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Integrating Grid Computing and Server-based Geographical Information Systems to Facilitate a Disaster Management System

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Hayatta en hakiki mürşit ilimdir!
Ilim ve fennin dışında yol gösterici aramak dalgınlıktır, bilgisizliktir, doğru yoldan sapmaktır! Yalnız, ilim ve fennin yaşadığımız her dakikadaki gelişimini kavramak, ilerlemeleri zamanında izlemek şarttır.

Science is the most committed guide to success!
Searching for another guide is ignorance and absence of mind. Understanding the development of science and observing contemporary improvements are essential.

M.K. Atatürk

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DEDICATION

This thesis is dedicated to my family who has supported me all the way since the beginning of my studies.
Also, this thesis is dedicated to my fiancé who has been a great source of motivation and inspiration.
Finally, this thesis is dedicated to all those who believe the richness of learning.

ABSTRACT

Each year, disasters like floods, forest fires, and earthquakes cause of deaths and damage to property around the world, displacing thousands of people from their properties and damaging the livelihoods. Many of these deaths and losses could be prevented if sufficient information was available regarding the onset and course of such disasters. Several technologies offer the potential to improve prediction and monitoring of hazards, risk mitigation and the disaster management. In this sense the integration of sensor networks, computational modeling and Grid computing (a form of distributed computing for faster and more reliable processing) with geographical information systems (GIS) hold great potential for numerous fields of application. Today Grid computing is commonly considered as the third information technology wave after the Internet and Web. This research field seems strong enough to build up the main structure of the next generation of services and applications that are going further in the research and development of GIS related fields. Therefore, a multidisciplinary approach is needed, especially for dealing with fast evolving phenomena, such as flash floods after a forest fire, to be modeled with high accuracy and computational performance, and spatial resolution. The European Union (EU) funded project SCIER (Sensor & Computing Infrastructure for Environmental Risks) was designed on the base of this cognition. It is one of the first interdisciplinary research projects of that kind in the EU region. In this context several data sources are employed to identify their applicability for natural hazards namely floods and forest fires in Europe. The project SCIER was intended to evaluate this issue in several test-sites. This thesis and the related work are integrated into this project and composed at the Faculty of Civil Engineering and Geodesy, the Research Group of Geographical Information Systems, Technische Universität München.

Public awareness should be raised in preparedness to respond by adding early warning systems into disaster management plans and policies. In this sense the current improvements in the field of GIS are mainly driven by increasingly complex problems and pushed by increasingly powerful technology. Today GIS specialists face the common IT problems in several projects. The exponential growth in data volume forces the limits of the storage capabilities, in addition to the diversity and complexity of datasets exist in the market. Of course this causes a bottleneck in system workflows by the three main data issue, namely storage, access and preservation. Meanwhile advance visualization techniques come up with the highly demanding solutions. In this situation the challenge is how to manage these so that vast amounts of data can be used by all scientists in an easy-to-use environment. We as the geo-scientists shall find a way how to build a framework to exchange data and help preserving collected data sets, by collaborating with IT specialists. Once large volume datasets are accessed the solution must provide the proper visualization techniques to get a better understanding of each dataset. By doing so, the visualization system shall help scientists analyze large and complex datasets dynamically. Partnerships among the geo-scientists and the IT-specialists shall overcome the challenges like "how to build a system that helps scientists run advance software without having access to significant resources" which may also help scientists to focus on science rather than technological challenges/problems.

The awareness of the current situation given above, builds this thesis on the fundamentals of the state-of-the-art technology. Accordingly this research focuses on the ways in which a GIS based disaster management system could be made with a better performance by using Grid computing capabilities. In this context the following research questions are formulized to emphasize the focus of this research. What would it mean if you could a) get the results of a complicated simulation in seconds? b) perform an interpolation of billions of points in minutes rather than hours? c) significantly accelerate the overall system performance? d) cut the cost and the hardware requirements in half while increasing the functionalities? The answer is found within a key enhancement so called "Grid Computing". This thesis and the related implementation work focus on integration efforts on GIS and Grid computing. Basic formulation of the hypothesis proposed that Grid computing can bring tremendous productivity and efficiency to GIS projects facing the challenges of an on demand world. Eventually the most innovative element in this research was the incorporation of real-time sensor information for fire distribution and flood modeling and real time representation of the modeling results via the SCIER-GIS platform, which is a new concept that can be very important for non-usual flash floods and fire spread conditions. For enabling such functionalities properly, we had to make sure that there is a powerful and seamless communication between Grid and the GIS component of the project. This core issue actually increased the research capability of the research objective. Based on this objective the final implementation was built in a form of Web-GIS with user friendly Web applications.

ZUSAMMENFASSUNG

Jährlich verursachen Hochwasser, Waldbrände, Erdbeben und ähnliche Katastrophen weltweit Tod und Zerstörung. Viele Menschenleben könnten gerettet und viel Sachschaden vermieden werden, wenn ausreichend Information bezüglich der Auslösung und des Verlaufs einer solchen Katastrophe verfügbar wären. Verschiedene Technologien haben in Kombination mit verfügbaren Geodaten das Potential und bieten auch die Möglichkeit, Vorhersage und Überwachung von Gefahren zu optimieren sowie Risikominimierung und Katastrophenmanagement zu betreiben.

In diesem Sinne stellt die Integration von Sensornetzwerken, rechnergestützter Modellierung und Simulation sowie das Grid Computing (eine Art netzbasierter Verarbeitung zur schnelleren und zuverlässigeren Datenverarbeitung) in einem Geoinformationssystem (GIS) ein großes Potenzial für zahlreiche Geo-Anwendungen dar. Heute wird das Grid Computing häufig als die dritte Welle der Informationstechnologie nach dem Internet und dem Web Computing dargestellt. Dieses Forschungsgebiet ist neu und sehr umfassend und auch stark genug, um die Basis für Dienste und Anwendungen der nächsten GIS-Generation für Forschung und Entwicklung zu bilden.

Es ist ein interdisziplinärer Ansatz notwendig, um die Phänomene von Katastrophen behandeln zu können, die sich sehr schnell entwickeln können und in ihrem Ablauf stark variabel sind, wie dies zum Beispiel bei Hochwasserwellen oder nach einem Waldbrand der Fall ist. Die Modellierung solcher und ähnlicher Phänomene mit einer hohen Genauigkeit und Rechnerleistung steht hierbei im Vordergrund. Das von der Europäischen Union (EU) finanzierte Projekt SCIER (Sensor & Computing Infrastructure for Environmental Risks) wurde auf Basis dieser Anforderungen ausgearbeitet. Hierbei handelt es sich um eines der ersten interdisziplinären Forschungsprojekte dieser Art innerhalb der EU. So wurden verschiedenste Datenquellen verwendet, um ihre Anwendbarkeit im Rahmen des Naturgefahrenmanagements und insbesondere des Hochwasser- und Waldbrandmanagements zu überprüfen. Das technologieorientierte Projekt SCIER wurde ins Leben gerufen, um dieses Thema anhand diverser Test-Fälle zu evaluieren. Diese Dissertation und die damit verbundene Forschungsarbeit basiert auf Teilbereichen dieses Projekts und auf Forschungsschwerpunkten des Fachgebiets Geoinformationssysteme im Bereich WebGIS und GeoWeb Services.

Um Naturgefahren entgegenzutreten und ihnen entgegensteuern zu können, ist es sehr wichtig und sinnvoll, sich in das Bewusstsein der Öffentlichkeit und der Bevölkerung hineinzuversetzen. Die gegenwärtigen Innovationen und Verbesserungen im Bereich GIS kommen vor allem daher, dass die Prozesse und Fragestellungen immer komplexer werden und die Technologie immer leistungsfähiger wird. Heutzutage treten GIS-Spezialisten diesen allgemeinen IT-Problemen in vielen verschiedenen Projekten und Aufgabenstellungen gegenüber. Vor allem das exponentielle Ansteigen der Datenvolumina durch neue Erfassungsmethoden zeigt die begrenzte Möglichkeit der Datenspeicherung auf. Dies führt zu einem Engpass im Systemfluss innerhalb der drei großen Bereiche Speicherung, Zugriff und Analyse der Daten. Gleichzeitig werden Visualisierungstechniken immer weiter verbessert. In dieser Situation besteht die Herausforderung nun darin, einen Weg zu finden, wie mit diesen großen Datenvolumina umzugehen ist, so dass sie schnell zugänglich und einfach zu handhaben sind. Wir als Geowissenschaftler sollten in Zusammenarbeit mit IT-Spezialisten in der Lage sein, einen Weg zu finden, einen einfachen Online-Datenaustausch zu ermöglichen und Hilfestellungen zu geben, damit Datenansammlungen optimal genutzt werden können. Wenn die Verarbeitung von großen Datenmengen realisiert ist, so müssen zusätzlich auch Visualisierungstools bereitgestellt werden, um ein besseres Verständnis der meist komplexen Prozesse zu erzielen. Die Zusammenarbeit zwischen Geowissenschaftlern und IT-Spezialisten muss so strukturiert werden, dass große Projekte wie Naturkatastrophen in Teilprozesse zerlegt werden, damit Technik und Methodik sich ergänzen. Das heißt: „Wie muss ich ein System aufbauen, damit die Software von Geo-Wissenschaftlern genutzt werden kann, ohne dass diese Informatik-Spezialisten sein müssen". Dies würde Wissenschaftlern helfen, den Fokus tatsächlich auf die Methodik und nicht auf die eingesetzte Technologie legen zu müssen.

Diese Arbeit baut auf den Grundlagen der State-of-the-Art Hardware- und Software-Technologien von GIS und Grid Computing auf. Im Speziellen beschäftigt sich diese Arbeit mit den verschiedenen Möglichkeiten, wie ein GIS-basiertes Katastrophenmanagementsystem mit einer besseren Leistungsfähigkeit unter dem Einsatz von Grid Computing aufgebaut werden könnte. In diesem Zusammenhang wurden folgende Fragestellungen formuliert, die im Rahmen der Arbeit untersucht werden:

Was würde es bedeuten, wenn

a) Ergebnisse einer komplexen Simulation innerhalb weniger Sekunden verfügbar wären?

b) Eine Interpolation zwischen Millionen von Punkten innerhalb weniger Minuten und nicht mehrerer Stunden möglich wäre?

c) Die generelle Systemleistung signifikant bis zur Echtzeit-Simulation gesteigert werden könnte?

d) Die Kosten und Hardwareanforderungen um die Hälfte reduziert werden könnten aufgrund erhöhter Funktionalitäten?

Dabei soll die Frage beantwortet werden: Wie groß ist der Nutzen von Grid Computing in Kombination mit GIS. Diese Dissertation und die damit verbundene Implementierungsarbeit behandeln deshalb vor allem die Anforderungen, welche an ein GIS in Zusammenhang mit Grid Computing gestellt werden.

So wird die Hypothese aufgestellt, dass Grid Computing einen enormen Vorteil verschaffen kann, was die Leistungsfähigkeit, Effizienz und Produktivität der Modellierung von weltweiten Herausforderungen im Bereich der Naturgefahren und des Katastrophenmanagements anbelangt. Der wohl innovativste Teilbereich der Arbeit ist die Einbettung eines Echtzeitsensors in die Modellierung eines Waldbrand- und Hochwasserszenarios und die über die SCIER-GIS Plattform zur Verfügung gestellten Echtzeitdaten der Ergebnisse. Dies kann als neues Konzept angesehen werden, welches sehr bedeutsam ist für die Modellierung der schwer erfassbaren Bedingungen für die Entstehung von Hochwasserwellen sowie der Entwicklung von Waldbränden. Um die benötigten Funktionalitäten bereitstellen zu können, musste eine sehr leistungsstarke und nahtlose Verbindung zwischen den GIS- und den Grid-Komponenten sichergestellt werden.

Die Verwirklichung dieses Forschungsanspruchs an meine Doktorarbeit hat meine Motivation. Ausgehend von diesem Ziel, wurde abschließend die Implementierung in Form eines Web-GIS mit benutzerfreundlichen Web-Applikationen realisiert.

1 INTRODUCTION

The integration of computational modeling, Grid computing (a form of distributed computing) , and sensor networks, with geographical information systems (GIS) holds great potential for numerous fields of application. As the development of GIS technologies goes further, an increasing amount of geospatial and non-spatial data are involved in GIS due to more diverse data sources and development of data collection technologies. GIS data tend to be geographically and logically distributed as well as GIS functions and services do. Spatial analysis and geoprocessing are getting more complex and computationally intensive. Sharing and collaboration among geographically dispersed users with various disciplines with various purposes are getting more necessary and common. A dynamic collaborative model is required for the new generation GIS applications. In the scope of this research, Grid computing has been chosen as a suitable solution for the complex GIS functionalities. Today Grid computing is considered as "the third information technology wave" (Ahmed, 2008) after the Internet and Web. Basically, the Grid computing concept is intended to enable coordinate resource sharing and problem solving in dynamic, multi-organizational virtual organizations by linking computing resources with high-performance networks.

Regarding to the facts given above, this research field is going to outline the main structure of the next generation of services and applications that are going to foster quickly the research and development of GIS and related areas. Therefore, a multidisciplinary approach is needed for modeling rapidly evolving phenomena like flash floods after a forest fire, with high accuracy and computational performance in an adequate spatial resolution. The EU funded project SCIER (Sensor & Computing Infrastructure for Environmental Risks) was designed on the base of this cognition. It is one of the first interdisciplinary research projects of that kind in the EU region. In this sense several data sources are employed to identify their applicability for natural hazards namely flood and forest fire in Europe. The project SCIER was intended to evaluate this issue in several test-sites. This thesis and the related work are integrated into this project and composed at the Faculty of Civil Engineering and Geodesy, Chair of Geographical Information Systems, Technical University of Munich.

This chapter provides an overview of the main research objectives and the research capabilities within the integration of Grid computing and GIS. It briefly presents the outline for multi-disciplinary approach at this research. Then, it sums up the technological background of this research. The chapter ends with a discussion on the organization of the rest of this thesis.

1.1 Problem Statement and Motivation

The Earth is a dynamically changing planet. Disasters like floods, forest fires, volcano outbreaks and earthquakes cause of deaths and damage to property around the world, displacing thousands of people from their properties and damaging the livelihoods each year. Many of these deaths and losses could be prevented if better information were available regarding the onset and course of such disasters. Several technologies offer the potential to improve prediction and monitoring of hazards, risk mitigation and disaster management. Helpful application of these technologies requires a solid base of political support, legal frameworks, administrative regulations, institutional responsibility and capacity, and technical training. Public awareness should be raised in preparedness to respond by adding early warning systems into disaster management plans and policies. On the other hand, the current improvements in the field of geoinformatics (or GIScience) are mainly driven by increasingly complex problems and pushed by increasingly powerful technology. And the scientific focus in GIS today seems to be more based on computation, data analysis, and collaboration as on the efforts of individual experimentalists and theorists. Even though computer power, data storage, and communication continue to improve rapidly, computational resources are failing to be accessible for scientific applications and purpose. While scientific research is moving towards an integrated system approach, we would better try to look at scientific tools as a whole to solve out the communities' requirements raised.

Today GIS specialists face common issues with information technology[1] (IT) in several GIS projects. The exponential growth in data volume forces the limits of the storage capabilities, in addition to the diversity and

[1] "Information technology (IT) is the study, design, development, implementation, support or management of computer-based information systems, particularly software applications and computer hardware" (ITAA, 2008).

complexity of datasets exist in the market. Of course this causes a bottleneck in system workflows by the three main data issue, namely “storage, access and preservation”. Meanwhile advance visualization (3D/4D) techniques come up with the highly demanding solutions. In this situation the challenge is how to manage these data so that vast amounts of data can be used by all scientists in an easy-to-use environment. And we as the geo-scientists shall find a way how to build a framework to exchange data and help preserving collected data sets, by collaborating with IT specialists. Once large volume data sets are accessed the solution must provide the proper visualization techniques to get a better understanding of each geospatial-dataset. By doing so, the visualization system shall help scientists analyze large and complex data sets dynamically.

On the other hand the GI industry has also vital computational issues to overcome, such as developing and accessing community codes and parallelizing software for efficient runs. Doubtless this challenge could be solved out with a strong technical expertise to use high-end systems, no matter how small or very large clusters to be accessed. Partnerships among the GI scientists and the IT specialists shall overcome the challenges like “building a system that helps you run advance software without having access to significant resources”. This may also help specialists to focus on core objectives rather than technological challenges.

1.2 The Study Objectives

Rapidly increasing world population and unplanned urbanization spreading into the natural ecosystems in recent years, causing more dangerous situations, with natural hazards at the regions that are inhabited, or with houses built at the foot of dikes, where the safety of life and economic goods tends to vanish during prolonged periods of hazards. One of the major challenges is therefore to link recent progress in information technology and the geo-spatial content to improve real time disaster management. Flood and forest fire simulation engines improved not only in the reliability of the modeled endangered areas, but also the model resolution gap between the atmospheric science and hydrology has become narrower. Hydrology and fire models have proven their ability to model specific events with a reasonable accuracy in terms of model results at the geospatial platform.

From the information technologies perspective, to work efficiently with a Grid environment by using GIS, the development and deployment of a number of services had been required; which were successfully met during this research life-time. These services include low-level solutions such as security, information, directory, resource management and high-level services/tools for application development, resource management and computational interfacing which are based on the Grid characteristics (Foster & Kesselman, 1999) (Baker & Fox, 1999) (Buyya, Abramson, & Giddy, 2000).

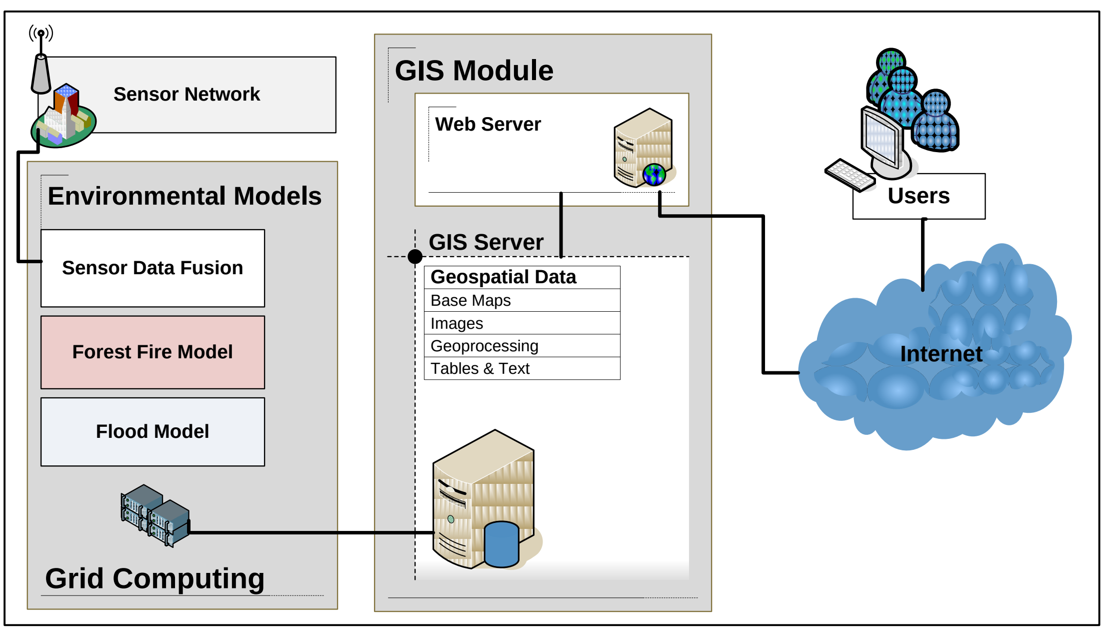

Figure 1-1: Proposed realization of the research objective.

The awareness of the current situation given above builds this thesis on the fundamentals of the state-of-the-art in Grid computing and GIS. Accordingly this research focuses on the ways in which a GIS based disaster management system could be made with a better performance by using Grid computing capabilities (Figure 1-1). The related research capabilities in this field of work mainly deal with the intensive integration efforts which will be given as a high-level overview in next chapters.

1.3 Research Questions

It's worth mentioning following questions to emphasize the focus of this research; What would it mean if an approach could (a) significantly accelerate the overall system performance? (b) perform an interpolation of thousands of points in minutes rather than hours? (c) get the results of a complicated simulation in seconds? (d) cut the cost and the hardware requirements while increasing the functionalities?

The answer is found within a key enhancement so called "Grid computing". As mentioned before increasing amount of complex data and processes are involved in GIS due to more diverse data sources and development of data collection technologies. Data sources and functionalities of GIS tend to be geographically and logically distributed while geoprocessing tasks are getting more power demanding. Sharing and collaboration among geographically dispersed users with various disciplines with various purposes are getting more necessary and common. A dynamic collaborative model is required for the new generation GIS applications. Various organizations have been using Grid technologies for several years, solving some of the most complex and important problems facing mankind. Now Grid computing is becoming a critical component of new scientific activities including GIS. Today's challenging business climate is requiring continuous innovation to differentiate products and services. Modern GIS solutions should adjust dynamically and efficiently to marketplace shifts and customer demands. This thesis and the related implementation work focus on the integration efforts. Basic formulation of the hypothesis proposed that Grid computing can bring tremendous productivity and efficiency to GIS projects facing the challenges of an on demand world. Accordingly the following research questions have been taken to keep the integration efforts realistic and applicable in the real world:

- What are the best strategies developing a successful disaster management system by using distributed GIS approach?
- What is the most convenient system that helps GIS specialists to focus on science rather than performance issues in IT?
- How can a web-enabled GIS solution be used to monitor and model natural hazards in critical and sensitive areas in Europe?
- How can the hydrology and fire model outputs be successfully combined over a disaster management system?
- What kind of key factors should be tested and taken into consideration when defining the ways of integration of GIS and Grid computing?
- What is the proper implementation of Grid-enabled GIS to overcome increasing performance requirements in geoprocessing tasks?

1.4 Research Capability in Grid-enabled GIS

Briefly Grid computing allows for the sharing of processing power, enabling the attainment of high performances in computing, management and services. Unlike the conventional supercomputer that does parallel computing by linking multiple processors over a system bus, this approach breaks up a problem in many jobs (processes) in order to run them simultaneously on a manifold of computers. In this approach "parallel processing" is the key item which stands for the use of multiple CPU's to execute different sections of a program together. Cluster or clusters of machines play the main role on which the GRID middleware operates. To solve performance issues in GIS solutions, there has been much research into the area of parallel processing of GIS information. This involves the utilization of a single computer with multiple processors or multiple computers that are connected over a network working on the same task. There are many different types of distributed computing, two of the most common are clustering and grid processing.

Following research contributions were made to support the research capability of the topic, so that a significant value was provided to the GIS community, service providers and users by advancing in Grid-enabled GIS; compared to traditional system-centric approaches:

1. The thesis proposes a Grid-enabled GIS approach for effective management of GIS-based environmental modeling in Grid computing by handling the large-scale heterogeneity, distribution, and decentralization inherent in them. The solution was generic enough to accommodate two different environmental models well onto the user requirements in a disaster management system. Its implementation leverages many existing technologies and provides additional services for resource sharing and their integration.
2. The research activities were focused on several geoprocessing and visualization algorithms based on enterprise GIS architecture. By adding Grid capabilities in performance of the overall system, we were able to deploy Grid-enabled GIS services. For example forest fire model in the thesis project has a unique structure which enables and runs within the GIS module - to trigger a simulation and visualize results-, and Grid computing – for a fast and reliable processing of the model.
3. The thesis and the related research activities articulate the following key functionalities that Grid-enabled GIS solutions shall support in order to increase the value of the utility and quality of services delivered to users for a successful decision support tool. That is, the framework provides (a) a means to express their requirements, valuations, and objectives, (b) programming interfaces to translate them to resource allocations in Grid environment, and (c) mechanisms to enforce the full integration of differential services, and dynamic adaptation to changes in their availability at runtime.
4. The thesis presents the design and development of a Grid-enabled enterprise GIS prototype that realizes the system architecture by investigating current GIS and Grid capabilities. It uses a component-based layered architecture that enables the deployment of GIS services on Grid technologies with an optimum development effort. To realize the ultimate goal of delivering fully integrated modeling and simulation services, this research focuses on the powerful and effective geoprocessing tools. The prototype was precisely developed to be able to host two different environmental models and related visualization requirements in Web.
5. The thesis presents the design and development of a EU funded project which is one of the first interdisciplinary research projects of that kind in EU. In this sense several data sources are employed to identify their applicability for natural hazards namely flood and forest fire in Europe. The project supports modeling and simulation of heterogeneous geospatial inputs, and application models. It also provides crucial services for creation of geoprocessing tasks, mapping of tasks to geospatial data, and their management.
6. The thesis demonstrates the effectiveness and application of Grid computing and GIS for solving real-world problems by creating a virtual laboratory environment for distributed GIS services. As a final product, the developed GIS module of the project enables access to Grid-enabled services. Several test and validation activities demonstrate that users can easily access to the Web-GIS interfaces and contribute to this decision support system. The fact that users have the option of giving the time interval manually which creates an interactive disaster management environment.

From the user's point of view, there are many benefits in using Grid computing for environmental modeling, which provide the starting point to set the requirements for this research and the related work. The first case is leaving the user's computer free for other tasks by providing a Web based geoprocessing. However the high performance at massive environmental models with parallel simulation tools is also a key issue. Accordingly processing of huge terrain data in a secure and a rapid way should be provided. At last all this system integration efforts should be able to automate executions of complete geoprocessing workflows for environmental modeling.

In this step to clarify the approach given above, the primary reasons for using Grid computing within this research shall be represented as the following:

- Provide concurrency (do multiple things at the same time), and accordingly saving time. Solving larger problems for more complicated geoprocessing tasks.
- Taking advantage of non-local resources - using available computing resources on a wide area network, or even the Internet when local computing resources are scarce.
- Cost savings - using multiple affordable computing resources instead of paying for time on a supercomputer.
- Overcoming memory constraints - single computers have very finite memory resources. For large problems, using the memories of multiple computers may overcome this obstacle.
- Limits to serial computing - both physical and practical reasons pose significant constraints to simply building ever faster serial computers.
- Limits to miniaturization - processor technology is allowing an increasing number of transistors to be placed on a chip. However, even with molecular or atomic-level components, a limit will be reached on how small components can be.

During the past 10 years, the trends indicated by ever faster networks, distributed systems, and multi-processor computer architectures (even at the desktop level) clearly show that parallelism is the future of computing. Basically, the concept of Grid computing is intended to enable coordinate resource sharing and problem solving in dynamic, multi-organizational virtual organizations by linking computing resources with high-performance networks. Grid computing technology represents a new approach to collaborative computing and problem solving in data intensive and computationally intensive environment and has the chance to satisfy all the requirements of a distributed, high-performance and collaborative GIS. Some methodologies and Grid computing technologies as solutions of requirements and challenges are introduced to enable this distributed, parallel, and high-throughput, collaborative GIS application. Grid computing has the chance to lead GIS into a "new Grid-enabled GIS era" (Liu, Huang, & Zhao, 2009) in terms of computing paradigm, resource sharing pattern and online collaboration.

1.5 The Project SCIER

An EU-funded project SCIER[2] (Sensor & Computing Infrastructure for Environmental Risks), introduces a new approach to the GIS based disaster management. The project has already mobilized partners from research institutes, academia, public authorities and service providers from Greece, Czech Republic, Switzerland, UK, France, Spain and Portugal), which combine specialized skills with complementary expertise to fully cover the project requirements (Bonazountas, et al., 2009). All related GIS applications have been developed by the team of GIS in Technische Universität München (TUM) including the author (TUM) and Christian Aigner from ESRI Germany GmbH. As a member of this team, the author's involvement briefly covers the GIS integration and GIS-Server administration tasks. In addition TUM also guaranteed the physical installation of the SCIER-GIS Server Environment in its own premises in GIS-Lab in Weihenstephan.

[2] "SCIER" Sensor & Computing Infrastructure for Environmental Risks - EC RTD Contract no.: IST-5-035164 – available at www.scier.eu

Participant Name	Country	Participant's Role
Epsilon International SA	Greece	C
Technische Universitaet München (Prof. Jörg Schaller)	Germany	S
National Kapodistrian University of Athens – Communication Networks Laboratory (NKUA)	Greece	P
DHI Hydroinform a.s.	Czech Republic	P
National Agricultural Research Foundation	Greece	P
Centre Suisse d'Electronique et de Microtechnique SA	Switzerland	A
Group 4 Securicor Security Services	UK	P
Greek Research and Technology Network	Greece	P
Centre d'Essais et de Recherche de l'ENtente	France	P
TECNOMA S.A.	Spain	P
Associação para o Desenvolvimento da Aerodinâmica Industrial	Portugal	P

* C = Coordinator / P = Principal contractor / A = Assistant Contractor / S= Sub-Contractor

Table 1-1: A list of the participating partners is given in the this table (Bonazountas, et al., 2009).

"SCIER designs, develops and demonstrates an integrated system of sensors, networking and computing infrastructure, aimed to detecting, monitoring, predicting and assisting in crisis management of natural hazards or accidents at the "urban-rural-interface" (URI), i.e., areas where forests and rural lands interface with homes, other buildings and infrastructures. The goal of SCIER is to make the much neglected URI zone safer for the European citizens against any type of natural hazards or accidents" (Bonazountas, et al., 2009). To achieve its objective, SCIER pushes the state of the art and combines technologies and use as (Metelka, Caballero, & Kirklis, 2008):

- self-organizing, self-healing re-configurable sensor networks for the detection and monitoring of disastrous natural hazards,
- advanced sensor data fusion and management schemes capable of deducing the required information needed for accurately monitoring the dynamics of multiple interrelated evolving hazardous phenomena (multi-risk),
- environmental risk models for predicting the evolution of hazardous phenomena using a robust GRID computing infrastructure,
- the public-private sector cooperation (e.g., house/land owner, security-company) as an "active player" in the URI zone protection and the monitoring of hazardous events.

Each citizen is in a waiting position when present in a dwelling. In this positioning case, he has to be informed of the potential disaster (fire, flood…) he may be subjected to. This information has to enable the citizen to:

- Confirm the reception of the message and thus his presence in the area.
- Anticipate his actions to optimize his safety and protection of his belongings.
- Be informed of an action check list to follow.
- Inform the other citizen as tourists for example of the incoming danger

The dynamic follow-up of the disaster must be done in a bilateral way. Indeed, the citizen who receives from the authorities the evolution of the disaster will in turn be able to inform the authorities on the situation and scope of the disaster. If the citizen is absent, the authorities then know that they are the only ones in charge of protecting the belongings. This information is capital for the establishment of the most appropriate tactic for the situation (Metelka, Caballero, & Kirklis, 2008).

1.6 Structure of the Thesis

In the following figures the organizational overview on this research and the methodological approach is given.

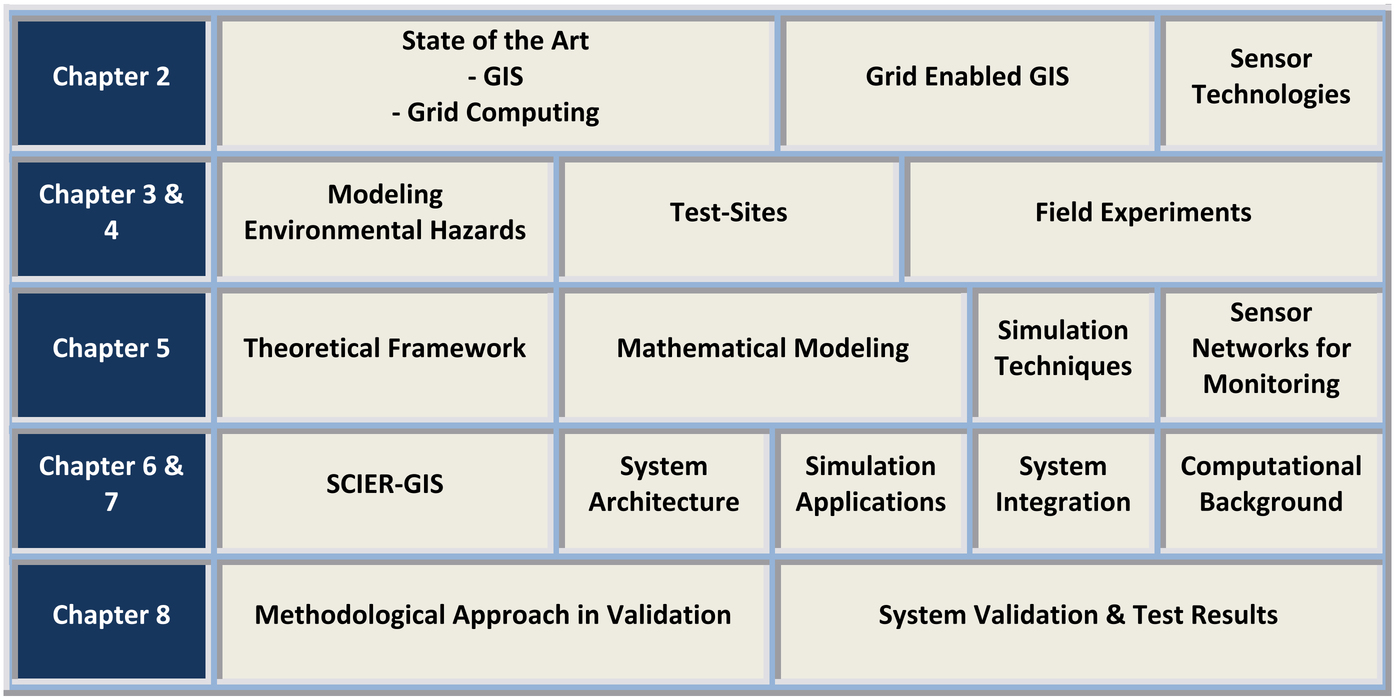

Figure 1-2: Organizational overview on themes focused.

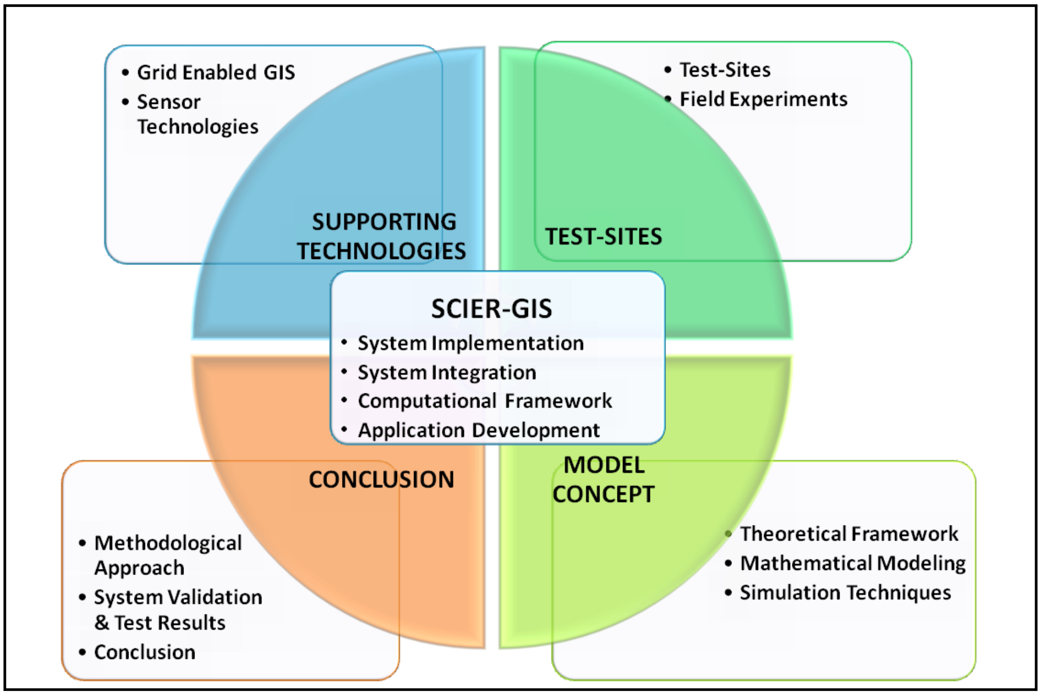

Figure 1-3: Methodology and the structure of the research

The rest of this thesis is organized as follows.

Chapter 2 presents state-of-the-art Grid and GIS technologies from areas concerned with traditional and computational GI based management solutions. On the other hand it gives an technology overview by which keeps the relation among different system components of the project SCIER. The content consists of the state-of-the-art sensor technologies as well.

Chapter 3 presents a brief overview in environmental disaster modeling and the main aspects in GIS based spatial analysis. This chapter gives a summary of an intensive review in theory of the environmental models. Of course, the awareness of the current issues has been building the backbone of the model concept developed and used in this research.

Chapter 4 introduces the test-sites which were selected for the simulation and field experiments in the frame of the project SCIER. What makes these regions special is the extraordinary history of flood and forest fire hazards. You will find the very detailed physical characteristics of the selected regions from France, Portugal, Czech and Greece.

Chapter 5 approaches from the perspective of the theoretical framework, to present the success of the system which uses state-of-art technology. To achieve this, mathematical modeling and simulation techniques are investigated and reported for the phenomena of floods and forest fires. This chapter also discusses the role of the wireless sensor networks for monitoring the outbreak and evolution of natural hazards by the integration of the other system components. It proposes several modeling and simulation techniques which are the cornerstones of SCIER's effort to achieve its objectives.

Chapter 6 and 7 presents the system architecture and implementation of the SCIER GIS that uses a Grid computing driven framework for triggering the simulation applications and based on a GIS-server environment for managing spatial data and geo-processing tasks. It discusses the system integration efforts in a technical view by giving computational background for each and every components of SCIER.

Chapter 8 introduces the methodological approach for the system validation developed in this research. It presents the methodology for the overall system validation by explaining the test results. This chapter also briefly discusses the tests on SCIER-GIS applications for several conditions and performance issues in hazard modelling and monitoring.

2 THE SUPPORTING TECHNOLOGIES

This chapter presents a detailed content of the technologies used with major emphasis on key definitions. It discusses some of the important technological advances that have led to the emergence of modern geographical information systems, Grid computing and sensor networks. It presents the taxonomy of the systems that built the backbone of this research, briefly followed by a deep literature overview.

2.1 Geographical Information Systems

This section provides an overview of Geographical Information Systems (GIS). It examines what GIS is, what it can do and, in brief, how it works. GIS is firstly defined, and a range of issues and ideas associated with its use identified. We then continue with a look at the types of generic questions GIS can answer.

2.1.1 What is GIS?

There have been so many attempts to define GIS that it is hard to pick one and only definition. According to Grimshaw, "The terms geographic information systems and geographical information systems are regarded as synonymous, the former having established in North America and the latter term being more prevalent in Europe. Traditionally geographical information systems (GIS) have been used to help solve problems in the environmental domain. The term GIS has taken on many meanings in the literature" (Grimshaw, 1994). In this sense, Maguire et al. (1991) come up with 11 different comprehensive definitions of GIS. Pickles (1995) has given a clear explanation; "by the fact that any definition of GIS will depend on who is giving it, and their background and viewpoint" (Pickles, 1995). He also considers that definitions if GIS are likely to change quickly as technology and applications develop further.

One of the clearest – and probably the most famous – definitions was given in the Chorley Report:

"A system for capturing, storing, checking, manipulating, analysing and displaying data which are spatially referenced to the Earth."

Definition 1: The Chorley Report (DoE, 1987).

From a local government or a project-oriented institution's perspective GIS seems more valuable to reduce costs in time and labour. In this sense we have seen a specific definition as GIS got mature in practice:

"A computer technology that combines geographic data (the locations of man-made and natural features on the Earth's surface) and other types of information (names, classifications, addresses, and much more) to generate visual maps and reports."

Definition 2: In local governments (Harrison, Kelley, & Gant, 1996)

Lately we have received a modern definition from Dr. Jaenicke who formulates it according to the GfGI's - German Society of Geoinformatics- glossary by combining academics perspective (GfGI, 2005). She emphasizes Geo-information technology as a development which includes all the elements of hardware and software for modelling and analysis of spatial structures and processes.

"A geographic information system (GIS) is a computerized system consisting of hardware, software, spatial data and human beings. The system is used for modelling and analysis of spatial structures and processes."

Definition 3: Kathrin Jaenicke (Jaenicke, 2007).

As Heywood et al. (2006) suggest that the definitions of GIS cover three main components. Firstly they reveal that GIS is a "computer system" which includes hardware, software and appropriate procedures. Secondly GIS is defined a platform which uses "spatially referenced" or "geographical data". Then the third issue could be covered by a GIS definition is "management and analysis tasks" on the geo-data, including their input and output.

In addition to the well-formulated definitions, GIS has particular value when you need to answer questions about location, patterns, trends and conditions such as those below (Heywood, Cornelius, & Carver, 2006):

> *Location.* Where is the nearest bookshop? Where are areas of forestry in which fire possibility can be high? Where are the zones under danger after a possible flood hazard?
>
> *Patterns.* Where do high concentrations of students live in this city? What is the flow of traffic along this motorway? What is the distribution of natural hazards in Europe?
>
> *Trends.* Where have glaciers retreated in the European Alps? Where have changes to the population of polar bears occurred?
>
> *Conditions*. Where can I find holiday?
>
> *Implications*. If I move to a new home in this location, how far will I be from the office, gym or coffee shop? If we build a new theme park here, what will be the effect on traffic flows? What would be the time saving it we delivered our parcels using this route, rather than an alternative?

Related to the requirements stated above, O'Looney finds the exact boundaries of GIS "impossible to define, partly because of the evolution of the technology" (O'Looney, 2000). As hardware and software capabilities expand, capabilities that were once in separate areas become incorporated into the new applications. In the field of GIS, the latest systems may partly or wholly include some of the following capabilities and systems, which are adapted from O'Looney (2000) given as follows:

> *Statistical analysis or spatial statistical analysis:* ability to generate statistics, including statistics based on user-defined geographic regions.
>
> *Web based application development:* ability to meet requirements of internet users by creating publicly available websites with GIS functionalities.
>
> *Geocoding and global positioning systems (GPS):* ability to identify a particular location with standard map coordinates.
>
> *Database management systems (DBMS):* standard database manipulation capabilities like sorting, querying, joining, appending, updating, restructuring, and relating tables and fields.
>
> *Network analysis:* ability to calculate distances, to calculate the most efficient routes, and to summarize network flow rates in relation to the other data.
>
> *Spatial decision support systems (SDSS):* ability to analyze geographic data to support decisions (e.g., identify all residential areas under the danger of flood within the 200 meters distance)
>
> *Customizable user interface:* ability to be customized by third party software or programming languages (e.g., customization in .Net or Java programming environments).

Today GIS draws on concepts and practices from too many disciplines. GIS as a technological term has been adopted to refer to the science behind the systems. Today GIS draws on fields of science as diverse as surveying, city planning, photogrammetry, engineering, remote sensing, landscape architecture, environmental sciences, geodesy, cartography and computer science. Geographical Information Science involves the study of the fundamental issues arising from the creation, handling, storage, and use of geo-spatial information. Of course it also examines the impacts of GIS on individuals and society and the influences of society on GIS (Grimshaw, 1994), (Maguire, Goodchild, & Rhind, 1991), (Jaenicke, 2007), (Heywood, Cornelius, & Carver, 2006).

2.1.2 The Brief History of GIS

40 years ago, some geographers conceived a system for storing and organizing spatial information in a computing environment. During the last decade, this rapidly growing technology has come to be known as geographical information systems (GIS). In 1963 the English-born Canadian geographer Dr. Roger Tomlinson began developing what would eventually become the first true GIS in order to assist the Canadian government with monitoring and managing the country's natural resources.

Dr. Tomlinson for a chance had met on an airplane in 1961 with Lee Pratt, recently named head of the Canada Land Inventory. Pratt's mandate was to develop a land use map of about one million square miles of Canada's inhabited and productive land, showing things like agricultural land, forests, wildlife, land suitable for tourism, and other uses. It would have taken 536 trained geographers working full-time for three years to accomplish the task. There was just one tiny problem: there were only about 60 trained geographers in the country. Dr. Tomlinson told Pratt about his idea of computerizing the overlays, and three months later Pratt called to commission a technical and economic feasibility study. In November 1962, Dr. Tomlinson published the study, and was asked to join the government and develop the system, making Canada the first country in the world to have a computerized GIS - adapted from an interview of Greiner (2009). As a result of this, Dr. Tomlinson has become known as the "father of GIS[3]" particularly for his use of overlays in promoting the spatial analysis of convergent geographic data. CGIS lasted into the 1990s and built the largest digital land resource database in Canada. It was developed as a mainframe based system in support of federal and provincial resource planning and management. Its strength was continent-wide analysis of complex datasets. The CGIS was never available in a commercial form (URISA, 2005).

Briefly GIS was developed in the early 1960s, spurred by pioneering work by the Canadian Land Inventory in 1963 and the establishment of the first academic GIS Lab at Harvard University in 1964. Since then, a broad area of application has been developed. Paralleling advancements in the technology has been the growth of GIS applications and implementations (Longley, Goodchild, Maguire, & Rhind, 2005). From high-quality cartography to land use planning, natural resource management, environmental assessment and planning, tax mapping ecological research, emergency vehicle dispatch, demographic research, utilities, business applications and more, GIS has already proved to be one of the largest computer applications ever to emerge (ESRI, 1995). The role of GIS in these application areas is to provide the users and decision makers with effective tools for solving the complex and usually ill- or semi-structured spatial problems. “Why the growing interest in GIS?” asks Jack Dangermond, and answers as “…because, GIS technology provides a means of integrating information in a way that helps us understand and address some of the most pressing problems we face today. GIS helps us to organize data about these problems and to understand their spatial relationships, providing a basis for making more sensitive and intelligent decisions” (ESRI, 1995). Fast development of geographical information and computer-science integrated technology demonstrates that spatial information is widely used in people’s everyday lives. GIS efficiently combines sciences like graphics, image, geology, geography, remote sensing, mapping, artificial intelligence and computer science.

Today some authors believe that the use of internet to disseminate maps and spatial information has been perhaps the biggest development in GIS over the past few years (Heywood, Cornelius, & Carver, 2006) (Longley, Goodchild, Maguire, & Rhind, 2005). It’s almost impossible not to agree on that statement from these valuable GIS specialists. In fact at the very beginning, the Internet was only used to give wider access to users by publishing geo-spatial data in simple image formats and in form of associated reports. Eventually the industry has acted quickly to develop the possibilities of the web for more interactive and dynamic access to GIS in web. Users are now able to interrogate map data, compose new maps and update and share geo-spatial data. In addition there have been map collections (e.g., ArcGIS Online) online for some years now and interactive and searchable map tools like Google Maps or MapQuest. A recent development has been the arrival of virtual globes or Earth Viewers such as Google Earth, Virtual Earth, and ArcGIS Explorer. These applications allow everyday users to interactively explore anywhere on the Earth’s surface using common interfaces that combine maps, terrain models, satellite imagery and attribute information with geo-spatial search engines. Lately most GIS software packages have web mapping extensions to complement stand-alone systems. So that users can publish spatial content to their clients or colleagues without expensive software licenses and data transfer.

2.1.3 The Enterprise Geographic Information Systems

Today we are witnessing rapidly increasing importance of the geo-spatial data which becomes a key element for effective planning and decision-making in a variety of application domains (Paul, Ghosh, & Acharya, 2006). This has generated the need of sharing the spatial data repositories, collected/maintained by diverse

[3] In recognition of his numerous achievements in the industry, the GIS Certification Institute in early 2004 awarded Dr. Tomlinson the GISP Certificate for Lifetime GIS Achievement and he was awarded a lifetime membership in URISA.

organizations mostly for their own application domain. As it was deeply investigated in this research by mobilizing different organizations from all around Europe, an enterprise GIS was decided to be deployed at the center of the web-base GIS solution. The GIS module implementation within this research explores the integration possibilities between GIScience and Grid computing. The main focus of the conceptual approach was to propose an architecture for integrating diverse spatial tasks and data for geographic applications using a Service Oriented Architecture (SOA). "As a final product, the system architecture of the GIS module -developed in this research- is based on the state of the art computation technologies in Grid and the enterprise GIS. Environmental model results are being processed (geo-processing) and visualized on a web based enterprise GIS platform by exploring Grid technology as an innovative approach to mathematical environmental modeling. At this point of the development, the most advanced and available GIS technology has been applied and adapted in a form of enterprise GIS solutions" (Schaller & Ertac, 2008).

The term "enterprise GIS" has a common and often wrong understanding in practice. It is generally referring to an enterprise software license, to a centralized repository, a common mapping website, and other tangible items. Of course these components can be the parts of an Enterprise GIS; they do not alone define a comprehensive GIS approach that aligns with the priorities of the larger organization. Enterprise GIS is an organization-wide approach to GIS implementation, operation and management of these diverse spatial data repositories. In this context, Mangan (2008) gives the definition as "an Enterprise GIS provides a comprehensive suite of capabilities, integrated into operational workflows that support and help attain enterprise priorities". And she presents the core characteristics of an Enterprise GIS as following:

- Alignment with Enterprise Priorities
- Comprehensive, Accurate, and Timely Data
- Accessibility at all user levels
- Relevance to Operational Workflow
- Integration with Enterprise Systems & Data
- Demonstrated Return on Investment
- Sustainability
- The maturity model will evaluate these characteristics in detail at each level.

Finally we clearly see that enterprise GIS involves an integrated database and system architecture that provides users with different types and levels of access and functionality. It has to be tailored to support complicated geo-processing task, location based queries, and variable computing environments as well. As a crucial role, its design also integrates with other data and systems within an organization. Although it is enabled by technology tools, enterprise GIS is accepted and implemented as a management approach within this research.

2.2 Grid Computing

At a quick look at the brief history of Grid technologies, it's easy to say it has been rapidly evolving since the mid 1990s as the origin of the concept has been initiated in the early 90's. They are primarily concerned with the issues of integrating large-scale computational resources and services (Baker, Buyya, & Aforenza, 2002). The increasing diversity of computational and human resources created a "Grid problem" which requires new mechanisms for sharing resources dynamically (Foster, Kesselman, & Tuecke, 2001). Accordingly efforts were started to deploy several Gigabit test-beds such as Aurora, Blanca, Casa, Nectar, and Vistanet (Lyster, et al., 1992) (Bermann, Fox, & Hey, 2003) projects to link supercomputing sites across the USA. At that time, the approach was known as "metasystem and metacomputing" (Stevens, Woodward, Defanti, & Catlett, 1997). The success of these test-beds inspired the Information Wide Area Year (I-WAY) experiment in early 1995 (Stevens, Woodward, Defanti, & Catlett, 1997) to integrate existing high bandwidth networks (Roure, Baker, Jennings, & Shadbolt, 2003). These experiments motivated some important application driven projects such as the National Technology Grid, which coined in 1997 the term Grid (Stevens, Woodward, Defanti, & Catlett, 1996). The Grid is not only a computing paradigm for providing computational resources but also a distributed computing infrastructure that supports flexible, secure, coordinated resource sharing and problem solving in dynamic, multi-institutional virtual organizations. The Grid was initially motivated on sharing geographically distributed high-end computational power, resources and persistent infrastructure for advanced science and engineering research and applications and emerged with the vision of sharing computing resources just like content on the Web (Foster, Kesselman, & Tuecke, 2001).

Let me continue with the listing current definitions of the Grid computing, since we may easily get confused with the variety of the definitions available in the field of informatics.

Foster and Kesselman (1999) define Grid computing as "A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities". In his famous literature "What is the Grid?" Foster (2002) lists three main attributes of a proper computational Grid system:

- Computing resources are not administered centrally.
- Open standards are used.
- Nontrivial quality of service is achieved.

Plaszczak and Wellner (2005) define grid technology as "the technology that enables resource virtualization, on-demand provisioning, and service (resource) sharing between organizations".

IBM's definition naturally is focused on the situation in the IT market today, and defines grid computing as "the ability, using a set of open standards and protocols, to gain access to applications and data, processing power, storage capacity and a vast array of other computing resources over the Internet. A grid is a type of parallel and distributed system that enables the sharing, selection, and aggregation of resources distributed across 'multiple' administrative domains based on their (resources) availability, capacity, performance, cost and users' quality-of-service requirements" (IBM, 2007).

Buyya et al. (2000) define grid as "a type of parallel and distributed system that enables the sharing, selection, and aggregation of geographically distributed autonomous resources dynamically at runtime depending on their availability, capability, performance, cost, and users' quality-of-service requirements".

CERN, one of the largest users of grid technology, talk of the Grid as "a service for sharing computer power and data storage capacity over the Internet" (CERN, 2008).

Grids can be categorized with a three stage model of "departmental grids, enterprise grids and global grids" (Foster, Kesselman, & Tuecke, 2001). These correspond to a firm initially utilizing resources within a single group i.e. an engineering department connecting desktop machines, clusters and equipment. This progresses to enterprise grids where nontechnical staff's computing resources can be used for cycle-stealing and storage. A global grid is a connection of enterprise and departmental grids that can be used in a commercial or collaborative manner.

2.2.1 Grid Computing Overview

We have seen an outstanding improvement in commodity computer and network performance, mainly as a result of faster hardware and more sophisticated software in the last decade. On the other hand, there are still gaps in science and business solutions, which cannot be effectively dealt with using the current generation of supercomputers. Because of the performance requirements and complexity, these problems are often resource (computational and data) intensive and consequently entail the use of a variety of heterogeneous resources that are not available at one address. Probably the key factors of a rapidly changing computing landscape are the universality of the Internet and the availability of powerful CPUs.

Technology opportunities mentioned above have led to the possibility of using wide-area distributed computers for solving large-scale problems, leading to what is popularly known as "Grid computing" (Foster & Kesselman, 1999) (Waldspurger, Hogg, Huberman, Kephart, & Stornetta, 1992). The term Grid is chosen as an analogy to "the electric power Grid that provides consistent, pervasive, dependable, transparent access to electricity, irrespective of its source. Such an approach to network computing is known by several names: metacomputing, scalable computing, global computing, Internet computing, and more recently Peer-to-Peer (P2P) computing" (Oram, 2001). Grids today are enabling share, selection, and aggregation of a wide variety of resources including supercomputers, storage systems, data sources, and specialized devices. Grids are geographically distributed and owned by different organizations for solving large-scale computational and data intensive problems in science, engineering, and commerce.

At the very beginning, the concept of Grid computing was just a project to link geographically dispersed supercomputers. Today it has moved far beyond its original intent. This new computing infrastructure is capable benefiting many applications, including collaborative engineering, data exploration (geo-spatial and non-spatial data), high throughput computing (in environmental modeling and simulation), distributed GIS solutions and service-oriented computing. Moreover, due to the rapid growth of the Internet and Web, there has been a growing interest in Web-based distributed computing, and many projects have been started and aim to exploit the Web as an infrastructure for running coarse-grained distributed and parallel applications. "The Web has the capability to act as a platform for parallel and collaborative work, which is a key technology to create a pervasive Grid-based infrastructure." (Baker, Buyya, & Aforenza, 2002).

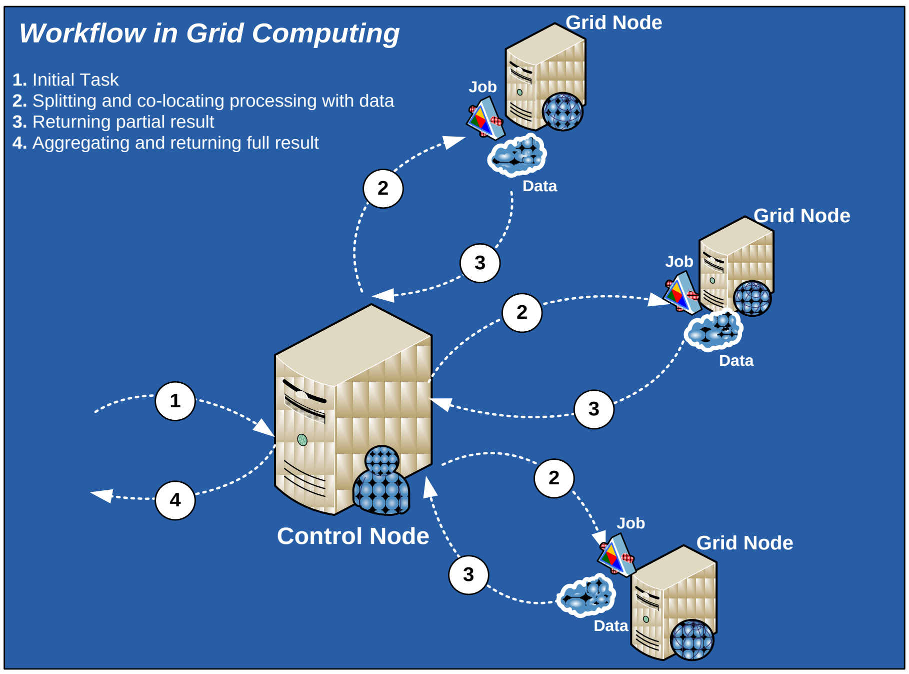

Figure 2-1: What happens in this case is that when a request comes in on the processing node it gets split into sub-tasks. Each sub-task then travels to a grid node that contains the data needed by that sub-task, effectively establishing affinity between processing and data.

There are two modes of realizing grid computing (Foster, Kesselman, & Tuecke, 2001; Cheng & Li, 2009):

1. Distributed Parallel Computing Mode: Figure 2-2 displays the frame of distributed parallel computing mode which is also put in practice in this research. This way of application is mainly constituted by host computers and numbers of client computers (distributed computing container, computing code and computing task). Host computers have more than one client computer, and are in charge of distributing the computing code and computing task of decomposition to relative client computers. Client computer receives the computing code and computing task from the host computer, and can return the result to the host computer after completing computing. At the same time, every client computer can become a host computer and has its own client computers. Besides, every host computer itself can also look upon as client computer, which deals with computing tasks.

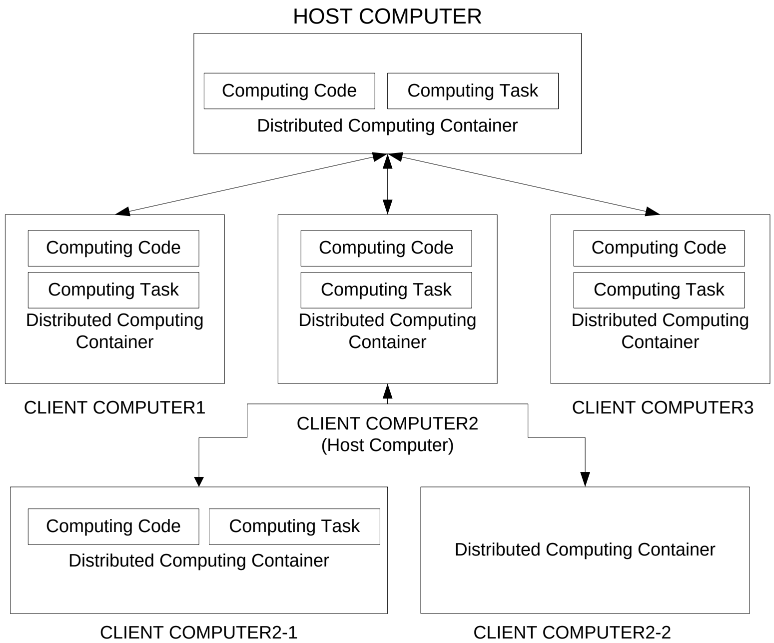

Figure 2-2: Framework of distributed parallel computing mode (Adapted from Cheng and Li (2009)).

2. Cooperation Computing Mode: This is the cooperation working mode. The architecture of cooperation computing mode can be divided into three types, as shown in Figure 2-3.

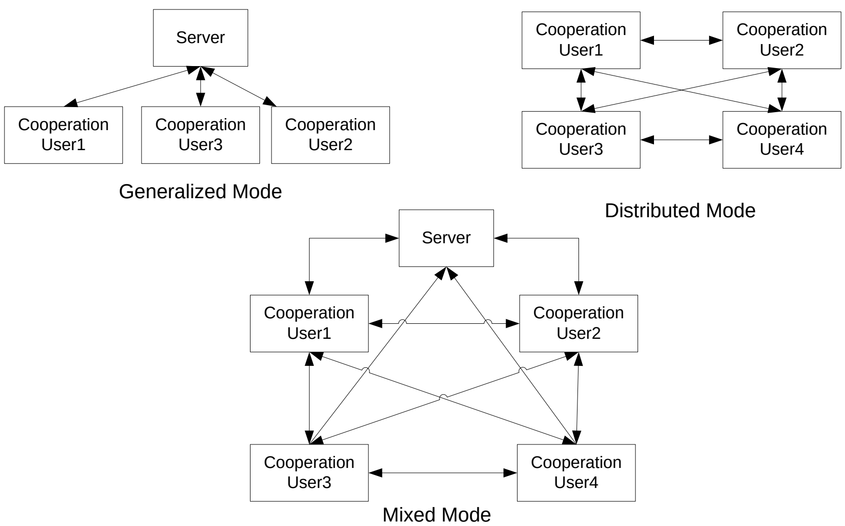

Figure 2-3: Framework of cooperation computing mode (Adapted from Cheng and Li (2009)).

Multi-disciplinary and large-scale processing applications of Grid couple resources that cannot be replicated at a single site, or may be globally located for other practical reasons. These are some of the driving forces behind the foundation of national Grids. As it was explored in the SCIER Project (Priggouris, et al., 2009), national Grid of Greece was put in practice successfully. The Grid allows users to solve larger-scale problems by pooling together resources that could not be coupled easily before. Hence, the Grid is not only a computing infrastructure, for large applications, it is a technology that can bond and unify remote and diverse distributed resources ranging from meteorological sensors to data vaults and from parallel supercomputers to personal digital organizers. Four main aspects characterize a Grid to provide users a seamless computing environment (Foster I. , 2002) (Foster & Kesselman, 1999):

- Multiple Administrative Domains and Autonomy: Grid resources are geographically distributed across multiple administrative domains and owned by different organizations. The autonomy of resource owners needs to be honored along with their local resource management and usage policies.
- Heterogeneity: A Grid involves a multiplicity of resources that are heterogeneous in nature and will encompass a vast range of technologies.
- Scalability: A Grid might grow from a few integrated resources to millions. This raises the problem of potential performance degradation. Consequently, applications that require a large number of geographically located resources must be designed to be latency and bandwidth tolerant.
- Dynamicity or Adaptability: In a Grid, resource failure is the rule rather than the exception. In fact, with so many resources in a Grid, the probability of some resource failing is high. Resource managers or applications must tailor their behavior dynamically and use the available resources and services efficiently and effectively.

The steps necessary to realize a Grid include (Foster I. , 2002) (Buyya, 2002):

- The integration of individual software and hardware components into a combined networked resource (e.g., a single system image cluster).
- The deployment of:
    - Low-level middleware to provide a secure and transparent access to resources.
    - User-level middleware and tools for application development and aggregation of distributed resources.
- The development and optimization of distributed applications to take advantage of the available resources and infrastructure.

2.2.2 Grid History at a Glance

The key improvements from 60's to date in computing and networking technologies that led to the establishment of Grid computing is shown in Figure 2-4. 1960 was the year that IBM was providing mainframes for computing needs. Later on DEC introduced less expensive minicomputers that took over mainframes market share. In the 80s, vector computers and later computers were meeting the requirements of complex computing applications. As it's given in the following figure, during this period the rise and fall of different systems have been observed. (Buyya, 2002)

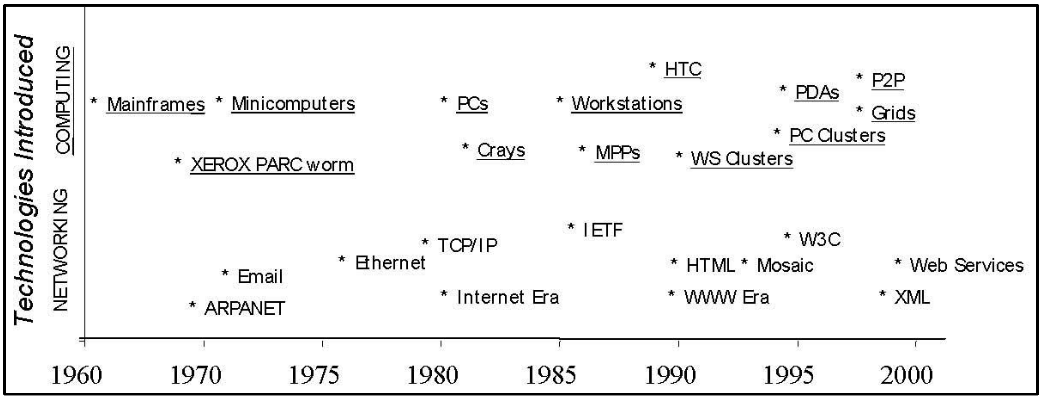

Figure 2-4: Major milestones in networking and computing technologies from the year 1960 onwards-adapted from Buyya (2002).

The key element of the computational Grid environment is the Internet which plays a crucial role as the main communication infrastructure. The Internet began as a modest research network actually, which was supported by the ARPA (Advanced Research Projects Agency) of the US Defense Department. The ARPA's effort started as a response to the USSR's launch of Sputnik, the first artificial earth satellite in 1957 (Zakon, 2006). The ARPANET with four nodes was first established in 1969 at the University of California at Los Angeles, Stanford Research Institute, University of California Santa Barbara, and University of Utah during the September, October, November, and December months respectively. In 1970s, the ARPANET Internet work embraced more than 30 universities, military sites and government contractors and its user base expanded to include the larger computer science research community.

On the other hand Bob Metcalfe's Harvard PhD Thesis outlined the idea for the Ethernet in 1973. It was actually established in 1976 (Metcalfe & Boggs, 1976). In 1974, V. Cerf and B. Kahn proposed the Transmission Control Program (TCP), which was split into TCP/IP in 1978. By 1983, the network still consisted of a network of several hundred computers on only a few local area networks. In 1985, the National Science Foundation (NSF) arranged with ARPA to support a collaboration of supercomputing centers and computer science researchers. The IETF (Internet Engineering Task Force) was formed during 1986 as a loosely self-organized group of people who contribute to the engineering and evolution of Internet technologies. In 1989 by the exchange of the management of the ARPANET, to the academically oriented NSF; much of the Internet's etiquette and rules for behavior were established. (Buyya, 2002).

The invention of the Web (Berners-Lee, 1999) in 1989 by Tim Berners-Lee of CERN (CERN, 2008), Switzerland, for sharing information with ease has fueled a major revolution in computing. It provided the means for creating and organizing documents in html with links and accessing them online transparently, irrespective of their location (using http, browsers, and servers). The World-Wide Web consortium -W3C- (W3C, 1994) formed in 1994 is engaged in developing new standards for information interchange such as XML (eXtended Markup Language) Web services for providing remote access to software and applications as a service.

When computers were first linked by networks, the idea of harnessing unused CPU cycles was born in 1970s. In these years some experiments with distributed computing ran on the Internet's predecessor (Metcalfe & Boggs, 1976). By the year of 1990, with the improvements in the Internet and Web technologies along with the availability of powerful CPUs, distributed computing scaled to a new global content (Buyya, 2002). The availability of powerful PCs and workstations, and high-speed networks as commodity components has led to the emergence of clusters (Berners-Lee, 1999) serving the needs of high performance computing users (Buyya, 1999). The ubiquity of the Internet and Web technologies along with the availability of many low-cost and high-performance commodity clusters within many organizations has prompted the exploration of aggregating distributed resources for solving large scale problems of multi-institutional interest. This has led to the emergence of computational Grids and P2P networks for sharing distributed resources (Bermann, Fox, & Hey, 2003). The Grid community is generally focused on aggregation of distributed high-end machines such as clusters, whereas the P2P community is looking into sharing low-end systems, such as PCs connected to the Internet and contents (e.g., exchange music files via Napster (napster, 2003) network). Given the number of projects and forums (Baker, Buyya, & Aforenza, 2002) started all over the world in early 2000. Today it is clear that interest in the research of Grid computing technologies is rapidly growing. New application domains like simulations and parameter sweep applications like GIS and ecological modeling, where large processing problems can easily be divided into sub-problems and solved independently, are taking great advantage of Grid computing.

2.2.3 Grid Research Activities in European Union

This section presents the results of a detailed review about the Grid research projects funded under FP7 and past framework programmes[4] of European Union. It is compiled from the several sources like the ICT Results service which publishes regular news articles on research results and projects. In Europe, major Grid activities started at the beginning of 2000, both at national and EU level. At the EU level, funding for Grid projects (EU-ICT, 2008) came from the framework programmes (FP5 and FP6). Scrutiny of the many diverse, sometimes overlapping projects, and the discovery of the considerable amount of funding spent in carrying them out - both at national and at EU level - prompted the idea of making an attempt to improve coordination among funding authorities at both levels, to avoid fragmentation and duplication of efforts, and to consider launching joint research projects with the critical mass required to create a breakthrough. This idea is further supported by the ERA initiative. The objective of the ERA (European Research Area) (EU-ERA, 2008) initiative combines three related and complementary concepts: the creation of an ‘internal market’ in research, an area of free movement of knowledge, researchers and technology, with the aim of increasing cooperation, stimulating competition and achieving a better allocation of resources; a restructuring of the European research fabric, in particular by improved coordination of national research activities and policies, which account for most of the research carried out and financed in Europe; and the development of a European research policy which not only addresses the funding of research activities, but also takes account of all relevant aspects of other EU and national policies.

Country	million EUR
AT	2,7
FR	98,3
DE	58,8
HU	8,6
IT	40,7
NL	20,0
PL	9,1
ES	4,5
SE	2,3
UK	155,0
Total	400,0

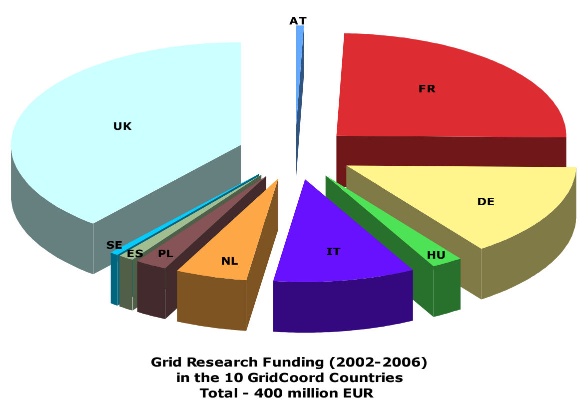

Figure 2-5: The Grid research funding in the 10 GridCoord countries (GridCoord, 2006).

[4] Framework Programmes are the EU's main instrument for funding research and development activities covering almost all scientific disciplines runs for a specific period. FP4: Fourth RTD Framework Programme, 1994-1998; FP5: Fifth RTD Framework Programme, 1998-2002; FP6: Sixth RTD Framework Programme, 2002-2006

Software development tools, either programming languages or libraries, assist the programmer in the development of complex Grid applications, exploiting concepts and abstractions at the programming level, leaving Grid management issues to the tools. Grid middleware allows programmers or higher-level tools to handle all Grid-related details: applications built on this middleware can fully exploit the services offered by the chosen middleware and the unique properties of Grids that they present at the programming level. Several tools and techniques are being studied to assist programmers and users in the development and exploitation of complex Grid applications. Middleware is of the utmost importance when speaking of Grid technologies, and often there is a tendency to label most of the Grid-related software technologies as middleware, even if it is not appropriate (GridCoord, 2006).

Countries	million EUR
AT	2,7
FR	98,3
DE	58,8
HU	8,6
IT	40,7
NL	20,0
PL	9,1
ES	4,5
SE	2,3
UK - research	155,0
UK e-Science	158,0
FP5 projects	58,0
FP6 Grid research	125,0
FP6 Grid deployment	100,0
Total	841,0

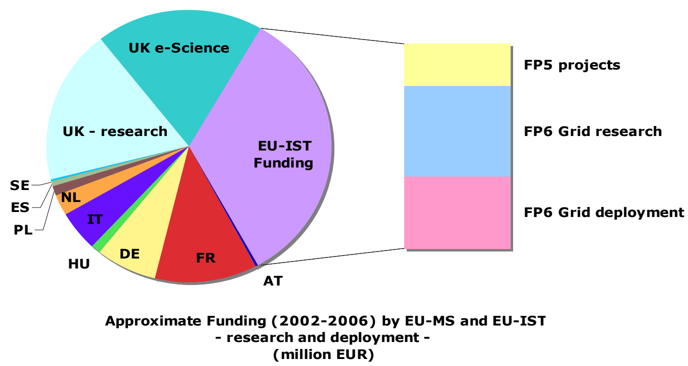

Figure 2-6: EU FP5 projects (from 2002 onwards) and the FP6 projects (GridCoord, 2006).

Grid research related to the hardware/software infrastructure that is deployed as a Grid comprises: network technologies, deployment and management of large-scale platforms, and the service infrastructure that must be operational for a collection of resources to become a Grid. A software infrastructure is needed to build dependable, consistent and pervasive services that are needed for a collection of heterogeneous resources to become a Grid. Developing full-featured Grid infrastructures for research or enterprise use requires huge efforts. Several EU-funded projects are currently prototyping and deploying such infrastructures for use by research communities. Other projects carry out research and development activities for business Grids satisfying industrial requirements, which usually go beyond those of the research communities (GridCoord, 2006).

2.2.3.1 Grid projects funded by the EU under FP5

The Grid-related projects funded by the EU under the Fifth Framework Programme (FP5) are given in a list in the Appendix A, which are being monitored by Unit F2 (Grid) of the European Commission's DG Information Society (EU-ICT, 2007).

2.2.3.2 Grid-related projects monitored by other Units

The other Grid-related projects are being monitored by other services in the European Commission's DG Information Society (see the Appendix B for the detailed list of the projects (GridCoord, 2006).

2.2.3.3 Achievements of FP5 Projects

Under FP5, the IST programme launched a total of 24 European Grid-related research projects, representing total EU funding of around EUR 58 million. These focused primarily on developing and integrating the intermediate software (or middleware) and validating the Grid concept in application areas. The achievements of EU Grid research during FP5 can be summarised as follows (EU-ICT, IST-Web, 2007):

- Creation of a strong Grid research community;
- Strengthening of Europe's position in Grid middleware development and standardisation;
- Leading position established for vertical Grid middleware orientated towards specific application requirements;
- First steps taken towards maturing Grid technologies for industrial and business use;
- Grid concept proven in e-Science application pilots followed by application by deployment in research infrastructures;
- Identification of emerging opportunities for service providers coupled with understanding that more commercial exploitation is critical for wider adoption of Grid Technologies.

The table below provides an overview of the key technical achievements of 16 individual FP5 Grid projects.

Table 2-1: The key technical achievements of 16 individual FP5 Grid projects (EU-ICT, IST-Web, 2007).

Project	Standardization	Middleware development	Commercial applications	Scientific applications	Interoperability	Grid Developer tools	Web Services
BioGrid			•			•	•
CrossGrid		•		•	•	•	
Damien		•	•			•	
DataGrid	•	•		•		•	
EGSO				•	•	•	•
EuroGrid	•	•	•	•			
FlowGrid		•	•			•	
GEMSS		•	•				•
GRACE	•	•	•	•			
GRASP		•	•			•	•
GRIA		•	•			•	•
GridLab		•		•		•	
GRIP	•	•			•		
MammoGrid			•	•			•
OpenMolGrid			•	•		•	
WebSi		•	•				•

2.2.3.4 Grid projects funded by the EU under FP6

“In the summer of 2004 the European Commission launched 12 research projects in the area of Grid technologies that will receive 52 M€ of EU funding. The bulk of the EU funding is going to 4 projects - SIMDAT, NextGRID, Akogrimo and CoreGRID - which each are receiving an EU contribution of around 9 M€. Together with 8 smaller projects, these bring together dozens of universities, research institutes, large and small companies from across Europe to muster the "critical mass" of expertise and resources necessary to trigger change” (EU-ICT, 2008).

Their approach to Grid research combines "technology push" (developing underlying technologies and interoperability standards), with "application pull" (developing the enabling technologies needed for real-world applications, such as modeling, simulation, data mining and collaborative working tools).

“In the summer of 2006 the European Commission launched 20 new Grid projects receiving more than 70 M € of EU funding. They included three large Integrated Projects: BEinGRID, BREIN and XtreemOS. In the beginning of 2007 three additional projects were launched focusing on the cooperation with China on Grid Technologies” (EU-ICT, 2008).

For information on individual projects, including the scope of the project's research work and the partners involved, please refer to each project's 'Supplementary information sheet' provided in IST-Web (EU-ICT, 2008). The alphabetic list of the projects is given in the table in Appendix C.

2.2.3.5 Grid projects funded by the EU under FP7

The Grid-related projects funded by the EU under the Seventh Framework Programme (FP7) are given in the list in Appendix D, which are being monitored by Unit F2 (Grid Technologies) of the European Commission's DG Information Society (EU-ICT, 2008).

2.3 Coupling GIS and Grid Computing

By using GIS software and data sources, you can access to an unprecedented amount of high-resolution and high-quality environmental data through scanners, remote sensing devices, GPS receivers, etc. These datasets usually belong to different custodians, but could be used by others from different fields with different respective. So GIS can benefit from parallel and distributed computing. But also, the volume and variety of these environmental data, metadata, applications arise issues of interoperability, data and processing standards, which again are general problems in Grid computing. (Hawick, Coddington, & James, 2003)

This research is based on the foundation of “coupling Grid computing with GIS”. Nowadays GIS tends to be more distributed in terms of data repositories, user background and purpose, and group collaboration. On the other hand it needs higher performance to process massive amount of data in relatively shorter time, sometimes even real-time. Grid computing could provide a solution for high-performance distributed GIS. Today in distributed GIS, it’s really hard to find sophisticated projects focused on Grid and GIS (Hawick, Coddington, & James, 2003) (Chervenak, et al., 2003) (Aloisio & Cafaro, 2003). On the other hand it’s worth mentioning several attempts in the last couple of years. A proper starting point for studying the interconnection between Grid and GIS is a deep review for the recent research and development projects in this area:

- Huang et al. (2008) discussed several implementation methods, including global directory construction and global parsing algorithm. Through the Grid infrastructure, integration of distributed geospatial data was achieved by them. They implemented an actual prototype system named GeoGrid.
- Xie et al. (2008) propose that real-time GIS applications require sub-second response time to analytical operations on large and highly dynamic datasets for timely decisions. This approach is actually a great use-case of the scientific focus of this research. Their work describes this approach on using Grid computing to support near real-time geospatial applications with near real-time routing as an example. It is demonstrated that the Grid-enabled geospatial applications can enhance the computing efficiency by harnessing distributed computing resources.
- Lee and Percivall (2009) focus on the worldwide development and integration of geo-data by easing the combination of the initiatives of the Open Grid Forum (OGF) and the Open Geospatial Consortium (OGC). With this, they present the need for a standardization of web-services, transfer protocols and description languages.
- Aspects of whether to parallelize the data or the tasks, data quality issues, system architecture decisions, and workflow orchestration were deeply investigated by Werder and Krüger (2009). The research described in their work was a part of the GDI-Grid project (Spatial Data Infrastructure Grid) which will be cited in following paragraphs.

- Padberg and Greve (2009) present the approaches developed in the GDI-Grid project to bridge architectural gaps between GIS and Grid technologies without changing the well-known service interfaces specified by the OGC. In addition to highlighting fundamental differences of grid infrastructures and SDIs, they focus on suitable methods for grid-enabling OGC processing (i.e. Web Processing Service - WPS) and data services (i.e. Web Feature Service, Web Coverage Service).
- Woolf and Shaon (2009) investigate the integration of Grid computing capability within a WPS. Their approach is based on the use of the Job Submission Description Language (JSDL) being developed by the Grid community as a standardized description of computational jobs to be executed on heterogeneous Grid platforms.
- Another research activity focuses on WPS tools and the architecture for geo-processing in the Grid. At the case study of flood modeling that is very related to this dissertation work of mine Kurzbach et al. (2009) show which benefits can be generated in spatial data infrastructures by using grid technology (Kurzbach, Pasche, Lanig, & Zipf, 2009). This work emphasizes the GDI-Grid project as an extension to regular OGC-based SDI service.
- Cheng, and Li (2009) analyze the weakness and problems of traditional GIS, and then give the method of solving these problems with the technology provided by grid computing and web services. With the technology of middleware, this research presents the architecture of Grid GIS and lists the techniques it needs.
- Zhang et al. (2009) has been working on a design framework for developing GIService web portals which are supported by Grid computing and Service-Oriented Architecture (SOA). They focus on a technical implementation plan which is outlined toward building Grid-enabled high performance GIService web portals using the state-of-the-art computing technologies. A prototype demonstrates the feasibility of their system architecture.
- Liu et al. (2009) investigate Grid-enabled geospatial databases. Their research results indicate that the grid geospatial database can solve the problem of data management, data sharing and magnanimous data storage well under the isomerism environment. They emphasize that their method has good practicality, which can be applied in GIS widely.
- Zhou and Wan (2010) states that "in the network environment, how to integrate multi-sources heterogeneous spatial data has become a hot and difficult problem of GIS". Their research aimed to solve the problem by grid computing technology, and put forward a model of multi-sources heterogeneous spatial data integration based on it. They use Globus Toolkit and OGSA-DAI to establish a heterogeneous data integration platform. Based on the platform, various heterogeneous data sources can be connected seamlessly.

As an additional literature review in international level, some more research activities have been detected and given as following:

- The German GDI-Grid (GDI-Grid, 2009) integrates OGC and OGF standards on the German eScience infrastructure D-Grid (D-Grid, 2007). Based on three selected use cases (flood simulation, noise propagation and emergency routing) a spatially-enabled Grid middleware will be developed. Also running on D-Grid is the Collaborative Climate Community Data and Processing Grid (C3-Grid, 2005). C3Grid develops a grid-based research platform for earth systems research.
- The British SEE/SAW-GEO project (JISC, 2009) focuses the integration of security mechanisms into spatial data infrastructures by utilizing Grid technologies. SEE-GEO is an acronym for Secure Access to Geospatial Services). SAW-GEO on the other hand focuses workflows within spatial information systems and is the short form of Development of Semantically-Aware Workflow Engines for Geospatial Web Service Orchestration.

- The European project Cyber-Infra-structure for civil protection Operative Procedures (CYCLOPS, 2008) utilizes Grid technologies for civil protection and also operates on spatial data sets.
- The Global Earth Observation Grid (GEO-Grid) is a world-wide initiative for the Earth Science community. It aims to integrate a great variety of Earth Science Data (satellite imagery, geological data, etc.) through virtual organizations while keeping use restrictions on classified data sets (GEO-Grid, 2006).

Main technical requirements of the advanced GIS technologies are proposed and applied in this research according to the development of GIS and Grid computing. These crucial requirements include distributed multi-resources, high-performance computation and data transfer. Challenges of building such a GIS are presented, such as standard programming languages and operating systems to facilitate distributed GIS, load balance issue for parallel computing, flexible sharing relationship, multi-resource management, various usage modes and security issues. Current Grid computing technologies do not address all these problems. A recent emerging wide area parallel computing technology called Grid computing is introduced as a possible solution for the next generation of GIS. The Grid computing concept has the chance to satisfy all the requirements of a distributed, high-performance and collaborative GIS.

2.3.1 Current Situation in Coupling GIS and Grid

As GIS goes further, new issues show up, new solutions are asked, and new technologies are needed. After the first GIS applications (Longley, Goodchild, Maguire, & Rhind, 2005) developed GIS sciences and technologies have become more and more mature and sophisticated. GIS has been used in more and more fields with different disciplines. Today it plays more vital role in several fields. As everything else, development of GIS naturally raises issues that need to be solved.

Data has the most crucial role in GIS related solutions. As stated before, GIS users today have access to a huge amount of high-resolution and high-quality geo-spatial data, which also includes non-spatial data. Recourses of these datasets are getting more diverse. As the consequence of development of data collecting devices and information networks, the updating of GIS data is getting more frequent. Eventually larger volume of data sources are involved in GIS. Accordingly development environments used in GIS are getting more various, which means a GIS is required to support multiple data formats from different operating systems. All these issues make it harder to store all datasets in a single site.

Complex spatial analysis and geo-processing functionalities must be considered as well. The more GIS and processes get sophisticated, the more spatial analysis methods and geo-processing algorithms are developed. In ideal conditions new algorithms are more complex than previous ones, which means more computation is involved. When these methods and algorithms are implemented within GIS, consequently more CPU time and memory allocation are required. Meanwhile, as a significant trend in recent years, less responding time of GIS is required. In too many cases real-time computing is necessary.

As another key factor, the information network technologies, makes it possible for GIS users to share resources even though they are dispersed geographically and logically. By the help of web-services like Simple Object Access Protocol (SOAP), today shared resources include not only GIS data, but also methods and models, software components, computing capabilities, services, etc. For the most convenient environment of sharing, network linking technologies have been established geographically distributed individuals or agencies that have partially overlapping objectives; based on this network they can pool complementary core competencies. Since users and data repositories of GIS tend to be geographically dispersed, and collaborations among users with various disciplines are getting more necessary.

2.3.2 GIS Requirements

When we had a quick look at the development of GIS, some characteristics of the next generation of GIS could be presented as following.

GIS data could be geographically and logically distributed, while GIS functionalities could be distributed geographically and logically. Software components and geo-processing models could be located in different sites, and be requested by geographically distributed users in form of services. This GIS should provide some tools to manage and access massive distributed resources including datasets and services. So, GIS should be more distributed in future.

GIS should respond to requests from users, process multi-site data and perform complicated geo-processing in relatively short time, in real-time too. GIS built on distributed computing system, has to deal with the data transport issue to achieve preferable high performance. So, GIS should have real high-performance in terms of computing.

GIS should facilitate appropriate user interfaces for geographically dispersed multi-users in order to accomplish common objectives. A GIS should provide protocols and tools to enable some characteristics like connectivity, propose, technology, and boundary (Shao, Liao, & Wang, 1998). So, GIS should be collaborative.

2.3.3 Problem Statement

Each problem in the market brings a chance for enhancements in technology. So it is in GIS. Every development in information technology provides a chance to improve GIS technology, but introduces some challenges to it as well. For instance, to make GIS to be distributed computing systems, it needs to be established to enable interoperability. Since more data providers and technologies are involved in GIS, it's getting harder to establish a single universal data format. As a solution distributed GIS could consist of multiple geographically and logically dispersed GIS functions providing services to end-users. In this context, the goal of Open GIS Consortium is to establish standards for GIS data and geospatial data processing service. However this is a much more difficult problem and there has been little progress so far (Hawick, Coddington, & James, 2003).

Since we are talking about Grid computing technologies, we should be able use GIS as a parallel computing system. So, resource management and task allocation need to be concerned in order to achieve the most appropriate load balance among multiple processors. When computing is implemented in parallel paradigm, data or task needs to be decomposed into parts, and loaded to processors efficiently according to performance of processors and bandwidth of networks among processors. In addition to the basic requirements and the expectations in technology, GIS should meet following technical concerns of the current stake-holders (Foster, Kesselman, & Tuecke, 2001):

- Highly flexible sharing relationships, varying from client/server to peer-to-peer;
- Complex and high levels of control over shared resources, including security issue such as authentication and authorization, implementation of local and global policies;
- Highly variety of sharing resources, including datasets, documents, models, software components, computers, instruments and networks;
- Diverse usage modes, varying from single user to multi-user, from performance intensive to cost intensive.

2.3.4 Conceptual Approach

GIS technologies today do not address all these concerns and requirements mentioned in the previous sections. Present distributed GIS still focuses on handling geographically distributed data. Even some of them provide remote geo-processing functionalities. The services provided are relatively simple but not quick and intelligent enough in terms of computation. Current parallel GIS needs expensive supercomputers or computer clusters which blocks users who have no access to these high-cost facilities. Most of them address communication and information exchange among computers but not the coordinated use of resources at multiple sites for computation. Some of them focus on enabling sharing resource within a single development environment like Enterprise Java. The recent distributed computing trend indicates a new approach for the next generation of GIS, which is called Grid computing. Today Grid computing technology has the chance to satisfy all the requirements of a distributed, parallel and collaborative GIS. In this sense, EU-funded project SCIER has been proposed and developed to explore next generation GIS functionalities.

2.4 Sensor Networks

Wireless sensor networks have been attracting many research efforts during the past few years. Sensor networks, usually composed of a few sinks and a large quantity of inexpensive and small sensor nodes, have been deployed in a variety of applications (Akyildiz, Su, & Cayirci, 2002) such as habitat monitoring (Szewczyk, Polastre, Hamilton, Mainwaring, & Estrin, 2004), forest fire detection, etc. In this context, the sensing system used in the SCIER project is composed of two components, the wireless sensor network (WSN) and the sensing system proxy, as shown in Figure 2-7. The role of the wireless sensor network is to collect measurements from the deployed sensors and to send them to a base, through a sink node, using wireless transmission. The sensing system proxy provides the access point to the Local Alerting Control Units (LACU) and the higher layers of the SCIER system in general. It is the front-end of the sensor network: it collects all data and passes them to the LACU in the appropriate format. It also receives and executes commands coming from the LACU.

The Local Alerting Control Units (LACUs) are deployed all over the area that needs to be secured from potential emergency situations, arising from environmental risks, such as forest fires or floods. LACU controls a network of variable type sensors, receives input from them, runs fusion algorithms on the received data and sends the fused data to the Computing Subsystem (CS) for further processing. From an architectural point of view the LACU can be thought as a set-top-box device, which stands between the back-end infrastructure (Computing Subsystem) and the sensors that have been deployed in the WUI. In SCIER, two types of LACUs are identified:

- Public LACU (P-LACU). This type of LACU is installed and operated by public authorities and controls a wireless network of Public Owned Sensors.
- Private LACU (R-LACU). This type of LACU controls Citizen Owned Sensors and is installed by individuals in order to protect their private properties.

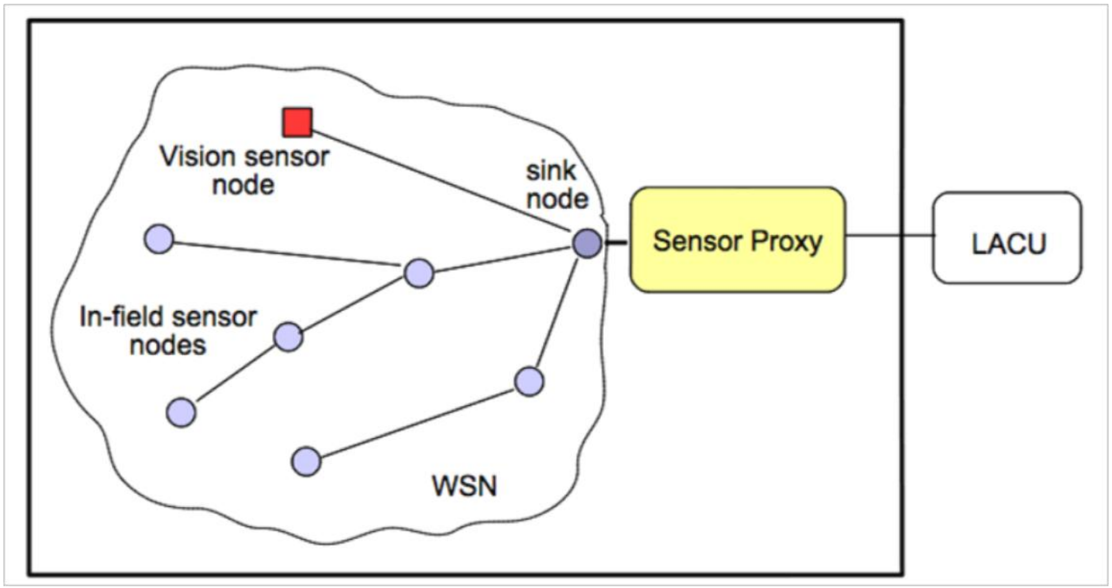

Figure 2-7: SCIER Sensing System (Bonazountas, et al., 2007)

The third release of the sensing system (RS3) extends the release specifications 1 (RS1) and 2 (RS2). RS1 and RS2 comprised an operational sensing system that integrated a couple of in-field sensors as well as a vision sensor (out-of-field sensor). The sensors were able to regularly report measurements and respond to requests coming from the LACU. RS3 extends the system functionality mainly by finalizing the operation of the vision sensors and by adding a sensor network management capability, in order to monitor the system and react to abnormal events, like a missing node or the addition of new nodes.

3 MODELING ENVIRONMENTAL HAZARDS

Disasters come in many forms. Natural disasters kill a plenty number of people around the world each year, and leave millions homeless. Natural disasters may include earthquakes, floods and flashfloods, landslides and mud flows, forest fires, winter storms, and others. The key to minimizing or controlling the cost and death toll of disasters is prevention. This is not to say that we can prevent natural disasters but we can minimize their effects. What this research focuses is how we can evaluate, prepare for, react to, and minimize damage brought on by emergencies and disasters. Of course we should benefit the state of the art technology to provide faster and more reliable disaster management systems. In this context, this chapter represents the basic approaches to identify hazard modeling techniques, pre-planning and preparation processes. This will be giving the fundamental theory in understanding natural hazards. After having this quick look, implementation methods will be deeply investigated in the test sites from Europe in the following chapter.

3.1 Identifying Disasters

Emergency preparedness, response, recovery, and mitigation are based on a careful and comprehensive hazards analysis process (Pine, 2009). “Emergency preparedness and operations plans must be based on a careful examination and understanding of the types of hazards that the community or organization faces” (Tierney, Lindell, & Perry, 2001). An assessment of a community’s social-cultural, economic, and environmental capital is the initial step of this effort. Community assessment and hazard identification is thus a critical part of the emergency preparedness process and forms the basis for a risk analysis and the determination of community adjustments to reduce vulnerabilities (EPA, 1987). These adjustments are accomplished through intentional problem solving throughout the hazards analysis process. Through the problem-solving process decision makers are able to see issues more clearly by looking beyond just the symptoms of a problem and acknowledge that their organizations must address problems that make the communities more vulnerable to disasters.

“The community decision makers must understand how hazards could affect their community and form a basis for strategic risk management strategies and hazard mitigation decisions. They point out that hazard identification is the foundation for many decisions associated with emergency management” (Deyle, French, & Patterson, 1998) Deyle et al. (1998) also stress that it is an essential foundation for emergency management, upon which a hazards analysis is based. The U.S. Environmental Protection Agency (EPA, 1987) stresses the importance of hazards identification within the hazards analysis process. Hazards identification is the initial step in the hazards analysis process, includes a description of the community, and provides an analysis through environmental modeling of the nature of the threat. A key element in the hazards identification process is gathering data about hazards and the inclusion of public, private, and not-for-profit partners in the community.

“Natural disasters result from the interface between the natural geophysical systems and human systems, both constructed and personal (Figure 3-1)” (Smith, 2004). Our capacity to minimize adverse effects of disasters depends on our human adaptation to natural events, including our building codes, land use regulation, and the design of our critical infrastructure. Our resiliency or capacity to withstand or to recover from a disaster is influenced by human adaptive actions. Mankind is not a helpless object, but can take steps to protect his social, economic, and natural systems from harm. “The environment is neither benign nor hostile. It is in fact neutral, for human action within a hazard zone establishes our vulnerability” (Burton, Kates, & White, 1978). Therefore, we must examine our natural, human, economic, and constructed systems to fully understand what actions may be taken to reduce our vulnerability and enhance our resilience to natural hazards. Fundamental to this process is an identification of the hazards that face our communities and organizations. The United Nations stresses the importance of understanding hazards and that slowly evolving hazards such as drought and environmental degradation should be included in our analysis (Pine, 2009).

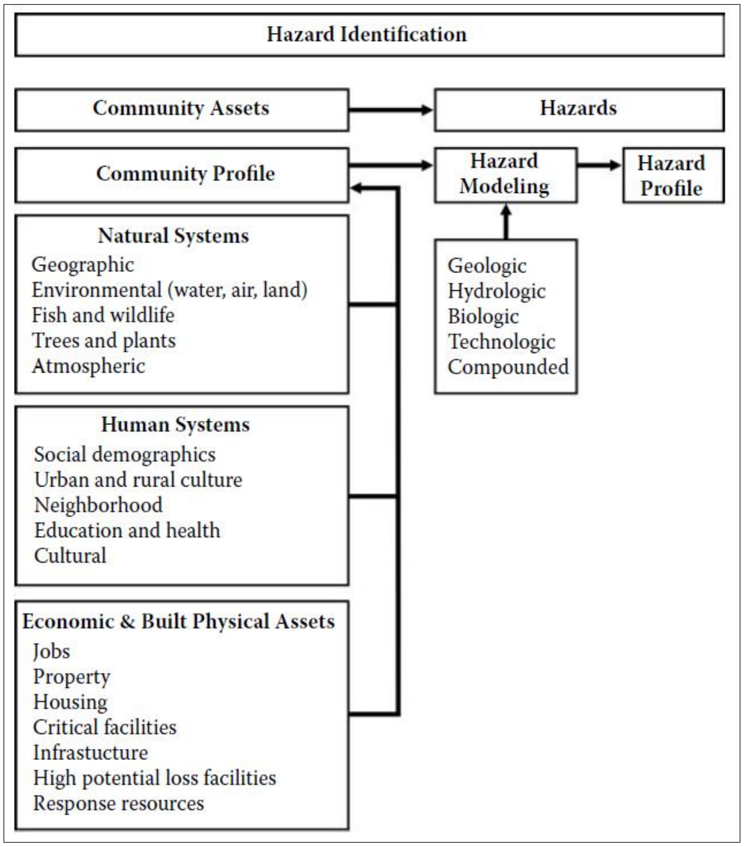

Figure 3-1: The linkages between community assets and hazards (Smith, 2004).

The goal of the hazard identification and characterization process is to describe hazards that could impact the community or organization. It also provides a basis for future steps in the hazards analysis process. In order to do this, we need to first look at our community and to determine just what is at stake in our community from our people, our economy, the environment, and building and infrastructure. When creating a hazards profile, we categorize hazards into groups by type. However, a hazard in one category may result in a secondary hazard included another category. Heavy rains could cause flooding and lead to chemical spills or an avalanche. The sequence that a hazard evolves and the nature and extent of the resulting disaster will influence how we perceive the threat of the hazard to the community. The division of hazards into these categories helps to provide structure for identifying and characterizing risk to a community or organization and helps us to understand the impacts of hazards (Pine, 2009). Hazard identification is an ongoing process that enables communities to establish a culture of hazards risk management and hazard mitigation. It acknowledges that natural hazards may reveal more fundamental weaknesses in local systems that must be addressed to truly ensure community resiliency.

3.1.1 Modeling Natural Disasters

A plenty number of public and private institutions have utilized hazard modeling and mapping for many years to clarify the nature and extent of tropical cyclones, inland flooding, wind, fire, earthquakes, explosions, radiological and nuclear hazards, landslides, chemical releases, and volcano hazards. Some of them have also been leaders in the initiative to characterize the nature of hazards using hazard models and maps (Pine, 2009). “Models are a simplified representation or a physical phenomenon (Brimicombe, 2003; Drager, Lovas, & Soma, 1993)”. In the case of hazards, models simulate the nature and extent of a disaster event. We use models to represent natural events, and for determining how a specific hazard could affect a community. Sophisticated computational models are based on complex mathematical formulas and assumptions. Models are quantitative and attempt to reflect the dynamics of physical, economic, natural, and social processes. Models can be reflected in regression lines predicting an output and based on input variables and mathematical formulas that use complex processes within a computer program (Pinkowski, 2008).

Models provide many uses within a scientific context. According to Chorley and Haggett (1968), models help us to:

- Visualize complex processes and interactions that add to people's understanding
- Provide teaching and learning
- Describe a physical phenomenon or process
- Compare and contrast events, situations or processes
- Collect and manipulate data
- Explore or construct new theories or expand current ones

Most of the environmental hazard models that we use today are based on deductive reasoning. That is, one starts with specific observations of the environment and suggests a theory that is based on a hypothesis. An experimental design is determined and based on real data and results in a predicted outcome or phenomena. The model results either verify an outcome, or the assumptions must be adjusted to correct for an error (Pine, 2009; Rothermel, 1972; DHI, 2000; Cartalis, Varela, Eftichidis, Asimakopoulos, & Feidas, 1994).

As part of the emergency management and disaster science community today, we are able to take advantage of computer technology advancements to use hazard models, but also interpret their outputs. Many environmental hazard models address a broad range of disasters and run easily on various computing environments.

3.1.2 Nature and Types of Models

Mathematical models come in different forms such as statistical, dynamic, or combination (statistical and dynamic together). Statistical models are used to predict or forecast future events by utilizing data from the past. These models compare current hazard characteristics with historical data of similar events. Historical records may cover many parts of the world and include data for over 100 years. Note that data collection methods have changed over time, and our understanding of extreme weather or geologic events is far more detailed today than prior to the application of sensitive direct and remote sensing technology (Pinkowski, 2008).

3.1.2.1 Deterministic

Deterministic models are based on relationships which can be seen in many environmental applications. For example, a DEM (digital elevation model) provides a description of locations on the Earth's surface as measured by points or contours related to nearby points (Xie, Esaki, & Zhou, 2004). We are able to determine the flow of water on the Earth's surface by examining the relationship between contours or points spatially. An interesting dynamic that is seen in this type of deterministic model is that location matters. Tobler (1970) explains that the "first law of geography" is that "everything is related to everything else, but near things are more related than distant things."

3.1.2.2 Probabilistic

Statistical probabilistic models (Schneid & Collins, 2001) such as HEC1 (HEC, 2000) has been used in the National Flood Insurance Program for many years. The model estimates flood flows having given recurrence intervals or probabilities; these calculations are needed for floodplain management efforts and the design of hydraulic structures. The program estimates annual peak flows on recurrence intervals from 2 to 500 years. It characterizes the magnitude and frequency of annual peak flows for water features.

Most hazard models (IACWD, 1982) determine a risk vulnerability zone for a specific hazard and suggest that individuals in the risk zone could be injured or, even worse, a casualty. Flood models could suggest that residential, commercial, and industrial property could be at risk or vulnerable to flooding if structures are located in an area near a water feature. To determine if specific structures would actually be flooded, additional information is needed about the precise location of the structure, if the building is elevated, and the ground elevation of the structure. If this type of data is not available, then the model would not be able to determine the extent of flooding for a single building in the flood zone. It might flood, or the water might not reach the flood elevation of the structure.

3.1.2.3 Dynamic

Dynamic models function differently and use real-time data to forecast extreme climatic events. For example, a dynamic model might take current wind, temperature, pressure, and humidity observations to forecast a specific storm (Caballero, Martinez-Millán, Martos, & Vignote, 1994). This type of model is very useful where we have extensive data on the nature of the environment. This is more likely the case for numerous data sources along coastal areas of the United States and water features in inland areas. The use of powerful computers with real-time hazard data collection has led to great improvements in dynamic models.

3.1.2.4 Combination

Combination models can take advantage of both dynamic and statistical approaches. For areas of the world where precise data measurements are not available, combination models can take a more global perspective and provide good predictions of hazard events on a regional basis (Cartalis, Varela, Eftichidis, Asimakopoulos, & Feidas, 1994).

3.2 GIS and Environmental Models

A modern approach from Brandmeyer and Karimi (2000) established a typology for categorizing how GIS and environmental models interface. The most simplistic relationship is one of “one-way data transfer,” which allows for a one-way link between the GIS and an environmental model.

A more complex relationship is described in a loose-coupling type of integration (Pine, 2009). In this category, there is a two-way interchange between the model and the GIS, allowing for data exchange and change. Processing of environmental data may be made in a GIS using spatial analysis tools, and then the data is moved to the model as a data input (Goodchild, Parks, & Steyaert, 1993).

On the other hand Kara (1996) defines “a shared-coupling design” that links shared data sets for the GIS and the model. This kind of systems includes a utility to allow the GIS to display residential, commercial, industrial building data and so on. A joined-coupling design may also be established where both the modeling and GIS use common data sets, but integration occurs in common script language for both the modeling and GIS. Newer versions of hydrological models have been developed so that as environmental conditions change data inputs may be used to revise hazard outcomes as well as GIS displays (Goodchild, Parks, & Steyaert, 1993). The highest level of integration is one where the modeling and GIS are combined in a common user interface and likely on the same computer. Many functions are joined and shared within the programs including data management, spatial data processing, model building and management, model execution, and finally visualization of model outputs in a GIS.

3.2.1 Spatial Analysis

In his latest book, Pine (2009) mentions Dr. John Snow who unraveled the causes of cholera in the mid-ninth century in London by recording on a map the incidence of cholera. Dr. Snow was able to observe from his map the relationship between a public water pump in the center of the cholera outbreak. “Although his use of maps to track the cholera outbreak did not prove the cause, it raised a question as to the relationship between drinking water and the public health outbreak” says Pine (2009). Stronger evidence was obtained to confirm his contention when the water supply was cut off and the outbreak subsided. His illustration provides several critical elements of the productive use of spatial analysis in a hazards analysis. Firstly he collected accurate health data and made accurate geo-reference placement of this data on a map. He visualized on his map other related items, such as the public water pump. The scale of the map was of a small area within London and provided an appropriate scale in which to test his hypothesis. More importantly, Snow simply used his analysis of spatial data to raise a hypothesis that had to be further studied or tested. His methodology was goal directed and determined the scope of his analysis. The key to spatial analysis is clearly stating what we intend to accomplish and determining a methodology that is suitable to achieve the desired results.

“Spatial analysis is a set of tools and methods that are used to examine the relationships between social, cultural, economic, ecological, and constructed phenomena” (Pine, 2009). Investigating hazards and their impacts, spatial analysis provides tools of understanding the nature of hazards and their social, economic, or ecological impacts. Spatial analysis is the center of how geographic information systems are used in transforming and manipulating geographic data. It provides the methods that are used to support organizational decision making by government agencies, businesses, and nonprofits (Longley, Goodchild, Maguire, & Rhind, 2005; Openshaw & Clarke, 1996). The methods and tools provided by spatial analysis thus give us a means of turning raw data such as what Dr. John Snow collected, into useful information. In the case of understanding natural hazards, you can easily enhance your understanding of the nature of hazards and their impacts by using spatial analysis. The results of such analysis can also help you to better communicate within organizations and with the public. “Spatial analysis adds meaning, content, and value to our quest to better understand hazards and their impacts” (Schneid & Collins, 2001).

Statistical methods are used in the analytical methods, but spatial analysis is much more that just crunching numbers. Through spatial analysis, we are able to reveal patterns and processes that otherwise might not have been observed and confirm or disprove the hazard-related hypothesis. Accordingly, Pine (2009) classifies the types of the GIS based spatial analysis as the following:

- *Queries:* Following questions would be answered by using typical spatial analysis; How many people, commercial businesses, or residential homes might be impacted by a flood? How many roads or bridges are in the area with the deepest flooding? How many structures are in the high-wind zone of a hurricane? How many renters or homeowners may be displaced by a flooding event? What is the average income of population of a community directly impacted by a volcano eruption?
- *Measurements:* A flood event effect many communities in a metropolitan area. Accordingly spatial analysis would help us to give right decisions in the effected region. What was the area flooded in the city? What is the average residential parcel or lot size in flood areas of the city? Using land-use classification data for the city? How much commercial or industrial property was flooded? How much public property for parks and open space was flooded? would be just a few questions to perform crucial measurements.
- *Transformations and Buffering*: These analysis tools allow the user to transform GIS data sets to reveal relationships and dynamics of the physical environment. Buffer analysis is used for identifying areas surrounding geographic features. The process involves generating a buffer around existing geographic features and then identifying or selecting features based on whether they fall inside or outside the boundary of the buffer. Examples include buffering a point, line, or area to highlight potential change. If a new school were to be built in a specific location, what is the population in a two-mile area? If a commercial area were to be flooded, what other enterprises in a three-mile area could handle the additional business? If a rail line was damaged as a result of an earthquake, how many industrial enterprises within a ten-mile area could be impacted?
- *Descriptive Summaries*: Geospatial data that reflect unique elements of a disaster provide opportunities for understanding potential relationships between a disaster and associated human characteristics.
- *Optimization Techniques:* Spatial analysis is also used in site selection and transportation routing to help locate the ideal setting for an emergency shelter, medical clinic, or police substation, or the shortest evacuation route of multilane roads and highways. Evacuation routes that are scenario specific can be developed to aid community planners in evacuating large populations from a metropolitan area.

Geospatial data analytical techniques perform a variety of functions within a GIS and are important for the types of questions and concerns that policy makers address in private, public, and nonprofit organizations (Fischer, Scholten, & Unwin, 1996). Fischer (1996) further stresses that using geospatial relationships provides a very good framework for understanding the meaning of data within a GIS. As you may remember from the previous chapters, GIS based spatial analysis evolved in the early 1960s as part of quantitative geography and the application of statistical processes in examining spatial relationships of points, lines, and area surfaces (Greiner, 2009). A spatial temporal perspective was added to allow us to examine these relationships over time as well.

3.2.2 Geospatial Data

Spatial data relating to hazards comes in many forms and enables us to characterize both the nature and extent of the hazard event and the many elements that help shape or characterize the hazard. The accuracy of the spatial data, which provide the input into the model, influences the validity of the modeling outputs. In the following chapters, data requirements for a successful flood and forest fire model will be represented in detail.

3.2.3 Quality of the Geospatial Data

It's broadly acknowledged that any data set will not be totally accurate. Errors and uncertainty are inherent in any data set or information system and should be acknowledged as part of the hazards analysis process (Goodchild, Parks, & Steyaert, 1993; Openshaw & Clarke, 1996). You shall also acknowledge that the computer model is just a tool that includes assumptions about the environment and the relationships between its variables. We should be very clear as to the limitations of the data inputs and the assumptions that the model makes in simulating a complex environmental hazard.

Errors in data that are inherent in geospatial data used in a hazards analysis occur because of changes over time. Changes in water features, land use, or landscapes may occur naturally or because of human interventions. We must examine any data set that is part of our hazards analysis to understand if changes have occurred and that these are noted in our methodology (Pinkowski, 2008). On the other hand, as we discuss data quality, that modelers assess the quality of their outputs by comparing the results of simulated disasters with actual events. The National Weather Service (NWS) has customarily compared model results from hurricanes with weather data from sensors in coastal environments (Pine, 2009). These comparative studies provide the basis for adapting hurricane models and improve their predictive capacity for future storms.

3.2.4 Visualization of the Geospatial Data

Probably the most crucial part of the spatial analysis process is displaying the results. Hazards are geospatially oriented, and thus being able to show the results of our analysis is a key element in supporting individual, organizational and community decision making. Whether the results of our analysis comes from a modeling program, such as earthquake, flood, or volcano eruption, displaying geospatial data is a critical means of conveying information to users of our final hazards analysis or as we work with the data using spatial analysis techniques. Spatial data is meant to be viewed as maps, and a GIS allows us to interactively change these maps to help us reveal information from the landscape in a variety of ways. We can add different spatial layers, such as where people live, transportation routes, quarantine areas, key facilities, or infrastructure, and display them over high-resolution images of a community (Goodchild, Parks, & Steyaert, 1993).

3.3 Advantages and Disadvantages of Hazard Models

Environmental hazard models that are based on comprehensive geospatial data may provide an accurate representation of a complex environmental dynamic. If this data is up to date, accurate, and in a format that may be used by modelers, then the modeling outputs are more likely to be received in a constructive manner. If users have severe reservations concerning data quality that would be used by an environmental hazard model, then they will resist the application of the model in community policy making (Openshaw & Clarke, 1996; Pinkowski, 2008).

GIS based hazard models are based on a set of assumptions that should be conveyed to the model user and in outputs from the model. These assumptions could involve decisions by model developers that a geographic area mapped was flat, in a rural area, and that data such as weather conditions did not vary over the study zone (Pine, 2009). Goodchild et al (1993) states that many hazard models include assumptions that are not fully understood by users. In this sense, Kirkwood (1994) suggests that environmental hazard models may not provide an accurate representation of the risk to local citizens. It's totally agreed here that, when we fail to communicate clearly the nature of environmental risks, public officials and citizens alike can have a false sense of security, or if risk is overestimated, it can consequently cause fear. In too many cases environmental models require trained users to interpret the results.

Hazard models that are coupled with GIS can provide more complex information at a higher level of analysis (Fischer, Scholten, & Unwin, 1996). Risk zones based on different considerations of individual vulnerability can be displayed on a map. Combining maps and graphics gives us an additional tool to provide clear communication to those who want to understand the result of environmental models. Many models may also be able to change data inputs to incorporate environmental and social changes so as to facilitate an accurate understanding of levels of risk or variations of the consequences to disasters.

Another crucial aspect is the metadata which should be associated with any geospatial data used in modeling hazards. Metadata provides information about the data set and includes its purpose, an abstract, when it was developed, by whom, any geographic parameters, sponsoring agency, how it is distributed, contact information for anyone who has questions, and use constraints (Openshaw & Clarke, 1996).

4 TEST SITES

The functionality of the SCIER platform on forest fire and flood hazards was demonstrated through a series of trials. At this moment the deployment in four test sites around the Europe is foreseen. However, final decisions on the selection of test areas will be done throughout the lifespan of the project, as natural hazards at prone areas cannot be forecasted so much earlier. The test sites and the reason for the selection are given as following:

- The Czech Test-site, which is the Bečva River (the left tributary of the Morava River which is the main river of the Moravian part of Czech Republic) were used for flood testing.
- The Portuguese test-site was chosen at Gestosa, where experimental and controlled burns took place in order to assess fire monitoring capabilities of the SCIER system. Considering that in Gestosa burns are controllable, the selection of this site is finalized from the beginning of the project. The site was used for testing SCIER's functionality both the first and the second year of the project.
- The French test-site was selected at the south of France, namely Aubagne, aiming to assess project's functionality in forest fire hazards.
- The Greek Test-site, near the small town of Stamata, a suburb of Athens located 25 km north of it, where several forest fires have occurred in the last years. The test-site was used for fire model tests.

4.1 The Test-Site for Flood Modeling

The River Bečva is the left tributary of Morava River (which is the main river of the Moravian part of Czech Republic). Bečva river watershed (local hydrological numbers 4-11-01 and 4-11-02, catchment area of 1630 km^2) lies in the east part of Morava river basin and is bordered by Odra Mountains and Moravskoslezské Beskydy mountains. Bečva river catchment covers mainly Vsetín, Přerov and Kroměříž districts and partly districts of Nový Jičín and Opava. The spring area of Bečva river catchment is one of the extremely wet areas of Czech Republic while the middle part of the catchment ranks among the moderate wet areas. The whole river system has a highland character. Rožnovská Bečva, Senice, Bystřička and Juhyně are the most important tributaries. Bečva River is 120 km long. The first part of the river is called Vsetínská Bečva (58,8 km) , the second part (downstream of its junction with Rožnovská Bečva) is called Bečva and its length is 61,2 km. Bečva is the most important tributary of the Morava river watershed and has a significant influence on discharges in the Morava river itself. All tributaries in the spring area have a character of mountain torrents. The river slope of Bečva river decreases up to 1,2 ‰ after Hranice na Moravě City, approximately 40 km upstream from Bečva tribute to Morava river (Priggouris, et al., 2009).

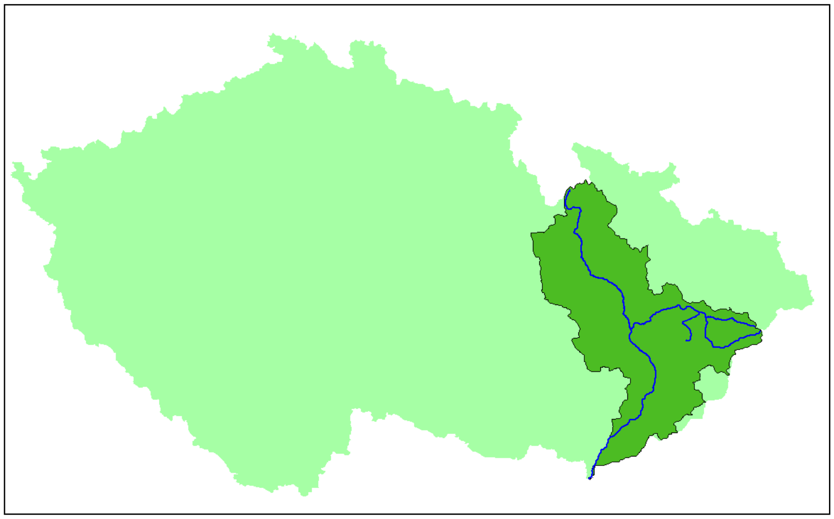

Figure 4-1: Overview map of Czech Republic with Morava River basin and Morava and Bečva rivers (Priggouris, et al., 2009).

This test case area was used for the SCIER project for flood hazard models. All the land use types from forest and agricultural land through villages and small cities like Teplice or Lipník nad Bečvou up to medium size cities like Hranice nay Moravě (approx. 30 000 inhabitants) or Přerov (approx. 50 000 inhabitants) are present in the flood plain area of Bečva river. Floods are formed in the upstream mountain part of Bečva catchment. In this area, all floods respond very fast on rainfall and it is possible to say that this is the area of flash floods that give the inhabitants a very short time for the preparation and evacuation. Downstream of Hranice na Moravě city, the river has a smaller slope and floods become slower, wider and with longer flooding time and higher flood damages due to larger villages along the river valley. Mountain part of this catchment is suitable for rainfall-runoff modeling, while downstream part of Bečva valley is dedicated for more complex hydrodynamic models (Metelka & Bonazountas, 2007).

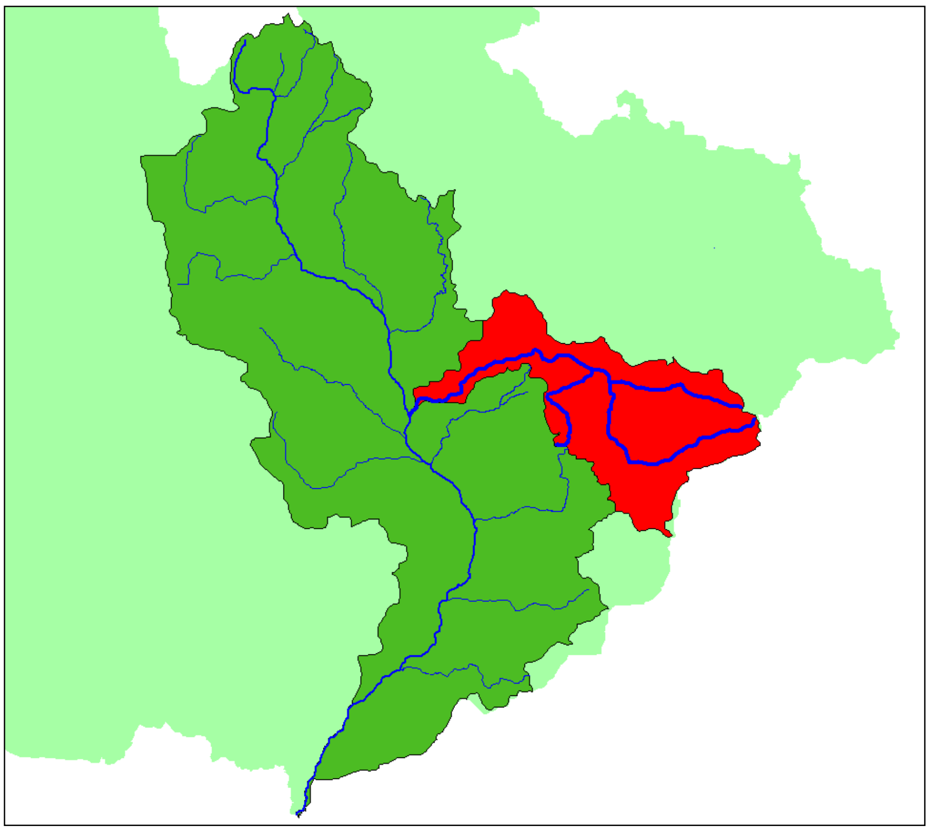

Figure 4-2: Detail on the Morava (green) and Bečva (red) river basins (Priggouris, et al., 2009).

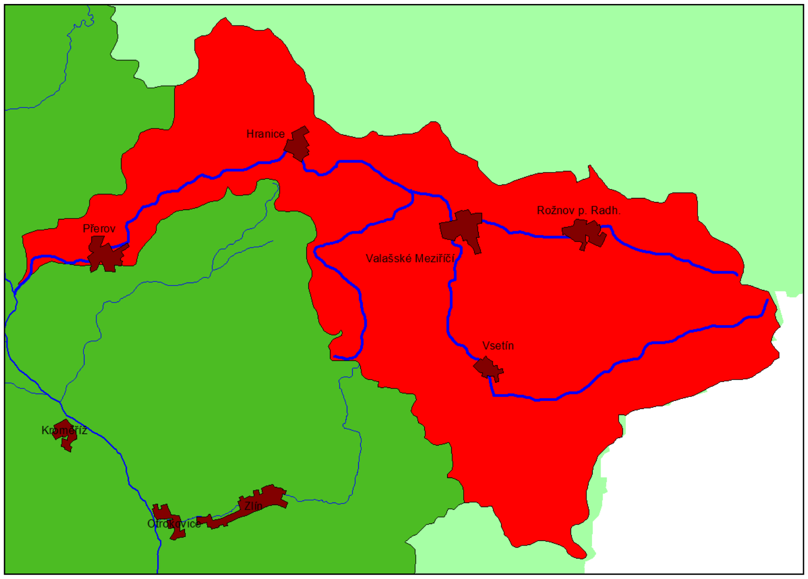

Figure 4-3: Detail view on Bečva river basin including main cities (Priggouris, et al., 2009).

For the installation of sensors, small city on the river Rožnovská Bečva was chosen. Horní Bečva city has about 2500 inhabitants and is situated in the Beskydy National park, 12 km east from Rožnov pod Rodhoštěm city (administrative city). It is the typical Czech mountain city, central square has the altitude of 505 m a.s.l. Exact place of installed sensors was 300 m far from the river at the altitude of approximately 580 m a.s.l. This place was chosen because of its location in the upstream part of Rožnovská Bečva river, 6,5 km downstream from the spring. This part is known for "often" flash flood. Another reason for choosing it was that the spring area of Bečva catchment belongs to extremely wet areas of the Czech Republic. The main advantage of this area is its short distance from the CHMI sensor which was used for sensors calibration. The processes, which have been modeled for the Bečva catchment, include rainfall/runoff and hydrodynamics. The floods of August 1985 and of June 1986 were chosen for the calibration -1985- and verification -1986- (Priggouris, et al., 2009).

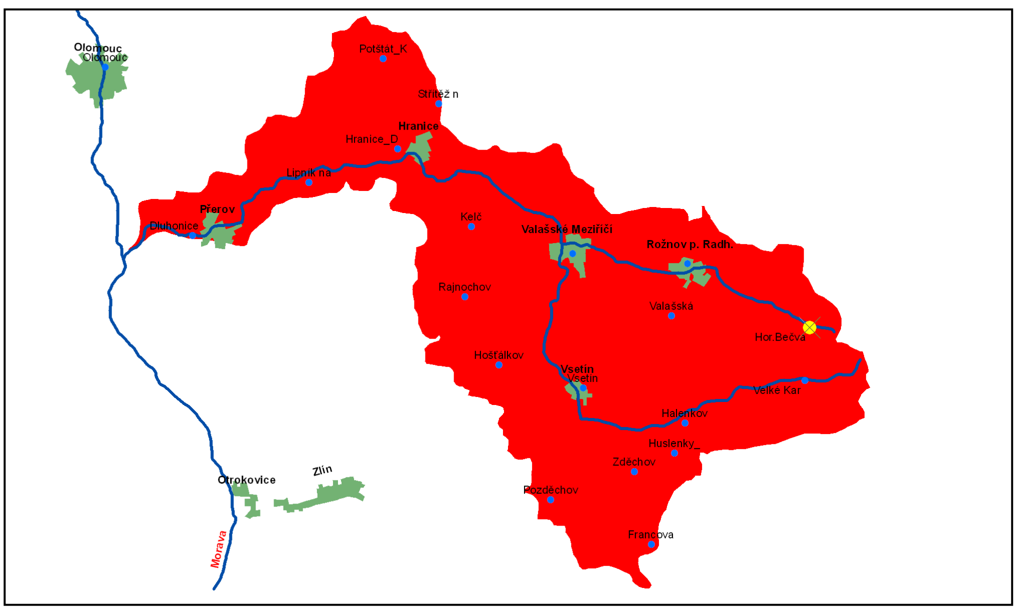

Figure 4-4: All SCIER sensors were installed in Horní Bečva city (yellow point) (Priggouris, et al., 2009).

Rainfall/runoff modeling

For modeling the rainfall/runoff process, the Bečva catchment has been divided into 5 subcatchments – Jarcová, Krásno, Teplice, Kelč and Dluhonice, as shown in Figure 4-5.

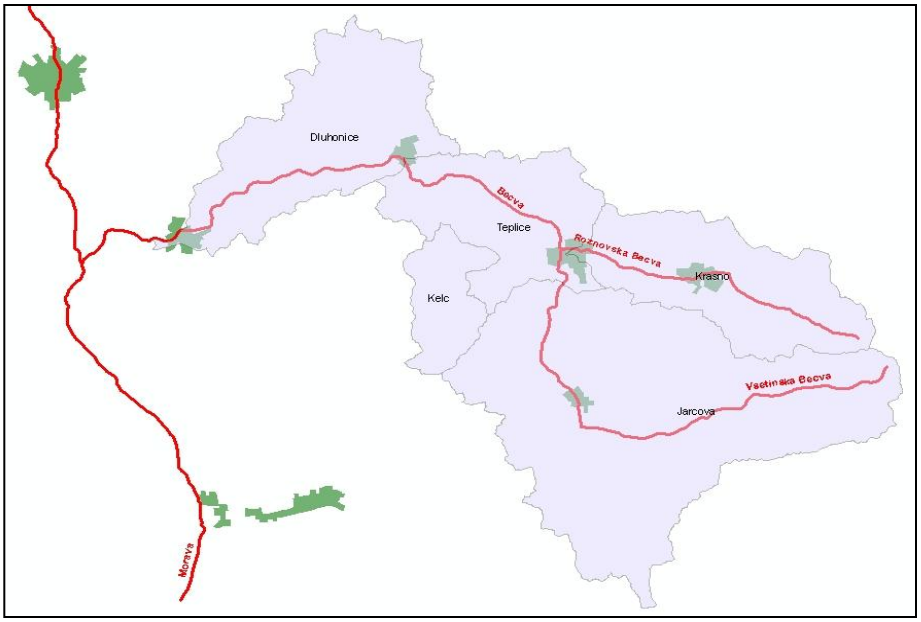

Figure 4-5: Subcatchments in the Bečva river basin (Metelka & Bonazountas, 2007).

	Dluhonice	Teplice	Kelč	Krásno	Jarcová
Area [km^2]	301.0	217.0	86.5	253.3	723.6
Average altitude [m a.s.l.]	354	328	470	564	562

Table 4-1: Subcatchments data (Priggouris, et al., 2009).

The required data for calibration and application of the NAM and UHM models for each of the subcatchments, supplied mainly by the CHMI (Czech Hydro Meteorological Institute), comprise:

- daily rainfall data
- daily average temperatures
- daily observed discharge
- monthly potential evaporation

19 CHMI stations have been located in the whole area - 9 stations in Jarcová basin, 2 stations in Krásno basin, 2 stations in Teplice basin, 1 station in Kelč basin and 5 stations in Dluhonice basin. Assessment of CN curve – regular points network has been generated for the whole area, the CN curve has been assigned for each point of the network (based on Land use, Soil type and Slope). Land use – 29 types of Land use (e.g. water, arable land, industrial area, forest etc.), 4 groups for soil type (A - infiltration is very good, D - infiltration is almost impossible) and 2 groups for slope (bigger or smaller than 3%) were specified. For all the points CN curve has been assigned, the median, the average and most frequent values for each catchments were counted.

	Dluhonice	Teplice	Kelč	Krásno	Jarcová
CN curve	54	67	64	57	59
Hydraulic length [km]	44.7	32	18.5	32.2	50.3
Slope [%]	5.5	5	9	12	13

Table 4-2: Rainfall/runoff parameters – unit hydrograph module - UHM (Priggouris, et al., 2009).

	Dluhonice	Teplice	Kelč	Krásno	Jarcová
Umax	7	7	7	7	5
Lmax	15	15	15	18	15
CQOF	0.9	0.9	0.9	0.6	0.9
CKIF	700	600	600	650	900
CK	15	15	15	25	17
TOF	0	0	0	0	0
TIF	0.9	0.9	0.9	0.8	0.9
TG	0	0	0	0	0
CKBF	900	700	700	1000	1000
Cqlow	0	50	50	0	0
Cklow	0	5000	5000	0	0

Table 4-3: Rainfall/runoff parameters – NAM (Priggouris, et al., 2009).

Where:

Umax = maximum water content in surface storage

Lmax = maximum water content in root zone storage

CQOF = overland flow runoff coefficient

CKIF = time constant for interflow

CK = time constants for routing overland flow

TOF = root zone threshold value for overland flow

TIF = root zone threshold value for inter flow

Tg = root zone threshold value for ground water recharge

CKBF = time constant for routing baseflow

Cqlow = lower base flow. Recharge to lower reservoir

Cklow = time constant for routing lower baseflow

Hydrodynamic Model

61.2 km of the river course has been modeled in 4 river branches, described by 92 cross section profiles and 8 structures – weirs. No bridges were included into the hydrodynamic model because of their sufficient capacity. Outputs from the rainfall/runoff models (discharges) were applied as the upstream model boundary conditions (3 of them as the point sources and 2 as the distributed ones) whereas rating curve was used for the downstream boundary. The identified roughness values in the calibrated models vary from n = 0.028 to n = 0.030 (Manning) (Priggouris, et al., 2009) (Metelka, Caballero, & Kirklis, 2008).

Calibration

Calibration of hydrodynamic model consists from setup calibration parameters to proper values so, that result of mathematical models corresponds to real measured values. Strait afterwards step of calibration in mathematical models developing is process of verification. During verification is used calibrated model for another real situation them calibration was, and verifies rightness of calibrated values. Values, which are checked during calibration, are water levels, discharges and time flow of calibration events. Calibration parameters, which are during calibration process set-up, are mainly roughness characteristics (Priggouris, et al., 2009). In used software MIKE11 it is possible to change roughness parameters globally, along longitudinal profile and varied with cross section width. In MIKE11 it is possible to select among three basic description of bed resistance (DHI, 2000):

Manning – Strickler	M $[m^{1/3}s^{-1}]$
Manning coefficient	n $[s/m^{1/3}]$
Chezy coefficient	C $[m^{1/2}s^{-1}]$

"In this project Manning´s description of bed resistance was selected as it is normally used in Czech Republic" (Metelka, Caballero, & Kirklis, 2008).

Several historical flood events were obtained from CHMI, which were observed in pass on Becva basin for purpose of calibration. They were these periods: 1970, 1972, 1985 and 1986. Each of those events were recorded in different accuracy and in different number of gauging stations as hourly time series of water levels and corresponding discharges. Discharges were derived through currently valid rating curves for each flood and gauging stations. To each provided flood events were obtained also daily rainfall time series for Bečva catchments for three month (month before flood, month of flood and month after flood). Those time series were used for reconstruction of un-gauged or unrecorded tributaries, which were not possible to neglect. Further technical data, which were used for calibration purposes were rating curves of several gauging stations.

4.2 The Experimental Burn Trials

The completion of the first version of the SCIER system modules and a first integration of the system components was to be followed by "proof of concept" testing and validation in experimental fires in Portugal. More specifically, it was specified that this will be done in two field experimental fires in Gestosa, Portugal where every spring ADAI organized such burns provided that conditions allow it (Pita, Ribeiro, Viegas, Pangaud, Seneclauze, & Faist, 2008).

As the project consortium planned and organized, these experimental burns were carried out in May 2008. This chapter is a description of these experiments and their relevant results, but also includes a description of additional experimental work carried out with this opportunity in order to further test the concepts and components of the system.

The field experiments took place in the Gestosa Field Experiments Site. The area is located in Central Portugal, in the mountain of Lousã (1204 m above sea level) at a distance of 70 km from Coimbra by car. This place offers very good conditions to perform this type of experiments. The test plots were established according to the specific objectives of the experiments taking into account all considerations on fire safety during the performance of the experiments, good road accessibility, visibility to the plots from different positions, fuel bed and slope homogeneity (Xanthopoulos, et al., 2008).

Seven plots of various sizes with a roughly rectangle shape were established in a specific site in the municipality of Castanheira de Pêra, in the forest perimeter of Gestosa, in public lands managed by Forest Associations and Local Authorities (Figure 4-6). The total area covered by the plots is approximately 9.3 ha. The layout of the plots is documented in image 2. Plot dimensions were as follows:

Plot 1 (1001): 25 x 30 m2

Plot 2 (1002): 25 x 40 m2

Plot 3 (1003): 25 x 50 m2

Plot 4 (1004): 25 x 60 m2

Plot 5 (1005): 35 x 80 m2

Plot 6 (1006): 25 x 50 m2

Plot 7 (1007): 25 x 50 m2

Contacts with the land managers were done in order to get the respective permissions to use this area. These authorizations were never a problem even when the test area was owned by private for-esters, once that the acceptance of the test program by the authorities and by locals was very good.

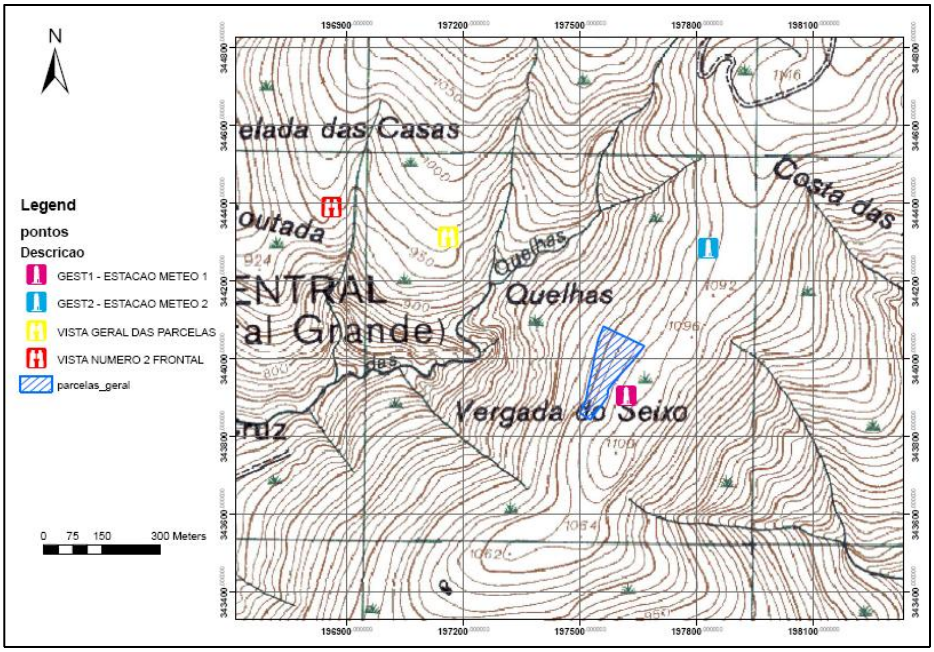

Figure 4-6: Location of the experimental plots on the map (Xanthopoulos, et al., 2008)

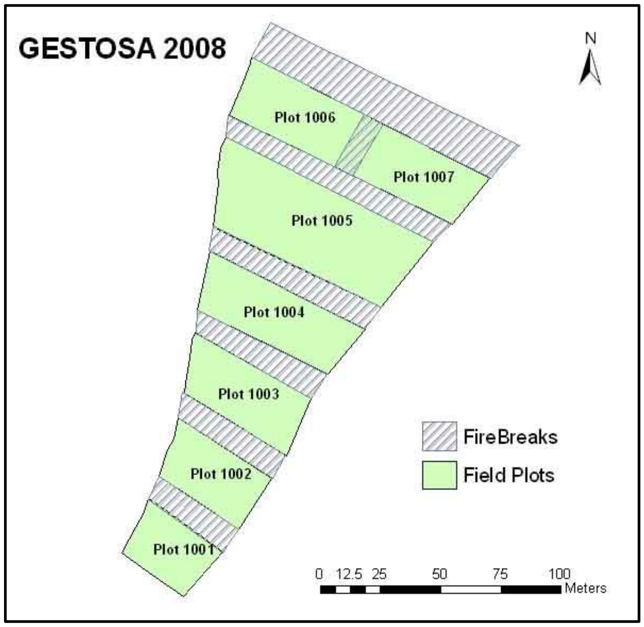

Figure 4-7: Layout of the plots (Xanthopoulos, et al., 2008)

“Preparation of the plots, fuel bed sampling, and opening of fire breaks using hand tools and pre-scribed fire was carried out by the ADAI team during the weeks that preceded the experiments with the support of local fire fighters and forest workers hired to perform this work. The bad weather conditions that prevailed during the month of April created several difficulties to perform this task. All teams were present at the test site at about 9:00h on May 6, 2008, and began setting the sensors and preparing the measuring equipment. There was a briefing with the fire fighters at 9:30h to establish the work program and the safety plan. Some fire fighters were fitted with portable smoke and particle detection devices for the needs of the FUMEXP project. Each experimental burn at Gestosa was given a name corresponding to its plot number, as shown in image 2 (e.g. plot 1001, plot 1002, etc.).” (Xanthopoulos, et al., 2008).

Plot	**Area (m^2)**	**Slope (%)**	**Start**	**End**	**Remarks**
1007	1049	30	10:43	10:55	One linear ignition at the top for safety and then a linear ignition at the bottom; very fast propagation.
1006	1089	42	11:13	11:38	Two linear ignitions made on both sides of the plot. After that a linear ignition was made at the bottom
1004	1493	40	12:57	13:17	A linear ignition to create a safety area at the top of the plot. A second linear ignition was made at the bottom of the plot.
1005	2642	37	13:57	14:12	Plot instrumented with SCIER sensors.
1001	820	37	15:53	16:10	Suppression exercise for the fire-fighters
1002	959	51	16:34	16:42	Two linear ignitions on the top left side of the plot to create a safety area. Third linear ignition was made at the bottom of the plot
1003	1228	45	17:30	17:40	Plot instrumented with SCIER sensors.

Table 4-4: Order and time of burning of the seven experimental plots at Gestosa. The plan was established beforehand and in spite of changing weather conditions it was possible to follow it quite accurately. The times indicated in the table are the actual start and end times of the main burns of each plot (Xanthopoulos, et al., 2008).

Test Results

The initial schedule for the entire week had to be modified due to weather conditions. Despite the time limitations that came about from this alteration, it was possible for the participating members of the SCIER consortium to fully monitor two of the experiments, (1005 and 1003), after examining all of the available alternatives. Plot 1005 was chosen because it was the largest and, having good safety buffers around it, could be burned with an intense fire. Plot 1003 was selected because it was the last one to be burned, allowing more time for plot instrumentation (Pita, Ribeiro, Viegas, Pangaud, Seneclauze, & Faist, 2008). “All of the burned plots were recorded visually using video cameras and digital still photo-graphs. In some plots fire and smoke detection were also tested. Focusing on the two experiments on which it was possible to fully deploy monitoring equipment, (cameras, sensors, thermocouples, etc) it is possible to derive some useful results. From the first experiment the team managed to get a full range of temperature measurements and to conduct the correlations between sensors and thermocouples. From the second experiment there were no reliable measurements from the sensors.” (Xanthopoulos, et al., 2008).

Experiment Number	Sensor #	Maximum Temperature reported before sensor destruction (^{o}C)
1005	21	82.8
1005	49	124.2
1005	55	63.4
1011	36	120.1
1011	3	81.1

Table 4-5: Maximum temperature reported by the network before sensor destruction (^{o}C) during the Gestosa experiments (Pita, Ribeiro, Viegas, Pangaud, Seneclauze, & Faist, 2008).

Analysis of the data sets showed that the sensors used are capable of fire detection. That is, if properly deployed on the test areas, they will monitor the ambient temperature correctly and will detect its alterations. The temperature level at which the sensors are destroyed is higher than 124.2 ^{o}C as indicated for sensor #49 in Table 2. However, as seen with sensor #55, the last recorded temperature before destruction can be as low as 63.4 ^{o}C. This is because of the low reporting frequency: it is quite probable that after reporting this measurement, the sensor measured much higher temperatures before being destroyed but because of the low reporting frequency it did not have the chance to report them (Xanthopoulos, et al., 2008). This creates a question in regard to using a threshold temperature, such as 70 ^{o}C as the limit for setting off a fire detection alarm. Logically then, the fire detection algorithm should not only be based on sensor reported temperature but should incorporate some other information such as relative humidity evolution and reporting of stable values by the network after sensor destruction.

The experiments also showed that the network did not function properly throughout all the experiments providing incomplete data series to the LACU. There were cases of 5 minute sensor “silence”, before it finally woke up. In a fast moving fire that could mean loss of alarming capability. Also, it appeared that there is a limitation of the network in regard to the node load it can handle. Increasing the number of sensors requires lower reporting frequency. Judging from the results of the experiments, especially looking at the rates at which the thermocouple temperatures climbed in the corresponding graphs, a reporting rate of 10 seconds or less is needed in order to achieve reliable alarms (Pita, Ribeiro, Viegas, Pangaud, Seneclauze, & Faist, 2008).

4.3 The French Test-Site

The test area is located in south of France at Aubagne (Figure 4-8, Figure 4-9), a city of 40 000 inhabitants distant of 30 km from Marseille. This test site was chosen because it is a fire and flood prone area located near many dwelling places with very dense vegetation and near an outdoor center where a lot of children spend time, particularly during the summer, when forest fire hazard is the most important. This east part of Marseille is a typical wild land-urban area interface (Bonazountas, et al., 2009).

Figure 4-8 : Location of the test area (ESRI, ESRI ArcGIS Online, 2008).

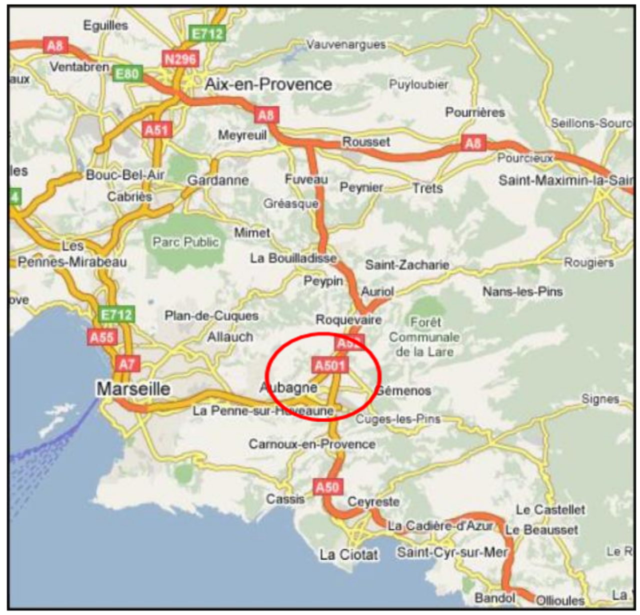

Figure 4-9 : Aubagne location (ESRI, ESRI ArcGIS Online, 2008).

Moreover in this area, a 52 km long river, the Huveaune regularly floods in raining season. This test site is ideal to work on flood and forest fire hazard and thus on flood and forest fire simulation.

First LACU location

Firstly, the LACU was located in a house of the neighborhood. After several tests, this location turned out too far from the sensors (the distance between the sink and the sensors was around 800 m). Moreover, this house was located at the bottom of a bowl. This geographical configuration did not allow a good work of the radio antenna. Thus, a new location for the LACU had to be chosen (Priggouris, et al., 2009).

Sensors Deployment

After the choice of the test site area and the LACU (sink) location, the sensors had to be located ones according to others. Eight sensors have to be deployed in suitable locations in order to inform operational people and scientists of temperature, hygrometry and pluviometry values in key points of the test area. The visual sensor has to be installed to have a complete view of the test site. In this region of France, the dominant wind called “mistral” is oriented north-west. Besides, sensors locations have to be chosen in order to protect the outdoor center. To this end, a “sensor belt” was made with the 5 temperatures and hygrometry sensors (33, 15, 47, 39, 53) in the north-west of the outdoor center. The 3 pluviometer sensors were deployed at the bottom of the hill (the lowest point of the test area). The exact “deployment zone” of the sensors had to be chosen in function of the “visual angle” previously quoted. Thus, the final location of sensors was determined by testing the reception or no-reception of each sensor (Priggouris, et al., 2009).

The test results revealed that it was impossible to deploy sensors behind the big house (in yellow) in front of the outdoor center. The final deployment is showed on the picture below.

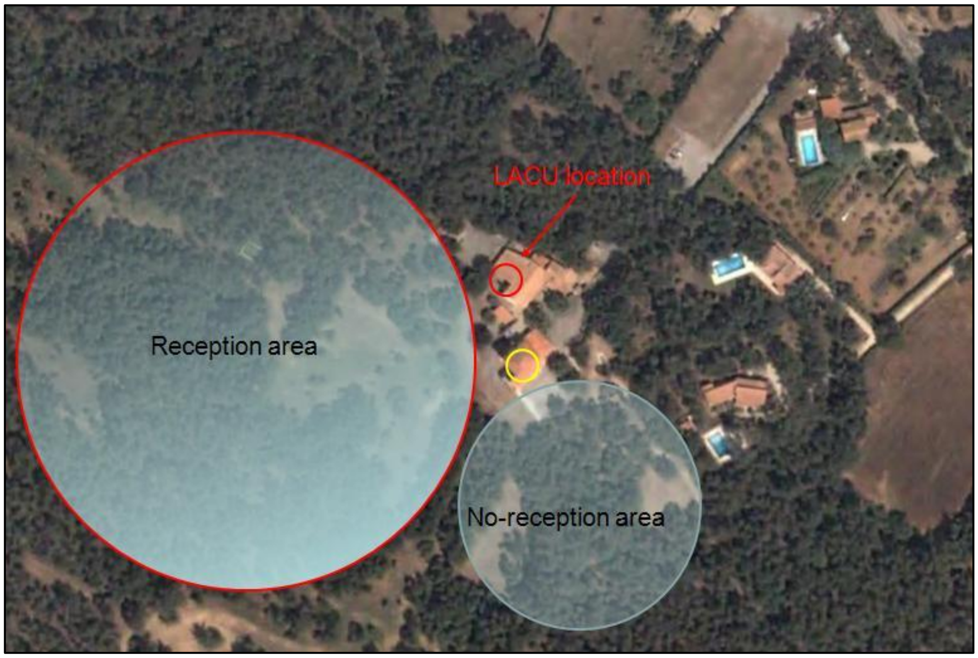

Figure 4-10 : LACU location, and reception and no-reception areas (Bonazountas, et al., 2009).

Figure 4-11 : Selected area and SCIER deployment -T: Temperature Sensor, H: Humidity Sensor- (Priggouris, et al., 2009)

Sensors are deployed in the park in front of the outdoor center (Figure 4-11). In the selected area (400 x 250 m²) the 9 positions for sensors were found. Even if CSEM explained that in the ideal conditions, 2 km was the maximum range for sensors (Bonazountas, et al., 2009).

Vision sensors

The vision sensors are used to detect smoke during the day and flame during the night. They have to be installed to "see" a complete view of the test site, and in height. Moreover, their batteries need to be reloaded once a day. Thus, one of the two vision sensors was located on the second floor of the outdoor center, on the outside. A wood protection box has been developed in order to protect the vision sensors against rainfall (Figure 4-13) (Priggouris, et al., 2009).

Figure 4-12 : Vision sensor deployed in Aubagne (Priggouris, et al., 2009).

Figure 4-13 : Protection box of the vision sensor (Priggouris, et al., 2009).

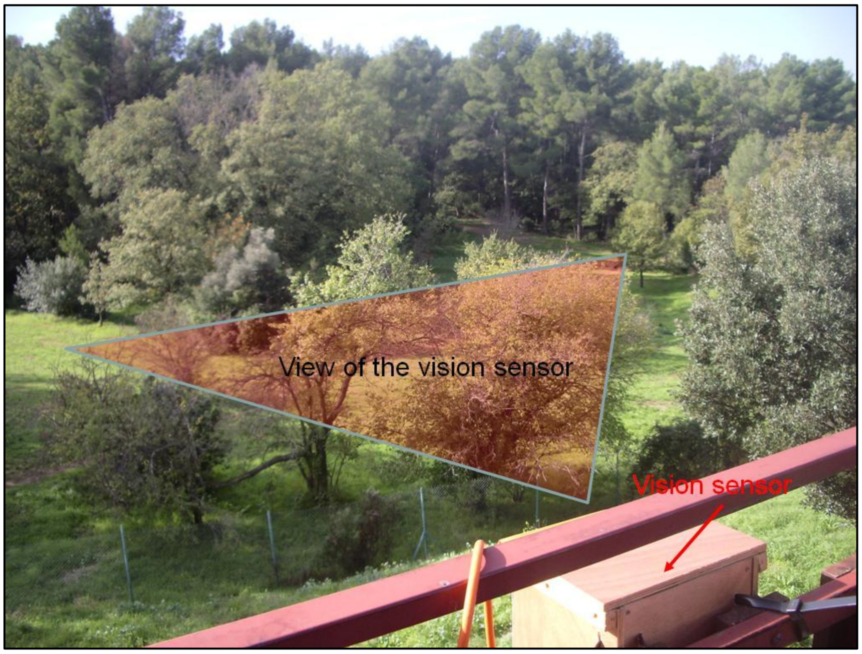

Figure 4-14 : View of the vision sensor. The location of the vision sensor allowed having a global view of the test area (Priggouris, et al., 2009).

As a result the SCIER system was deployed in Aubagne. "After several tests concerning the efficiency and the reliability of the sensors and the whole system, the SCIER system seemed to be still at a prototype state. Some problems were met concerning connection between sensors and sink" (Priggouris, et al., 2009).

5 THE MODEL CONCEPT

Floods and forest fires are the represent two of the most devastating natural disasters globally. On many occasions the damage that these disasters can cause to the natural environment and/or civil infrastructures is devastating, let alone the loss of human lives. As stated before in the first chapter, "SCIER designs, develops and demonstrates an integrated system for the detection, monitoring and prediction of the evolution of these natural hazards" (Bonazountas M. , 2006). From the perspective of the theoretical framework, to achieve the success, the system uses state-of-art technology in the following areas:

- mathematical modeling and simulation techniques, for emulating the phenomena of floods and forest fires,
- a wireless communication sensor network, to monitor their outbreak and evolution,
- an advanced specialized and custom built computing infrastructure, to collect and process the sensor data and execute the simulation processes.

Mathematical modeling and simulation of these phenomena was the cornerstone of the project's effort to achieve its objectives. In fact, that is what SCIER is about: "to collect real-time measurements and data from a land under investigation and use them to perform computer simulations of flood or forest fire using specialized mathematical models developed for this purpose" (Bonazountas M. , 2006).

The development of such models is an effort initiated many decades ago, brought about by a scientific interest to study in depth the way in which forest fires and floods form and evolve. Modeling these two phenomena aims at interpreting the intrinsic processes that govern their development with mathematical means, using the laws of physics. In general, this is achieved by developing mathematical equations and formulas that represent the behavior of the phenomenon at a micro-scale. It was an attempt to better understand these phenomena, determine and examine those factors that control their development and specify the mechanism and natural laws that drive their evolution. If a model can accurately achieve all these, then it would be possible to predict, to a certain extent, the propagation of the phenomenon. The accuracy of such a prediction depends on the degree of convergence of the mathematical model to the real case (Metelka, Caballero, & Kirklis, 2008). This chapter outlines the most important models available for floods and forest fires, their advantages and disadvantages and also gives a short review of their theoretical basis and their success history.

5.1 Flood Simulation Models

"Flood simulation requires as well GI for the morphology of the river basin, the terrain layout for areas along riverside, etc. This information is empirically embodied in the mathematical simulation model during set-up and configuration procedures" (Bonazountas, Kanellopoulos, Schaller, Kallidromitou, & Martirano, 2009). Following a review of the literature and of the available knowledge on the problem of determining the relationship between surface and water discharge, an attempt was made with the cooperation of DHI -as the key partner for flood models in SCIER- to supplement the area of hydrology with new methods and procedures. Hence, the basic suggestion of incorporating modern methods of mathematical modeling for making consumption curves more accurate was defined as applicable for this task (Metelka, Caballero, & Kirklis, 2008).

5.1.1 Overview

In the context of this project the mathematical models -henceforth referred to as 'models'- of river hydraulics has been the main concern (Bonazountas M. , 2006). The process of spatial water flow can be described in detail with the aid of the basic control equations. They actually deal with in various software, various behaviors and in varying degree of simplification. The individual terms of the control equations can be either disregarded or solved using either a constant or simple relations or solved by more complex models, which supplement the entire calculation system. Similarly, a simplified generalization of the flow in a specific direction can be calculated. For instance under the assumption that the vertical flow in the riverbed is negligible and the pressure differentiation along the vertical is hydrostatic then one element of flow can be removed and the problem solved just in two dimensions (2-D). It is the level of simplification for these basic models that separates them into several different categories (Metelka, Caballero, & Kirklis, 2008).

According to the manner of schematizing the problem there are one-dimensional (1-D), two-dimensional (2-D) models. Depending on the schema of the control equations used, they can be divided to static or dynamic. Depending on the application area, they can be divided to hydraulic, hydrological and comprehensive models dealing with both parts of the global water cycle. There are of course more ways to further classify models but in this case we will only focus on using models in relation to consumption curves and their categorization depending on the manner of schema (Metelka, Caballero, & Kirklis, 2008) (DHI, 2000).

> *1-D models* are presently "the most widespread, not just in terms of number and price of the commercially available software, but also in terms of their practical usage in water management practice" (Metelka, Caballero, & Kirklis, 2008). It concerns a group of models based on the principle of simplifying the transverse flow to one point.
>
> *2-D models* are "currently making their mark on the market primarily due to the rapidly developing computational technology, which was the main limiting factor to their mass usage" (Metelka, Caballero, & Kirklis, 2008). This category of mathematical models uses a two-dimensional horizontal schema, which can be simply characterized as an aerial view of the territory in question, where the computational network covers the territory in question. Various products from the category of 2D hydraulic models have started appearing on the market, but their mass usage for solving integrated areas is the exception rather than the rule primarily thanks to the aforementioned limitations stemming from the high demands placed on the computing technology and the time needed for the special calculations and also due to the relatively high price of such models (DHI, 2000). The most common application of 2-D models is local studies of flow in sites with complicated hydraulic conditions, where it is necessary to have a detailed knowledge of the area, i.e. velocities, depths and discharges. A classical example of these types of studies is localities in the immediate vicinity of bridges, confluences, flow in complicated inundation territories, flows in the urban areas of municipalities and other (Metelka, Caballero, & Kirklis, 2008).

5.1.2 One-Dimensional Flood Models

One-dimensional hydrodynamic mathematical models serve, as the name suggests, for dynamic steady-state uneven calculations of water flows in open channels using one-dimensional schema. According to the inferred basic theory of using a 1-D mathematical model, stemming from the Saint Venant's equations (Flynn & Frocht, 1961; DHI, 2000; Levine, Quintanilla, & Payne, 2005), it is dependent of the applicable control equations and of the type of flow considered for the area. The tolerable level of the general schema of the spatial flow is very important. The basic assumptions of the derived control equations are (Metelka, Caballero, & Kirklis, 2008):

- The liquid is non-pressurized and homogenous, i.e. changes in density are ignored.
- The longitudinal slope of the riverbed is so small that there is no river flow with a Froud's number less than one. Torrent flow is simulated by simplified assumptions (limiting the effect of the dynamic term in the moment equation).
- The wavelength is marked in comparison with the depth, i.e. the vertical component of acceleration can be neglected and a hydrostatic division of pressure along the vertical is assumed.
- Friction losses under unsteady state flow are in the same order as under the conditions of steady state flow.
- There is unsteady flow when there are small depths. (The concept of an average cross-sectional velocity U and a horizontal level H can be permitted in the transverse profile).
- Advection dispersion - Transport of substances is simulated on the basis of a one-dimensional equation preserving the amount of the soluble and insoluble substances, under the condition that the substance is conservative and perfectly mixed over the entire cross-sectional area of flow.

The fundamental of such mathematical models is formed by a hydrodynamic module, which ensures the calculation of the basic hydrodynamic parameters and the dependent variable functions: discharge Q, the state of the water H and the cross-sectional velocity v. The logic is based on an approximation to the control equation, or the movement and continuity equations for two functions of dependent variables and two functions of independent variables (x, t):

Continuity equation

$$\text{—} \qquad \text{—} = q \qquad \text{(Equation 1)}$$

Source: (DHI, 2000; Levine, Quintanilla, & Payne, 2005)

Equation of Motion

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\alpha \dfrac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2 AR} = 0 \qquad \text{(Equation 2)}$$

Source: (DHI, 2000; Levine, Quintanilla, & Payne, 2005)

where:

Q discharge [m3/s],

A discharge surface [m2],

q lateral inflow [m2/s],

h height of water [m],

C Chezy velocity coefficient [m1/2/s],

R hydraulic radius [m],

α coefficient of the effect of an uneven distribution of momentum in the transverse cross-section.

An approximation to the control equation is given by the finite differences method or the finite elements method for instance with the aid of a numerical operator of the Abbott-Ionescu type, which is also applied to staggered grids for the MIKE 11 model (DHI, 2000).

The basic input data for the construction, calibration, verification and application of a 1-D mathematical model can be given as following (Metelka, Caballero, & Kirklis, 2008):

The basic topological data for a one-dimensional model is information on the shape of the channel and the inundation territory in the form of transverse profiles with information on their positional location in the watercourse (kilometer spacing).

The hydrological data is necessary for determining the marginal and initial conditions of the model and primarily use, in the form of a time series, values for the discharges and the gauge readings.

The calibration data, according to its designation, serve to calibrate the compiled model. The calibration of a mathematical model means the process of setting up the model parameters and constants at values such that the results of the mathematical calculation best agree with the measured values.

In practice, 1-D models are often used in general water management. “It can be said that the 1D mathematical model has become a common tool for the water management engineer, such as the CAD application in design practice” (Metelka, Caballero, & Kirklis, 2008). The main area of usually employing 1D mathematical models in practice are, studies for anti-flood measures, studies of runoff ratios and studies determining the flood zones.

It’s worth mentioning here that 1-D mathematical models have replaced the classical methods of calculating the position of the surfaces on the majority of the important watercourses in water-management (Metelka, Caballero, & Kirklis, 2008). This enormous development was primarily contributed to by the comparable data demands, similar to the traditional methods of calculating by hand, and the incomparable level, extent and amount of results provided. Also the time for calculating a 1-D mathematical model is relatively short and, in contrast to the traditional methods, provides results in much greater detail and in a digital form. This fact makes it markedly simpler to further process the results into related design work or incorporate them into information systems or GIS. The fundamental expansion that mathematical models have brought into water-management practice is the gradual shift from steady state calculations to dynamic simulations of flood waves.

From the standpoint of the extent of the interest areas 1D mathematical models can be applied to small and localised areas ranging from several hundreds of square meters to extensive and complicated grid models for urban agglomerations and even up to global models for integral watersheds such as the entire watershed for the Morava and Bečva Rivers (see chapter 4.1The Test-Site for Flood Modeling for the Bečva Basin).

5.1.3 Two-Dimensional Flood Models

2-D hydrodynamic mathematical models describe dynamic unsteady uneven water flows in open channels with the aid of a 2-D schema of the Reynolds’ equations of motion (Reynolds, 1886; Song, Seo, & Schultz, 2003) together with the continuity equations (DHI, 2000). According to the basic theory the prerequisites for using a 2-D mathematical model depend on the derived control equations being valid and the type of flow to be considered in the area to be appraised. The derived control equations of a 2-D unsteady flow stem from similar principles as the derivation for the 1-D models. It is essential that both control equations derived for describing the 1-D flow be expanded by the effect of another dimension. In this context, the basic conditions for deriving the control equations are (Metelka, Caballero, & Kirklis, 2008):

- The liquid is not pressurized and homogenous, i.e. negligible changes in density.
- The longitudinal incline of channel i0 is so small that under the river conditions there is a Froud’s number of less than 1, the local emergence of torrent flow, e.g. at the interface of the inundated and non-inundated territory can be accepted.
- The wavelength is marked in comparison with the depth, i.e. the vertical component of acceleration can be negligible assuming a hydrostatic distribution of pressure along the vertical.
- Friction losses under unsteady flow are in the same order as under the steady-state conditions.
- The control equations are given in a two-dimensional form where the component in the z-axis is integrated along the vertical.
- The equations are derived for a horizontal model and small depths; the limit depth is understood to be when the assumption of the velocity vector integrated along the vertical can be accepted.

“The basic movement equations, together with the continuity equation, represent a system that describes the spatial behaviour of a liquid in motion assuming a joint course for the incorporated parameters. Through the vertical integration of these equations for a three-dimensional flow a new system of equations emerges that are valid in the horizontal level, applicable only under the assumption that the hydrostatic distribution of pressure along the vertical is valid” (Metelka, Caballero, & Kirklis, 2008). In contrast to the 1-D mathematical models, in 2D models the calculation takes place in a grid that covers the entire area of interest. The logical endeavor of the developmental team taking part in developing mathematical models is to optimize the size of the calculation grid without losing information. One of these approaches is the use of an irregular curvilinear orthogonal calculation grid as used (DHI, 2000).

2-D mathematical models require the same type of data as that for 1-D models. The input data can be divided up into topological, hydrological and calibration. “However, it differs in the form and extent required for a detailed 2-D schema. It is necessary to get the data for the entire area of the interest area in a sufficient density” (Metelka, Caballero, & Kirklis, 2008).

> *The topological data* in the form of transverse profiles is, on the whole, insufficient for a 2-D schema since it is also necessary to have area information in the form of the terrain’s relief in the regions between the individual transverse profiles.
>
> *The hydrological data* is primarily used to determine the initial and marginal conditions, however in accordance with the principle of the 2-D schema it is also necessary to obtain this information in greater detail, which greatly exceeds the capacity of the state’s monitoring network of the Czech Hydro-meteorological Institute (ČHMU).
>
> *The calibration data* is represented by the values of the resistance characteristics. Similarly as for the topological and hydrological data it is essential to also define the resistance characteristics throughout the interest area. Generally this problem is dealt with in the form of maps of ruggedness constructed on the basis of terrain reconnaissance, aerial and satellite images and maps.

The use-cases in which 2D mathematical models are practically applied are continuously expanding. However the 2-D mathematical models are still more demanding on time and finances than the 1-D models and therefore it is necessary to seriously consider their usage. “A frequently applied compromise is to use the 2D model just for defining an area of heightened interest and to supplement the surroundings of the detailed 2-D model with 1-D calculations” (Metelka, Caballero, & Kirklis, 2008).

A classic example of using 2-D models is areas in which it is necessary to know detailed information about the areal distribution of velocity and discharges, or where it is assumed there is a significant transverse surface incline. With regards to the aforementioned demands a detailed description places on the computing power, investigators always try to effectively optimize the size and extent of the interest area so that the calculation grid is as small as possible whilst covering the interest are as best it can.

5.2 Forest Fire Simulation Models

Forest fire modelling has gathered a lot of attention in the research centres during the last 50 years. In these years a number of models have been developed which explain the relationship between the environment variables and the fire behaviour. Taking as a starting point the characterisation of the forest fuel, the terrain and the meteorological conditions, a number of mathematical expressions have been derived which have served as baseline for the complex simulation systems developed (Caballero, Viegas, & Xanthopoulos, 2001).

Forest fire behaviour simulation models are, generally speaking, a set of equations expressing theoretical balances or experimental observations, or both, the solution of which render the temporal and spatial evolution of variables that explain the physics of fire evolution (such as propagation rate, fire intensity or fuel consumption rate). According to this a generic classification of models, according to the approach followed, can be (Bonazountas, et al., 2007):

- Theoretical models, generated from the laws of fluid dynamics and heat transfer.
- Empirical models, generated from equations derived from experimentation and study of historic fires.
- Semi-empirical models, generated from physical laws and completed with experimental data.

According to the studied variables, different models are considered and coupled to render a complete solution of the fire behaviour. These models are (Caballero, 2006) (Bonazountas, et al., 2007):

- Models of flame geometry, in which equations are formulated to obtain the flame height, width and tilt angle, as well as the residence time.
- Models of fire propagation, which provide the mechanisms to obtain the main variables that govern the fire spread (such as fire spread rate, released heat and fuel consumption rate).
- Models of fire initiation and potential fire behaviour, formulated from meteorological data that evaluate the probability of a fire outbreak and the associated danger (in most cases expressed as indexes).

According to the type of fire addressed, the models can be classified as (Caballero, Viegas, & Xanthopoulos, 2001):

- Models of ground fires, where the physical model is mainly governed by the fuel in the immediate layer at ground level and the organic layer in touch with the mineral bed.
- Models of surface fires are the most numerous and explain the most frequent fires in the real-world, where the addressed physical model looks into the fire behaviour in the vegetation layer between the ground and the base of the tree crowns.
- Models of crown fires, where the physical system addresses the fire behaviour on the surface and the aerial vegetation layer. Normally, a secondary model is coupled with this type which explains the behaviour of generation of flying embers and appearance of spot fires, which are frequent in these fires.

The WUI Area

Tecnoma SA has recently introduced Multi-Risk RTD in forest fires and flash floods in Wildland Urban Interface (WUI) and non-WUI areas (i.e WARM, Autohazard Pro, Medigrid, Orchestra) and its staff has participated in several forest fires projects and flash floods. The company has: (i) fine-tuned a methodology for the application of hydrologic and hydraulic models for the identification and characterisation of risks due to flood danger levels, (ii) set-up a battery of models and procedures for the characterisation of risk due to forest fire danger levels, and (iii) has tested methods in the AUTOHAZARD, MEDIGRID and ORCHESTRA projects. These activities have provided a good baseline of User Requirements in regards to SCIER, and have been incorporated in this document (Caballero, Viegas, & Xanthopoulos, 2001) (Bonazountas, et al., 2009).

Wild-land-Urban-Interface (WUI) environments can be described as composite systems where various structures (most notably private homes) and other human constructions meet or are intermingled with forest, wild land and other vegetation fuels. The WUI in the European environment is therefore a complex spatial domain with many interrelated social, natural resource and wildfire components. Settlements in the Mediterranean region for example are mostly compound of individual lots including one or more buildings, forming a number of WUI situations according to the house-vegetation pattern observed.

A preliminary classification of these WUI areas can be given according to their house-vegetation pattern. Thus, considering vegetation and house density and in the other hand the degree of clustering of both components, the following table is obtained:

			VEGETATION			
			SPARSE		DENSE	
			Uniform	Clustered	Uniform	Clustered
HOUSE	SPARSE	Uniform	Not Considered	Not Considered	Sparse Intermix	Sparse Intermix
		Clustered	Not Considered	Not Considered	Clustered Intermix	Clustered Intermix
	DENSE	Uniform	Urban	Urban	Intermix	Occluded Urban Interface
		Clustered	Urban	Urban	Urban Interface	Clustered Urban Interface

Urban: Dominated by housing occupation. Not considered.
Sparse Intermix: Typical structure in rural areas, self-protection plans is needed.
Clustered Intermix: Same as (1). Small clusters of few houses, isolated.
Intermix: Typical structure in high-value, tourist areas, physical plan, emergency plan and also self-defence plans are needed.
Urban Interface: A well-defined boundary exists between house-dominated and vegetation- dominated areas. Physical plan and emergency plan are needed.
Occluded Urban Interface: Typical structure of large wild land parks inside cities, physical plan is needed to isolate fire and minimise effects on the surrounding houses.
Clustered Urban Interface: Same as (4). Urban Interface but in continuous groups.

Table 5-1: WUI definition (Bonazountas, et al., 2009).

WUI situations are located in the landscape, which has specific conditions and factors, such as topography, vegetation, meteorology, infrastructure and fire defence resources. To assess the risk of a W-UI situation, a first analysis has to be done at landscape level, to provide planning strategies aimed at the prioritisation of actions and quantification of the WUI problem. In this way, a WUI situation (settlement, housing area etc.) should be understood as a single structure, much in the way that buildings are planned for fire contingency (Bonazountas, et al., 2009).

Looking the landscape surrounding the settlement, and the settlement itself, the risk assessment requirements should account for:

- How and where the fire will be approaching the settlement
- How and where the fire will enter the settlement
- How and in which extension the fire will propagate inside the settlement
- How many, and which type of houses will be “visited” by the fire
- Which will be the degree of destruction of the houses visited by fire
- Which are the fire fighting and civil protection operation opportunities
- How many people will be affected by fire, or smoke, to which degree

To answer these questions, which are associated to each WUI situation, the behaviour of the fire should be predicted and the damage level estimated, through the study of the following steps:

Behaviour of the approaching fire, which can reach the settlement in two ways:

- A fire front approaching settlement boundary
- By firebrands flying inside settlement

Behaviour of the fire inside the settlement:

- The fire propagates in the settlement thanks to the existing fuel, topography and wind conditions.
- To this we must add the unburnable structures, which could act as barriers. But in the other hand we must consider again fire front propagation and firebrand production.
- The propagation inside the settlement is expected to occur through a non-uniform fuel pattern in a non-continuous flame front.
- The presence of large plots of vegetation, more specifically in micro-canyons, is of special importance as they can develop new, secondary and very dangerous fire fronts.

Behaviour of fire in the vicinity of houses:

- Fire behaviour in the vicinity of the house is conditioned, mostly, by the presence of fuels and the wind.
- Radiation and convection are both related to the heating and destruction of the exterior house and properties outside, particularly when this entails flame contact.
- In many cases, firebrands falling in horizontal elements of the house entail the destruction of the house
- Fire entering or breaking into the house and destroying the house inside.

In order to delimitate the scope and application of the SCIER system, the following general competency question (objective) was tried to be answered:

“Provide a monitoring system based on sensor network and a forecast system based mainly on models to predict in advance the possible evolution of a source of danger (floods, fires) into a WUI area” (Bonazountas, et al., 2009).

5.2.1 Existing Forest Fire Models Overview

A large number of models have been developed following the approaches mentioned above. Some of these are presented below. At this point it should be mentioned that despite the number of models available only a few have trespassed the walls of the research centres and have been incorporated into the operational protocols of the fire fighting command centres. The scalability of the models is another issue which lies behind the success of a system’s adoption and operational use.

5.2.1.1 The ‘BEHAVE’ Model

The widely used semi-empirical fire spread model of R. Rothermel (Rothermel, 1972) has been adapted in many applications to solve one or more of fire management problems, although the requirements for these systems goes beyond what could be expected from a single model. The BEHAVE modelling system for prediction of fire behavior and fuel has been developed further (Andrews, 1986) (Andrews & Chase, 1989) to cope some of the problems addressed.

BEHAVE organises a host of models for describing fuels, fuel moisture, wind, topography, fire size and shape, flame length, spotting, ignition probability, tree scorch etc into user-friendly programs. Simplified methods of fuel appraisal are described that do not require extensive inventory, where the mentioned methods are applicable to surface fires.

The BEHAVE Fire Behaviour Prediction and Fuel Modelling System is a set of 5 programs and has been in application since 1984:

- FIRE1
- FIRE2
- RXWINDOW
- NEWMDL
- TSTMDL

The original BEHAVE Fire Modelling System has been updated and improved in the BEHAVE+ version and will replace the old one. BEHAVE gathers available fire models into a system that is driven by direct user input. The fire modelling capabilities are significantly expanded with the updated BEHAVE+ system (Andrews, Bevins, & Seli, 2003).

BEHAVE has been used for a variety of applications including:

- Projection of an ongoing fire
- Prescribed fire planning
- Fuel hazard assessment
- Initial attack dispatch
- Fire prevention planning
- Training.

BEHAVE is based primarily on physically-based fire models and therefore can be applied anywhere. BEHAVE is run by user-supplied input. Requested values depend on the modelling choices made by the user. For example, fuel model, fuel moisture, wind speed and direction, terrain slope are used to calculate rate of spread, flame length and intensity.

Time since ignition will allow calculation of an estimate for fire size. Line construction rate as an input allows calculation of final fire size given that suppression action. A description of the over-story allows calculation of tree mortality and spotting distance.

Models currently in BEHAVE (Andrews, 1986), and also in BEHAVE+ (Andrews, Bevins, & Seli, 2003), are:

- Surface fire spread, intensity, flame length
- Area and perimeter of a point-source fire
- Spotting distance
- Probability of ignition
- Scorch height
- Tree mortality

Improved models that are in BEHAVE+ are:

- Fine fuel moisture from hourly weather data
- Containment, with additional suppression options

Models developed and added to BEHAVE+ are:

- Transition to crown fire
- Crown fire spread
- Large fuel burnout behind the fire front
- Consumption of organic ground fuel
- Emission production
- Soil heating

BEHAVE is a flexible, easy to use set of programs. BEHAVE+ has an improved interface and additional fire modelling capabilities, a major advantage of using an existing fire model and prediction system is the speed at which results can be obtained.

Nevertheless there are some limitations on the use of the original BEHAVE:

- Interface is old and outdated.
- Crown fire models and other available models are not included
- There are no direct linkages to other systems such as fire danger rating
- These disadvantages are being addressed with the update
- BEHAVE is designed to operate for a given point assuming uniform conditions for fire spread
- It is not connected to a GIS platform nor renders propagation layers.

Original BEHAVE is written in FORTRAN and can be run on almost any computer. BEHAVE+ is written so that it can be run under various operating systems including Windows, NT, and UNIX.

5.2.1.2 The 'NEXUS' Model

NEXUS is presented as a Microsoft Excel workbook consisting of several worksheets and charts that linked existing models of surface and crown fire behaviour to produce a system of models in order to assess the potential for crown fires at the stand level.

Crown fires present special problems to managers. Crown fires are more difficult to control than surface fires. Their rate of spread is several times faster than surface fires (Rothermel, 1983). Thus, the main goal of the NEXUS system is the availability to predict the Crown fire hazard. And the potential users will be people directly involved in fire management that must take into account this kind of fire.

Inputs consist of a description of the fuel complex, the site, weather factors (wind), and multipliers for adjusting inputs and model operation. The main inputs (Anderson, 1982) are:

Surface Fuel Model

- Models 1-13 − correspond to the standard Fire Behaviour Fuel Models used in other programs
- Dead Fuel Moisture − not estimated within NEXUS, the user must determine what moisture contents to use using experience, other models, or published values.
- Live Moisture − the user must determine what moisture contents to use using experience or published values.

Canopy Fuels

- Canopy bulk density − the mass of available canopy fuel per unit canopy volume. It is a bulk property of a stand, not an individual tree.
- Foliar moisture content − moisture content (dry weight basis) of live foliage, expressed as a percentage. Effective foliar moisture content incorporates the moisture content of other canopy fuels like lichen, dead foliage and live and dead branch wood.
- Canopy base height − the lowest height above the ground at which there is a sufficient amount of canopy fuel to propagate fire vertically into the canopy. Canopy base height is an effective value that incorporates ladder fuels like shrubs and under-story trees
- Canopy fuel load − used to determine the maximum available fuel energy (at 100 percent crown fraction burned) for estimating the intensity of a crown fire.

Site Characteristics

- Slope steepness − entered as percentage
- Open wind speed − the wind speed measured 20 feet above the vegetation. In an open field, this is 20 feet above the ground, but in a timber stand it is 20 feet above the tallest trees. Open wind speed is multiplied by the wind reduction factor to estimate mid-flame winds.
- Wind direction − must be entered in degrees clockwise from uphill. Up-slope winds are indicated by 0 or 360 degrees. Down-slope winds are indicated by 180 degrees.
- Wind direction − used to vector wind and slope effects.
- Wind reduction factor − dimensionless ratio of the mid-flame wind speed to the open wind-speed.

Multipliers

- Surface ROS − this multiplier affects the predicted spread rate of the fire, and therefore it also affects fire line intensity. Heat per unit area is not affected. The multiplier acts linearly on spread rate and fire line intensity; a multiplier of 2 means the spread rate and fire line intensity will be twice the normal prediction.
- Crown ROS − the Rothermel crown fire model used in NEXUS has not been well tested and has limited geographic applicability. The uncertainty in using this model can be accounted by adjusting predicted crown fire spread rate in the underlying model. The crown ROS multiplier acts linearly on the spread rate predictions from Rothermel's (Rothermel, 1991) model. It directly affects the Crowning Index and therefore the final spread rate.
- Surface load & depth − examination of the Rothermel surface fire model reveals that fuel load has a linear effect on spread rate, provided all other factors remain constant. One factor that must remain constant is fuel bed bulk density, which can only be held constant if fuel bed depth is changed in proportion to the fuel load. The load/depth multiplier acts linearly on the fuel load by size class so that surface-area-to-volume ratio is unchanged, and also acts linearly on fuel bed depth so that bulk density is constant. The multiplier acts linearly on spread rate, and on heat per unit area. It has a squared effect on fire line intensity, because spread rate and heat per unit area are multiplied together to compute fire line intensity.
- Surface fire intensity − this multiplier acts on the heat per unit area of the surface fire prediction. It has no effect on spread rate, but affects fire line intensity linearly.

The NEXUS system is constituted by an Excel spreadsheet, so the system must run in a Windows environment and the additional software to execute it is the Microsoft Excel (Anderson, 1982).

5.2.1.3 The 'FARSITE' Model

FARSITE is a fire growth simulation model. It uses spatial information on topography and fuels along with weather and wind files. FARSITE incorporates the existing models for surface fire, crown fire, spotting, and fire acceleration into a 2-dimensional fire growth model. FARSITE runs in Windows operating systems (Windows 3.1x, 95, NT, XP, Vista) and features a graphical interface. Users must have the support of a geographic information system (GIS) to use FARSITE because it requires spatial landscape information to run (USDA, 2007) (Scott & Burgan, 2005).

FARSITE is used for long-range projections of active wildland fires and for fire planning purposes (USDA, 2007):

- Long-Range Projections on active fires are made for different weather scenarios to analyse how fire growth patterns may change under on different weather conditions. These are most appropriate for prescribed natural fires (PNFs) in National Parks and wilderness areas.
- Fire Planning applications use FARSITE to examine how effective fuel treatments may be, or what could happen if a fire started in a given location under given weather scenarios.

FARSITE has been distributed mostly in the continental United States, but also to users in Europe and South America. Most users are employed by federal land management agencies. Other users are associated with universities, public and private land management agencies and private consulting companies.

FARSITE requires the support of a GIS (either GRASS or ARC/INFO) to provide and manage spatial data themes. 5 GIS themes are required (Scott & Burgan, 2005):

- Elevation (ft or m)
- Slope (degrees or percent)
- Aspect (degrees)
- Fuels (fire behaviour fuel models (e.g. FBPS 1-13 or custom models)
- Canopy Cover (% or 4 categories)

3 GIS themes are optional for crown fire calculations:

- Height to Live Crown Base (ft or m)
- Tree Height (ft or m)
- Crown Bulk Density (kg/m3 or lb/ft3)

FARSITE also requires weather and wind files (called streams)

- Weather Stream contains maximum and minimum temperatures and humidities; for calculating fuel moisture during the simulation
- The Wind Stream contains wind speed and direction changes in time (e.g. hourly or down to the nearest minute).

FARSITE requires ignitions to be located with a mouse or from imported polygons showing fire edge. FARSITE produces many types of outputs (Scott & Burgan, 2005):

- 2D & 3D visible maps of fire growth and behaviour, saved as colour bitmaps
- Graphs of fire area & perimeter versus time, saved as bitmaps or printed
- Tables of fire area & perimeter vs. time, saved as bitmaps or printed
- GIS vector and raster files of fire growth and behaviour (spread rate, intensity etc.) that can be imported to GRASS or ARC/INFO for display and analysis
- Zooming windows of 2D and 3D landscapes
- Runtime modification of ignitions, control lines, fuel changes

Within the scope of SCIER project, some relevant pros and cons of FARSITE application are:

- FARSITE automatically computes fire growth and behaviour for long time periods under heterogeneous conditions of terrain, fuels, and weather using the existing fire behaviour models.
- FARSITE is a deterministic model, meaning that can relate simulation results directly to your inputs.
- FARSITE produces outputs that are compatible with PC and Workstation graphics and GIS software for later analysis and display
- FARSITE can be used for fire gaming, asking multiple "what-if" questions and comparing the results
- FARSITE accepts both GRASS Ascii and ESRI’s raster data themes.

FARSITE is maths and data intensive. The choice of hardware strongly affects its performance time. Nevertheless the existing personal computer platforms are fast and capable enough to perform most of the simulations in minutes. Originally FARSITE was designed to run under a minimum machine as specified below (USDA, 2007):

- Hardware minimum: 80486 DX processor, 8MB RAM, 20MB free hard disk space
- VGA colour monitor, mouse or trackball pointing device
- Hardware recommended: Pentium 100MHz or Pentium Pro processor (or compatible clone processor) 16MB + RAM (32MB is better), 100MB free hard disk
- Space for data and outputs SVGA colour monitor, 17" Windows Accelerated Video
- Card, 2MB RAM, mouse or trackball pointing device
- Software Minimum MS Windows 3.1
- Software recommended: MS Windows XP, or Vista

FARSITE is currently distributed freely as version 4.0 (USDA, 2007).

5.2.1.4 The ‘FIRESTATION’ Model

FireStation falls in the BEHAVE coupled with the grid-cell category of simulation models.

FireStation software was developed under the environment of the CAD application Microstation, from Bentley Company. The decision of developing the software within this environment was made on the grounds that Microstation provides a user-friendly interface and developing tools that proved to fulfill the needs for the development of the system. The underlying software was written in MDL language.

The fire behavior model is based on the Rothermel's surface fire spread model (Rothermel, 1972). The preference of such model to predict surface fire spread in one dimension within the system is based on the applicability of such model to any potential fuel complex throughout the world, such as logging slash (Bevins & Martin, 1978), grasslands and shrub lands (Marsden-Smedley & Catchpole, 1995) (Lopes, Cruz, & Viegas, 1998). In fact, other models are currently available, although with a more narrow range of applicability than the Rothermel's model (Rothermel, 1972). Empirically based models - e.g. Alexander (1998), Stocks (1989), Marsden-Smeley and Catchpole (1995) - for fire spread have limited applicability to fuel complexes (and fire environment conditions) other than the original ones.

FireStation is a semi-empirical model developed essentially from results obtained on a quite considerable amount of laboratory experiments. This model has some limitations concerning the heat transmission mechanisms allowed. Thus, this model cannot predict, for example, the fire spread occurring due to the projection of burning embers.

The simulation of fire growth is based on a mathematical description of fire shape, by means of two different models: one proposed by Anderson (1983) and the model by Alexander (1985). Fire growth simulation is based on a process of contagion between burning and non-burning cells in a grid array, a process which is carried out in the following way: at a generic time instant, the time taken for the fire to propagate from one burning cell to the adjacent one is computed using the models previously described. The adjacent cells are thus assigned numbers representing the shortest time interval in which 'ignition' would take place as a result of contagion from the already burning cells.

Fire behaviour predictions given by FireStation aim at supporting decision-making on forest and fire management activities at a local scale. Besides, the system also incorporates a fire danger rating system applicable at a broader scale, namely at regional and national level. Given the importance of using an accurate wind field, FireStation implements two different wind models: NUATMOS, a linear model and CANYON, a Navier-Stokes solver. NUATMOS takes as input the values of wind speed and direction measured at discrete points in space. As a first step towards the solution, an initial velocity field is computed by simply interpolating and extrapolating velocity values into all grid points of the area under study. This initial velocity field is then adjusted following a method of variation analysis (Lopes, Cruz, & Viegas, 1998).

The FireStation system for decision support is made up of three modules that are interdependent regarding the flow of information. The hierarchical organization is the following:

- Wind Speed Module
- Fire Danger Rating Module
- Fire Spread Module

Wind speed calculations are performed in a 3-D grid. FireStation is able to generate automatically the required grid, based on the terrain description given in a standard GIS format.

A set of meteorological stations must be defined for the calculation of the different components of the FWI System. The spatial distribution of the different indexes may then be mapped on the physical space. The value in each location is obtained from the value calculated at each station, applying a weighted average based on the inverse of the distance.

The main input for this module is a file containing the x,y,z coordinates of the terrain, defined in a uniformly spaced grid. Additionally, for each node this file stores a number identifying the corresponding fuel type. Optionally, this information may be imported from a GIS platform.

The characteristics of each fuel type, which are input parameters for the fire rate of spread calculation, are defined in the corresponding dialog box. Optionally, the fuel moisture may be defined in this dialog box as percentage, for each fuel type and different particle dimensions. The specification of the fire ignition is done by employing a Tool Box. Ignition may be defined as a single point, a line or a closed area. User may also define fire break lines, which represent the boundaries beyond which the fire cannot propagate (Lopes, Cruz, & Viegas, 1998).

The output of the FireStation software has a broad range of possible applications from site specific fire effects on soil and plants, to hydrology at a drainage scale, to fire management planning at local scale, to operational fire fighting strategic planning and training and to national level fire-fighting resource allocation.

FireStation has been evaluated through the analysis of its outputs for specific tasks:

- wildfire simulation
- support to fuel management decisions, and
- large area fire danger based planning.

Although the system capabilities were not subjected to a thorough analysis, the cases examined showed the usefulness of the system in supporting decision-making in such situations. The use of FireStation in supporting fuel management decisions allowed the definition of critical areas subjected to potential extreme fire behaviour, and in that way the optimisation of resource/treatment allocation in a given area (Lopes, Cruz, & Viegas, 1998).

5.2.1.5 The 'FIRE-LINE ROTATION' Model

The Fire-line Rotation Model (FRM) is a semi-empirical model developed by a SCIER Project partner ADAI (Portugal) and is based on the heat transfer by convection and the feedback effect on the chemical reaction physical models.

The model includes the results of the study of the evolution of a linear flame front in a homogeneous fuel bed in a slope, for arbitrary values of the initial orientation of the fire front. With the exception of initially horizontal or down-slope propagating fire lines, the propagation is considered not stationary. Instead, in its movement the fire front rotates, tending to become parallel to the slope gradient direction. The concept of fire line rotation as a tool to interpret and describe the evolution of a fire front is implemented in this model. Experimental results developed at a laboratory scale in a 30º slope have been obtained to support this. Tests have been conducted to validate its application in the case of a point ignition fire in a slope (Oliveras, Piñol, & Viegas, 2006).

FRM requires, as inputs, geographical information on terrain slope, reference wind velocity and the basic spreading rate of the fuel bed. FRM provides, as output, the temporal evolution from a linear fire front in a slope or from a point ignition fire in a slope. This model is under development in order to incorporate arbitrary conditions of wind and slope, as well as arbitrary terrain and fuel bed changes.

5.2.1.6 The 'FMIS' Model

FMIS, developed by Algosystems[5] (Greece), is a stand-alone application for the assessment of a number of aspects in forest fire management and fire prevention planning. Among other components, FMIS includes a fire simulation tool, based on BEHAVE and using grid-cells contagion cellular automata approach. The FMIS system requires the following kinds of input data (Sphyris, 2001):

- Static or near-static geographical data, such as boundaries, digital elevation model, slope map and fuel coverage map of the target area, some parameters of combustion of fuels
- Dynamic data, such as the values of meteorological parameters that influence the occurrence and behaviour of a fire, the time period (simulation period) in which a simulated fire is assumed to propagate, the simulation step and the point(s) of ignition.

[5] www.algo.com.gr : Companies' emphasis has laid on the forest fire management systems through the development and use of intelligent FMIS (Fire Management Information System) system that forms an integrated information collection, processing and exploitation database for geographical information sources used for supporting the prevention and suppression decision process of forest fires.

The fire simulation component renders an abstract representation of a series of contours that (as sets of cells in the target area) indicate the projected state of a fire at the various points in the simulation period; each of these contours corresponds to a point in time which lies an integer multiple of the step, away from the start of the simulation period. The fire simulation component computes the propagation of the fire, based upon the inputs. The user is also able to request the estimation of the burnt area and the length of the outermost front of the simulated fire. The meteorological parameters used by this simulation model (SM) are the following (Sphyris, 2001) (Cartalis, Varela, Eftichidis, Asimakopoulos, & Feidas, 1994):

- temperature of air
- relative humidity of air
- wind speed
- wind direction
- rainfall of the last 24 hours

The component takes the meteorological parameters supplied by the IM and carries out the following processes:

- spatial interpolations to compute the temperature and relative humidity raster maps
- utilization of the NUATMOS (Bachmann & Allgower, 1997) module to compute the wind field

Subsequently, the SM will use these to compute another raster map for the Fine Fuel Moisture Content (FFMC); the computation will be based either on the meteorological parameters or on the basic set of FFMC values provided by the user.

Besides, the user is required to enter a number of ignition points from which the simulated fire is assumed to propagate. As in other similar systems, the user is also required to enter a well-defined simulation period and simulation step.

The component simulates the propagation of the fire that starts at the entered fire outbreaks. The simulation is represented as a series of contours that indicate the projected state of the fire at time intervals in the simulation period at integer multiples of the time step from the beginning of the period.

Making use of the fuel combustion parameters, the simulation component computes the fire spreading rate at each point of the raster map. A set of mathematical equations based on the BEHAVE (Andrews, 1986) system is employed to compute this rate. Having computed the above raster map, the component then computes the propagation of the fire. This is done by a recursive algorithm over the list of the burning cells; the module keeps track of the simulation time and checks whether the cells adjacent to a burning cell will be burning at the current point in the simulation period. If a cell will be burning, it will be added to the list. The starting point of the algorithm is, of course, the set of ignition points originally provided by the user. By the time the simulation period ends (in simulation time), the list contains all those cells that keep burning or have been burnt (Sphyris, 2001).

The code of this fire simulation component has been written in Borland C++ v5.02 and can be run on a standard PC in MS Windows version 98 or higher. The component is standalone and does not require any specific environment. The code and executable, developed by Algosystems, have been implemented and improved in several research projects.

5.2.1.7 The ‘CARDIN 3.2’ Model

“CARDIN is a deterministic model of simulation of surface forest fire spread that has been under continuous development since 1990 in the Escuela Técnica Superior de Ingenieros de Montes (UPM), including in its version 3.2 the fire-fighting simulation. It runs on a standard PC in Microsoft based operating systems.” (Caballero, Martinez-Millán, Martos, & Vignote, 1994)

It uses digital information of slopes, aspects, and vegetation fuel models (the 13 fuel models of BEHAVE system of USDA Forest Service), and is able to predict the fire spread over variable topographic and vegetation patterns. CARDIN has been designed to be a user-friendly simulation system running on a standard PC. In this way no extra supporting GIS platform is needed to digitise the information required for the fire spread simulation (fuel models map, topography etc.) as CARDIN includes its own autonomous and simple digitising system (Digicar) (Caballero, et al., 1999).

Besides, information provided in the format of common GIS platforms can also be transformed to CARDIN format using specific programs. For example, in 1996, in the project ARCAR, vegetation and topographic digital information (as well as standard scanned maps in TIFF format) of Andalusia has been converted from ArcInfo format and is now available for simulations by the regional forest services of Andalusia (Condés, Flores-Moya, Soto, Altamirano, & Sánchez, 1996).

Forest fire behaviour and fire fighting simulations take place in a square zone of 400x400 cells, each of them containing information about elevation, slope, aspect and fuel model. Simulation results can be shown over different backgrounds such as forest fuel, land use, or common topographic maps, allowing users to easily locate the fire perimeter on the terrain. In all cases, contours and straight lines representing various ground elements, such as roads or rivers, can be overlaid.

Such elements (roads, rivers, firebreaks) are used by CARDIN in two different ways: can be considered as fire barriers with a certain degree of efficiency (depending on their characteristics) and/or can be used also as part of the trajectories assigned to the fire-fighting elements. CARDIN simulation model has been described in detail in many papers (Martínez-Millán, Martos, Vignote, & Caballero, 1991) (Caballero, Viegas, & Xanthopoulos, 2001).

This theoretical model gives more general shapes than the usual ellipses. These approximate shapes can also be obtained from the CARDIN model as a particular case. In order to display the fire spread simulation on a computer’s screen, the time required for the fire to reach any of the 8 adjacent fuel cells-pixels of a burning cell-pixel is computed. The same pixel can be analysed from different burning points; this implies a different angle w and different fire access times; the minimum of those is the one that determines the pixel contagion time. If some of these pixels are incombustible or have been already burnt, they are not taken into account in the analysis (Caballero, 2006).

5.2.2 The ‘Tecnoma FSE’ Simulation Model

This chapter is written according to SCIER forest fire simulation model, namely ‘Fire Spread Engine’ (FSE). The main reference is a project deliverable which was called “Library of Models” (Metelka, Caballero, & Kirklis, 2008) written by the consortium members.

“The main objective of the FSE model is to estimate the propagation of a surface during the first moments of a wildfire’s outbreak, providing a set of basic spatial data and rendering fundamental values explaining the most important aspects of fire behaviour, such as fire spread rate, flame length and fire linear intensity” (Caballero, 2006). This application is flexible enough to be embedded in GIS platforms and architectures, such as the one developed in SCIER, or coupled with other models, such as the hydrological model developed by DHI and presented in the chapter 5.1 above.

5.2.2.1 Assumptions and limitations

This model was based on a set of assumptions which should be taken under consideration in order to effectively implement the resulting computer code (Metelka, Caballero, & Kirklis, 2008) (Caballero, 2006):

- The model is designed to compute the fire behaviour in the flaming area, which is the fire line.
- The primary force driving the fire spread is the fine fuel fraction, i.e. those fuel particles that are less than 1/4 inch in diameter; large fuels are not considered into the final computation.
- The model will consider only surface fires where the flames are running over surface fuels, not canopy.
- As long as uniform spread conditions are considered (moisture contents, wind speed and direction etc.) only projections of fire spread over periods of 2 to 4 hours are recommended.
- Although crown fires are not modelled, it is possible to forecast the appearance of crowning effect and spotting areas. Fire twirls and firebrand effects are not considered.
- Forest fuels are considered to be static; no moisture corrections due to fire front heating are made.
- Fires are modelled at 6 ft. (2 m.) height, and neither 3-D vectors nor 3-D components of convection currents are considered.
- Heat sources are not considered in the modification and distribution of local winds.
- Although fire front acceleration occurs in the initial phase and under certain conditions, this is not considered in this version of the model.

Moreover, before employing this application, a number of limitations have to be considered (Metelka, Caballero, & Kirklis, 2008):

- If the starting points are located in non-burnable areas (model value 0), the simulation will not progress.
- In case that there is high value of moisture content, low wind velocity or/and flat topography, the resulting fire access time can be very high, showing a very slow propagation with a low number of cells affected.
- Some models have an associated limit on wind speed, beyond which the fire will not progress faster.
- In some cases the moisture content can reach and overpass the extinction moisture value, which is characteristic of each model complex. In such cases the propagation will not progress.
- For cells rendering very low speed, the simulation will output a fire access time of 6000 min.; this indicates that there is no propagation.

The TECNOMA FSE is a computer application in the form of a standalone, autonomous executable program, which estimates the fire front expansion on surface forest fuels, using spatial data about topography, moisture content, type of fuel and wind vector field. The engine uses the Rothermel-Frandsen semi-empirical approach (Rothermel, 1983) and calculation processes similar to those found in BEHAVE (Rothermel, 1991) system, and the application of a cellular-automata algorithm for the estimation of the fire spread. The application is an independent, standalone command-line executable running under Linux OS, which can be invoked by (Metelka, Caballero, & Kirklis, 2008):

```
scier_fse
```

The application searches for the mentioned data files under the current directory, then proceeds with reading and loading data on the memory. Subsequently, the simulation is launched. The application performs a series of previous calculations on the fuel models which are present in the analysis area (which is determined by the file headers) by applying BEHAVE algorithms (Rothermel, 1983). Initially, the application performs a fire spread projection limited to 3 hours (180 minutes), as it is suggested to use this application for the estimation of an initial fire and not for long-term simulations of several hours or days (Metelka, Caballero, & Kirklis, 2008).

Although the application is designed to perform simulations of any number of hours, it is suggested not to go beyond 3 hours due to the cumulative effect on the spread calculation error (as no new boundary conditions about the position and nature of fire front can be entered). Then the application proceeds with the application of the local spread law, obtained in each square cell, and apply the cellular-automata for the progression of fire. To do this, local values of slope, aspect, fuel model, fuel moisture and wind vector are used in each cell, which lead to local spread laws which are then integrated into a single resulting fire front. After the simulation, the application writes the resulting analysis in a set of files, also in GRASS-ASCII format, and also corresponding to the same analysis area extension and resolution, as indicated in the input maps. The application also informs about the number of points analysed. This is variable according to the spread conditions in each simulation; fast forest fuels (as number 1 or 2) in low moisture and high wind conditions will render many more cells analysed in the same time interval (Metelka, Caballero, & Kirklis, 2008).

5.2.2.2 Modifiers

The application command line has a number of associated modifiers that allow an extra degree of control on the way a simulation is performed. The procedure for applying these modifiers is by writing a space followed by the name of the modifier and separated by a space between each other. The order in which modifiers are written is irrelevant. If the modifiers are repeated, only the last one in the command line is taken into account. The modifiers not identified or wrongly written are ignored, and the command line is not case sensitive (Metelka, Caballero, & Kirklis, 2008):

scier_fse modifier1 modifier2 …

The application allows passing parameters to some of the modifiers, by including the equal symbol (=) followed by the correspondent value:

scier_fse modifier1=value1 modifier2=value2 …

The application informs about the accepted modifiers and the associated values – some of them limited between a minimum and a maximum value.

5.2.2.3 Mechanism of cellular automata

The Tecnoma FSE is based on an adapted version of the CARDIN simulation system. The main modification is that this version uses the elliptical shape as the fundamental spreading law curve under uniform conditions, instead of the pseudo-cardioid proposed in the CARDIN model (Martínez-Millán, Martos, Vignote, & Caballero, 1991) (Caballero, Martinez-Millán, Martos, & Vignote, 1994). All the other parts have been revised and implemented in several previous projects, e.g. E-FIS (Caballero, Viegas, & Xanthopoulos, 2001) FORFAIT, AUTOHAZARD and WARM.

The engine bases its operation on cellular-automata that calculates the time taken for the fire to travel from a burning cell to the surrounding eight cells. Thus, the state of these cells, regarding the fire spread, could be one of the following three (Metelka, Caballero, & Kirklis, 2008):

- Intact
- Flames burning
- Extinguished

Essentially the process is simple: the spread law is calculated using the values encountered in analysing a cell relative to slope, aspect, fuel model, and wind speed and direction. For each spread direction corresponding to each of the eight neighbouring cells, a projection of the spread law is obtained, giving the rate of propagation in that direction. As distance between cells can be easily estimated by considering the distance between their centres, the time taken for the fire to travel from one centre to the other is obtained by dividing the distance by the speed of propagation.

Hereafter, the analysing cell will be addressed as A, the analysed cell as B and the reference cell as R. The reference cell corresponds to the latest position where significant changes in some of the spread law factors (slope, aspect, wind or fuel) were found. For the first analysing cell the reference cell is itself and the same applies for the first eight surrounding cells being analysed. All this process is governed by an engine matrix where the information for each burning cell is stored, just like this (Caballero, 2006):

PTR	**X**	**Y**	**t**	**XR**	**YR**

Where;

PTR (pointer) the order number (from 1 to the number of burning cell) and it is used to point to the current analysing cell;

X,Y the position of the cell; t is the fire access time;

XR, YR the position of the reference cell (i.e. the cell that is used as the origin of the spread law).

This matrix, obviously, is continuously being updated as new cells, those resulting from the analysis, are inserted and re-sorted by ascending time (Caballero, 2006). When a fire starts a new matrix is generated and a new cell is inserted. This is the only initial point for each fire, as they are considered point-wise in origin. The procedure must check whether the inserted point is non-burnable (e.g. water, rocks or other non-burnable material) or has already been burned out due to a previous fire; if any of the above applies the procedure will not insert the initial point (Metelka, Caballero, & Kirklis, 2008).

8	1	2
7	A	3
6	5	4

Each of the surrounding cells for a given analysing cell A has a unique direction of analysis, represented by an integer from 1 to 8, starting from the north position in a clockwise direction for positive values of angle. Thus, position 1 corresponds to an angle of 0º, position 2 is 45º etc. When a fire starts the matrix is created and a new cell is added. For example:

PTR	**X**	**Y**	**t**	**XR**	**YR**
1	100	100	5	100	100

The position is the current position of the cell where the fire starts; the access time t is the moment at which the fire starts and the reference position, for this case, is the cell itself, as there is no other cell to which refers the analysis. Once the matrix is fed for the first time, then the process runs iteratively as described below (Metelka, Caballero, & Kirklis, 2008).

The system gives an analysis threshold time t_{max} that marks the end of each procedure run; for each cell in the matrix whose access time t is equal to or less than this maximum time value, a complete analysis of its surrounding cell is performed. The procedure reads the values required for the spread law calculation at A that belongs to this cell. The spread law procedure returns the maximum spreading rate and its direction, as well as the fire line intensity. These values will be used to obtain the spreading rate for each of the eight defined directions. For each of these eight directions the procedure calculates the position X_B, Y_B, of the analysed cells. The distance and the direction angle between positions A and B can be easily deduced (extended taxicab distances) (Caballero, 2006):

DIR	X_B	Y_B	ANGLE Ί	DIST
1	X_A	Y_A+L	0º	L
2	X_A+L	Y_A+L	45º	L√2
3	X_A+L	Y_A	90º	L
4	X_A+L	Y_A-L	135º	L√2
5	X_A	Y_A-L	180º	L
6	X_A-L	Y_A-L	225º	L√2
7	X_A-L	Y_A	270º	L
8	X_A-L	Y_A-L	315º	L√2

Where

X_A, Y_A the position of the analysing cell and L the cell resolution.

5.2.2.4 Simulation of Local Wind Instability

The FSE application considers the quasi-erratic behaviour of the wind vector direction (WDIR) which is present in many forest fires as experience shows and which is so difficult to predict, by implementing a specific functionality. This functionality is the modifier WRAN (from 'random wind vector') (Metelka, Caballero, & Kirklis, 2008). This function has an associated parameter; the wind vector aperture (AA) expressed in degrees. This aperture defines a minimum (WDIR-AAº) and a maximum (WDIR + AAº) value between which the wind vector direction oscillates randomly, according to the local atmospheric instability. The following table (Figure 5-1) presents the Pasquill classes of atmospheric instability and the associated wind vector horizontal angle aperture (Caballero, 2006):

ATMOSPHERIC STABILITY PASQUILL CATEGORIES	CODE	STANDARD DEVIATION OF WIND VECTOR HORIZONTAL ANGLE
Extremely unstable	A	25
Unstable	B	20
Slightly Unstable	C	15
Neutral	D	10
Slightly Stable	E	5
Stable	F	2.5
Extremely Stable	G	1.7

Figure 5-1: The Pasquill classes of atmospheric instability and the associated wind vector horizontal angle aperture (Caballero, 2006):

By applying this, the resulting wind vector fields are distorted versions of the original ones, thus providing an easy way to generate a number of possible perturbations of this factor governing the fire behaviour. This functionality is being used in the generation of possible futures which is simulated in the GRID.

6 SYSTEM IMPLEMENTATION OF A WEB-BASED GIS COMPONENT

GI science is the science and art of acquiring, archiving, manipulating, analyzing, communicating, and utilizing spatially explicit data for understanding physical, biological, and social systems on the Earth's surface or near the surface. In order to share distributed geospatial resources and facilitate the interoperability, the Open Geospatial Consortium (OGC), "an industry-government-academia consortium, has developed a set of widely accepted web-based interoperability standards and protocols" (OGC, 2000). On the other hand, Grid Computing is a rapid developing technology, originally motivated and supported by science and engineering requiring high-end computing, for sharing distributed high-end computing resources (Foster, Kesselman, & Tuecke, 2001). "The vision of Grid is to enable resource sharing and coordinated problem solving in dynamic, multi-institutional virtual organizations" (Foster I. , 2002).

The value of integrating computational modeling and geographic information has been vividly demonstrated in recent natural disasters around the world. In this sense, SCIER within the GIS module explores the relationship between GI science and grid technology. Unfortunately there isn't a fully integrated extension and application of GIS in Grid technology. All around the world, recent research activities like D-GRID (D-Grid, 2007) – see Figure 6-1 – in GIScience focused on making Grid technology more geospatially enabled as the SCIER GIS Component tries to overcome this challenge via intermediate windows based computing environments. Services in this approach follow SOAP (W3C, 2008) Web Services Architecture for creating, managing, and exchanging information among organizations. These services also provide human interaction to manage user interfaces, graphics, and to present compound documents. The development, manipulation, and storage of data, conceptual schemas, and datasets are managed by SCIER Consortium Members. Specific tasks or work-related activities are supported by computational methods and interfaces. Fully integrated system components perform sophisticated computations. Therefore, it made easier to integrate existing non-standardized multi-sources and multi-scales data with the developments according to project related services.

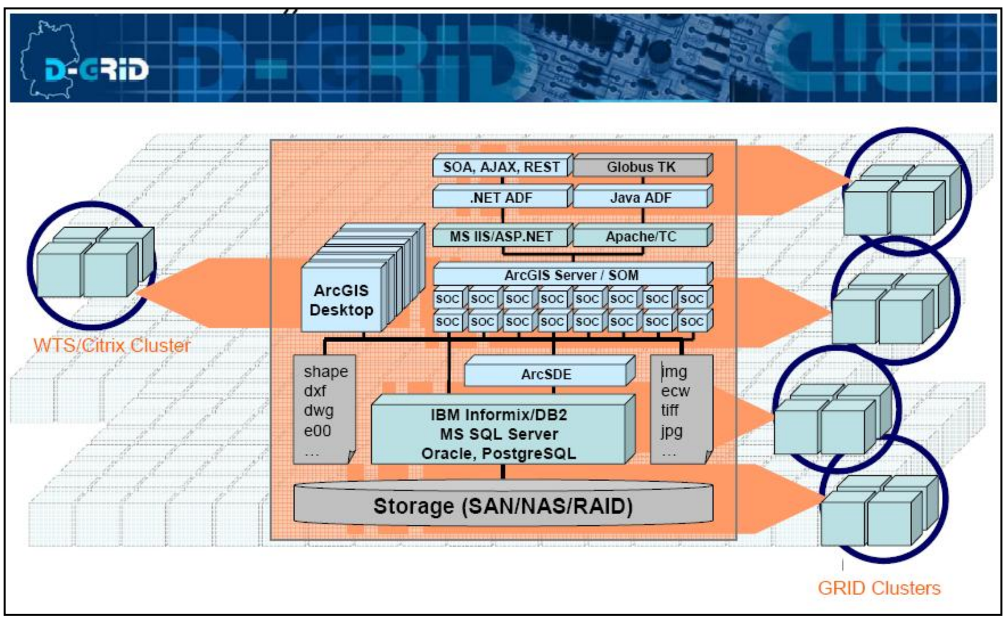

Figure 6-1: The research project D-GRID from ESRI-Conterra and 7 German Universities (D-Grid, 2007).

6.1 SCIER Computational System Overview

This chapter provides a foundation for understanding the software and the hardware components, and platform configuration options available to support distributed GIS operations via SCIER GIS platform. Understanding application architecture and associated configuration strategies provides a foundation for improving the distributed SCIER GIS Module; while enterprise-level GIS applications support a variety of users throughout an organization, all requiring access to shared spatial and attribute data sources.

The SCIER platform is an integrated system which consists of technologies and structures from different scientific fields like *wireless sensor networks, environmental engineering and modeling, Grid computing for parallel processing*. Integrating such sophisticated technological platforms is so difficult that requires an excellent knowledge and understanding of operational specifications for each module in separate, with a well designed integration strategy. It is customary that the architecture of such a large scale integrated system is visualized by a vertical, bi-directional flow-chart divided into different layers (Figure 6-2). Each layer performs a specific set of activities. In the project SCIER, three architectural layers were defined by the coordination of National Kapodistrian University of Athens (NKUA) as the team leader for computational integration (Bonazountas, et al., 2009). The NKUA team has involved in the modelling methodology and the flexible simulation tools. They coordinate the IT guidelines and the core requirements in computational infrastructure.

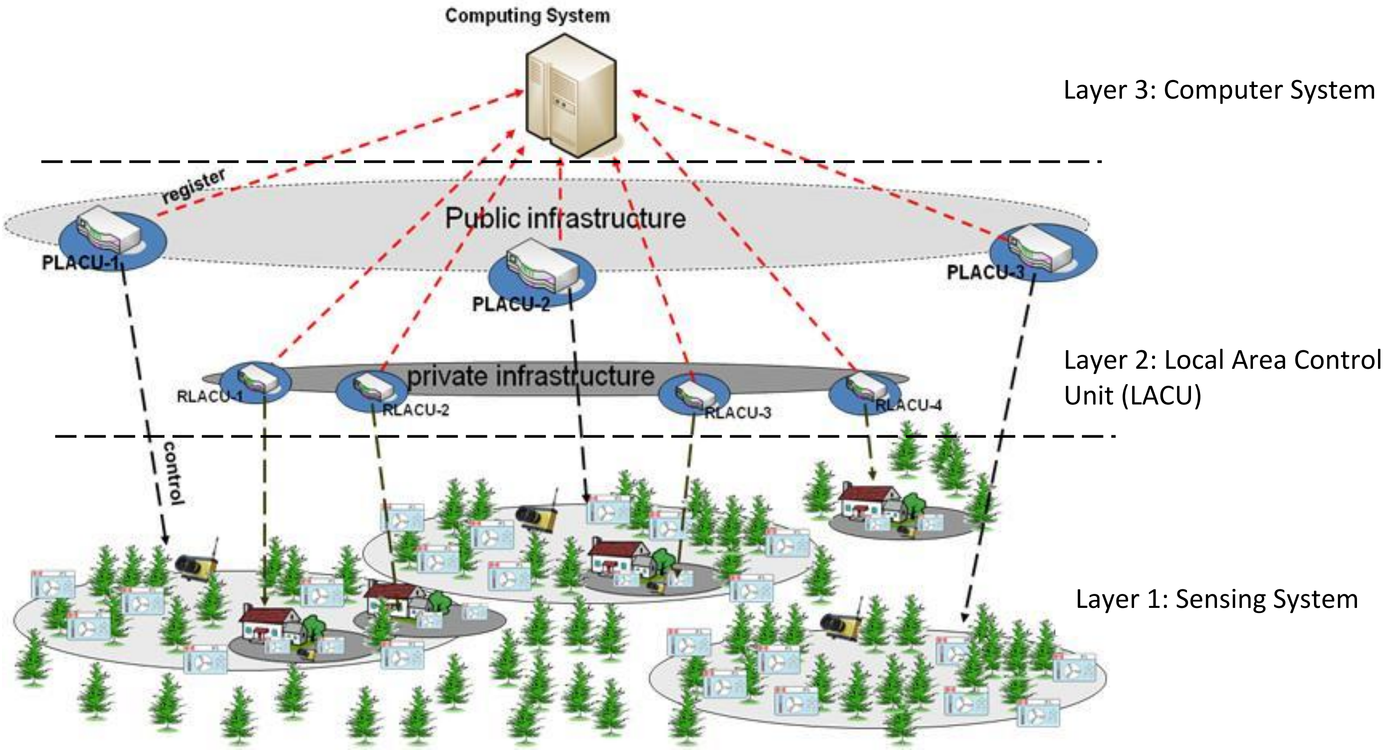

Figure 6-2: SCIER's Layer Architecture (Bonazountas, et al., 2009)

Each layer embraces a new set of sub-systems with their computational interfaces and operational specifications. In the previous chapters, the interfaces between different layers were already emphasized. Before getting into details of GIS implementations, detailed system workflow can be seen in the following figures (Figure 6-3 & Figure 6-4):

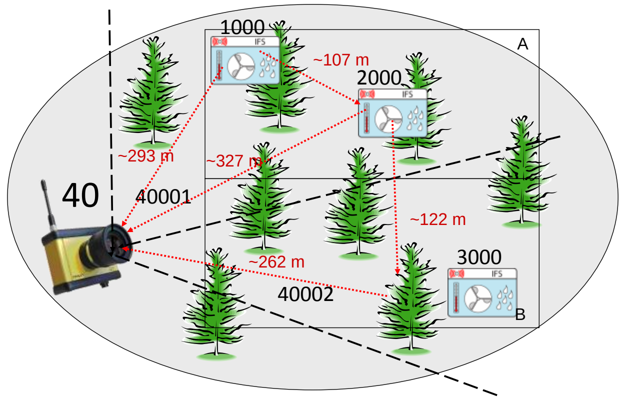

Figure 6-3: Scenario a LACU setup (Bonazountas, et al., 2009)

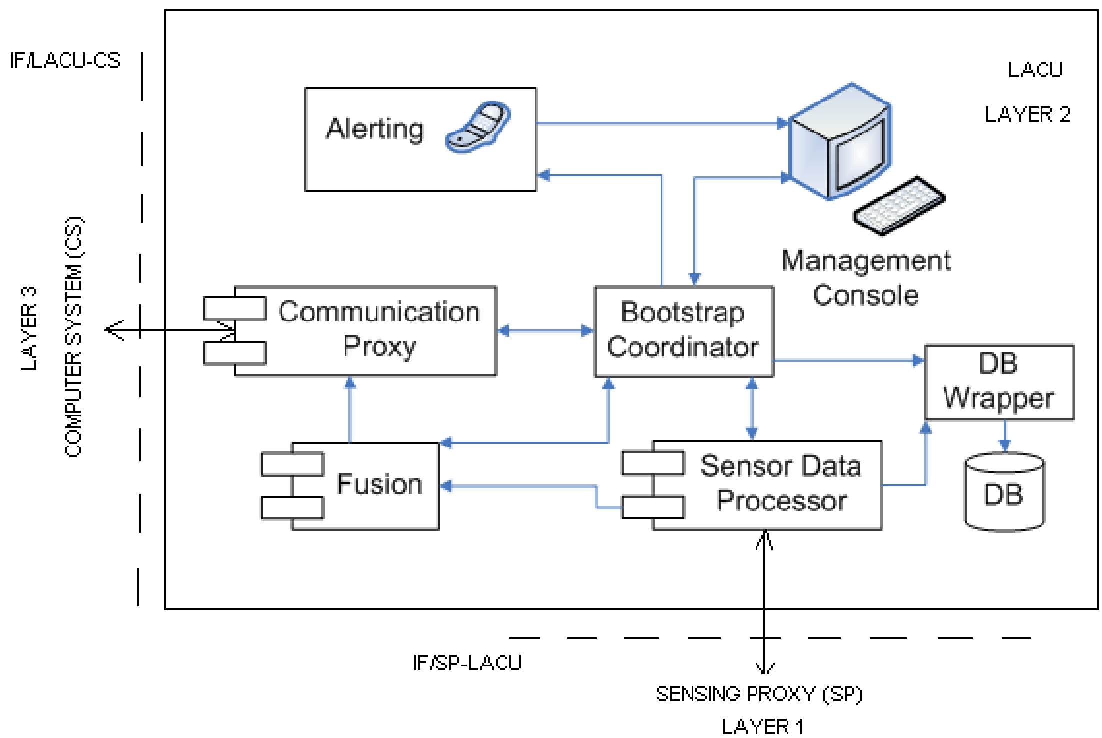

Figure 6-4: Local Area Control Unit (LACU) Modules and Interfaces (Kanellopoulos, Bonazountas, Kirklis, Metelka, Hadjiefthymiades, & Faist, 2008)

6.2 Basic Functionality of the GIS Module

Due to the mentioned actual state of research before, to overcome the integration issues the SCIER project the most applicable solution was to provide the state-of-the-art GIS server technology to fulfill the basic SCIER requirements. As described in the document of the SCIER User Requirements (Bonazountas, et al., 2007) there are several references to the functionality of the GIS, which are the follows:

"The Computing Subsystem is the heart of the SCIER architecture. It is based on GIS (e.g., region, URI) where the fused sensor information is systematically pinned. SCIER also incorporates GIS-enabled mathematical environmental models of different time scales for predicting the evolution of tracked phenomena and related risks. Multiple models for each phenomenon (e.g., fire, flood) are used in order to establish a globally acceptable, highly accurate tracking of the phenomenon.

1. SCIER attempts to develop a GIS based technology, considering land-use, population patterns, and other parameters (e.g., economic) to define the Urban Rural Interface (URI) area in a standardized format.
2. The sensing infrastructure is coupled with the SCIER GIS platform for assessing the spatial distribution of the sensing components.
3. The sensing subsystem is also carefully monitored through the SCIER-GIS to constantly keep track of the required sensor density and other related characteristics.
4. CSS renders models output on the GIS model, thus creating a visual representation of its evolution, as well as of any emerging related risks, and, it iteratively performs this task, using a possibly different time quantum in each iteration.
5. SCIER will fully model Fires and Floods hazards and the spatial results are visualized on a GIS platform by exploring GRID technology – an innovative approach to mathematical environmental modeling" (Bonazountas, et al., 2007).

As it's stated several times, eventually the most innovative element in this project was the incorporation of real-time sensor information for fire distribution and flood modeling and real time representation of the modeling results via the SCIER-GIS platform, which is "a new concept that can be very important for non-usual fire spread conditions" (Kanellopoulos, Bonazountas, Kirklis, Metelka, Hadjiefthymiades, & Faist, 2008). For enabling such functionalities properly, we had to make sure that there is a powerful and seamless communication between Grid and the GIS component of the project. This core issue actually increases the research capability of this PhD work of mine.

6.3 System Components of the GIS Module

6.3.1 Central Spatial Data Server

Shared spatial and tabular database management systems provide central data repositories for shared geographic data. In this sense SCIER GIS module has a state-of-the-art database management system which is located on separate data server platform in this configuration:

- 2x Intel Xeon E5430 Quad Core, 4GB RAM
- 2x 250GB SATA Harddrive (RAID1), RAID Controller
- Installed Software: Oracle 10g Database, ArcSDE 9.2, ArcGIS Server Enterprise 9.2

6.3.2 Web Application Server

GIS applications are supported within the distributed configuration by hardware platforms that execute GIS functions within the SCIER-GIS Module. In SCIER's centralized solution, Windows Terminal Server[6] and Web application server platforms provide host compute services to required number of concurrent GIS clients. Windows Terminal Server hosts GIS desktop applications on centrally managed server farms allowing remote terminal clients to display and control applications executed on the terminal server platforms. Web application server supports a variety of Web applications and services accessed by standard browser clients or other desktop applications.

6.3.3 Desktop Workstations

Display and execution of application processes are supported by desktop workstations, which are PCs that also can function as Windows terminal clients or Web browser clients.

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[6] Windows Terminal Server (WTS) is a multi-user server operating system that provides the ability to host multiple simultaneous thin-client sessions on remote client devices. All client processing is performed locally at the Terminal Server and only display, keystroke, and mouse commands are transmitted over the network to the client device. The Remote Desktop Protocol (RDP) from Microsoft – as a thin-client protocol – is used with WTS.

6.4 GIS Module

The SCIER GIS Module aims to share a system design methodology that promotes successful deployment of GIS technology. Guidelines include appropriate rationale and logic to deploy and support a system that will satisfy initial performance needs for most of the users. Once the initial implementation is operational, the system environment can be further tuned and adjusted to fit specific user requirements.

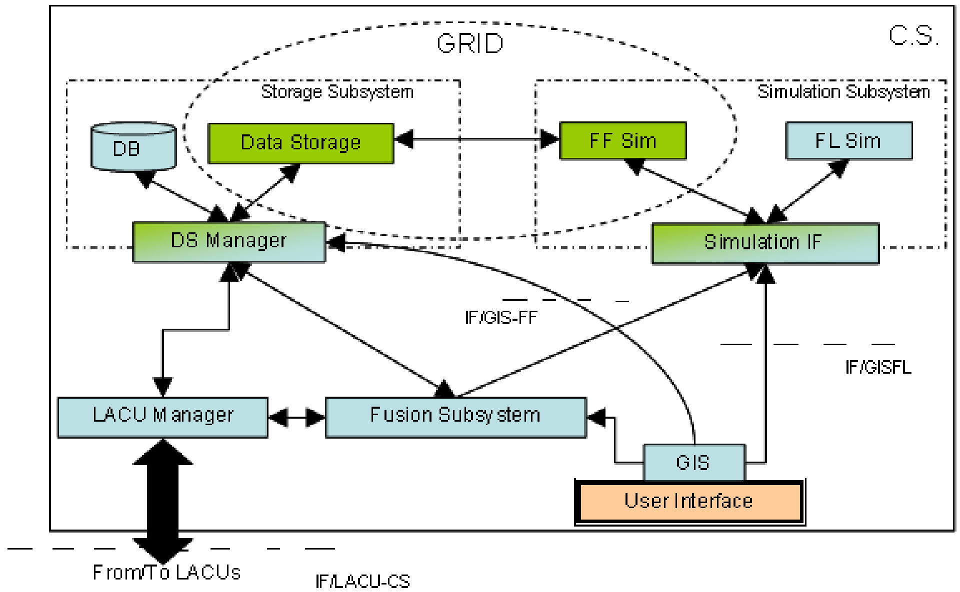


Figure 6-5. SCIER and SCIER-GIS system integration - adapted from Kannellopoulos *et al.* (2008).

SCIER GIS module which is managed by ESRI ArcGIS Server 9.2 technology runs on Windows environment without any integration problems with the other system elements of the SCIER project. This component is developed for the users that need to share geographic data, maps, and analyses with the highest level of system flexibility and scale-ability. Users can leverage an unlimited number of clients over the Internet or intranet. In technical side of the module implementation, the components of the SCIER GIS-Server (Figure 6-6) are (a) GIS server, (b) Web server, (c) Clients.

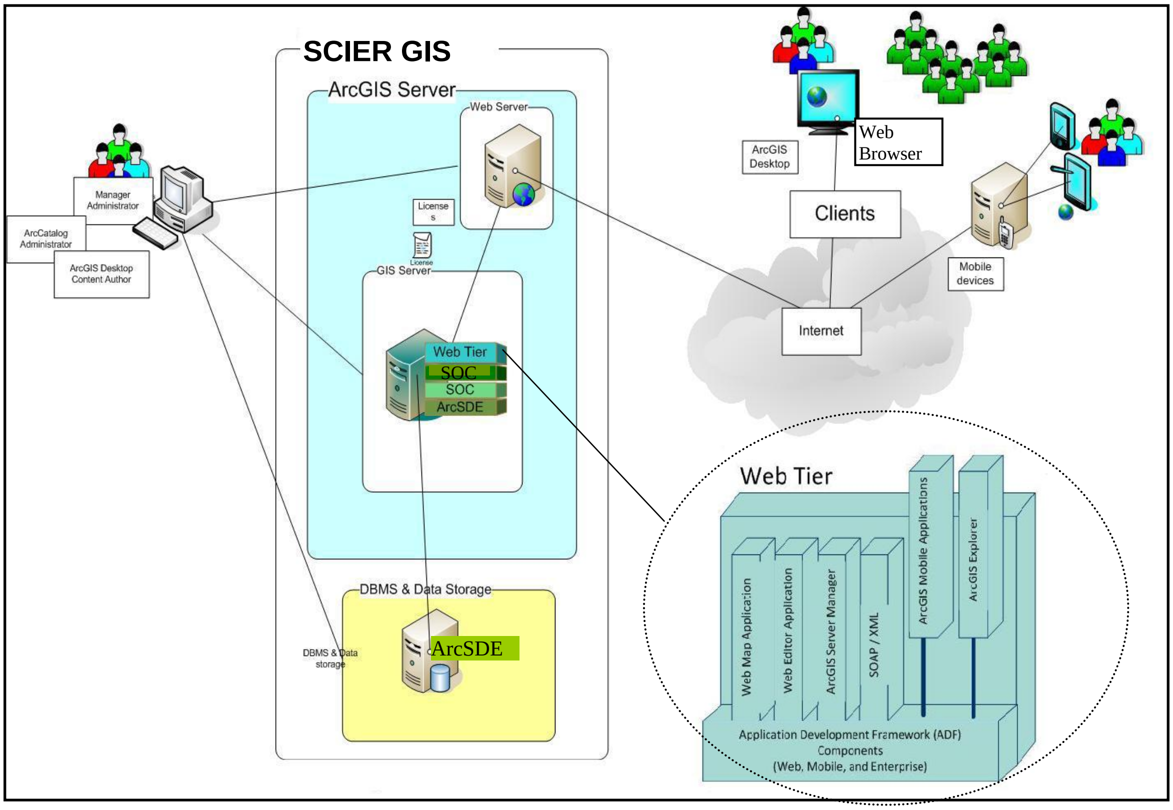


Figure 6-6: SCIER GIS Module system components – adapted from the System Architecture of ESRI's ArcGIS Server 9 series (ESRI, 2007).

The SCIER GIS Module aims to support existing infrastructure requirements; and it provides specific recommendations for hardware and network solutions based on existing and projected user needs. Application requirements, data resources, and people within the organization are all important in determining the optimum hardware solution as shown in the system architecture design process figure. The system architecture of the GIS Module provides specific deployment strategies and associated hardware specifications based on identified operational workflow requirements.

SCIER GIS Server – within its advanced enterprise configuration – offers the following advantages:

- Scale-ability to support many users and browser-based access to GIS.
- Integration with other enterprise systems.
- It provides foundation for geospatially enabling SOA.
- Support for interoperability standards in both the GIS and the IT domain
- Ability to create custom applications using .NET or Java programming languages.

The following chapters will give a detailed technical description on

- The GIS Server architecture
- Hard- and Software requirements
- Data Management within the GIS Component
- Programming Work for the SCIER Web Applications
- The prototype web-GIS applications of SCIER

6.5 Server Architecture

According to software components that have been identified for development requirements; the intention of the GIS module is claimed to gather all required data in a system which is managed by ESRI ArcGIS Server technology. ArcGIS Server is a platform for Enterprise Applications. It offers a central, server-based GIS for multi-user applications with extended GIS functionality. It is a cross-platform application (Windows, Linux, Unix) with interfaces to .Net (DotNet Framework) and Java. It offers a wide range of out-of-the-box functionality for administration, mapping, and geocoding via Local Area Network (LAN) or Internet. It is designed primarily for developers to design sophisticated server-based GIS applications like;

- Web-mapping applications
- Geo Web-services (WMS)
- Desktop applications.

It doesn't only deal with data storage but also delivery of them in an interoperable way via internet in EU and International GIS standards like ISO, OGC, W3C, and INSPIRE. ArcGIS Server (ESRI, 2009) is in the family of ESRI's ArcGIS 9.2 products, and its main role is simply to serve up GIS functionality to a wide array of clients. It can access data from either an RDBMS, or from some file-based data source. It is important to mention that ESRI's ArcGIS Server technology is an IT compliant and interoperable package since it offers support for interoperability standards in the GIS domain (Open Geospatial Consortium, Inc.) as well as the broader IT domain (World Wide Web Consortium [W3C]).

At the heart of this centralized architecture approach is the idea that the application server can be enhanced to encompass not only the data management but also the mapping and spatial analysis. Running all the GIS components on a server means that thin (browser) client can be used to initiate processing requests and display the results of GIS tasks. In this context this centralized GIS implementation is referred as a competent example of enterprise geographic information servers. It allows both thin (browser) and thick (desktop and mobile GIS) distributed clients to access data and processing capabilities over a local or wide area network (ESRI, 2007).

GIS module of SCIER is developed for the users that need to share geographic data, maps, and analyses with the highest level of system flexibility and scale-ability. Users can leverage an unlimited number of clients over the internet and/or intranet. An ArcGIS Server system also includes a set of services; Web applications, ArcGIS Explorer Maps, and KML network links that have been published on the server, as well as a Manager application for creating and organizing them. This group of services and applications, with its associated Web server and GIS server, is called an *ArcGIS Server instance* (ESRI, 2007). In technical side of the module implementation, the components of the SCIER's GIS Server are as before (Figure 6-6).

6.5.1 GIS Server Environment

SCIER's GIS server can host the GIS resources, such as maps, globes, and address locators and exposes them as services to client applications.

- The SCIER GIS server itself is composed of two distinct parts: the Server Object Manager (SOM) and Server Object Containers (SOCs). As the name implies, the SOM manages the services running on the server. When a client application requests the use of a particular service, it's the SOM that actually gives one out for the client to use.
- The SOM connects to one or more SOCs. The SOC machines — also referred to as container machines — contain, or host, the services that the SOM manages. Depending upon the configuration, the user can run the SOM and SOC on different machines and also have multiple SOC machines.

SCIER Data server

The data server contains the GIS resources that have been published as services on the GIS server. These resources can be map documents, address locators, globe documents, geo-databases, and toolboxes (contains tools for Geo-processing tasks supported by ArcGIS Technology).

SCIER Web server

The Web server hosts Web applications and Web services that use the resources running on the GIS server. The GIS server consists of a Server Object Manager (SOM) and one or more Server Object Containers (SOCs).

Clients

Web browsers can be used to connect to Web applications running in the Web server. Desktop applications can connect either through HTTP to ArcGIS Web services running in the Web server, or connect directly to the GIS server over a LAN or WAN.

6.5.2 System Administrators

SCIER's GIS Server can use either ArcGIS Server Manager or ArcCatalog to publish GIS resources as services. You can see a detailed system overview for the administrator on the figure below (ESRI, 2007) (Schaller & Ertac, 2008):

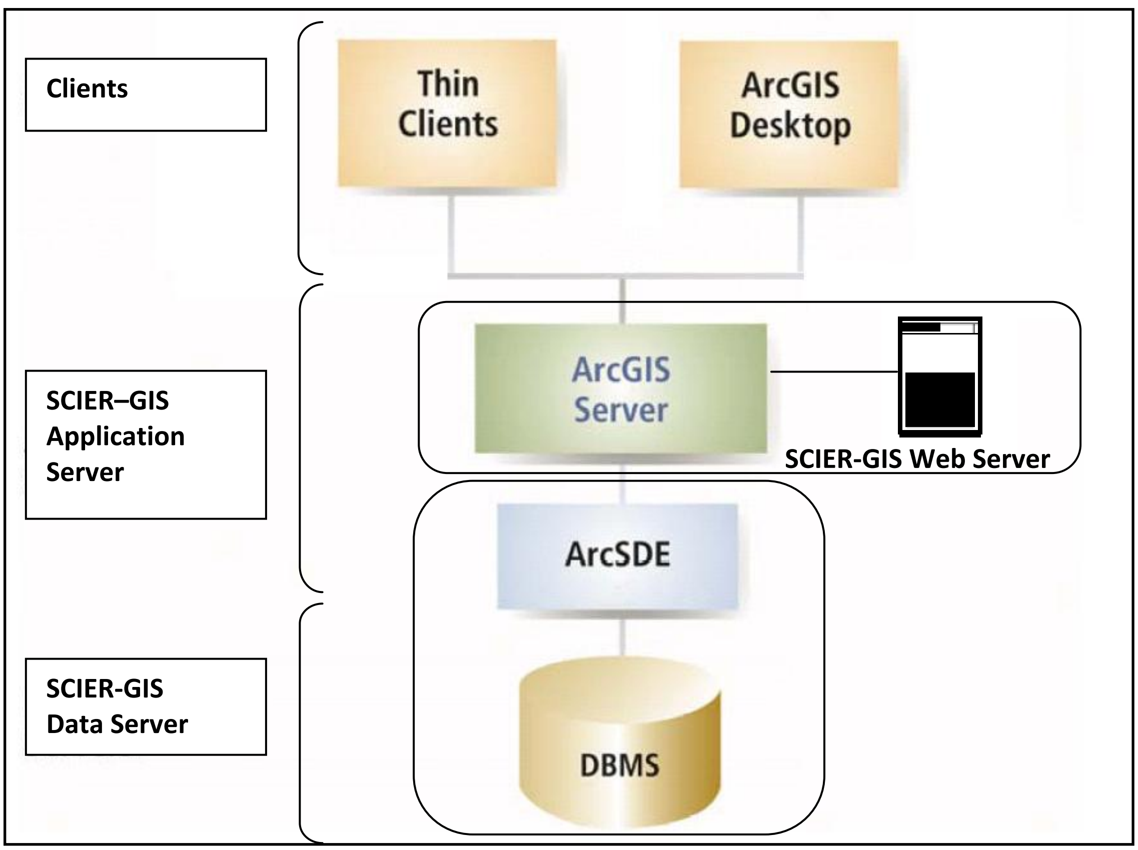


Figure 6-7: SCIER GIS module – the system detail for the system administrator. – adapted from the System Architecture of ESRI's ArcGIS Server 9 series (ESRI, 2007).

- ArcGIS Server Manager is a Web application that supports publishing services, administering the GIS server, creating Web applications, and publishing ArcGIS Explorer maps on the server.

- ArcCatalog includes a GIS Server node which can be used to add connections to GIS servers for either general server usage or administration of a server's properties and services.
- ArcGIS Desktop content authors– To author the GIS resources such as maps, geo-processing tools, and globes that will be published to your server; you will need to use ArcGIS Desktop applications such as ArcMap, ArcCatalog, and ArcGlobe. Additionally, if a cached map service is created, ArcCatalog is used to create the cache.

6.5.3 User Categories

Most users access SCIER-GIS Server via web applications with their internet browser. These users have normally no or only limited GIS knowledge. Therefore the user interfaces of the SCIER web applications are free-scalable from basic functions to the broad GIS functionalities.

ESRI GIS software, ArcCatalog and ArcMap can access to the SCIER-GIS Server with the administrator privileges. The server objects that run on the GIS server are derived from the same resources that the user works with in ArcGIS Desktop. On the other hand, the access to SCIER-GIS Server can be directly or indirectly via “http://www.scier.eu”.

6.6 Minimum System Requirements

As it’s given in ArcGIS Server online help system and the software package (ESRI, 2006), the minimum system requirements to operate server-based GIS operations are given as follows:

6.6.1 Software

Product: ArcGIS Server 9.2 for the Microsoft .NET Framework

Operating System: Windows 2003 Server R2 Standard, Enterprise & Datacenter

Service Packs/Patches: SP1, SP2

Web Server: Internet Information Server

Web Server Version: 6.0

Developer System Requirements:

- The development environment requires Visual Studio 2005 (Web Developer Express, Standard, Professional, or Team Editions) and .NET Framework 2.0.
- .NET Framework 2.0 is installed with Visual Studio .NET 2005. The redistributable is available to developers who want to include the .NET Framework installation with their .NET applications.
- .NET Framework 2.0 is also provided in a DotNet20 folder on the ArcGIS Server DVD media for your convenience.

6.6.2 Hardware

CPU Speed: 1.6 GHz recommended or higher

Processor: Intel Core Duo, Intel Pentium or Intel Xeon Processors

Memory/RAM: 1 GB minimum, 2 GB recommended or higher. If using the ArcGIS 9.2 (ArcSDE) Personal and Workgroup Editions for Microsoft SQL Server Express software, 2 GB of RAM is required.

Display Properties: Greater than 256 color depth in 1024 x 768 resolution recommended or higher at Normal size (96dpi)

Swap Space: Determined by the operating system, 500 MB minimum.

6.6.3 Minimum Requirements at the Client

Internet Browser Requirements: SCIER-GIS Web User Interface requires a minimum installation of Microsoft Internet Explorer Version 6.0 or 7.0 SP1. If you do not have an installation of Microsoft Internet Explorer Version 6.0/7.0 SP1, you must obtain and install it prior to installing ArcGIS Server. (Please also see Microsoft Internet Explorer Version 7.0 Limitations). Firefox 1.5 or higher versions are also capable.

Additional Requirements:

- 24-bit capable graphics accelerator
- DVD-ROM drive

An OpenGL 1.2 or higher compliant video card is required, with at least 32 MB of video memory, however 64 MB of video memory or higher is recommended.

7 DEVELOPMENT OF THE WEB-GIS APPLICATIONS

This chapter presents the design and implementation of the GIS module of SCIER that uses a Grid computing driven framework for triggering the simulation applications and based on a GIS-server environment for managing spatial data and geo-processing tasks. It discusses the system integration efforts from the state-of-the-art technology perspective by giving computational background for integrating GIS with the other components of SCIER. The requirements for simulating complex systems are identified. Cook-book style operating manuals for using Web-GIS applications are given in detail as well.

The Web-GIS applications had been designed in Microsoft™ Visual Studio 2005 with the Web mapping application libraries of ESRI™ ArcGIS Server® ™ 9.2 Web ADF, which offer advanced map display, navigation, and interactive capabilities. In this context two Web user interfaces was developed for SCIER Flood and Forest Fire Models. Both of the web applications are dynamically connected to SCIER-GIS relational database and other computational SCIER components such as the computational subsystem, DS Manager and the simulation interface. All these system components will be discussed in coming sections in this chapter.

7.1 An Innovative Approach in GIS and GRID Integration

Web Services Description Language (WSDL) (W3C, 2001) that defines a XML-based language for describing web service interfaces, including Simple Object Access Protocol (SOAP) interfaces, was used for establishing high-level computational communication in SCIER. "WSDL is a widely used specification to describe networked XML-based services. It provides a simple way for service providers to describe the basic format of requests to their systems regardless of the underlying protocol (such as Simple Object Access Protocol or XML) or encoding" (Ogbuji, 2000). This is such a high level web-service standard that performs all transactions between the SCIER-GIS module and the Grid Computing Environment. This service assures that all input/output files concerning the fire modeling are safely received/delivered from/to the GIS component.

The relation between WSDL and SOAP can be simply explained as follows:

1. A client may have no knowledge of what Web Service it is going to invoke. So, the first step to ask the Web Service to *describe* itself.
2. The web service replies in a language called WSDL.
3. We finally know where the web service is located and how to invoke it. The invocation itself is done in a language called SOAP. Therefore, we will first send a SOAP request.
4. The web service will kindly reply with a SOAP response which includes the result of the request, or maybe an error message if the SOAP request was incorrect.

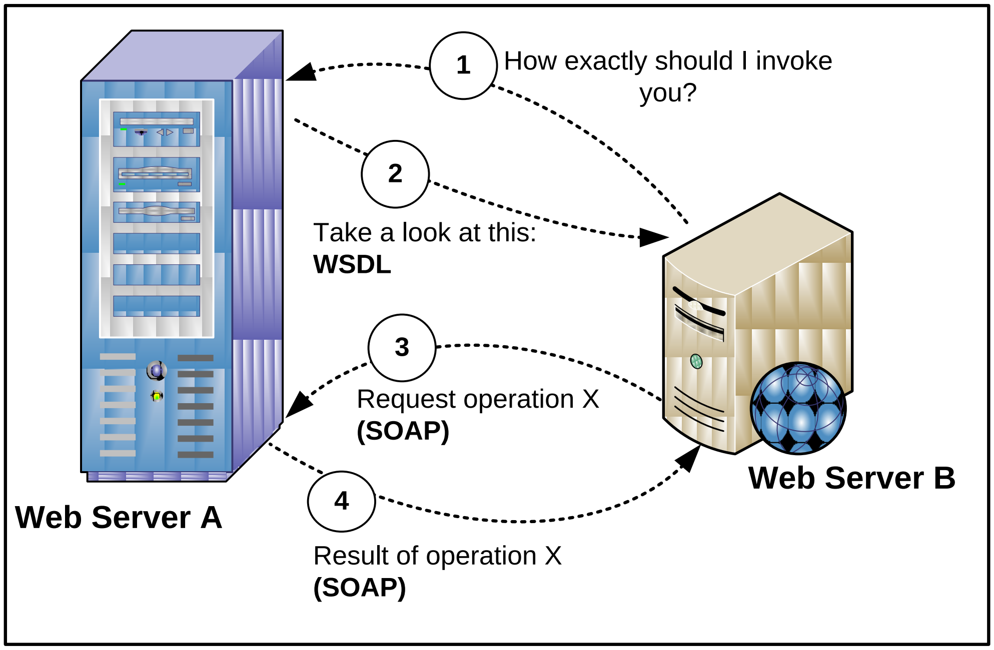


Figure 7-1: The steps involved in a complete Web Service invocation.

After seeing different players in a web service, let's take a closer look at the Web Services Architecture (W3C, 2001) (W3C, 2008):

- *Service Description:* One of the most interesting features of web services is that they are self-describing. This means that, once you've located a Web Service, you can ask it to 'describe itself' and tell you what operations it supports and how to invoke it. This is handled by the WSDL.
- *Service Invocation:* Invoking a web service involves passing messages between the client and the server. SOAP (Simple Object Access Protocol) specifies how we should format requests to the server, and how the server should format its responses. In theory, we could use other service invocation languages (such as XML-RPC, or even some ad hoc XML language). However, SOAP is by far the most popular choice for Web Services.
- *Transport:* Finally, all these messages must be transmitted somehow between the server and the client. The protocol of choice for this part of the architecture is HTTP (HyperText Transfer Protocol), the same protocol used to access conventional web pages on the Internet. Again, in theory we could be able to use other protocols, but HTTP is currently the most used one.

As a matter of fact, environmental modeling services have to be grid-enabled in order to be used in the Grid. Grid-enabling a part of software has become known under the term “gridification” (Lee & Percivall, 2009). Aspects of gridification are making use of grid computing standards like the Web Services Resource Framework (WSRF) to develop stateful grid services, and to submit computationally intensive tasks into a computing cluster. In recent years there have been a few efforts to provide SOAP/WSDL interfaces for OGC Web Services (OWS) as parts of the standards. “Modeling services shall be implemented as OWS, so gridification includes harmonizing or adapting the interface to the WSRF” (Kurzbach, Pasche, Lanig, & Zipf, 2009).

7.1.1 SCIER Web Services at a Glance

In the project SCIER, NKUA, as a key partner in software development, performed an outstanding preparation to come up with the best communication tool (Hadjiefthymiades, et al., 2008). After the author’s contribution to the project, the project team agreed on performing all computational integration based on web services namely

WSDL. Since there was not enough time and resources to put GIS directly into the GRID environment, it was simply decided to keep communication with web services. Probably the most important step was the formulation of the right computational interfaces and methods to force two different tools speaking the same language. For this purpose a detailed documentation was prepared so called SCIER Models & Computing Subsystem Design and Specification (Hadjiefthymiades, et al., 2008).

Firstly let us have a look at the services published from other components of the SCIER:

A web service so called LacuManager (Figure 7-2) was responsible for publishing methods and interfaces to perform sensor-related tasks. In case you need to get sensor information, you must consume this service and call the relevant methods to get results.

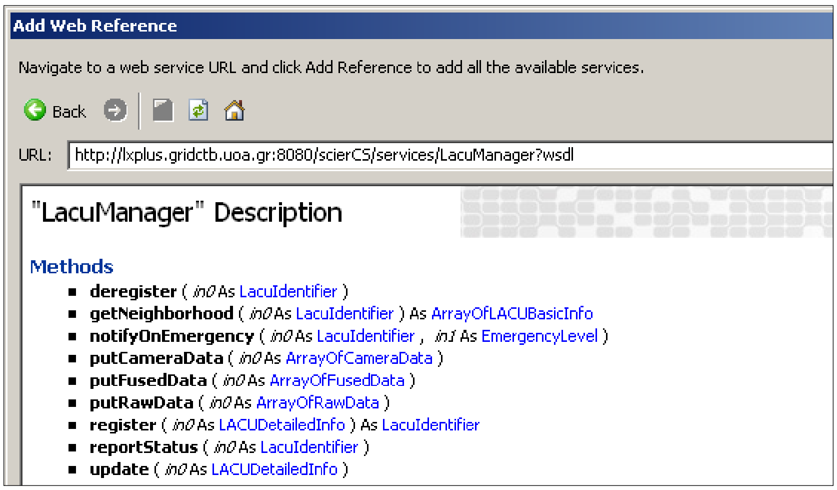


Figure 7-2: The Web Service LacuManager from GRID Environment.

Another web service provided by the GRID in SCIER was called DSManager which was responsible for all data stored in GRID databases. DSManager has the most vital information to perform environmental modeling tasks.

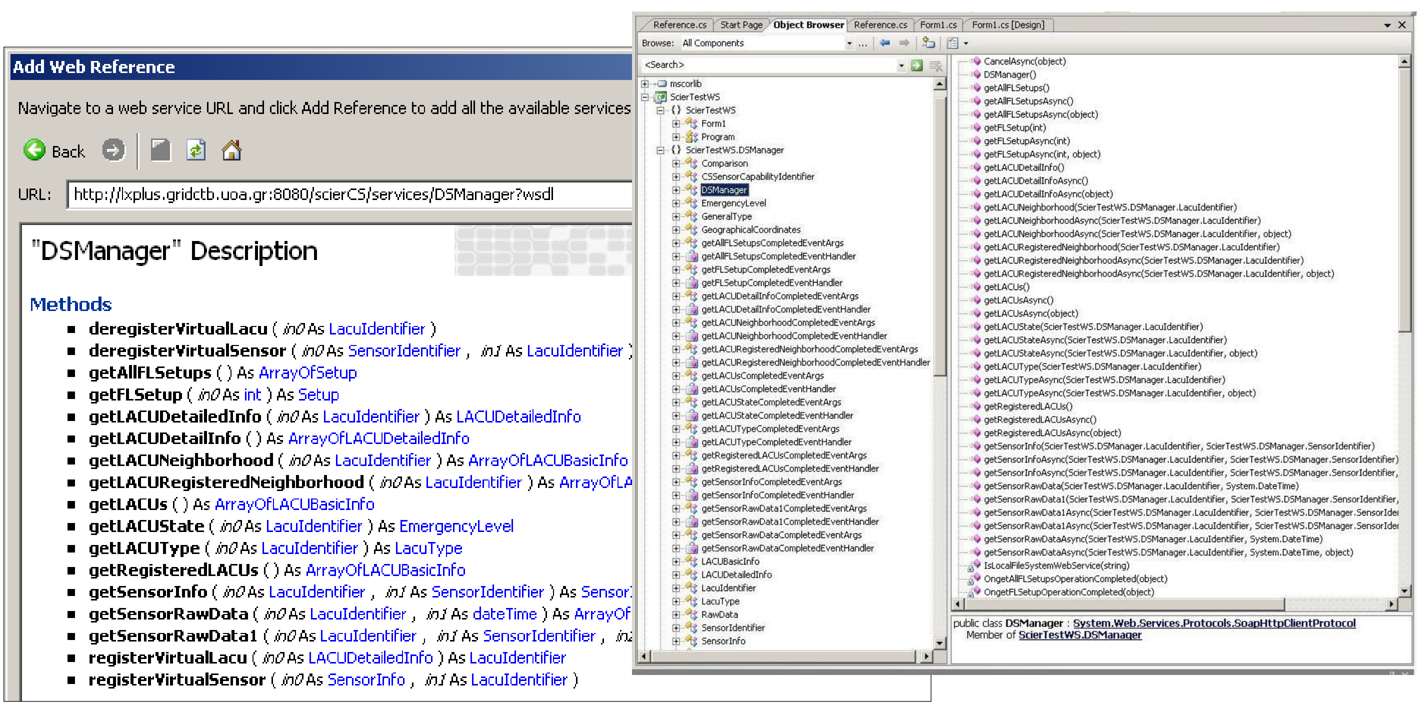


Figure 7-3: The Web Service DSManager from GRID Environment.

The key web service for the flood modeling is the SimulationInterface (SIF) which doesn't work in the GRID environment. This unique service is developed and deployed by the SCIER partner DHI. When we want to trigger a flood simulation, we consume this service to reach GRID environment to receive sensor information. And the result of the simulation actually carried by the method *floodSimulationFinishedCallBack.*

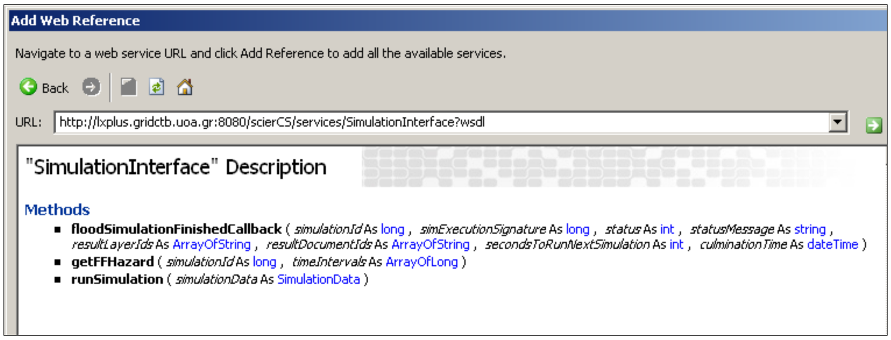


Figure 7-4: The Web Service SimulationInterface from DHI.

7.1.2 Web Services from SCIER-GIS

According to the specifications described in the project documentation, SCIER-GIS was designed to be able to serve WSDL capable methods and interfaces. In addition it is able to consume web services provided by the GRID environment of SCIER. In this chapter, the detailed explanation of the web service developed within the SCIER-GIS will be given. The computational requirements fulfilled (Ertac & Aigner, 2008) in a relatively short period of time during the lifetime of the project. Here the services will be also briefly presented which were published from the GRID. The content of the services will be widely given in following chapters which will describe the web applications developed for flood and forest fire modeling.

The crucial web service which is developed within the SCIER-GIS module is called UpdateService. UpdateService has all capabilities to publish required data for the other project components. Although the fire modeling application will be deeply investigated in the following chapters, it's important to mention that UpdateService serves required model inputs. The data within the physical boundary (Bounding Box) are prepared by the SCIER-GIS according to the user request. This web service's task is to publish SOAP methods to retrieve model input. GRID can easily consume this service to trigger a fire model.

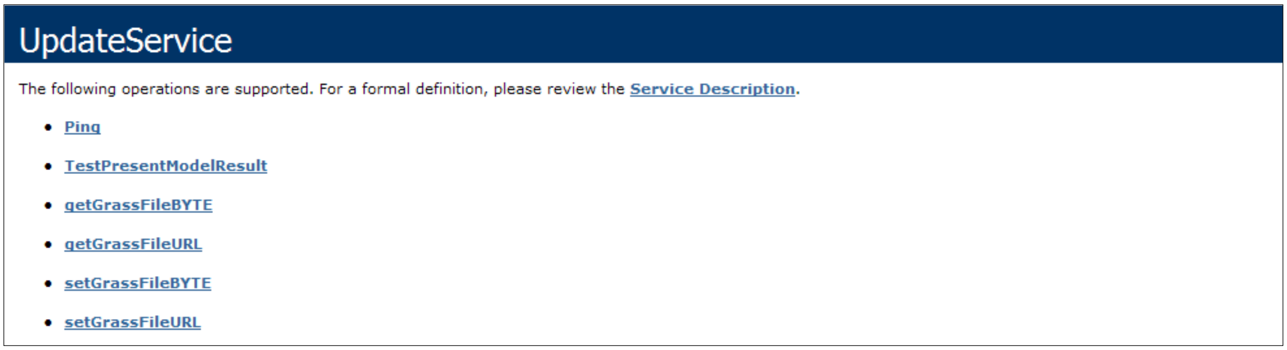


Figure 7-5: The Web Service developed within the GIS Module

If we have a closer look in the methods published here, you can see a method called *getGrassFileByte* (Figure 7-6). This method retrieves a file in grass ascii format for the rectangular area from lowerLeft corner to upperRight one. The type of data that the file contains is determined by the type parameter (Hadjiefthymiades, et al., 2008). It describes the parameters like *lowerLeft: GeographicalCoordinates*, *upperRight: GeographicalCoordinates*, which defines the bounding box for the fire modeling area. On the other hand, *setGrassFileByte* (Figure 7-7) method helps SCIER-GIS to retrieve results from the fire model in GRID. All the methods used in this web service will be explained in use cases in the following chapters.

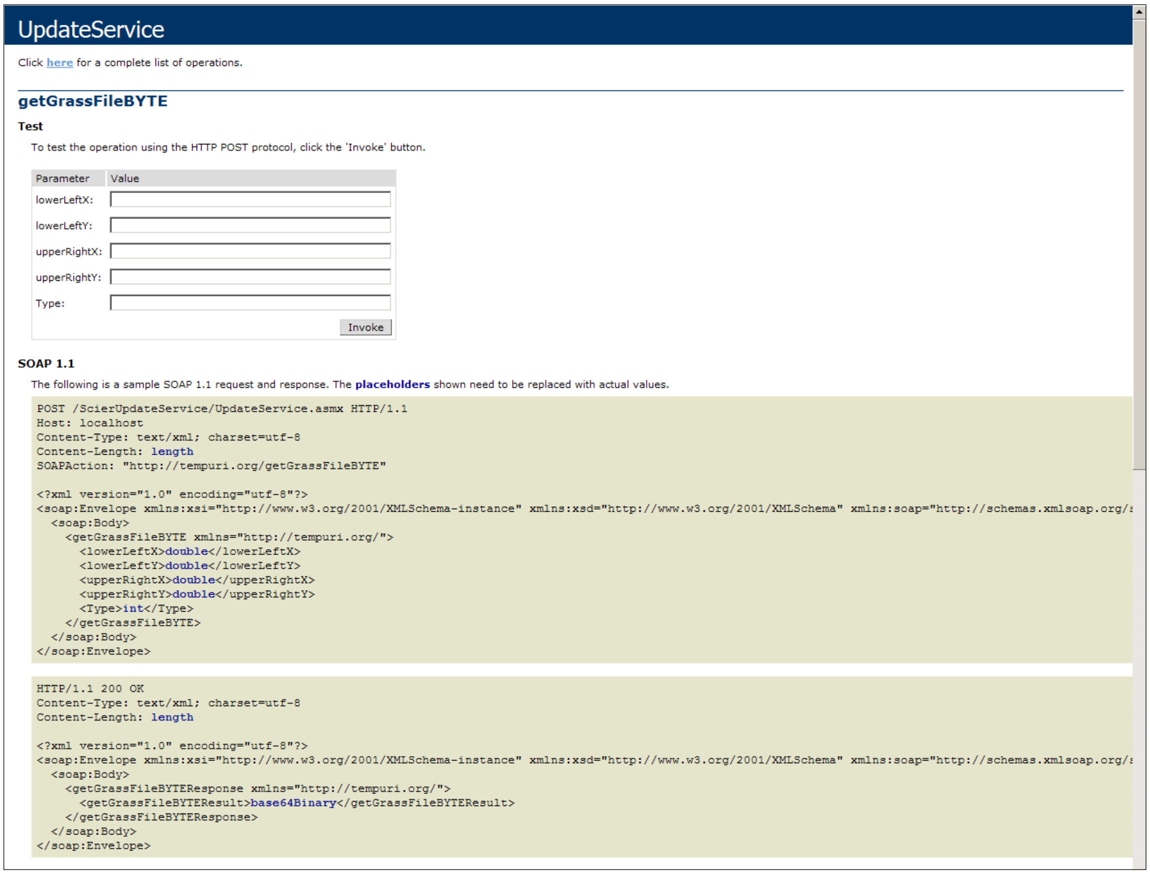


Figure 7-6: *getGrassFileByte* method in detail.

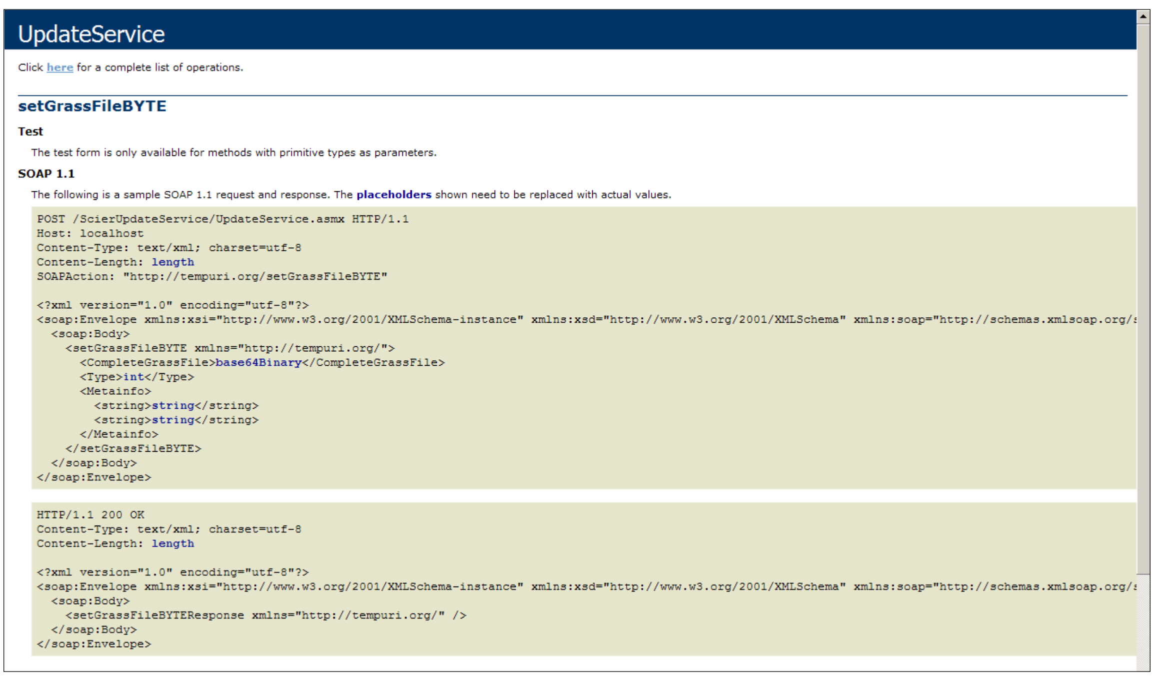


Figure 7-7: *setGrassFileByte* method in detail.

7.2 SCIER-GIS Data Management

SCIER GIS Module requires geographical data for visualization and geo-processing purposes. In this sense, all relevant partners – DHI, Nagref and Tecnoma – provided a large number of geo-spatial data to meet main requirements for the best cartographic production while delineating the model results. For the web-GIS application, three different investigation areas have been chosen which are Czech (Becva), Spanish (Catalonia) and Greek (Stamata) test areas. Becva test region is investigated for the flood modeling, while Catalonia and Stamata is prepared for the fire modeling purposes.

7.2.1 Data for Flood Modeling

DHI submitted a data package covering the Czech test area within 4 folders, which have the following content (Table 7-1):

Name	Fields	Content
all.shp	CAD export: ID, Level, Layer, color, etc…	Stream network
all_k.shp (Figure 7-8)	CAD export: ID, Level, Layer, color, etc…	Street network
all_o.shp (Figure 7-9)	CAD export: ID, Level, Layer, color, etc…	Buildings.
Landuse	CAD export: ID, Level, Layer, color, etc…	Land-use information
Land_use_all.shp	Typ, katastr, okres…	Land-use information

Table 7-1: The data package covering the Czech test area (Schaller & Ertac, 2008).

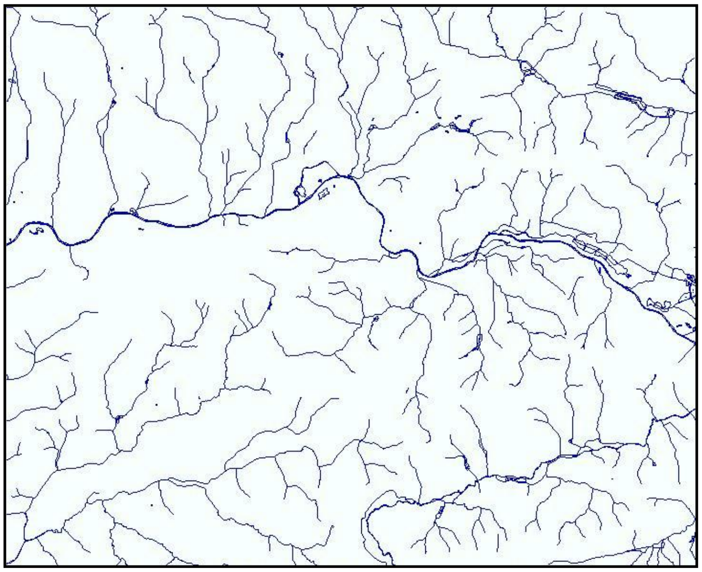


Figure 7-8: Stream Network (Provided by DHI)

Figure 7-9: Buildings (Provided by DHI)

Pre-calculated output data of the flood modeling – delineated by the flood simulation engine of DHI – were also delivered (see chapter 5.1). The folder consists of fifteen .dxf files as polyline feature type. After the delivery, they are all converted to polygon in ArcGIS environment (Figure 7-10).

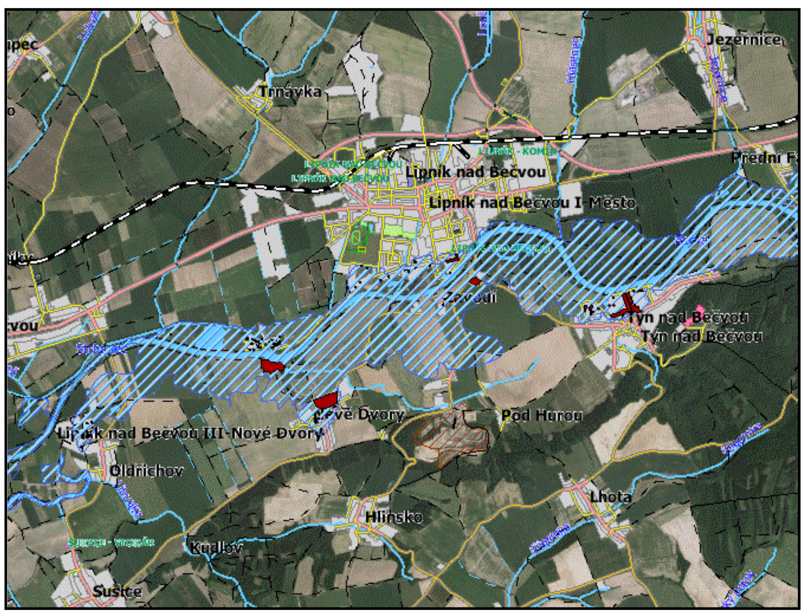


Figure 7-10: Output data of the flood modeling (Provided by DHI)

Other data delivered by DHI are;

- Scanned cadastral maps in .tif format. In tiles and all-in-one.
- A tile of orthophoto images.

7.2.2 Data for Forest Fire Modeling

SCIER Project partners, Tecnoma and Nagref provided a dataset that contains the crucial data package for the investigation area from Spain and Greece. These data don’t only consist of basemaps required but also model input data like moisture, slope and fuel maps, and wind directions. The following list presents the data from the investigation areas from Spain and Greece:

- Administrative borders and residential areas (Figure 7-11),

- Aspect map in raster format,
- Road network in shapefile format,

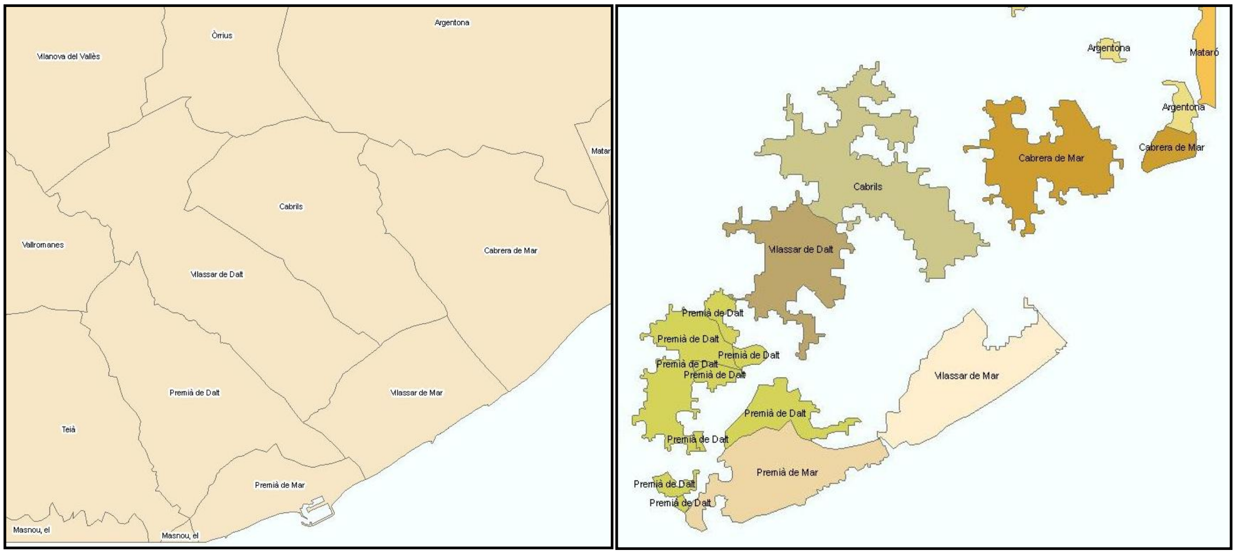


Figure 7-11: Administrative borders and residential areas (Provided by Tecnoma).

Input data for the Fire Spread Engine (Figure 7-12):

- 2 different fuel maps in raster format,
- Moisture map,
- Slope raster,
- Wind directions.

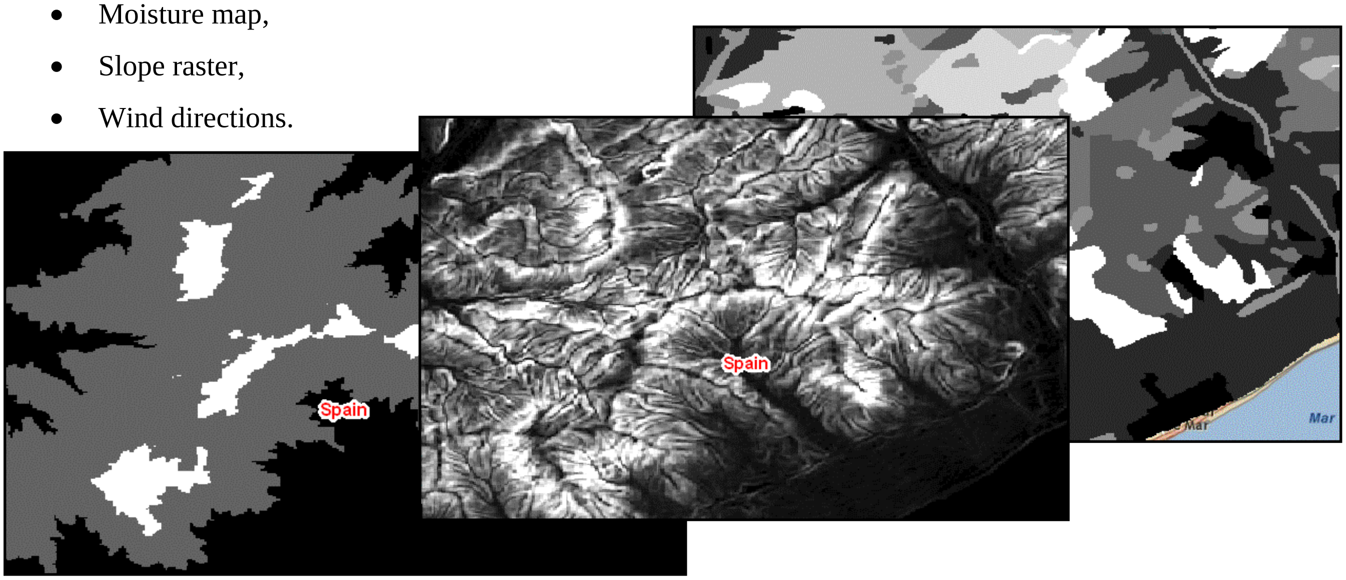


Figure 7-12: Some of the input data for the fire spread engine (Provided by Tecnoma).

- Two different masks to define the investigation areas.
- ESRI ArcGIS Online™ World Street Map© (ESRI, 2008) is used as a basemap at the Forest Fire Web User Interface (Figure 7-13). All the fire modeling tasks and the input data has been overlayed on this basemap. Officially this worldwide street map presents highway-level data for the world and street-level data for the United States, Canada, Japan, Southern Africa, and a number of countries in Europe and elsewhere. This comprehensive street map includes highways, major roads, minor roads, railways, water features, administrative boundaries, cities, parks, and landmarks, overlaid on shaded relief imagery for added context.

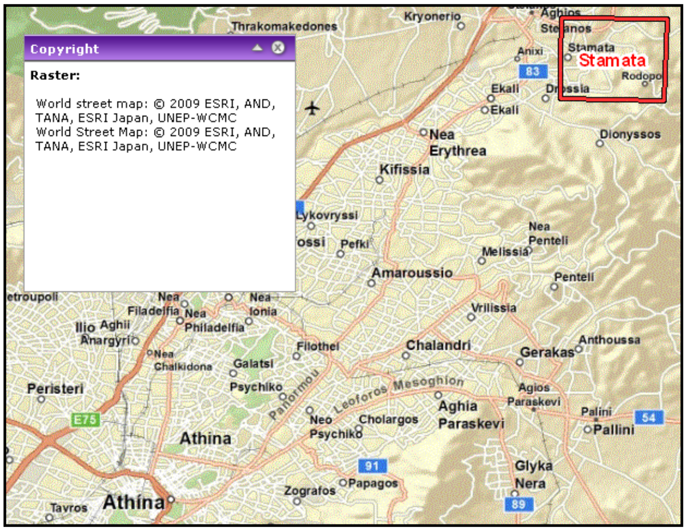


Figure 7-13: ESRI ArcGIS Online™ World Street Map© as a basemap at the Forest Fire Web User Interface

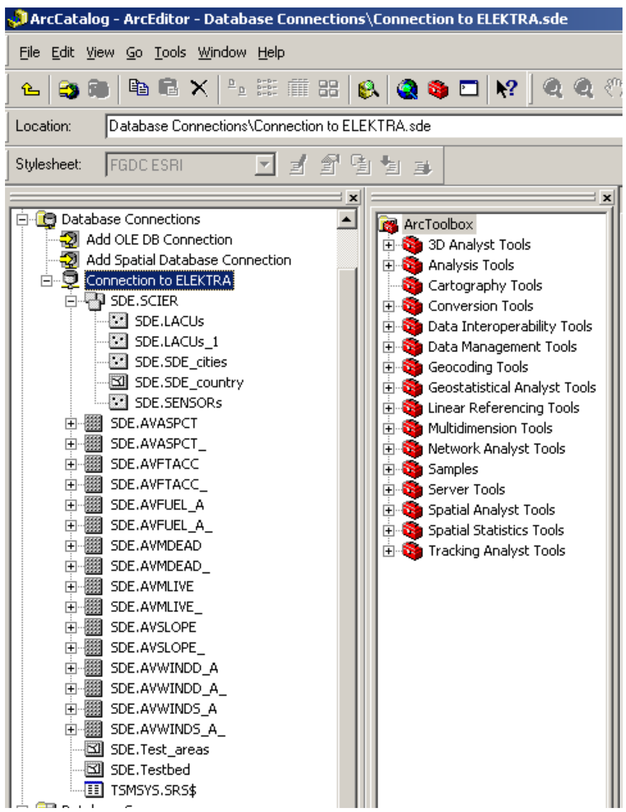


Figure 7-14: Geospatial data stored in the SCIER-GIS server.

7.2.3 Data Projection

All data acquired has been processed to get the most accurate and interoperable data storage within the SCIER GIS Module. So that coordinate system was set for each data received. For these conversion tasks ArcGIS desktop application – ArcMap – has been used.

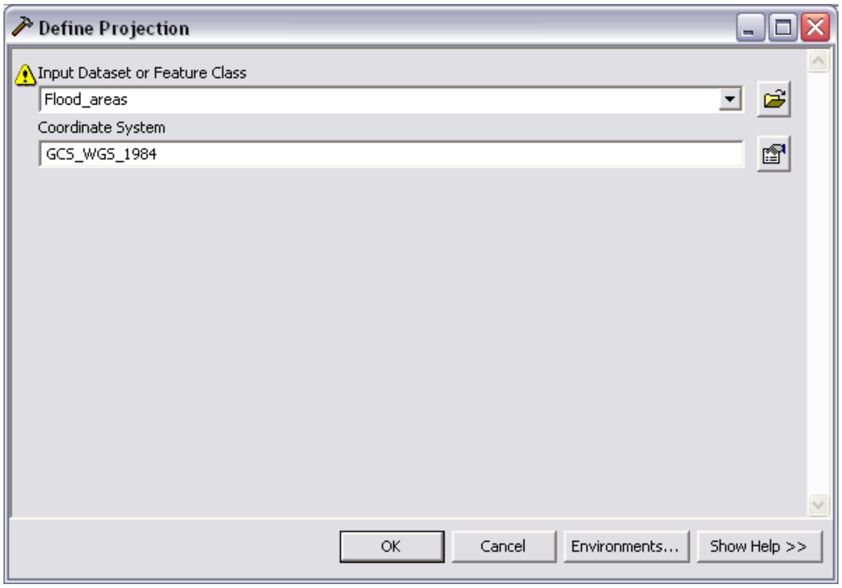


Figure 7-15: “Define Projection” tool from ArcGIS.

A sample projection file is created below:

“PROJCS["GCS_WGS_1984",GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]],PROJECTION["Transverse_Mercator"],PARAMETER["False_Easting",500000.0],PARAMETER["False_Northing",0.0],PARAMETER["Central_Meridian",3.0],PARAMETER["Scale_Factor",0.9996],PARAMETER["Latitude_Of_Origin",0.0],UNIT["Meter",1.0]]“

7.3 Web-GIS Programming Environment in the GIS Module

The SCIER-GIS web applications consist of a collection of different components that had to be developed for this purpose. The SCIER-GIS web application prototypes are developed in C# with .NET Visual Studio 2005. In each user interfaces there is a full integration of the ArcGIS Server libraries and .Net Web ADF with their functions.

The ArcGIS Web Application Developer Framework (ADF) for the Microsoft .NET Framework enables us to integrate GIS data and capabilities into the Web applications. The ADF includes a set of Web controls, classes, frameworks and APIs which are used to build the SCIER Web applications. The Manager, an administrative Web application, is included within the ArcGIS Server, guides through a comprehensive Web application designer to generate a web site. Alternatively, the web application had been realized in Visual Studio with the Web Mapping Application template, which offers basic map display, navigation, and interactive capabilities.

“The Web ADF is built on top of the Microsoft .NET 2.0 Framework and leverages many capabilities provided with ASP.NET 2.0 such as the callback framework and embedded resources. The diagram below highlights the primary components and their basic relationships in the Web ADF (Figure 7-16). There are four distinct sections to consider: Web controls, Task framework, Common Data Source API, and Web ADF graphics and consolidation classes. All sections work in conjunction with one another” (ESRI, 2009). Most of the Web ADF components reside solely on the SCIER Web server. At runtime some client-side support content, such as Web ADF JavaScript libraries, will be loaded by the browser. A set of data sources supported precisely by the Web ADF are included for reference, but are not required for the Web ADF to be utilized. Depending on the data source, Web ADF JavaScript may be able to take advantage of browser technologies to interact directly with data source result and content, such as accessing a map image available via a public virtual directory which is needed for the SCIER-GIS applications.

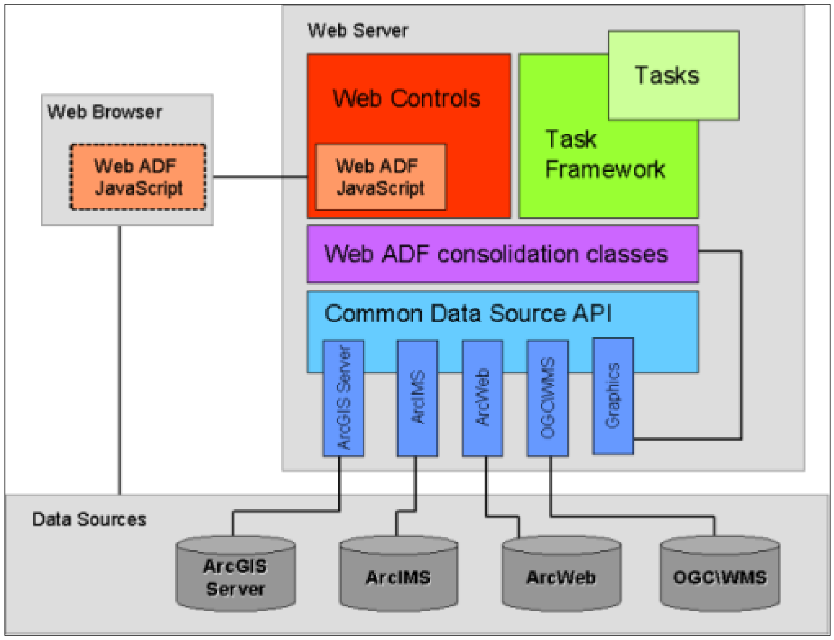


Figure 7-16: The ArcGIS Web Application Developer Framework (ADF) for the Microsoft .NET Framework (ESRI, 2009)

The functional requirements of the SCIER Web User Interface are realized in form of tasks which are defined by the SCIER processes. Functionality and GUI are defined by Web controls and tasks.

A set of assemblies are included with the Web ADF which contain tangible components associated with each section. The following diagram highlights the standard nomenclature for the Web ADF assemblies used for the SCIER Web System development.

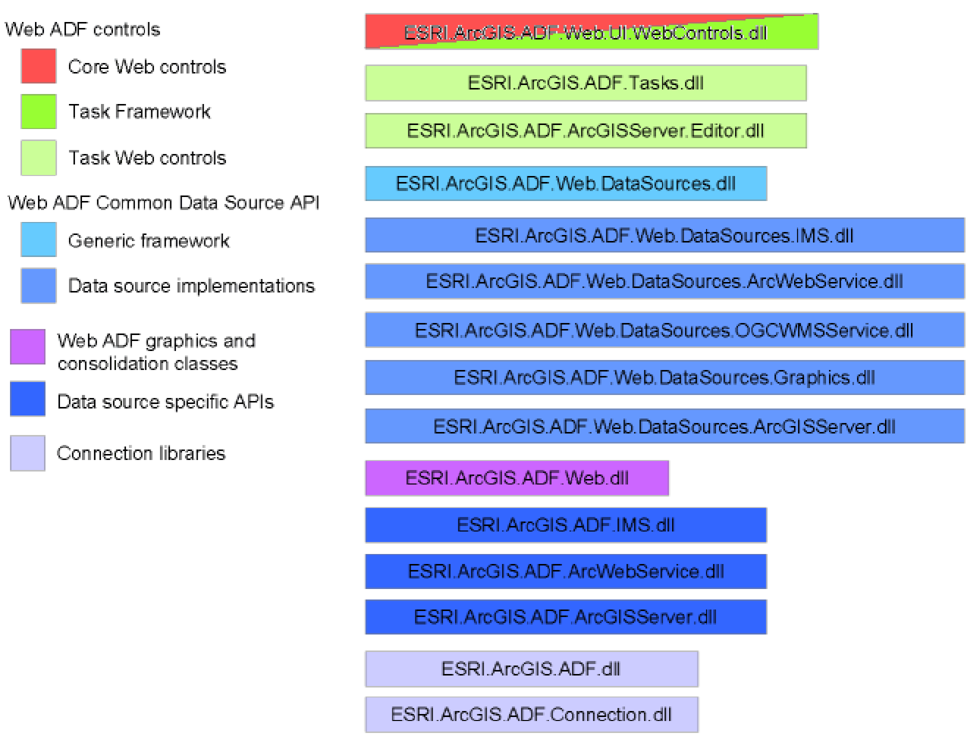


Figure 7-17: The standard nomenclature for the Web ADF assemblies (ESRI, 2009)

The standard terminology for "the Web ADF assemblies" (ESRI, 2009) is given as follows:

7.3.1 Web Controls

The Web ADF includes a set of AJAX (asynchronous JavaScript and XML) enabled Web controls that extend the ASP.NET 2.0 architecture (see Figure 7-18). The Web controls utilize a set of JavaScript libraries to process asynchronous interaction between browser and Web application components as well as remote resources. By default, Web ADF JavaScript libraries are embedded in the Web ADF control assemblies. Each Web ADF control supports AJAX via the ASP.NET 2.0 Callback framework. State between the client browser and the Web application on the server is maintained using Web ADF CallbackResults. The CallbackResults class is designed to store Callback strings in a format that can be processed by Web ADF JavaScript to update browser content dynamically (Garrett, 2005; EDN, 2008).

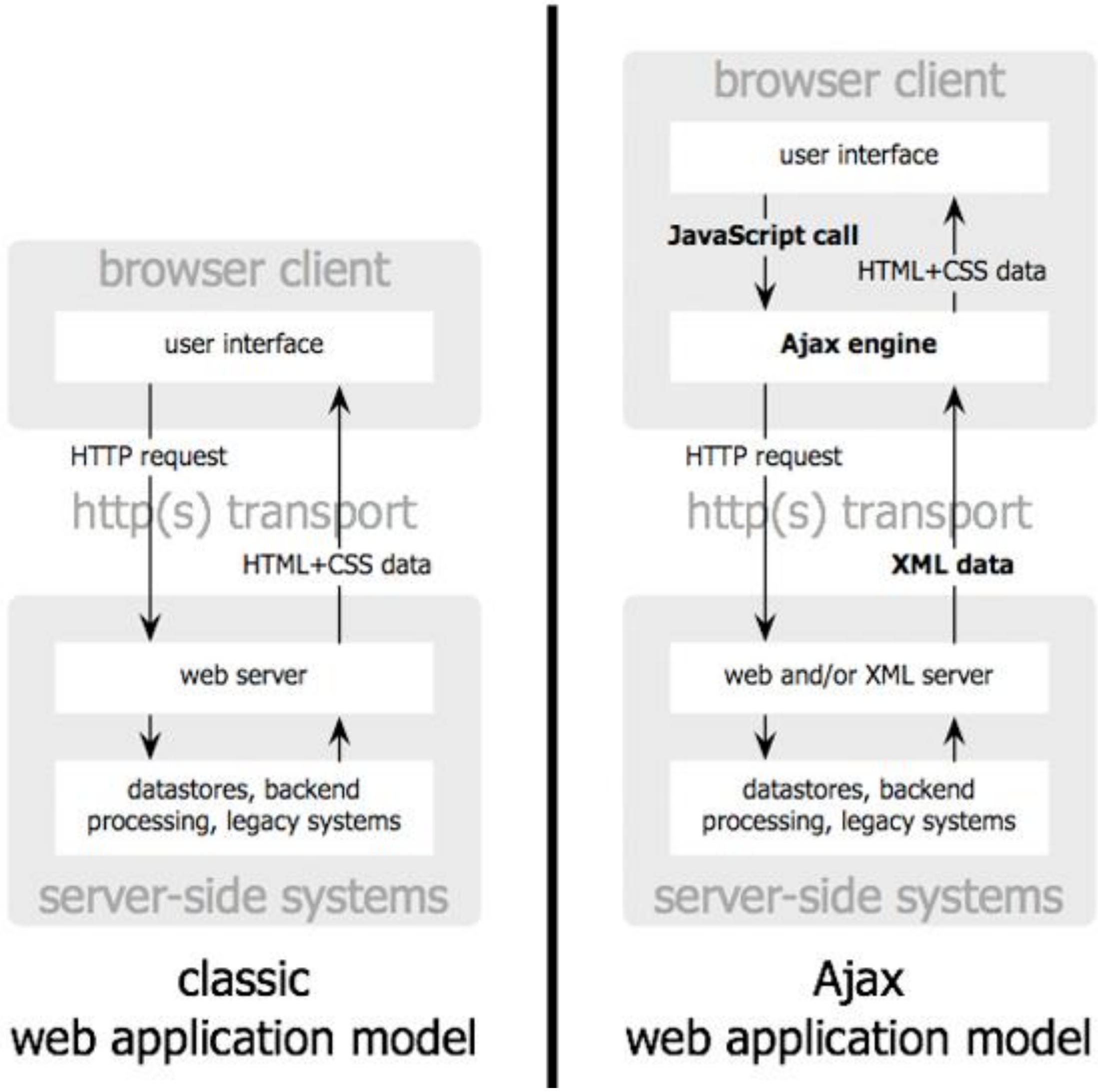


Figure 7-18: The traditional model for web applications compared to the Ajax model (Garrett, 2005)

The ESRI.ArcGIS.ADF.Web assembly contains namespaces with classes, interfaces, and enumerations for working with the Web ADF. These classes are used by the Web controls in ESRI.ArcGIS.ADF.Web. UI.WebControls in displaying and interacting with GIS data and maps.

Namespace	Description
ESRI.ArcGIS.ADF.Web	contains common and utility classes and enumerations used by other namespaces in the ESRI.ArcGIS.ADF.Web assembly.
ESRI.ArcGIS.ADF.Web.Display.Graphics	contains classes for managing and displaying dynamic graphics layers in a Map control and a MapResourceManager.
ESRI.ArcGIS.ADF.Web.Display.Renderer	contains classes, interfaces and enumerations for rendering layers in a Map control. Rendering translates the map data into a visible representation on the map. Renderers can display all features in a layer the same way, and with different symbols depending on values of an attribute field or at certain map scales.
ESRI.ArcGIS.ADF.Web.Display.Swatch	contains classes that the Web controls, especially the table of contents (TOC) control, uses to create swatches for map legends.
ESRI.ArcGIS.ADF.Web.Display.Symbol	contains classes for displaying symbols for features in a map layer. Currently these are used only for graphics layers.
ESRI.ArcGIS.ADF.Web.Geocode	contains utility classes used in performing geocoding in the Web ADF.
ESRI.ArcGIS.ADF.Web.Geometry	contains classes used to represent feature geometry. These are used for graphics layers, such as when features are retrieved when querying a map layer and then drawing the returned features on a graphics layer on the Map.
ESRI.ArcGIS.ADF.Web.SpatialReference	contains classes for working with projections (coordinate systems) of map resources. The SpatialReference class defines the projection of a resource by means of its CoordinateSystem property. This property accepts one of several types in this namespace that extend SpatialReferenceInfo.

Table 7-2: ESRI.ArcGIS.ADF.Web assembly with namespaces and descriptions for working with the Web ADF (EDN, 2008).

7.3.2 Task Framework

The SCIER-GIS's Task Framework is an extensible architecture by which a developer can integrate and deploy custom functionality as "Web tasks" within a Web ADF application. In general, a "Web task" is a Web control that encapsulates a set of related actions to generate results. It is a modular component that can be distributed and "plugged into" Web ADF applications via Visual Studio or the ArcGIS Manager application. The task framework provides the ability to effectively integrate a custom Web task into the Web ADF and Manager.

Namespace	Description
ESRI.ArcGIS.ADF.Tasks	Contains task controls and related classes for using tasks.
ESRI.ArcGIS.ADF.Tasks.Design.Designers	Contains designers used for setting properties of tasks at design time in Visual Studio.
ESRI.ArcGIS.ADF.Tasks.Design.Editors	Contains forms used when setting properties for tasks at design time in Visual Studio.
ESRI.ArcGIS.ADF.Tasks.Geoprocessing	Utility classes for running geoprocessing tasks.

Table 7-3: ESRI.ArcGIS.ADF.Tasks assembly with namespaces and descriptions for working with the Web ADF (EDN, 2008).

Note that, "tasks in this assembly include FindAddress Task, FindPlace Task, Geoprocessing Task, Query AttributesTask, SearchAttributesTask, and EditorTask. All but EditorTask are in ESRI.ArcGIS.ADF.Tasks. The base classes used in tasks are located in ESRI.ArcGIS.ADF.Web.UI.WebControls" (ESRI, 2009).

7.3.3 Common Data Source API

The SCIER-GIS is designed to support data from multiple sources, including ArcGIS Server and OGC Standards which is a basic requirement of future SCIER applications extended to large areas within the European Union. The multi-source of this architecture allows integrating and interacting with data from different sources at the same time, in the same application. To accomplish this, the Web ADF needs a common framework in which data sources can be integrated with Web ADF components. This framework is the Common Data Source API, or in short, the Common API.

Namespace	Description
ESRI.ArcGIS.ADF.Web.DataSources	contains interfaces, classes and enumerations for implementing and consolidating the use of data sources within the Web ADF. These interfaces are implemented to define the capabilities of a data source as a resource in the Web ADF.
ESRI.ArcGIS.ADF.Web.DataSources.Exceptions	Contains exceptions that may be thrown when using a data source.

Table 7-4: ESRI.ArcGIS.ADF.Web.DataSources assembly with namespaces and descriptions for working with the Web ADF (EDN, 2008).

The Common API consists of a set of classes and interfaces in the ESRI.ArcGIS.ADF.Web.DataSources.dll assembly. These classes and interfaces make up the generic framework that Web ADF controls use to interact with different data sources in a common way (thus "Common" API). A set of data sources are supported including ArcGIS Server, ArcIMS, ArcWeb, OGC\WMS, and Web ADF graphics datasets. Each Common API implementation is contained within a separate assembly included with the Web ADF (ESRI, 2009).

7.3.4 Web ADF Graphics and Consolidation Classes

Different sources of data can be combined and utilized in a common way (Common API) in the SCIER-GIS. As a result, the Web ADF includes a set of components designed to support and enhance working with multiple resources in the Web-tier. Most of these components reside in the ESRI.ArcGIS.ADF.Web.dll assembly (EDN, 2008). The Web ADF includes a set of geometry types, renderers and symbols to manage and display graphic elements in Web ADF graphics layers. Since Web ADF graphics capabilities are managed in the Web-tier and a Common API implementation is provided, they can be integrated and utilized as map resources. Web ADF graphics help the SCIER-GIS Web-mapping Interface to manage selected features, dynamic data, and custom feature data sources.

Namespace	Description
ESRI.ArcGIS.ADF	includes enumerations and utility classes used throughout the Web ADF.
ESRI.ArcGIS.ADF.BaseClasses	contains abstract classes that may be used to construct new custom classes that work with the Web ADF.
ESRI.ArcGIS.ADF.COMSupport	contains utility classes for working with COM and .NET in the Web ADF.
ESRI.ArcGIS.ADF.Web.DataSources.Graphics	contains classes that implement interfaces in ESRI.ArcGIS.ADF.Web.DataSources. These enable working with dynamic graphics-layer data sources in the Web ADF.
ESRI.ArcGIS.ADF.Web.DataSources.Graphics.Design	ESRI.ArcGIS.ADF.Web.DataSources.Graphics.Design contains classes for setting properties of graphics data sources at design time in Visual Studio.

ESRI.ArcGIS.ADF.Web.UI.WebControls	ESRI.ArcGIS.ADF.Web.UI.WebControls contains most of the Web controls for the Web ADF. It also has related support classes, interfaces, etc.
ESRI.ArcGIS.ADF.Web.UI.WebControls.Design.Editors	ESRI.ArcGIS.ADF.Web.UI.WebControls.Design.Editors contains editor forms used in setting properties of Web controls at design time in Visual Studio.
ESRI.ArcGIS.ADF.Web.UI.WebControls.RenderingEngine	ESRI.ArcGIS.ADF.Web.UI.WebControls.RenderingEngine contains classes that assist with rendering the ADF Web controls on the page.
ESRI.ArcGIS.ADF.Web.UI.WebControls.Tools	ESRI.ArcGIS.ADF.Web.UI.WebControls.Tools contains interfaces and classes for tools tied to a Map control, which the user interacts with on the Map.

Table 7-5: ESRI.ArcGIS.ADF graphics assembly with namespaces and descriptions for working with the Web ADF (EDN, 2008).

Other sections of the Web ADF rely on the Web ADF graphics and consolidation classes to do work and interact with one another. The Map control needs to maintain a spatial reference and define display settings for a map resource to generate a map image. A task control may use task results to display graphics on a map with Web ADF graphics layers. A developer may use the generic interfaces of the Common API to execute a query using a spatial filter composed of Web ADF geometry. In addition, a set of Converter classes are included in the Web ADF to provide convenient methods for converting between client, Web ADF and data source specific data types. In a true consolidation environment such as the Web ADF, managing the translation of information between application tiers and source types is essential to maximizing usability.

7.4 Web-GIS Implementation for Flood Modeling

The figure below (Figure 7-19) shows the web user interface of the SCIER flood simulation which is publicly available online. The selected test area is Becva, in Czech Republic. The window is split into two parts: On first part there are available components to start a flood simulation. Accordingly it's called "Run Simulation". In this part user can select the test area with choosing a simulation setup. He/she can select the time interval to run a simulation as well. The simulation result window consists of two subdivisions in which a map view (and the tabular data available to give model results. The map view has the state-of-the-art web-mapping functionalities which gives user a clear representation of the effected areas. A toolbar with several functions is available for navigational purposes, such as zoom in and pan. A legend is also available to clarify the map content. A scale bar helps to meet visualization requirements as well.

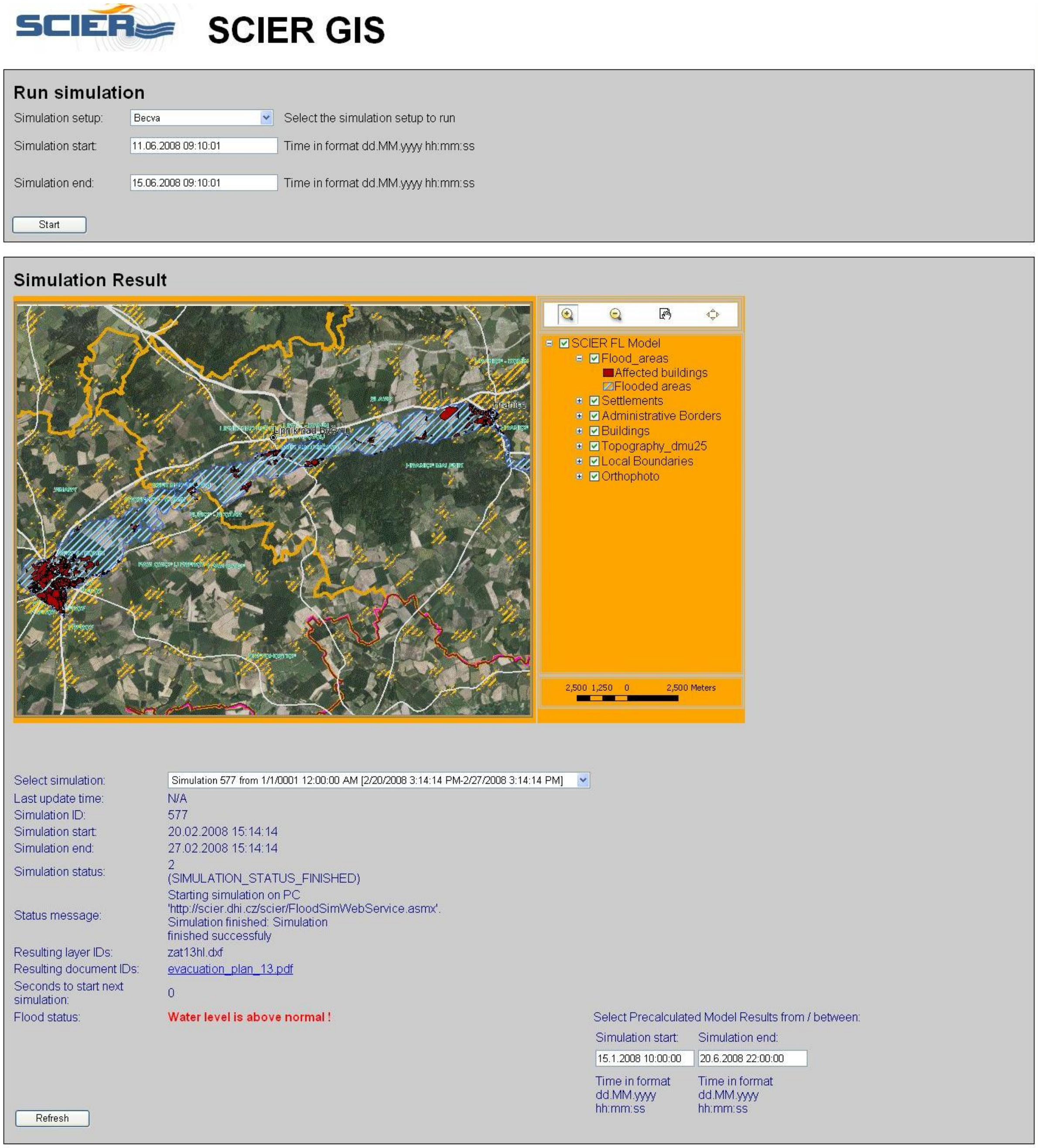


Figure 7-19: The SCIER-GIS Web User Interface for Flood Modeling (DHI, Aigner, & Ertac, 2008).

7.4.1 GIS Module and the Flood Model Integration

This particular simulation model is executed outside the GRID infrastructure. In fact the server environment was located in the DHI premises devoted to run flood model. Communication between the GRID and the aforementioned flood server is established through the SOAP Web Services (see Section: An Innovative Approach in GIS and GRID Integration). Input and output files are transferred via regular Web services protocols. Following figure (Figure 7-20) gives the detailed workflow for flood modeling. All related information will be given step by step.

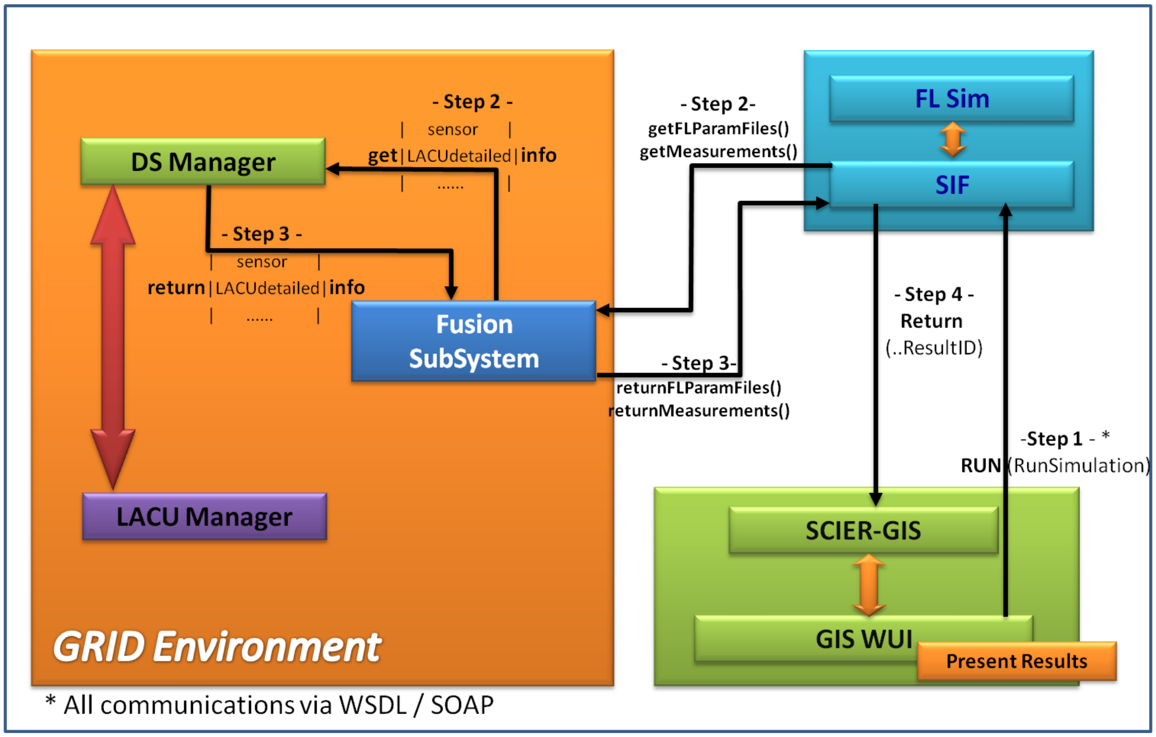


Figure 7-20: Flood Modeling (FL) Workflow

7.4.1.1 Step 1

In the first phase of the model run, the model can be triggered via Web-GIS application (GIS WUI). When the user gives the required time parameters and clicks *RUN*, GIS consumes specific methods in the SIF web service.

In the following code you can see the background of the “Start” button in the flood modeling interface (Figure 7-19) which has a real-time web-service connection with SIF to run a simulation (This code is developed with the cooperation of DHI):

```
    protected void _buttonSifInvoke_Click(object sender, EventArgs e)
    {
        try
        {
            // invokes the simulation by connecting to SIF in DHI
            SIF.SimulationInterface sifWs = new SIF.SimulationInterface();
            sifWs.Url =
"http://dxplus.gridctb.uoa.gr:8080/scierCS/services/SimulationInterface";

            SIF.SimulationData simData = new SIF.SimulationData();
            simData.setupId = 1;
            simData.setupIdSpecified = true;
            simData.simulationType = 2;
            simData.simulationTypeSpecified = true;
```

```
            simData.startTime = DateTime.Parse(_textSifSimulationStart.Text,
      _culture);
            // Sets the date parameters
            simData.startTimeSpecified = true;
            simData.endTime = DateTime.Parse(_textSifSimulationEnd.Text, _culture);
            simData.endTimeSpecified = true;
            simData.timeoutSeconds = 300;
            simData.timeoutSecondsSpecified = true;
            simData.forceRun = true;
            simData.forceRunSpecified = true;

            sifWs.runSimulation(simData);

            // Informs user if the simulation triggered in success
            _labelSifStatus.Text = "Simulation invoked successfuly";
            _labelSifStatus.ForeColor = Color.Green;
        }
        catch (Exception ex)
        {
            _labelSifStatus.Text =
HttpUtility.HtmlEncode(ex.ToString()).Replace("\n", "<br />");
            _labelSifStatus.ForeColor = Color.Red;
        }
    }
```

7.4.1.2 Step 2

When SIF receives the call of the GIS, immediately communicates with GRID environment via Fusion Subsystem to get required parameters from the field sensors. DSManager delivers the requested information by contacting LACU Manager (responsible for real-time sensor information).

7.4.1.3 Step 3

DSManager returns all relevant information via Fusion SubSystem to the SIF. So that SIF can trigger the simulation in flood modeling engine (FL Sim).

7.4.1.4 Step 4

At the last step SIF returns the result with a layer identification code (SLAYERID). Measurements on water level and flow at defined locations are checked against a pre-set threshold values. If threshold values are exceeded, the warning routine is switched on. Simulations are executed and a prediction on water level and flow is accomplished. For each level of the water height a pre-calculated map is defined, which depicts the extent of the phenomenon for this particular level. Measured values of water level give maps which depict the actual situation while predicted values give maps which visualize the flood evolution in the short term. These maps are stored the GIS module to be visualized in Web-GIS application (Metelka, Caballero, & Kirklis, 2008). As you can see in the following figure, the SLAYERIDs are the unique codes for this pre-calculated flood map.

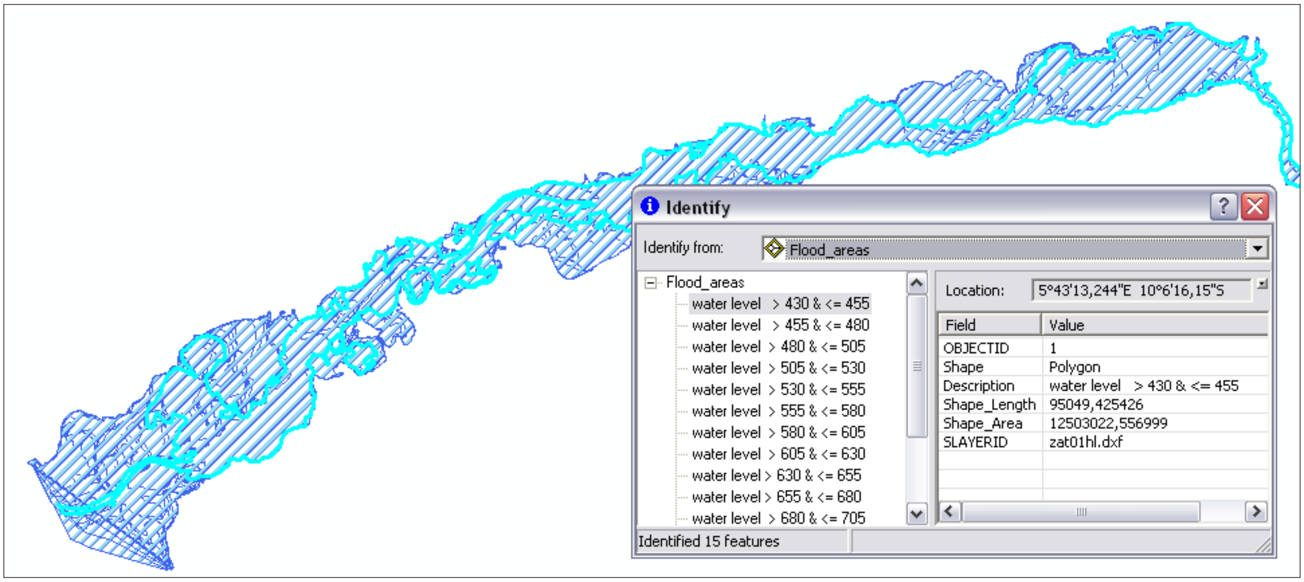


Figure 7-21: The pre-calculated flood map, Source: Deliniated by DHI using Mike11 modeling software (DHI, 2000)

OBJECTID	Description	Shape_Length	Shape_Area	SLAYERID
1	water level > 430 & <= 455	95049,42543	12503022,56	zat01hl.dxf
2	water level > 455 & <= 480	94783,5113	15602115,13	zat02hl.dxf
3	water level > 480 & <= 505	105966,5989	17172144,68	zat03hl.dxf
4	water level > 505 & <= 530	111946,0464	19549262,38	zat04hl.dxf
5	water level > 530 & <= 555	110691,0079	21165638,27	zat05hl.dxf
6	water level > 555 & <= 580	108562,771	22083556,62	zat06hl.dxf
7	water level > 580 & <= 605	112345,3189	26174497,84	zat07hl.dxf
8	water level > 605 & <= 630	103206,8479	30301921,15	zat08hl.dxf
9	water level > 630 & <= 655	100135,1651	31374839,23	zat09hl.dxf
10	water level > 655 & <= 680	99705,7676	32688754,52	zat10hl.dxf
11	water level > 680 & <= 705	97911,24663	35311977,14	zat11hl.dxf
12	water level > 705 & <= 730	88042,12603	36710118,68	zat12hl.dxf
13	water level > 730 & <= 755	84723,61341	37324715,24	zat13hl.dxf
14	water level > 755 & <= 780	85053,91268	37407993,16	zat14hl.dxf
15	water level > 780	85045,57134	37499221,89	zat15hl.dxf

Table 7-6: Attribute table of pre-calculated flood map, Source: Deliniated by DHI using Mike11 modeling software (DHI, 2000)

And the code behind the scene, receives the SLAYERID, performs the filtering on the pre-calculated flood map according to the SLAYERID and visualizes the relevant data (Geo-spatial and non-spatial). Following partial code is developed for this purpose:

```
            //Receive the resulting layer
            string layerId = null;
            if (simResultData != null && simResultData.resultLayerIds != null &&
simResultData.resultLayerIds.Length > 0)
            {
                layerId = simResultData.resultLayerIds[0];
            }

            if (layerId != null)
            {
                _labelFloodStatus.Text = "Water level is above normal !";
                _labelFloodStatus.ForeColor = Color.Red;
            }
            else
            {
                if (simResultData != null)
                {
                    _labelFloodStatus.Text = "Water level is normal, no flooding
hazard...";
                    _labelFloodStatus.ForeColor = Color.Green;
                }
                else
                    _labelFloodStatus.Text = NA;
            }
            if (layerId != null)
            {

            //After receiving the ID for the flood, following partial code was
      deployed to use ESRI Web ADF capabilities:
            //Use ESRI Web ADF tools for the web-mapping
            ESRI.ArcGIS.ADF.Web.DataSources.ArcGISServer.MapResourceBase mrb =
      (ESRI.ArcGIS.ADF.Web.DataSources.ArcGISServer.MapResourceBase)
            MapResourceManager1.GetResource(0);

            ESRI.ArcGIS.ADF.ArcGISServer.MapDescription mapdesc =
mrb.MapDescription;
            ESRI.ArcGIS.ADF.ArcGISServer.LayerDescription layerdesc =
mapdesc.LayerDescriptions[0];

            //Visualize the result map by using a method for filtering.
                layerdesc.DefinitionExpression = "SLAYERID IN ( '" + layerId +
"')";
            }
```

At the final phase an intermediate intersection code computes a geometric intersection of the input features overlap in all layers and/or feature classes is written to the output (Figure 7-22). This tool calculates the buildings in the flood zone, by deploying following code within the application:

```
// Process: find all affected buildings
gp.Intersect_analysis("Buildings; Flood_areas")
```

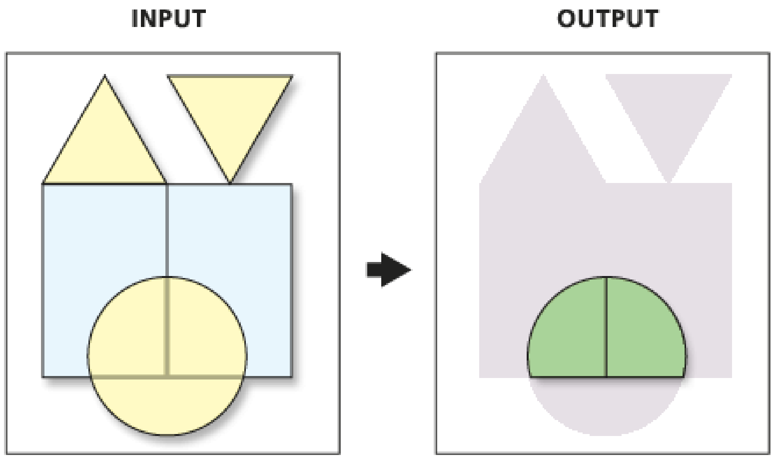


Figure 7-22: An illustration for the intersect tool.

And the result map looks exactly like in the figure below:

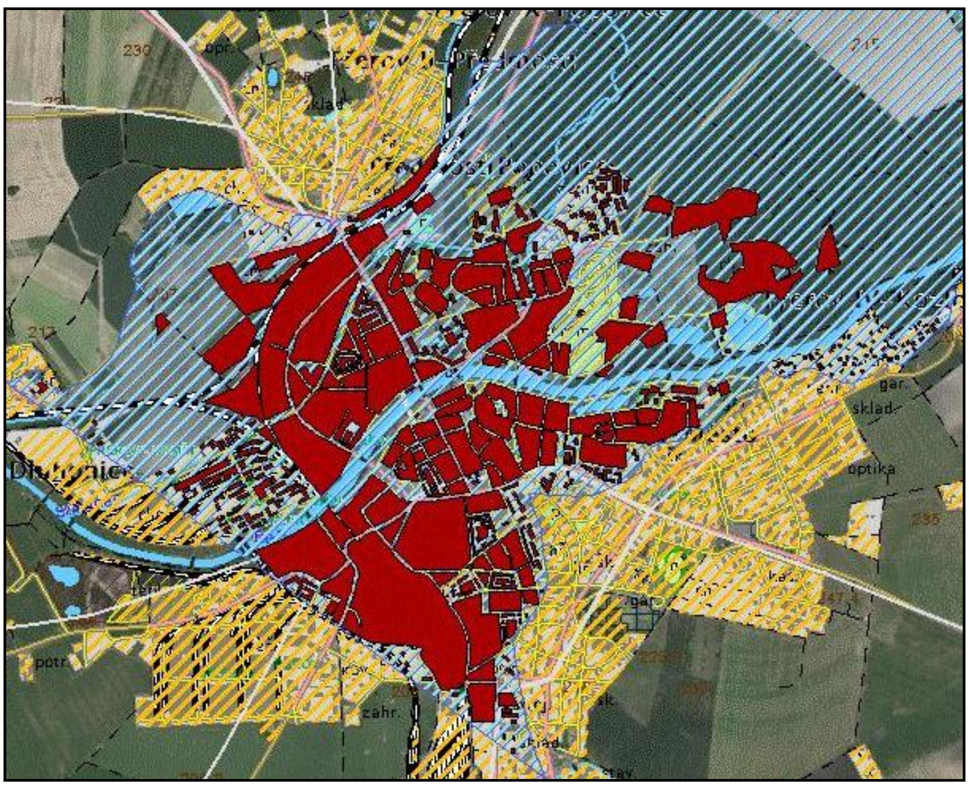


Figure 7-23: Affected buildings as the output of the intersect tool.

Finally SCIER-GIS saves the information about the simulation internally, and is then able to show the information about the simulation and resulting layers and documents to a user. The technical implementation is done as a local windows service.

When a flood model has been triggered an internal method populates the content of an XML file on the SCIER-GIS computational environment. All the configuration information necessary to store simulation output information, and also to update flood map by visualizing the simulation results, is stored in PreProcessedModelResults file. The model results file is a simple XML file of the following form:

```
<NewDataSet>
  <xs:schema id="NewDataSet" xmlns="" xmlns:xs="http://www.w3.org/2001/XMLSchema"
xmlns:msdata="urn:schemas-microsoft-com:xml-msdata">
    <xs:element name="NewDataSet" msdata:IsDataSet="true" msdata:MainDataTable="PreResults"
msdata:UseCurrentLocale="true">
      <xs:complexType>
        <xs:choice minOccurs="0" maxOccurs="unbounded">
          <xs:element name="PreResults">
            <xs:complexType>
              <xs:sequence>
                <xs:element name="startTime" type="xs:dateTime" minOccurs="0" />
                <xs:element name="endTime" type="xs:dateTime" minOccurs="0" />
                <xs:element name="forceRun" type="xs:boolean" minOccurs="0" />
                <xs:element name="setupId" type="xs:int" minOccurs="0" />
                <xs:element name="simulationId" type="xs:int" minOccurs="0" />
                <xs:element name="resultLayerIds" type="xs:string" minOccurs="0" />
                <xs:element name="status" type="xs:int" minOccurs="0" />
                <xs:element name="statusMessage" type="xs:string" minOccurs="0" />
                <xs:element name="resultDocumentIds" type="xs:string" minOccurs="0"/>
              </xs:sequence>
            </xs:complexType>
          </xs:element>
        </xs:choice>
      </xs:complexType>
    </xs:element>
  </xs:schema>
  <PreResults>
    <startTime>2008-01-18T00:00:00+01:00</startTime>
    <endTime>2008-01-22T00:00:00+01:00</endTime>
    <forceRun>true</forceRun>
    <setupId>1</setupId>
    <simulationId>598</simulationId>
    <resultLayerIds>zat2hl.dxf</resultLayerIds>
    <status>0</status>
    <statusMessage>Starting simulation on PC
    <resultDocumentIds>mydoc.pdf|otherdoc.pdf</resultDocumentIds>
  </PreResults>
.................
.................
  <PreResults>
    <startTime>2008-05-31T13:49:17+02:00</startTime>
    <endTime>2008-06-04T13:49:17+02:00</endTime>
    <forceRun>true</forceRun>
    <setupId>1</setupId>
    <simulationId>639</simulationId>
    <resultLayerIds>zat2hl.dxf</resultLayerIds>
    <status>2</status>
    <statusMessage>Starting simulation on PC
'http://scier.dhi.cz/scier/FloodSimWebService.asmx'. Simulation finished: Simulation finished
successfuly
</statusMessage>
    <resultDocumentIds>mydoc.pdf|otherdoc.pdf</resultDocumentIds>
  </PreResults>
</NewDataSet>
```

Figure 7-24: The model results file is a simple XML (DHI, Aigner, & Ertac, 2008).

By these model results, GIS gets the enough information to show the most adequate flood map. The key parameter is of course “resultlayerIDs” which consists of unique layer ID. Users can easily follow the time series by the help of “startTime” and “endTime” parameters. They also receive a detailed status message via SCIER-GIS user interface. That function includes any comment on the model result, which is provided by the “statusMessage” line within the PreProcessedModelResults.xml file. In addition SCIER-GIS’ web user interface is able to present some related documents by a given attribute in “resultDocumentIds”. For instance some predefined evacuation plans shall be added in .pdf format.

In summary geospatial data is not transferred real-time through the GIS module. The simulation of flood is only partly held in real-time, since basic simulation structures concerning the river basin of the monitored area are designed and implemented in advance. However, these model results are delineated once and do not change according to the evolution of the phenomenon. In detail, rainfall dataset is received by the simulation model. Real-time rainfall data are used as boundary condition for the model and in addition short-term predictions on rain rate are taken into consideration. Predictions on rain rate lead to several scenarios for real time simulation, e.g. continuous constant rainfall intensity for a defined period of time or severe rain fall for a short period.

Briefly input files contain time series on the measured rain rate and water level and flow at the area under surveillance. Both types of data require a simple ASCII format. As the output, the simulation engine returns a prediction on the water level and flow at the monitored area. These simulations are visualized through pre-calculated maps stored in the GIS Module. The flood model runs a sequence of simulations at regular time intervals using new sets of rainfall data until emergency situation passes.

7.4.2 Computational Background

With respect to flood simulations and GIS integration, only one method is needed (Hadjiefthymiades, et al., 2008):

SCIER-GIS : FL
void setSimulationResults(SimulationData simData, SimulationResultData simResultData)

The method setSimulationResults is called from SIF via SOAP web-services after the execution of a single simulation is finished. The content of SimulationData structure has been described above; the content of SimulationResultsData structure follows.

Property name	Data type	Description
Status	int	Simulation status (succeeded, failed, …)
StatusMessage	String	Text description of simulation status.
SecondsToNextSimulation	int	Recommendation for next simulation run.
CulminationTime	DateTime	Time of flood culmination.
ResultLayerIds	String[]	List of results.
ResultDocumentIds	String[]	

Table 7-7: Properties of SimulationResultsData structure (Hadjiefthymiades, et al., 2008).

7.4.3 Operating Manual

There are two main methods to deal with the Flood Simulation via SCIER-GIS Web User Interface:

7.4.3.1 Method 1

The first way is to run a simulation by giving a specific time period and clicking “Start” button. (See the Figure 7-25).

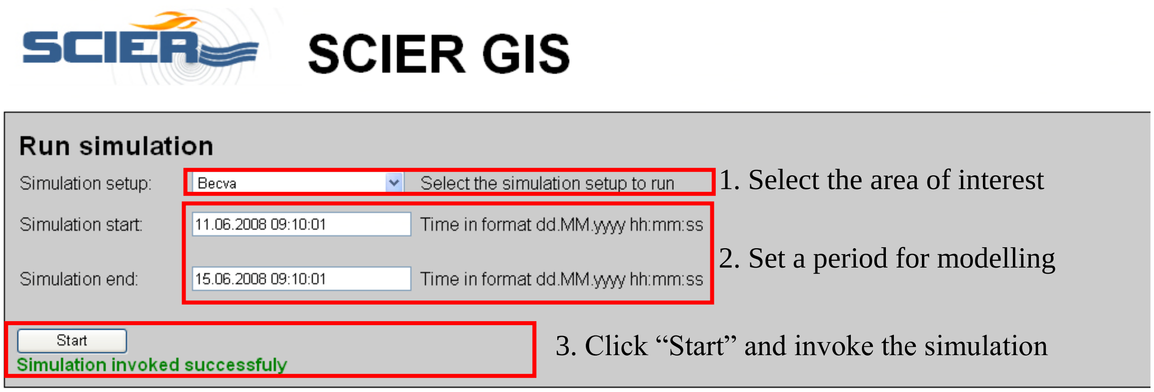


Figure 7-25: Simulation invoke

To see the results in map, the user should proceed with the bottom of the page. There, he/she shall give simulation period which must cover the dates for requested model results. After the period is set, you can get the results by clicking "Refresh" button located on the left end of the page. See the Figure 7-26.

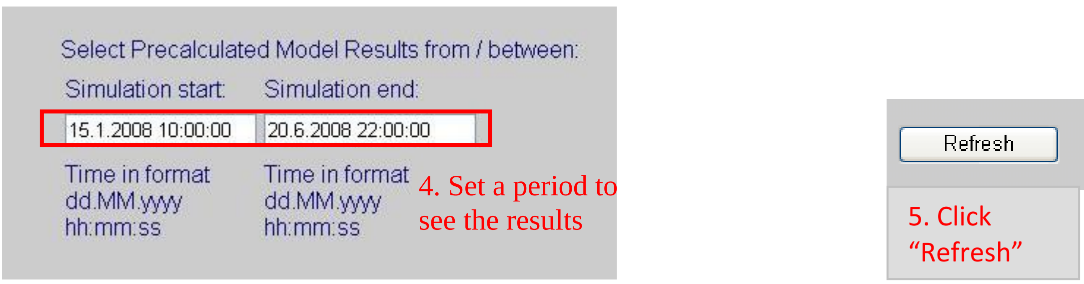


Figure 7-26: Query window for simulation results

Usage Tip: The wider the period you give, the more results will be shown on the "Simulation Results" dropdown list.

Now you can select a model result by clicking a line in "Select Simulation" dropdown list. See the Figure 7-27.

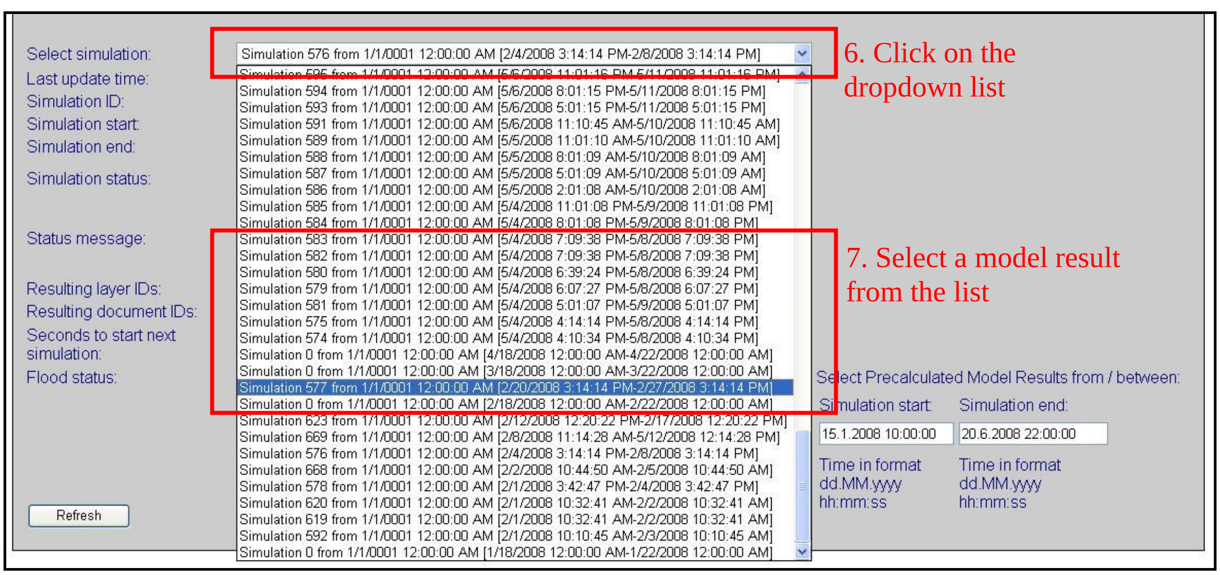


Figure 7-27: Select Simulation dropdown list to visualize model results

The details of the results are given in the Chapter 7.4.4.

7.4.3.2 Method 2

The other way to see some model results is to check former simulation calculations by skipping the "Run simulation" method. A user shall start with the Simulation Result window. There, you shall give a simulation period as you wish. After the period is set, you can get the results by clicking "Refresh" button located on the left end of the page (Figure 7-28).

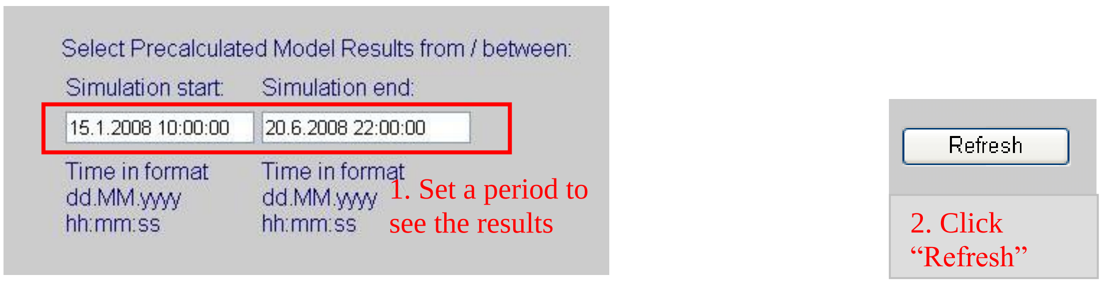


Figure 7-28: Query window for simulation results

Usage Tip: The wider the period you give, the more results will be shown on the "Simulation Results" dropdown list.

Now you can select a model result by clicking a line in "Select Simulation" dropdown list. See the Figure 7-29.

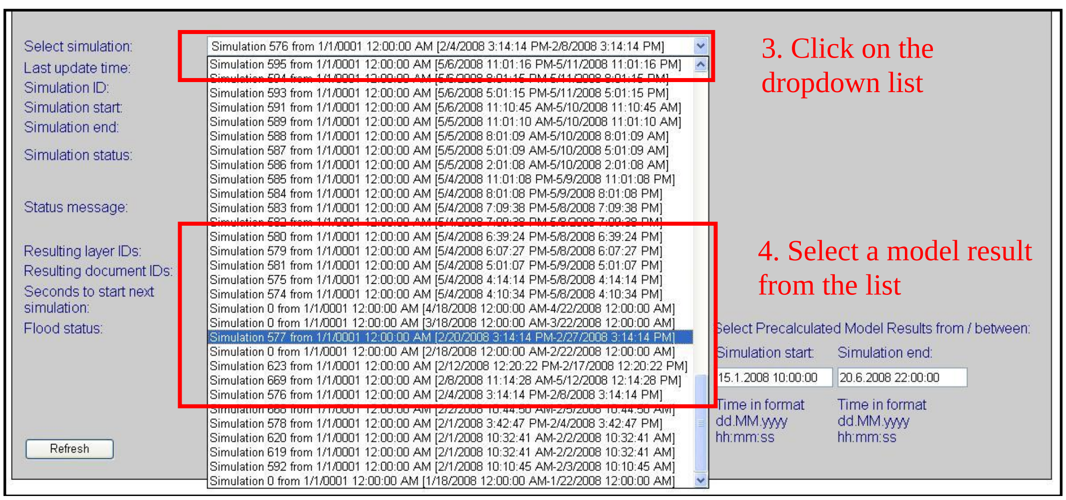


Figure 7-29: Select Simulation dropdown list to visualize model results

The result will be shown on the map (Figure 7-30)

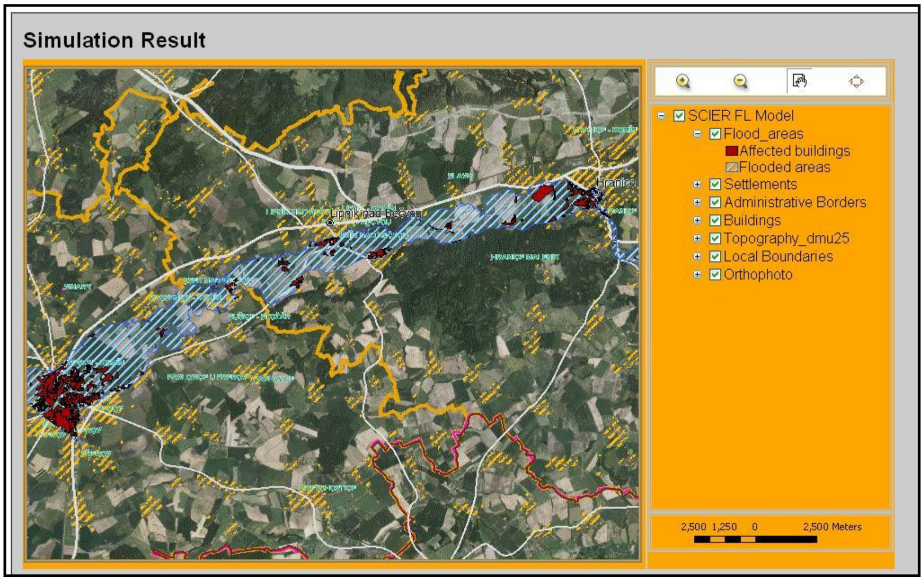


Figure 7-30: Model results in SCIER-GIS Web Mapping Environment

Note: For the details of the results see the following chapter 7.4.4.

7.4.4 Representation of the Results

As a result of the mentioned methods above, the result will be shown on the map. The simulation result window consists of two subdivisions in which a map view (and the tabular data available to give model results. The map view has the state-of-the-art web-mapping functionalities which gives user a clear representation of the affected areas. A toolbar with several functions is available for navigational purposes, such as zoom in and pan. A legend is also available to clarify the map content. A scale bar helps to meet visualization requirements as well.

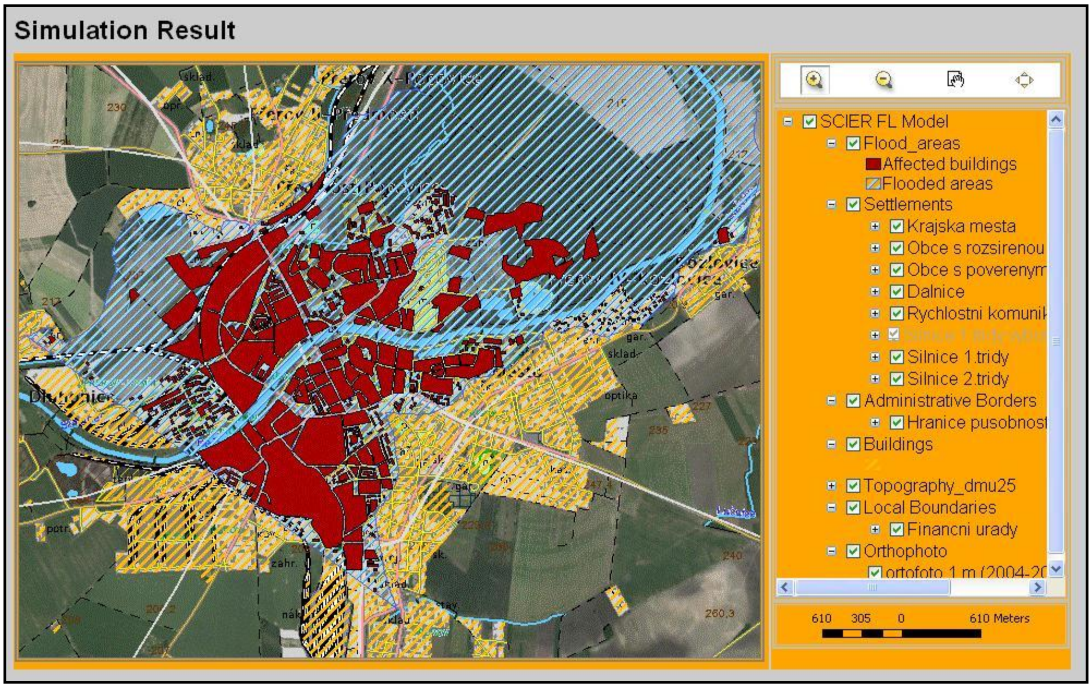


Figure 7-31: The map view to visualize simulation results

"The simulation result" part of the web user interface gives all related information about SCIER Flood Modeling as can be seen on the figures. In addition to the map visualization, users are able to have some extra information, such as simulation Id, Simulation Start and End, etc. If there is extra information like an evacuation plan, users are able to download the content in .pdf format (See, Resulting Document IDs).

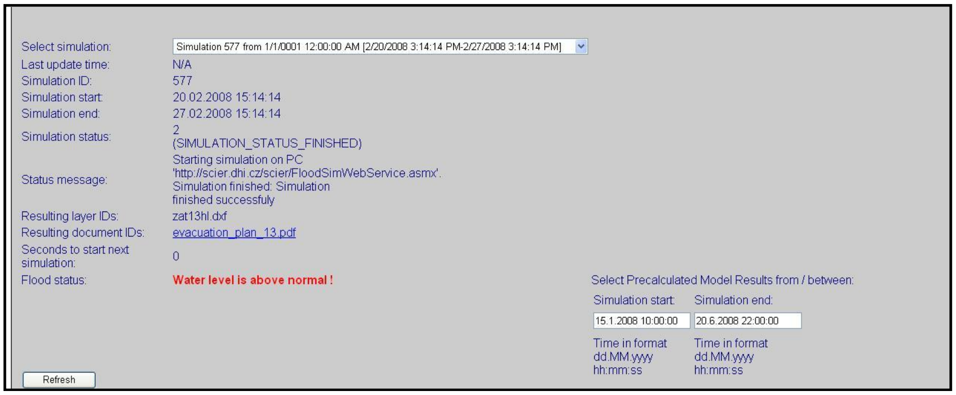
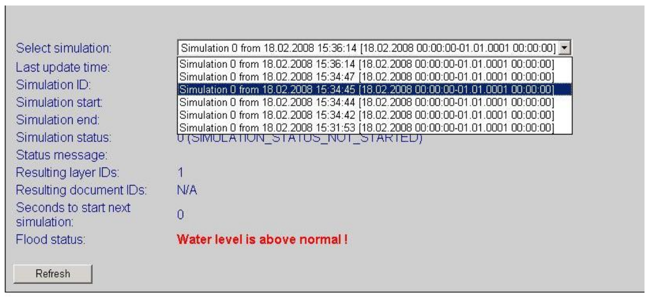


Figure 7-32: Additional Information for SCIER-Flood Simulation Results

By clicking the dropdown list in Select Simulation, the user can select another calculated simulation as well.



7.5 Web-GIS Implementation for Forest Fire Modeling

The following Figure gives an overview on how the GIS component interacts with the Forest Fire (FF) Simulation Engine for two cases, either with or without user's intervention.

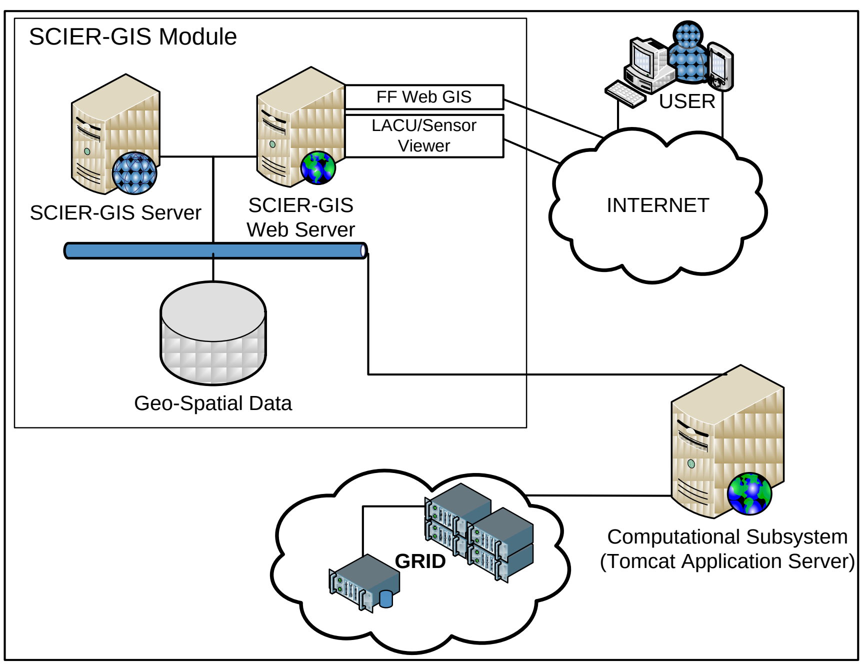


Figure 7-33: Integration of the SCIER-GIS Module in SCIER. Adapted from Kanellopoulos et al. (2008)

To comment this particular figure:

- SCIER-GIS database delivers geospatial data for a specific area
- Two types of web-applications was developed for the fire modeling (Bonazountas, et al., 2009):
    - Forest fire (FF) Web-GIS applications: There are two different but combined user interfaces for forest fire modeling in this project. At the first Web-GIS application, one can find a user interface with a map in which the user can initiate and trigger a fire simulation. The second one is developed for the model results.
    - Web Services: A high level Web Service (see Chapter 7.1 for the list of available Web Services) that performs all transactions between the SCIER-GIS module and the computing system in Grid. This service assures that all input/output files concerning the fire modeling are safely received/ delivered from/to the GIS component.

7.5.1 GIS Module and the Fire Model Integration

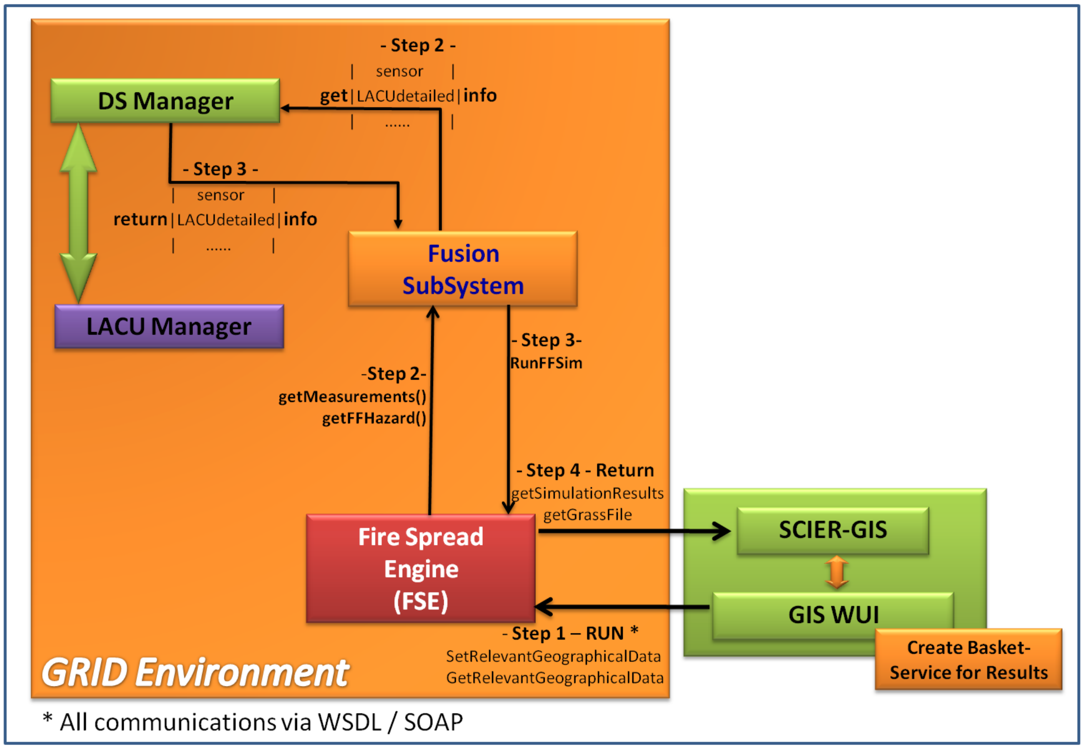


Figure 7-34: Fire Modeling (FF) Workflow. Adapted from Hadjiefthymiades, et al. (2008)

7.5.1.1 Step 1

In the first phase of the model run, the model can be triggered via Web-GIS application (GIS WUI). The user must firstly give the required time parameters, then click on *the model run center* button and click on a place on the map. The user can also define other ignition points if he wants to see the results for simultaneous fire starting points. In background, SCIER-GIS consumes Web Services and uses specific methods from the Fire Spread Engine (FSE).

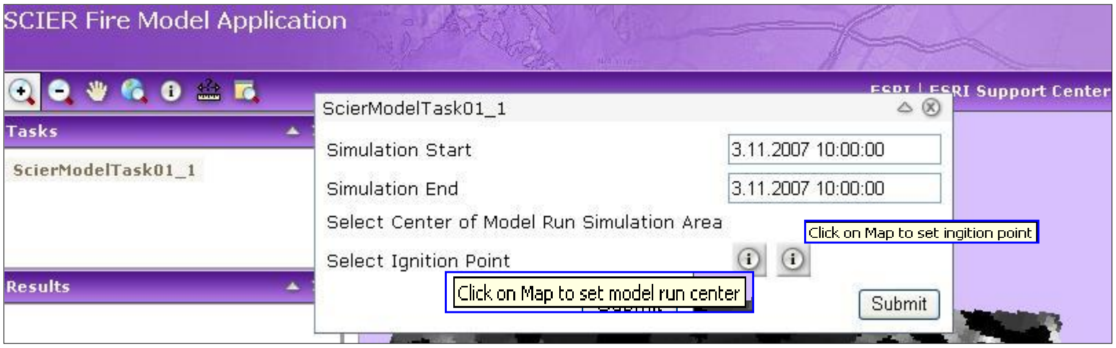


Figure 7-35: SCIER Model Task in SCIER Fire Model Web-GIS Application.

In the following code, partially you can see the background of "Scier Model Task" in the forest fire modeling interface, which has a real-time Web Service connection with FSE to run a simulation (Ertac & Aigner, 2008):

```
namespace ScierModelTask
            //X (longitude), Y (latitude)
            object[] inputs = Input as object[];

            string SimStart = inputs[0].ToString();
            string SimEnd = inputs[1].ToString();

            //Model Run Center
            ESRI.ArcGIS.ADF.Web.Geometry.Point mappt = Page.Session["pt"] as
ESRI.ArcGIS.ADF.Web.Geometry.Point;

            //Model Ignition Point
            int ptind=Convert.ToInt16(Page.Session["ptcnt"]);

            SIF.GeographicalCoordinates[] gc = new SIF.GeographicalCoordinates[ptind];
            for(int i=0;i<ptind;i++)
            {
                ESRI.ArcGIS.ADF.Web.Geometry.Point mappt2 = Page.Session["pt2_" + (i+1).ToString()] as
ESRI.ArcGIS.ADF.Web.Geometry.Point;
                gc[i] = new SIF.GeographicalCoordinates();
                gc[i].longitude = Convert.ToDouble(mappt2.X);
                gc[i].longitudeSpecified = true;
                gc[i].latitude = Convert.ToDouble(mappt2.Y);
                gc[i].latitudeSpecified = true;
            }
            ESRI.ArcGIS.ADF.Web.UI.WebControls.TaskResultNode trNode = new
ESRI.ArcGIS.ADF.Web.UI.WebControls.TaskResultNode(inputs[0].ToString() + " / " + inputs[1].ToString());
            trNode.BackColor = Color.BlanchedAlmond;
            trNode.Expanded = false;
            try{
                SIF.SimulationInterface sifWs = new SIF.SimulationInterface();
                sifWs.Url = "http://dxplus.gridctb.uoa.gr:8080/scierCS/services/SimulationInterface";

                SIF.SimulationData simData = new SIF.SimulationData();
                simData.setupId = 1;
                simData.setupIdSpecified = true;
                simData.simulationType = 1;//1....fire
                simData.simulationTypeSpecified = true;
                System.Globalization.CultureInfo _culture = new System.Globalization.CultureInfo("de-
DE");
                simData.startTime = DateTime.Parse(SimStart, _culture);
                simData.startTimeSpecified = true;
                      simData.endTime = DateTime.Parse(SimEnd, _culture);
                      simData.endTimeSpecified = true;
                simData.timeoutSeconds = 300;
                simData.timeoutSecondsSpecified = true;
                simData.forceRun = true;
                simData.forceRunSpecified = true;

                simData.region = new ScierModelTask.SIF.BoundingBox();
                simData.region.lowerLeft = new SIF.GeographicalCoordinates();
                simData.region.lowerLeft.latitude = mappt.Y - 0.5;
```

```
simData.region.lowerLeft.latitudeSpecified = true;
simData.region.lowerLeft.longitude = mappt.X - 0.5;
simData.region.lowerLeft.longitudeSpecified = true;
simData.region.upperRight = new SIF.GeographicalCoordinates();
simData.region.upperRight.latitude = mappt.Y + 0.5;
simData.region.upperRight.latitudeSpecified = true;
simData.region.upperRight.longitude = mappt.X + 0.5;
simData.region.upperRight.longitudeSpecified = true;
simData.ignitionPoints = gc;
sifWs.runSimulation(simData);
if(trNode.Nodes.Count>0)
    Results = trNode;
else
    Results = new SimpleTaskResult("Success", "Model Execution was triggered!");
```

Forest fire modeling works with Ascii files in both Grass-Ascii and ESRI-Ascii formats. The only difference between such Ascii files are the headers. Following table shows one sample Ascii file from each formats.

ESRI-Ascii	**Grass-Ascii**
ncols 501	north: 3451250
nrows 501	south: 3438850
xllcorner 442000	east: 298960
yllcorner 4593000	west: 290860
cellsize 20	rows: 10
NODATA_value -9999	cols: 5
7 7 7 7 7 7 2 2 2 2 2 2 7 2 2 2 2 2	0 1 1 0 11 1 0 0 1

Table 7-8: Comparison of Grass-Ascii and ESRI-Ascii files.

The files given in the list below are stored in ESRI-Ascii format in the GIS module which are converted to Grass-Ascii during the data transaction with the Grid environment. The input files for an operational fire modelling are given as follow (Kanellopoulos, Bonazountas, Kirklis, Metelka, Hadjiefthymiades, & Faist, 2008):

orign.asc (real-time): contains the ignition points defined either automatically inside the CS as a result of data fusion or under user's request

mdead.asc (real-time): contains dead fuel moisture (%)

mlive.asc (real-time): contains live fuel moisture (%)

modcb.asc (static): contains the Fuel Map (NFFL Model – scale 1-13, 0 is a non-burnable area)

slope.asc (static): contains slope (%)

aspct.asc (static): contains aspect value in degrees

windd.asc (real-time): contains Spatial Distribution of Wind Direction

winds.asc (real-time): contains Spatial Distribution of Wind Speed

Only static files (slope.asc, aspct.asc, modcb.asc) are retrieved from the SCIER-GIS module. Each static map is cropped and converted to Grass-Ascii according to the user's simulation submit click on the Web-GIS user interface. The file containing the fire-origins is generated inside the CS from the coordinates delivered either by the user or the data-fusion inside the CS. Ascii files containing information on the wind field (windd.asc, winds.asc) are non-static. To generate these two files, measurements from anemometers distributed along the area of interest arrive at the CS and then, values are extrapolated in space to get a field of the aforementioned wind parameters ("field" calls for a value per cell). Next, they are replicated into N different versions which are perturbed in comparison with the original file so that at the end of the day N different meteo-scenarios are generated (Kanellopoulos, Bonazountas, Kirklis, Metelka, Hadjiefthymiades, & Faist, 2008).

7.5.1.2 Step 2

When FSE receives the call of the GIS, immediately communicates with the Fusion Subsystem to get required parameters from the field sensors. DSManager delivers the requested information by contacting LACU Manager (responsible for real-time sensor information). For the records, this step of the forest fire simulation was totally built within the Grid environment. NKUA and Tecnoma developed a simulation engine fully integrated within the Grid.

7.5.1.3 Step 3

DSManager returns all relevant information via Fusion SubSystem to the FSE. So that FSE can trigger the simulation.

7.5.1.4 Step 4

At the final phase, FSE consumes the Web Service from SCIER-GIS to deliver simulation results. As mentioned before, all the computational methods are explicitly shared via WSDL, so that FSE is enabled for data transaction. A detailed perspective on Web Services is already given in previous sections (Section 7.1 An Innovative Approach in GIS and GRID Integration).

Fire model returns two main output Ascii files for the visualisation of the model results which are given in the following list (Kanellopoulos, Bonazountas, Kirklis, Metelka, Hadjiefthymiades, & Faist, 2008):

ftacc.asc: contains the period of time in minutes necessary for a cell to be affected by fire

flame.asc: contains for the aforementioned period of time, the length of flame per cell

The CS returns N×2 such files to the SCIER-GIS. The following partial code lines represent this step from a computational view:

```
string GrassFileUrl=@"http://141.40.224.68/asci/Two.txt";
        int Type=2;
        string[] Metainfo ={ "metinf1", "metinf2" };
        string targetfolder = @"C:\scier_data\webserviceworkingdirectory";
        Random r = new Random();
        int zz = r.Next(1000000);
        string targetfile = "IMP" + zz.ToString();
        string sOutFname = @"C:\Inetpub\wwwroot\sciercontainer\" + targetfile + ".txt";
        #region writehelperfile
        System.IO.FileStream fs1 = System.IO.File.Create(targetfolder+ "\\" + targetfile + "HELP.txt");
        System.IO.StreamWriter sr = new System.IO.StreamWriter(fs1);
        sr.WriteLine(Type.ToString());
        for(int i=0;i<Metainfo.Length;i++)
            sr.WriteLine(Metainfo[i]);
        sr.Close();
        fs1.Close();
        #endregion
[WebMethod]
    public void TestPresentModelResult()
    {
        string simdata = "SimulationData (simulationId=785, simulationType=1, setupId=0, startTime=Thu
Jul 17 21:43:04 EEST 2008, endTime=Fri Jul 18 00:43:04 EEST 2008, timeoutSeconds=0, region=LowerLeft
corner=[3.682447 W,41.473022 N,0.0] - UpperRight corner=[3.56347 W,41.563744 N,0.0],
ignitionPoints=null, simulatedIntervals=null)";
        string[] zipfilenames=new string[8];
        zipfilenames[0] = "IMP27828.zip";
        zipfilenames[1] = "IMP453990.zip";
        zipfilenames[2] = "IMP192202.zip";
        zipfilenames[3] = "IMP453990.zip";
        zipfilenames[4] = "IMP27828.zip";
        Random rr = new Random();
        int nnn=rr.Next(0,8);
        string zipfilename = zipfilenames[nnn];
        int bnmb = rr.Next(1, 6);
        this.PresentModelResult(simdata, "Basket" + bnmb.ToString(), zipfilename);
    }
    private void PresentModelResult(string simdata1,string basketname1, string zipfilename1)
    {
        string simdata = simdata1;
```

```
string basketname = basketname1;
string zipfilename = zipfilename1;
string zipfilefolder = @"C:\scier_data\webserviceworkingdirectory\";
#region exportresult
string fns = zipfilename.Replace(".zip", "");
string targetfolder = zipfilefolder + fns;
System.IO.Directory.CreateDirectory(targetfolder);
ICSharpCode.SharpZipLib.Zip.FastZip fz = new ICSharpCode.SharpZipLib.Zip.FastZip();
fz.ExtractZip(zipfilefolder + zipfilename, targetfolder, "");
System.IO.DirectoryInfo di = new System.IO.DirectoryInfo(targetfolder);
MapDocument mdoc = new MapDocument();
mdoc.New(zipfilefolder + basketname + ".mxd");
int i = mdoc.MapCount;
IMap pm = mdoc.get_Map(0);
```

As you can see in the scripts above, Web Services play a crucial role in this integrated system. The GIS module receives data in compressed format and stores under the directory …\webserviceworkingdirectory. Then it creates the .mxd files to be published in the next step as Web Mapping Services within the GIS Server.

In the following lines of the source code, you can see how all relevant geospatial data –background images– got combined:

```
ESRI.ArcGIS.Geodatabase.IWorkspaceFactory pRasterWSFact = new
ESRI.ArcGIS.DataSourcesRaster.RasterWorkspaceFactory();
        ESRI.ArcGIS.DataSourcesRaster.IRasterWorkspace pRasterWS = pRasterWSFact as
ESRI.ArcGIS.DataSourcesRaster.IRasterWorkspace;
        pRasterWS = pRasterWSFact.OpenFromFile(targetfolder, 0) as
ESRI.ArcGIS.DataSourcesRaster.IRasterWorkspace;
        ESRI.ArcGIS.DataSourcesRaster.IRasterWorkspace pRasterWS1 = pRasterWSFact as
ESRI.ArcGIS.DataSourcesRaster.IRasterWorkspace;
        pRasterWS1 =
pRasterWSFact.OpenFromFile(@"C:\scier_data\webserviceworkingdirectory\backgroundfeatureclasses", 0) as
ESRI.ArcGIS.DataSourcesRaster.IRasterWorkspace;
        IRasterDataset pRasDat1 = null;// pRasterWS1.OpenRasterDataset("final_gr") as IRasterDataset;
        if (false)
            pRasDat1 = pRasterWS1.OpenRasterDataset("final_sp") as IRasterDataset;
        else
            pRasDat1 = pRasterWS1.OpenRasterDataset("final_gr") as IRasterDataset;
        IRasterLayer pRl1 = new RasterLayerClass();
        pRl1.CreateFromDataset(pRasDat1);

        IRasterDataset pRasDat2 = null;// pRasterWS1.OpenRasterDataset("final_gr") as IRasterDataset;
        if (false)
            pRasDat2 = pRasterWS1.OpenRasterDataset("final_sp2.img") as IRasterDataset;
        else
            pRasDat2 = pRasterWS1.OpenRasterDataset("final_gr2.img") as IRasterDataset;
        IRasterLayer pRl2 = new
RasterLayerClass();
        pRl2.CreateFromDataset(pRasDat2);
        pm.AddLayer(pRl1);
        pm.AddLayer(pRl2);
```

All data – including basemaps and background satellite images – mentioned above in the code was actually stored in the SCIER-GIS database as you can see in the figure on the right.

For a better visualization result, it is preferable that all results are depicted on reference maps including satellite-images, orthophotos, urban/road/ railway topologies etc. These geo-spatial data are already stored in the database of the GIS module and are not involved in web-transactions for the fire modeling. The visualization will be presented in the following section (Step 5).

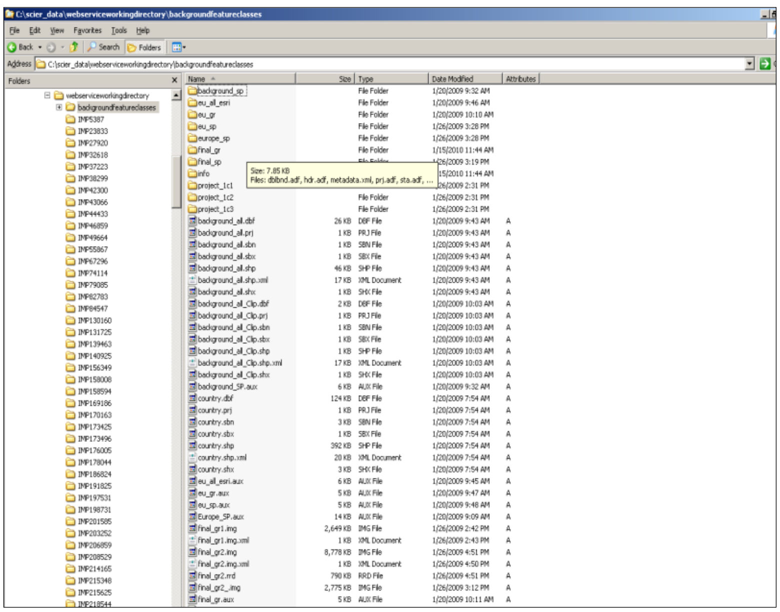


Figure 7-36: Web Service storage directory.

7.5.1.5 Step 5

The fire model results are delivered as a fully automatic application through the Web-GIS application. For this purpose an intelligent application so called "*basket-service*", developed inside the SCIER-GIS Module which handles automatically all possible scenarios of use. The computational subsystem was already upgraded by NKUA to support these specifications. The basket-service was built for the automatic representation of the fire model results as an output of the processes. Such as http://141.40.224.68/Basket4/default.aspx presents a series of model results, in which every time when a model run triggers this automated mechanism, it generates a random number which is the index of the next basket (Figure 7-45). Specifications on the operational workflow of the basket-service are given as follow:

- The basket-service is connected to the user via forest fire web application and to the SCIER's computational subsystem (CS) via Web Services in order to detect a simulation triggered.
- When a simulation is triggered, a response is sent to the user through the SCIER-GIS Module to confirm that data have been received and simulation is executed, and then CS provides to SCIER-GIS Module the bounding box which in turn defines the rectangular field of simulation.
- Some metadata are attached to each simulation and then they are returned to the SCIER-GIS Module along with the simulation-results. Metadata:

AREA:	Greece or Spain
START TIME:	date:hour
END TIME:	date:hour
SIMULATION ID:	number_ID

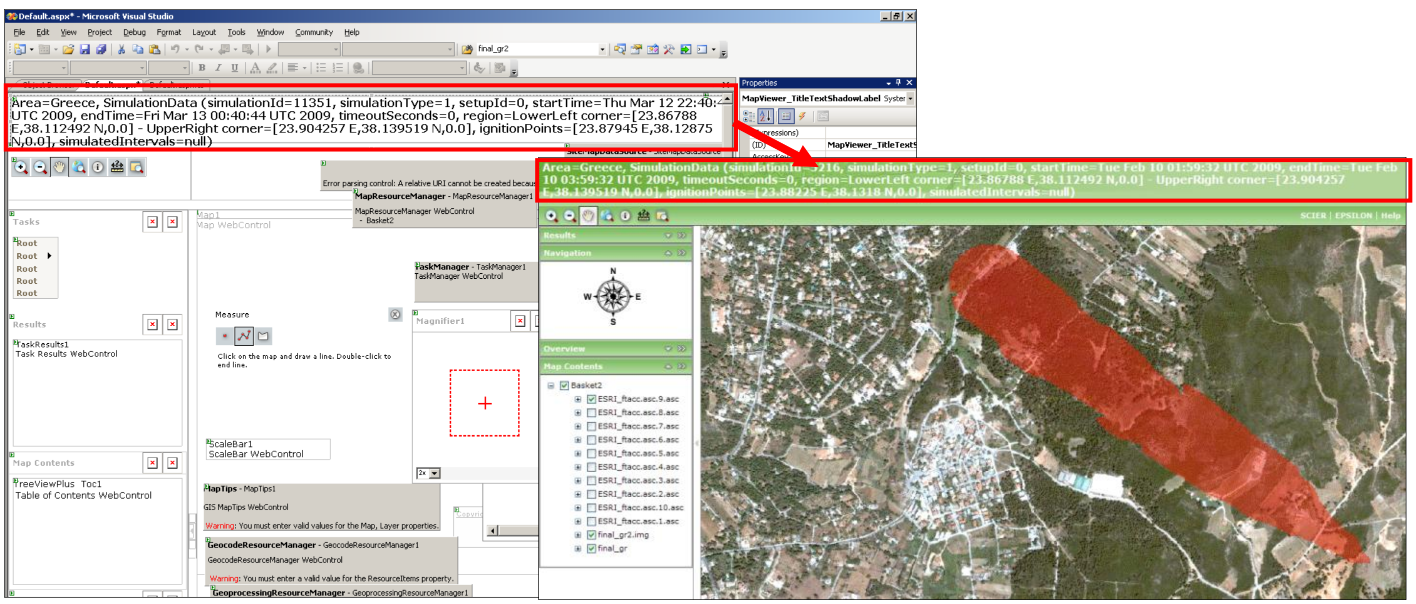


Figure 7-37: Usage of Metadata in the Web User Interface of Forest Fire Simulation.

- The user can select a model result by typing displaying the basket-service (e.g. http://141.40.224.68/Basket1/default.aspx) in a web browser, in which all relevant data combined (see Figure 7-38).

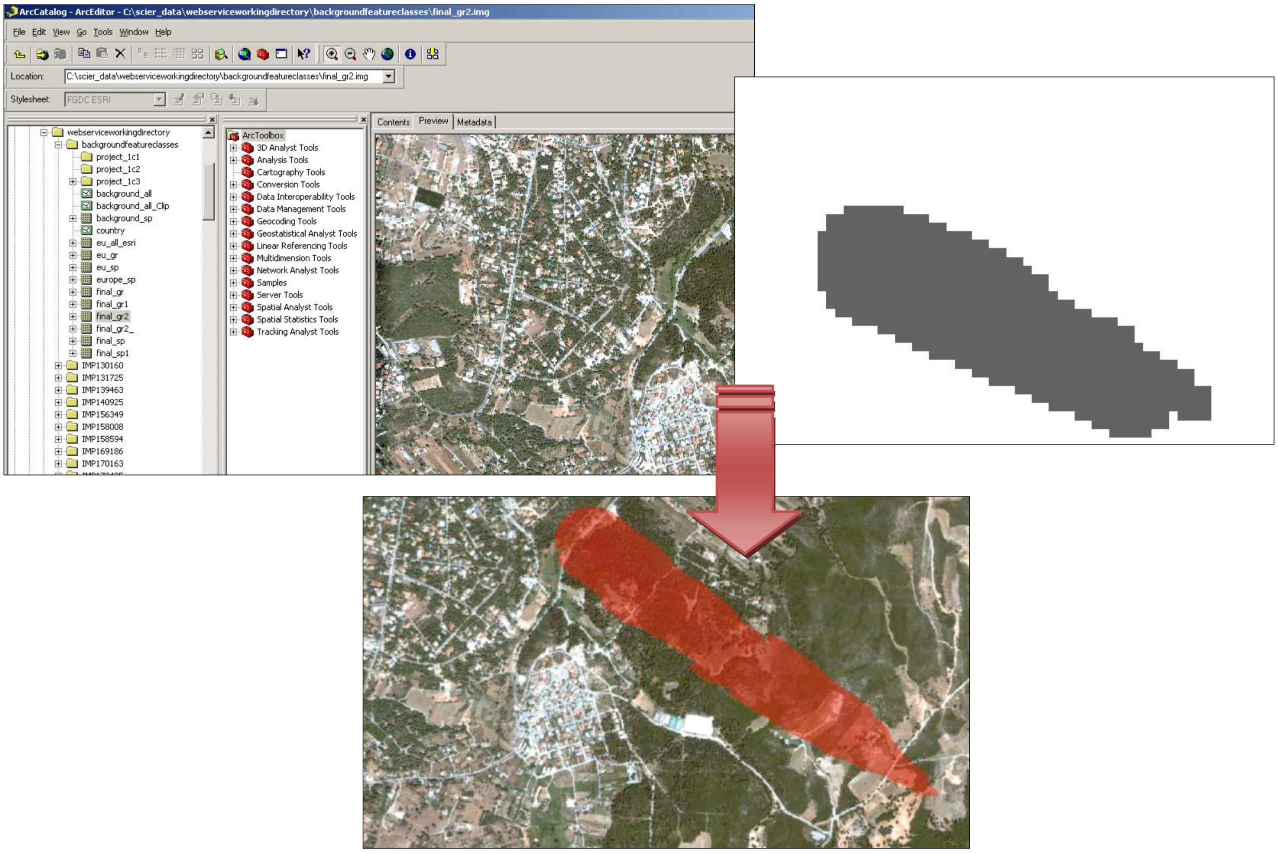


Figure 7-38: SCIER-GIS module combines all relevant data and publishes in Web.

Basket-service uses state-of-the-art Web mapping libraries (see section: 7.3Web-GIS Programming Environment in the GIS Module) from ESRI's ArcGIS Server 9.2 technology. Computational details of the basket-service can be seen in the following figure:

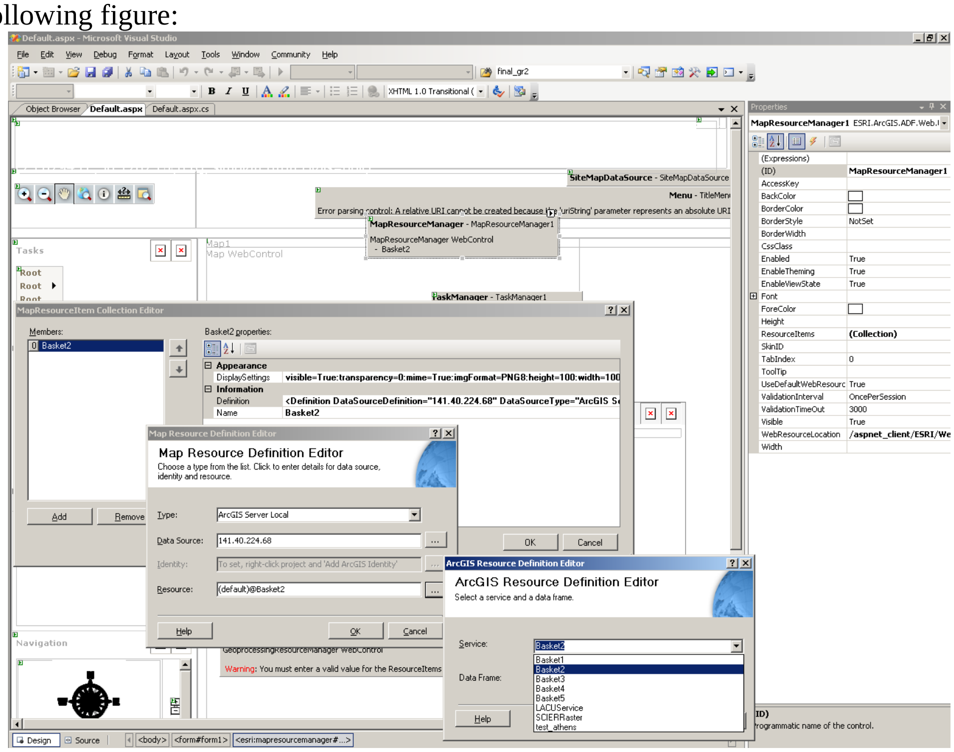


Figure 7-39: Basket Service in Map Resource Definition Editor.

As a summary of the work flow in fire modeling via GIS module is given as a flowchart below (Figure 7-40).

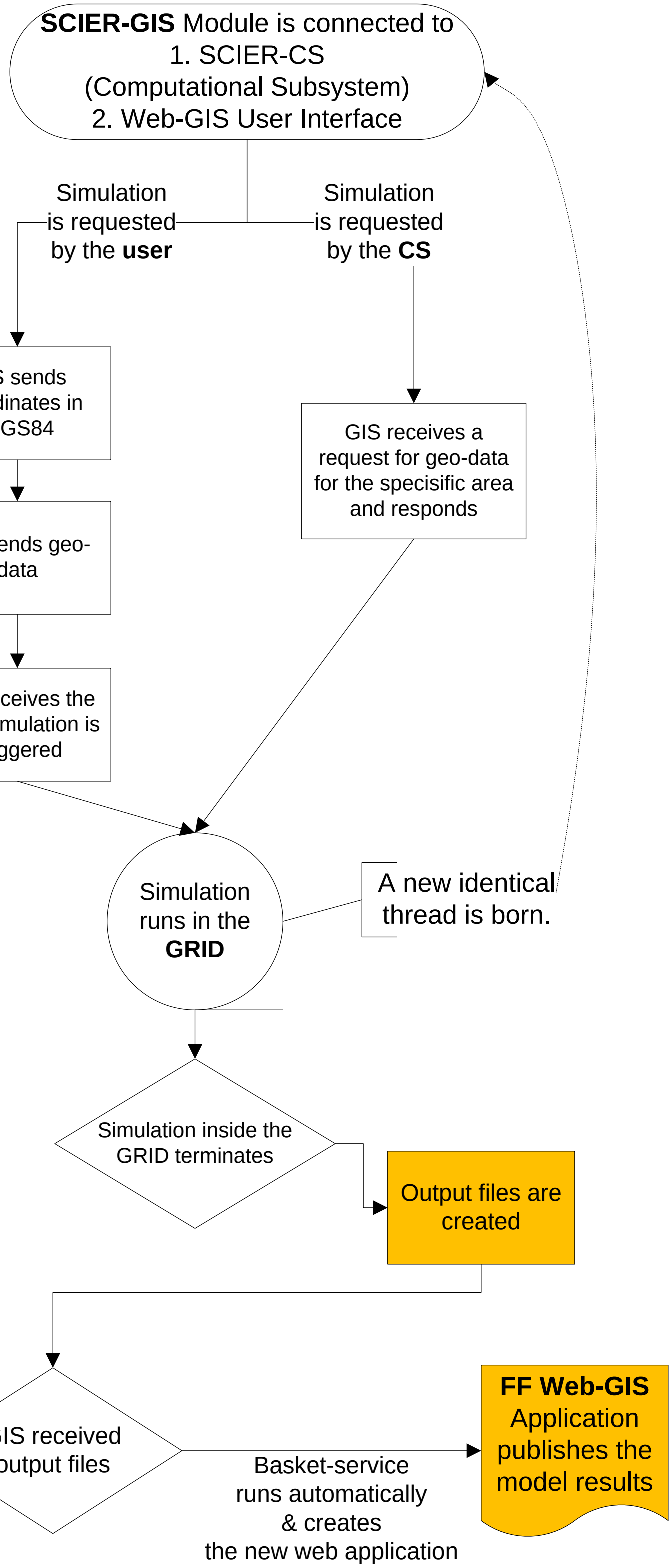


Figure 7-40: A flowchart explaining the workflow of the fire modeling via SCIER system components. Adapted from Hadjiefthymiades, et al. (2008)

7.5.2 Computational Background

The Web user interface developed in the GIS module sets a simulation is to be triggered to run. This is done either upon user's request or when sensor emergency calls indicate a possible fire event. Once the simulation interface (SIF) receives a request for a fire model (FF) run, it checks that all necessary data is already in the geo-database, and if so, it invokes the simulation in the fire modeling engine. Since the entire process takes place inside the Grid as a series of jobs, all interactions between the simulation interface and the DSManager are the parties of the jobs. Produced results are evaluated with the contribution of real-time data arriving from sensors (Hadjiefthymiades, et al., 2008).

With respect to fire modeling and GIS integration, several methods are needed and defined as given in the following tables below. So called the raster update service within the SCIER-GIS module is a SOAP web service and it implements the following methods to meet the requirements (Hadjiefthymiades, et al., 2008):

SCIER –GIS : FF
runSimulation(simData: Simulation) : void getFFHazard(simId: long, timeIntervals long[]): File getSimulationResult(simId: long) : SimulationResultData getSimulationStatus(simId: long) : int

Method Name	Input parameters	Output parameters	Description	Comments
runSimulation	simData: Simulation	SimulationResultData	Runs a simulation with the provided parameters. Input parameters provide the SimulationType	void
getFFHazard	simId: long, timeIntervals: long[]		Calculate the fire hazard metric (possibility that the fire will reach specific areas in specific time intervals) based on the FF simulation with id simId and for the provided timeIntervals	A map file
getSimulationResult	simId: long	SimulationResultData	Return the resulting output data from the simulation with ID simId	
getSimulationStatus	simId: long	Int	Returns the status of the specified simulation (ie running, completed etc)	

Table 7-9: Further description of each method and the supplied functionality in detail. Adapted from Hadjiefthymiades, et al. (2008)

A detailed overview of each method and the supplied functionality is provided in the following tables (Hadjiefthymiades, et al., 2008):

SCIER-GIS : FF
public void setGrassFileBYTE(byte[] CompleteGrassFile, int Type, string[] Metainfo)

The *setGrassFileBYTE* method is for loading Grass-Ascii files into the Geodatabase. The input format of the Grass-Ascii file is a byte-field. The information contained in the Grass-Ascii file can be of several types. Therefore the "Type" parameter is made for. It can have a value between "0" and "2". Each number is attached to a raster layer in the Geodatabase. The number describes the index of 3 Raster results layers which are created to store results. The string-field "Metainfo" is used to attach information about each raster loading process. This information is used to create a protocol text file (Hadjiefthymiades, et al., 2008; Bonazountas, et al., 2007).

SCIER-GIS : FF
public void setGrassFileURL(string GrassFileURL, int Type, string[] Metainfo)

The *setGrassFileURL* is for loading Grass-Ascii files into the geodatabase. The input format of the file shared is a URL where the server which is hosting this service can download the Grass-Ascii (Hadjiefthymiades, et al., 2008).

SCIER-GIS : FF
public byte[] getGrassFileBYTE(double lowerLeftX, double lowerLeftY, double upperRightX, double upperRightY, int Type)

This *getGrassFileBYTE* is developed for loading Grass-Ascii files from the geodatabase. The parameters lowerLeftX, lowerLeftY, upperRightX and upperRightY are describing the rectangle extent in WGS 84 coordinates. The "Type"-parameter is the index of a source layer in the geodatabase. Possible layer index values are values until "7" (Hadjiefthymiades, et al., 2008).

Here the relations between index and layer names:

1 … aspect

2 … dead moisture

3 … live moisture

4 … slope

5 … wind direction

6 … wind speed

The return format is a byte field which contains the Grass-Ascii.

SCIER-GIS : FF
public string getGrassFileURL(double lowerLeftX, double lowerLeftY, double upperRightX, double upperRightY, int Type)

This *setGrassFileURL* is developed for loading Grass-Ascii files from the geodatabase. The parameters lowerLeftX, lowerLeftY, upperRightX and upperRightY are describing the rectangle extent in WGS 84 coordinates. The "Type"-parameter is the index of a source layer in the geodatabase. The return format is an URL where the Grass-Ascii files can be downloaded from (Hadjiefthymiades, et al., 2008).

As mentioned before, the user through the Web-GIS user interface specifies the area of interest to run a fire simulation. The GIS module provides this area to the simulation system in an appropriate GRASS-Ascii format in order to be used for the simulation along with all related data of this area. Figure 7-41 shows the sequence diagram for user request for running a simulation for a specific area and time whereas Figure 7-42 is the sequence of method invocations for a user to retrieve simulation output of a pre-calculated (so called Basket-service) simulation.

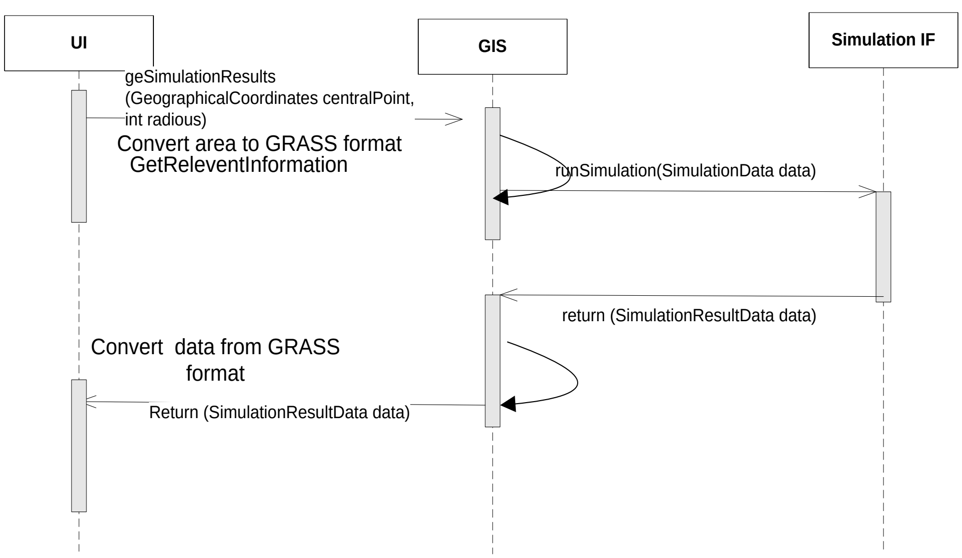


Figure 7-41: User request for a fire simulation of a specific area. Adapted from Hadjiefthymiades, et al. (2008)

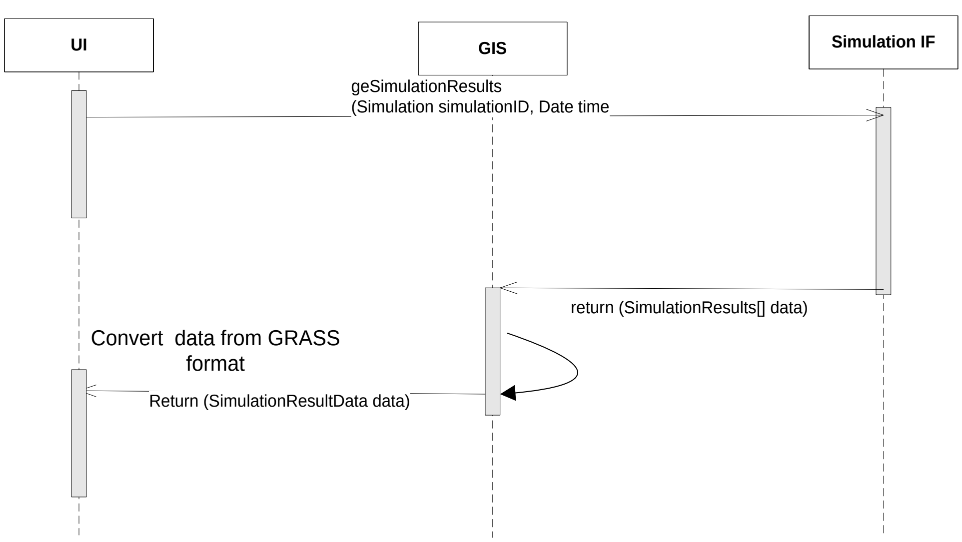


Figure 7-42: User request for retrieve pre-calculated simulation results. Adapted from Hadjiefthymiades, et al. (2008)

7.5.3 Operating Manual

The figure below (Figure 7-43) shows the web user interface of the Forest Fire Model which is publicly available online in Web. The window is split into several windows: On the left side is the tree-view situated showing all available databases, namely "Map Contents". The user can expand the tree structure (by clicking on the little "+"-sign) and access the map legend.

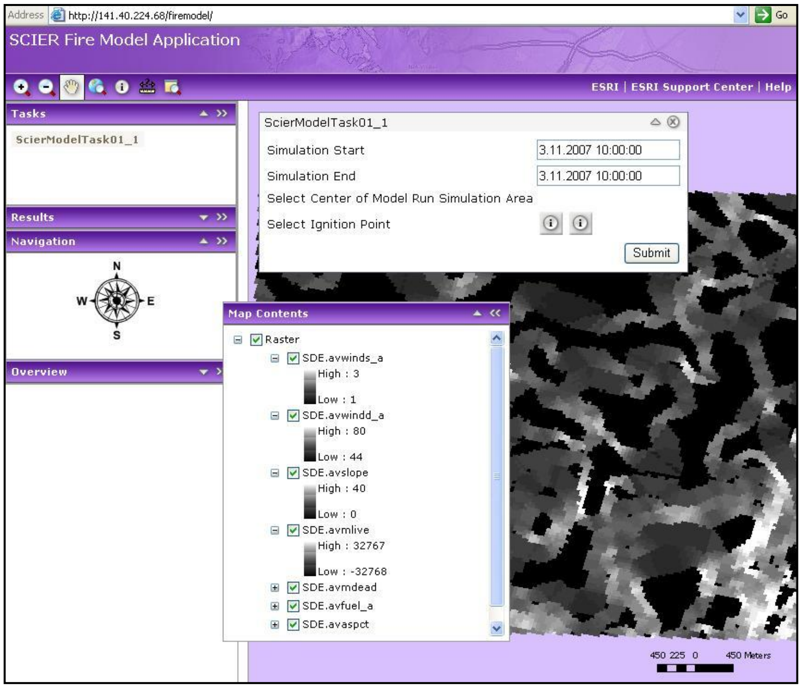


Figure 7-43: The SCIER-GIS Web User Interface for Forest Fire Simulation

On the leften side is the map view. Another key element is the "Tasks" window (Figure 7-44) which consists of all available tasks for SCIER Fire Modeling. All results produced out of the tasks are being shown in Results window.

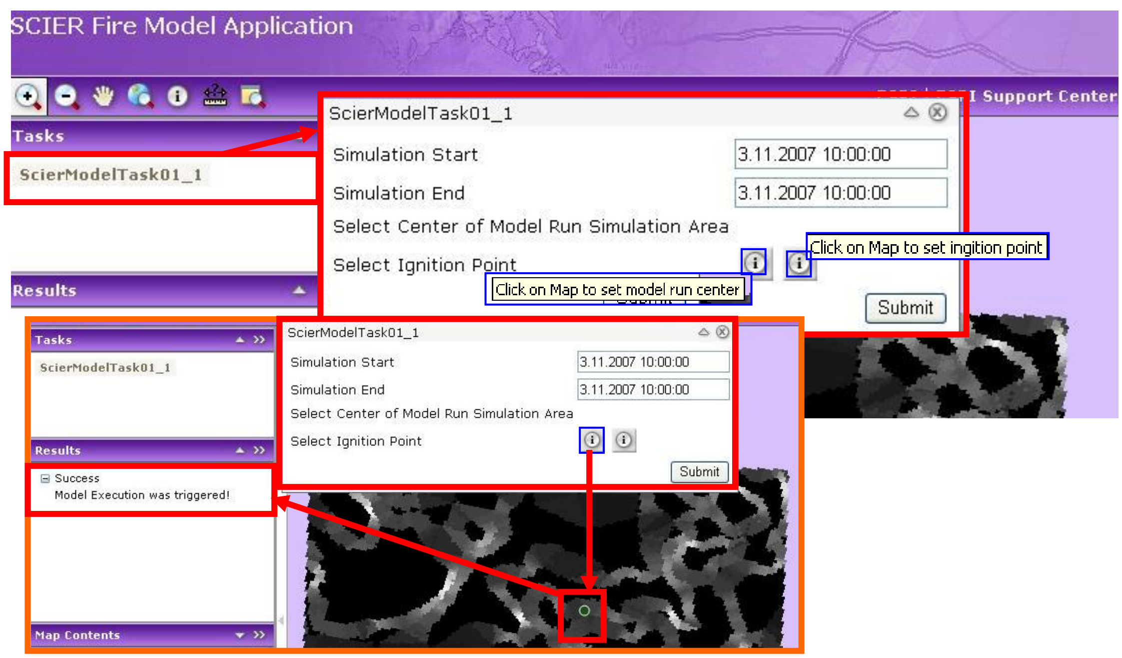


Figure 7-44: Fire Modeling task used at the SCIER-GIS Web User Interface

7.5.4 Representation of the Results

For the user interface, a service so-called "Basket-service", as explained in detail in previous section, was built for the automatic representation of the fire model results. Such as http://141.40.224.68/Basket4/default.aspx. Every time when a model run triggers this mechanism, it generates a random number which is the index of the next basket (Figure 7-45).

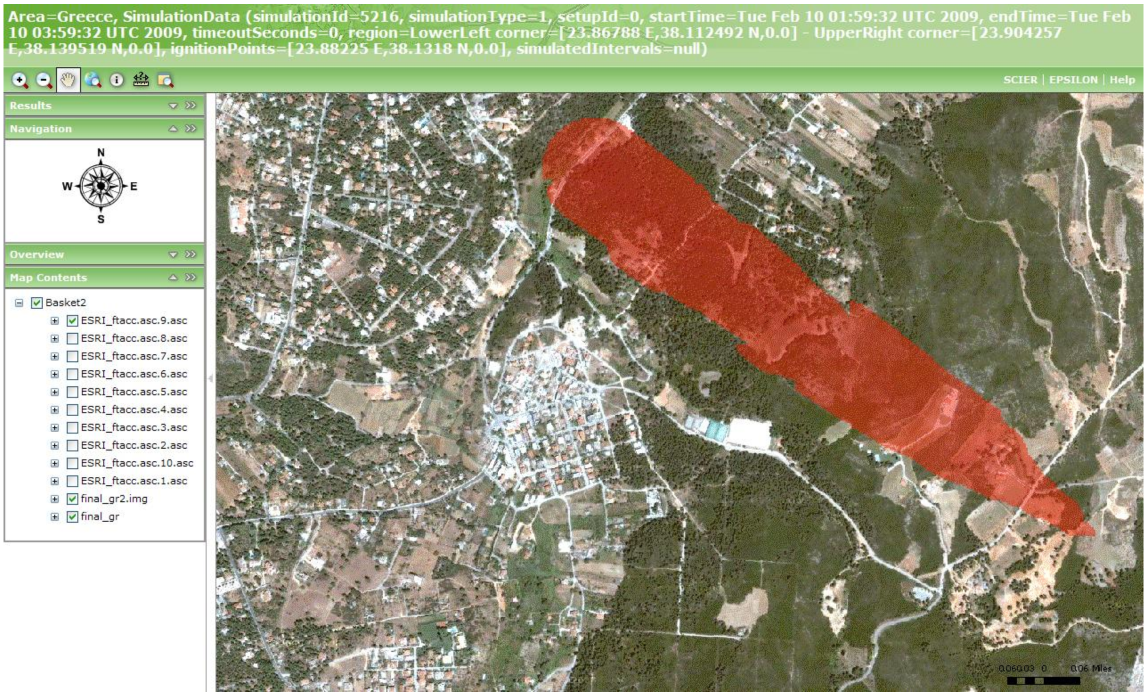


Figure 7-45: Fire Model results at the SCIER-GIS Web User Interface for the Fire Simulation

On the map, the user is able to see the temporal evolution of the fire through color differentiation: more intense colors would refer to cells that are almost instantly affected, while pale colors would refer to cells that are supposed to be affected after a significant period of time from the fire-burst. Model results appear on a reference map (i.e. satellite image). Such maps are of high resolution and they are stored in geodatabase (static base-maps) in the GIS module.

In summary the Web-GIS user interface and the application developed in the SCIER's GIS module for fire performs in following workflow:

- collecting and storing input parameters for a model run,
- run the model according to the parameters given by the user or the computational subsystem of SCIER,
- preparing geo-spatial data for the other system components to be consumed via Web services,
- uploading required files to the Grid environment for a model run,
- downloading and processing the model results received from the Grid,
- changes the format of each Grass-Ascii files to ESRI-Ascii format,
- creating maps by overlaying model results received,
- publishing the map by a web mapping service,
- changes the basket-web application and adds the meta-information in the headline

8 THE SYSTEM VALIDATION

8.1 GIS Module Validation

The GIS server environment used state-of-the-art GIS standards for the SCIER test purposes as mentioned in several project documentation (Bonazountas, et al., 2007; Bonazountas, et al., 2009; Hadjiefthymiades, et al., 2008; Metelka, Caballero, & Kirklis, 2008). The SCIER's GIS database and the software environment are not only based on the existing standards, they have been created from different GIS data sources and were tested for several conditions and assessed on their performance for the SCIER's modeling requirements.

8.1.1 Validating Metadata Content

Metadata is critical for sharing tools, data, and maps and for searching to see if the resources you need already exist. Metadata describes GIS resources in the same way a card in a library's card catalog describes a book. Once you've found a resource with a search, its metadata will help you decide whether it's suitable for your purposes. To make this decision, you may need to know how accurate or current the resource is and if there are any restrictions on how it can be used. Metadata can answer these questions. Any geo-spatial data in SCIER's GIS environment has metadata.

Metadata is divided into properties and documentation in SCIER-GIS. Documentation is descriptive information supplied by me as the system administrator using a metadata editor, for example, a description of and legal information about using the resource. In this common approach, each GIS resource has its own discrete metadata document. Metadata created is stored as XML data, within the SCIER's geodatabase in ArcSDE® database management system. In the geodatabase, metadata is stored in the GDB_UserMetadata table as a BLOB of XML data. For instance, in a metadata XML document, the title is stored as follows: <title>My Document</title>. The XSL stylesheet selects the title and defines how to display it in HTML format as follows: <P><B><xsl:value-of select="title" /></B></P>. The metadata then appears in the Metadata tab in ArcCatalog (see Figure 8-1).

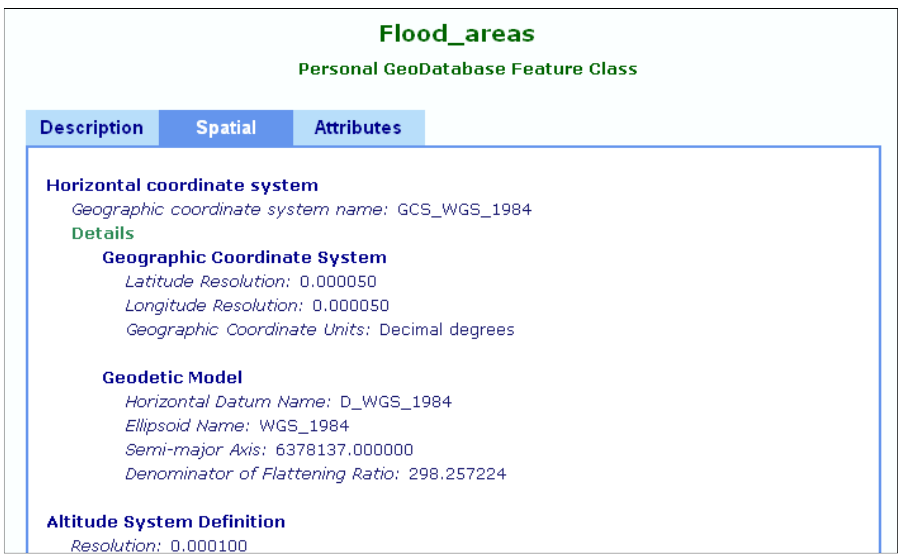


Figure 8-1: Visualization of the metadata content of flood maps in ArcCatalog.

Metadata in SCIER-GIS is stored in an ESRI-defined XML format that combines elements defined in the esriprof80 and ESRI_ISO1 DTDs. The esriprof80.dtd file defines the storage format for metadata adhering to the ESRI Profile of the Content Standard for Digital Geospatial Metadata. The ESRI_ISO1.dtd file defines the ESRI-ISO format for metadata adhering to the ISO 19115 standard, Geographic Information Metadata.

One aspect of validation is checking metadata content against a metadata standard's rules to see if all of the appropriate information has been provided. Another aspect of validation is checking a metadata XML file's structure against the standard's rules to see if it is properly formatted.

8.1.2 Tests on Web-GIS Applications

As stated in the initial system validation tests, the SCIER-GIS Module was tested with the following functionalities:

- Manual simulation start,
- Simulation result storage,
- Simulation result computation,
- Simulation result visualizations.

Since the other system components were capable of running the simulations and of providing the output information to the GIS component, the related tabular and GIS data was totally integrated with Web-GIS user interfaces. Functionality of SCIER-GIS was tested and the results are given in following:

- Simulation parameters can be setup in GIS environment and they are used for the simulations in forest fire and flood,
- Simulation results are placed in the geo-database within the SCIER-GIS,
- Simulation results were successfully presented by the GIS based Web user interfaces.

In summary, several tests and technical work has been finalized successfully. The integration of the models on the GIS platform has been validated with regard to the identification of requirements and functional description of the processes, specifying the objective, dependencies, input and output data. Not only the initial implementation is operational, but also the IT environment of the SCIER-GIS was fine-tuned and adjusted to fulfill the SCIER user requirements.

8.2 End-to-End System Validation

This section outlines the validation results for the SCIER system which is adapted from the SCIER Project deliverable D4.2. Operational SCIER Platform Validation Report (Priggouris, et al., 2009) . The term validation can be interpreted as an experimental procedure or a testing method, in general, by which it is verified that the implemented system performs according to its design specifications.

SCIER's computational system is based on state-of-art technologies in the areas of computer modeling and simulation and of wireless sensor networks. These technologies are fused into one integrated system that facilitates the disaster management of forest fires and floods. Therefore, it is a highly complicated system in which all components will be put into operation either in series or simultaneously in parallel to obtain the specified results within specified accuracy ranges (Priggouris, et al., 2009).

All SCIER subsystems and the integrated SCIER platform faced intensive testing to verify that operate normally and as expected. This is a complicated process through which the system's full functionality was validated. First, each subsystem component was proof tested individually in order to verify that it functions normally and according to its specifications. Second, as the subsystem implementation progresses, a series of tests were carried out at each stage of development that involves the addition of a new feature and/or component. Third, the fully implemented subsystems were tested with simulated sensor data and finally, the fully integrated system was tested both in the laboratory and in the field (Bonazountas, et al., 2009; Priggouris, et al., 2009).

The validation of the SCIER system was established by the successful outcome of a series of testing sessions which covers the stages like;

- Ad-hoc ('bench') testing of the subsystems and their components and interfaces during implementation.
- Testing of the subsystems and of the integrated system functionalities through laboratory (indoors) and field experiments (outdoors) in order to test their performance under semi-operating conditions.

- In-situ testing of the integrated system under real operating conditions through field trials.
- Tests analysis and assessment of the overall system performance with respect to the design specifications and the user requirements.

The validation and evaluation aims at proving and substantiating that the system performance is in accordance with the general and specific objectives of the project.

8.2.1 Sensor Visualization

During the system tests, large amount of values were collected per sensor. These entire data were properly transferred into the CS database. Meanwhile the system implementation has been carried out and applied within the SCIER-GIS as planned. So called the UpdateService was made for to update the LACU and the Sensor layer in the geodatabase which includes all LACU related information. The computational implementation was based on a local web service. It briefly consumes the related Web service in DSManager every 300 Seconds and loops through the list of LACUs and for each LACU it loops through each sensor which is registered for each LACU. This information is collected and written to the corresponding database in the layer for LACUs and Sensors. During its iteration through the list of LACUs and sensors the component checks if the LACU or one of its sensors are already written to the database. If it detects a dataset for such an entity it updates all attributes with the values from the DSManager; without changing the geographical position. Due to the behavior of the session management in the SCIER-GIS and its session in a geodatabase connection it can take some time until a change on the geodatabase is visible in the map (Priggouris, et al., 2009). At the end of this step of the validation, SCIER-GIS successfully visualized sensor related information via Web-GIS user interface.

8.2.2 Testing Flood Modeling

There were approximately 400 computations launched in the CS environment and registered in the CS database. Results of the simulations were presented in the Web-GIS user interface. All system components were tested with the cooperation of DHI, NKUA, and Epsilon for a quite long period of time. Stability of the CS and GIS was very good after solving initial problems within the configuration. The simulation was run for historical rain event stored in the database. In this case the simulation is executed via Web-GIS application. Values from the virtual sensors were multiplied to create rainfall big enough to create flooding. In conclusion this scenario works smoothly without any problem (Priggouris, et al., 2009).

8.2.3 Testing Forest Fire Modeling

After the successful data transfer into the SCIER-GIS, numerous computations were initialized in the CS environment with the contribution of the GIS. As it was planned, the results of the simulations were presented in the Web-GIS application. Briefly SCIER-GIS was tested to fulfill following functionalities which were successfully performed (Priggouris, et al., 2009):

- Collecting, processing and storage of the input files for a model run
- Running the model with the specified parameters via web user interface
- Providing GIS data by the SCIER-GIS geodatabase access
- Performing required processing for the data received as a model result changes (Grass-Ascii to ESRI-Ascii),
- And publishing maps and results via a Web-GIS applications.

9 CONCLUSION AND RECOMMENDATIONS

The dramatic increase of natural hazards in the last years has lead to an urgent social and economic demand for improved prediction and sustainable prevention. Counteracting measures require reliable information on the characteristic features of floods and fires, the temporal evolution and spatial extent, which can be investigated by means of sophisticated simulation techniques by the help of field sensors. One of the major tasks in GIS based disaster management is to link recent progress in atmospheric and hydrological sciences to improve forecasting and control. In this context, the main objective of the EU funded project SCIER was to make the much neglected URI zone safer for the European citizens against two types of natural hazards namely, forest fires and floods. It provides Civil Protection Authorities with a means for managing crisis situations caused by these natural disasters.

The presented study, prepared within the SCIER project, focused this issue on Grid and GIS integration activities. Referring to the research questions and the hypothesis that stated in the first chapter of this thesis, several implementations and an intensive development work was performed as proof of concept. As a final product, the GIS component has the following characteristics:

- The sensing infrastructure is coupled with the SCIER GIS platform for assessing the spatial distribution of the sensing components,
- The sensing subsystem is also carefully monitored through the SCIER-GIS to constantly keep track of the required sensor density and other related characteristics.
- Computational subsystem of the project delivers model outputs to the GIS, thus the user interface creates a visual representation of its evolution, as well as of any emerging related risks.
- Results of the disaster models are visualized on a Web-GIS platform by exploring Grid technology.
- The GIS component provides a user-friendly interface where simulations can be triggered & simulation-results can be visualized.

The crucial research question (see 1.3Research Questions), which was of integrating GIS and Grid computing for an increasing performance has been dealt, from the GIScience perspective within this research. An attempt has been made to develop a communication platform based on Web Services. This platform was applied successfully in terms of extensibility and flexibility, for the modeling of space, time and attributes. Flexibility means that object attributes and operations can be adapted at any time and any test area. Implementations within this research, demonstrated that GIS and Grid integration can be designed and implemented by utilizing these concepts from the conceptual level to the physical level.

Web based environmental modeling for forest fire and flood simulations require a huge computational effort. As presented in previous chapters above they are also based on multiple resource-intensive processing steps, which are nowadays often executed on a single computer limiting the size of environmental models, blocking the computer for the time of a simulation, and clustering the local hard drives with heaps of simulation results. Grids deliver computational power and storage capacities on demand and without the administrative effort of local computing systems. Making use of grid computing for geoprocessing and simulation tasks is thus a logical consequence.

Three major contributions were made: 1] implementing the Web based GIS server environment, 2] design of the communication tools between GIS and Grid environment, 3] the development of Web-GIS applications. All of them are based on the core issues in GIS and IT in such multi disciplinary approaches. The first contribution took more time than expected, since the server environment had to be moved to a quad-core CPU solution for the sake of overall system performance. It could have been faster and stronger system, but it was a matter of time and the budget. It is clear that there is always a better solution in such subjects but deadlines and related responsibilities had to be taken into account.

By the contribution of the all partner institutions and individual effort, the SCIER platform was successfully finalized as an operational integrated system which embodies technologies and structures from different scientific fields: wireless sensor networks, environmental engineering and modeling as well as Grid computing for parallel processing. The system was evaluated against user requirements and functional processes descriptions. The simulation parameters can be setup in a GIS environment and can be used for the computation, simulation results are stored in the GIS database and the results of simulations can be selected and presented via GIS based Web User Interfaces. The project demonstrates various key benefits of integrating sensor networks, computational modeling and Grid computing with geographic information systems. By making different systems interoperable, the combination of information from different sources is greatly facilitated. This results in enhanced information availability, better information quality, streamlined processes and improved decision support for disaster management.

In the implementation phase of this research and the related work within the SCIER Project, ESRI's ArcSDE geodatabase management system, ArcGIS Server and Desktop Technologies have been used for storing, editing, viewing spatial data, and publishing model results via Web-GIS. The delivered GIS-module meets all of the requirements for a solid and consistent operation of SCIER platform. In fact,

- The GIS module that developed for SCIER performs successfully in all use-cases,
- All Interfaces between the GIS and the Grid environment have been checked and operating successfully,
- GIS module publishes all services via Web; so that the overall system can be managed via Web based GIS solutions.

Both forest fire and flood simulations for the test areas can be triggered, either on user's request or an automatically in an alarm raised by cooperation of the field sensors and the fusion in Grid. In the first scenario, the user triggers a simulation by defining fire ignition points on the map and the rectangular box that embraces the area of interest. The user also gives the period of the simulation. On the other hand, for flood simulation, only the starting and ending time-stamp is necessary. Meteorological data on current conditions are either retrieved in real time from field sensors, or they are virtually generated at the Grid component of the project. In the second scenario, an alarm is generated by the sensor network and Grid. The fusion algorithms are deployed to elaborate sensor measurements and return a decision in Grid whether there an actual danger exists or not. This alarm triggers the simulation. This time, ignition points are referenced on the map according to the measurements received by the sensors. The rectangular box is automatically defined so that all ignition points are within the bounding box.

Finally in both use cases, the simulation results are georeferenced and visualized on a cartographic production. The results are visualized on proper satellite or aerial image from the project partners. Results of the fire simulation use a color palette to depict the time necessary for the fire-front to reach a specific pixel. The reference time-stamp is the initial starting moment. Dark colors are assigned to pixels that are affected first while Light colors are assigned to pixels that are affected last. An explanatory color palette can be found on the legend of the Web application. The network of Sensors was deployed along the test sites by the responsible project partners of SCIER. Thank NKUA and CEREN's outstanding effort on operational sensor solution, the administrators or the end-user can easily monitor the sensor network & view the current condition in real-time.

Regarding all requirements, Web-GIS applications produced accurate positioning and overlaying on the map. However, the responsiveness of the application was found quite poor at the first hardware configuration of the GIS server. Accordingly the user had to wait relatively long time for the response of the application. After upgrading to a quad-core CPU solution, the performance issue was solved. The user interface worked quite well in the case of flood and fire simulation visualizations. The scenarios were requested and after their execution in the CS, results were retrieved and visualized as expected. Moreover, visualization for all possible fire spreads instances was easy to understand. Based on concerns of the project partners, certain technical decisions were taken, in order to overcome the performance issues of the module. Several prototypes were designed and implemented, which covered all main requirements. The last implementation was a great improvement over the previous ones. Fire evolution was clearly visible, through the use time-specific curves displaying burnt area with an increasing step of minutes. Finally, a great improvement in performance (in terms of response time) was achieved. Finally the overall Web-GIS interfaces were much faster and reliable.

As the recommendation, it is strongly suggested here that the importance of computational performance in GIS is indisputable. The last two decades have witnessed the development of GIS and Grid based activities from various perspectives. But there are a number of problems associated with the design and implementation. Many researchers have endeavoured to provide insight into the various issues associated with such integration efforts. Plenty of issues and barriers have been identified in the implementation, such as the full integration of GIS within the Grid, computational requirements, spatio-temporal modeling, architecture, system design, clustering, algorithms, and technological development.

This research does not address all aspects relating to developing GIS applications in Grid environment. This thesis just touches the tip of the iceberg. Yet the research does provide a basis for further GIS enhancements within the Grid computing. The main areas for future work directly relevant to the research and require extra effort are as follows:

- The complexity of the environmental models shall be investigated with different datasets and more time series data. It would provide better evaluation if this model could be compared with different spatiotemporal models in terms of database size and data accessing time.
- In the future, it will be necessary to find one and only portal to connect all environmental models. Accommodate services via only one state-of-the-art Geo-portal, instead of separate Interfaces. Currently, SCIER uses one Interface for Flood-simulation and three Interfaces for Fire simulation: triggering, viewing results, monitoring the sensor network.
- The research does not address the GIS and Grid standardization issues. How to formulate and officialise such integration issues is another active area of research for OGC and Open Grid Forum (OGF). However, the data structure provides a sufficient basis for visualizing space-time, such as the space-time cube.
- When the standards are well-defined, we can also provide geo-spatial services for the free of charge Earth Viewers like ArcGIS Explorer, MS Virtual Earth or Google Earth. So that a detailed basemap and imagery could be also provided for viewing simulation results.
- It is so important extending the functionality of the platform as a Web portal that it can include services for emergency management and decision making such as fleet and resource management, optimum routing, and evacuation plans.

For future applications a total integration of GIS within the Grid computing will be an important step towards faster and more durable hazard predictions. Coupled GIS and Grid will then be a more applicable tool for such early warning systems. On the hand, close cooperation between the relevant standardization organizations like OGC and Open Grid Forum (OGF) plays a crucial role. Standardization will provide a solid ground for application developers and service providers. Interoperability between Grid computing environments and GIS applications is the first step towards an even broader acceptance of Grid computing within the geo-spatial sciences.

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APPENDICES

Appendix A: The list of Grid projects funded by the EU under FP5

ASP-BP

Focus: Development of a framework for 6 experiments regarding ASP technology-based applications applied in different industrial fields.

Start date: 01/05/2002, End date: 30/04/2004, Contract Type: Accompanying Measure

CROSSGRID

Focus: Development of techniques for large-scale grid-enabled real-time simulations and visualisations.

Start date: 01/03/2002, End date: 28/02/2005, Contract Type: RTD

FLOWGRID

Focus: On-demand Computational Fluids Dynamics simulation and visualisation using Grid computing.

Start date: 01/09/2002, End date: 31/12/2004, Contract Type: RTD

GRACE

Focus: Development of a search and categorisation engine for flexible allocation of computational and data storage resources in Grid environments.

Start date: 01/09/2002, End date: 28/02/2005, Contract Type: RTD

GRASP

Focus: Development of architecture and business models for delivering ASP services over the Grid-enabled networks.

Start date: 01/04/2002, End date: 30/09/2004, Contract Type: RTD

GRIA

Focus: Development of business models and processes that make it feasible and cost-effective to offer and use computational services securely in an open Grid marketplace.

Start date: 01/12/2001, End date: 30/11/2004, Contract Type: RTD

GRIDLAB

Focus: Development of software capable of fully exploiting dynamic resources.

Start date: 01/01/2002, End date: 31/12/2004, Contract Type: RTD

GRIDSTART

Focus: Accompanying measure with objective of maximising the impact of EU-funded Grid and related activities through 'clustering'.

Start date: 01/04/2002, End date: 31/03/2005, Contract Type: Accompanying Measure

GRIP

Focus: Interoperability of Globus and UNICORE, two leading software packages central to the operation of the Grid.

Start date: 01/01/2002, End date: 29/02/2004, Contract Type: RTD

OPENMOLGRID

Focus: Development of tools for molecular design based on UNICORE enabled distributed computing environments.

Start date: 01/09/2002, End date: 30/11/2004, Contract Type: RTD

SELENE

Focus: Identification of technologies for managing, syndicating and personalising online education resources.

Start date: 02/11/2002, End date: 31/10/2003, Contract Type: Accompanying Measure

WEBSI

Focus: Data-centric web services integration to support the development and deployment of ASP-based business applications.

Start date: 01/05/2002, End date: 30/04/2004, Contract Type: RTD

Appendix B: The list of Grid-related projects monitored by other Units

DAMIEN

Focus: Development of essential software supporting the Grid infrastructure.

Start date: 01/01/2001, End date: 30/06/2003, Contract Type: RTD

DATAGRID

Focus: Development of techniques supporting the processing and data-storage requirements of next generation scientific research.

Start date: 01/01/2001, End date: 31/12/2003, Contract Type: RTD

DATATAG

Focus: Development of techniques to support reliable and high-speed collaboration across widely distributed networks.

Start date: 01/01/2002, End date: 31/12/2003, Contract Type: RTD

EUROGRID

Focus: Development of core Grid software components.

Start date: 01/11/2001, End date: 31/10/2003, Contract Type: RTD

MAMMOGRID

Focus: Application of Grid technology to develop a European-wide database of mammograms and to support effective co-working between EU healthcare professionals.

Start date: 01/09/2002, End date: 31/08/2005, Contract Type: RTD

LeGE-WG

Focus: Thematic Network facilitating the establishment of a European Learning Grid Infrastructure by supporting the systematic exchange of information and by creating opportunities for close collaboration between the different actors.

Start date: 01/08/2002, End date: 31/07/2004, Contract Type: Thematic Network

BIOGRID

Focus: Trial for the introduction of a grid approach in the biotechnology industry.

Start date: 01/09/2002, End date: 31/08/2004, Contract Type: RTD

COG

Focus: Demonstration of the applicability of Grid technologies to industry.

Start date: 01/09/2002, End date: 29/02/2004, Contract Type: RTD

GEMSS

Focus: Development of new Grid-enabled tools for improved diagnosis, operative planning and surgical procedures.

Start date: 01/09/2002, End date: 28/02/2005, Contract Type: RTD

Appendix C: The list of Grid projects launched by the European Commission under FP6 (EU-ICT, 2008).

Acronym	Title	Contract Type
Akogrimo	Access to Knowledge through the Grid in a mobile World	Integrated Project
ARGUGRID	ARGUmentation as a foundation for the semantic Grid	Specific targeted research project
AssessGrid	Advanced Risk Assessment and Management for Trustable Grids	Specific targeted research project
A-WARE	An easy way to access GRID resources	Specific targeted research project
BEinGRID	Business experiments in GRID	Integrated Project
BREIN	Business objective driven reliable and intelligent grids for real business	Integrated Project
BRIDGE	Bilateral research and industrial development enhancing and integrating GRID enabled technologies	Specific targeted research project
CHALLENGERS	Support Action on CHALLENGEs in GRidS	Specific Support Action
Chemomentum	Grid services based environment to enable innovative research	Specific targeted research project
CoreGRID	European Research Network on Foundations, Software Infrastructures and Applications for large scale distributed, Grid and Peer-to-Peer Technologies	Network of excellence
DataMiningGrid	Data Mining Tools and Services for Grid Computing Environments	Specific targeted research project
DEGREE	Dissemination and exploitation of grids for earth science	Specific Support Action
EC-GIN	Europe-China grid InterNetworking	Specific targeted research project
EchoGRID	EC-China strategic GRID Roadmap	Specific Support Action
Edutain@Grid	A scalable QoS-enabled business grid environment for multi-user real-time online interactive applications	Specific targeted research project
g-Eclipse	An integrated, grid enabled worench tool for grid application users, grid developers and grid operators based on the eclipse platform	Specific targeted research project

GREDIA	Grid enabled access to rich media content	Specific targeted research project
Grid@Asia	Advanced Grid Research Workshops through European and Asian Co-operation	Specific support action
GridCOMP	GRID programming with Components: an advanced component platform for an effective invisible grid	Specific targeted research project
GridCoord	ERA Pilot on a co-ordinated Europe-wide initiative in Grid Research	Specific support action
GridEcon	Grid economics and business models	Specific targeted research project
Grid4All	Self- Grid: Dynamic virtual organizations for schools, families, and all	Specific targeted research project
GridTrust	Trust and security for next generation grids	Specific targeted research project
HPC4U	Highly Predictable Cluster for Internet-Grids	Specific targeted research project
InteliGrid	InteroperabilIty of Virtual Organisations on Complex Semantic Grid	Specific targeted research project
KnowARC	Grid-enabled Know-how sharing technology based on ARC services and open standards	Specific targeted research project
K-WF Grid	Knowledge-based Workflow System for Grid Applications	Specific targeted research project
Nessi-Grid	Networked European software and services initiative-grid	Specific Support Action
NextGRID	The Next Generation Grid	Integrated Project
OntoGrid	OntoGrid: Paving the way for knowledgeable Grid services and systems	Specific targeted research project
Provenance	Enabling and Supporting Provenance in Grids for Complex Problems	Specific targeted research project
QosCosGrid	Quasi-opportunistic supercomputing for complex systems in grid environments	Specific targeted research project
SIMDAT	Data Grids for Process and Product Development using Numerical Simulation and Knowledge Discovery	Integrated Project
SORMA	Self-organizing ICT resource management	Specific targeted research project
UniGridS	Uniform Interface to Grid Services	Specific targeted research project
XtreemOS	Building and promoting a Linux-based operating system to support virtual organizations for next generation grids	Integrated project

Appendix D: The list of Grid projects funded by the EU under FP7

ACTION-GRID

Title: International cooperative action on grid computing and biomedical informatics between the European Union, Latin America, the Western Balkans and North Africa

Research area: ICT-2007.5.3 Virtual physiological human

Funded under 7th FWP (Seventh Framework Programme)

Project start date: [2008-06-01]

ADMIRE

Title: Advanced data mining and integration research for Europe

Research area: ICT-2007.1.2 Service and Software Architectures, Infrastructures and Engineering

Funded under 7th FWP (Seventh Framework Programme)

Project start date: [2008-03-01]

AVERT-IT

Title: Advanced arterial hypotension adverse event prediction through a novel Bayesian neural network

Research area: ICT-2007.5.2 Advanced ICT for risk assessment and patient safety

Funded under 7th FWP (Seventh Framework Programme)

Project start date: [2008-01-01]

COMIFIN

Title: Communication middleware for monitoring financial CI

Research area: ICT-SEC-2007.1.7 Critical infrastructure protection

Funded under 7th FWP (Seventh Framework Programme)

Project start date: [2008-09-01]

HD-MPC

Title: Hierarchical and distributed model predictive control of large-scale systems

Research area: ICT-2007.3.7 Network embedded and control systems

Funded under 7th FWP (Seventh Framework Programme)

Project start date: [2008-09-01]

MOBESENS

Title: Mobile water quality sensor system

Research area: ICT-2007.6.3 ICT for environmental management and energy efficiency

Funded under 7th FWP (Seventh Framework Programme)

Project start date: [2008-06-01]

PREDICT

Title: Computational prediction of drug cardiac toxicity

Research area: ICT-2007.5.3 Virtual physiological human

Funded under 7th FWP (Seventh Framework Programme) Project start date: [2008-06-01]

RESERVOIR

Title: Resources and services virtualisation without barriers

Research area: ICT-2007.1.2 Service and Software Architectures, Infrastructures and Engineering

Funded under 7th FWP (Seventh Framework Programme)

Project start date: [2008-02-01]

SEMSORGRID4ENV

Title: Semantic sensor grids for rapid application development for environmental management

Research area: ICT-2007.6.3 ICT for environmental management and energy efficiency

Funded under 7th FWP (Seventh Framework Programme)

Project start date: [2008-09-01]

SHAMAN

Title: Sustaining heritage access through multivalent archiving

Research area: ICT-2007.4.1 Digital libraries and technology-enhanced learning

Funded under 7th FWP (Seventh Framework Programme)

Project start date: [2007-12-01]

SHAPE

Title: Semantically-enabled heterogeneous service architecture and platforms engineering

Research area: ICT-2007.1.2 Service and Software Architectures, Infrastructures and Engineering

Funded under 7th FWP (Seventh Framework Programme)

Project start date: [2007-12-01]

SMARTHOUSE/SMARTGRID

Title: Smart houses interacting with smart grids to achieve next-generation energy efficiency and sustainability

Research area: ICT-2007.6.3 ICT for environmental management and energy efficiency

Funded under 7th FWP (Seventh Framework Programme)

Project start date: [2008-09-01]

SMARTLM

Title: Grid-friendly software licensing for location independent application execution

Research area: ICT-2007.1.2 Service and Software Architectures, Infrastructures and Engineering

Funded under 7th FWP (Seventh Framework Programme)

Project start date: [2008-02-01]

TIPS

Title: Thin interconnected package stacks

Research area: ICT-2007.3.6 Micro/nanosystems

Funded under 7th FWP (Seventh Framework Programme) Project start date: [2008-09-08]

LIST OF ABBREVIATIONS

ADAI: Associação para o Desenvolvimento da Aerodinâmica Industrial

ADF: Application Developer Framework

AJAX: Asynchronous JavaScript and XML

AoI: Area of interest

API: Application Programming Interface

AVHRR: Advanced Very High Resolution Radiometer

CEREN: Centre d'Essais et de Recherche de l'Entente

CNL: Communications Network Laboratory

CS: Computing Subsystem

CSA: Critical Source Area

DAG: Direct Acyclic Graph

DEM: Digital Elevation Model

DHI: Danish Hydraulics Institute

DLR: Deutsches Zentrum für Luft- und Raumfahrt: German Aerospace Centre

DSM: Data Storage Manager

DSS: Decision Support Systems

DST: Dempster Shafer Theory

EC/DGINSFO: EC DG Information Society & Media

EEA: European Environment Agency

EGEE: Enabling Grids for E-sciencE

EPSILON: Epsilon International SA

ESCIMO: Energy Snow Cover GIS Integrated Model

ET: Evapotranspiration. It is the sum of evaporation and plant transpiration. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and waterbodies. Evapotranspiration plays an important role in the water cycle.

EU: European Union with 27 Member States

FF: Forest Fire modeling

FL: Flood modeling

FSE: Fire Sread Engine

G4S: Group 4 Securicor Security Services

GDI-Grid: Spatial Data Infrastructure Grid Project

GIS: Geographical Information System

GEO-Grid: Global Earth Observation Grid

GRASS: Geographic Resources Analysis Support System

GRID: Grids and Grid technologies for wide-area distributed computing

GSIFTP: Grid Security Infrastructure File Transfer Protocol

IR: Infrared

JDL: Job Description Language

LACU: Local Area Controlling Unit

LAI: Leaf Area Index

LAM: Limited Area Model

LB: Logging and Bookkeeping

LCG: LHC Computing Grid

LFN: Logical File Name

MAP: Mesoscale Alpine Program Meso-NH Mesoscale Nonhydrostatic Model

MIKE11: A software technology for mathematical one dimensional flood modeling

MSM: Combined METEOSAT - Station Measurement technique

NNQ: Lowest runoff ever measured

NWP: Numerical Weather Prediction

OGC: Open Geospatial Consortium

OGF: Open Grid Forum

OWS: OGC Web Services

PAR: Photosynthetically Active Radiation

PDUS: Primary Data User Station

PET: Potential evapotranspiration

PP: Perfect Prog

RDP: Remote Desktop Protocol

SDI: Spatial Data Infrastructure

SIF: Simulation Interface

SOA: Service Oriented Architecture

SOAP: Simple Object Access Protocol

SOC: Server Object Container

SOM: Server Object Manager

SOP: Special Observation Period

SRMAX: Maximum storage in the upper soil layer

SVAT: Soil-Vegetation-Atmosphere-Transfer

TFM: Temperature Field Model

TOPMODEL: TOPographic MODEL

URI: Urban-Rural Interface

USDA: United States Department of Agriculture

UTM: Universal Transversal Mercator

VO:	Virtual Organisation
WD:	Wind Direction
WMS:	Web Map Service
WFS:	Web Feature Service
WPS:	Web Processing Service
WN:	Worker Node
WS:	Wind Speed
WSN:	Wireless Sensor Network
WSRF:	Web Services Resource Framework
WTS:	Windows Terminal Server
WUI:	Wildland Urban Interface