Virtual story in cyberspace: Valley of Geysers, Kamchatka

UNESCO Natural Heritage Site in Cyberworld

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***Abstract* — Virtual 3D model of the Valley of Geysers, Kamchatka provides virtual travelling and interactive storytelling in the cyberspace and serves for scientific visualization, geodynamical processes modeling, disaster preparedness and response, environmental studies, ecological education, and virtual ecotourism.**

Heritage in cyberspace; Shared virtual worlds; Virtual collaborative spaces; Mixed and virtual reality; Cyberworlds and their impact on the real worlds; Neogeography; Virtual story; Situational awareness; Valley of Geysers, Kamchatka

I. Introduction

This paper presents the project of developing virtual model of the Valley of Geysers, Kamchatka [1-4]. Methods of neogeography, virtual environment and situation awareness are used to build geo-referenced 3D model and provide free access for virtual traveling and interactive storytelling in the cyberspace. The model can serve for scientific visualization, geodynamical processes modeling, disaster preparedness and response, environmental studies, ecological education, and virtual ecotourism. Two versions of the model are available: open Internet model and detailed 3D model for stereo projection systems. Both versions are developed on the same base and will be combined in the future as more personal 3D displays become available. The project is aimed at development of approaches for building virtual natural heritage environments.

The Valley of Geysers is one of the largest geyser fields in the world and the only one in Eurasia [5]. It is located in the Kronotskiy State Natural Biosphere Reserve on Kamchatka peninsula, Russia, that is a part of UNESCO World Heritage Site "Volcanoes of Kamchatka". Dozens of geysers and other springs are concentrated in an extremely hard to access canyon of the Geysernaya River in the central eastern part of Kamchatka, 20 km away from the Pacific Ocean coast, Fig.1. The Valley of Geysers was discovered only in 1941 by Kronotskiy reserve geologist Tatyana Ustinova and observer Anisifor Krupenin. Since then it became a renowned tourist destination in Kamchatka. In 2008 the Valley of Geysers was voted as one of seven Wonders of Russia (along with the Baikal Lake, Mt. Elbrus and Man-Pupu-Ner rock pillars).

The project addresses fundamental scientific problem of ecological monitoring of natural and technical disasters using modern methods of geodata visualization. It will allow developing methods of geodata modeling and visualization in a cyberspace of geo-referenced 3D model for clear visual representation of complex volumetric and dynamic data and effective interdisciplinary communication of researchers from different branches of science.

II. Relevancy

Only several thousand people visit the Valley of Geysers every year because of its remote location and reserve status. It is a tiny percentage of people who would like to see it. Tourist routes from the south (P.-Kamchatskiy city) and from the north (Klyuchi) are very difficult. Tourist route from the ocean coast (Zhupanovo cordon) was popular in Soviet time but is not supported now. Only helicopter tours are available now with a technical limit of 2-3 thousand tourists per year. Even recovery of tourist routes cannot raise attendance of the Valley of Geysers to more than several thousand people per year. Unlike geysers of Yellowstone, Iceland and New Zealand that are available to visit by car, the Valley of Geysers in Kamchatka always was hard-to-reach and low-attended tourist attraction and will remain the same in the nearest future. It makes creation of free-access virtual model of this place and development of virtual tourism very relevant.

The Valley of Geysers has seriously suffered from the landslide on June 3, 2007. About a half of all geysers were buried in the landslide and flooded with the landslide-dammed lake [6]. Only by chance no people had been injured. The landslide had not damaged lodges and the central part of the Valley with the most popular Stained Glass geyser spot and the largest geyser Giant. At the same time, the landslide had buried the Triple geyser group (the one with the largest geyserite shield), the dammed lake had flooded the Lesser geyser (the one with the largest water discharge). The Firstborn geyser (the first one discovered in 1941) was buried with debris and become a pulsating spring. Debris flow buried 30-m waterfall at Waterfall creek and 30-m rocks called "Triumph Gates" in a lower part of the canyon. Natural disaster damaged badly not only tourist attractions in the Valley of Geysers but also unique natural objects of great scientific interest. Unfortunately new landslides will definitely affect this region in geological scale of time. Analysis of landslide danger reveals high possibility of new landslides in the Valley of Geysers [7]. It makes relevant landslide hazard analysis, monitoring, modeling and forecast based on detailed virtual model.

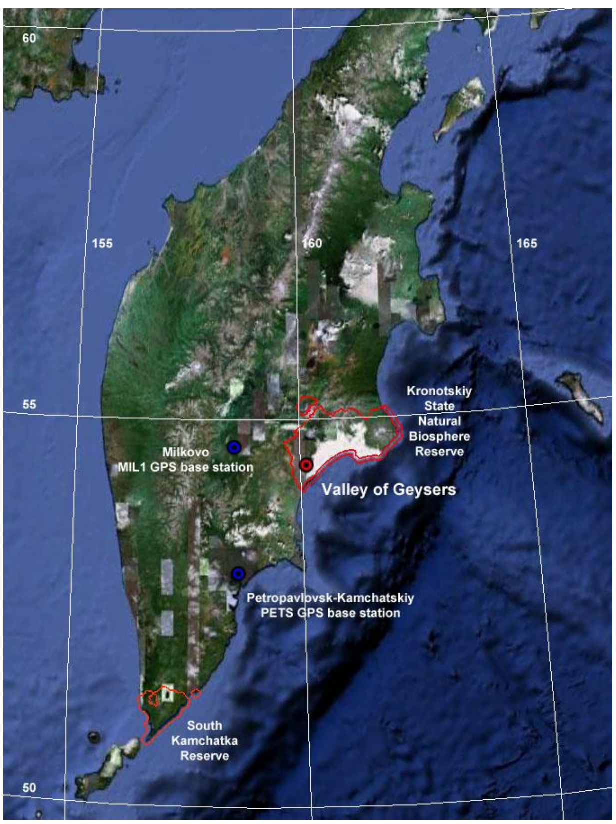

Figure 1. Kamchatka peninsula, Kronotskiy reserve borders and the Valley of Geysers. Reference GPS base stations are also shown.

As the unique natural object and a part of UNESCO World Heritage changes irretrievably due to natural processes, it can be reconstructed and preserved in a form of virtual model. In the same way as antique towns and architectural monuments are reconstructed in a digital form as a "Virtual Cultural Heritage Site", natural object can be preserved in a digital form as a "Virtual Natural Heritage Site". Detailed reconstruction using neogeography and virtual environment technologies allows saving a lot of visual information about the place and its dynamics. It will help in developing the methods of building virtual natural heritage environments for digital reconstruction of natural objects affected by natural processes or human activity. Development of "Virtual Natural Heritage" in a form of free-access cyberspace with virtual models of cultural, architectural and natural attractions should be a major field of activity for any country that wants to expand its culture and develop its image around the world. It makes relevant detailed digital reconstruction of unique natural attractions such as the Valley of Geysers.

III. Goals

Project is aimed at developing open virtual 3D model of the Valley of Geysers and its future expansion to include the whole area of the Uzon-Geysernaya volcano-tectonic depression. The model is intended for scientific visualization, ecological education, landslide modeling and other scientific, ecological and educational tasks. The following goals are outlined for the first stage of the project.

- Development of detailed geo-referenced base (virtual landscape), including digital elevation model (DEM) and satellite imagery; precise positioning of the objects in ITRF/WGS84 coordinate systems.
- Development of database with information about geo-referenced objects, including text descriptions, actual and archive photos, panoramas, 2D video, 3D video, and vector models.
- Development of model visualization tools for free internet access (based on KML data format and free digital earth models) and for stereo projection systems (based on Open Scene Graph and Avango).
- Development of vector 3D models and other tools for volumetric scientific data visualization, including geological structures, seismic data, biological and ecological information.
- Building interactive stories in a cyberspace of the model, development of 4D animation (3D + time) of natural processes and object dynamics, creating avatars in a space of the model.
- Numerical modeling of landslide with use of detailed DEM and smoothed particle hydrodynamics (SPH) methods, landslide hazard monitoring and forecasting, research of disaster response scenarios.

IV. Methods and Approaches

Our approach to the model development is based on the modern methods of geodata visualization, including approaches of neogeography, virtual environment, interactive storytelling, and situation awareness.

Neogeography means "new methods of visualization of geodata". This term primary refers to using free geo-referenced satellite imagery and DEMs of high resolution, real coordinate systems ITRF/WGS84, open KML data format, multi-scale digital earth model, interactive objects with hyperlinks and embedded information, 3D and 4D geo-referenced models, collaborative work over Internet, permanent updating of model as a “live document”. These principles made Google Earth geo-service extremely popular, as it became the first "neogeography" implementation in a form of open software tool. Other similar tools are also available such as ERDAS Titan, etc.

Virtual environment (VE) means computer-simulated interactive 3D environment that allows user to feel “immersed” in the cyberspace. VE provides natural interface to the space of the model so that user interaction with a model can be similar to user behavior in real world. This activates emotions and free associations of the user as well as logical and language-based perception and thus provides “immersion” effect. VE allows understanding of abstract constructions and large amounts of complex data in a form of simple and visually meaningful 3D models and provides user-friendly and intuitive interaction with huge digital data arrays. Practical VE implementations are widely represented by “mixed reality” applications (Paul Milgram, 1994). It is either augmented reality (virtual objects embedded in real environment, especially 3D models) or augmented virtuality (real objects embedded in virtual space, especially 3D video of real persons or objects). Embedding 3D video of geysers and animals in a virtual landscape is one of the main ideas of our virtual model.

Interactive storytelling, or virtual story, means a way to organize interaction between user and virtual environment. Indeed, almost any virtual environment represents a combination of entertainment (game) and substantial information flow. The more freedom the user has – the more difficult it gets to concentrate his/her attention on substantial information. This so-called “narrative paradox” is the main issue to solve in any edutainment system. Interactive story is a way to give some freedom to the user in the cyberspace but at the same time to provide some scenario of his travel in virtual world. It is a plot of meaningful events, or points, where user must do some actions or receive substantial information. At the same time user has some freedom of movement between events and freedom of choosing his way through the plot [8]. Scenario (plot) is a main feature of the virtual story in cyberspace. On one hand, it provides less freedom to the user of virtual model, but on the other hand it guarantees that comprehensive amount of information will be received by the user from a story.

Situation awareness (SA) means “the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (Mica Endsley, 1995). To say simple, it is an approach to handling data referring some situation. SA approach includes the following steps: collect all meaningful data referring situation under research, represent all data in the common cyberspace, understand data in a comprehensive and synthetic manner, forecast situation dynamics for the nearest future, and plan your activity and group actions. Distributed situation awareness (DSA), or shared situation awareness, means SA applications for multiple users. Situation awareness is a goal of building any decision support system. Virtual 3D model of the natural object in a cyberspace implements DSA principles as it allows users to get comprehensive data about the object and forecast its dynamics.

V. Virtual Landscape

Virtual landscape in our model is based on multispectral satellite image GeoEye-1 of 06.09.2009 with a resolution 0.5 m and digital elevation model (DEM) with a resolution of 2.5 m. DEM is built on Cartosat satellite stereo pair of 19.09.2007. Imagery and DEM courtesy by R&D Center ScanEx, Moscow and GeoEye Foundation.

Rough geo-referencing of the model has been done using open SRTM 90 m DEM. Precise geo-referencing of the model was made using satellite positioning (via GPS) in the region of the Valley of Geysers in Sep 2009. Finally the model was positioned in ITRF/WGS84 coordinate systems with decimetric accuracy that corresponds to the model resolution.

Field GPS positioning included the following steps. First, we chose appropriate points on the image with linear dimensions about 0.5 m (i.e. similar to the resolution of the image). It was not possible to make special markers on the territory before satellite photography because of reserved status of the region. So we used only existing points like infrastructure elements (especially helicopter pads marking and paths crossings) or natural objects (especially detached stones), Fig.2. Second, we measured coordinates of the chosen points with an absolute accuracy of about 0.1 m.

Figure 2. Choosing a point for GPS positioning.

Field works were performed on Sep 18-22, 2009. We used dual-frequency GPS receiver Trimble 5700 and Trimble Zephyr Geodetic antenna (courtesy by Navgeocom Engineering, Moscow). Data were processed in Trimble Business Center software tool. To achieve decimetric accuracy we implemented differential corrections using two GPS base stations of Kamchatkan Geophysical Dept. of

Geophysical Service of RAS (MIL1 at about 105 km distance) and Geophysical Service of RAS (PETS at about 185 km distance), Fig.1.

As a result, ITRF/WGS84 coordinates of twelve points were measured with an accuracy of about 10 sm [9]. Using these data we accurately positioned virtual landscape and thus prepared geo-referenced base for the model.

VI. Database with Georeferenced Objects

Several dozen objects were chosen for the first stage of the model. Objects were grouped by classes (geysers, springs and thermal features, other natural objects, lost objects, infrastructure, and locations). Each object is positioned using geo-referenced virtual landscape and thus accurate coordinates of each object are defined. Information about objects includes texts, photos and panoramas, 2D and 3D videos.

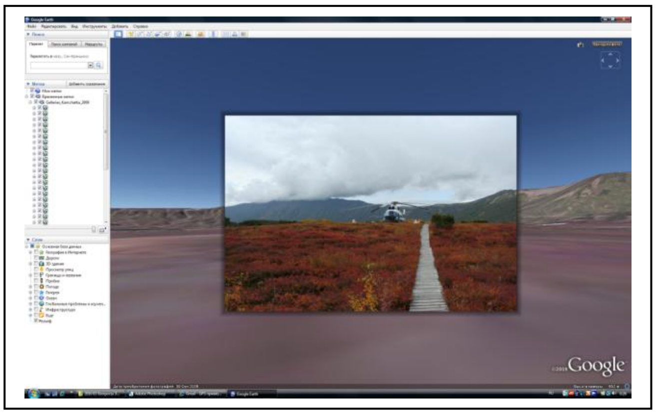

Figure 3. Georeferenced photo in Google Earth interface.

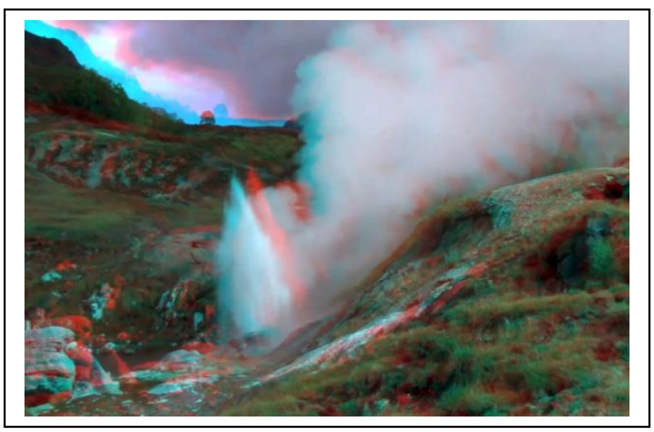

Figure 4. Stereo video of the Pearl geyser (anaglyph mode).

Text descriptions are done in Russian and English languages and adopted to voice synthesis (text-to-speech). Text is primary used in Internet version of the model, while synthesized voicing of the text is intended primary for the model representation in 3D virtual environment.

Recent and archive photos are being collected from different professional and amateur sources as well as from our own expeditions. Some photos are geo-referenced not only by location but also by azimuth and angle of shot, Fig.3. Panoramic (360 degrees) photos were taken during Sep 2009 field works along all tourist paths in the Valley with a step of 25 m. These data will be used to implement “Street View” technology and allow one more way of virtual travel through the Valley. Photos are used mainly in Internet version of the model.

Figure 5. The model in Google Earth client interface.

Stereo video of main geysers (Giant, Greater, Pearl, Crack and some others) was filmed in Sep 2009. We used two digital HDTV cameras Canon XH G1 with a basis of 120 mm (minimal basis allowed by cameras dimensions). Cameras were synchronized by GenLock. Video format is HDV 1920x1080 50i. More than 7 hours of stereo video was filmed and used for making stereo clips on individual objects as well as full 3D movie about the Valley, Fig.4. 3D videos are embedded in virtual environment representation of the model using “mixed reality” approach. 3D videos in anaglyph mode and 2D versions of the same videos are used in Internet model.

VII. Internet Model

Internet version of the model is created using KML data format that is openly available. Model is developed in Google Earth client software, Fig. 5. Landscape is modeled using open SRTM 90 m DEM and precisely positioned GeoEye-1 0.5 m satellite image. Unfortunately embedding more precise DEM in the model is not available in Google Earth. Several data layers are presented in the model including geo-referenced information from the database as well as additional data (image overlays and vector models).

KML model is integrated in the website www.valleyofgeysers.com using Google Earth plug-in, Fig.6. Control menu for the web interface is developed additionally in JavaScript. The menu is generated automatically on the model web page using information about KML file structure. The menu allows model control and switching on/off visibility of different layers and objects. Web site is optimized for Mozilla Firefox 3.6 and also tested in Internet Explorer 7 and 8 and Google Chrome.

Internet model includes the following data layers:

- Descriptions of geo-referenced objects from the database (Placemarks)

- Geo-referenced photos and 360° panoramas (Photo Overlays)
- Raster images (topographic maps 1:200 000, 1:10 000, 1:2 000, geology maps, landslide hazard schemes), manually positioned on the landscape model (Ground Overlays)
- Vector models of rivers, paths, routes etc. (Paths)
- 2D vector models of lake and inner locations (Polygons)
- 3D vector models of geological structures and infrastructure elements
- 4D vector model (animation) of the 2007 landslide (Polygons + TimeSpan tags)

Open servers are used to store photo and video files (photofile.ru, picasaweb.google.ru, youtube.com), as well as our own servers. KML model includes only hyperlinks to large photo and video data files, thus model size is quite small (50 Kb). It makes it easy to send or download the model file, but comfortable browsing of the model requires broadband Internet connection.

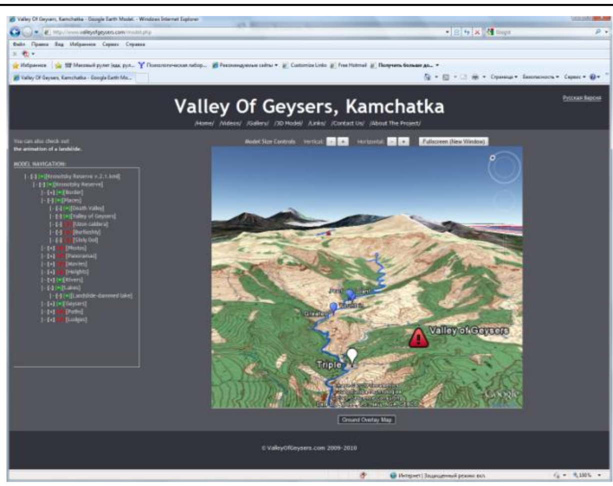

Figure 6. The model in web-site interface (Google Earth plug-in).

The main drawback of the Internet model is rough DEM. Google Earth uses SRTM 90 m and no user refinement of the DEM is allowed yet in publically available Google Earth tools (Basic and Pro). Google Earth Enterprise software is not officially sold in Russia. Rough visualization of the landscape decreases the quality of the model representation significantly.

VIII. 3D Model in Virtual Environment

Detailed 3D model in virtual environment is developed in Open Scene Graph (OSG) software. This version of the model is intended for presentation on stereo projection systems and 3D displays. Precise DEM 2.5 m and GeoEye-1 image 0.5 m are used to reconstruct landscape of the Valley. Model can be presented as a stand-alone scene in OSG with a panoramic photo on the backplane, Fig.7, or as an embedded region of the digital globe, Fig.8. Model is precisely positioned on the globe using GPS survey data discussed above.

Geo-referenced information from the database is presented in the 3D model as interactive markers. Primary data to be represented in the 3D model are 3D videos of geyser eruptions ("augmented virtuality" approach) and synthesized voicing of the text descriptions. User can travel through the model using 3D mouse (3D Connexion). Digital globe allows user to be free in his/her movement and not to be limited by the model scene. Adding interactive story scenario to the 3D model provides comprehensive virtual travel experience over the Valley.

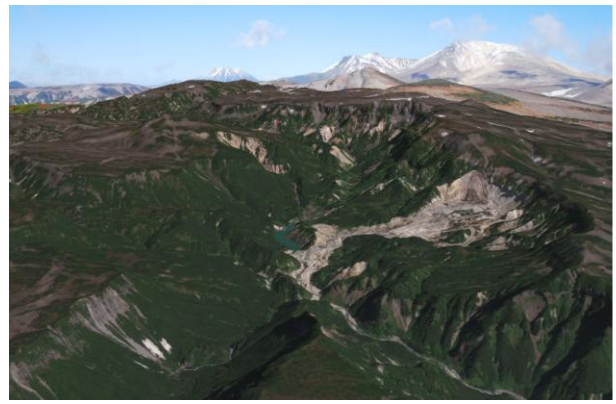

Figure 7. Stand-alone virtual landscape (panoramic photo on the back).

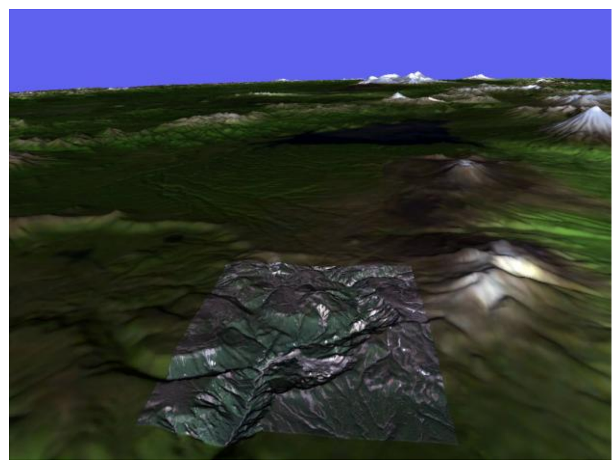

Figure 8. Virtual landscape embedded in the digital globe.

"Immersion" effect of the 3D model in virtual environment is much stronger than in Internet version of the model. But availability of stereo visualization devices like stereo projection systems and 3D displays is still limited for most users. As more stereo displays will be used, 3D version of the model will become more publically available. For now, 3D model is intended for presentation on stereo projection system in the museum of Kronotskiy State Natural Biosphere Reserve for virtual tours in the Valley of Geysers.

IX. Landslide Modeling

One of primary scientific tasks of the model is landslide modeling on the virtual landscape and landslide hazard forecasting. First, we have created animation of the 2007 landslide using expert estimations of its characteristics, Fig.9. Second, we have been developing numerical model of the landslide using precise DEM and smoothed particle hydrodynamics (SPH) methods on the CUDA (Compute Unified Device Architecture) computing engine.

A set of geodata available for the region of the Valley of Geysers provides an excellent foundation for landslide modeling. The region topography and geological structure is well researched. Stereo aerial photography imagery is available for the period since 1970s. It makes possible the reconstruction of detailed DEM of the region before the landslide [10]. DEM of the region after the landslide is already reconstructed.

The 2007 landslide in the Valley of Geysers was the largest landslide in Kamchatka in historical period. The landslide body and debris flow were spread over the complex landscape with multiple variations in the flow width, changes of the main movement direction and formation of several lateral toes. As a result, the landslide finally took the complex branched shape in a canyon of the Geysernaya River. It provides a unique opportunity for numerical modeling of the landslide and comparison of the model results with actual data.

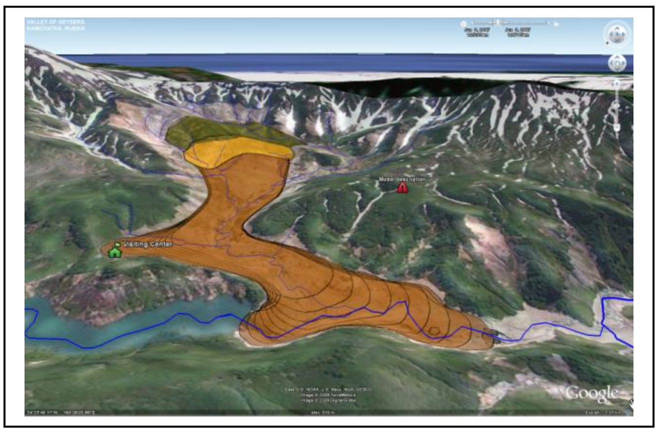

Figure 9. Animation of the 2007 landslide (expert estimations).

The animation of the landslide uses 2D polygons representing consequent landslide positions with a step of 15 sec. Each polygon is visible for the time period defined in TimeSpan tag. Two main bodies of the landslide and main debris flow are reconstructed in the animation in real time. Dammed lake formation, river breaking through the dam and new river course formation are reconstructed in non-real time to achieve combination of different time scales (several minutes and several days) in one animation.

Next step of the modeling includes: developing of the numerical model of the flow using precise DEM data; performing calculations on the CUDA engine; visualization of calculations results in the cyberspace of the model; and adjustment of the model variables to achieve correspondence with actual data about the landslide dynamics and its final shape. The goal of this step is to define a parameter space where the model results correspond to actual data.

This way of modeling does not use any data about real rock features. It is based only on visual representation of an abstract numerical model. But we suppose that correspondence between model results and actual data in this case allows us to use the model as one of acceptable methods for landslide hazard forecasting and disaster response planning in this particular region. Exploring relations between model variables and real rock features could be a topic of an additional research.

X. Conclusions

Building virtual model of the Valley of Geysers in cyberspace is a task of great scientific and cultural importance. It allows free virtual travel to the UNESCO World Heritage Site that has restricted opportunities for physical attendance and provides open cyberspace for scientific data visualization and natural disaster modeling. For now, the model is being developed in two versions, one for free Internet access (based on the open KML data format) and another for 3D virtual environment systems (created using free OSG software).

Methods and approaches presented in the article demonstrate the use of neogeography and virtual environment technologies for building virtual models of complex natural objects and virtual stories in cyberspace of the models. They can be used for developing virtual tourism applications for reserved and hard-to-access tourist attractions, supporting ecological education and environmental research, complex geodata visualization in open cyberspace, modeling of natural disasters and disaster response scenarios.

Future plans for the model development include:

- Developing landscape model, adding vegetation and water surface models.
- Adding information to the database, developing 3D models of infrastructure.
- Building interactive stories and virtual tours in the cyberspace of the model.
- Animation of landscape dynamics and geodynamical processes.
- Visualization of underground volumetric geodata, including geological structure and seismic activity.
- Landslide numerical modeling and visualization in the cyberspace of the model.
- Building decision support system for disaster forecasting and disaster response planning.

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References

[1] A. V. Leonov, A. A. Serebrov, A. A. Aleynikov, V. A. Droznin, E. N. Eremchenko, et al., "Virtual natural heritage: 3D model of the Valley of Geysers", proc. of V scientific conference "Tourism and recreation: fundamental and applied researches", Moscow State University, Moscow, 2010.

[2] A. V. Leonov, A. A. Serebrov, A. A. Aleynikov, V. A. Droznin, E. N. Eremchenko, et al., "Developing virtual model of the Valley of Geysers using neogeography and virtual environment", proc. of 52nd scientific conference of Moscow Institute of Physics and Technology, Dolgoprudny, 2009.

[3] A. V. Leonov, "Developing virtual model of the Valley of Geysers, Kamchatka in Google Earth and landslide hazard visualization", proc. of scientific conference "GeyserValley2009", Institute of Volcanology and Seismology FEB RAS, P.-Kamchatskiy, 2009.

[4] A. V. Leonov, "Visuaization of the Valley of Geysers, Kamchatka in Google Earth", proc. of IV scientific conference "Tourism and recreation: fundamental and applied researches", Moscow State University, Moscow, 2009.

[5] V. M. Sugrobov, N. G. Sugrobova, V. A. Droznin, G. A. Karpov, and V. L. Leonov, Pearl of Kamchatka — the Valley of Geysers. P.-Kamchatskiy: Kamchatpress, 2009.

[6] T. K. Pinegina, I. F. Delemen', V. A. Droznin, E. G. Kalacheva, S. A. Chirkov, et al., "The Valley of Geysers, Kamchatka after the June 3, 2007 Disaster", Vestnik DVO RAN, 2008, N.1, pp. 33-44.

[7] V. L. Leonov, "Geological preconditions and capability to forecast the landslide of June 3, 2007 in the Valley of Geysers, Kamchatka", proc. of scientific and technical conference "Geophysical Monitoring and Problems of Seismic Safety of Russian Far East", Geophysical Service RAS, vol. 1, V. N. Chebrov and V. A. Saltykov, Eds., P.-Kamchatskiy, 2007, pp. 91-95.

[8] D. A. Baigozin, Yu. M. Baturin, M. Göbel, S. V. Klimenko, A. V. Leonov, et al., "Interactive storytelling in virtual environment: educational system "Virtual Planetarium", Numerical Methods and Programming, 2004, vol. 5, N. 2, pp. 192-205.

[9] M. N. Anikushkin, A. V. Leonov. Report on satellite geodesy positioning results in the region of Valley of Geysers, Kamchatka. Institute of Computing for Physics and Technology, Protvino, 2009.

[10] V. N. Dvigalo and I. V. Melekestsev, "The geological and geomorphic impact of catastrophic landslides in the Geyser Valley of Kamchatka: Aerial photogrammetry", Journal of Volcanology and Seismology, 2009, vol. 3, N. 5, pp. 314-325.