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RESEARCH ARTICLE

Architecture of distributed geoinformation technology for snow cover monitoring in circumstances of limited telecommunications accessibility

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Abstract
Objectives. Snow cover has a complex multifactorial impact on the environment as a link between global climatic processes and the system of the Earth's surface. Snow cover monitoring is one of the key tasks of hydrometeorology which also requires the systematic regular collection of its indicators. This work aims to develop an architecture of geoinformation technology for snow cover monitoring with the purpose of addressing the problem of automating the collection of snow cover indicators and their further maintenance. This architecture can also be used for other hydrometeorological monitoring tasks.
Methods. This paper analyzes the existing fundamental basis of snow cover data collection and uses the method of systems approach to describe the architecture of distributed geoinformation technology.
Results. The paper presents an architecture of distributed geoinformation technology focused on snow cover monitoring from measurements, data aggregation, and validation to their transfer to a centralized processing system. A prototype of portable user terminal modules for testing this technology is developed.
Conclusions. The proposed architecture is capable of functioning in circumstances of limited telecommunication availability, while ensuring data integrity control and personalization of responsibility by introducing an electronic signature of each measurement session. This architecture can be expanded by developing and implementing modules for other types of measurements.

Keywords: snow measuring route, snow measuring survey, data collection, geoinformation system, monitoring, geoinformation system architecture

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НАУЧНАЯ СТАТЬЯ

Об архитектуре распределенной геоинформационной технологии мониторинга снежного покрова, функционирующей в обстоятельствах ограниченной телекоммуникационной доступности

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Резюме

Цель. Снежный покров оказывает комплексное многофакторное влияние на окружающую среду, являясь связующим звеном между глобальными климатическими процессами и системой земной поверхности. Мониторинг снежного покрова является одной из ключевых задач гидрометеорологии, в рамках которого проводится систематический регулярный сбор его показателей. Целью работы является разработка архитектуры геоинформационной технологии мониторинга снежного покрова, комплексно решающей проблему автоматизации сбора показателей снежного покрова и их дальнейшего сопровождения, а также расширяемой для других задач гидрометеорологического мониторинга.

Методы. Используется метод анализа существующей фундаментальной базы в области сбора данных снежного покрова, а также метод системного подхода при описании архитектуры распределенной геоинформационной технологии.

Результаты. Разработана архитектура распределенной геоинформационной технологии, ориентированная на мониторинг снежного покрова, от выполнения измерений, агрегации данных и их валидации до их передачи в централизованную систему обработки. Разработан прототип модулей носимого пользовательского терминала, позволяющий провести апробацию данной технологии.

Выводы. Предложенная архитектура способна функционировать в обстоятельствах ограниченной телекоммуникационной доступности, а также обеспечивать контроль целостности данных и персонализацию ответственности за их получение путем введения электронной подписи каждого сеанса измерений. Данная архитектура может быть расширена путем разработки и внедрения модулей для других типов измерений.

Ключевые слова: снегомерный маршрут, снегомерная съемка, сбор данных, геоинформационная система, мониторинг, архитектура геоинформационной системы

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INTRODUCTION

Snow cover has a complex multifactorial impact on the environment. It is a link between global climatic processes and the Earth's surface system. It determines the following factors: magnitude of annual runoff; the level of spring flooding; the ice regime of rivers; the intensity of ice and avalanche processes; and the annual balance of glaciers [1]. The combined radiative, reflective and insulating properties of snow cover significantly reduce the arrival of shortwave radiation to the earth's surface. This impacts the climatic component and leads to air cooling and the formation of surface radiation temperature inversions [2, 3]. At the same time, by reducing heat losses to the atmosphere, it reduces soil freezing and the amplitude of temperature fluctuations, preventing the freezing of agricultural crops [4].

Snow cover is an indicator of atmospheric air pollution and subsequent pollution of soil, surface and groundwater [5]. This allows us to estimate the total pollution parameters in winter [6, 7]. In addition, snow cover provides water resources for a significant part of the Earth's population [8].

Therefore, snow cover monitoring is one of the key tasks of hydrometeorology, involving systematic regular collection of snow cover indicators such as:

- total snow cover height;
- distribution of snow cover density by its thickness;
- presence and concentration of admixtures: suspended solids, carbon oxide, nitrogen dioxide, hydrogen sulfide, phenol, toluene, xylene, benzene, formaldehyde, and benz(a)pyrene.

These in turn make it possible to assess the key indicators for business activity:

- water stock (water equivalent) in the snow cover;
- annual river flow volume;
- spring high water level;
- river ice conditions;
- intensity of ice and avalanche processes;
- annual glacier balance;
- duration of snow cover accumulation;
- timing of snow cover breakdown (in order to determine the duration of the vegetation season).

At present, there are many approaches to measuring snow cover indicators based on methods of remote sensing of the Earth by means of space [9, 10, 11] and in-atmosphere vehicles[1] [12] including modern unmanned aerial vehicles [13, 14]. Other methods involve the direct presence on the ground of automated measuring stations[2] which collect, inter alia, visual (photo-video) materials [15, 16], or meteorologists [17] who use both destructive and non-destructive techniques, for example, based on laser[3] or radio emission [18]. The use of mobile devices, e.g., for pressure measurements, allows us to ensure unprecedented coverage density and spatial coverage [19]. Furthermore, their use for precipitation data collection allows us to compile complementary forecast maps [20].

Unfortunately, the current level of technology development does not enable us to collect all the necessary indicators without the use of field methods, most importantly, without the regular presence of a qualified specialist-hydrometeorologist "in the field." Moreover, in domestic practice there is no systematic approach to the problem of automation of field work of meteorologists. Much of the work is done manually, using analog instruments and paper logs for the measurement results. This requires their subsequent digitization, and consequently can be a potential source of errors and vulnerability of the system to the human factor.

According to [21][4] there have been changes to the working plan of the meteorological network, in particular the reduction of snow measurements, due to the lack of instruments and insufficient qualification of personnel.

The purpose of the work is to develop the architecture of geoinformation technology for snow cover monitoring, in order to comprehensively resolve the problem of automating the collection of snow cover indicators and their further maintenance. A further aim is to make them expandable to other tasks of hydrometeorological monitoring.

RESEARCHING THE REQUIREMENTS FOR THE GEOGRAPHIC INFORMATION SYSTEM

For the purposes of this objective, a functionally scalable and integratable system needs to be created which will allow us to interact with a multitude of potential data consumers. These include already extant information and geoinformation systems, as well as automated measuring complexes, individual primary (measuring) converters, receivers of satellite navigation systems (GPS, GLONASS, etc.), photo-video

[1] Koch F., Appel F. et al. *GPS-based measurements of snow cover properties for snow-hydrological, risk and snow quality applications.* Conference: EGU General Assembly At: Vienna; 2019.

[2] State registration certificate. *Automated meteorological stations "Snow"*. State registration number: 52771-13 (in Russ.).

[3] Roy A., Langlois A., Montpetit B., Royer A., Champolion N., Ghislain R., Domine F., Fily M. *Field measurements of snow grain specific surface area using near-infrared photography and laser reflectometry in Northern Canadian tundra*. AGU Fall Meeting Abstracts. 2010.

[4] *Review of the State of the Hydrological Observing System, Data Processing and Preparation of Information Products in 2020*: Reference Edition. St. Petersburg: RIAL; 2021. 56 p. (in Russ.).

fixation means and specialized measuring equipment, without excluding the following.

Due to the potentially high importance of the information collected, all primary and intermediate data, as well as related information, need to be collected and stored in such a way that both the fact of measurement and the correctness of the measurement procedure can be confirmed later, and that all the required calculations can be reproduced. It is also necessary to ensure that each series of measurements can be certified by an electronic signature associated with a specific person performing the measurements or with a separate measuring instrument or system.

Monitoring the vast and heterogeneous territory characteristic of the Russian Federation requires that the geographical distribution of observation points be taken into account. This includes hard-to-reach areas and the level of their technological equipment.

The main requirement for the technological equipment of the potential system is that it takes into account the limited availability of telecommunications: absence or irregularity of access to public telecommunication networks for portable user terminals and the local network of the observation point; poor communication between the user terminal and the local network of the observation point; slow and unstable communication channels, including asymmetric ones. In some cases, direct telecommunication accessibility may not be possible, and data transmission may be possible only by means of removable data carriers.

A significant part of the computer equipment at the individual observation sites, mainly portable user terminals, can operate under extreme conditions. This implies a high probability of the failure of individual devices. In order to create a functional system, this must be compensated for by redundant storage of the most valuable data.

Consumer mobile devices based on the Android platform, such as smartphones and tablets, may be used as portable user terminals. Other system components can be based on personal computers, general-purpose servers, and specialized devices with limited computing resources.

GEOINFORMATION SYSTEM ARCHITECTURE

The key solution of the proposed architecture is a peer-to-peer communication model. This implies the formation of the system as a set of homogeneous nodes which exchange unchangeable data packets. This model is conceptually similar to distributed data storage networks, for example, interplanetary file system (IPFS)[5].

[5] Benet J. *Content Addressed*, Versioned, P2P File System. IPFS. 2014.

It can be considered as a simplified version of another development by the authors [22], which differs only in data collection, but without providing them (or services based on them) to consumers.

The unit of data storage and transmission between network nodes is a *packet*. Each packet in the system is uniquely identified by the following set of metadata:

- date and time of creation according to Coordinated Universal Time (UTC);
- the identifier of the node which created the packet (universally unique identifier (UUID));
- UUID may be repeated for several packets in case they belong to the same series of measurements;
- packet priority;
- packet type code;
- content hash sum.

A packet can be unambiguously represented as a file, enabling the user to apply any method available to them for transmission.

For operational convenience, the system core can directly support multiple file exchange protocols. Any file-oriented protocol can be used, if there is direct telecommunication availability, even intermittent. Modern cryptographically secure protocols are represented by SFTP (secure file transfer protocol)[6] and UFTP (UDP-based file transfer protocol, UDP—user datagram protocol)[7]. An important advantage of UFTP for the purposes of this system is the possibility of its application in communication channels with high bandwidth, but high latency. This is typical, for example, of satellite communications used in hard-to-reach areas. In the absence of direct telecommunication availability, data transmission based on removable media can be used. This is also referred to as SneakerNet [23]. A software package which can be used to achieve the necessary functionality is NNCP (node to node copy)[8].

Packet prioritization enabled the data most valuable for operational processing to be transmitted first.

Assumed packet types and priorities are summarized in Table 1.

The diagram of the network node is shown in Fig. 1.

In addition to the basic modules common to all nodes, there are separate types of nodes oriented to different tasks in the network:

[6] Ylonen T., Lehtinen S. *SSH File Transfer Protocol draft-ietf-secsh-filexfer-02.txt.* SSH Communications Security Corp. October, 2001. URL: https://datatracker.ietf.org/doc/html/draft-ietf-secsh-filexfer-02. Accessed November 01, 2023.

[7] UFTP—Encrypted UDP based FTP with multicast. URL: https://uftp-multicast.sourceforge.net/. Accessed November 01, 2023.

[8] NNCP. URL: http://www.nncpgo.org/. Accessed November 01, 2023.

Table 1. Types and priorities of data packets in a distributed geoinformation system

Priority	Type	Description
1	Manifest	Declares the fact that measurements are present. Contains limiting rectangles that enable the construction of a spatial index of the data without their presence. Must be of minimum size
2	Measurement result	Contains a valuable measurement result for further processing
3	Initial data	For complex measuring instruments, it contains initial data allowing the repeat calculation of the result
4	Associated data	Contains data of no direct value, but enables confirmation of the validity of the results obtained, e.g., photo-video data, satellite navigation system tracks, etc.

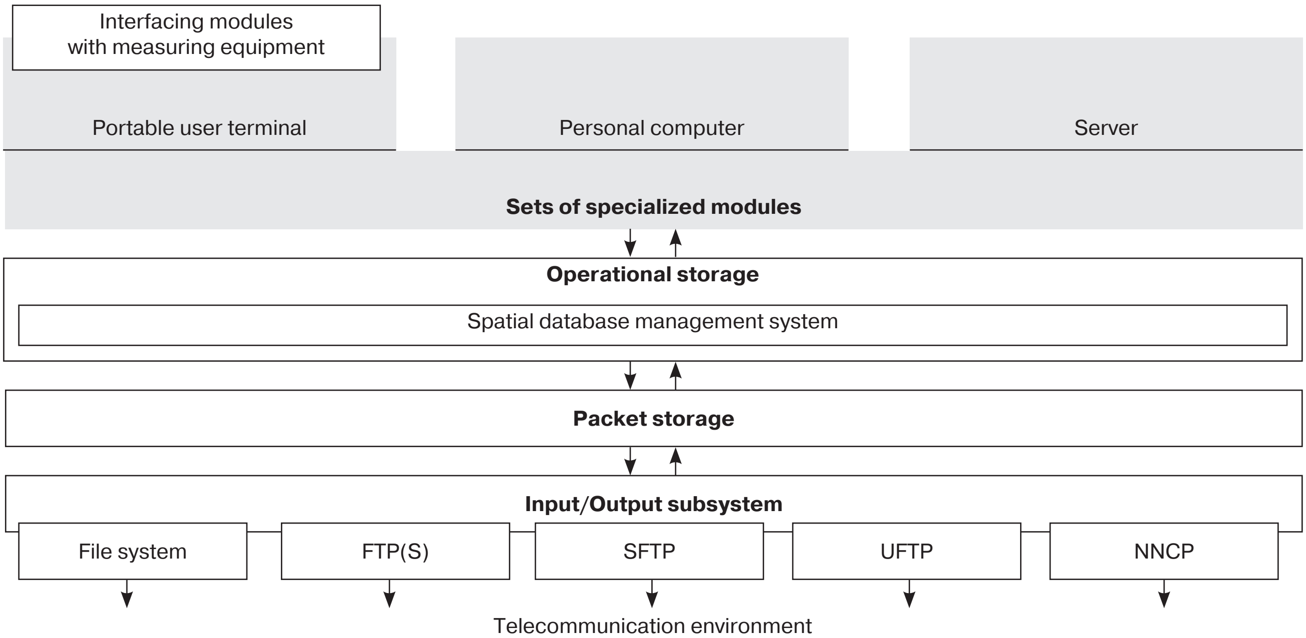

Fig. 1. Principle diagram of the distributed geoinformation system node. DBMS is database management system, FTP(S) stands for file transfer protocol + secure sockets layer

- portable user terminals: data acquisition, manual input, interaction with measuring equipment;
- automated data acquisition units: saving data from measuring equipment;
- observation site personal computers: data aggregation, primary analysis, visualization;
- server: aggregate data from a large number of sources, store large amounts of data, provide a web interface.

Node levels and the following rules are introduced to direct data flows between nodes:

- level 1 is assigned to portable user terminals that directly collect data;
- higher levels are assigned to nodes of local observing sites, and further to regional and federal nodes;
- when nodes of the same layer interact, data is synchronized in both directions, providing backups;
- when nodes of different levels interact, data is transferred from a lower-level node to a higher-level node, providing information aggregation.

AUTOMATION OF THE FIELD MEASUREMENT PROCEDURE

Automation of the field measurement procedure is performed by software modules designed to be placed on a portable user terminal. They provide for the possibility of primary input and the correction of measured values, performing calculations, as well as visualization of data in tabular and graphical formats.

The measurement results are entered into the appendix directly during measurements on the route. The calculation of average parameters and water reserve is done automatically.

In order to perform a snow survey, a gauge rod and a weight snow gauge are required. The snow survey process involves collecting data for the following measurements:

- snow cover height (counting on the scale of a gauge rod);
- reading from the scale of the cylinder on the weighing snow gauge;

- reading from the scale bar of the weighing snow gauge;
- ice crust thickness (measured on the scale of a gauge rod);
- thickness of the snow layer saturated with water (counted on the scale of a gauge rod);
- snow cover structure;
- snow coverage degree;
- ice crusting degree;
- condition of the soil surface under snow (melted, frozen).

Observations of snow cover on snow gauge trails begin when there are 6 points or more of snow coverage of the visible neighborhood. They end when stable snow cover has been destroyed (less than 5 points of coverage).

The procedure for making observations using the developed program modules is as follows:

1. Identification and authentication by a specialist meteorologist.
2. Enabling geopositioning at the first snow cover height measurement point.
3. The snow cover height is measured every twenty meters, and the measurements are recorded in the corresponding cells. The MEASURE #_ cell indicates how many measurements were taken.
4. The first point for measuring the mass of snow cover is chosen at a distance of 50–100 m from the beginning of the route. Further measurements are made every 200 m. The total number of snow cover density measurements is 10. Measurements of the snow cover height on the cylinder are taken, in order to calculate the snow cover density. Data regarding the snow cover height from the cylinder of the weighing snow gauge is entered in the corresponding cell. The CYLINDER SCALE REPORT #_ cell indicates how many snow cover height measurements were made with the cylinder.
5. After measuring the snow cover height on the cylinder of the weighing snow gauge, the snow cover is weighed. The weighing data is entered into the appropriate cell. The REPORT #_ BY WEIGHTS cell indicates how many measurements are required to determine the mass of the snow cover. The density is calculated automatically. Density calculation can be viewed by clicking on the DENSITY tab. The numbering of DENSITY #_ cells shows how many measurements have been made for the purpose if density calculation. In addition to density measurements at selected points, the thickness of the meltwater layer, the water saturated snow layer, the thickness of the ice crust, and the condition of the soil under the snow cover (frozen or melted) are measured. The data entry boxes are opened one by one after the measurement results for each point have been entered. If no measurements were made due to missing data, a dash is entered. The soil surface condition is selected from the list: thawed, or frozen. The presence of snow crust inside the snow cover and on the surface of the snow cover is noted: yes, no.
6. After passing the route, the meteorologist takes a snapshot of the field and uploads it to the app, in order to characterize the entire snow measuring route. The image is automatically saved.

AUTOMATION OF THE FIELD MEASUREMENT VALIDATION PROCEDURE

Automation of the field measurement validation procedure is performed by modules designed to be placed on the portable user terminal, as well as on the nodes where additional quality control of measurements is performed.

At the present time, checks which may result in a warning being issued to a user are based on the following developed algorithm:

- the number of measurements on the snow measurement route must be within the permissible range;
- the average snow cover height on the route line shall be greater than or equal to the minimum snow cover height or less than or equal to the maximum snow cover height on the rod;
- the average snow density calculated from the snow route measurements shall be greater than or equal to the minimum snow density, and less than or equal to the maximum snow density calculated from snow measurement route data;
- the average water content in the snow cover calculated from the snow route measurements shall be greater than or equal to the minimum value of the snow route, and less than or equal to the maximum water content of the snow measurement route.

Using the graph displayed in the appendix, questionable (potentially poor-quality) measurements can be identified directly on the route and re-measured. Poor measurements can occur due to human error. In some cases, the meteorologist may make a mistake when entering measurements. The route line on the chart is formed on the basis of measurements made directly on the snow survey route.

PROTOTYPE OF THE GEOINFORMATION TECHNOLOGY

The authors have designed a prototype of modules for a wearable user terminal (Android operating system version 10 or higher). Special attention is paid to those elements which enable the data quality to be enhanced by promptly detecting questionable measurements directly in the process of snow surveying. Thus, the snow measurement route graph (Fig. 2) reflects the number of the snow survey, the number of meteorological station, the length of the route traveled, the length of the remaining route, as well as the minimum and maximum measurement altitudes. Given that the meteorologist surveys the snow survey route well in advance of the snow cover, they have a schematic plan of the route line with indication of gradients and elevations, as well as markings of the location of objects (road, trees, bushes, etc.) located on the route line and in the area surrounding the perimeter of the route line. The sub-map data allows questionable measurements to be identified from the snow survey data. Points on the line highlighted in a distinctive color indicate elevation differences in the snow gauged route. The table of average parameter calculations helps dubious measurements to be identified immediately on the snow measurement route. Such dubious values are highlighted in a separate font, indicating possible measurement error (Fig. 3).

CONCLUSIONS

The architecture of the distributed geoinformation technology proposed by the authors is designed to support snow cover monitoring procedures based on measurements, data aggregation and validation to their transfer to a centralized processing system. It is capable of functioning in circumstances of limited telecommunication availability, as well as ensuring data integrity control and personalization of responsibility for their receipt by introducing an electronic signature of each measurement session. This architecture can be extended by developing and implementing modules for other types of measurements.

A prototype of the wearable user terminal modules has now been developed, in order to enable their validation.

Further research by the authors will focus on snow gauge route data collection using species information.

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Authors' contribution. All authors equally contributed to the research work.

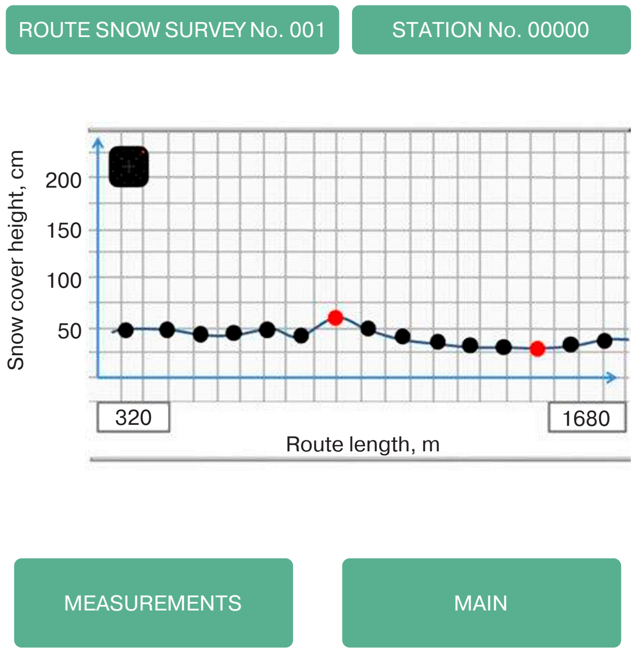
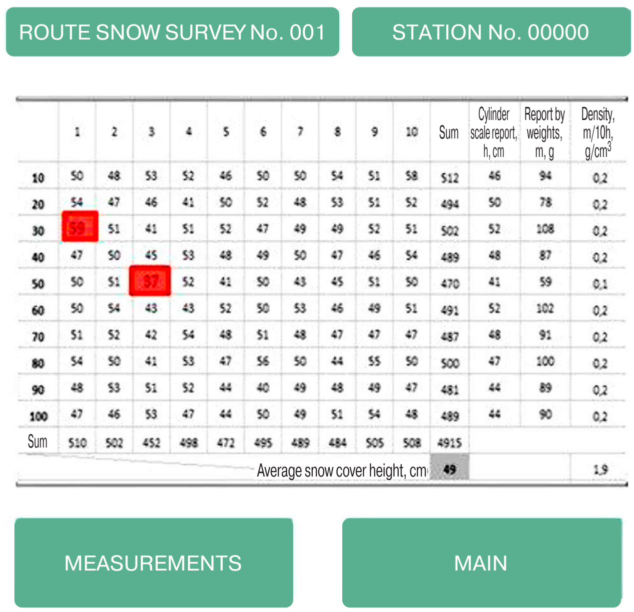


Fig. 2. Diagram of snow survey route with marking of measurement points



	1	2	3	4	5	6	7	8	9	10	Sum	Cylinder scale report, h, cm	Report by weights, m, g	Density, m/10h, g/cm^3
10	50	48	53	52	46	50	50	54	51	58	512	46	94	0,2
20	54	47	46	41	50	52	48	53	51	52	494	50	78	0,2
30	59	51	41	51	52	47	49	49	52	51	502	52	108	0,2
40	47	50	45	53	48	49	50	47	46	54	489	48	87	0,2
50	50	51	37	52	41	50	43	45	51	50	470	41	59	0,1
60	50	54	43	43	52	50	53	46	49	51	491	52	102	0,2
70	51	52	42	54	48	51	48	47	47	47	487	48	91	0,2
80	54	50	41	53	47	56	50	44	55	50	500	47	100	0,2
90	48	53	51	52	44	40	49	48	49	47	481	44	89	0,2
100	47	46	53	47	44	50	49	51	54	48	489	44	90	0,2
Sum	510	502	452	498	472	495	489	484	505	508	4915			
Average snow cover height, cm											49			1,9

Fig. 3. Table of general measurements with the calculation of the average parameters of the snow cover on the route snow survey

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