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Problems of Implementing Web GIS Technologies for Processing, Analysis and Visualization of Geophysical Data

A. V. Vorobev[1,2], **G. R. Vorobeva**[2]

[1]Geophysical Center of the Russian Academy of Sciences, Moscow, Russia
[2]Ufa University of Science and Technology, Ufa, Russia
* **Correspondence to:** Vorobev A. V., geomagnet@list.ru

Abstract: The modern trend towards widespread use of software and tools for processing geospatial (including geophysical) data for a wide range of consumers contributes to the development of web-oriented solutions to the associated problems. A special complexity in the context of program implementation as well as the client computing capabilities is the visualization of geospatial information, which in the web environment is associated with the need to ensure acceptable rendering reactivity, on the one hand, and spatial image quality, on the other. Two main problems can be highlighted here: spatial image artifacts that appear as breaks in level lines, and the impossibility of technically combining heterogeneous spatial primitives into a single layer for retrospective dynamic visualization. The paper is concerned with the solutions to eliminate the above problems using geostatistical models and methods, as well as web design algorithms, patterns, and technologies. Using a web GIS for visualizing geophysical parameters as an example, the operability and effectiveness of the proposed software and algorithmic solutions are confirmed.

Keywords: geophysical data, geoinformatics, data visualization, spatial layers, spatial isolines.

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1. Introduction

Modern geoinformation technologies provide solutions to a wide range of problems concerned with processing, analysis and visualization of geophysical data [*Gorokhov et al.*, 2021; *Papadakis et al.*, 2022]. However, the majority of GIS solutions are implemented as desktop applications, which significantly limits the possibilities of their use in development, especially for web-oriented applications.

One of the common approaches to visualizing spatial data in general and geophysical data in particular supposes generation of contour lines. There are libraries, services, and APIs that perform such a transformation of the spatial data for web applications, both on the client side and on the server side [*Kumari et al.*, 2022]. However, the increase in the volume and complexity of data lead to the fact that the formation of an array of isolines using known libraries is usually accompanied by visual artifacts, which complicate the analysis of the spatial distribution of the parameters, on the one hand, and reduce the quality of rendering the spatial image, on the other.

Another problem of programming visualization of geospatial data is the low efficiency and limitation of frame-by-frame change of spatial layers with a time reference. There can be outlined the impossibility of synchronous switching of a group of spatial layers by a time parameter, which negatively affects the results of assessing the temporal anisotropy of the spatial data [*Pakdil et al.*, 2021; *Podany et al.*, 2022].

In this regard, there is a need to develop algorithmic and programming solutions that provide highly responsive web-oriented visualization of geospatial (geophysical) data

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in the format of spatial isolines, allowing retrospective frame-by-frame processing of the corresponding layers, on the one hand, and free of visual artifacts during rendering, on the other.

2. State of art

It is reasonable to consider the problem of visualizing geophysical data as a set of spatial isolines. When visualizing spatial isolines on a cartographic base, they may be accompanied by so-called artifacts – visual distortions of spatial lines that complicate their analysis and interpretation. They may be caused by both the imperfection of algorithms and programming libraries for constructing spatial contour lines, as well as the limited capabilities of visualization tools, taking into account the reactivity of applications, rendering speed, projection, etc. [*Kachanov et al.*, 2016; *Traxler et al.*, 2017]

So, the problem of eliminating these artifacts can be defined as the detecting of open contour lines by comparing the number of pairs of spatial points and the segments connecting them. It is necessary to complete the contour line connecting the corresponding extreme spatial points. Here two main approaches are possible: the missing points can be built by one of the interpolation methods, or an approximation function obtained analytically can be used. In the case of using the first of the mentioned approaches, it seems reasonable to analyze the spatial anisotropy of the original data to determine the interpolation method that best takes into account such variability.

Another highlighted artifact is the “noise” in spatial contour lines, which is largely determined by the insufficient number of initial spatial points, which attribute values are implemented with algorithm of contour lines generating. The spatial isoline is built along the basic regular grid, in the nodes of which the initial spatial points with the corresponding attribute values are placed. If the number of initial points does not coincide with the number of nodes of the spatial grid modeled for visualization, then an isoline is formed that fragmentarily repeats the lines of its rectangular cells, resulting in “kinks” characteristic of such an isoline. To solve the problem, it is necessary to apply a filter to the generated spatial isolines. In this case, the use of smoothing filters should be performed in accordance with the features of the spatial distribution of the processed data.

Another problem of geoinformation programming libraries in the visualization of geospatial data is the low efficiency and limitation of frame-by-frame changes of a group of spatial layers with a time reference. Among the most significant difficulties of visualization, there can be outlined the impossibility of synchronous switching of a group of spatial layers by a time parameter, which negatively affects the results of assessing the temporal anisotropy of the spatial data.

3. An approach to eliminating contour artifacts in geophysical data

To eliminate artifacts expressed by the gaps in spatial contour lines, it is proposed to connect them together. It is obvious that connecting spatial contour lines is possible only if they correspond to the same level value. Therefore, at the initial stage, it is necessary to combine the available spatial contour lines into groups based on the value corresponding to each of them [*Sun et al.*, 2019]. For each group of contour lines, a sequential search procedure is performed in order to identify open contour lines whose start and end points do not coincide. For each open contour lines, a search is performed for another open line in the same group, and from the set of available ones, the one with the shortest distance from the original is selected. A pair of selected open contour lines is connected, forming one closed spatial isoline. Similar actions are performed for all open contour lines in each group.

A formal distinction is made between two types of gaps in spatial contour lines. A gap of the first type occurs if the end point of an arbitrarily selected fragment of a polyline does not coincide with the start point of the nearest fragment following the fragment of the polyline under consideration (and vice versa). To eliminate a gap of this type, it is necessary to connect the start and end points of adjacent fragments in a sequence, supplementing the contour line with synthesized fragments. In this case, intermediate points are introduced to avoid additional artifacts. A gap of the second type occurs if the start and end points of a contour line do not coincide. To eliminate this gap of break, two solutions are proposed: to close the open isoline on itself or to connect it with the nearest open contour line of the same level [*Prince Czarnecki et al.*, 2022].

It is necessary to introduce descriptions of the initial isoline:

$$(x_1y_1, x_2y_2, x_3y_3, \dots, x_{n-2}y_{n-2}, x_{n-1}y_{n-1}, x_ny_n),$$

and the spatial contour line closest to it:

$$(x'_1y'_1, x'_2y'_2, x'_3y'_3, \dots, x'_{n-2}y'_{n-2}, x'_{n-1}y'_{n-1}, x'_ny'_n).$$

Here there are possible options for connecting pairs of open isolines.

1. Connecting the initial point of the source and the initial point of the spatial isoline closest to it:

$$(x_ny_n, x_{n-1}y_{n-1}, x_{n-2}y_{n-2}, \dots, x_3y_3, x_2y_2, x_1y_1),$$
$$(x_ny_n, x_{n-1}y_{n-1}, x_{n-2}y_{n-2}, \dots, x_3y_3, x_2y_2, x_1y_1,$$
$$x'_1y'_1, x'_2y'_2, x'_3y'_3, \dots, x'_{n-2}y'_{n-2}, x'_{n-1}y'_{n-1}, x'_ny'_n).$$

2. Connecting the end point of the initial and the end point of the isoline closest to it:

$$(x'_ny'_n, x'_{n-1}y'_{n-1}, x'_{n-2}y'_{n-2}, \dots, x'_3y'_3, x'_2y'_2, x'_1y'_1),$$
$$(x_1y_1, x_2y_2, x_3y_3, \dots, x_{n-2}y_{n-2}, x_{n-1}y_{n-1}, x_ny_n,$$
$$x'_ny'_n, x'_{n-1}y'_{n-1}, x'_{n-2}y'_{n-2}, \dots, x'_3y'_3, x'_2y'_2, x'_1y'_1).$$

3. Connecting the starting point of the initial and ending points of the isoline closest to it:

$$(x'_1y'_1, x'_2y'_2, x'_3y'_3, \dots, x'_{n-2}y'_{n-2}, x'_{n-1}y'_{n-1}, x'_ny'_n,$$
$$x_1y_1, x_2y_2, x_3y_3, \dots, x_{n-2}y_{n-2}, x_{n-1}y_{n-1}, x_ny_n).$$

4. The connection of the end point of the initial and the starting point of the isoline closest to it:

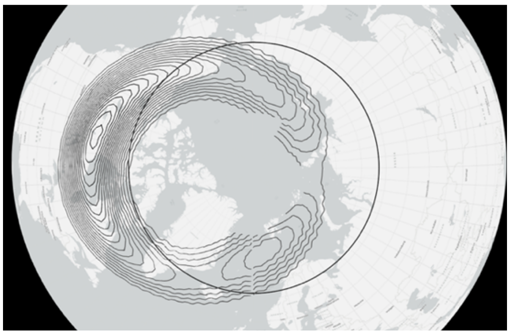
$$(x_1y_1, x_2y_2, x_3y_3, \dots, x_{n-2}y_{n-2}, x_{n-1}y_{n-1}, x_ny_n,$$
$$x'_1y'_1, x'_2y'_2, x'_3y'_3, \dots, x'_{n-2}y'_{n-2}, x'_{n-1}y'_{n-1}, x'_ny'_n).$$

To maintain a balance of distance between points, it is necessary to determine the points in the middle of the segment connecting the points of the initial and the closest open contour lines:

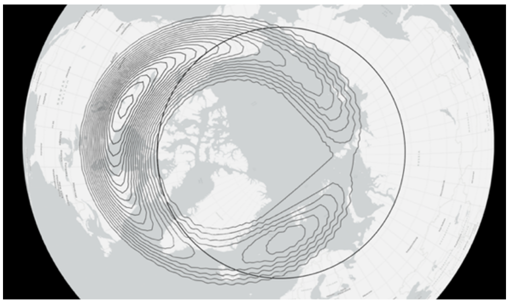
$$B_x = \cos\varphi_2 \cdot \cos\Delta\lambda,$$
$$B_y = \cos\varphi_2 \cdot \sin\Delta\lambda,$$
$$\varphi_m = \operatorname{atan2}\left(\sin\varphi_1 + \sin\varphi_2, \sqrt{(\cos\varphi_1 + B_x)^2 + B_y^2}\right);$$
$$\lambda_m = \lambda_1 + \operatorname{atan2}(B_y, \cos\varphi_1 + B_x),$$

where φ_1, λ_1, φ_2, λ_2 are latitude and longitude of the starting and ending points, m is the index of the midpoint on the line connecting the starting and ending points.

The proposed method and algorithm for eliminating spatial isoline artifacts were implemented for the web application "Aurora-forecast" (https://www.aurora-forecast.ru), developed to visualize geophysical parameters in the auroral oval area. The spatial isolines array is generated on the server side using Python scripts [*Figueiredo et al.*, 2021; *Horbiński et al.*, 2020a]. For clarity, Figure 1 shows the results of visualizing the spatial isolines layer in two cases: generating an array of spatial contour lines based on the original data (Figure 1a) and visualizing isolines after detecting and eliminating artifacts [*Vorobev et al.*, 2020; 2021; *Vorobev et al.*, 2022a; *Vorobev et al.*, 2022b] (Figure 1b).



(a)



(b)

Figure 1. An example of visualization of spatial isolines in the application "Aurora-Forecast".

4. An approach to constructing a retrospective spatial layer

The formation of a geospatial image from heterogeneous spatial data can be described as follows [*Breunig et al.*, 2020; *Chen et al.*, 2013; *Dintu et al.*, 2022; *Ma*, 2017; *Zhu et al.*, 2019]. First, it is necessary to bring data to a single discretization step, which requires defining the rules for converting the time intervals taking into account the units of measurement used, which, in turn, may differ. At the second (optional) stage, it is necessary to bring the processed spatial data to a single coordinate system, since data coming from different sources are not necessarily presented in the same coordinate system. If the coordinate systems used are the same, this stage is skipped. Then, all geospatial primitives used in the processed data are identified, the rules for their transformation and reduction to a single graphic primitive are determined to form an integrated spatial layer.

The most difficult problem here is concerned with transforming some geospatial primitives into others used in the target layer. The task of forming a target spatial layer from the obtained group of layers should be reduced to the use of a single geospatial primitive in each of the initial data, for example, a spatial point, where the transformation rule is generally specified by the function [*Alkaradaghi et al.*, 2022; *Yu et al.*, 2018; *Zhang et al.*, 2019]:

$$f_{lp} = l \rightarrow p = \{\text{lat}\} \rightarrow \{\text{pat}\} : p = \{x, y, (z)\}\,;$$
$$l = \{\{x_1, y_1, (z_1)\}, \ldots, \{x_n, y_n, (z_n)\}\}\ ,\ n \in \mathbb{N}.$$

Since in the initial version the attribute and time parameters were tied to the spatial polyline as a whole, when decomposing the polyline into points it is necessary to perform their redistribution [*Mohd Napi et al.*, 2021; *Peuquet et al.*, 1995]:

$$l_T = \{x_1, y_1, (z_1), a_1, t_1\}, \ldots, \{x_n, y_n, (z_n), a_1, t_1\}, \ldots, \{x_1, y_1, (z_1), a_D, t_D\}, \ldots, \{x_n, y_n, (z_n), a_D, t_D\},$$

where l_T is the transformed polyline, $t_i (i = 1, \ldots, D)$ is a generalized time parameter integrating the sampling steps for data sets X and Y with coefficients c and e respectively.

If the initial data X and Y are represented by spatial points and polygons, then the corresponding transformation of the layer group into the target layer is the following [*Oswald Beiler et al.*, 2021; *Rachmatullah et al.*, 2017; *Yu et al.*, 2018]:

$$r_T = \{x_1^1, y_1^1, (z_1^1), a_1, t_1\}, \ldots, \{x_n^m, y_n^m, (z_n^m), a_1, t_1\}, \ldots, \{x_1^1, y_1^1, (z_1^1), a_D, t_D\}, \ldots, \{x_n^m, y_n^m, (z_n^m), a_D, t_D\},\ \ m, n \in \mathbb{N}.$$

Similarly, taking into account the spatio-temporal binding of the polygon, there can be defined a redistribution as follows [*Oswald Beiler et al.*, 2021; *Rachmatullah et al.*, 2017; *Yu et al.*, 2018]:

$$r_T = \{x_1^1, y_1^1, (z_1^1), a_1, t_1\}, \dots, \{x_n^m, y_n^m, (z_n^m), a_1, t_1\}, \dots, \{x_1^1, y_1^1, (z_1^1), a_D, t_D\}, \dots, \{x_n^m, y_n^m, (z_n^m), a_D, t_D\},\ m, n \in \mathbb{N},$$

where $t_i (i = 1, \dots, D)$ is the a generalized time parameter integrating the sampling steps for data sets X and Y with coefficients c and e respectively.

A spatial polyline is a basic geospatial primitive and is widely implemented, including programming libraries. A spatial polyline typically has a "LineString" attribute in its metadata, as is seen, for example, in the GeoJSON format, which has become the de facto standard for representing geospatial information as spatial layers [*Moins et al.*, 2016]. Here it is appropriate to formalize the expressions [*Ding et al.*, 2021; *Horbiński et al.*, 2020b; *Moins et al.*, 2016; *Oswald Beiler et al.*, 2021; *Rachmatullah et al.*, 2017]:

$$f_{pl} = p \rightarrow l : p = \{x, y, z, a, t\}; l = \{p,\ p\} = \{\{x, y, z\}, \{x, y, z\}, a, t\};$$
$$f_{pr} = p \rightarrow r : p = \{x, y, z, a, t\}; r = \{p,\ p, p\} = \{\{x, y, z\}, \{x, y, z\}, \{x, y, z\}, a, t\}.$$

The quality assessment of the proposed solutions was performed at the level of its programming implementation. Within the framework of the developed research prototype of the web application, a variant of three-dimensional visualization of an integrated layer constructed from three sets of spatial data taking into account the specified timestamps was presented (Figure 2).

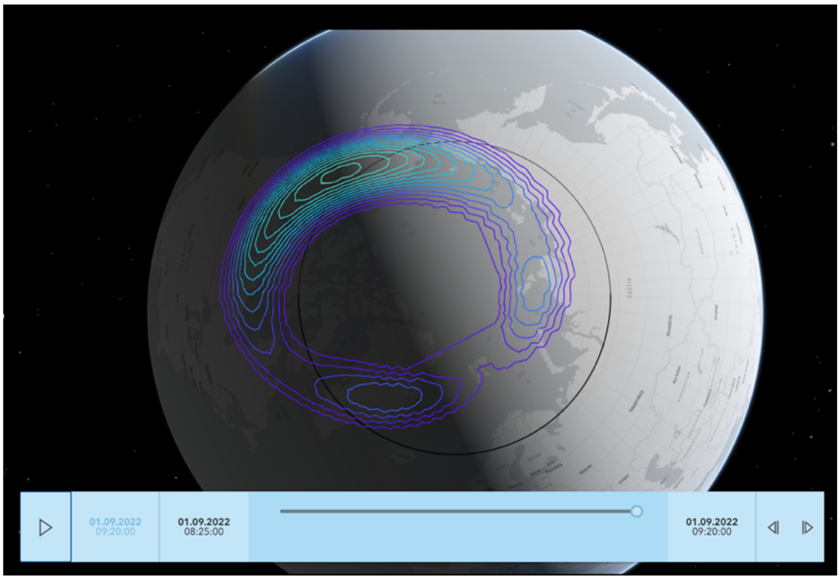


Figure 2. Screenshot of the application.

5. Conclusion

The problem of programming processing of spatial data in the context of modern technological development and exponential growth of volumes and complexity of such information is becoming especially relevant in the development of information systems for decision support in applied areas. Tendencies towards widespread distribution of relevant programming tools for a wide range of users contribute to the development of web-oriented solutions for such a problem. At the same time, developers face a number of problems in the implementation of relevant programming solutions that distort the visual representation of spatial data, on the one hand, and negatively affect the responsiveness of existing web applications, on the other.

The authors propose a method and algorithm for identifying and eliminating spatial isoline artifacts. It is based on the process of step-by-step detection of open isolines and determining the closest ones to them to form a closed contour line. In this case, various options for connecting polylines by starting and ending points are considered in such a way as to prevent new artifacts (by calculating and placing intermediate points).

In addition, an approach is proposed that involves the formation of a single integrated spatial layer based on a group of heterogeneous spatial layers. A method for mutual transformation of geospatial primitives is proposed, allowing spatial data to be converted to a given graphic object regardless of its original characteristics without losing attributive and temporal information. The novelty of the method lies in its universality in relation to vector graphic data, which will allow, after software implementation, to apply it in addition to known geoinformation libraries and tools.

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