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Research paper

# Geological and hydrological visualization models for Digital Earth representation

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ABSTRACT

This paper presents techniques and interactive models for multi-dimensional analyses and geospatial visualization in virtual globes based on three application examples: (1) earthquakes around the world, (2) groundwater well levels in Texas, and (3) geothermal subsurface heat indexes in Texas.

While studies are known that represent multi-dimensional geospatial data points, we develop and suggest multi-dimensional models for virtual globes using KML and KMZ (compressed KML files) with a complete and static time series data set. The benefit of this approach for the user is the ability to view and analyze time-based correlations interactively over the entire time span in one instance, which is not possible with animated (dynamic) models.

The methods embedded in our models include: (a) depth layered cueing within subsurface Earth visualization for a better orientation when maneuvering below the ground, (b) a technique with Ternary Visual Shape Logic (TVSL) as a quick indicator of change over time, and (c) different visual representations of multiple dimensions for the addressed case study examples. The models can be applied to a variety of problems in different disciplines, especially to support decision-making processes.


## 1. Introduction

In recent decades, computer graphics visualization and imaging have experienced a rapid growth and captured the interest of governments, scientists, and business representatives (Fox and Hendler, 2011). The idea of a virtual globe (a computer application allowing users to browse and search data projected on a cartographic representation of the Earth) emerged at the end of the last millennium (Bailey, 2010). The development of the XML-based markup language KML (Keyhole Markup Language) – open source, tag-based scripting language, interactive digital cartography became possible in all major virtual globes (NASA World Wind, Google Earth, Microsoft Virtual Earth, and ESRI's ArcGIS Explorer) (De Paor and Whitmeyer, 2011). Visualization techniques have been acknowledged to provide a powerful way to '*take advantage of human abilities to perceive visual patterns and to interpret them*' (Andrienko et al., 2003; see also: Costabile and Malerba, 2003; Kopanak and Theodoulidis, 2003; Compieta et al., 2007).

Nowadays, most research studies apply two- and three-dimensional (2D and 3D) models (Rowe and Frank, 2011; Xu et al., 2010; Mao and Ban, 2013), especially for satellite imaginary (Zhang et al., 2007), 3D web graphics (Evans et al., 2014) or topography maps (Guo et al., 2009). Also, other multi-dimensional analyses using 4D models have been conducted over the years (Baum et al., 2007; Thomas et al., 1996; Li et al., 2011). However, most of those models and their standard spatial visualization in the existing geographical applications are not always adequate and sufficient for decision-support systems. New solutions are necessary that would include not only a static graphical view of the results, but that would also offer the possibility to interact with data in a spatial and temporal view (Compieta et al., 2007; Dransch et al., 2010; Shneiderman, 2002; Van de Weghe et al., 2014).

The goal of this paper is to provide several geotemporal models that extend the current knowledge in the field and meet the scientific and visualization needs as specified above. We emphasize practical benefits of the models with three examples: earthquakes worldwide, groundwater well levels and geothermal subsurface heat indexes in Texas.

Several studies are known representing multi-dimensional visualization examples. For instance, Zhu et al. (2014a) developed a 3D KML model for visualizing borehole well information in virtual globes. Zhu's et al. model, though valuable for research purposes, presents only an above-the-surface perspective using height, size, and color of the spheres to represent the same variable (4D models). Also, Postpischl et al. (2011) developed 3D and 4D

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visualization models, using KML beach balls for their earthquake visualization. However, also this study offers only a 3D or 4D perspective with a flat shape representation, not fully utilizing virtual globe environment.

The models presented here build upon and extend previous research in the field by: (1) presenting both the above-the-surface perspective and below-ground subsurface perspective, and (2) using the size of the sphere and color of the sphere independently of the geolocation, thus creating an additional 5th visualization dimension (5D model). The presented models can be used with different virtual globes and on smartphone or mobile devices, which has not been reported in the previous literature yet.

Nowadays, most 3D models are based on and apply specific visualization software that is not always freely accessible to everyone, requires specialized graphic cards or hardware and/or is difficult to use as it involves a long learning process. Virtual globe applications, used for this research, do not have any special technical requirements in this regard and are capable of loading and rendering standard KML files. This feature allowed us to use KML files in a unique way to develop models that would be accessible to anyone with very few limitations if any at all. The interactive models overcome the current limitations in the field making visualization easily accessible and interactively applicable for all computer users with Internet access, and thus fostering scientific and educational learning.

Furthermore, the developed models can be classified as a visualization analytics tool that, according to Andrienko et al. (2011), benefits from combining the strengths of human and electronic data processing, and where '*by means of visualization and interactive visual interfaces*, *humans and computers can converse and cooperate*' (Keim et al., 2008). The models also provide an exploration tool that, as advocated by Fox and Hendler (2011),'*scientists can use throughout the research life cycle*' not only to represent the final research results, but to look for and interactively explore hidden patterns and relations that would not be detectable solely with raw data sets.

The benefits, unique features, and contributions of the presented models to the multi-dimensional visualization field can be summarized as follows:

1. They provide an *interactive visualization* platform that allows the user to adjust the input parameters and specify the research needs more accurately. The platform is defined as any virtual globe, e.g., Google Earth, NASA WorldWind, ArcGIS Explorer, ArcGIS Earth, and Cesium.
2. They offer a *multi-dimensional perspective* in a single KML framework.
3. They allow for *spatio-temporal analyses* covering both geographical location and the time variable without animation.
4. They are *freely accessible* to the end user (open access models) and do not require advanced software or license access keys.
5. They can be used on *any computer system*: Windows, Linux, Apple, smartphones, or touch pads.
6. They can be easily transferred to and are *compatible with other software packages* like e.g. ArcGIS or QuantumGIS.

The models and an interactive data framework represent natural Earth measurements and human-induced changes across geospatial time frames, at the global, national, and state levels. The techniques used in this paper will allow other researchers to view subsurface data with existing virtual globes to interact and see patterns in earthquake events, geothermal heat indexes, and groundwater well levels over time. The outcomes can be useful for further research in the field and to stakeholders to support decision-making processes related to earthquake emergency management, geothermal energy extraction, and sustainable water planning and management.

## 2. Challenges for visual representation of complex data using static virtual globes

This research applies virtual globes as currently the most comprehensive platform to represent multi-dimensional data. Despite their benefits, virtual globes still face several technological and methodological challenges. While we acknowledge those limitations briefly pointing them out in this section, we also provide solutions for the presented models and research examples.

For many decades, the 3D dimension has always been (and still is) a natural human part of comprehending real world information represented with several dimensions in virtual globes. Therefore, representing information from multi-dimensional data sets becomes the more challenging, the more dimensions we add to the visualization model. Furthermore, if the data is not grouped and/or categorized in a meaningful visual way, the usefulness of a model might be lost. In addition, tools for manipulating data are not always readily available for specific types of multi-dimensional data sets from different disciplines. Several programs are available for displaying or converting data, like e.g. COLLADA, but more options are needed to provide a comparison benchmark.

Another challenge is subsurface representation in virtual globes. Techniques of this kind are rather recent, and they were not originally developed with the purpose of representing data below the Earth's surface. While 2D cross sections and pop-up planes or blocks that come above the surface of the Earth are common (Dobson, 2012), they display solely pieces of subsurface as pop-up blocks. The subsurface models presented with this paper represent the subsurface of the Earth as a whole and are interactive meaning that they allow the user to fly-through and navigate under the Earth's subsurface.

Currently, when a user zooms into a highly populated cluster of data, orientation and location may be lost. In cases like this more information about the subsurface surroundings is needed to keep on track and better understand the information and orientation.

Moreover, currently animations are often used with temporal data in virtual globes. However, if the time intervals are not set correctly, subtle information might be missed. Another issue with animating large data sets arises when loading them into limited memory space, which may prohibit viewing any of the data at all. In order to overcome this limitation, intelligent clustering and reducing the size of the data is needed. Even the application of intelligent clustering comparisons within a time-based static cluster will not insure a proper understanding of the data. Natural visual representation of the data as geometric shapes would considerably improve human understanding of complex data sets.

Another potential limitation might be difficulty to present level of detail and memory restrictions. However, using WebGL-based virtual globes like Cesium and OpenWebGlobe (open source platforms) can alleviate this impediment.

## 3. Methodology

### 3.1. Specifications of the KML/KMZ models

This paper develops new application methods and presents four types of models from different scientific disciplines: geophysics, geology, and hydrology to represent earthquake events around the globe (with a subsurface and above-the-surface representation – two separate models), geothermal heat indexes, and groundwater well levels, respectively. Each model is standalone, as it has unique application properties and features, while at