Cloud Computing Applied to Calibration of Flood Simulation Models

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Abstract. Flood water simulations have to be accurate in order to prevent losses and must therefore be based on well calibrated rainfall runoff models of sufficient complexity. IaaS cloud computing has be proven useful as a fast and cost-efficient extension of local computers, in the case, using the calibration of the hydrologic modeling system ArcEGMO as an example. On the other hand, cloud-based systems cannot serve as a replacement for a local computer, as long-term usage is still too expensive and there surely are performance differences regarding the offered architectures. Ultimately, the usage of cloud computing as a viable extension of local computing capacities is only reasonable if state of the art computer technologies with a fair pricing sytem can be offered by IaaS providers.

Introduction

Flood waters and flash floods are an ever-leading cause for significant destruction in the areas surrounding rivers [1]. In Germany, for example, the Elbe floods of 2002 and 2013 caused damages totaling millions of euros [2]. The simulation of flood waters, used to determine design parameters for the planning of flood protection measures, also serves to aid in predicting a flood event. Thisis of high importance in the preemptive assessment of possible risks from flood waves, allowing ample timeto implement measures for prevention [3]. The simulation itself can be subdivided into one hydrological part to express the runoff processes in the area and another hydraulic part to illustrate the actual flood characteristics. In urban areas the contribution of urban drainage is often added as well [4].

This study focuses on the hydrological aspect of flood water simulation, which is used for general rainfall runoff models.

Depending on the chosen model complexity, the calibration of a rainfall runoff model can be a very time-consuming process. Robust values for the model parameters can often only be determined by a large number of model runs. Additionally, high-resolution models found in large-scale applications risk reaching the limits of computing capacity rather quickly. If one would like to test several parameterizations, he would first have to think about alternative methodsof computation.

The computing technologies available are constantly changing, and there are now various ways to involve greater computing capacity for a more detailed description of hydrological processes. These new technologies include multi-core and many-core architectures of current processors and graphics chips [e.g. 5], and non-local computational resources, which can enhance the local ones. Among the latter, cloud computing is one of the most prominent of these technologies.

Here, the modeler outsources his calculations onto virtual computers which can be generated on demand from server farms of cloud service providers.

The particular potential of the cloud lies in the scaling of resources: for every application, a corresponding configuration of computing power, memory, disk space, and operating system can be found, enabling the potential coupling of multiple virtual machines.

Cloud computing is still in an early stage. Reliable findings on the use of cloud computing in the field of hydrology and, in particular, for the simualtion of flood events are not yet available. There are few reports on the application of cloud computing in hydrology, whereas their focus is mainly on other aspects such as uncertainty analyses, by using precalibrated models [e.g. 6].

Because cloud projects can be implemented quickly and at comparatively low monetary costs, it is reasonable to gain first-hand experience in small pilot projects [7]. In this paper, the outsourcing of model calculations for calibrating a rainfall runoff model for flood simulation on virtual machines in the cloud will be discussed. Within this study, particular emphasis is placed on the attainable computing power and the scalability of resources. A company that creates and maintains the models is also always trying to balance the monetary costs with the resulting benefit, which is why the cost aspect is considered here as well.

The paper is organized as follows: in Chapter 2, the hydrological modeling system ArcEGMO is presented as a basis for flood simulations. Also, the potential of cloud computing is briefly discussed, which is then used to frame the requirements for using clouds in the context of flood simulation. Chapter 3 presents the configurations and the setup of an investigation on cloud services based on an example scenario. In Chapter 4, the results of the application example are presented, thereby demonstrating how cloud computing can meet the requirements set in Chapter 2. In Chapter 5, the potential of cloud computing for complex hydrological model calibration is finally evaluated in terms of computing power and monetary cost efficiency, accompanied by an outlook on further developments.

1 Requirements for Cloud Computing to Assist Rainfall Runoff Model Calibration

1.1 Rainfall runoff modeling with the hydrological modeling system ArcEGMO

The hydrological modeling system ArcEGMO can be applied for physically sound simulations of all relevant processes of the water balance and flow regime in catchments of different forms and scale ranges in space and time [8, 9]. Its modular design, the possibilities for a variable surface structure and a set of interfaces for coupling with other models allow for the processing of a large variety of practical and scientific problems (Figure 1).

ArcEGMO has been used successfully in a variety of studies on flood generation for different landscape types and field sizes [e.g. 10, 11]. It became clear that the parameterization of the model is crucial for the realistic representation of catchment processes and dynamics. Since the calibration of the model based on real measured values is an iterative process, a large number of model runs is needed to assess the effect of different parameter values on the ability to correctly predict river runoff. With complex models, the computation time can quickly become a limiting factor in the search for optimal parameters. Therefore, in the following it should be evaluated to what extent cloud computing can be specifically helpful as a way of fast acquisition of additional computing capacity to expand locally limited resources.

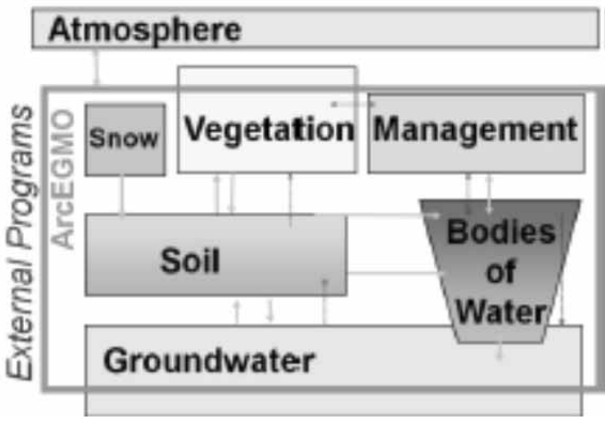

Figure 1. Domains of ArcEGMO.

1.2 Potential of Cloud Computing

Cloud computing is a form of flexible and reliable deployment and use of IT resources and IT services. This may be IT infrastructure (network, servers, storage), platforms or applications of all kinds. These are provided as a service over the internet with minimal administrative effort in real time and charged according to consumption [7]. Cloud services are generally subdivided in the three levels of ‘Infrastructure as a Service (IaaS)’, ‘Platform as a Service (PaaS)’ and ‘Software as a Service (SaaS)’. IaaS provides a minimum infrastructure for computing, used for storing data and network connectivity. The separation from PaaS is blurred, but the latter is usually associated with the development and deployment of Web services.

With SaaS, complete software is directly provided for online use [12]. Due to the focus on pure processing power IaaS is used in this study and briefly described below.

With IaaS, IT resources are provided as virtual instances with complete virtual hardware and an operating system. From the user's perspective, IaaS looks like actual physical hardware: the user can control the entire operating system and the software running on it, and there are no restrictions in terms of applications that can be hosted by the system. To manage the infrastructure, specific web services are made available, which a user can use to start as many instances (virtual servers) as needed for a particular task in just a few minutes, as well as remove them quickly. The disadvantages of IaaS include the fact that an automatic scaling of the computing entities can be difficult to implement, the cost can increase rapidly if used for an extended period of time, and that there is at least the theoretical possibility of an instance failure [13] .

Companies invest in cloud computing especially because of its potential for cost reduction in situations where extended compute resources are needed only from time to time. Further benefits are in the shift from fixed costs (investments, etc.) to variable costs, as seen in the increase of the flexibility and scalability of IT resources as well as in the demandbased billing of IT services [7].

1.3 Requirements for the calibration of ArcEGMO on IaaS clouds

A well-calibrated rainfall runoff model is the key ingredient for reliable flood simulations and predictions for preventing damage. The effort required to run several model for an iterative search of robust parameter values can be lowered by cloud computing,but only when the calculation times are the same or shorter as for local computers and the resulting monetary costs remain low. For payment models without longterm booking, the costs depend partly on the time between generating and removing an instance, as well as on additional fees for data storage, data backup and communication with or between instances [14, 15]. The additional services listed above were not considered in this study, because the size, and with that the monetary costs of transferred input and output, are negligible, as is the loss of information and the expected additional costs due to sudden failure of an instance regarding model calibration.

In this survey, the computing times are the determining criterion for assessing the benefits of cloud computing for the calibration of rainfall runoff models. The time consumed by delays in data transfer is important as well, but is usually small compared to computation time, especially when calibrating with lots of spatial elements.

The cloud services of Amazon and Microsoft offer configurations which are comparable to those of regular desktop computers, but also instance types, which are on the same level as modern server computers [16, 17, 18]. The services of Amazon EC2 and Microsoft Windows Azure are therefore used for the upcoming considerations. In addition to the computation times and the monetary costs, the extent to which computing power can be increased by each provider will also be investigated, as well as how the costs evolve in those cases.

2 Configuration of IaaS Services for the Calibration of Flood Simulations

2.1 Example scenario

To oppose monetary costs and benefits of cloud computing, many different approaches are already available which focus on the profitability at the scale of larger companies and governmental institutions. These are, for example, based on heuristic methods or break-even analyses [e.g. 15, 19, 20]. Here, the chosen method is also heuristic, but the focus is on the performance of the various types of instances. In the following, we will show based on a realistic scenario, how powerful virtual IaaS machines are in terms of rainfall runoff model calculations with ArcEGMO, with regard to simultaneous consideration of the respective costs. The description of the scenario in terms of the configuration of the model and the IaaS services are the topics of this chapter.

2.2 Setup of the modeling system ArcEGMO

ArcEGMO is applied to a real world example catchment, which, in general, is also used for training purposes [9]. The catchment comprises an area of 59km² with lowland characteristics and consists of 362 spatial elements (hydrotropes), whereas a period of 5.5 years in daily resolution is calculated.

The model input data consists of different hydrological and meteorological time series for runoff, precipitation and climate variables. The runoff data is used as the target during model calibration.

After ArcEGMO has been prepared based on its control files, a simulation can be started. The initialization stage of a model run is dominated by file reading and writing processes on the hard drive, while the simulation stage is characterized by memory access. For this reason, a subdivision of the overall calculation time regarding these two stages is applied.

ArcEGMO works sequentially, that is, only one processor core per simulation is used. The amount of memory in use is governed by the number of spatial elements that have to be processed during simulation. In this example scenario, the number is comparatively small, and, therefore, the computation time is short. Because of the sequential processing of ArcEGMO, only scalability based on the different processor types and disk architectures can be considered here. Since currently only Amazon provides multiple computing and storage architectures, the investigation on scalability refers only to EC2.

2.3 The applied IaaS services

Windows Azure possesses properties both of PaaS and IaaS, and thus covers a large range of possibilities for the development and operation of its own software, with a focus on web applications. Amazon's Web Services (AWS) concentrate on flexibility and the combination of resources provided for any kind of use with focus on IaaS. Moreover, there is a wide range of operating systems which, if chosen, already have additional software and software development tools preinstalled.

Within AWS, EC2 is the service to deploy virtual computing resources. Billing is exact to the hour, additional hard drive and communication capacities can be booked with surcharge [16]. In Windows Azure, virtual machines are started and monitored via the Azure user interface. The selected configuration of the instance and the use of additional services or storage capacities determine again the final costs per hour [18].

2.4 The Selection of instance configurations

For both considered cloud providers, configurations have been selected which correspond to the hardware of a local desktop computer.

An exact match and comparison between all three configurations is not possible since both providers use different hardware vendors (Intel for Amazon, AMD for Microsoft). The comparison can therefore be performed only in an approximate way.

The local computer has an E7400 dual-core processor from Intel with 64bit architecture and 2.8 GHz per core, 3 GB RAM, and HDD hard drive. The Amazon m1.large configuration was chosen as the appropriate instance, with 2 cores of an Intel Xeon processor (the clock frequency has not been specified by Amazon), and 7.5 GB RAM [17]. For Windows Azure the A2 configuration with AMD Opteron 2377 EE processor (2 x 1.6 GHz cores) and a total of 3.5 GB of memory has been selected [18, 21]. Table 1 summarizes all configurations.

Amazon EC2 m1.large	Windows Azure A2	Local Computer
- Intel Xeon Processor, 2 Cores, 64bit - 7 GB RAM - Windows Server	- AMD Opteron Processor, 2 Cores à 1,6 GHz, 64bit - 3,5 GB RAM - Windows Server	- Intel E7400 Dual-Core à 2,8 GHz, 64bit - 3 GB RAM - Windows 7

Table 1. Hardware configuration of the local desktop computer and the selected cloud instance types.

Table 2 shows a summary of both providers for the pricing models that do not require a reservation or subscriptions. The costs are exact to the hour. The costs per 30 days are related to a continuously active instance. Additional fees can be incurred for additional services such as storage, databases, network infrastructure, etc., but these services were not needed here, so their cost has been excluded. A local machine was not listed in this table, since variable and fixed costs must be considered together, which prevents an exact comparison.

	Amazon EC2 m1.large on demand	Windows Azure A2 pay-as-you-go
Price [Euros per hour]	0.26	0.135
Price [Euros per 30 days]	190.66	97.20

Table 2. Costs for cloud computing on Amazon's EC2 and Microsoft's Windows Azure for the pricing models 'on demand' and 'pay-as-you-go' (source: 16, 18).

In this study, only the pricing models 'on demand' and 'pay-as-you-go' have been investigated. These relate to a spontaneous provision of instances without having them reserved in advance.

To investigate the potential performance increase with improved cloud resources, instances furnished with the latest processor generation were included into the survey. The m3 instances use Intel Xeon E5- 2670 Sandy Bridge processors and provide SSD hard drives, as well as c3 instances, which, in turn, are equipped with Xeon E5-2680v2 - Ivy Bridge processors [17]. For both the m3 and c3 instance types architectures with two cores have been acquired.

On Windows Azure, there currently is only one generation of instances available, which is why the used processors and hard disk capacity should be on the same level of performance. Additional test confirmed this assumption, but the according results are not presented here.

3 Results of the Investigation of IaaS Services for the Calibration of Flood Simulations

3.1 Comparison of all configurations

For Microsoft and Amazon, hardware configurations can be found which are similar to those of the local computer, even though a direct comparison is not possible due to differences regarding the hardware component suppliers for both computing services. Furthermore, Amazon also offers the latest processor generation at the level of current server computers. Regarding the long term monetary costs, the acquisition of a local device is cheaper: currently, a computer as it is used and presented here is available for approximately 600€ [22].

Also, if other variable costs like e.g. electricity are taken into account as well, IaaS services with costs of around 200€ and 100€ for a month of demand to pay at Amazon and Microsoft, respectively, are of benefit only in cases of short and shortterm application (Table 2). Pricing models with reservation or subscription were not considered here, since in this case the hiring of server capacities would be more favorable [e.g. 23].

3.2 Results for ArcEGMO model runs

Figure 2 shows the calculation times utilized by each provider in general and in comparison to the local computer. It is noteworthy that the virtual machines consume more time than the local device. These differences arise mainly during the simulation phase. This suggests that the pure computing power of technologically similar cloud instances is less than that of a corresponding local computer. Reading and writing processes on the hard disk during the model initialization are thus characterized by a very similar consumption of time.

However, if instances of the latest hardware generation can be applied, as provided by Amazon, there will be a significant performance improvement (Figure 3).

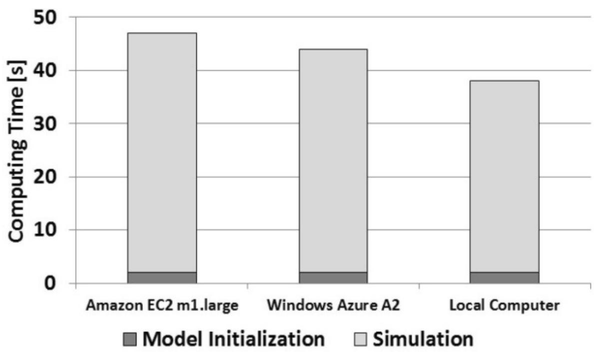

Figure 2. Computing time of ArcEGMO on different platforms.

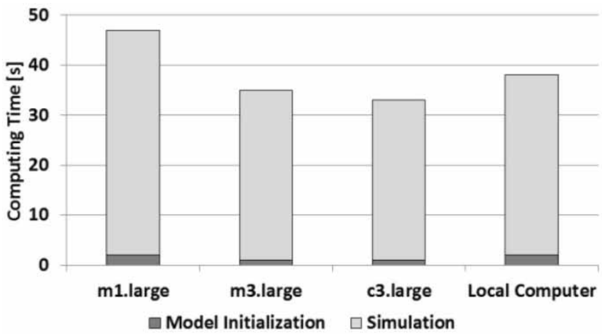

Figure 3. Differences between the Amazon EC2 instance types and the local machine in the required computing time.

If the number of cores per instance is increased, the speed of computing, as expected, cannot be increased, since these additional resources are not applicable due to the sequential programming of the model (results are not presented here). Surprisingly, in Amazon's pricing model, the acquisition of the latest processor hardware is cheaper than using older generations [16; Figure 4].

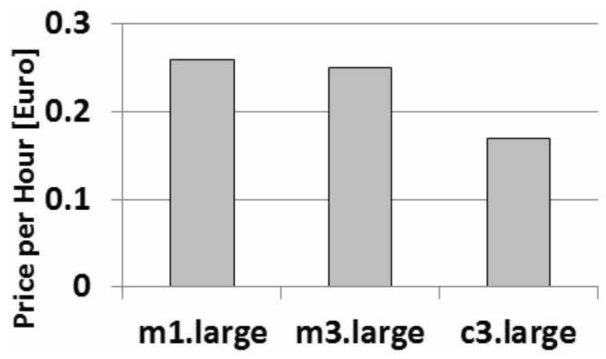

Figure 4. Price per hour for different Amazon EC2 instance types with no additional fees.

Considering Amazons 'on demand' prices without reservation on a monthly basis (180 € and 125 € for m3.large and c3.large), long term use is still too expensive. For less complex areas where the overall computation time is small, the monetary costs without additional storage and communication services are below 20 cents per hour for an instance with the latest and most powerful computing hardware.

However, if large, highly spatially resolved models are calibrated so that the computing power and memory demands increase drastically for several days, costs are quickly increased. If, in that case Amazon instances equipped with the latest hardware generation are applied, one can still expect good operation performance of the model compared to a local device.

4 Conclusion and Outlook

Flood water simulations must be reliable in order to prevent losses and therefore need to be based on well calibrated rainfall runoff models of sufficient complexity. Using the hydrological modeling system ArcEGMO, it could be demonstrated that multiple model calculations, as necessary for model calibration, can also be implemented on virtual machines in IaaS clouds. However, the computing power is slightly below that of a comparable local computer with similar hardware. The outsourcing of model calculations is only reasonable if the latest computer hardware generation is offered by IaaS providers. The costs incurred thereby are low, especially for models with little complexity.

Due to the sequential structure of the modeling system ArcEGMO, additional processor cores cannot yet be exploited for a model run, which is why only a small increase in performance through improved processor technology in the cloud can be achieved. In this case, cloud computing is currently only an alternative in the particular circumstances of a shortterm, increased computational demand, which can not be fulfilled by local computing resources.

The trend of recent years towards technologies of software parallelization will have an influence on the development of novel hydrologic models. The conversion of the model system ArcEGMO towards the integration of multiple cores is currently tested by the authors. The advantage is that calculations can be distributed to multiple cores, which reduces the computing time per simulation depending on the proportion of parallelizable source code. Disadvantages are the major programming effort and the greater need for technical expertise. Existing code is not indefinitely parallelizable, so cloud computing will remain attractive in the long run, since parallelization is well supported due to the scaling of virtual hardware and since the pricing levels are expected to decrease.

Basically, there are further possibilities to decrease the amount of time required for model calibration. Optimization methods for automated model calibration, for example, can be instructed to distribute the individual model runs during calibration on multiple processor cores and to assume the management of the model runs, if supported. Correspondig studies by the authors, which also take cluster computers into account, are in preparation.

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