Using spatial-temporal maps for visualization of the karst development dynamics

R V Sharapov[1]

[1]Vladimir State University, Orlovskaya street 23, Murom, Russia, 602264

Abstract. There is a problem of visualization dynamics of karst processes during territory monitoring. For this can be used geographic information system. All information on existing forms of karst processes can connected to the map based on the coordinates. But there is a need to include into GIS the information about the dynamics of the karst processes. There is a big problem to solve this task in traditional GIS. Development of karst processes has features that affect their visualization in GIS: the shape and the state of karst objects may change; existing karst forms can be replaced with new objects; the frequency of state changes and appearance of new objects is small; cartographic basis (map) may change as a result of the impact of natural phenomena and human activities. To solve the problem can be used spatial-temporal GIS. In paper the basic features of the karst processes development that affect their storage and display on maps are given. The questions of organization of karst processes dynamics visualization on the basis of spatial-temporal maps are presented. Practical issues of linking the objects in map, display of them geometry, determine temporal boundaries of objects existence are describes.

1. Introduction

In 2009, there were plans to build a Nizhny Novgorod nuclear power plant near the village of Monakovo. But there is one serious problem: Monakovo lies in the zone of active karst-suffusion processes.Karst processes have a significant impact on the safety of civil and industrial facilities.Actual tasks are objective assessment of karst hazard of a particular territory and reducing to a minimum the probability of catastrophes on newly constructed buildings caused by the development of karst processes.

For a long time, the staff of Murum institute of Vladimir State University are monitoring the development of karst processes in the area of the village Monakovo and the karst lake Svyato [1].In this case there was a problem of the linking karst forms data to cartographic basis and its visualization. With the advent of geographic information systems (GIS) there was new direction - the computer cartography. It has been actively used in different spheres of activity. Unlike paper maps, the use of computer technology allows users to select the desired information and produce its visualization in a user friendly manner.This may change the level of detail - enables or disables display of various layers of maps (topography, water bodies, roads, buildings, etc.), carried out generalization when zooming. In addition, GIS allow interactive display of information with support for interacting with objects on the map (for example, information about the selected object). All this inspired us to implement linking karst processes observing system to GIS.

At the initial stage of the project there was almost no difficulties - all information on existing forms of karst processes was linked to the area map based on the coordinates.But later it became necessary to make information on the dynamics of development of karst processes. For example, in early 2014 formed a new sinkhole in village Chud that has absorbed already existing sinkhole (Fig. 1). There is a problem: what to do with information on the sinkhole - to link it to new sinkhole, remove or remain unchanged? A similar problem arose after filling with water several karst forms formation and in their place a small pond.

a)  b) 

c) 

Figure 1. Sinkhole in village Chud: a – The place of sinkhole in 2013, b – The place of sinkhole in 2014, c – State of sinkhole in the summer of 2014.

Of course, to display the current status sufficient to store information about currently available forms of karst. In this case, the mapping of the previous states is not required. On the other hand, to obtain a full picture of the development of karst processes necessary to have data about their dynamics. This gives rise to new task: to visualize not only the current state of karst processes, but also the previous state (getting maps for a given timestamp, for example, one year ago, 10 years ago, etc.). In other words, there is a need to compile retrospective (time) maps.

Purpose of work - consider the practical aspects of data linking of karst processes observing system to the geographic information system for the visualization of their development.

2. Main features of karst processes observations

In the observation system for karst processes for each of karst forms there are one or more the descriptions (observations). Each observation can be given as a full or partial (only the important characteristics or changes) description. For a number of observations can be traced to the development of karst processes and the changes (evolution) karst forms.

Let’s consider the example of the evolution of karst forms (see. fig. 2). At the initial time there is a sinkhole №122 (Fig. 2a), which is located between a residential house and a bath. During the development of karst processes formation a new karst form №633 (sinkhole), affecting existing object №3396 (bath), and causing its partial destruction (Fig. 2b). During the further lowering of the surface object №122 and №633 combined into a single complex objects №694, which is partially filled with water (Fig. 2c). As can be seen, in the latter case there was a change of the cartographic basis - disappeared (was disassembled) object number 3396 (Bath).

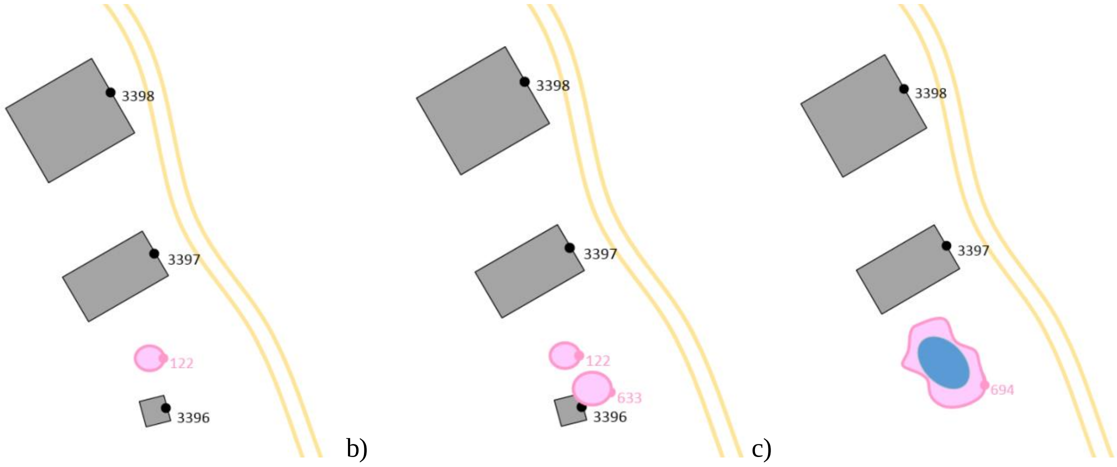

Figure 2. An example of the evolution of karst forms on the map: a – One karst form, b – The appearance of the second karst forms with the partial destruction of the object, c – Union of karst forms in a partially filled with water.

Let's consider the features of karst processes, affecting their visualization in GIS:

- form and the state of observation objects (karst forms) can be changed;
- the position of karst forms in space remains constant (except for changing their geometry);
- existing karst forms can be replaced with new objects (such as merging several sinkholes into a single object);
- the frequency of changes in the state and the emergence of new objects is small;
- cartographic base may vary as a result of the impact of natural phenomena and human activities.

3. Approaches to building spatial-temporal maps

There are two basic approaches to create a spatial-temporal maps [2, 3, 4]:

- Creating a set of spatial-temporal maps showing the status of research in specific periods of time (e.g., once a month, once a year, etc.)
- Automatically generating maps based on observation data (including animation dynamic changes).

The most famous example of the implementation of maps of the first kind are the historical maps (satelliteimagery) in Google Earth (fig. 3). Creation a set of spatial-temporal maps is quite laborious. It requires the involvement of specialists to create the next map. Due to this, the process of creating maps is moderated and controlled to eliminate human error. Moreover, in the preparation of each new map it is possible to use the updated cartographic base (map of area).

The second variant does not require specialists to generate a maps - it happens automatically. As a result - errors may occur. However, the variant of automatic generation of maps is more attractive.

There are quite a number of works devoted to the creation and use of spatial-temporal maps. Such maps are used to monitor traffic, road load, display the current status and weather forecasts, the spread of pollution, etc. There are solutions for displaying dynamics of various processes, including real-time. For this purpose special Spatial-Temporal GIS and Temporal GIS.

In [2] discussed questions retrospective (temporal) presentation information in a GIS. A model of time in cartography and variants for presentation of spatial-temporal data using models of space-time cube, sequential images, the base of states with changes and the space-time combination.

In [5] given the basic model for the implementation of temporal GIS: models based on the position of objects, on the objects or their features, on the time, event model, process-oriented models, causal models.

Each object can be described as a triplet (o_i, s_i, t_i), where o_i – object features, s_i– the spatial position of the object, t_i– timestamp when o_i exists in s_i (see. fig. 4) [5].

Models based on the object's position, considering moving along the axis of “space”. In this case, the model is a set of parallel planes “Feature-Time” $\{(o, s_j, t)\}$, where $1 \leq j \leq n$ [2].

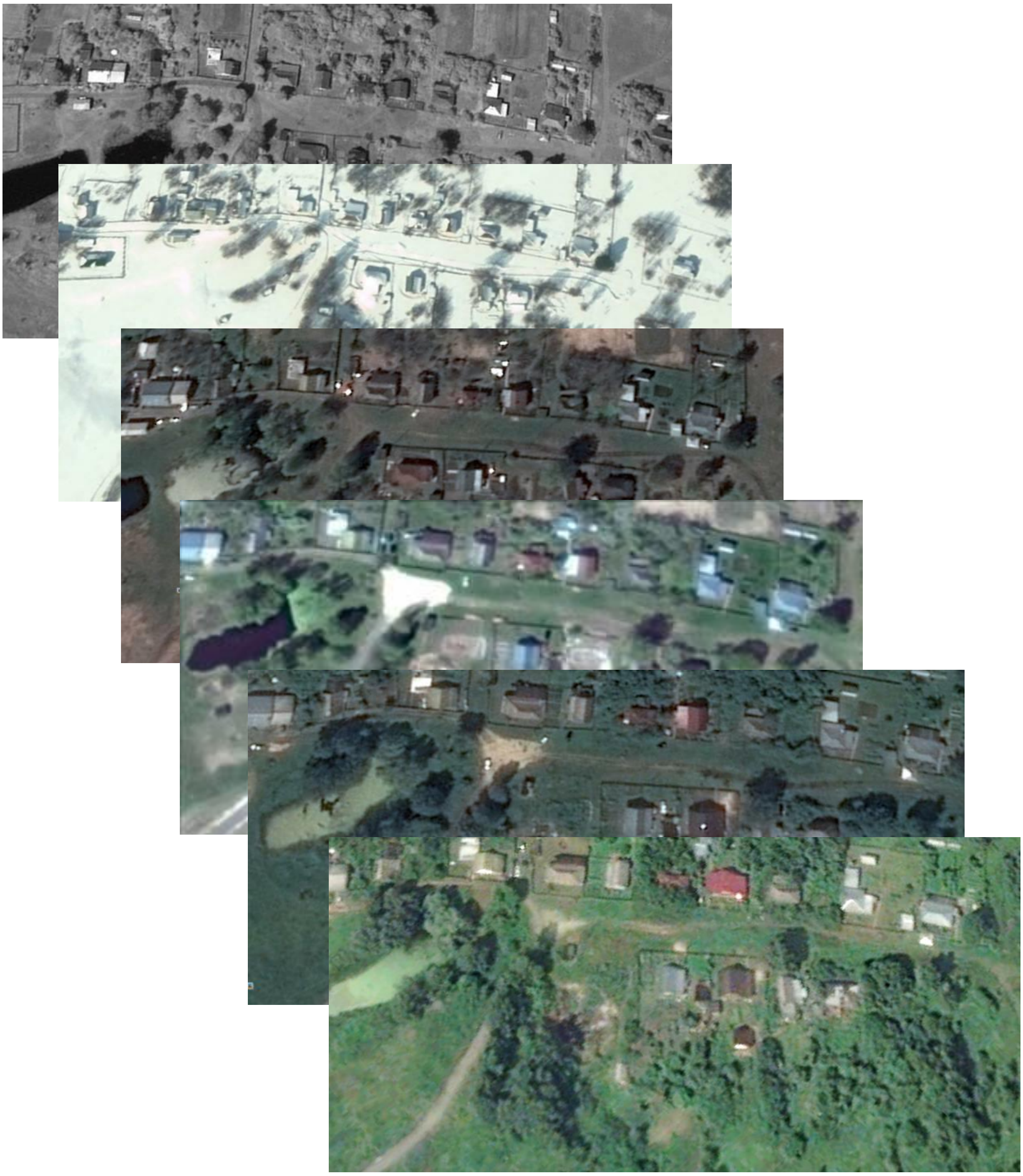

Figure 3. Set of satellite images of territory taken at different times.

Models based on the objects or features considering moving along the axis of "Feature", and is a set of parallel planes, "Space-Time" $\{(o_i, s, t)\}$, where $1 \leq i \leq m$ [6, 7, 8, 9, 10].

The models based on time, make temporary snapshots of reality (of planes "Space-Feature") $\{(o, s, t_k)\}$, where $1 \leq k \leq l$ [5, 11].

In the event model, state transition represents an event. Events can be represented as lines connecting the two states in the data space [12, 13, 14]. In the a process-oriented models are considered occurring processes, such as changing a single object, the functional relationship between objects or modify the spatial structure associated with some aspects [15].

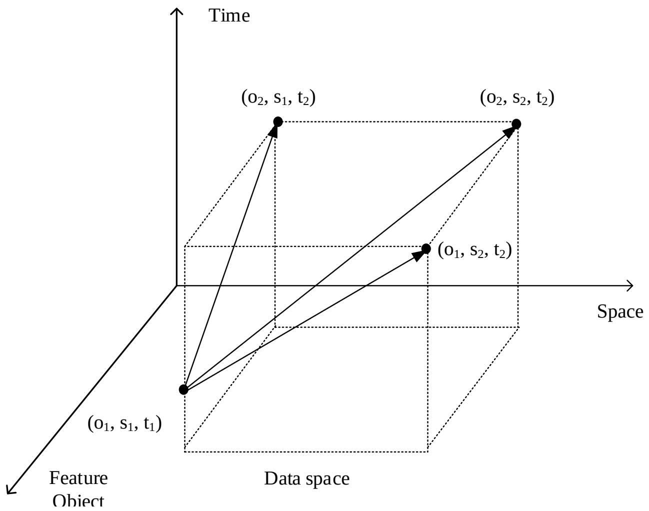

Figure 4. 3D data space.

Questions of modelling and management of spatial and temporal data considered in papers [16, 17]. Thus, there are a number of solutions in the field of presentation space-time (retrospective) information in a GIS. The use of a decision is largely due to the set in each case the task.

4. Presentation of data for visualization

4.1. Data model.
In accordance with the task, it is needed only display the time information, i.e. creation of retrospective maps. For this reason, the basic information for visualization to be objects (karst) and their status (geometry, water availability, etc.).

4.2. Spatial reference object.
As a basis for spatial reference karst forms the basis used to map GPS coordinates of objects. Because objects do not move in space, their coordinates on the axis "space" remain constant.

4.3. Object geometry.
Manifestations of karst processes (sinkhole) are closed, often circular, shape. For this reason, the map can be presented either in the form of an ellipse or a closed polyline. In the first case it is sufficient to store the coordinates of the ellipse center and the radius the major and minor semi-axes. Additionally, it may indicate the angle of rotation of the axes of the ellipse. In the second case, a sequence of pairs of coordinates storage defining the contours of the object. In this last pair of coordinates must be equal to the first.

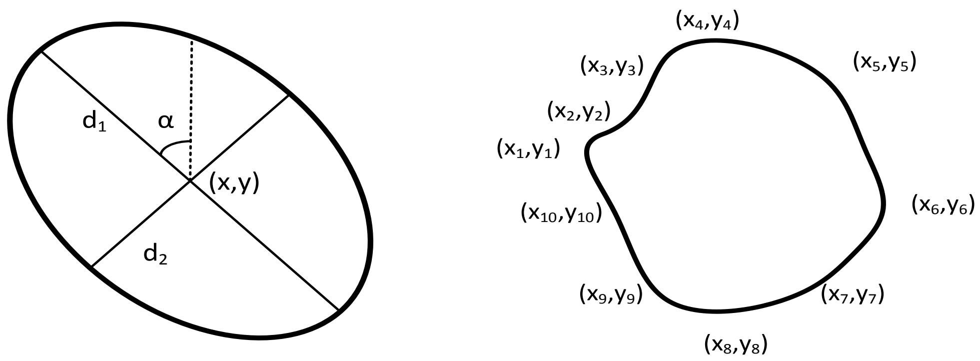

Figure 5. Object geometry.

4.4. Evaluation time presence of the object.
Since karst forms can occur at different times, there is the problem of determining time slots, where a form will be displayed on the map (the axis of "Time"). To determine the initial interval may use information about the time of occurrence the karst forms or data first describe it. The time of occurrence can not always be determined: sinkholes are formed slowly, and the old sinkholes can not be properly described. In this case, the first time is used to describe an object.

The upper boundary of the time display object is set only if the status of an object indicates that it has ceased to exist (moved to another facility, or has been removed). In the this case, the date of the last of the description (in which the status was changed and the object) and read by the upper boundary of the time display.

4.5. Feature of the object
To determine the features of karst forms (axis “Feature”) used observations. Specific features of the objects selected from a set of data represented in each observation. Karst object can change its state. For example, sinkholes can be filled with water, turn into swamp or dry.

Since observations may be incomplete and often describe only certain changes to detect feature changes necessary to analyze not only current, but previous observations of objects. Status change has s_i if $s_i \neq s_j$, where $s_j \neq 0$ (a set value) and $i > j$. Since not all states can be described in the observations, adopted a set of default conditions (such as lack of water in karst, the lack of vegetation, etc.).

4.6. Object status.
The development of karst-suffusion processes, objects can be combined with each other. With active business karst may disappear (e.g., falling sinkholes at the earthworks). For this reason, it is necessary the introduction of the status of the object. The default status for any object – “object exists”. When combined with other objects are labelled as “object merged”, the transformation of the object (for example, the conversion of the sinkhole to water bodies), set the status “object is transformed”. With the disappearance of the object status is set to “object does not exist”.

4.7. Temporal Database
It is necessary to develop a database that allows to effectively manage all necessary information for storage of spatially temporary data. A lot of works are devoted to the creation of such databases [18-25]. For this, both specialized structures and relational databases can be used [26-27].

Implementing data storage with relational databases seems to us more promising and convenient. Currently, there is a large number of both commercial (Microsoft SQL Server, Oracle Database, Informix) and freely distributed DBMS (MySQL, SQLite, FireBird). The solutions implemented in them allow users to work with large amounts of data, perform fast search and processing of information, perform transactions and control access to data.

In the general case, each object in the database must have the attributes of the observation time. This corresponds to the axis of "Time". Such attributes must have the objects themselves, their properties and their geometry. In most DBMSs, these attributes can be a pair (FromDate, ToDate) of data type values.

The FromDate value indicates the date from which the property becomes relevant. It contains the date of observation. The property ToDate contains the date when the next observations were received and the property ceased to be relevant (replaced by a new value). This property for the currently relevant data contains the NULL value. The value of ToDate takes on the value of FromDate of new observation, when new observations appear. It is necessary to correctly update ToDate values to exclude anomalies in the database. For this purpose triggers can be usedin DBMS.

5. Practical implementation
On the basis of presented approaches has been implemented visualization module of karst processes observations in a GIS. Open Source Geographic Information System QGIS was used for practical implementation. By default, the visualization of the current status of the map with karst, confirmed in the most recent observations.The user can select the desired time stamp and the module calculates the

existence of objects. All objects, while the presence of (being) which overlaps with the selected time stamp, is automatically drawn in separate dynamic layers (karst holes, sinkholes, water bodies, etc.).
The results of the practical implementation of the visualization system on the example of studies of particular area in Nizhny Novgorod region [28].

During the implementation of the project, we faced several serious problems.Firstly, this is a great deal of time consuming filling the database. This is due to the need to make not only observations and geometry of objects, but also accounting for the transformation and disappearance of objects. And these operations are most often performed in manual mode.

Secondly, the question arose: timestamps should be set for each graphic primitive and object property or for the whole data packet of one observation. The first option is very laborious, complicates the database and increases the redundancy. The second option complicates the search for changes, because as a result of new observations, not all data change.In the end we had to choose the first option.

Thirdly, we are faced with incomplete data. This is due to the periodicity of observations, not complete coverage of the territory with each new observation, fixing not all characteristics of the observed objects.Because of this we had to look through the entire list of subsequent observations for many objects, in order to avoid erroneous disappearances and subsequent occurrences of objects on the map.

Fourthly, in the study area, earthwork were carried out in connection with the preparation of the site for construction Nizhny Novgorod nuclear power plant and road construction.Because of this, the relief was changed, part of the karst forms was covered with soil.Due to incomplete data last observation was not clear - whether some karst forms were destroyed (transformed) or their study simply was not carried out. To eliminate this ambiguity, we were forced to conduct an additional expedition for field research.Nevertheless, the issue of eliminating these ambiguities in the future remains open.When conducting new observations in the future, it is necessary either to collect a full range of data for all objects, or the status of unexplored objects will be inaccurate. The second option is not a very good solution, given the importance and danger of the planned NPP construction.

In this way, implementation of a system for the Nizhny Novgorod region has allowed us to see areas where karst processes are actively developing at present time. In addition, we were able to see the areas in which there are many karst forms, but they formed a long time ago and is currently active karst processes is not observed.

6. Conclusions

The proposed solutions connect the data observation system for karst processes to geographic information system and solve the problem of visualizing their development. Due to the fact that the display of karst on the map is carried out on a given timestamp automatically according to the observations, it is possible to observe the dynamics of development of karst processes in user-defined time frame.

Obtained with the help of GIS visualization of karst processes in time allows anew look at the problem of studies of karst territories. With this solution, the user can see the area as it was in the past. Without the use of a spatial-temporal GIS to user available maps showing only the current status of the territory.Observing the dynamics of karst process development is an important step for assessing the karst hazard of the territory.

It should be noted that the construction of spatial-temporal maps is a much more labor-intensive process than conventional maps. For this reason it makes sense to create such maps for areas with a dynamic terrain change and territories with important objects.

7. References

[1] Kuzichkin O R and Sharapov R V 2013 Monitoring of karst-suffusion formation in area of nuclear power plant *Proc. 7th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems* **2** 810-813

[2] Stuart N 1992 Time in Geographic Information-Systems *International Journal of Geographical Information Systems* **6** 547

[3] Al-Taha K and Barrera R 1990 Temporal data and GIS: An overview *Proc.GIS/LIS* (Bethesda, MD: American Congress on Surveying and Mapping) 244-254
[4] Egenhofer M and Golledge R 1998 *Spatial and Temporal Reasoning in Geographic Information Systems* (Oxford University Press: New York, NY) p 276
[5] El-Geresy B A, Abdelmoty A I and Jones C B 2002 Spatiotemporal geographic information systems: a causal perspective *Advances in Databases and Information Systems* 191-203
[6] Becker L, Voigtmann A and Hinrichs K H 1996 Temporal support for geo-data in object-oriented databases *Proc. 7th International Conference on Database and Expert Systems Applications DEXA* 79-93
[7] Voigtmann A 1997 *An Object-Oriented Database Kernel for Spatio-Temporal Geo-Applications* (Münster: WestfälischeWilhelms-Universität) p 260
[8] Ramachandran S, McLeod F and Dowers S 1996 Modeling temporal changes in a GIS using an object-oriented approach *Proc. 7th International Symposium on Spatial Data Handling* **2** 518-537
[9] Frank A 1998 Different types of “times” in GIS S*patial and Temporal Reasoning in Geographic Information Systems* 40-62
[10] Segev A and Shoshani A 1993 A temporal data model based on time sequences *Temporal Databases: Theory, Design, and Implementation* 248-270
[11] Hornsby K and Egenhofer M 1997 Qualitative Representation of Change *Spatial Information Theory -A Theoretical Basis for GIS, International Conference* 15-33
[12] Peuquet D J and Duan N 1995 An Event-Based Spatiotemporal Data Model (ESTDM) for temporal Analysis of Geographical Data *International Journal of Geographic Information Systems* **9** 7-24
[13] Claramunt C and Theriault M 1995 Managing time in GIS: An event-oriented approach *Recent Advances on Temporal Databases* 23-42
[14] Dorling D and Openshaw S 1992 Using computer animation to visualise space–time patterns *Environment and Planning B: Planning and Design* **19** 639-650
[15] Cheng T and Molenaar M 1998 A process-oriented spatio-temporal data model to support physical environment modelling *Proc. 8th International Symposium on Spatial Data Handling* 418-429
[16] Wang X Y, Zhou X F and Lu S L 2000 Spatiotemporal data modelling and management: a survey *Proc. 36th International Conference on Technology of Object-Oriented Languages and Systems TOOLS-Asia* 202-211
[17] Worboys M F 1992 A model for spatio-temporal information *Proc.Fifth International Symposium on Spatial Data Handling* **1** 602-611
[18] Freksa C 1992 Temporal reasoning based on semi-intervals *Artificial Intelligence* **54** 199-227
[19] Montanari A and Pernici B 1993 Temporal reasoning *Temporal Databases: Theory, Design, and Implementation* (The Benjamin/Cummings Publishing Company, Inc.) 534-562
[20] Tansel A U, Clifford J, Gadia S, Jajodia S, Segev A and Snodgrass R 1993 *Temporal Databases: Theory, Design, and Implementation* (The Benjamin /Cummings Publishing Company, Inc.) 633
[21] Wuu G and Dayal U 1992 A uniform model for temporal object-oriented databases *Proc. of the International Conference on Data Engineering* 584-593
[22] Snodgrass R 1992 Temporal databases *Theories and methods of spatio-temporal reasoning in geographic space* 22-64
[23] Edsall R, Kraak M-J, MacEachren A, Peuquet D 1997 Assessing the effectiveness of temporal legends in environmental visualization *Proc. GIS/LIS* (Cincinnati, USA) 677-685
[24] Denisova A Y and Sergeev V V 2015 Impulse response identification for remote sensing images using gis data *Computer Optics* **39(4)** 557-563 DOI: 10.18287/0134-2452-2015-39-4-557-563
[25] Belim S V and Larionov S B 2016 An algorithm of image segmentation based on community detection in graphs *Computer Optics* **40(6)** 904-910 DOI: 10.18287/2412-6179-2016-40-6-904-910

[26] Gadia S K and Yeung C S 1988 A generalized model for a relational temporal database *Proc. of ACM SIGMOD International Conference on Management of Data* 251-259

[27] Vorobiova N S, Sergeyev V V and Chernov A V 2016 Information technology of early crop identification by using satellite images *Computer Optics* **40(6)** 929-938 DOI: 10.18287/2412-6179-2016-40-6-929-938

[28] Sharapov R 2015 Visualization of the karst development dynamics by spatial-temporal maps *Proc. 15th International Multidisciplinary Scientific GeoConference SGEM* **2(1)** 913-920