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O. Kolditz, K. Rink and G. Scheuermann (Editors)

Short Papers

Visualisation Strategies for Modelling and Simulation Using Geoscientific Data

K. Rink[1] and L. Bilke[1] and O. Kolditz[1,2]

[1]Department of Environmental Informatics, Helmholtz Centre for Environmental Research, Leipzig, Germany
[2]Chair of Applied Environmental System Analysis, TU Dresden, Germany

Abstract

We present a number of strategies to visualise a wide range of geoscientific data for the modelling of natural phenomena. Input data sets as well as simulation results of hydrological or thermal processes can be assessed and potential problems when incorporating data sets in a model can be detected and resolved. Algorithms for the demonstration of modelling case studies within specialised environments are presented and examples are given for a region in central Germany.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality

1. Introduction

Understanding complex natural phenomena is becoming increasingly important as we are faced with problems such as climate change, overpopulation and the need to change from fossil fuels to green energy. Given a sufficient ... Comprehending hydrological processes is vital to predict floods [MMKK08, Sch12], develop water management schemes for arid regions [GSSAS12, HMR09, WOG*12] or simulate the contamination of drinking water [BH12, Sch04]. An understanding of thermal processes is needed for geothermal applications such as extraction of geothermal energy [Hue10, TPKM10] or the safety of nuclear waste deposits [SHLPK13, WHGN09]. Many more applications can be found in literature.

In order to simulate such processes, it is necessary to set up models based on a large number of data sets to account for as many of the significant natural characteristics for a given process as possible. These data sets usually differ vastly in structure, spatial and temporal resolution, area of influence or reliability. From a structural point of view, a possible classification is:

- Time series data: Sensors measuring temperature, precipitation, soil moisture, etc. at a specific location.
- Geometric data: Courses of streams acquired via GPS, boundaries (e.g. of model regions, river catchments, etc.) or borehole data.
- Raster Data: Maps, climate data such as weather surveillance radar, remote sensing data acquired via satellite or airplane (e.g. digital elevation models (DEM), hyperspectral imagery, etc.), or using geophysical monitoring techniques such as ground-penetrating radar, gamma spectroscopy or electromagnetic induction.

For hydrological models, the model domain is often defined using a DEM in combination with interpolated subsurface information gathered from borehole stratigraphies while boundaries are either defined, measured or calculated (such as the boundary of a river catchment). For simulation the resulting domain is discretised, e.g. into a finite element mesh. Additional information is integrated, for instance from land use maps to include water bodies, cities or agricultural areas. Boundary conditions are often based on time series data gathered from observation sites such as precipitation- or gauging-stations. Using process equations, such a model results in one or more simulated parameters within the domain over time such as groundwater recharge, temperature or the distribution of chemicals in the environment.

A concurrent visualisation of all the specified data sets is a crucial part of the workflow prior as well as after the actual simulation. It will show potential problems while creating the model and will show the plausibility of the results in comparison to the input data. Nevertheless, data visualisation functionality is not part of most common simulation programmes.

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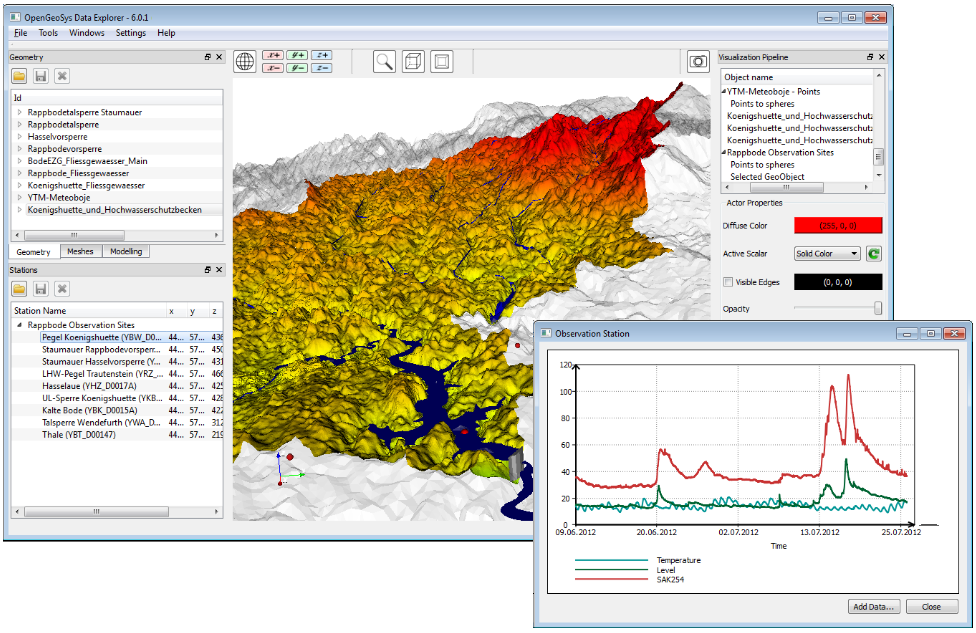

Id
- Rappbodetalsperre Staumauer
- Rappbodetalsperre
- Hasselvorsperre
- Rappbodevorsperre
- BodeEZG_Fliessgewaesser_Main
- Rappbode_Fliessgewaesser
- Koenigshuette_Fliessgewaesser
- YTM-Meteoboje
- Koenigshuette_und_Hochwasserschutzbecken

Station Name	x	y	z
Rappbode Observation Sites			
Pegel Koenigshuette (YBW_D0...	44...	57...	436
Staumauer Rappbodevorsperr...	44...	57...	450
Staumauer Hasselvorsperre (Y...	44...	57...	431
LHW-Pegel Trautenstein (YRZ_...	44...	57...	466
Hasselaue (YHZ_D0017A)	44...	57...	425
UL-Sperre Koenigshuette (YKB...	44...	57...	428
Kalte Bode (YBK_D0015A)	44...	57...	422
Talsperre Wendefurth (YWA_D...	44...	57...	312
Thale (YBT_D00147)	44...	57...	219

Object name
- YTM-Meteoboje - Points
  - Points to spheres
  - Koenigshuette_und_Hochwasserschutz
  - Koenigshuette_und_Hochwasserschutz
  - Koenigshuette_und_Hochwasserschutz
- Rappbode Observation Sites
  - Points to spheres
  - Selected GeoObject

Diffuse Color (255, 0, 0)
Active Scalar Solid Color
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Opacity

Figure 1: *The* OGS Data Explorer *framework displaying various input data sets from the Rappbode reservoir system, including DEM [TKI*11], water bodies [ATK08], observation sites, time series data, rivers, etc. The time series data is attached to the selected observation site and shows the increase in dissolved organic carbon (measured via spectral absorption coefficient at 256 nm (SAK254)) after rising water levels due to heavy rainfall. (All additional data kindly provided by Karsten Rinke)*

2. Related Work

Despite the complexity of geoscientific data there exist surprisingly few tools for an adequate visualisation. The various Geographic Information Systems (GIS) such as *ArcGIS* [LC13] or *GRASS* [NM08] offer a wide range of functionality for 2D visualisation. A number of approaches employ the third dimension for additional social or climate context [FW10, HRM*12, ST11]. Simulation codes and libraries only rarely offer visualisation functionality. One of the rare exceptions is *FEFLOW* [DHI10] which comes with an extensive GUI. Due to the lack of existing software, visualisation is often limited to multi-purpose software such as ParaView [AGL05] or VisIt [Law]. These support the visualisation of a large number of graphics file formats for 3D data as well as time discretisation but for most cases cannot be employed directly using geoscientific or simulation data. Visualisation techniques for complex 3D or 4D data sets found in literature are rare [JMC*09]; most examples are applications for climate data [JBMS09, PWB*09, TDN11]

3. Data Visualisation and Presentation

An adequate visualisation allows researchers to get a feeling for their data, see correlations between data sets or potential problems for the subsequent modelling process and present results to stakeholders or the interested public.

We employ the *OpenGeoSys Data Explorer* framework [RFSK13] for data import and basic visualisation of geoscientific data as well as model information and simulation results (Fig. 1). Within the *Data Explorer* visualisation functionality is implemented using VTK [SML06]. Our framework allows complete scenes or single geoscientific data sets to be exported to VTK-formats, OpenSG [RVB02] as well as Unity3D [Gol11]. Additional VTK functionality for transformation or emphasis of certain aspects of the data can be either applied within the framework or after export using other software such as ParaView. Likewise, after conversion to either OpenSG or Unity3D, advanced rendering methods can be applied to objects or scenes within the respective frameworks. This workflow has already been applied successfully by experts for multiple hydrogeological studies, including model regions in Germany [RFSK13], China [SSW*12] and the Middle East [GRR*13].

3.1. Data Integration

Difficulties often arise when attempting to concurrently visualise heterogeneous data sets. These are due to inconsistencies between data sets and errors during data acquisition or transfer. Typical examples for inconsistencies include differences in scale, resolution, coordinate systems and the origin of the data sets. Often these issues are interconnected: if two data sets have large differences in scale, the data set with the small extent often has a finer resolution. This might

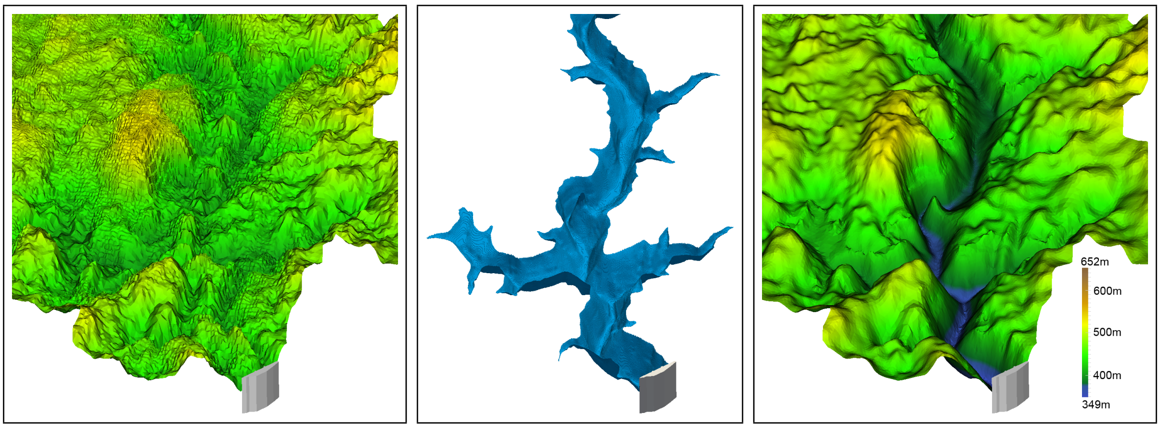

Figure 2: *Example for handling artefacts in data: (left) mesh with elevation-based colours generated from the original DEM including artefacts due to reflection of the reservoir surfaces, (centre) bathymetry of the Rappbode reservoir acquired via sonar, (right) corrected mesh using sonar data and gaussian lowpass filter of the mesh node elevation. (Bathymetry provided by* Landesbetrieb für Hochwasserschutz und Wasserwirtschaft, Sachsen Anhalt*).*

be caused by the data being acquired using different device (satellite imagery vs GPS) or using a different parameterisation. Also, different acquisition techniques often have different offsets for data or implicitly use different coordinate systems. Likewise, if data is generated based on other data sets, some of the original information might be lost. For example, geometric data created using GIS frequently is missing elevation information because this is considered insignificant in a 2D environment. Other errors might be caused by artefacts (e.g. cloud cover in satellite imagery, stained sensors at observation sites or extreme weather events) or random errors including inaccuracy during meter-reading, transposed digits or OCR-errors when digitalising data. Finally, errors might also occur due to discretisation of the data when creating FEM meshes, merging soil types, etc. Most of these problems can be seen quite easily in a concurrent visualisation of multiple data sets. However, even if several of the problems mentioned above occur quite frequently, most issues are too complex to check or fix automatically. If other data is available at the same location, outliers or errors might be mapped using this additional information (Fig. 2). Otherwise, an approximation using lowpass filters or interpolation is often the only solution.

3.2. Visualisation

We employ the *Visualisation Toolkit* (VTK) in our framework as it offers a wide range of functionality for transformation and modification of 3D objects. While we have applied a wide range of such visualisation algorithms for various models, a small subset has emerged that is applied frequently for the visualisation of geoscientific data sets. This includes basic functionality such as linear transformations (translation, scaling, etc.), transparency and applying user-defined colour look-up tables. A number of more advanced algorithms applied frequently include the representation of point data using glyphs (typically spheres and arrows) as well as geometric lines as tubes for visibility within large data sets. Raster data is often mapped as texture onto surfaces such as digital terrain models. Clipping-planes are used to show cross sections of volumetric data (e.g. subsurface data) and streamlines, iso-surfaces or glyphs for various kinds of flow visualisation. For some algorithms it is typical to be applied multiple times using varying parameter sets to ensure adequate visualisation based on the current zoom level (e.g. the radius of streamlines, size of glyphs, etc.).

3.3. Presentation

For presentations, we employ a virtual reality centre with a 6x3 metre video wall using stereoscopic projection and an optical tracking system (Fig. 3). Presentations within this environment are used frequently for discussions between scientists, presenting research results to stakeholders as well as informing the general public during open day events. For navigation within this environment and demonstration of the phenomena we employ two respective software systems: an OpenSG framework and the Unity3D game engine. For both we implemented functionality typically needed during presentations. Examples include predefined viewpoints that take the viewer to a specific point in the scene, convenient viewer movement via defined paths for rotation around an object or transit between two specific objects and the fading and hiding of objects or groups of objects when they are not needed. Navigation tools to freely move within the scene using special devices such as 3D mouse or flystick had to be integrated. During presentations interaction tools allow users to see additional information, e.g. by placing clipping planes within data sets, opening context menues for additional information, etc.

Figure 3: *(left) Stereoscopic visualisation of an* OpenFOAM *and* Min3P *simulation [TSM* 13] of stream flow in the hyporheic zone in a virtual reality environment. (Data kindly provided by N. Trauth), (right) Visualisation of the Rappbode reservoir in Unity3D, including camera paths and visual effects employed for interactive presentations.*

4. Case Study

As an example for the proposed techniques we present a visualisation project containing more than 70 data sets acquired within the TERENO initiative [ZBS*11] in Germany. TERENO is concerned with the prediction of possible impacts of climate change. Four areas in Germany have been selected and are now heavily instrumented to allow extensive studies and simulations for researchers from many different disciplines. Hydrogeological analysis in central Germany is being conducted in the catchment of the River Bode with a size of 3,100 km^2. Within that area a number of intensive test sites have been selected, such as the catchment of the Rappbode reservoir system (Fig. 1), used as a source of drinking water and electricity generation. The data sets concerned with the project range from raster data (DEM, soil moisture maps, land use classification, etc.) covering the complete area to observation sites covering only a few square metres or a small number of points (i.e. sensors). A surface mesh of the whole region consisting of 1.08 million triangles (max. edge length 90 m) has been created based on the ASTER-DEM [TKI*11], acquired via satellite and with a pixel size of 30×30 m. For intensive test sites refined meshes have been created, e.g. for the catchment of the reservoir system with a max edge length of 30 m For such a small region the inaccuracy of the data set in combination with other artefacts such as cloud-shadows or reflection on water surfaces are easily noticeable. Fig. 2 shows the effect of applying a Gaussian lowpass filter over the elevation of connected mesh nodes in combination with re-mapping parts of the surface using sonar data. These data sets have a resolution of three and five metres, respectively, and are much more reliable than the satellite imagery. Additional data includes stream information from ATKIS DLM [ATK08] as well as sensor positions before and after each of the reservoirs, monitoring temperatures, water levels as well as the spectral absorption for determining the amount of dissolved organic carbon within the water bodies [RKB*13] (Fig. 1). Simulations using such data sets are used to make predictions about the quality of drinking water or the interaction of streams with the groundwater (Fig. 3).

5. Conclusions

We presented a system for the concurrent visualisation of geoscientific and modelling data. The proposed system renders heterogeneous data sets in 3D space and offers functionality for meshing, mapping and filtering data sets. This functionality helps to detect errors and inconsistencies prior to modelling as well as evaluate the plausibility of simulation results. VTK is used for 3D visualisation and applying additional algorithms for enhancement of important aspects within the data. For presentations in a virtual reality environment an OpenSG framework and the Unity3D engine are employed. Additional functionality has been implemented in both for navigation, visual effects and user-interaction with specific data sets. Future enhancements of the system are added in coordination with experts and include user guidance during the modelling process to allow semi-automatic modification of data sets as well as additional scripting for a more straightforward handling of the Unity engine.

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