ISSN 0005-1179 (print), ISSN 1608-3032 (online), Automation and Remote Control, 2024, Vol. 85, No. 3, pp. 305–313.

TOPICAL ISSUE

On the Use of Digital Twin Data in Models Related to Considering the Environment Impact on Enterprises

E. D. Viazilov[*,a], D. A. Melnikov[*,b], and O. A. Minkov[,c]**

[*] *All-Russian Research Institute of Hydrometeorological Information — World Data Center, Obninsk, Russia*
[**] *Obninsk Institute of Atomic Energy — department of the National Research Nuclear University "MEPhI", Obninsk, Russia*
e-mail: [a] vjaz@meteo.ru, [b] melnikov@meteo.ru, [c] oaminkov@gmail.com

Received July 8, 2023
Revised September 23, 2023
Accepted January 20, 2024

Abstract—Digital twins reflect the state of the environment and the activities of enterprises affected by the hydrometeorological conditions. It is proposed to use models to calculate indicators for assessing impacts of natural hazards or of climate change; of forecasts of these impacts; damage estimates; of calculating the cost of actions to protect enterprises; of assessing the feasibility of carrying out preventive actions in order to optimize them. Requirements for impact assessment models working with a digital twin are given. The difficulties in using such models are presented. Proposals for the development of impact models are being considered. A diagram of the use of digital twins in modeling impacts of environmental on enterprises is shown.

Keywords: digital twin, impact assessment models, environment, natural hazards

DOI: 10.31857/S0005117924030064

1. INTRODUCTION

Global climate change problems are growing, business conditions are becoming difficult due to the increasing complexity of enterprises themselves and the growing dependence on hydrometeorological conditions (HMC). Information about the state of the environment is used by enterprise heads to solve business-process that depend on HMC. With the huge volume of hydrometeorological data, it is difficult for heads to understand which categories of observed, forecast or climate data should be used in business processes. Along with hydrometeorological data [1], some models use economic, financial, technical, social and other information about the enterprise. Impact prediction models rely on integrated data from different domains. Existing integration systems assimilate data that data providers make available for public use. This results in fragmented data delivery.

And the automation of the use of hydrometeorological data has reached such a level that immediately after measuring the parameter values about the state of the hydrometeorological conditions, complex indicators of the weather condition are obtained – comfort, severity, level of danger and others. In construction, building codes and regulations [2], manuals like [3] are used, which reflect empirical models that allow one to calculate snow and ice loads on the roofs of houses or determine the engineering protection of the territory from flooding. Simple software tools have been developed for the economic assessment of industry adaptation to climate change [4].

Digital twins (DTs) are being developed, including in the field of the environment [1, 5, 6]. DT is a new type of database that provides data in a standardized structure for identifying natural hazards, "modeling and forecasting the impact of natural hazards" [7], assessing damage and the cost of preventive actions, optimization and decision-making [1, 8]. Based on the DT, it becomes possible to model operating conditions and predict the state of enterprises and business processes when exposed to natural hazards. The potential of a DT lies in the ability to deliver data to models that are necessary to solve specific business tasks. The purpose of the study is to determine the preliminary composition of models for impact assessment of natural hazards on enterprises, which are used to improve the efficiency of hydrometeorological support for enterprises using DT objects.

2. SCHEME FOR USING DIGITAL TWINS IN MODELING

The areas of use of DT in the field of accounting for HMC are [6]:

1) Modeling the development of new industrial areas. When developing new industrial areas, building, constructing and operating enterprises, DT will make it possible to evaluate scenarios for the location of enterprises, taking into account climatic conditions, transport capabilities and economic benefits. This allows selecting a scenario for the development of industrial areas, taking into account environmental, hydrometeorological and transporting safety.

2) The location of enterprises within an industrial area and planning the delivery of raw materials and supplies between them. By using DT in models logistics operations that allow increasing the speed of delivery of materials and raw materials, optimizing the business processes of the enterprise (for example, increasing the safety of delivery of equipment and materials).

3) Analytics and optimization of solutions. Based on the DT obtains advanced analytics, and decisions are optimized by identifying anomalies, exceeding threshold values, calculating trends and other indicators of the state of the enterprise to issue a forecast of impacts and recommendations.

4) Management of risks. DT is used to take into account the level of danger of situations associated with the influence of HMC, for example, on the operation of transport, transported goods, loading and unloading operations.

A diagram of the use of DTs in modeling the effects of natural hazards is presented in Fig. 1. DT is considered here as a digital representation of the properties of the environment and related data to social, economic, and technological situations developing in enterprises. These data need to integrate. To integrate data, Roshydromet uses the Unified State System of Information on the Conditions in the World Ocean (ESIMO) [9]. Information resources in this system are stored in a unified form and are intended for use in self-service mode on the portal at http://esimo.ru. Data

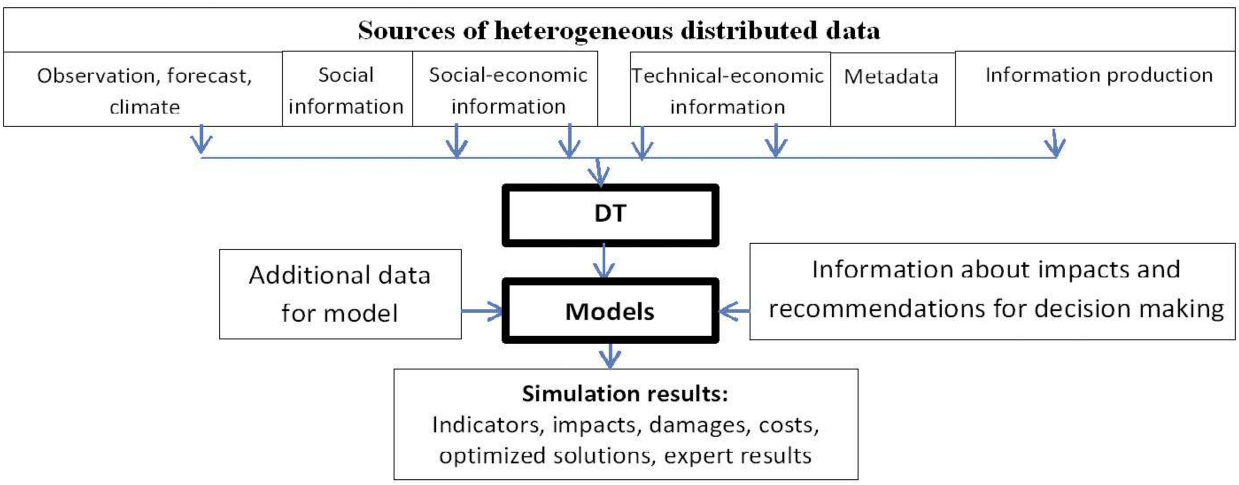

Fig. 1. Scheme for using CD in modeling.

that is not integrated into ESIMO is delivered to the DT using REST-services. DT reflects both data on the environment and other areas and is used in modeling environmental impacts.

In complex models, for example, in the computational complex for modeling oil spills included in ESIMO, the model works on a remote server and integrated data is regularly prepared and delivered to this server [9, 10]. The user, knowing the location, time of the spill and the volume of spilled oil, runs the model. The simulation results are transferred to the portal and are visualized there as an animation of the oil spill on the map. The user analyzes where the spill is heading and when it will reach the coast.

DTs are used for identification of natural hazards for specific enterprises based on local threshold values of indicators of the state of the HMC; of obtaining data in the composition, that needed by the enterprise; of using not only data on the state of the environment, but also "forecasting the possible impacts of natural hazards on the activities of an enterprise, assessing damage, calculating the cost of preventive actions" [5]; of modeling the impact of natural hazards on business processes of enterprises; for raising awareness among heads about HMC, for the impact assessment of natural hazards on enterprises and possible damage.

With the help of DT impacts of natural hazards is analyzed and simulated on a digital model of the object – roof destruction, accidents, product damage, etc. occur. Modeling of the effects of natural hazards on enterprises, carried out using DT, allows one to see new dangerous places or insufficient wind resistance of an object on a digital model.

Ways, methods and means for engineering research in the field of hydrometeorology, including models for calculating indicators of HMC, assessing the level of danger of natural hazards and modeling impacts on enterprise activities, are reflected in the manual [3]. Next, it will briefly consider models that use data from the DT.

3. DESCRIPTION OF MODELS

3.1. Weather Forecast Models

Weather forecast models air temperature, humidity, wind, atmospheric pressure with different spatiotemporal resolution scales are used in Russia and other countries [11, 12]. These models, based on observational data, using classical equations of atmospheric dynamics and thermodynamics, interpolate parameter values into nodes of a regular grid. The results of these models represent DT elements for servicing consumers, identifying dangerous conditions and forecasting the impacts of these phenomena on the population and enterprises. The resulting fields of distribution of observed, calculated and prognostic parameters are used to forecast hydrological, marine and other phenomena, and the transport of pollutants. For example, a forecast of the direction and height of waves or currents is calculated based on the wind. The spreading volcanic ashes after an eruptions volcano calculate on the based on weather forecasts [13, 14].

Today, consumers use information products derived from analysis and forecasting models. Information products include maps of the spatial distribution of individual parameters; tables with numerical data; graphs; descriptions of existing HMC, prepared on the basis of observed data. You can get acquainted in detail with information products in the form of visualization results of analysis and forecasts on the website of the Hydrometeorological Center of Russia (https://meteoinfo.ru/).

3.2. Calculation of Indicators for Assessing the Impacts of Natural Hazards

For some phenomena, instead of exceeding threshold values in the observed data, it is better to use complex indicators – severity and comfort of weather, of fire danger, characteristics of the resistance of enterprises to external influences of moisture, frost, drought, wind, waves heights. These indicators are calculated with using of observed and predicted parameter values based on

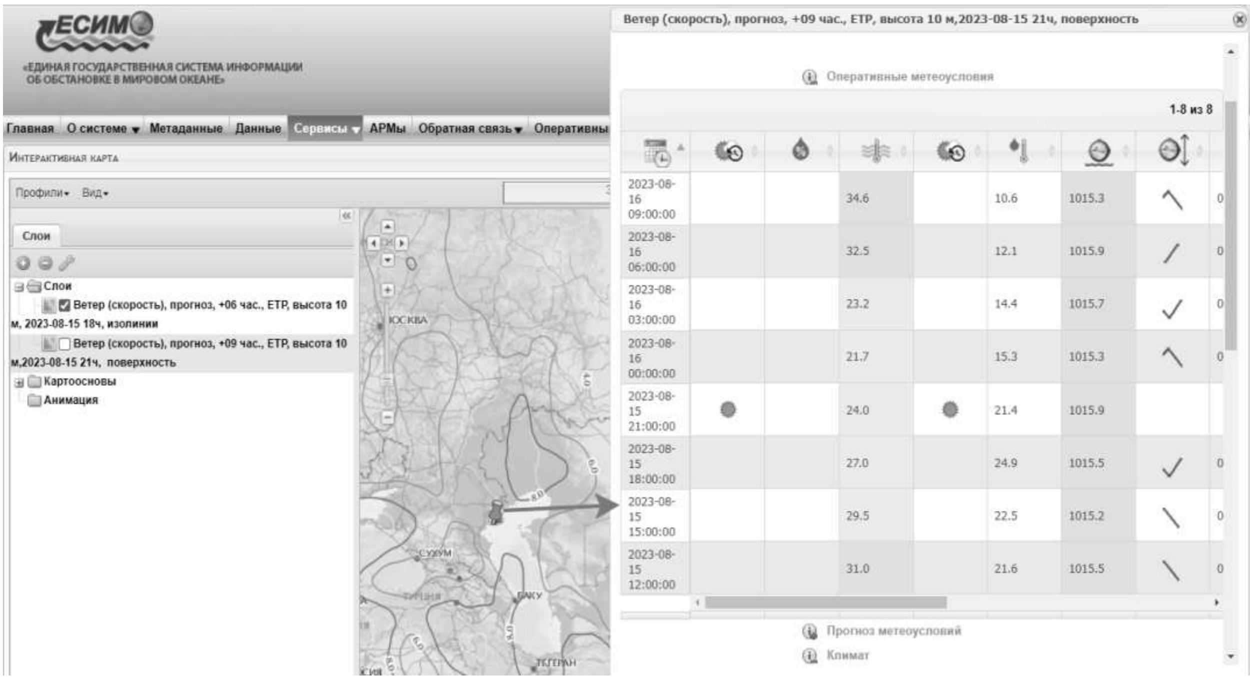

Fig. 2. Results of assessing the danger level for a point on the map.

physical or empirical models. The results of assessing the danger level of individual indicators and providing observed, forecast and climate data in one interface for a selected point on the map are presented in Fig. 2. Research on calculating indicators for climate and comfort of weather is presented at the conference [15, 16].

3.3. Forecast of Impact Intensity

Models for assessing the impact of environmental conditions on enterprises are individual and are developed to order, for example, during the construction of hydraulic structures, which are protective structures against floods, mudflows, etc. Such models are also used in the design of large enterprises and allow assessing possible impacts taking into account the characteristics of these objects.

Empirical models are based on the relationship between quantitative values of climate change indicators and the results of specific economic processes. When calculating the height of the breakwater, the rule is need used – the higher the level of the World Ocean rises, the higher the height of the breakwater. A compromise must be found between the cost of constructing the dam and the total annual cost of breakwater repairs. Many models are associated with predicting grain yields; with delivery of goods to the retail chain, taking into account changes in the population's needs for goods depending on the weather [17, 18]. Some examples of models given below:

— optimization of the location of enterprises and transport routes so that they are not covered with snow, taking into account the wind rose and the characteristics of the terrain;

— selection of parameters of ice protection structures for objects on the shore;

— optimization of cargo storage processes in the port depending on the storage conditions of cargo exposed to humidity, low or high temperatures;

— increasing the efficiency of public utilities – optimizing heating taking into account the outside air temperature, wind rose, and other characteristics.

3.4. Assessment of Possible Damage

A tanker accident leads to an environmental hazard. The list of damages caused by an oil spill and the costs of eliminating the consequences includes [19]: the cost of operations to clean water and coastlines from oil; insurance payments for damage. Damage occurs from decreased fish catches; from cargo loss with oil from the owner of the cargo; from beach pollution, biota death.

The Russian EMERCOM uses next calculation models [20]:

— of assessment of possible destruction, number of dead and injured during earthquakes;

— of rising water using a digital terrain model to calculate the duration of evacuation;

— of ground fire spread zones using wind direction and speed, humidity;

— of time for cooling the premises to sub-zero values indoors, depending on the air temperature.

The program "Calculation of the probable number of dead and rescued victims with injuries in maritime disaster" allows based on information on the number of passengers on the ship, the start time of the rescue operation, sea water temperature, distance from the shore calculate the number of deaths and victims in the disaster [21].

Material damage associated with natural hazards includes losses from enterprise downtime; the cost of lost products, repairs of damaged equipment and mechanisms; renovation of buildings. Damage for ships passing through difficult ice conditions is considered in the following options.

1) Icebreaker assistance – damage is associated with late delivery of cargo, with the cost of escorting the vessel with an icebreaker.

2) Waiting for favorable ice conditions – damage is determined by vessel downtime.

3) Passage of a vessel in difficult ice conditions without an icebreaker, possible options are the death or accident of the vessel. In the event of the loss of a ship, the loss includes the cost of the ship, cargo and ship property; damage to human health, including their possible death; payments for moral damage. In case of an accident, damages include loss of profit during the accident and repairs; cost of repairs; towing a damaged vessel, reward for rescue; fine, penalty, non-payment of freight due to late delivery of cargo.

3.5. Calculation of the Cost of Preventive Actions

"To make a decision, in addition to possible damage, it is necessary to know the cost of preventive actions" [22]. Before natural hazards, cargo that is afraid of moisture is covered, valuable cargo is evacuated to a safe place, etc. Most calculations of the cost of preventive actions consist of [23] employees' wages involved in preventive actions, the cost of rented equipment, additional equipment to enhance security of actions, advance construction of protective structures, consumables; of costs for evacuating people, etc. [7]. Non-recurring costs are incurred once for a specific enterprise, for example, the construction of a dam to prevent flooding, or a breakwater to prevent the passage of waves into the bay where the port is located. Fixed costs relate to a unit of time – annual preparation of housing and communal services for the winter season; operation of protective structures.

3.6. Optimization of Preventive Actions

Optimization models are used in the case of issuing recommendations for preventive actions projects that require large material costs to implement or to calculate the time for evacuating people and property. The recommendations proposed by the decision support system are refined using mathematical models [24]. Demonstration version of the model for calculating the cost of preventive actions and damage assessment [7] is implemented as a mobile application [8]. The application allows the head to decide whether or not to carry out preventive actions.

"The optimal solution is an economic decision of the consumer, made on the basis of information about the state of the environment and ensuring the maximum economic effect, or minimal damage, or the safety of work, people, and enterprises. Optimality criteria include average losses, minimum probability of losses exceeding a certain specified level of maximum possible damage, average gain, minimax, etc." [24].

For some natural hazards (mudflows, tsunamis, and tornadoes), "forecast methods do not always give accurate results, and the head is faced with a dilemma: to apply or not to apply protective actions when forecasting of natural hazards is. It has three strategies: never use protective actions; always apply protective actions; apply protective actions selectively, focusing on intuition or additional information" [7]. The use of economic models allows us to have a reasoned decision on the implementation of certain activities.

Damage assessment is probabilistic. When making a decision, the head does not know what values of natural hazards indicators will take at each point in time, and only considers the probability distribution of these values. Therefore, consumer losses are also probabilistic. To select a particular solution as economically optimal, the law of distribution of losses is first determined, which is used as a criterion for the optimal solution. For this purpose, statistically average losses are used. This method minimizes losses expected on average over an infinitely long time, and does not limit the probability of damage in any way.

It is advisable to find an optimal business strategy, adhering to which, the consumer would reduce the risk to a minimum. To find such a strategy in relation to each specific task, a model is built that reflects the object's response to environmental conditions and allows one to construct a utility function – the dependence of costs, damage, profit under HMC in the matrix form of the calculation of maximum, minimum and average costs. The criteria for decision-making under uncertainty are the Laplace, Savage, and Hurwitz criteria [24]. These criteria are used to determine the optimal cost value for minimizing the cost of dam construction and carrying out preventive actions for several flood probabilities [1].

Examples of other optimization problems are presented below:

— optimization of the allocation of warehouse space for goods that are afraid of environmental influences (perishable goods, or goods that are afraid of precipitation, etc.);

— towing dangerous, valuable or large cargo over long distances;

— calculation of port profit taking into account the timing of fast ice break-up in Arctic ports;

— recommended courses for ships depending on wind speed, wave height and ice conditions.

4. REQUIREMENTS FOR MODELS

4.1. Requirements for Mathematical, Economic and Other Types of Models Used for Impacts Assess of Environment on Enterprises

Difficulties in using models are [1]:

— lack of open data;

— immaturity and lack of interdisciplinary dialogue when analyzing data obtained from data providers;

— very small of interdisciplinary research devoted to modeling environmental impacts on enterprises;

— large amount of data presented to heads in the form of maps, charts, graphs, tables, which requires automation of analytical functions;

— insufficient integration of heterogeneous and distributed data from different activities spheres.

Taking these difficulties into account, the following requirements for models have been developed. Models are ready to run at any time (24*7*365) and the necessary up-to-date data is always ready for them. The models operate in a distributed environment. Data is delivered to models in JSON or XML exchange formats using REST, web or API-services. Forecast models are automatically launched within the time limits established by the regulations, associated with the receipt of new pieces of data. Impact assessment models are launched based on an event when natural hazards are identified and a hazard arises for the enterprise.

4.2. Digital Twin Data Model Requirements

The use of DT in models requires applying of a universal data model [25]. The objects of this model are registries, directories and enumerations. Registries – Represents records with attribute values and relationships between records related to the same object. Directories are classifiers used in registries. Enumerations are a list of multiple attribute values. Due to enumerations, several values of one property of an object are stored in one attribute. To implement the data model, the following principles are applied:

— DT includes two types of data (time series and data at grid points);

— each data type includes several objects related to different subject areas, the data of which are combined into a DT;

— objects of the same type are stored in the same data structure;

— each instance of a DT object has a unique identifier;

— DT objects have the same search attributes;

— multiple values for one object property are written in one attribute as a list of values separated by a separated by semicolons;

— each DT has an instance of metadata, making it easier to find;

— metadata is updated automatically after a new piece of data arrives;

— data for the DT is continuously downloaded, processed and delivered to consumers [10].

Time series are stored in the form of two tables – metadata and data. Metadata reflects information about time series – time resolution, point coordinates, point name, parameter name, etc. Time series data is presented as multiple values in a list for each parameter.

The data in the nodes of a regular grid also consists of two entities – metadata and data. Metadata includes information about the properties of the grid and each field's area coordinates date-time, grid spacing, parameter name, and other metadata attributes. Data in grid nodes is presented as multiple attribute values in grid points – latitude, longitude, time and parameter values. Connections with other DT objects and classifiers are organized in the form of links.

5. CONCLUSION

Approaches are presented for using data from DT to assess the impact of the environment on the activities of an enterprise using mathematical and economic models for calculating indicators of the resistance of enterprises to environmental influences; of identification of natural hazards; of impact forecast; of assessing damage, of calculating the cost of preventive actions and optimizing solutions. A unified data model for the DT is proposed as an object description, presented in the form of a one table. This allows you to have connections both between objects and individual instances of properties of the environment and enterprise.

The DT reflects the state of the environment and the activities of enterprises in four-dimensional space (latitude, longitude, altitude, time) in the form of time series and data in points of grid regularity. The resulting digital analogue of the state of the environment in the form of values of environment parameters and economic indicators of enterprises allows you to monitor environment natural hazard indicators for enterprises, model and predict impacts on the activities of enterprises. This will allow optimizing business processes, reducing damage from the effects of natural hazards and climate change, and increasing the efficiency of the enterprise.

REFERENCES

1. Viazilov, E.D., *Digital Transformation of Hydrometeorological Provision to Consumers*, Obninsk: RIHMI-WDC, vol. 2, Directions of use, 2022.

2. *Loads and impacts on hydraulic structures (wave, ice and from ships): SNIP 2.06.04-82. Gosstroy USSR*, Moscow: Stroyizdat, 1986.

3. *Engineering and hydrometeorological surveys on the continental shelf*, Moscow: Gidrometeoizdat, 1993.

4. *European Union's project ECONADAPT Toolbox provides easily accessible information on the economic assessment of adaptation*, https://econadapt-toolbox.eu/easy-access-guide. Accessed: 8 February 2019.

5. Viazilov, E.D., Digital twin for the environment, in *Collection of proceedings of the International Conference 'ENVIROMIS 2022' and the school of young scientists on measurements, modeling and information systems for environmental studies*, Tomsk: IMCES SB RAS, September 12–17, 2022, pp. 323–326.

6. Viazilov, E.D., About Creating a Digital Twins in Field of Earth Sciences, *Int. J. of Applied Sciences and Development*, 2022, vol. 1, Art. 6. DOI:10.37394/232029.2022.1.6. https://wseas.com/journals/asd/2022/a12asd-006(2022).pdf. Published: December 31, 2022, pp. 42–51.

7. Viazilov, E.D., New approaches to communicating information about natural hazards and increasing awareness among decision makers, *Conference "Problems of forecasting emergency situations." XVI All-Russian Scientific Conference. Moscow, September 27–28, 2017. Collection of materials*, Moscow: Russian EMERCOM, FKU "Antistikhia," 2017, pp. 40–44.

8. Viazilov, E.D., From Informing Users about Disasters to Issuing a Forecast of Possible Impacts and Recommendations, *J. Engineering World*, 2022, no. 4, pp. 34–43. https://wseas.com/journals/ew/2022/a12engw-5115-806.pdf

9. ESIMO. Unified state information system on the situation in the World Ocean. 2013. URL: http://esimo.ru . Access: 04.01.2023.

10. Viazilov, E.D., Melnikov, D.A., and Mikheev, A.S., On the development of a pipeline for processing hydrometeorological data, *Supplementary Proceedings of the XXIII International Conference on Data Analytics and Management in Data Intensive Domains DAMDID/RCDL*, 2021, vol. 3036. http://ceur-ws.org/Vol-3036/paper08.pdf

11. Olchev, A.V., Rozinkina, I.A., Kuzmina, E.V., Nikitin, M.A., and Rivin, G.S., Influence of forest cover changes on regional weather conditions: estimations using the mesoscale model COSMO, *IOP Publishing Ltd. 2018. IOP Conf. Ser.: Earth Environ. Sci. V. 107, 012105.* DOI:10.1088/1755-1315/107/1/012105

12. Dynamics of the field of the geophysical parameter of the atmosphere over the waters of the World Ocean: integral moisture content of the atmosphere (TPW), cloud water content (CLW) and surface wind speed (WND). Time step – 3 hours. The grid pitch is 0.25°. http://fire.fryazino.net/tpw.

13. Sorokin, A.A., Korolev, S.P., Girina, O.A., Balashov, I.V., Efremov, V.Yu., Romanova, T.M., and Malkovsky, S.I., Integrated software platform for comprehensive analysis distribution ash loops at explosive eruptions volcanoes Kamchatka, *Modern problems remote sounding Earth from space*, 2016, vol. 13, no. 4, pp. 9–19.

14. Ermakov, D.M., Chernushich, A.P., and Sharkov, E.A., Geoportal satellite radio thermal imaging: data, services, prospects development, *Modern problems remote sounding Earth from space*, 2016, vol. 13, no. 3, pp. 46–57.

15. Kospanov, A.A. and Konstantinov, P.I., Comparison of the influence of green and white roofs on the urban heat island using the example of 3 heat waves in Moscow, *International Youth School and Conference on Computing and Information Technologies for Environmental Sciences. (CITES '2023'). June 13–23*, 2023, Moscow, pp. 68–69.

16. Levischeva, T.P. and Konstantinov, P.I., Application of local meteorological models to reproduce urban microclimate using the example of Moscow. International Youth School and Conference on Computing and Information Technologies for Environmental Sciences. (CITES '2023'). June 13–23, 2023, Moscow.

17. Methodology for determining the amount of harm that may be caused to the life, health of individuals, property of individuals and legal entities as a result of an accident at navigable hydraulic structures. Approved By order of the Ministry of Emergency Situations of Russia and the Ministry of Transport of Russia dated 02.10.2007.

18. Khandozhko, L.A., *Economic meteorology*, St. Petersburg: Gidrometeoizdat. 2005.

19. Ivchenko, A.A., Zatsepa, S.N., Solbakov, V.V., and Zhuravel, V.I., Model complex SPILLMOD-RA for calculating statistical characteristics of the spread of oil spills in the sea based on a thematic data set of reanalysis of meteorological fields. Certificate of state registration of a computer program. Certificate number: RU 2020665648. 2020. Application number: 2020664664.

20. Alabyan, A.M., Zelentsov, V.A., Krylenko, I.N., and Petryasaev, S.A., *Scalable regional system for monitoring and operational forecasting of river floods: results of development and testing*, Moscow: EMERCOM of Russia, 2018.

21. Zakrevsky, Yu.N., Justification of the system for providing medical care and treatment for victims of maritime disasters. Abstract of the dissertation for the degree of Doctor of Medical Sciences in specialty 05.26.02 – "Safety in emergency situations," Arkhangelsk: "Northern State Medical University," 2013.

22. Viazilov, E.D. and Chunyaev, N.V., On the paradigm shift of hydrometeorological services with information about hazardous phenomena, *Proceedings of the Hydrometeorological Center of Russia, 2016, vol. 362. Hydrometeorological forecasts*, Nesterov, E.S., Ed., pp. 224–235.

23. Chunyaev, N.V., Information support for managing maritime activities in the event of hazardous natural phenomena, in *Proceedings of the Main Geophysical Observatory named after. A.I. Voeykova*, 2015, vol. 578, pp. 156–173.

24. Madera, A.G., *Mathematical Models and Decision Making in Management: A Guide for Top Managers*, Moscow: URSS, 2021.

25. Viazilov, E.D., Puzova, N.V., Mikheev, A.S., and Melnikov, D.A., Choosing a Data Model for the Environmental Digital Twin, *Supplementary Proceedings of the XXIV International Conference on Data Analytics and Management in Data Intensive Domains (DAMDID/RCDL 2022)*, Pleiades Publishing, Ltd. Special issue of the Lobachevskii Journal of Mathematics, 2023, vol. 44, no. 1, pp. 237–248. DOI:10.1134/S1995080223010444

This paper was recommended for publication by A.A. Galyaev, a member of the Editorial Board