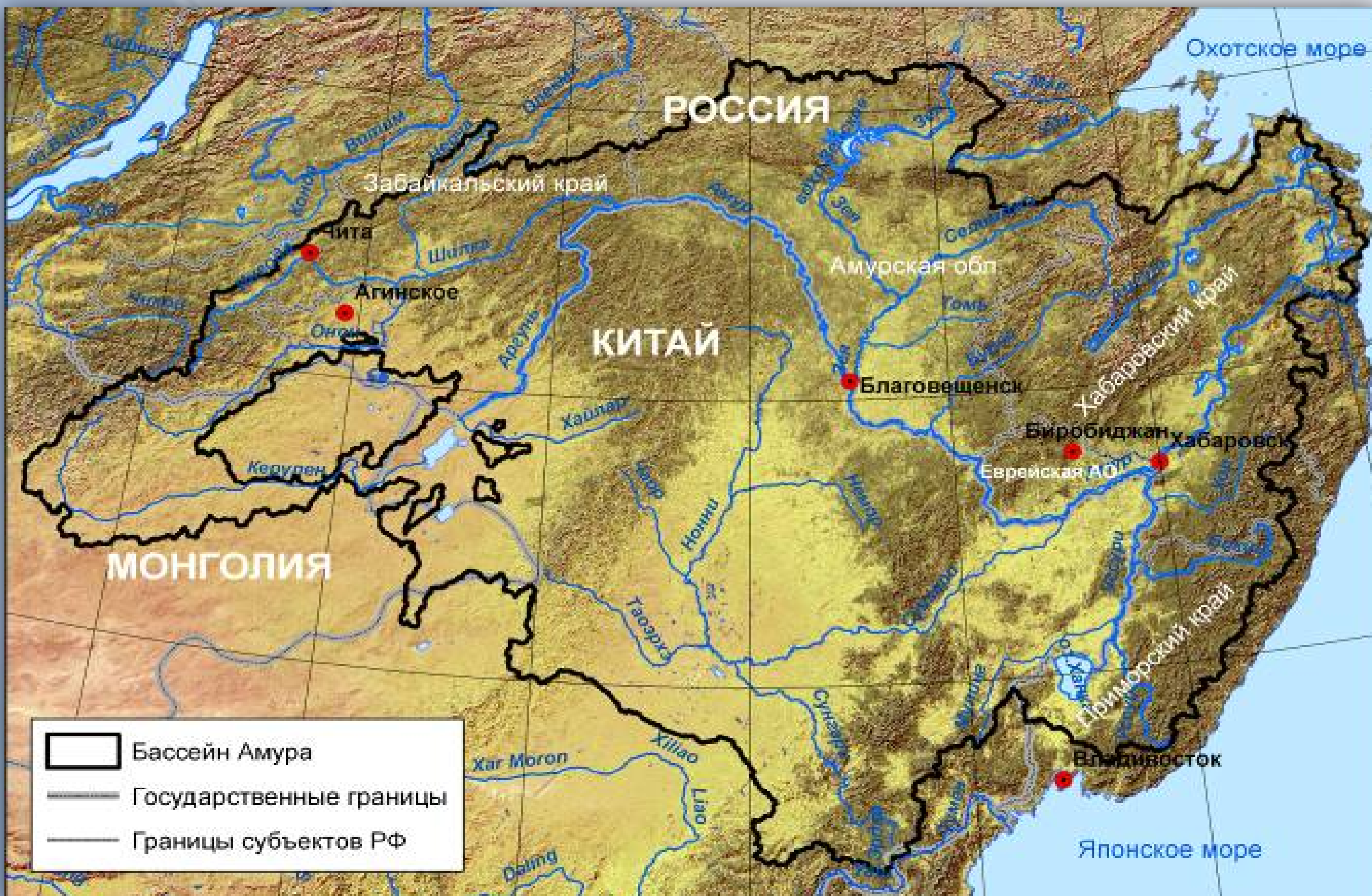
"Activities of the Hydrometeorological Service of Russia on the monitoring and forecasting of hydrological situation during the catastrophic flood in the basin of the Amur River in 2013"

Sergey Borshch (Hydrometeorological Center of Russia)

Second meeting for WGHS RA-II, Gyeongju, Republic of Korea, 14-16 April 2015

The Amur River at Khabarovsk (August – September 2013)

The Amur River is the main river of the Far East and one of the largest rivers in the world.
It is 2.8 thousand km long (from the confluence of the Shilka and Argun rivers)
and has a catchment area of 1.85 million km².
The average annual water discharge of the Amur River at Khabarovsk is 8.3 thousand m³/s
and at Komsomolsk-on-Amur, 9.6 thousand m³/s



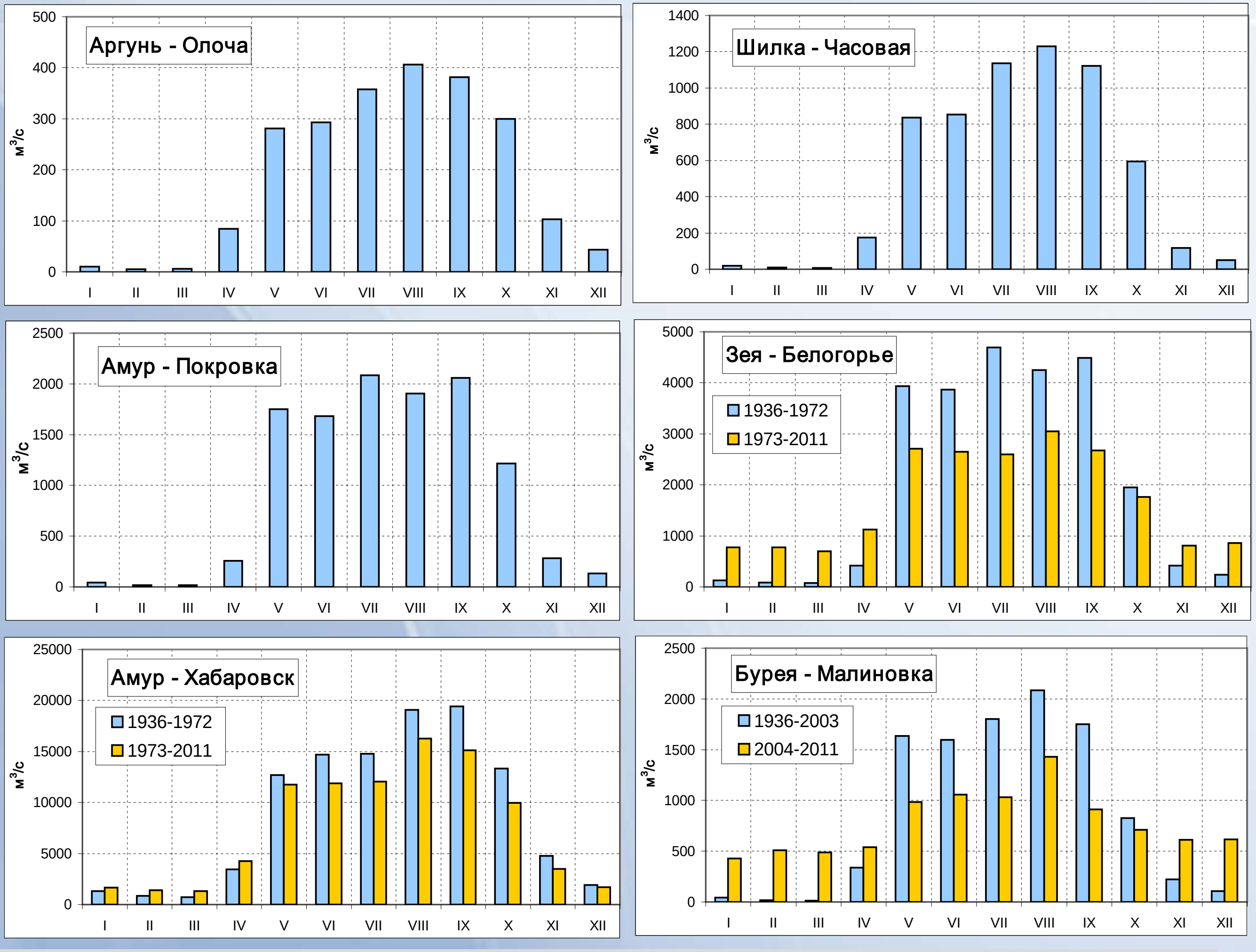
The Amur River is a transboundary river. Its basin is located in three states:

- **Russia (995 thousand km², about 54% of the catchment area);**
- **China (44% of the catchment area)**
- **Mongolia (2% of the catchment area).**

The Amur River is the longest transboundary river in Russia.

The Argun, Amur and Ussuri rivers form the state border between Russia and China, which is more than 3.5 thousand km long.

Distinctive features of hydrological regime of the Amur River



Intra-annual distribution of streamflow of the Amur River and its tributaries

The Amur River basin is located in a zone affected by Far Eastern monsoon climate, which determines the Amur River water regime.

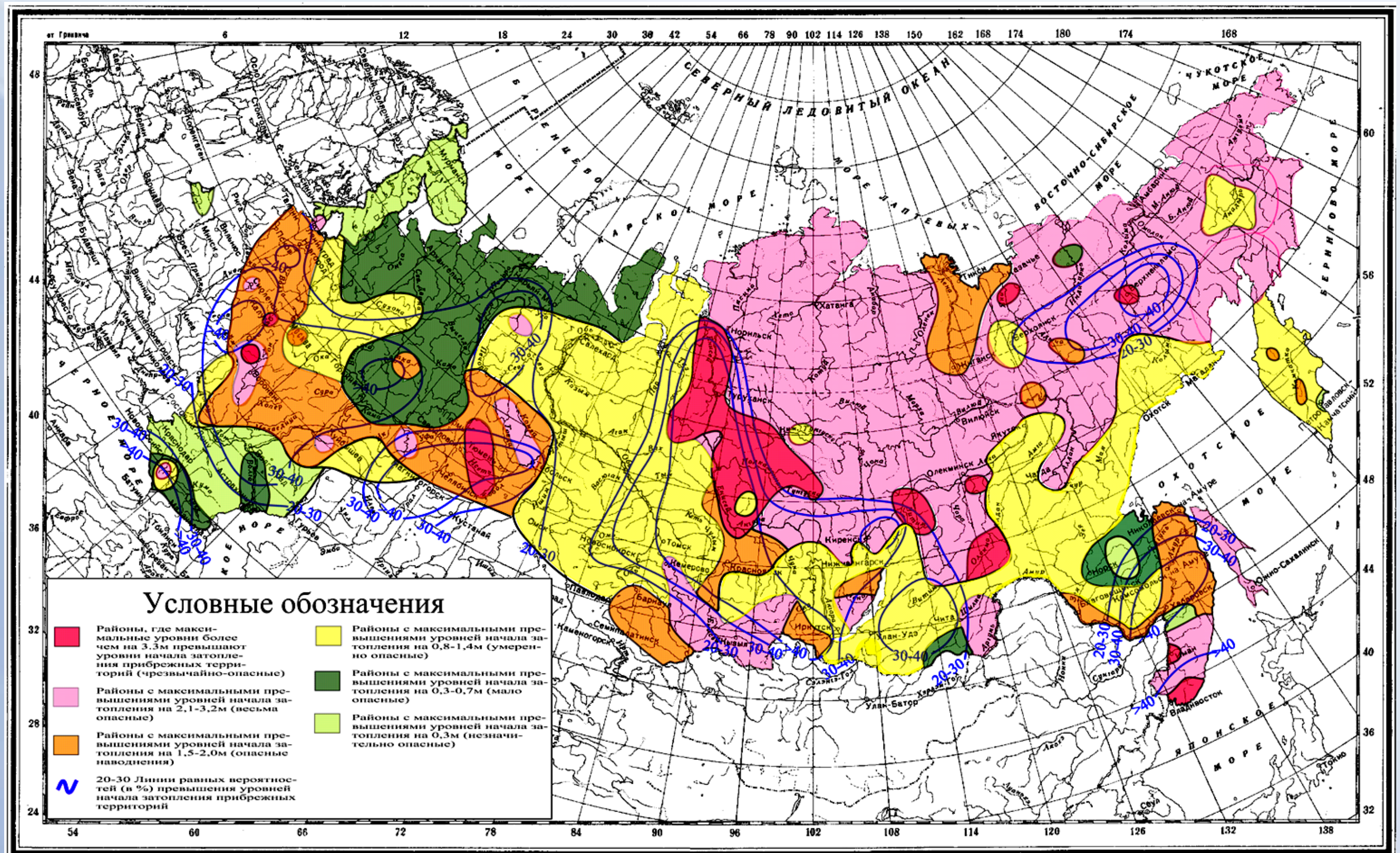
Summer and autumn monsoon rains form the main part of river runoff, often causing high floods on the Amur River and its tributaries.

The Amur River is fed mainly by heavy summer rains. The contribution of rains to the total river runoff is about 60-70%. The contribution of snowmelt waters is less significant.

Water regime of the Amur River:
- spring flood due to snowmelt waters is less significant as compared with summer rain flood in terms of magnitude and duration;
- in summer, floods caused by rains subsequently follow one another, forming high summer flood;
- in winter, low flow is observed.

Typically, summer floods occur during late July to early August, often resulting in catastrophic flooding. Flood extent may reach 10-25 km in the lower and middle Amur reaches.

Distinctive features of hydrological regime of the Amur River

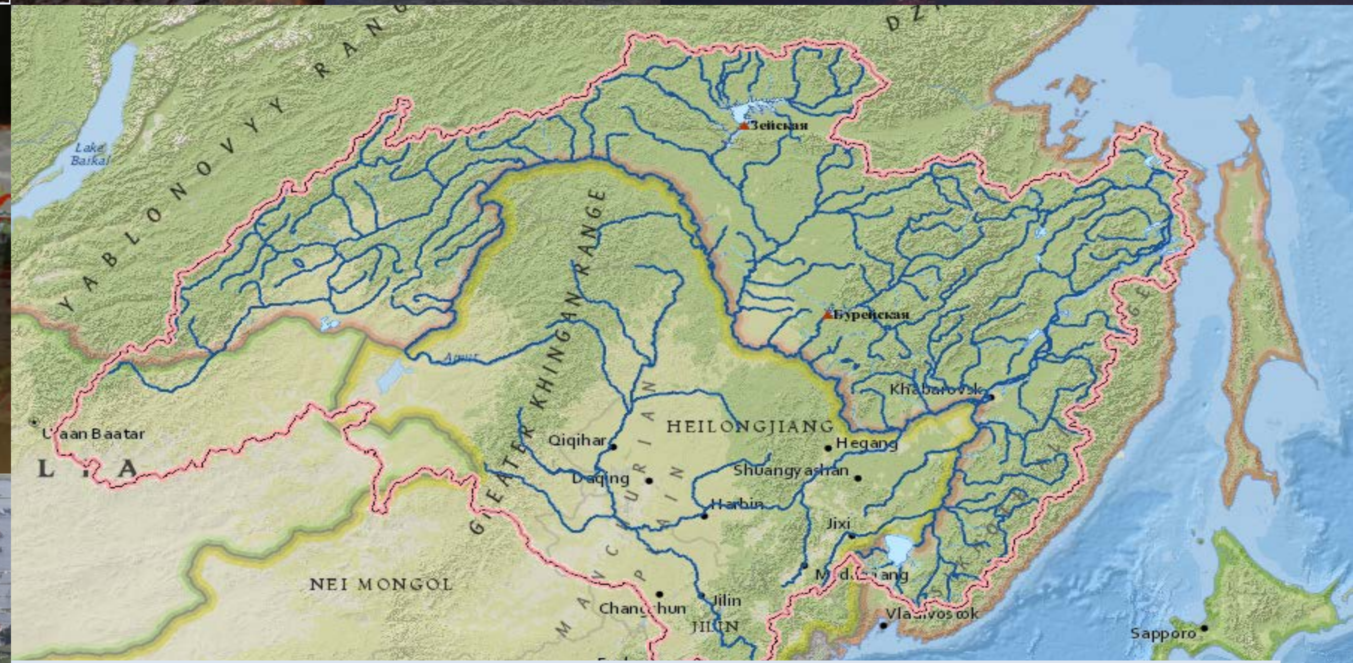


Map of potential flood hazard for different river basins in Russia

The Amur River basin is at high risk of flood.

On the average, floodings in the Amur River basin occur once every 3 to 5 years; downstream from the Songhua River mouth, floodings occur once every 2 to 3 years.

Possible inundation depth is 2-3 m; for some sections of the Amur River, it is more than 3 m.



In July-September 2013, a catastrophic flooding occurred in the Amur River basin, affecting vast areas of Russian Far East and northern China. It had become one of the largest natural disasters of recent decade in terms of duration, extent and economic losses.

http://www.airpano.ru/files/Amur-River-Flooding-Russia/2-2

COMPLEX ANALYSIS OF 2012-2013 HYDROMETEOROLOGICAL CONDITIONS IN THE AMUR RIVER BASIN FIGURED OUT THE FOLLOWING PRINCIPAL FACTORS OF THE CATASTROPHIC 2013 FLOODING IN THE AMUR RIVER BASIN:

(a) hydrological conditions prior to the flooding;

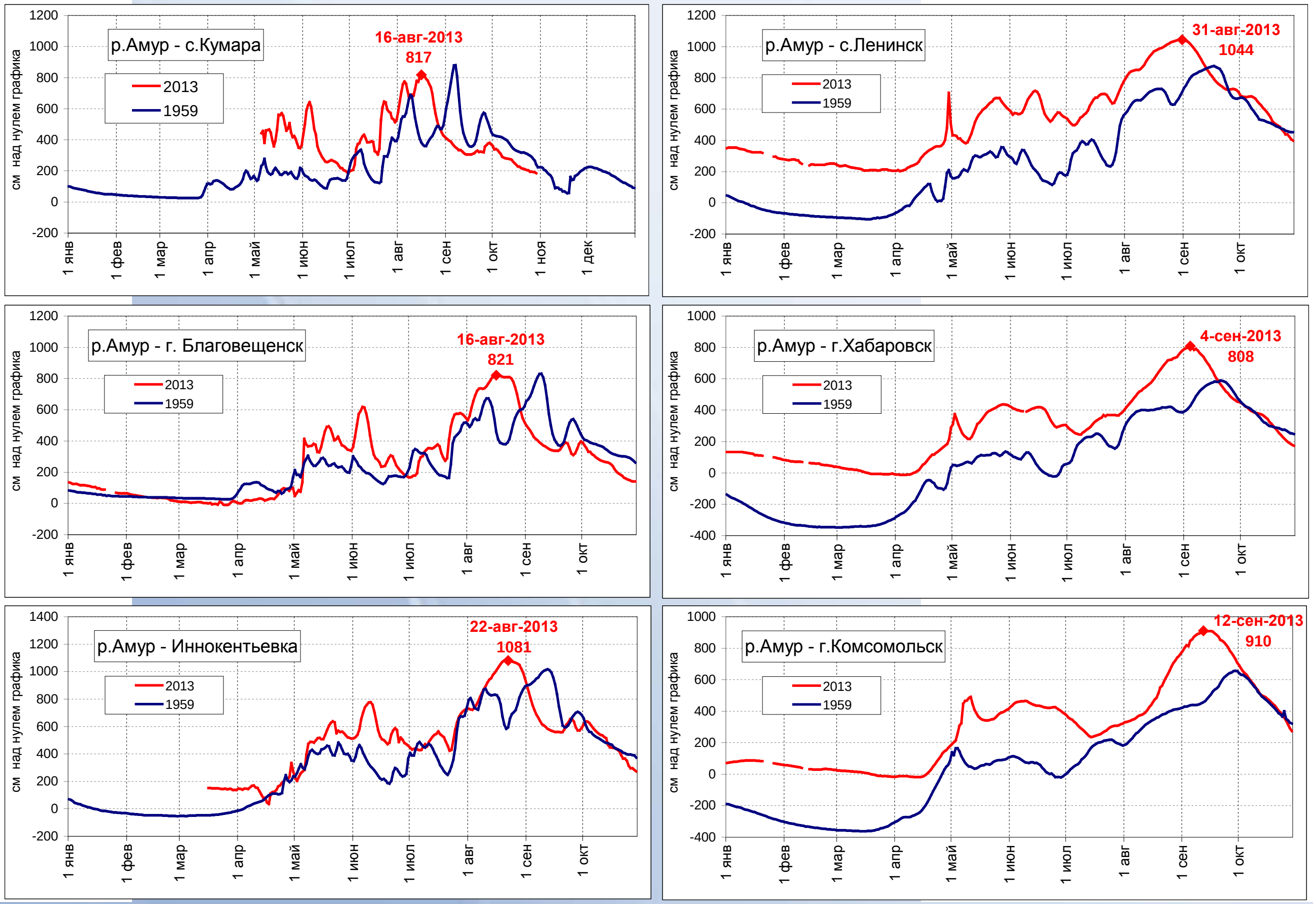
(b) meteorological conditions of 2013;

(c) superposition of flood wave peaks of main river and its tributaries;

(d) changes in channel and floodplain capacity – among other reasons, because of construction of bank protection structures and protection dams.

Factors of the catastrophic 2013 flooding in the Amur River basin

(a) hydrological conditions prior to the flooding



Daily water level 2013 hydrographs vs. 1959 hydrographs

Hydrometeorological conditions prior to the 2013 flooding significantly contributed to the flood formation:

1.Winter and spring water levels significantly exceeded their long-term mean values. The figure shows daily water level hydrographs for several streamflow gauging stations on the Amur River. The year 1959 ranks third for the period of observations in terms of peak water discharge and water level on the Lower and Middle Amur. Before the 2013 flooding, water levels were more than 2 m higher than those of 1959.

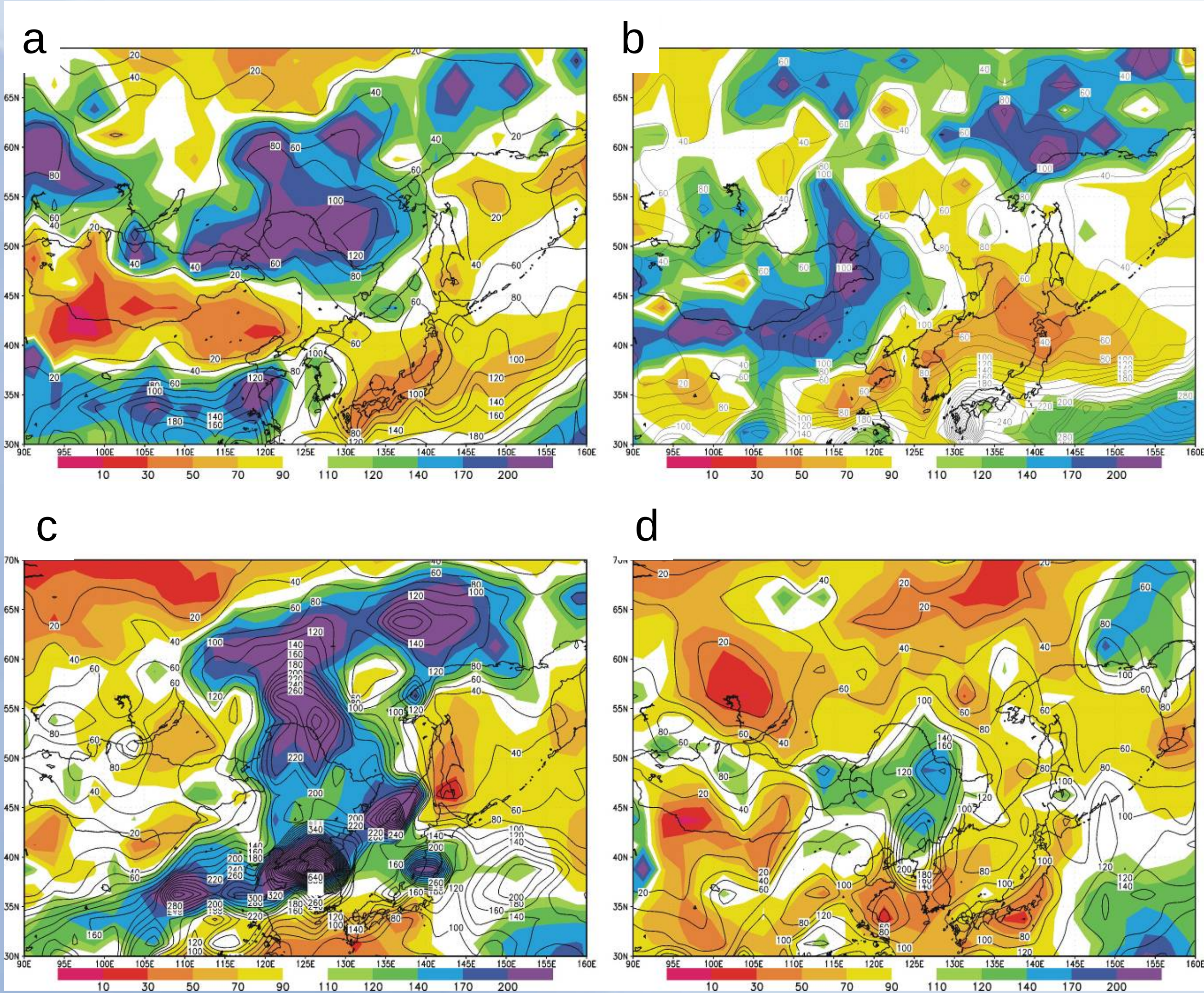
2. Precipitation amount of autumn 2012 (September - October) in the Amur River basin exceeded norm by 120-200%, locally by 250%, resulting in over-saturation of soils.

3. In 2013, there was a late and high spring flood.

4. In June and early to mid July, there was virtually no low-flow period; when the rains began, runoff losses were minimal.

Factors of the catastrophic 2013 flooding in the Amur River basin

(b) meteorological conditions of 2013



2013 precipitation amounts (mm, contours) and their ratio to the 1979-2012 norm (%,colour).
(a) May; (b) June; (c) July; (d) August

The analysis of macrosynoptic processes in the Far East region revealed their anomalous development in summer and autumn of 2013.

Due to the positive anomaly of sea surface temperature in the western equatorial Pacific Ocean, the strengthening of the subtropical anticyclone and its ridge occurred east of the Japanese archipelago. This resulted in anomalous advection of wet and warm sea tropical air to East Asia, which is subject to the East Asian monsoon.

On the other hand, the ridge development over Northern Europe and the trough development over East Siberia promoted anomalous lower-troposphere cold advection to Southeast Siberia and the Amur River basin.

The interaction of cold and warm air masses resulted in intensive development of upper-level frontal zone and related frontogenesis and cyclogenesis over the Amur River basin, which had predetermined the record 2013 summer rainfall .

In 2013, positive precipitation anomalies over the Amur River basin occurred during May to August; monthly precipitation amounts were more than twice the norm in some regions of the Amur River basin.

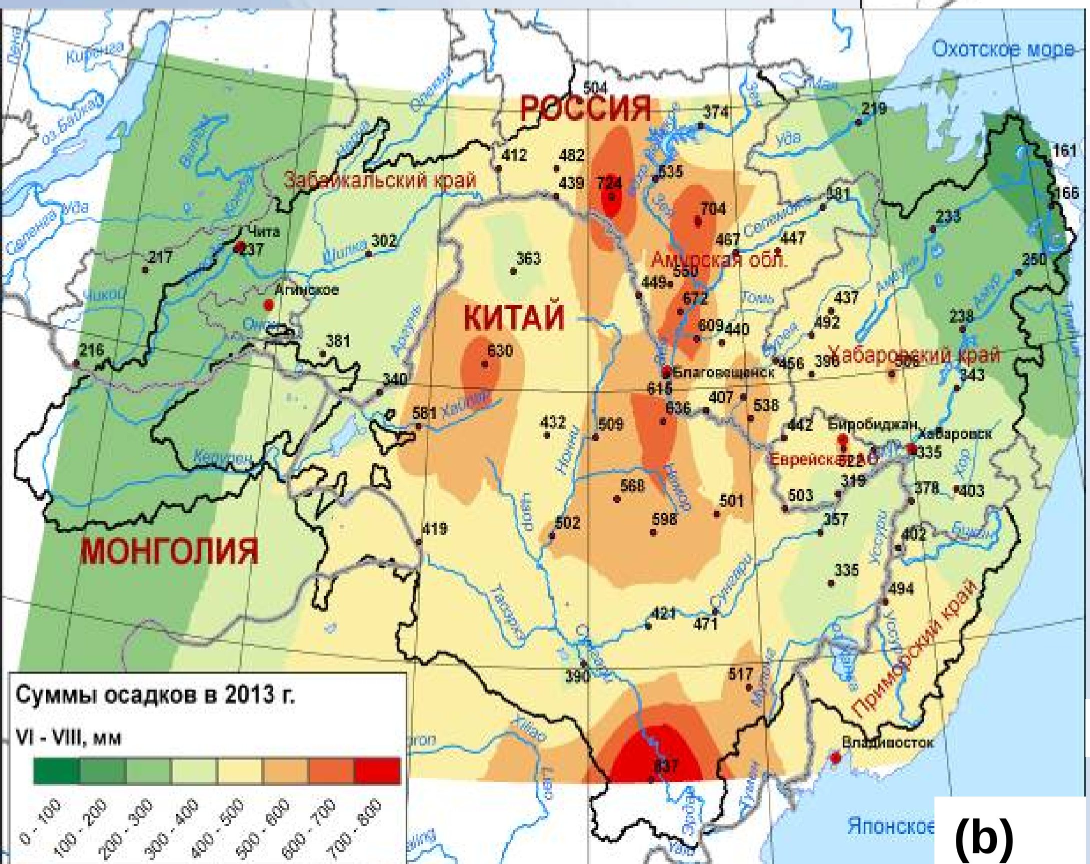
Especially heavy precipitation occurred in July (over 300 mm vs. 100–120 mm norm). In August, precipitation amount decreased to 150–180 mm and their maximum moved to the Songhua River basin (the Songhua River is a right tributary of the Amur River).

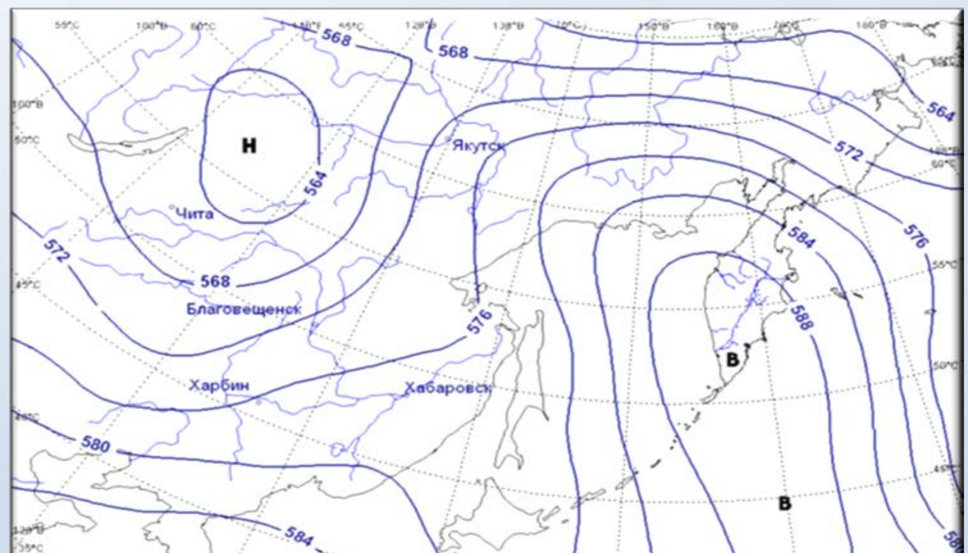
Total summer precipitation in the Amur River basin was more than 450 mm .

(b) meteorological conditions of 2013

Precipitation amounts of June-August 2013 in Russian and Chinese parts of the Amur River basin reached 700-800 mm; in the Russian part of the river basin, the norm was exceeded by 2-2.5 times

(a) Precipitation (% of normal) of July-August 2013 in the Amur River basin;
(b) Precipitation (mm) of July-August 2013 in the Amur River basin

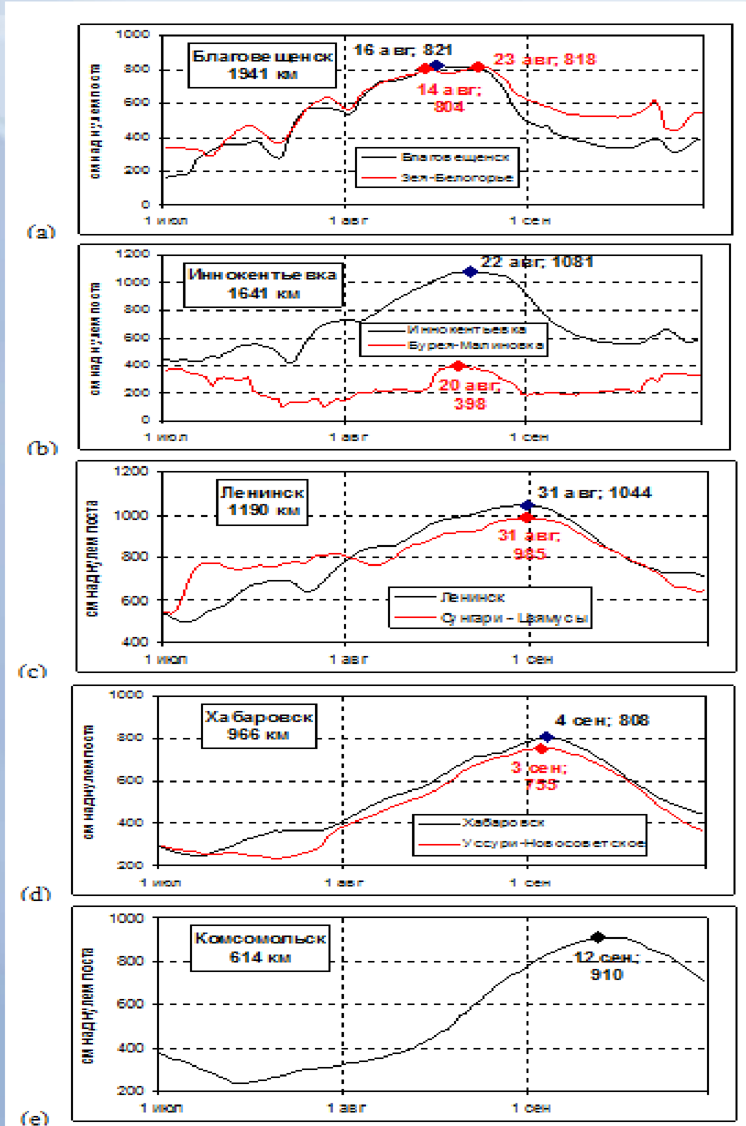




Pressure field at AT-500 GPa in July 2013

Factors of the catastrophic 2013 flooding in the Amur River basin

(c) superposition of flood wave peaks of main river and its tributaries



Propagation of flood wave on the Amur River (black lines) and its major tributaries (red lines) in 2013. The distance to the Amur River mouth (km) is given below the gauge name.

During the 2013 Amur River flooding, superposition of flood wave peaks of main river and its tributaries occurred, causing extremely high flood peaks.

As figures indicate, from 16 August to 12 September, the flood crest was moving downstream the Amur River; flood wave peaks of its major tributaries superposed the flood wave peak of the Amur River.

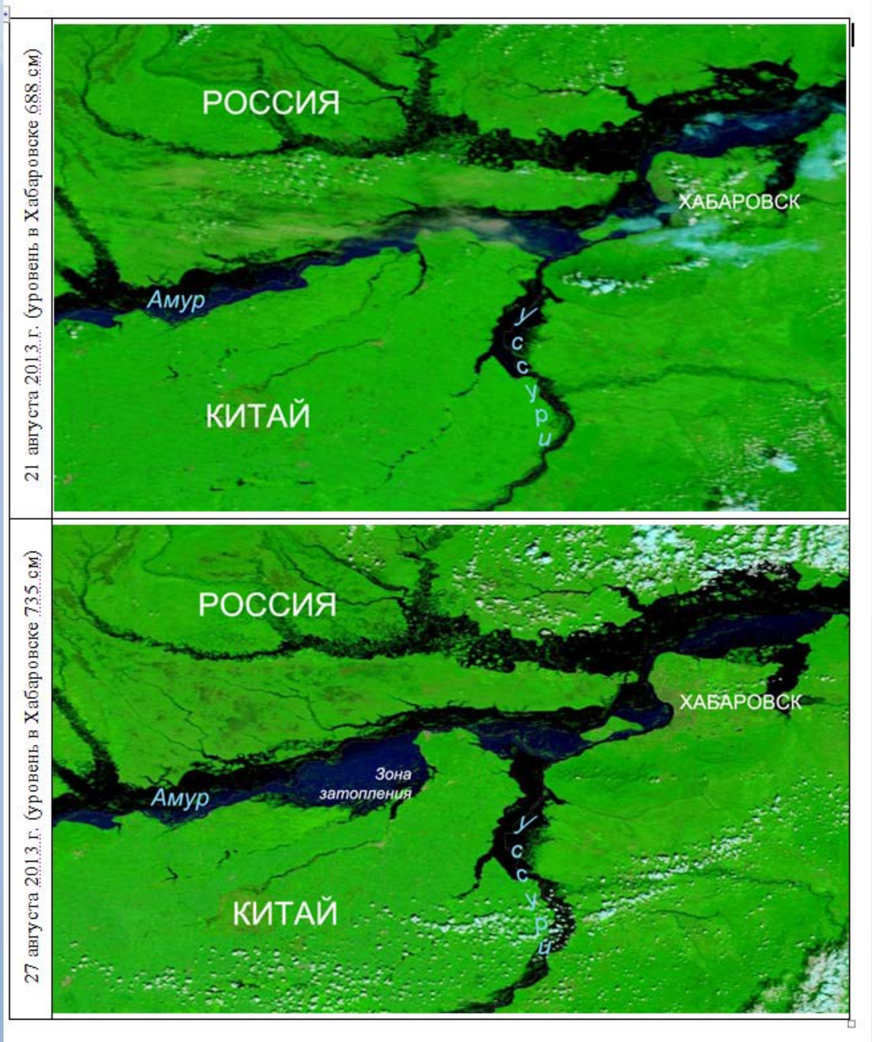
The flood on the Amur River near Blagoveshchensk (downstream from the Zeya River mouth) started on 5 July. The flood wave travelling down from upper Amur sections reached Blagoveshchensk on 16 August, combining with the Zeya River flood wave. As the result of flood wave superposition, the flood peak had increased twice.

The Amur River flood wave reached Khabarovsk on 4 September, combining with the flood wave travelling down the Ussuri River. Thus, the flood wave peaks from huge basin area reached Khabarovsk simultaneously, considering the travel time. Peak water level of 808 cm was registered at Khabarovsk on 4 September . It exceeded hazardous level by 2.08 m and the 1897 maximum level, by 1.66 m. On 5 September, peak water discharge of the Amur River at Khabarovsk at the level of 801 cm was 46000 m^3/s. Its frequency of occurrence was estimated as once in 200 years.

As the flood wave travelled down the Lower Amur reaches, it was still extremely high despite the transformation effect of floodplains. On 12 September, the flood peak reached Komsomolsk-on-Amur . Peak water level of 912 cm exceeded hazardous level by 2.62 m and the 1959 maximum level, by 2.11 m.

Factors of the catastrophic 2013 flooding in the Amur River basin

(d) changes in channel and floodplain capacity due to the construction of bank protection structures and protection dams



Flooding upstream of the Ussuri River mouth
after the breach of a flood control dam on 22 August 2013.
The right bank of the Amur River is Chinese territory.

In case of catastrophic flooding, there may be a threat of bank protection structures failure, first of all, flood control dam failure.

On the one hand, flood control dams protect floodplains from inundation; on the other hand, they reduce flood control capacity of floodplains, thus causing water level rise during floods.

Dam breaches and inundation of dam-protected lands may occur during major flood events, when flood stage exceeds design dam height. In this case, the damage is many times greater than possible damage prior the dam construction, because of intensive development of dam-protected lands.

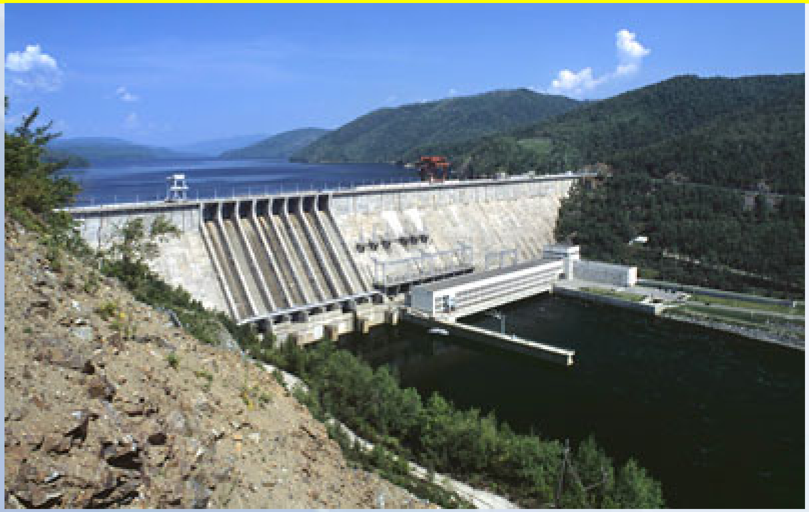
On 22 August 2013, a dam breach occurred in China on the Amur River upstream of the Ussuri River mouth (downstream of the river section shown in the figure).

According to Chinese data, 91 settlements were washed away during the flooding; 7 thousand farmers lost their homes. (These settlers came here 10 years ago to grow rice on dam-protected lands.)

The inundated area of 764 km^2 (according to Chinese data) can be identified from satellite images of 21 August (before the dam breach) and 27 August (after the dam breach).

Numerous breaches of flood control dams occurred on the Songhua River and its tributaries. No reservoir dam failures were registered.

The influence of the Zeya and Bureya reservoirs on the 2013 flooding



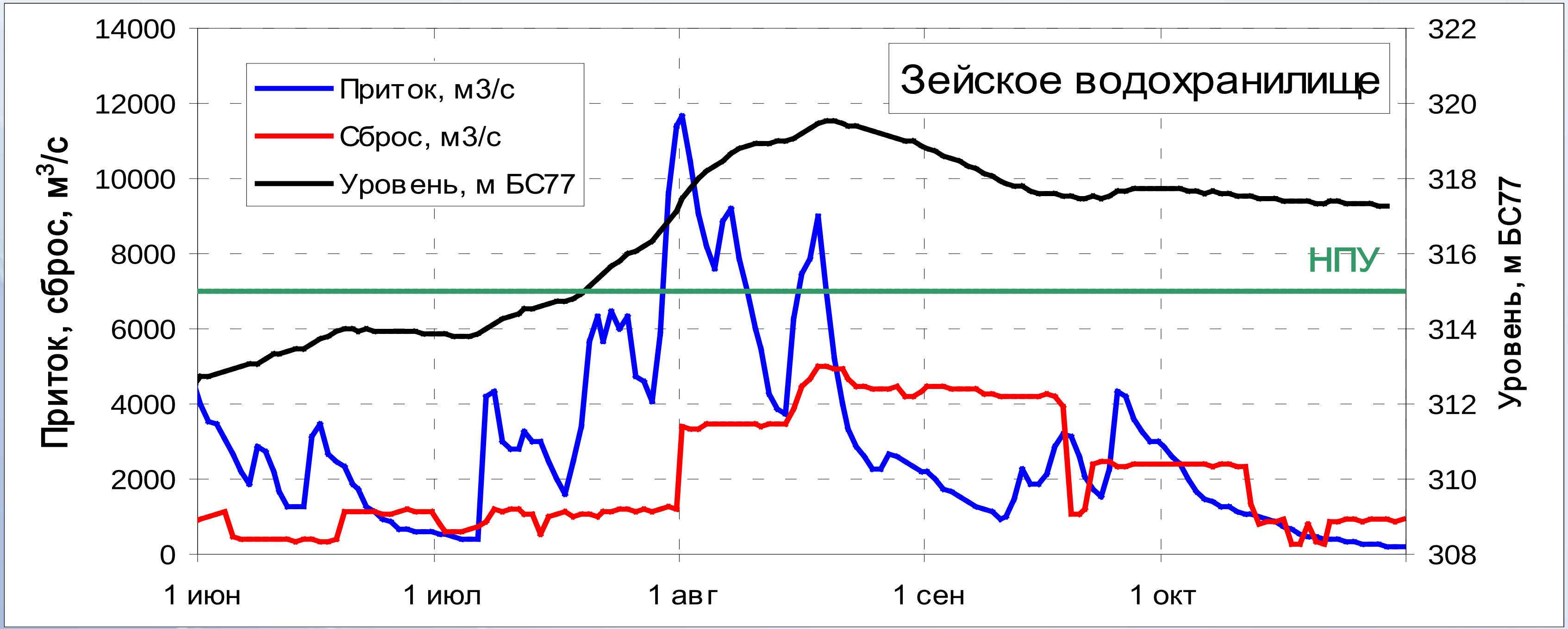
The Zeya and Bureya reservoirs, built on the main tributaries of the Amur River – Zeya and Bureya rivers, are operated for flood prevention and control.

The Zeya Reservoir has 2 419 surface km^2; its total storage is 68.42 km^3 and effective storage, 38.26 km^3.

At normal pool, *the Bureya Reservoir* has 750 surface km^2, at dead pool, 400 km^2; it is 234 km long and up to 5 km wide; total storage is 20.94 km^3; effective storage is 10.73 km^3.

Factors of the catastrophic 2013 flooding in the Amur River basin

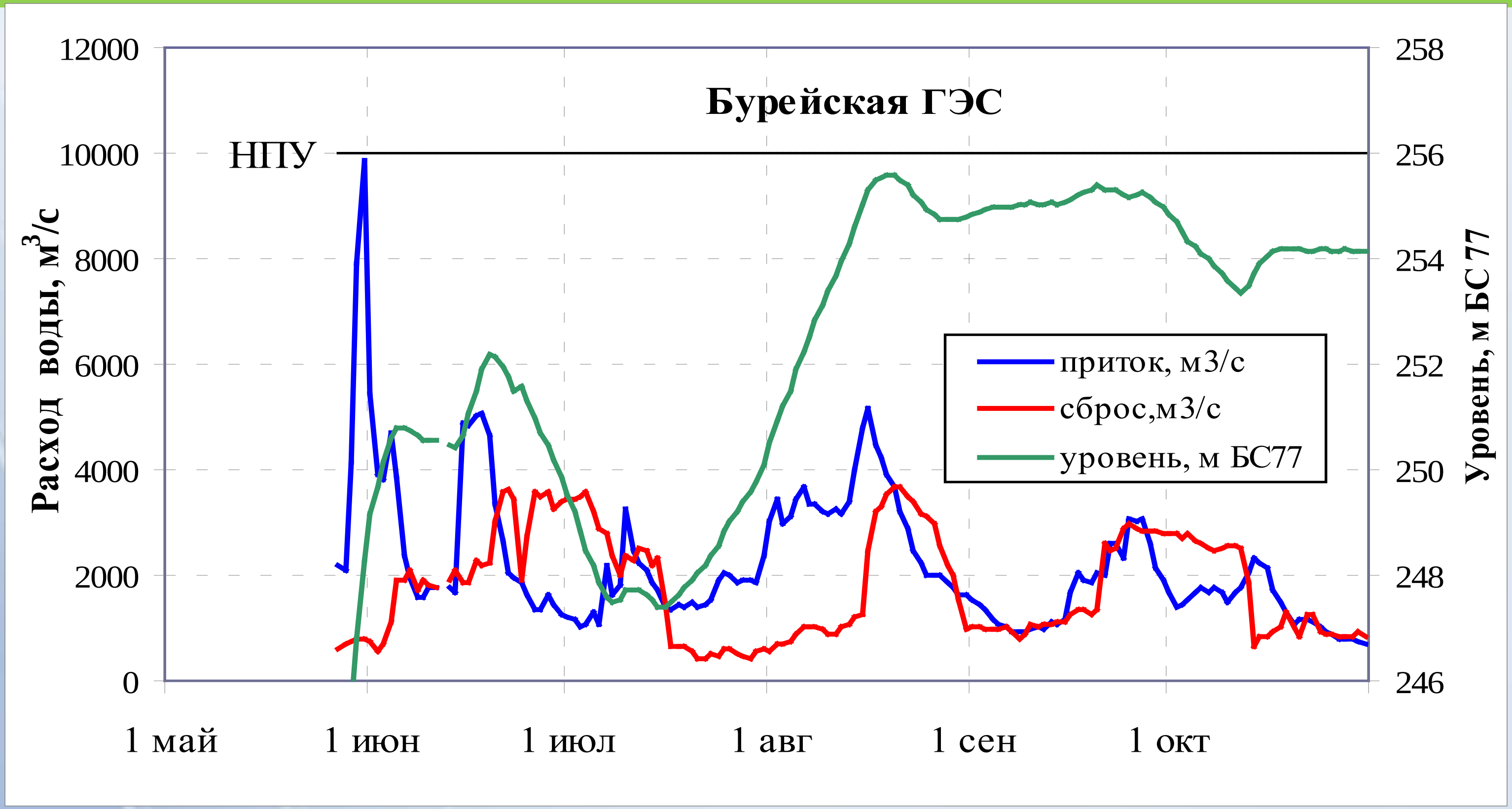
The influence of the Zeya Reservoir on the 2013 flooding



As the result of flow regulation, the Zeya River flood peak reduction below the Zeya Reservoir amounted from 20-30 cm to 1.5 m.

Factors of the catastrophic 2013 flooding in the Amur River basin

The influence of the Bureya Reservoir on the 2013 flooding



As the result of flow regulation, the Bureya River flood peak reduction below the Bureya Reservoir was about 50 cm.

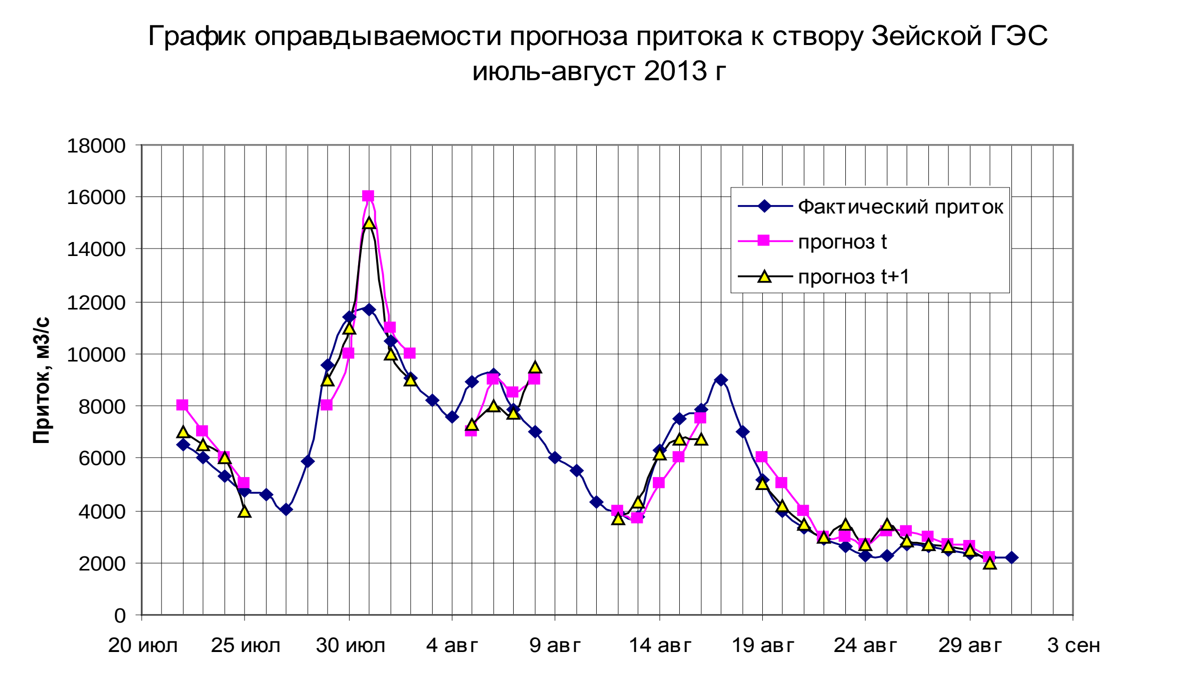
Roshydromet actions on monitoring and forecasting of hydrometeorological conditions during the 2013 flooding in the Amur River basin

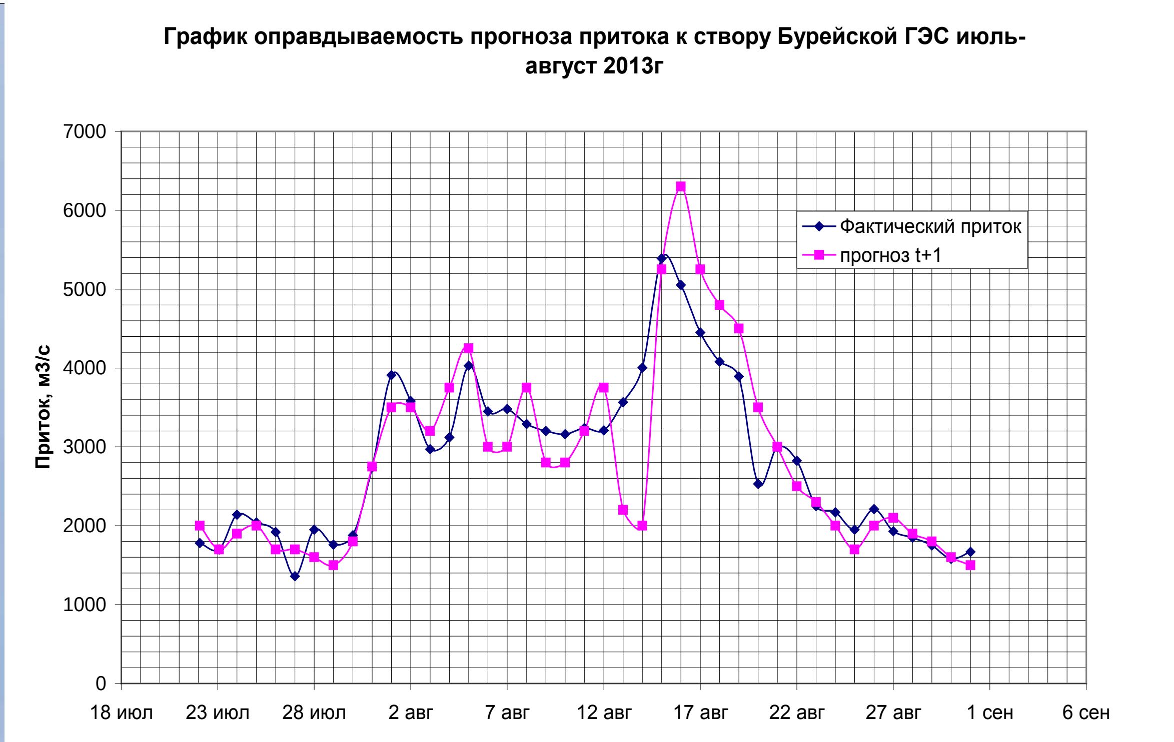
1.Since 2 July 2013 Roshydromet had started to issue forecasts of especially heavy rains; since 17 July 2013, of hydrological storm warnings on high floods on the Zeya River caused by heavy rains.

2.Since 2 August 2013, the levels of the Amur River and its tributaries had been forecasted to reach (and locally exceed) their historical maximum values. Forecast lead time was 7-10 days for Jewish Autonomous Oblast and 3-5 days for Amur Oblast.

3.During the 2013 flood, Roshydromet issued daily hydrometeorological bulletins to support flood protection activities. The bulletins provided information about actual hydrometeorological conditions and short-range hydrological forecasts of water level and reservoir inflow.

4.Since mid-July, the Zeya and Bureya reservoirs had begun rapidly filling . The water inflow to the Zeya Reservoir in July was near its maximum value for the whole observation period. Roshydromet issued short-range reservoir inflow forecasts for the Zeya and Bureya reservoirs with lead time of 1 to 3 days.





Actual (black line) and operational forecasts of water inflow into the reservoir in 2013 (pink points - lead-time of forecasts is1 day; yellow point - lead-time of forecasts is 2 day)

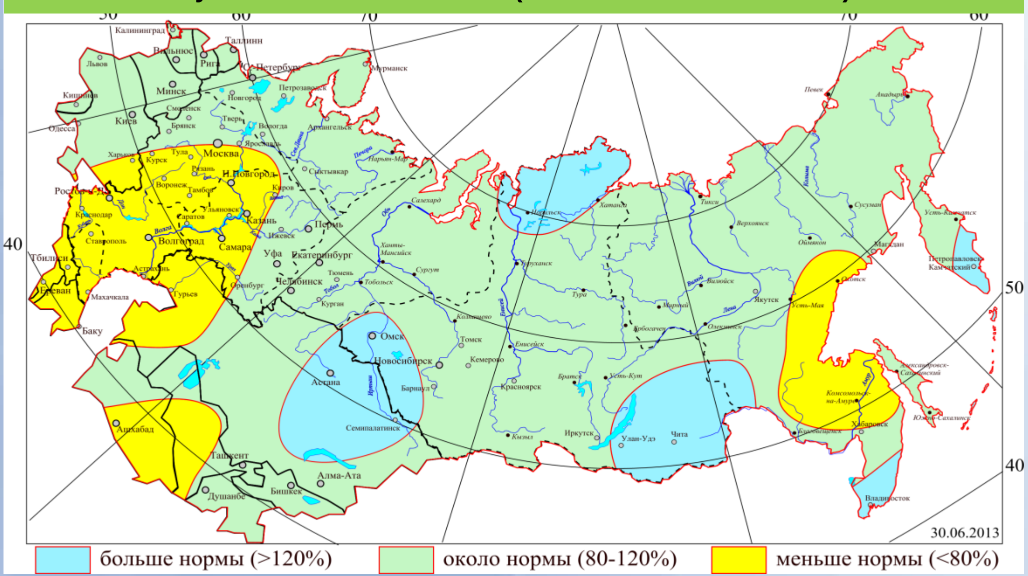
a) *Zeya* reservoir (pink points - lead-time of forecasts is1 day; yellow point - lead-time of forecasts is 2 day)

b) *Bureya* reservoir (pink points - lead-time of forecasts is1 day)

Roshydromet actions on monitoring and forecasting of hydrometeorological conditions during the 2013 flooding in the Amur River basin

1. The analysis of synoptic conditions had shown that stationary upper-level frontal zone had formed over the Amur River basin by early June 2013. Deep cyclones, saturated with tropical moisture, were moving along this zone. The abnormal position of upper-level frontal zone was caused by western air mass transfer blocking over the Pacific.
2. According to a long-term precipitation forecast over Russia issued in June 2013, the precipitation over the middle reaches of the Amur River and Southern Primorye could exceed norm by 120% in July.
3. The analysis of numerical precipitation forecasts of leading world weather centers for the summer 2013 had shown that small positive precipitation anomaly was forecasted only for northeastern China. Retrospective precipitation forecasts over this region, as well as over East Asia, showed poor skill. Therefore, long-term seasonal precipitation forecasts in Russia and worldwide are of low reliability, first of all, due to chaotic nature of atmospheric circulation. Low reliability of forecasts significantly hampers their use in operational practice.
4. Due to this fact, accurate deterministic forecasting of hydrological conditions over large time periods (month, season, and year) is hampered as well. Thus, the forecasts are represented in terms of their mean values for corresponding periods and their anomalies.

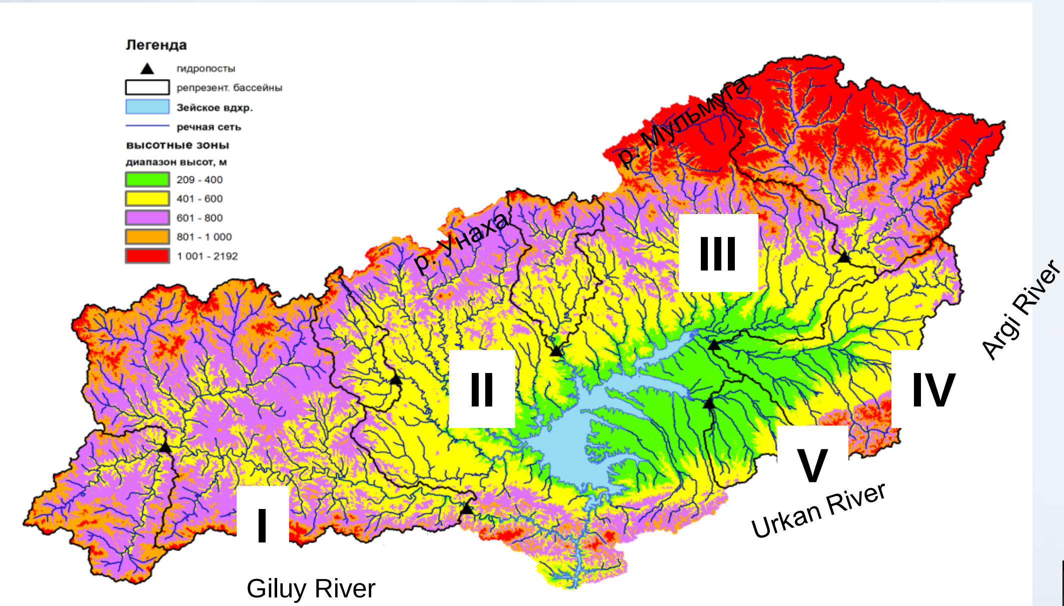
Long-term precipitation forecast for July 2013 (% of normal) of Hydrometcenter of Russia (date of issue – June 2012)



Actual precipitation of July 2013 (% of normal)

Conceptual model for daily inflow forecasting (Zeya reservoir)

Zoning Zeya River Basin under the terms of the runoff formation

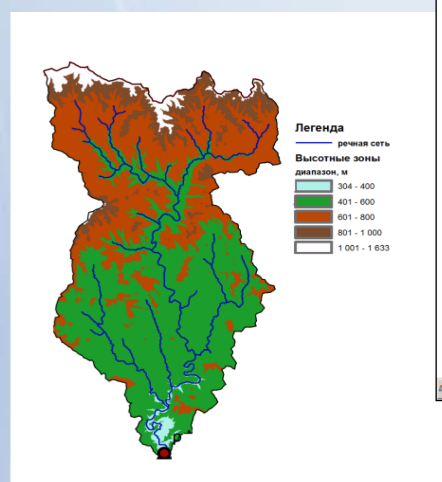


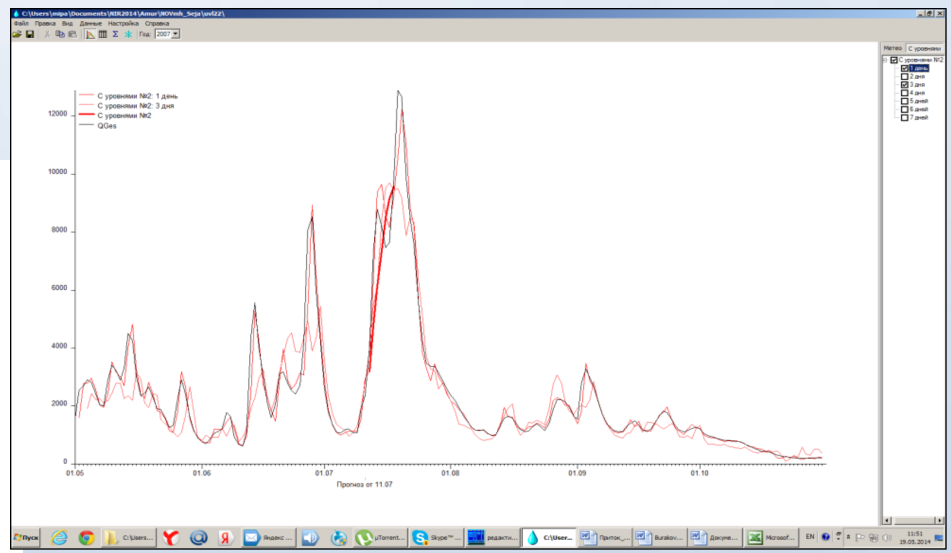
Areas and river-analogues to inflow calculate

Areas	*River-analogues*		*Ki*
I	Giluy River	*Qa1*	1,093
II	Unah River	*Qa2*	6,867
III	Mulmuga River	*Qa3*	5,616
IV	Argi River	*Qa4*	3,077
V	Urkan River	*Qa5*	4,116

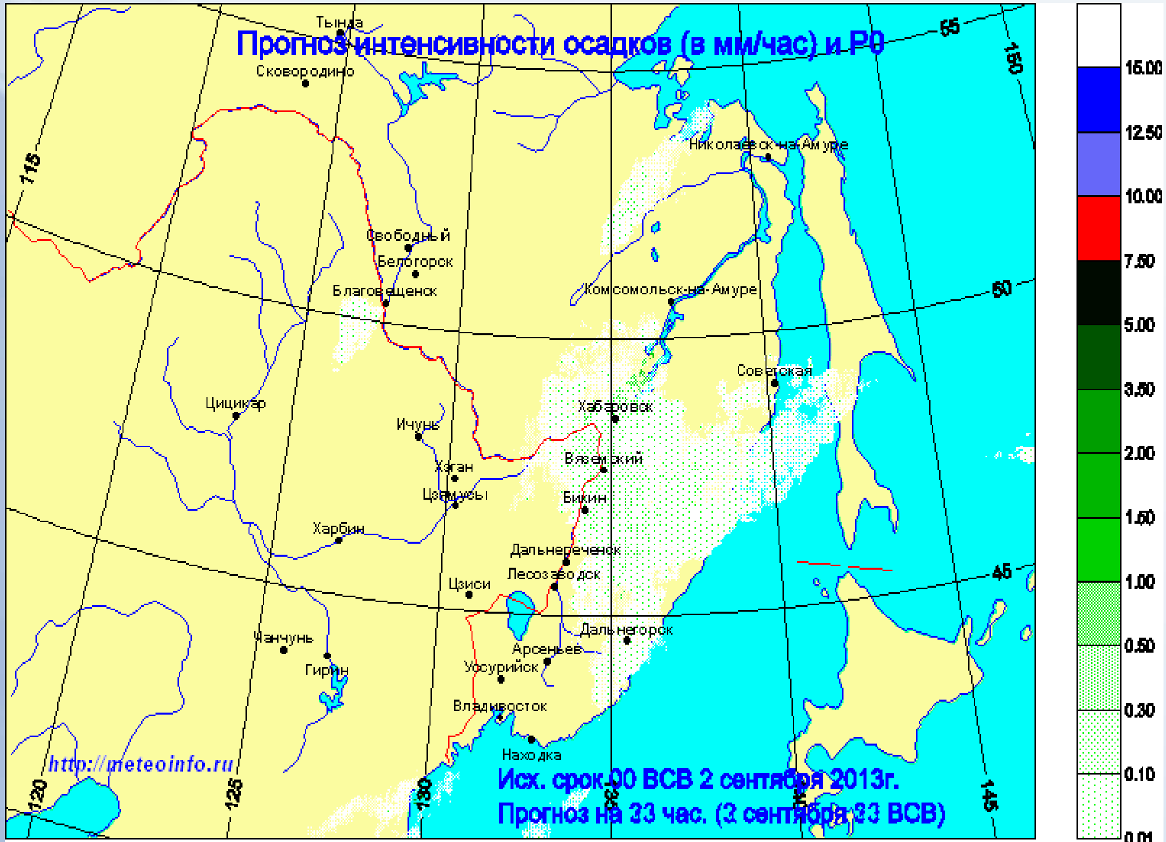
Structure of model

Calculation of snowmelt and area of snow cover
Calculation of water flow in channel network From snowmelt and precipitation
Calculation of dynamic water reserve on the slopes and the calculation of inflow in river channel
Calculation of moving water in the channel network





Forecast of lateral inflow to the Zeya Reservoir (floods 2013)



REGION precipitation rate forecast (mm/hour), lead time 36 hours (date of forecast issue: 2 September 2013, 00 UTC)

Quantitative precipitation forecasts were issued with lead time from 6 to 172 hours to provide information for forecasting of hydrological conditions in the Amur River basin.

The following meteorological models were used:

-COSMO-RU,
-REGION,
-Global spectral model of the Hydrometcenter of Russia

Characteristics of meteorological models used in forecasting floods in 2013

Meteorological model	Spatial resolution	Lead time
COSMO-RU	7 km	From 6 till 72h (step 12h)
REGION	20 km	From 6 till 48h (step 12h)
Global Spectral Model of The Hydrometeorological Centre of Russia	75 km	From 24 till 120h (step 24h)

Operative forecasts and warnings on expected hazardous water levels in the Amur River basin in 2013 (Lead times and skill of forecasts and warnings)

Accuracy of short-range and medium-range hydro-meteorological forecasts during the flood was 90-96%.

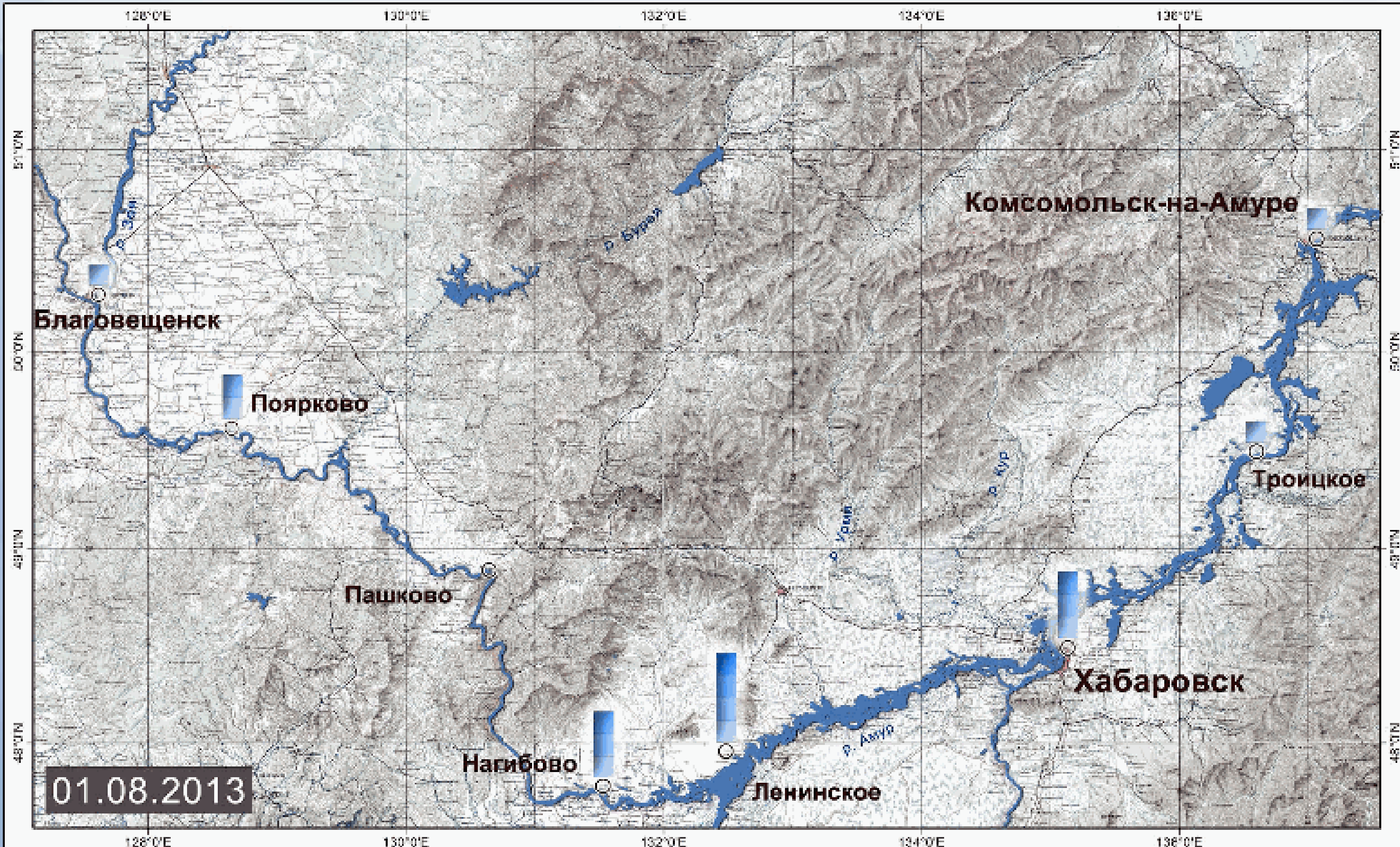
Lead time of hazard water mark accidence was: 2-5 days in the middle reach of the Amur River, and 7-10 days in the lower reach of the river.

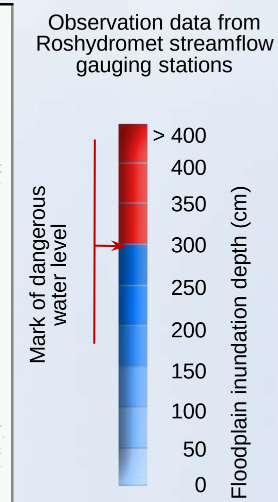
Forecast of the water level exceeds the historical maximum in the Amur River near Khabarovsk was issued with a lead time of 10 days.

Date of issur	Water level forecasts and warnings	Actual water levels (cm), date	Lead time in days
17 июля	Штормовое предупреждение о подъёме уровня с 19 июля в реках до опасных отметок		
02 августа	Штормовое предупреждение о подъёме 3-7 августа на участке Поляковский - г. Благовещенск уровня воды до опасных отметок близким к максималь-ным за весь период наблюдений (отметка ОЯ 800 см)	**717, 07 августа**	**5**
27 июля	Штормовое предупреждение о затоплении 2-4 августа поймы Амура		
01 августа	Штормовое предупреждение о подъеме 4-6 августа на р. Амур уровней воды выше опасных отметок (отметка ОЯ 800 см)	**841, 04 августа**	**3**
29 июля	Штормовое предупреждение о подъеме 5-7 августа уровня Амура у г. Хабаровска до отметок 500-550 см. Для территории левобережья опасной отметкой считается 530 см	**512, 07 августа**	**9**
5 августа	Штормовое предупреждение об ожидаемом 14-16 августа у г. Хабаровска уровне воды выше опасных отметок (отметка ОЯ 600 см)	**614, 16 августа**	**12**
8 августа	Штормовое предупреждение о подъеме16-18 августа уровня воды выше исторического максимума (642 см)	**649, 18 августа**	**11**
19 августа	Уточнение прогноза о достижении 24-28 августа уровня воды у г. Хабаровска 730-780 см	**743, 28 августа**	**7**
23 августа	Уточнение прогноза о достижении 2-3 сентября уровня воды у г. Хабаровска 780-830 см	**808, 3-4 сентября**	**10**
8 августа	Штормовое предупреждение о подъеме 22-24 августа уровня Амура у г. Комсомольск-на-Амуре до отметок 620-680 см	**602, 22 августа** **643, 24 августа**	**15**
13 августа	Штормовое предупреждение о подъеме 25-28 августа уровня Амура у г. Комсомольск-на-Амуре до отметок 680-720 см	**602, 25 августа** **671, 28 августа**	**13**
14 августа	Штормовое предупреждение о подъеме 27-31 августа уровня Амура у г. Комсомольск-на-Амуре до отметок 680-720 см	**706, 27 августа** **722, 28 августа**	**14**
23 августа	Штормовое предупреждение о подъеме 30 августа - 3 сентября уровня Амура у г. Комсомольск-на-Амуре до отметок 720-770 см	**752, 3 сентября**	**7**
27 августа	Штормовое предупреждение о подъеме 5-8 сентября уровня Амура у г. Комсомольск-на-Амуре до отметок 800-850 см	**859, 6 сентября**	**10**
2 сентября	Штормовое предупреждение о подъеме 11-15 сентября уровня Амура у г. Комсомольск-на-Амуре до отметок 930-980 см	**912, 12 сентября**	**10**

Roshydromet actions on monitoring and forecasting of hydrometeorological conditions during the 2013 flooding in the Amur River basin

Catastrophic flooding in the Amur River basin
(Satellite monitoring of floodplain inundation: August-October 2013)





State Research Center "Planeta" and its Far Eastern branch provided relevant and timely information on the flooding extent. High-resolution satellite images (resolution up to 10-50 m) allowed to correctly identify flood inundation areas.

(from Meteor-M №1, Canopus-B, Landsat-8, TERRA, and AQUA satellites)

Effects of the catastrophic 2013 flooding in the Amur River basin

According to the EMERCOM of Russia, the consequences of the 2013 flooding in the Amur River basin were as follows:

-over 200 settlements with population of about 80 thousand people
-and about 600 thousand hectares of agricultural land were flooded,
-about 1500 km of roads and about 1000 km of power transmission lines were damaged.

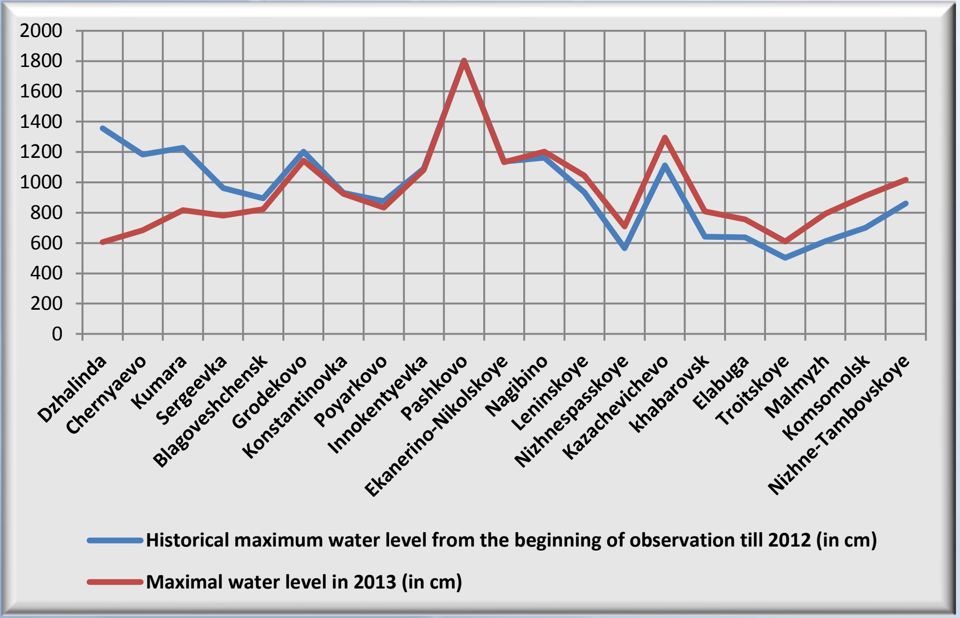
Large cities (Khabarovsk and Komsomolsk-on-Amur) suffered major flooding.

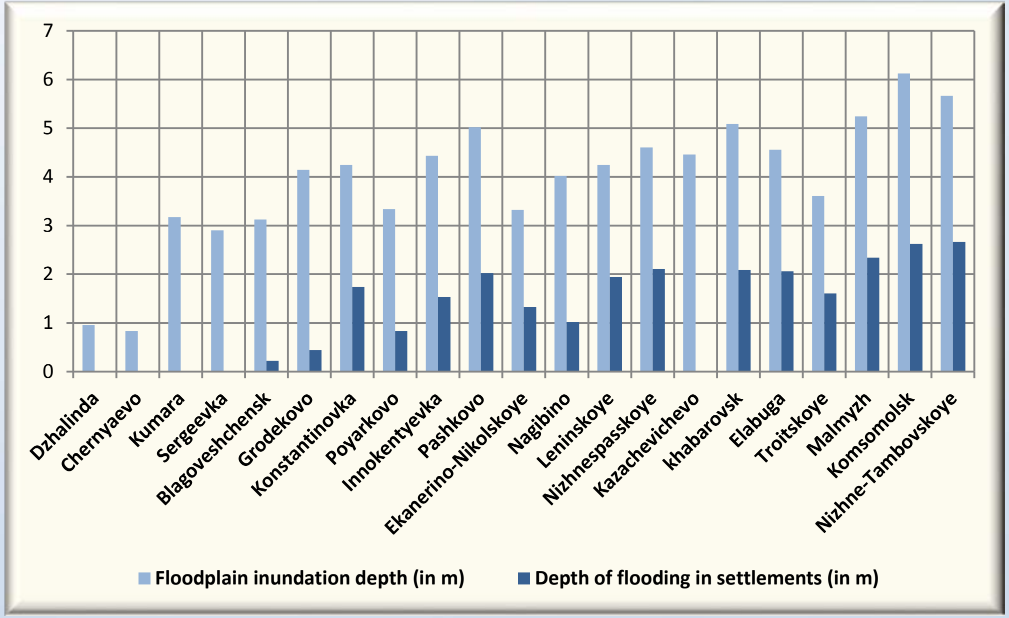
Thousands of houses were flooded; many of them are in no repair.

Tens of thousands of people were evacuated; many of them lost their homes and property.

Fortunately, there was no loss of life during the 2013 flooding in Russia.

Unfortunately, loss of life was reported in China.





Roshydromet actions on monitoring and forecasting of hydrometeorological conditions during the 2013 flooding in the Amur River basin

During the July-October 2013 flooding in the Amur River basin, an interdepartmental government commission was organized to support effective activities on minimization of negative flood impacts and ensuring life safety.
Wide range of specialists contributed to the Government Commission actions, from emergency officers and local authorities to water managers, hydropower specialists, and specialists in hydrometeorology.

Contribution of Roshydromet:
-**providing comprehensive and timely hydrometeorological monitoring data,**
- **forecasts of hydrometeorological conditions for the flood area.**

Timely issue of Roshydromet forecasts and storm warnings allowed federal authorities to take timely actions on population alert and evacuation, on vital and vulnerable infrastructure protection.

Roshydromet forecasts also allowed Federal Water Resources Agency to provide optimal scheduling of releases of the Zeya and Bureya reservoirs to control the water inflow to the middle reaches of the Amur River.

Extreme floods in the Amur River basin: causes, forecasts, and recommendations

After the normalization of flood situation in the Amur River basin the joint meeting of Roshydromet Council for Science and Technology, Russian Academy of Sciences Council for Science and Technology for Earth's Climate Theory Research, and Federal Water Resources Agency Council for Science and Technology was held at Roshydromet on 20 January 2014. During the meeting, a discussion was held on the theme "Extreme floods in the Amur River basin: causes, forecasts, and recommendations". As the result of discussion, recommendations were made for governmental bodies, Russian Academy of Sciences and large hydropower plant owners:

1. Carry out complex theoretical, field, and laboratory research to define channel capacity and conditions for floodplain inundation in the Amur River basin, particularly at the settlements.

2. Carry out detailed research of formation of extreme meteorological parameters, including extreme characteristics of atmospheric blocking events, Rossby waves, and circulation indices, causing extreme precipitation in East Asia.

3. Improve the methods of probabilistic long-term hydrometeorological forecasting (lead time: from a month to a season), forecasting of extreme hydrometeorological events and forecasting of characteristics with high degree of uncertainty.

4. Support the development of physical-mathematical hydrological models and methods for forecasting hazardous flooding in the Amur River basin and other Russian regions of high flood risk and their adaptation to operational Roshydromet observation network.

5. Support the development and implementation of geoinformation systems and technologies using high-resolution digital topography maps for visualization of actual and forecast hydrological information and operational decision making.

6. Carry out complex global and regional climate model based research on theoretical and empirical predictability of extreme Amur River floods and assessment of future changes in extreme flood statistics due to global and regional climate changes.

7. Within the frameworks of preparing the Second Roshydromet Assessment Report on climate changes in Russia, analyze the impact of climate warming on water resources and extreme hydrological events in the Amur River basin in the 21st century.

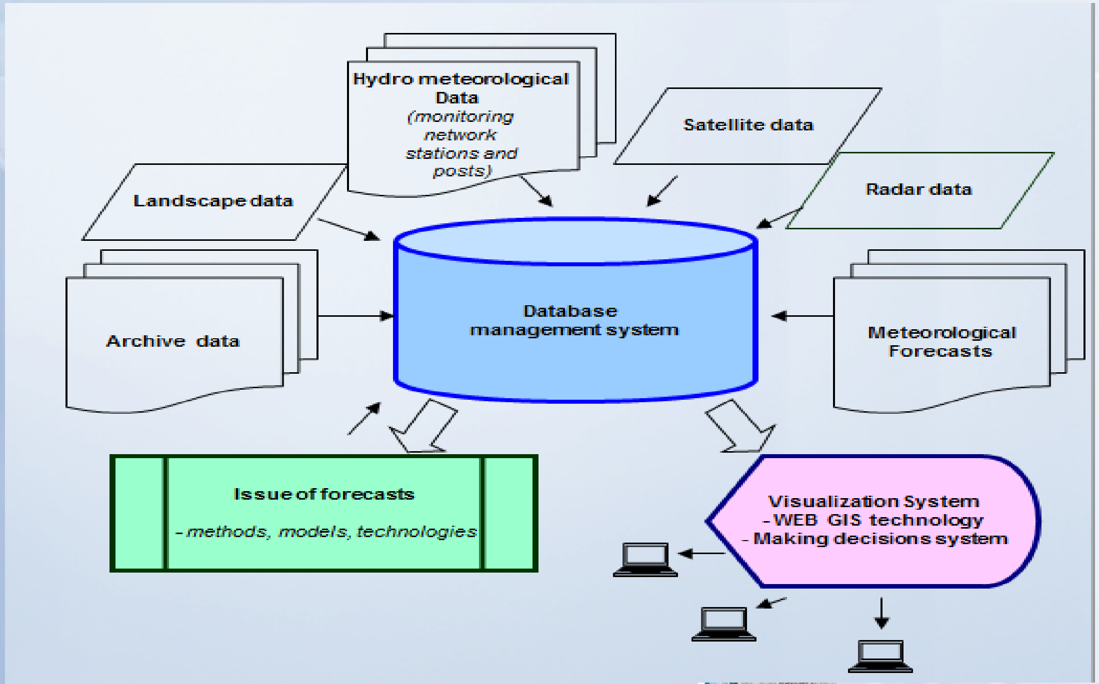
8. Develop complex approaches for interpreting global and regional climate model outputs (spatially detailed simulations, ensemble simulations, use of model systems which include global, regional and hydrologic models, climate risk assessment, etc.). Particular attention should be paid to the use of probabilistic climate simulation results in practical application.

9. Develop complex technical projects of recovery, modernization and development of hydrological observation network for the Zeya, Bureya, and Ussuri rivers and for the whole Amur River basin.

10. Provide hydrometeorological assessment of projects and activities ensuring the safety of land and hydraulic structures.

11. Provide urgent development of normative acts for flood risk mapping, for safe and rational use of flood-prone areas, for creating flood insurance system for flood-prone regions.

Floods Early Warning System in the Amur River basin
(http://hydro.meteoinfo.ru/amur)

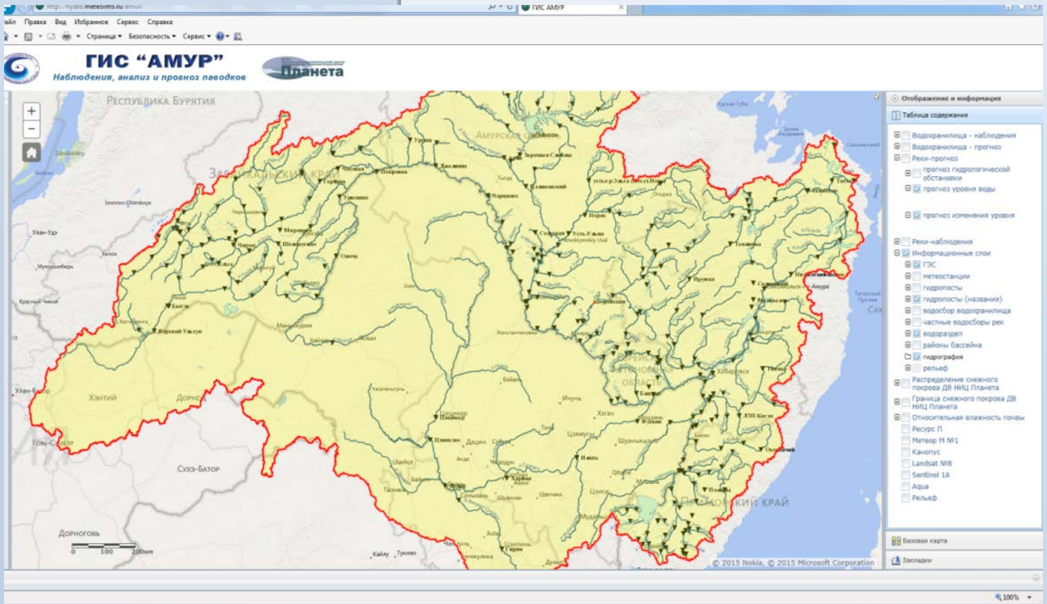


The forecasting system structure

After the flood in 2013 the automated system of hydrological monitoring and floods early warning in the basin of the Amur River was created.

The system is based on the use of web and GIS technologies.

Hydrological forecasting based on the joint operation of hydrological and meteorological models.



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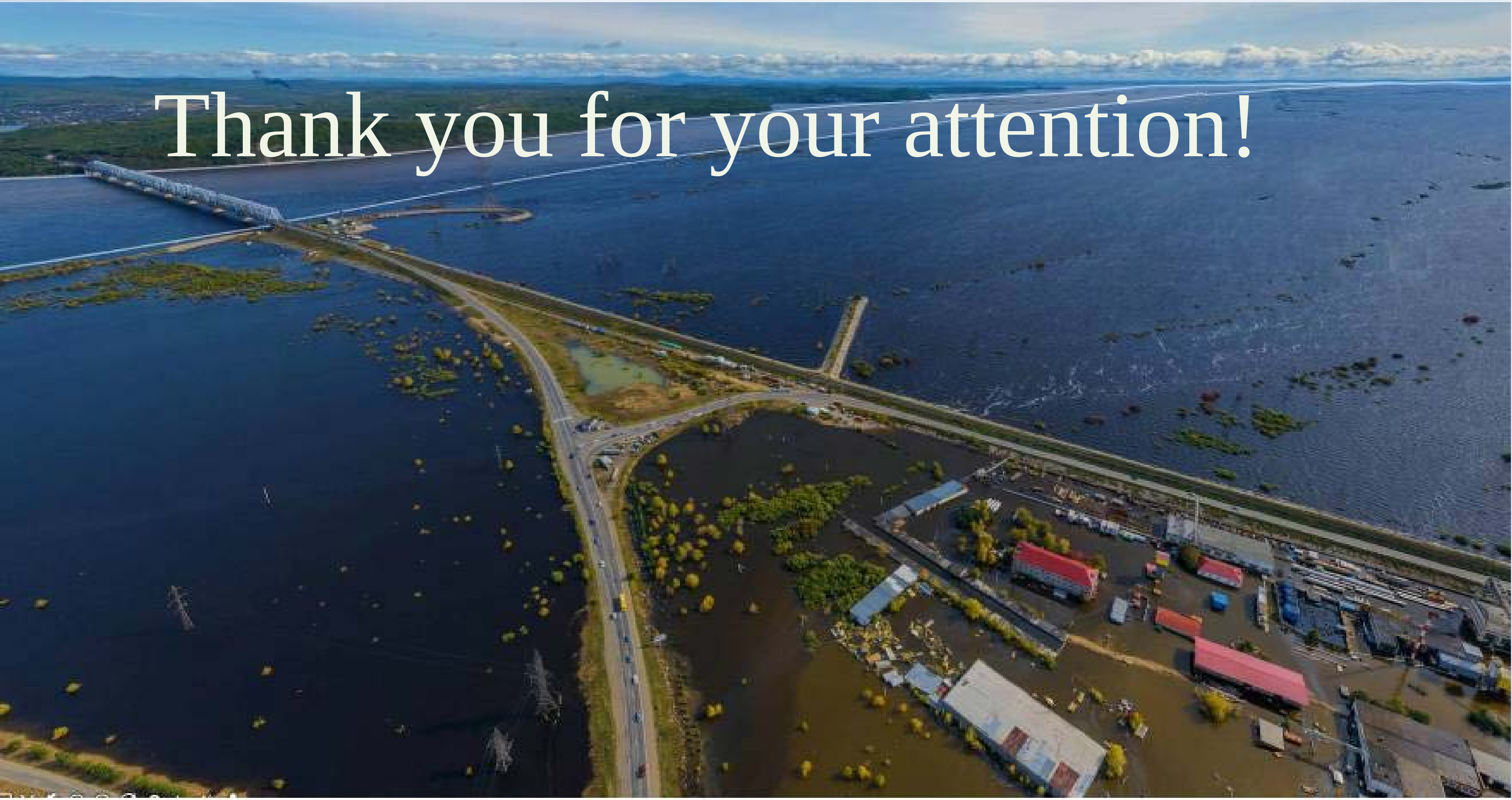

Floods Early Warning System in the Amur River basin
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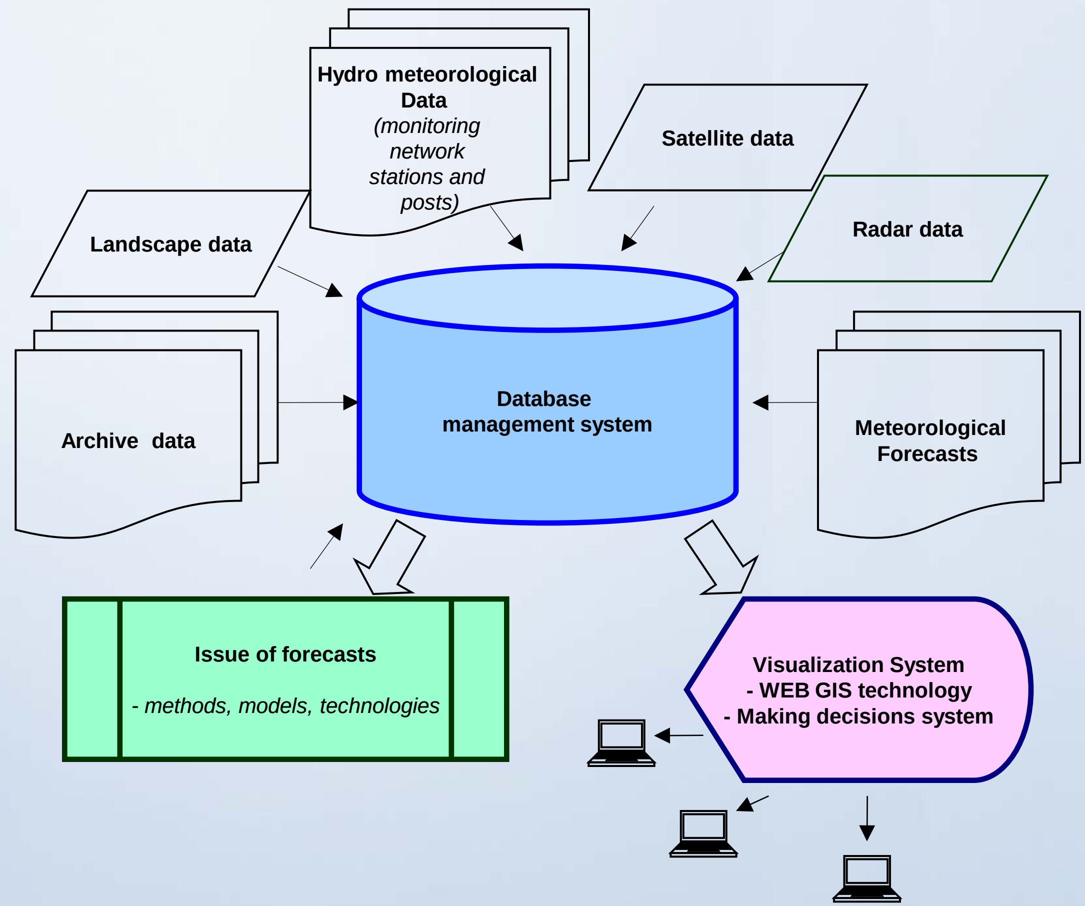
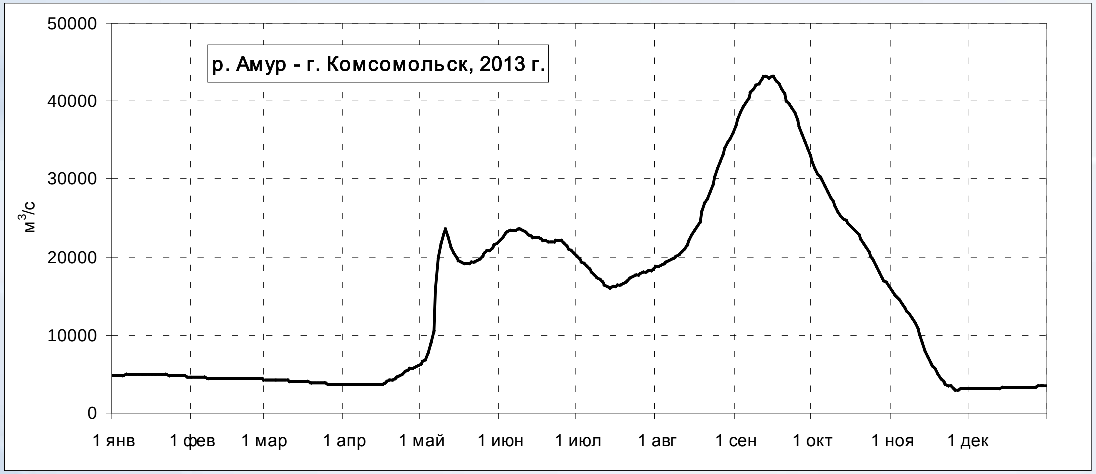
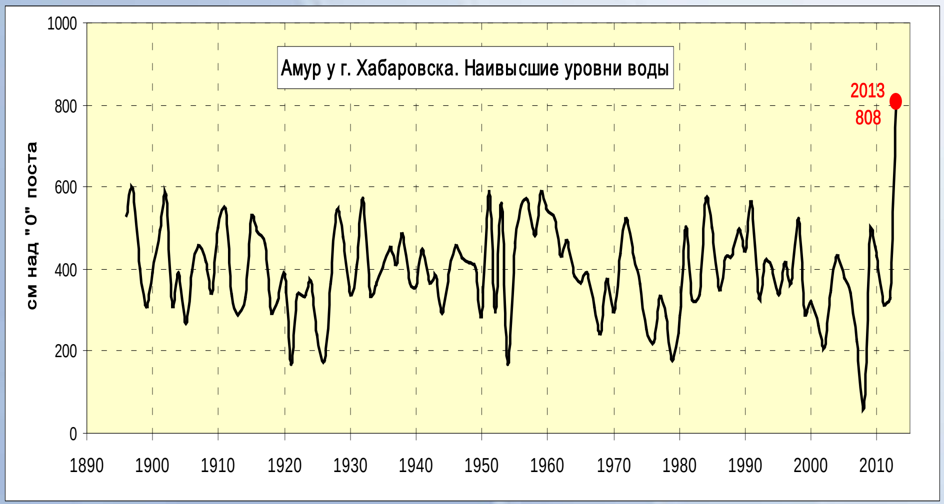
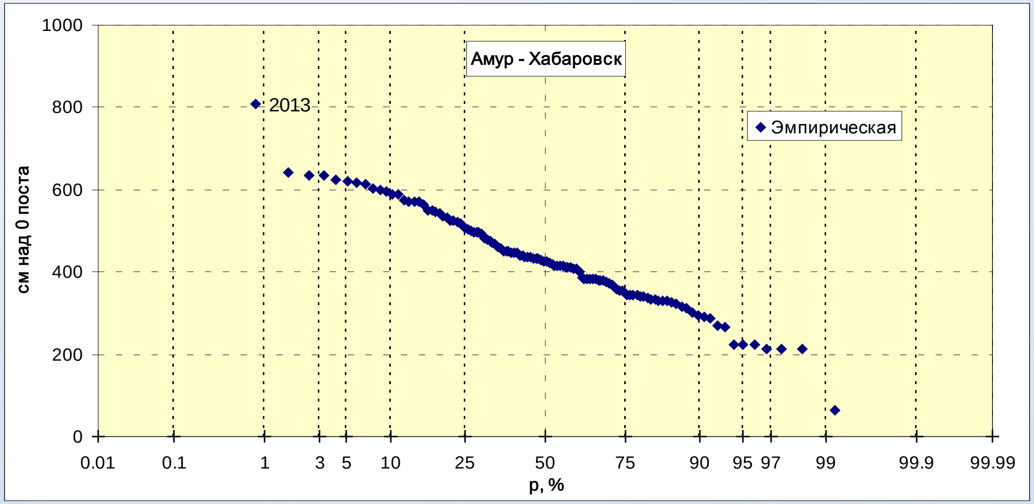
The forecasting system structure



Гидрограф стока Амура у г. Комсомольск-на-Амуре в 2013 г.







Многолетняя динамика (а) и эмпирическая кривая обеспеченности (б) наивысших уровней воды Амура у Хабаровска