large rivers regional problems, particularly important for the Northern regions, is the monitoring of snowmelt floods complicated by ice-jam events. The determination and prediction of the characteristics of ice-jam floods using complex statistical methods and modeling are challenging because of the lack of observation data and the complex nature of ice-jam flood phenomena [10, 23, 28].

This paper presents the research results related to the development of an intelligent system for monitoring and assessing the state of natural systems (PROSTOR) [4, 31]. the vicinities of the city of Velikiy Ustyug, located at the junction of the Sukhona and Yug rivers, giving the origin to the Northern Dvina River (being called there "the Small Northern Dvina"), were chosen as the key area for testing this system (Fig. 1). The vast valleys of these rivers are among the most vulnerable places in Russia to spring snow-melt floods, and ice-jams often induce inundation of lowlands at the city of Velikiy Ustyug and

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Thank you for the attention!