

# Environmental Modelling Using Cloud Computing Tools: Case Studies and Examples

**Lubos Matejicek**<sup>a,\*</sup>

<sup>a</sup> Charles University in Prague, Benatska 2, Prague, 12801, Czech Republic

\* Corresponding author: [lubos.matejicek@natur.cuni.cz](mailto:lubos.matejicek@natur.cuni.cz)

**Abstract:** Cloud computing represents an emerging computing paradigm, which offers delivering a variety of computing services in a way that has not been experienced previously. In order to develop advanced simulations, environmental modelling must be adapted to this more powerful and efficient computing tool. Traditional model calculations are taken into the sphere of interconnected data and more accessible software tools, which rationalize the way they manage their resources. Moreover, information systems such as GIS, and case-oriented software tools for data pre-processing and visualization can be accessible for a wide range of users participating in research projects. In order to document distribution of environmental models through cloud-computing tools, a few model studies focused on environmental pollution are included in the presentation. A wide community of users can directly manage environmental models and case analyses dealing with monitoring of air pollution, prediction of surface water pollution, waste management, noise assessment, and biomonitoring. The attached case studies are focused on modelling of surface water pollution, spatio-temporal analysis of air pollution data and modelling of the surface of a coal mine. The factors affecting the quality of the environment include particularly the impacts of industrial sites, residential areas, agricultural management, automobile traffic, water and energy management, waste management and sustainable land use. The former regime prior to 1989 managed the urban environment in a manner that greatly increased the burden. The attached model studies demonstrate the use of cloud-computing tools for spatio-temporal analysis and modelling using data that are spatially distributed as well as temporally related. This tool can support decision-making processes in the areas of interest and indicate potential solutions for similar regions.

**Keywords:** Environmental modelling; cloud computing; environmental pollution.

## 1. INTRODUCTION

The tools and methods of environmental modelling can be innovated by cloud computing, which has the potential to be one of the major advances in the history of computing over the past few years [Marston et al., 2011]. It can contribute to the success in the framework of education and research, which is documented by the attached list of lectures, exercises, and selected case oriented studies.

### 1.1 Cloud computing

Environmental models as we know them today continue to become more powerful and efficient, but the increasing complexity of managing the whole infrastructure of disparate data and software has made computing more complex and expensive. An opportunity for environmental modelling in the framework of cloud computing

can be found in the increased functionality of modelling services. This significantly simplifies the administration procedure and management, and reduces the upfront costs of computing. Cloud-based data management simplifies data storage and maintenance by providing a low-cost, scalable, location-independent platform.

A potentially formidable risk for missing or corrupting data must be avoided by audit services that are critical to ensure the integrity and availability of outsourced data and to achieve credibility in cloud computing. Thus, provable data possession, which verifying the integrity of data without retrieving it from an unreliable server, is used to perform audit services [Zhu et al., in press)].

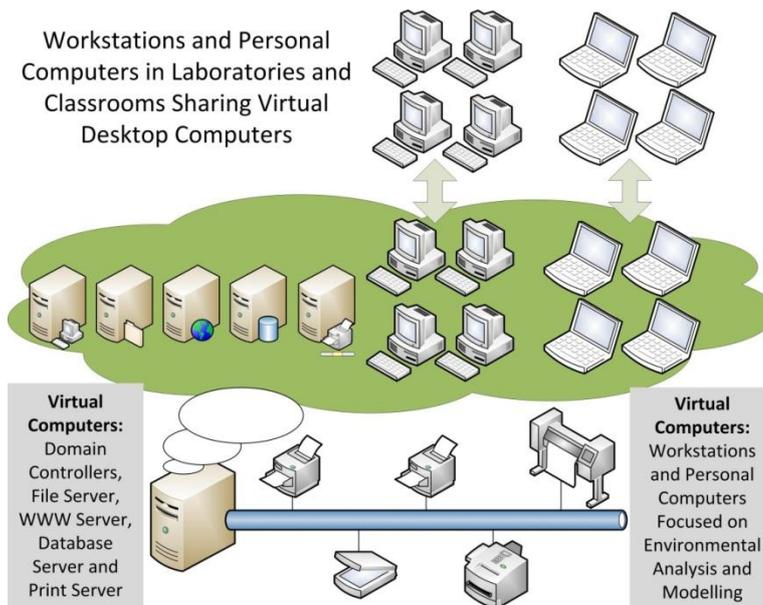
Environmental modelling based on cloud computing offers services to users worldwide. It enables energy-efficient hosting of model applications from scientific and business domains. However, data centres hosting cloud applications consume huge amounts of electrical energy, contributing to high operational costs [Beloglazov et al., in press; Berl and Meer, 2011].

The high rate at which model computing is changing places substantial pressure on organizational budgets. This situation will probably be made worse under the difficult economic conditions of educational institutions. However, cloud computing tools can provide many of these institutions with an opportunity to continue to take advantage of new developments in recent modelling tools at affordable costs. The potential of environmental modelling based on cloud computing for improving efficiency and cost is being recognized by a number of educational establishments. Many universities have found cloud computing to be attractive for use in their courses which are focused on environmental modelling [Sultan, 2010].

## **2. ENVIRONMENTAL MODELLING AND SPATIO-TEMPORAL ANALYSIS**

Environmental modelling deals with representation of processes that are believed to occur in the real world in space and time. The processes that transform the environment through time are mostly described by dynamic models based on differential equations [Jørgensen and Fath, 2011]. On the other hand, the spatial interactions and topological rules are mostly managed by Geographic Information Systems (GIS). In GIS, the data model is defined as a template into which the data required for a particular application can be fitted. The data models can include description of real objects such as sources of pollution divided in dependence on their shape to point, line and area features, and other objects including buildings, roads, rivers, railroads and monitoring networks arranged in layers [Maguire, 2005]. The integration of environmental models with GIS is emerging as a significant new area of GIS development and has been the topic of a number of conferences, research papers and books [Fedra, 1999; Goodchild et al., 1996; Wade et al., 2009]. Recently in coupled GIS/environmental modelling, GIS has been used to provide input variables required by simulation models and yield visualization and analysis of output data. The model operations and GIS may be completely separate or may be tightly coupled by a software linkage that arranges for data exchange between data shared by simulation tools, and data managed by GIS. Other ways are represented by direct integration of numerical modelling tools into the GIS results. In the past, GIS has been extended by case-oriented software tools for high performance in dynamic modelling. However, with the increasing power of GIS hardware and software, this relationship is being reconsidered.

In this contribution, environmental modelling using cloud-computing tools is focused on spatio-temporal data analysis and modelling. Various simulation tools together with GIS are used to demonstrate modelling of surface water pollution, spatio-temporal analysis of air pollution data, and modelling of the surface of a coal mine. In addition to dynamic modelling and GIS, other research is also focused on remote sensing, the global positioning system (GPS) and database management. The presented case studies and examples originated from research projects and support teaching in environmental courses. The cloud-computing environment helps to manage modelling tasks in computer laboratories and classrooms, Figure 1 and Table 1.



**Figure 1.** Cloud computing environment for environmental modelling supported by a set of virtual servers and virtual desktop computers (Windows Server 2008 Hyper-V: 1 virtual Windows Server 2008 extended by WWW server, FTP server, SQL server, print server and ArcGIS server with data based on the case oriented studies; 1 virtual Windows Server 2008 extended by domain controller services; 8 virtual desktops Windows 7 extended by ArcGIS desktop software, ENVI, eCognition, MATLAB, R software, ADOBE software, MS Office, and projects based on case oriented studies; all virtual computers are shared as remote desktop computers in the Windows 7 environment in our laboratories and classrooms).

**Table 1.** Education activities supported by cloud computing (remote desktops in the real computer environment of Windows 7 and, optionally, other OS).

Lectures, exercises and thesis (ERASMUS- exercises in English)	Term 2011/12	Number of regular students
Environmental Informatics	Summer	37
Environmental Informatics (ERASMUS)	Summer	4
Environmental Informatics (optional extension)	Summer	11
Environmental Modelling	Winter	18
Environmental Modelling (ERASMUS)	Winter	3
Geoinformatic Methods for Environmental Studies	Summer	7
Introduction to Environmental Informatics	Winter	8
Applied GIS	Winter	5
Applied Remote Sensing	Winter	1
Energy: Nature and Society	Summer	51
Energy: Nature and Society (optional extension)	Summer	18
Applied Ecology (exercises)	Winter	34
Diploma thesis and Ph.D. thesis		10

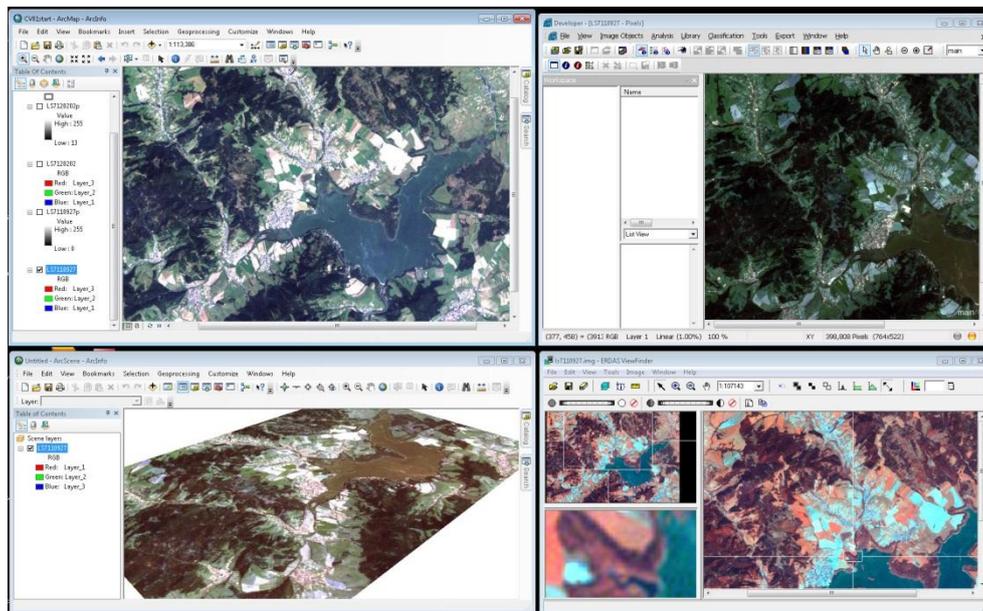
### 3. CASE STUDIES AND EXAMPLES

The attached model studies demonstrate the use of cloud-computing tools for spatio-temporal analysis and modelling using data that are spatially distributed as well as temporally related. This tool can support decision-making processes in the areas of interest and indicate potential solutions for similar regions. The factors affecting the quality of the environment include particularly the impacts of industrial sites, residential areas, agricultural management, automobile traffic, water and energy management, waste management and sustainable land use.

### 3.1 Modelling of surface water pollution

The quality of many surface waters is reduced by excessive nitrogen and phosphorus from point and nonpoint sources. Consecutively, management to reduce watershed nitrogen, phosphorus and other pollutants is a priority in regions with intensive human activities. Environmental models can predict surface water quality [Pullar, 2000]. The actual research is documented by a number of studies focused on visualization procedures [He, 2003], statistical analysis [Shrestha and Kazama, 2007; Petersen et al., 2001], simulation tasks [Miller et al., 2007], case oriented studies [Strager et al., 2010; Niemczynowicz, 1999; Wang and Yin, 1997], estimates of catchment parameters using satellite data [Yang et al., 2000], and integration of geospatial and time series data with dynamic models [Matejcek, 2003]. Spatio-temporal approach for quality modelling involves connecting geospatial data describing the physical environment with water quality analysis and water pollution process models. Nowadays, the advances in computing tools and GIS greatly enhance the ability of research scientists to developed environmental models through a new generation of data management and rapid simulation tools that can be built into a GIS as software extensions. A number of software tools are tested in order to develop an integrated approach for risk assessment of water pollution involving connecting geospatial data describing the physical environment with water pollution process models and water quality analysis [Pisinaras et al., 2010; Shen et al., 2005].

The attached case study was focused on implementation of the new modelling tools that includes GIS and remote sensing. The outputs of spatio-temporal model can be visualized together with satellite and aerial images. Use of GISs with data processed by image processing software shows more complex spatio-temporal analysis of changes in landscape as a result of anthropogenic activities studied using time-series Landsat images. The described modelling tools are accessible through the cloud computers in the computer laboratories and classrooms, Figure 2. It demonstrates integration of spatio-temporal data in the ArcGIS-ArcMap, object classification of satellite and aerial images using eCognition software tools, visualization of a part of the basin in the ArcGIS-ArcScene, and a view of image from Landsat satellite in the ERDAS Viewer.

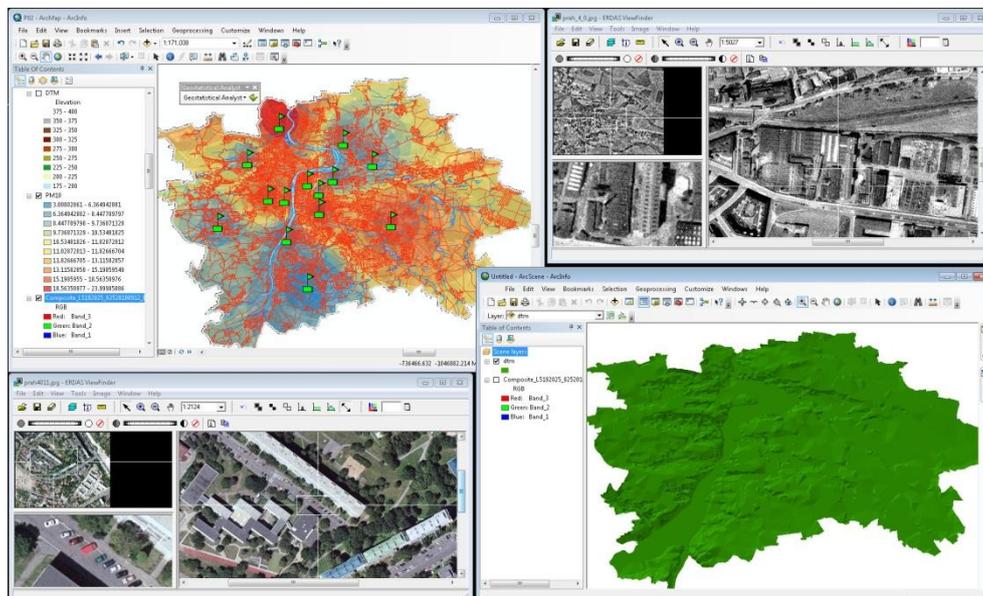


**Figure 2.** An example of the modelling of surface water pollution using virtual desktop computers. It illustrates integration of spatio-temporal data in the ArcGIS-ArcMap, object classification using eCognition software tools, visualization in the ArcGIS-ArcScene, and a view of satellite images in the ERDAS Viewer.

### 3.2 Spatio-temporal analysis of air pollution in urban areas

The increase in the transportation infrastructure has negative impacts on the environment of a large part of the population, especially in urban areas. One of the main factors appears to be the quality of the air contaminated by anthropogenic pollutants. Exploration of these processes by spatio-temporal analysis and environmental modelling becomes essential for understanding exact conceptions of the dispersion of pollutants in the atmosphere. This is evaluated on the basis of direct measurements. The density of a monitoring network is limited for economic reasons to individual observations in time and space. However, new data processing tools are required to provide exploratory spatial data analysis. In order to explore pollution processes in local and global scales, mathematical models have been developed for a few last decades to provide more exact description of transport processes [Silibello et al., 2008; Sokhi et al., 2008; Carnevale et al., 2006; Mediavilla-Sahagún and ApSimon, 2006; Rimetz-Planchon et al., 2008]. The analytical capabilities of the GIS through the map algebra provide tools to perform operations as well as local, focal, zonal, global and application functions [McCoy and Johnston, 2002; Mitchell, 2005; Matejcek et al., 2006]. Thus multicriteria analysis using cell-based modelling can help to explore environmental pollution such as finding the worst possible locations characterized by high levels of air pollution in short and long periods.

The sample concentrations of PM<sub>10</sub> in the area of the City of Prague are used to create a continuous surface by the spatial interpolation methods such as Inverse Distance Weighted Interpolation (IDW), polynomial interpolation and kriging [Cressie, 1999]. In order to provide risk assessment based on prediction maps, the GIS project contains a digital terrain model, a road network, aerial photographs of local sites and satellite images of the area of interest. With the outlined study accessible on the virtual computers, it is believed that assessment tools should lead to improved insights and generate a suite of better management strategies, Figure 3. Like in the previous, it demonstrates integration of spatio-temporal data in the ArcGIS-ArcMap, object classification of aerial images using eCognition software tools, a view of aerial image in the ERDAS Viewer and visualization of the whole city in the ArcGIS-ArcScene.

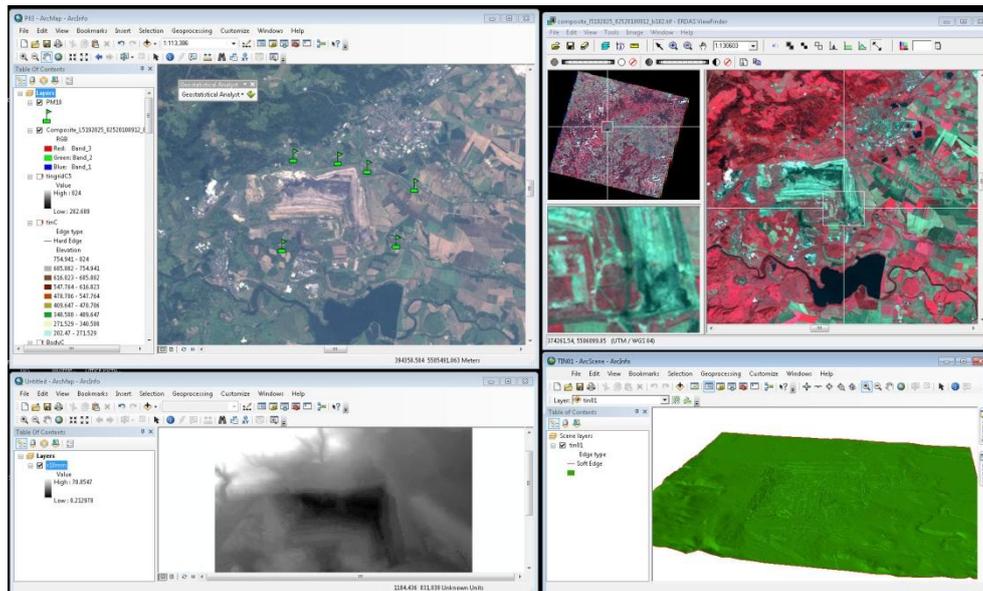


**Figure 3.** An example of spatio-temporal analysis of air pollution (PM<sub>10</sub>) in urban areas using virtual desktop computers. It shows integration of spatio-temporal data in the ArcGIS-ArcMap, object classification using eCognition, a view of an aerial image in the ERDAS Viewer, and visualization of the digital terrain model in the ArcGIS-ArcScene.

### 3.3 Spatio-temporal analysis of land-cover in the area of a surface coal mine

Land-cover changes around large surface cause serious environmental degradation that affects many sites, leading to a departure from this equilibrium. An approach for exploration of surface processes and their dynamics in the area of surface mines requires observation with frequent temporal coverage over a long period in order to identify natural changes from those associated with man-made activities. Because field observations and historical data in most surface mining areas are not available, remote sensing can be an alternative to standard research for studying middle-term land-cover changes [Yuan et al., 2009; Tømmervik et al., 2003; Remm, 2004; Felinks and Wiegleb, 2001]. More complex analyses can be processed in the framework of GISs [Matejcek et al., 2008] that mostly provide spatial processing and linking of the results with other data obtained by field exploration and automatic monitoring. A great deal of satellite data is commercially available in the digital archives that offer a wide range of resolution scales and multispectral channels. However, the USGS Landsat archive containing records of the Earth's surface and its availability over a number of decades and free-of-charge through electronic access via the Web represents an invaluable source for land-cover exploration.

The attached case study accessible through the virtual computers deals with GIS and remote sensing that provide land-cover information for assessing land-cover changes in a mining-dominated landscape and, to a certain degree, also in variable remediated post-mining sites, Figure 4. Integration of spatio-temporal data and satellite images is presented in the ArcGIS-ArcMap. A view of the satellite image (2-3-4 Landsat bands) is in the ERDAS Viewer environment. The digital terrain model of the surface coal mine is visualized in the ArcGIS-ArcMap and ArcGIS-ArcScene.



**Figure 4.** An example of spatio-temporal analysis of of land-cover in the area of a surface coal mine. It illustrates integration of spatio-temporal data and satellite images in the ArcGIS-ArcMap, a view of the satellite image in the ERDAS Viewer, visualization of the digital terrain model in ArcGIS-ArcMap and ArcGIS-ArcScene.

## 4. CONCLUSIONS AND RECOMMENDATIONS

Environmental modelling using cloud computing tools represents a new application domain that outlines new means in environmental research, and new trends in education. It promises to provide opportunities for delivering a variety of computing services in a way that has not been experienced previously. The attached list of

educations activities in Table 1, and described case oriented studies document our practical results in this field of study. The potential of environmental modelling based on cloud computing for improving efficiency and cost has been also recognized for a few years of our education and applied research.

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