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Development of a Technological Chain for a Background Streamflow Forecasting System in Russia

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***Abstract*—The hydrological forecasting methods that have been used for many years in Russia require precision input data, which are difficult to obtain. Until now, none of forecasting systems, developed by Russian hydrologists, has been officially implemented in practice. In the face of an increasing number of catastrophic and destructive hydrometeorological hazards, the development of a modern automated system for operational flash floods forecasting is highly relevant in Russia. In this paper, a new technological chain for background streamflow forecasting is presented. The authors have attempted to create such a chain under the conditions of the country's poor hydrometeorological network and difficulties in obtaining data and their assimilation. The chain presents a joined logistic scheme, which was developed based on analytical elaboration of scientific works of key Russian hydrologists. The paper also includes the analysis of the most efficient use of the hydrometeorological data available through the national observation network. This seems to be assimilation of satellite and radar data, in situ observations, numerical weather prediction models and catchment models outputs.**

Keywords—data assimilation, hydrological forecasting, radar and satellite data, surface observation network.

I. Introduction

In the Russian Federation, there are about 2.6 million streams, the vast majority of which are not studied hydrologically and are called "ungaged". About one third of the country's population lives in such catchments. Therefore, timely hydrological forecasting of hydrological hazards will always remain an important practical task for the entire hydrometeorological science of the country. In last few years, there were many destructive flash floods in the Far East and Krasnodar krai: the number of such phenomena has increased. To prevent negative consequences, it is necessary to have a modern forecasting operating system that enables making minimum lead time forecasts. Such a system can be developed based on background forecasts, since they do not require high accuracy and much input data. So far, there has not been an effective system for background streamflow forecasting, uniting all links of the forecasting process in a joined chain at all stages of the process, from data obtaining to presenting forecast production to the public and stakeholders.

The first block of the technological chain is the system for receiving and assimilation of observed hydrometeorological data. The surface observation network in our country, operated by the Ministry of Natural Resources and Ecology of the RF (Roshydromet), has a number of specific features. Let us focus on several important aspects in the context of operational streamflow forecasting.

First of all, the surface hydrometeorological observation network is characterised relatively low spatio-temporal resolution. There are only 2644 hydrological stations and 1915 meteorological observation points in Russia. Their characteristics are presented in Table I [1].

Table I. Characteristics Of The Hydrometeorological Observation Network In Russia [1]

Hydrological network	Meteorological network
2644 stations, 708 of them are equipped with Automatic Hydrological Complex (AHC) (27%) and 160 (6%) have automatic discharge indicators.	1915 observation points, 1808 of them are equipped with Automatic Meteorological Complex (AMC) (94%).
Only 340 of the stations are working in operational regime (high time resolution data).	316 observation points with data time resolution of 10-minutes.
216 (8%) stations are equipped with snow and rain gauges.	52% of meteorological data is transmitted immediately.
Advanced offices are in the North-Western, Irkutsk and Central branches of Roshydromet.	Advanced offices are in Bashkortostan, Tatarstan and Primorsky branches of Roshydromet.
One operational hydrometeorological station for 9440 km^2: the observational network density is three times lower than recommended by the World Meteorological Organization (WMO).	
Spatial heterogeneity: the observation network density in European Russia is quite good, but it is insufficient in the Asian part.	

Low spatio-temporal data resolution, insufficient equipment quality and staff qualification affect forecasting. For this research, these issues play an important role, limiting application of some techniques for assimilation data and forecasting models calibration and validation, which could be used in the case of a denser and better equipped observation network [2].

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Since 2012, the network has been under modernization, and some progress was made that can enhance forecasting. For example, modern operational development centers and software for them were established (AIS Duty Officer and Programming Complex ARM of Hydrologist [3]), which are included in the final chain.

Radar data is quite limited in the Asian part of Russia but it is easier available in the European part (Fig. 1). There are only 33 remote-sensing instruments in the country: 10 of them are in the Asian part and seven more are at the border with Belarus and the Ukraine. Seventeen radars are working with low time resolution (more than two hours) [4]. In general, the use of radar data allows enhancing the spatio-temporal discreteness of precipitation observations, what makes it possible to predict the development of floods based on distributed conceptual hydrological models.

Satellite data can serve as a good basis for floods forecasting, especially in poorly gauged areas. To forecast flood occurrence, data on the moisture content in the upper soil layer (2-5 cm from the surface) is in high demand, since it is required to correct the initial conditions while runoff modeling.

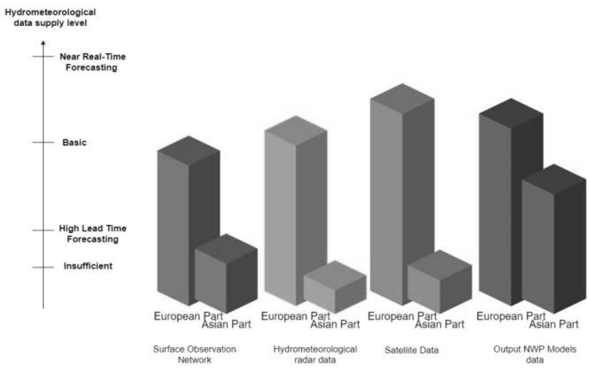

Fig. 1. Comparison of hydrometeorological data supply in the European and Asian parts of Russia (designed with [10]).

Besides, various snow cover characteristics are needed when predicting the development of spring floods of snowmelt genesis and mixed genesis floods.

For 2019, not a single meteorological satellite remains out of eight satellites that previously existed in Russia. In some areas, mostly in the European part of the country, it is possible to obtain data from foreign satellites. Other options are to use small low-orbit or general-purpose satellites as carriers of hydrometeorological sensors.

There is some progress in the development of the space data collection and transmission system (DATS), designed to "ensure the transfer of alphanumeric information from the estimate documentation of the Roshydromet network to the data collection and processing centre (Moscow) in real time" [5]. At the same time, nature-resource satellite financing has definitely decreased in recent years.

Using data from mesoscale weather patterns allows increasing the lead time of background streamflow forecasts up to 3-5 days. In the Hydrometeorological Centre of Russia, the Weather Research and Forecasting Model (WRF model) has been adapted for these purposes. It should be noted that the volume of information transmitted by such models is extremely high. For this reason, Global Ring Network for Advanced Application Development (GLORIAD) technology was developed – a global high-speed network infrastructure designed for telecommunication support of advanced scientific projects [6]. It is also used for international data exchange.

Summarizing, in Russia satellite data and mesoscale weather models outputs are considered to be the most suitable for streamflow forecasting. Other data sources require enhancing.

The sequence of the main technological steps, from obtaining data to receiving a forecast, is presented in Fig. 2. The system enables permanent forecasting: in background (qualitative) mode until there is no potential danger. As soon as flood risk appears, the system allows more accurate forecasting.

The next block of the technological chain is a technology for different genesis background streamflow forecasting. In this case, first of all, the type of flow, the available data set, and the lead time of the forecast matter.

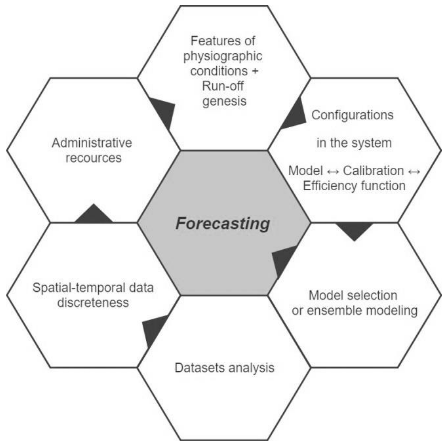

Fig. 2. Visualization of technological steps of streamflow forecasting (designed with [10]).

Considering the issues of applying the entire technological chain for particular genesis streamflow forecasting, the authors have come to the following conclusions, which seem to be actual for hydrological practices in the country:

1. Hydrologiska Byråns Vattenbalansavdelning Light (HBV Light) model is often used by key experts in hydrological forecasts and can be used in the technological chain in the case of rainfall floods genesis. The input data for models calibration usually include precipitation, runoff and soil moisture, which could be obtained from two main sources, described above [7].
2. Machine learning algorithms for model calibration are gaining popularity now (IHE Delft Institute for Water Education projects). Methods of machine learning are being introduced, so this is already present hydrometeorological forecasting.

3. Getting reliable forecasts is crucial, but it is also necessary to transfer them to clients for competent use as soon as possible. An automatic forecasting system is perfect for this task. This system involves a consistent prediction, at the beginning of the background streamflow forecasting, and then, in the case of potential danger, the specified.
4. Best results of the system operation are achieved by selecting for each specific catchment its own set of optimal configuration, including a suitable model, calibration method and objective function.

This configuration is selected for each catchment separately, depending on its size, physical and geographical conditions, climate, type of feeding and other features.

5. For Russia, using Multi-layer conceptual model 3 (MLCM3) and HBV Light is convenient because these models require input data that can be obtained from radars and satellites, but not from the surface observation network, which rarely provide operational data.
6. Additional parameters in the flood forecasting when refining forecasts can be added (for example, snowmelt characteristics), but this will increase the timing of the forecast and impose requirements on the source of these additional parameters. This is quite feasible for each specific user, if one needs it.

Connections between data-obtaining and forecasting procedures should be provided by the operational forecasting centres (and corresponding software) in the near real-time mode and data transfer and processing should be done based on top GIS technologies.

Management decisions must be made in accordance with the Predefined Decision system [8], in close cooperation with the country's special services (The Ministry of the Russian Federation for Civil Defence, Emergencies and Elimination of Consequences of Natural Disasters.). Risks should be compensated in the framework of a well-designed flood risk insurance system (analogue of The National Flood Insurance Program).

The technological chain includes three types of forecasts visualization: a discharge hydrograph with marked danger zones (probabilistic forecasting), flood zones visualization, dynamic interactive maps of the prognostic situation (nowcasting). All of them are possible to realize using abilities of [3].

The final version of the technological chain is presented in Fig. 3. The given technological chain is considered to be highly relevant in the conditions of growing climatic risks, an increase in the number of extreme hydrometeorological phenomena, including destructive floods [9], as well as the absence of an effective system of background forecasting of runoff in the country at the moment. This chain is an integral reflection of the experience gained in the country and also includes suitable internationally applyied approaches.

Such analytical surveys are designed to reduce the negative impact of high floods, including flash floods, for which this scheme provides mechanisms for possibile minimizing the forecast lead time.

It is worth noting, the existing restrictions on the implementation of this chain are: low spatial and temporal discreteness of data, insufficience of ground-based observation network for calibration and validation of models, poorly developed hardware and administrative complex and limited state funding provided to Roshydromet.

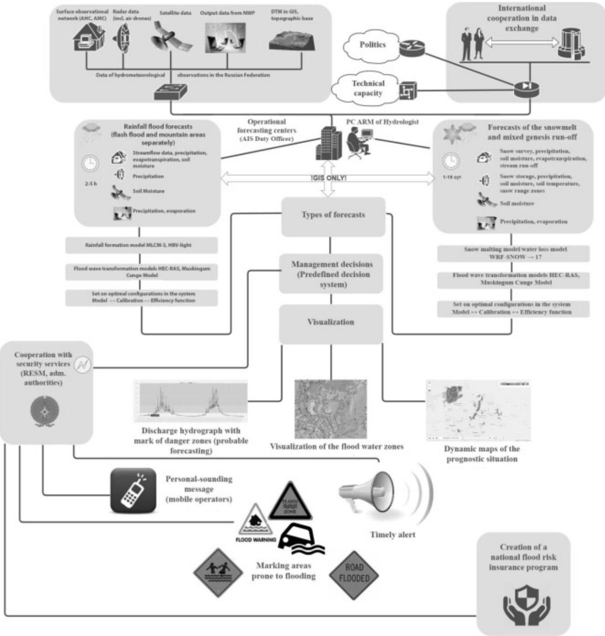

Fig. 3. Technological chain for a background streamflow forecasting system in Russia (designed with [10]).

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