İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

INTEGRATION OF DATA RELATED TO EARTHQUAKES FROM A VARIETY OF DISCIPLINES IN A WEB-GIS

Ph.D. Thesis by
Aslı GARAGON DOĞRU, M.Sc.

Department : **GEODESY AND PHOTOGRAMMETRY ENGINEERING**

Programme: **GEOMATIC ENGINEERING**

APRIL 2008

İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

INTEGRATION OF DATA RELATED TO EARTHQUAKES FROM A VARIETY OF DISCIPLINES IN A WEB-GIS

Ph.D. Thesis by
Aslı GARAGON DOĞRU, M.Sc.

(501022311)

Date of submission : **26 September 2007**

Date of defence examination: **16 April 2008**

Supervisor (Chairman): **Prof. Dr. Gönül TOZ**

Members of the Examining Committee **Prof.Dr. Orhan ALTAN (İ.T.Ü.)**

Prof.Dr. Onur GÜRKAN (B.Ü.)

Prof.Dr. Haluk EYİDOĞAN (İ.T.Ü.)

Prof.Dr. Niyazi TÜRKELLİ (B.Ü.)

APRIL 2008

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

DEPREM ARAŞTIRMALARINA YÖNELİK OLARAK FARKLI DİSİPLİNLERDEN GELEN VERİLERİN WEB TABANLI COĞRAFİ BİLGİ SİSTEMİNE ENTEGRASYONU

DOKTORA TEZİ

Y. Müh. Aslı GARAGON DOĞRU
(501022311)

Tezin Enstitüye Verildiği Tarih : 26 Eylül 2007
Tezin Savunulduğu Tarih : 16 Nisan 2008

Tez Danışmanı : **Prof.Dr. Gönül TOZ**

Diğer Jüri Üyeleri **Prof.Dr. Orhan ALTAN (İ.T.Ü.)**

Prof.Dr. Onur GÜRKAN (B.Ü.)

Prof.Dr. Haluk EYİDOĞAN (İ.T.Ü.)

Prof.Dr. Niyazi TÜRKELLİ (B.Ü.)

NİSAN 2008

PREFACE

I would like to thank my supervisor Prof. Dr. Gönül TOZ for her consultation and support. I wish to extend my thanks to Prof. Dr. Onur GÜRKAN and Prof. Dr. Orhan ALTAN for their guidance, comments, and suggestions during my study. I also would like to thank my colleagues in Geodesy Department of Kandilli Observatory and Earthquake Research Institute of Boğaziçi University, Assoc. Prof. Dr. Haluk ÖZENER and Prof. Dr. Gülay BARBAROSOĞLU for their supports and encouragement. I am greatly indebted to Dr. Doğan ŞEBER for his guidance and support from San Diego Supercomputer Center of University of California, and my friends Ashraf MEMON, Dr. Choonhan YOUN, and Ghulam MEMON, without their supports, this thesis would not be completed. I also would like to express my appreciation to Raif İLLEEZ who helped me throughout this study. I would like to give a special thanks to my husband Polat DOĞRU for his patience, understanding, encouragement, and support at every part of my life.

APRIL, 2008 Aslı GARAGON DOĞRU

ÖNSÖZ

Tez danışmanım sayın Prof.Dr. Gönül TOZ'a yol gösterimi ve desteği için teşekkürlerimi sunarım. Ayrıca, sayın Prof.Dr. Onur GÜRKAN ve sayın Prof.Dr. Orhan ALTAN'a çalışmam sırasındaki yardımları, yorumları ve önerileri için teşekkür ederim. Boğaziçi Üniversitesi Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü Jeodezi Ana Bilim Dalı'ndaki meslektaşlarıma, sayın Doç.Dr. Haluk ÖZENER'e ve sayın Prof.Dr. Gülay BARBAROSOĞLU'na destekleri ve yüreklendirmeleri için teşekkür ederim. ABD Kaliforniya Üniversitesi San Diego Süperbilgisayar Merkezi'nden sayın Dr. Doğan ŞEBER'e yol gösterimi ve desteği için müteşekkirim, arkadaşlarım Ashraf MEMON, Dr. Choonhan YOUN ve Ghulam MEMON'ın yardımları olmasaydı bu çalışma tamamlanamazdı. Ayrıca tez çalışmam sırasında yardımlarını esirgemeyen Raif İLLEEZ'e de teşekkür ederim. Eşim Polat DOĞRU'ya sabrı, anlayışı, yüreklendirmesi ve hayatımın her aşamasındaki desteği için en içten teşekkürlerimi sunarım.

NİSAN, 2008 Aslı GARAGON DOĞRU

TABLE OF CONTENTS

ABBREVIATIONS

AF	: African Tectonic Plate
a.k.a.	: Also Known As
apGrid	: Asia-Pacific Grid
API	: Application Programming Interface
APKIM	: Actual Plate Kinematic Model
AR	: Arabian Tectonic Plate
ASCII	: American Standard Code for Information Interchange
ASP	: Active Server Pages
BU	: Bogazici University
BSD	: Berkeley Software Distribution
CC	: Corelation Coefficient
CGI	: Common Gateway Interface
CMT	: Centroid Moment Tensor
CPU	: Central Process Unit
CORBA	: Common Object Request Broker Architecture
CORS-TR	: Continuously Operating Reference Stations Project for Turkey
CUAHSI	: Consortium of Universities for the Advancement of Hydrologic Science
D	: Dimension
DARPA	: Defense Advanced Research Projects Agency
DCOM	: Distributed Component Object Model
DNN	: DotNetNuke
EAF	: East Anatolian Fault
EPS	: Encapsulated PostScript File
ESRI	: Environmental Systems Research Institute
EU	: Eurasia Tectonic Plate
EU	: European Union
FEM	: Finite Element Method
GCM	: General Command of Mapping
GDAL	: Geospatial Data Abstraction Library
GEON	: Geoscience Network
GFW	: World Fike for GIF Image
GIF	: Graphics Interchange Format
GIS	: Geographical Information System
GMT	: Generic Mapping Tools
GNSS	: Global Navigation Satellite Systems
GNU	: GNU's not Unix (a recursive acronym)
GPS	: Global Positioning System
GRASS	: Geographic Resources Analysis Support System
HIS	: Hydrologic Information System
HPC	: High Performance Computing
HTML	: Hypertext Markup Language

HTTP	: Hypertext Transfer Protocol
IBM	: International Business Machines
IGS	: International GPS Service
IIS	: Internet Information Server
IMS	: Internet Map Server
IO	: Input-Output
IP	: Internet Protocol
IT	: Information Technology
ITRF	: International Terrestrial Reference Frame
ITU	: Istanbul Technical University
iVDGL	: International Virtual Data Grid
JPEG	: Joint Photographic Experts Group
JSP	: Java Server Pages
JSR	: Java Specification Request
J2SDK	: Java 2 Platform Software Development Kit
J2SE	: Java 2 Platform Standard Edition
JUMP	: Java Unified Mapping Platform
KOERI	: Kandili Observatory and Earthquake Research Institute
km	: Kilometer
LIDAR	: Light Detection and Ranging
M	: Magnitude
MIT	: Massachusetts Institute of Technology
MS	: Microsoft
NAF	: North Anatolian Fault
NASA	: National Aeronautics and Space Administration
NEAF	: Northeast Anatolian Fault
NEMC	: National Eearthquake Monitoring Center
NeSC	: National e-Science Centre
Nm	: Newton meter
NNR	: No Net Rotation
NPACI	: National Partnership for Advanced Computational Infrastructure
NSF	: National Science Foundation
NUVEL	: Northwestern University Velocity Model
OGR	: OpenGIS Simple Features Reference Implementation
OGC	: Open Geospatial Consortium
ORB	: Object Request Brokers
ORCHESTRA	: Open Architecture and Spatial Data Infrastructure for Risk Management
PCs	: Personal Computers
PHP	: Hypertext Preprocessor
PS	: PostScript File
RDBMS	: Relational Database Management System
RINEX	: Receiver Independent Exchange Format
SCEC	: Southern California Earthquake Center
SCOOP	: SURA (Southeastern Universities Research Association) Coastal Ocean Observing and Prediction
SLR	: Satellite Laser Ranging
SOA	: Service Oriented Architecture
SOAP	: Simple Object Access Protocol
SOEST	: School of Ocean and Earth Science and Technology

SQL	: Structured Query Language
SYNSEIS	: Synthetic Seismogram Generation Tool
TCP	: Transmission Control Protocol
TIFF	: Tagged Image File Format
TUBITAK	: Turkish Scientific and Technological Research Council
UDDI	: Universal Description, Discovery, and Integration
UK	: United Kingdom
UMN	: University of Minnesota
UNDP	: The United Nations Development Programme
URL	: Uniform Resource Locator
US	: United States
VB	: Visual Basic
VLBI	: Very Long Baseline Interferometry
VOs	: Virtual Organizations
VWD	: Visual Web Developer
WSDL	: Web Services Description Language
WSRP	: Web Services for Remote Portlets
WYSIWYG	: What You See Is What You Get
W3C	: World Wide Web Consortium
XML	: Extensible Markup Language
YTL	: New Turkish Lira

LIST OF TABLES

LIST OF FIGURES

SYMBOLOGY

x	: Coordinate of point A
x+dx	: Coordinate of point B
u(x)	: Displacement at A
u(x+δx)	: Displacement at B
ΔL	: Change of length
L	: Length
$\mathbf{e_x}$	: Strain
∂	: Derivative
$\mathbf{e_{xx}}$	: Component of strain in two-dimension
$\mathbf{e_{xy}}$	: Component of strain in two-dimension
$\mathbf{e_{yy}}$	: Component of strain in two-dimension
x,y	: Two-dimension coordinates of a point
u,v	: Rate of coordinate changes
$\mathbf{e_{ij}}$	: Strain in tensor form
ε_{ij}	: Symmetric part of strain tensor
ω_{ij}	: Anti-symmetric part of strain tensor
t	: Displacement of all points in solid body
ε_1, ε_2	: Principal axes of strain
θ	: Direction
π	: Pi
E,X	: Longitude
N,Y	: Latitude
$\mathbf{M_0}$	: Seismic moment
$\mathbf{m_{xx}, m_{yy}, m_{xy}}$	: Components of focal mechanisms solutions
$\mathbf{E_{vel}}$	: Eastward velocity
$\mathbf{N_{vel}}$	: Northward velocity
μ	: Shear modulus
V	: Cell volume
T	: Time period
$\mathbf{m_{ij}}$	: Unit moment tensor
r	: Radius of the Earth
u(r)	: Horizontal velocity field
$\mathbf{M_w}$	: Moment magnitude

INTEGRATION OF DATA RELATED TO EARTHQUAKES FROM A VARIETY OF DISCIPLINES IN A WEB-GIS

SUMMARY

The interaction between science and technology is an irrefutable fact. Scientific studies produce information and cause advances in technology while on the other hand technological progress provides us better circumstances on scientific researches. Today, there is an explosion of Earth science data in the world and it is available in digital form on the Internet. On one hand, Earth scientists have data and try to understand dynamics of the Earth. But on the other hand, each scientist develops own tool to analyse these data. However, it is better to reuse the functionality of existing systems in comparison to rebuilding them. Service-oriented technology can support strongly Earth sciences in this context. It is a practical and cost-effective solution for uniting information distributed between applications over operating system, platform, and language barriers that were previously impassable. Therefore in the past, solutions have been created for collecting, storing and accessing data, now it is a challenge to effectively share data, application and processing resources across many locations. In this study, a system was developed to access the Earth science data that is available now and data which will be coming online, and to provide users easy access to computation and visualization tools. The main goal of this study is to build an easy-to-use interactive data access and computational environment to study earthquakes in Turkey. This study also shows how the importance of Information Technology in Earth sciences has an outstanding rise.

Chapter 1 introduces the background to the research and gives an overall review of current Web-GIS applications in Earth sciences in the world, and then gives the thesis objectives. Chapter 1 also introduces background knowledge of the plate tectonic setting in Turkey and earthquake activities; briefly describes the plate tectonics theory; and finally gives a detailed introduction to the motivation of the study including definition of the problem. Chapter 2 presents the detailed information about the case study which is a strain analysis tool for seismic hazard assesment. Its main features, principle, functions, structure, and main algorithms of the programs are described in detail. Chapter 3 is about the implementation of the system. Which steps were taken specifically, which resources of information technology, and how they were used are mentioned. It explains how this system is able to solve the related problem. It also introduces data used in the study and the data storage. Chapter 4 expresses the outputs of the study. The benefits at the levels of decision making and scientific are divided into seperate titles and explained. Chapter 5 summarizes the thesis with conclusions and recommendations for future works.

DEPREM ARAŞTIRMALARINA YÖNELİK OLARAK FARKLI DİSİPLİNLERDEN GELEN VERİLERİN WEB TABANLI COĞRAFİ BİLGİ SİSTEMİNE ENTEGRASYONU

ÖZET

Bilim ve teknoloji arasındaki doğal etkileşim reddedilemez bir gerçektir. Bilimsel çalışmalar bilgi üreterek teknolojik gelişmeye yol açmakta, diğer taraftan da teknolojik gelişmeler bilimsel araştırmaların daha uygun şartlarda yapılmasını sağlayarak bilimsel gelişmeyi hızlandırmaktadır. Günümüzde, yer bilimleri verilerinde bir patlama yaşanmaktadır. Ve bu veriler internet ortamında sunulmaktadır. Yer bilimciler bir yandan sahip oldukları bu veriler ile Yer'in dinamiklerini anlamaya çalışmakta, diğer yandan, bu verileri analiz etmek için her biri kendi araçlarını yaratmaktadır. Halbuki mevcut sistemleri yeniden kullanmak, onları tekrar tekrar oluşturmaktan çok daha iyidir. Servis odaklı teknoloji, yer bilimlerine bu anlamda önemli bir destek verebilmektedir. Servis odaklı mimari, geçmişte mümkün olmayan, farklı işletim sistemleri ve platformlarda çalışan ve farklı programlama dilleri ile yaratılmış uygulamalardan elde edilecek dağıtık bilginin belli amaçlar için biraraya gelmesini sağlayan pratik ve düşük maliyetli bir çözümdür. Bu nedenledir ki geçmişte veri toplama, depolama ve ulaşma için çözümler üretilmeye çalışılırken artık günümüzde dünyada, veri, uygulama ve veri işleme kaynaklarının efektif olarak paylaşımı üzerine çalışmalar yürütülmektedir. Bu çalışmada, mevcut ve internet üzerinden gelecek olan yer bilimleri verilerine, hesap ve görselleştirme araçlarına kolay ulaşım sağlayan bir sistem geliştirilmiştir. Çalışmanın esas amacı, Türkiye'deki depremler ile ilgili çalışma yapmak isteyenlerin, kolay kullanımlı ve interaktif olarak veriye, hesap ve analiz ortamına ulaşmasını sağlamaktır. Çalışma aynı zamanda, bilgi teknolojilerinin yer bilimleri alanındaki gözeçarpan yükselişinin önemini de göstermektedir.

Birinci bölümde, araştırmanın geçmişi tanıtılmakta, dünyadan güncel Web-CBS uygulamalarına değinilmekte ve çalışmanın temel amaçları verilmektedir. Bu bölümde aynı zamanda, levha tektoniği teorisi kısaca tanımlanarak, Türkiye'nin tektonik yapısı ve depremselliği hakkında bilgi de verilmektedir. Son olarak, çalışmanın motivasyonu ve problem tanımlama ile ilgili detaylı bilgi de sunulmaktadır. İkinci bölümde, deprem tehlikesinin değerlendirilmesini sağlayan ve tezin örnek uygulaması olarak çalışılan gerinim analizi hakkında detaylı bilgi verilmektedir. Gerinim analizinin temel özellikleri, fonksiyonları, yapısı ve programların temel algoritmaları ayrıntılı olarak tanımlanmaktadır. Üçüncü bölüm, tezin uygulamasının gerçekleştirilmesi hakkındadır. Hangi adımların hangi bilgi teknolojisi kaynakları kullanılarak nasıl gerçekleştirildiğinden söz edilmiştir. Sistemin tanımlanan problemi nasıl çözdüğü açıklanmaktadır. Bu bölümde ayrıca, çalışmada kullanılan veri ve veri depolama hakkında bilgi de verilmektedir. Dördüncü bölümde çalışmanın çıktıları anlatılmaktadır.

Çalışmanın bilimsel anlamda ve karar vericiler düzeyindeki katkıları ayrı başlıklar altında değerlendirilmektedir. Beşinci bölümde, tezin sonuçları ve gelecekte yapılması planlanan çalışmalar özetlenmektedir.

1. INTRODUCTION

1.1 Introduction to Plate Tectonic Setting of Turkey and Earthquakes

Tectonic refers to rock-deforming processes and resulting structures that occur over large sections of the lithosphere. According to plate tectonics theory, the Earth's surface is characterized by relatively aseismic units or plates carrying both continental and oceanic crust **(Lambeck, 1988)**. The plates can either slide past one another, or they can collide, or they can move apart. These plates usually move at a velocity within a range of 1 to 15 cm per year. Today, the movement of tectonic plates can be directly measured by a variety of geodetic technologies, including SLR, VLBI, and GPS **(Shen, 2004)**.

Plate tectonics is a theory of geology which was developed to explain the observed evidence for large scale motions of the Earth's crust. It was originally proposed in 1912 by Alfred Wegener in Germany. Plate tectonics tells us that the Earth's rigid outer shell (lithosphere) is broken into a mosaic of oceanic and continental plates which can slide over the plastic aesthenosphere, which is the uppermost layer of the mantle. The theory has revolutionized the Earth sciences because of its unifying and explanatory power for diverse geological phenomena. Global tectonic plates, major earthquakes and tsunamis since the year of 1970 are displayed in Figure 1.1. It shows that there is a high correlation between earthquake activity and plate tectonic movements.

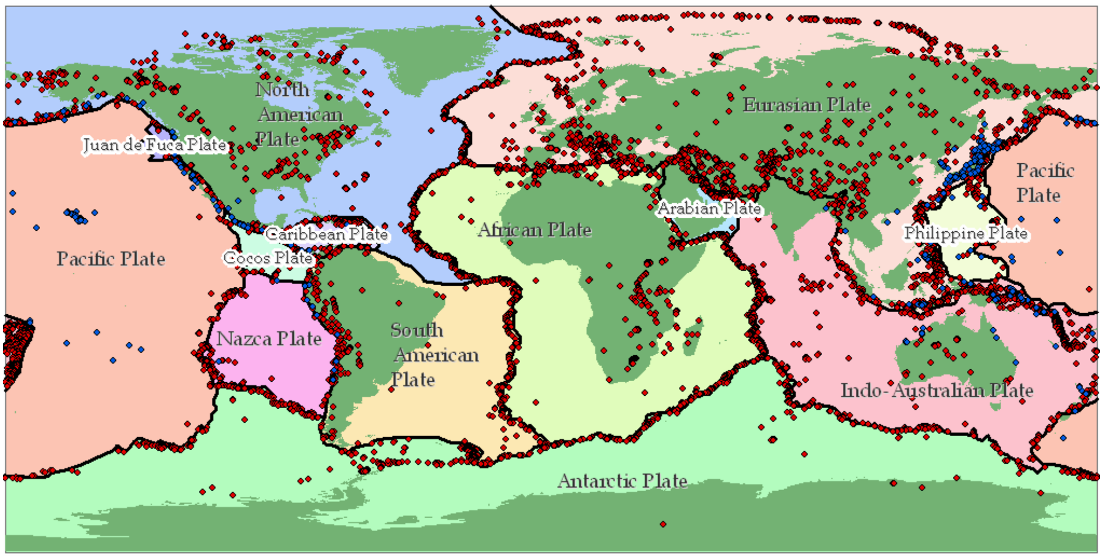

Figure 1.1: The tectonic plates of the world including earthquakes and tsunamis since 1970 (data provided by USGS)

There are seven major crustal plates which are subdivided into a number of smaller plates. They are about 80 kilometers thick, all in constant motion relative to one another. The tectonic framework of the eastern Mediterranean and Middle East region is dominated by the collision of the Arabian and African plates with Eurasia **(McKenzie, 1970; Jackson and McKenzie, 1988)** Figure 1.2 shows the tectonic plates of Turkey and surrounding regions.

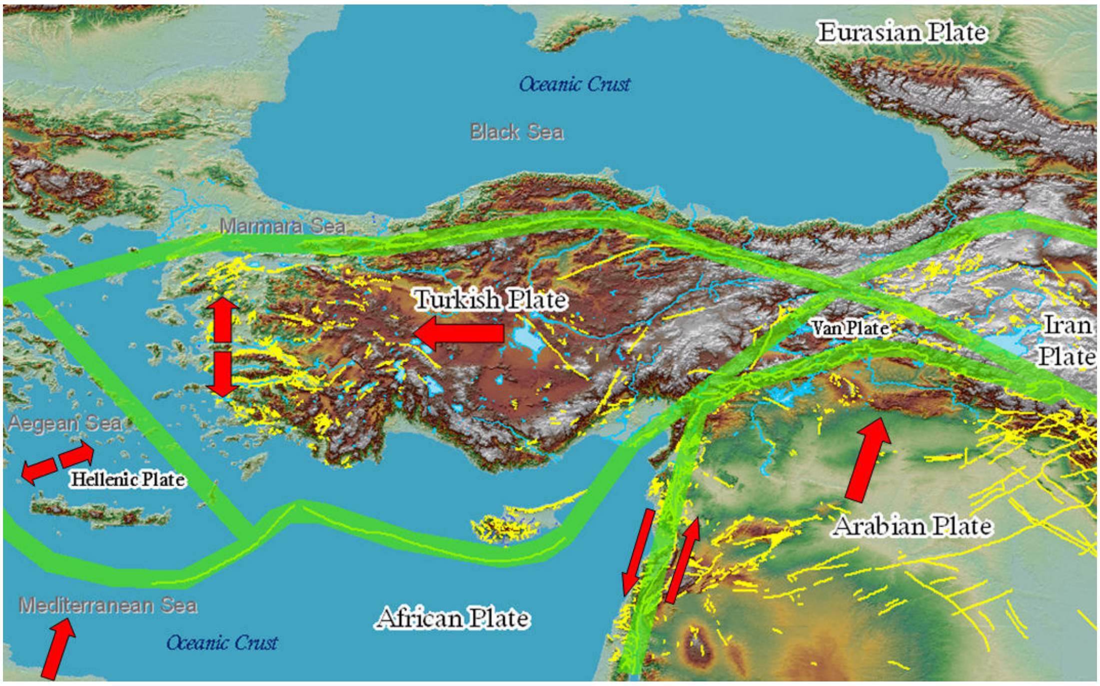

Figure 1.2: Tectonic framework of Turkey

The northward motion of Arabia is thought to contribute to westward extrusion of the Anatolian plate, which is accommodated by right-lateral slip on the North Anatolian fault and left-lateral slip on the East Anatolian fault **(McKenzie, 1970)**. GPS results provide direct estimates of Arabia-Africa-Eurasia motion, the counterclockwise rotation and associated westward motion of the Anatolian plate, and the rapid southward motion of the southern Aegean region relative to Eurasia. These results also quantify strain partitioning and crustal shortening in eastern Turkey and the Caucasus, fault-slip rates on the main active faults, and partitioning between seismic and aseismic deformation **(Reilinger et al., 2000)**. There has been three main active faults in Anatolia.

- The North Anatolian Fault (NAF), one of the most active seismic regions over the world, runs along the northern part of Turkey about 1200 km, from the Aegean Sea to the Karliova triple junction in the eastern Turkey. The North Anatolian fault is a right-lateral and continental strike-slip fault.
- The Northeast Anatolian Fault (NEAF) extends from Erzurum to the Caucasus mountains and consists of several segments with a total length of approximately 350 km **(Barka and Reilinger, 1997)**. Earthquake records are the evidence that NEAF is less active than North Anatolian Fault.
- The East Anatolian Fault (EAF) starts at around 41^{o} E (at a triple junction near Karliova) and extends southwest up to Antakya, where it joins with the Dead Sea Fault system There has been little major seismic activity associated with the EAF during this century **(Kiratzi, 1993)**.

The presence of large urban and industrial centers near the North Anatolian Fault Zone (NAFZ) around the Marmara Sea makes the assessment of the potential for large earthquakes there critical. In addition to the recent pattern of large earthquakes in western Turkey, longer-term studies of seismicity have suggested that the Marmara Sea region might be particularly susceptible to the occurrence of a large earthquake **(Meade et al., 2002)**. The eastern Turkey is also capable of generating major earthquakes in every 3-4 years. Figure 1.3 shows the seismicity of Turkey including earthquakes with magnitude 5 and more, and with depth less than 60 km. Earthquakes in the Anatolian fault system occur very near the surface and can therefore cause extreme damage. The west coast of Turkey is exposed to rather deep earthquakes from the Hellenic subduction zone.

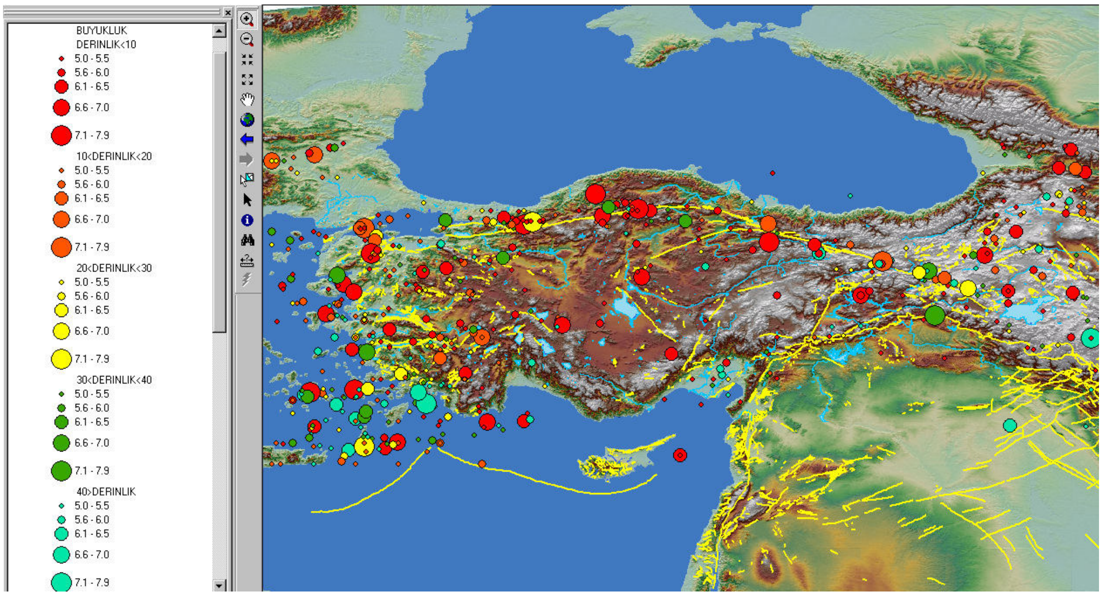

Figure 1.3: Earthquakes with magnitude 5 and more since 1900 (data provided by NEMC of KOERI)

As it is well known, Turkey is an earthquake-prone country. Earthquakes are frequent and occasionally severe. Devastating earthquakes struck Turkey several times. The large earthquakes that have occurred along the North Anatolian fault since 1939 progressed westward towards Istanbul like a line of falling dominoes. Through the horizontal movement of the Eurasian plate and the Anatolian plate past one another, pressure was built up over a long period of time. Once stress is relieved through one earthquake, it can add stress to neighboring fault segments, thus helping to set off the next earthquake. The 1939 earthquake struck the city of Erzincan and killed an estimated 30,000 people. In 1999, the Koacaeli earthquake, which struck the densely populated industrial heartland of Turkey, was responsible for 20,000 deaths and 45,000 injuries and displaced more than 300,000 people. UNDP announces Turkey as the third country after Iran and Yemen according to the number of deaths as a result of earthquakes **(Başbuğ, 2006)**. Future losses of life and property due to earthquake activity in Turkey are certain to occur.

1.2 Seismic Hazard and Seismic Risk

A natural hazard is an event that has an effect on people resulting from the natural processes in the environment. In understanding natural phenomena, it is necessary to explain concepts related to the natural hazards. Earthquake is a natural hazard that cannot be controlled or avoided. An earthquake is caused by a sudden slip on a fault **(USGS, 2008)**. Over a million earthquakes are detected by sensitive seismographs on the Earth every year. From the analysis of such records, one can conclude that small earthquakes occur more frequently than larger ones. However, over 50,000 of these earthquakes are large enough to be felt by people each year **(Morales, 2002)**. Some of the most significant earthquakes in recent times are the 9.3 magnitude 2004 Indian Ocean earthquake, the 7.6 magnitude 2005 Kashmir (Pakistan) earthquake and the 7.7 magnitude 2006 Java earthquake.

According to **Morales (2002)**, earthquake-related natural hazards can be divided into two parts: ground motion and collateral damage (Figure 1.4). As the name implies, ground motion occures when seismic waves reach the surface of the Earth. The most destructive of all earthquake hazards is caused by seismic waves reaching the ground surface at places where human-built structures, such as buildings and bridges, are located.

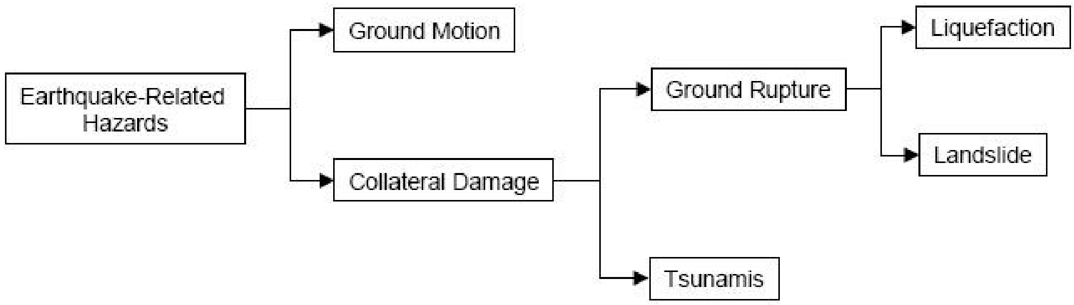

Figure 1.4: Classification of earthquake-related natural hazards **(Morales, 2002)**

The 20,000 buildings that collapsed during the Kocaeli earthquake was the principal cause of deaths and injuries. Although shaking of structures is responsible for more than 90 percent of the damage resulting from earthquakes, shifting and sinking of the ground surface can be even more destructive than shaking. Liquefaction, which transforms seemingly solid ground into a liquid-like material, caused many of the buildings during the earthquake to sink into the ground and sometimes fall over.

Natural hazards are dynamic and uncertain processes. They are dynamic because they do not always happen in isolation (as one event could trigger another, e.g. an earthquake could trigger a landslide) and because they can reshape the environment. And they are uncertain because their occurrence is generally difficult to predict.

However, earthquake-related natural hazards must be identified and determined for earthquake risk management process. How likely is it that a particular area will experience a large quake? Which kinds of damage are likely to occur with a quake of a certain magnitude, and how significant will that damage be? How many people's lives will be at risk? Answers to questions like these determine an area's seismic hazard and seismic risk **(ESRI, 2006)**. Hazard and risk are very close terms. It is important to understand the hazard. Because risk, which is quite different from hazard, is mathematically defined as the hazard **(USGS, 2008)**. Hazard is anything that can cause harm and the risk is how great the chance that someone will be harmed by the hazard. So determining seismic hazard involves attempting to estimate the likelihood of an earthquake of significant magnitude occurring in a particular region, while seismic risk seeks to quantify the amount of damage to people, property, and the environment such an earthquake would likely cause **(ESRI, 2006)**. So the formula can be expressed as follows:

$$\begin{aligned} Risk = {} & hazard\ (Probability\ of\ shaking)\ * \\ & vulnerability\ (Probability\ of\ breaking)\ * \\ & value\ (financial) \end{aligned} \qquad \textbf{(1.1)}$$

A natural disaster is the consequence of the combination of a natural hazard and human activities. A natural hazard does not result in a natural disaster in areas without vulnerability, e.g. strong earthquakes in uninhabited areas. Turkey as an earthquake country has a long history of natural hazards and disasters. And Earth scientists study for understanding Earth's crust structure and seismic hazard in Turkey. However, constructing models, accessing related data and analyse them are extremely slow in our country. However, with the help of the current information technology resources, Earth scientists in the world have now opportunities for conducting efficient research in Earth sciences to learn more about the structure of the Earth. For our country, a system can also be developed for visualizing and analysing of problems in Earth science requiring advanced computer programming skills. This system would have a potential to answer important questions to assess seismic hazrad, for example: How much stretching, squashing and shearing is taking place in different parts of Turkey? How does velocity change from place to place?

1.3 Contributions of Information Technology to Earth Sciences

The progress of the Earth sciences and the advancement of technologies associated with the understanding of the Earth during the 1940s and 1950s have forced geoscientists to develop a new way of looking at the world and how it works. Advances in information technology also have led to a fundamental change in science, and digital data collection is at the center of this change. The concept of "Digital Earth" has great impact and significance to many scientific fields. It became known in the late of 1997 for the first time and it is concerned by all over the world. The basic concept is to understand the past, present and future activities of the earth system information process, and integrate the theory and technology of Geo-sciences, information science, computer science, space exploration, digital communication, computation science and artificial intelligence to study the information progress of whole earth system (mechanical information process, physical information process, chemical information process and biological activity information process of the earth system) **(Siwen, 2001)**. There have been significant changes in the level of Earth sciences. Today, the hardware is more powerful in terms of speed and memory, the algorithms reduces the computing time, and the data and models are much more accurate and detailed then before. These significant advances have enabled scientists to do more science. Figure 1.5 expresses the interaction between the present-day IT and users.

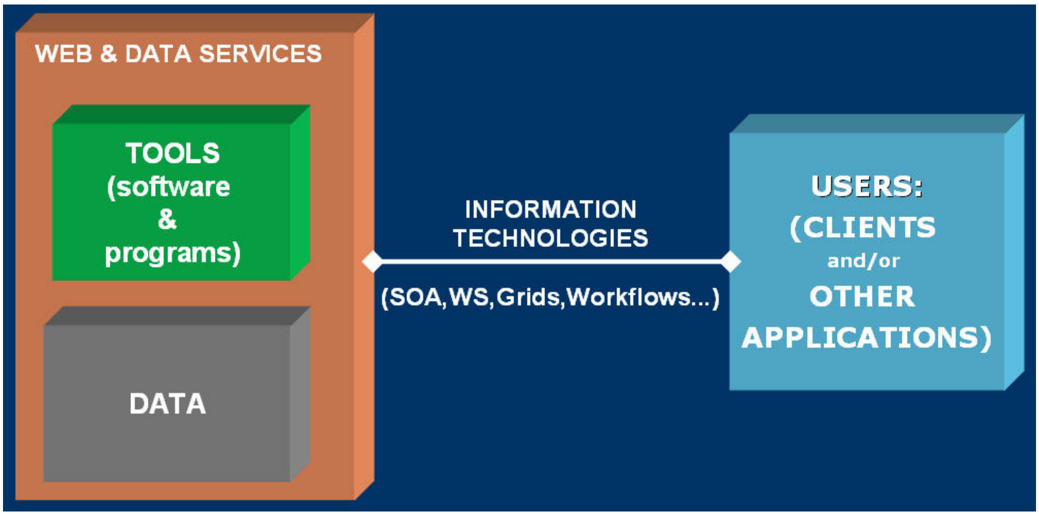

Figure 1.5: Interaction between information technologies and users

The use of GIS systems opens new avenues for comprehensive studies and solving complex problems related to integrated and dynamic earth systems. As we progress into the digital technology age, efficient ways of capturing, storing, organizing, manipulating, and updating data sets are needed so that we are not overwhelmed by the amount, diversity, and heterogeneity of the data. Clearly, GIS provides a convenient platform for data collection, organization, and research with multidisciplinary data sets. As more groups adopt GIS applications, the earth sciences community will be in a position to prepare a unified global database for more efficient, productive, and rewarding research **(Seber, 1997)**. Seismic hazard analysis can be defined as the integration of geophysical, geological, and geodetic data to estimate earthquake potential. If the seismic hazard can be analysed, the earthquake losses can be reduced. GIS is an important tool to analyse seismic hazards and risks and the information technologies provide successful solutions for delivering data and tools.

The beginning of the twenty-first century has witnessed a technological and cultural revolution in the Earth sciences. Advances in information technology coupled with the successful community planning and implementation of some efforts to organize and coordinate development of an Earth science cyberinfrastructure. The goal is for data to evolve into information and then into knowledge as quickly and effectively as possible. In order to do this, mechanisms needed to use distributed data and computational resources that exists. But current geospatial data sharing approaches are not pleasant. First of all, Earth scientists have a tradition of sharing of data. But they are willing to share data if asked. Besides, a large amount of human capital is wasted in duplicative efforts. Current tool sharing approaches are also unpleasant. Each research group develops its own tools. There is redundancy of development efforts and little interoperability amongst the tools. Even interaction amongst different tools is often not possible or requires extensive recoding. Information technologies have revolutionized the Earth sciences. But researchers and scientists often do not take advantage of existing tools, and therefore unknowingly create redundant tools. It is too hard to find and work with data that already exist. It is too hard to acquire software and make it work. Scientists have too little access to modern IT tools that would accelerate scientific progress. Therefore, there is too little time to do science **(Ludaescher, 2006 ; Sinha, 2006)**.

1.4 Review on Current Projects

The Earth sciences are a discipline that is strongly data driven. In the past, 80% or more of Earth science project's resources were consumed for collecting data or converting paper records to digital databases. Today, online geospatial data is available and it increases the power of GIS. But it is still to spend 80% or more of a project's resources on searching, discovering, retrieving, and reformatting data. Today, people who need geospatial data must visit many web sites, each having their own appearance and format. However, a common system can provide easy access to geospatial data for users, especially in Earth sciences. Such a system is very important for timely and efficient delivery of Earth science data and information. Geospatial data, which is difficult and costly to obtain, is stored on the Web to share and reuse it. The Internet and related technologies are used to transmit it among users. With this overflow of information on the Internet, it is becoming important to provide applications that make these data transmissions more effectively for both user and data provider. On the other hand, it is a challenge issue because of many problems such as chaotic distribution of available data sets and lack of tools to access them. The current Internet technology combined with GIS is the most appropriate solution to meet the requirements of interdisciplinary and multidisciplinary Earth science projects.

According to a current research **(Gantz, 2007)**, the amount of digital information created, captured, and replicated was 161 exabytes in 2006. It means that it is 161 billion gigabytes (One gigabyte is equivalent to four sets of encyclopedias at 29 volumes per set). This is about 3 million times the information in all the books ever written. Digital information (stored information like paper, film, magnetic, optical) and information flow (broadcasting, telephony, internet) surrounds humans. This incredible growth represents how information has moved from analogue form, where it was finite, to digital form, where it is infinite. By 2006, there were 1.1 billion users on the Internet and by 2010, it is expected another 500 million users. This information explosion is putting a considerable pressure on the existing IT infrastructures and force the organizations to develop more information-centric computing architectures. The research mentioned also states that over 95% of the digital universe is unstructured data which means that its content can not be truly represented by its location in a computer record. In addition, there is a lack of metadata or metadata is not enough to determine what is actually contained in a unit of information without some human or automated intervention. The digital universe is not only expanding, it is changing the character, expectations and habits of people who use and depend on information. Organizations today are beginning to re-architect their infrastructures to make them more dynamic and information-centric. They taking steps to keep up with the demands of an expanding digital universe by creating more service oriented infrastructures.

The interaction between science and technology is an irrefutable fact. Scientific studies produce information and cause advances in technology while on the other, hand technological progress provides better circumstances on scientific researches. As both science and technology have expanded their scope rapidly, they have come into contact more often. Moreover, the information technologies have revolutionized science, especially Earth sciences. Today, geospatial data and analysis tools, which are difficult and costly to obtain, are stored on the Web to share and reuse them. It went beyond this too, and information sharing on the Internet has been transformed to sharing of computing power and storing capacity on the Internet. Data and information storage has evolved from central to distributed environments by means of the systems that provide the use of information technology resources which are locationally independent. There is an overflow in all of the branches of science today, especially in Earth sciences. This situation causes problems on data storage and data processing, as well as accessing to these large size datasets and analysing them. Earth-related data are being collected every day using present-day technologies. By means of the satellite and computer technologies, it is now possible to study the Earth as a global system. Scientific instruments such as satellites generate terabytes and petabytes of data every day. There is a rapidly widening gap between data collection capabilities and the ability to analyse the data. Once the solutions have been created for collecting, storing and accessing data, now it is a challenge to effectively share data, application and processing resources across many locations.

It is obvious that the combination of compute, data, networking, visualization, and other resources are required to develop successful science and engineering applications. This combination can be made by using present-day information technologies. IT is concerned with the use of technology in managing and processing information **(Babylon, 2006)** and deals with the use of computers and computer software to convert, store, protect, process, transmit, and retrieve information. Information has to be extracted from the data and converted to knowledge to be useful. There is an unprecedented growth in the amount and quality of space geodetic data collected to characterize geodynamical crustal deformation at last decade. A United States initiative called EarthScope Plate Boundary Observatory network project, which is supported by National Science Foundation, is one of the most important examples in the world. EarthScope applies modern observational, analytical and telecommunications technologies to investigate the structure and evolution of the North American continent and the physical process controlling earthquakes and volcanic eruptions (Figure 1.6).

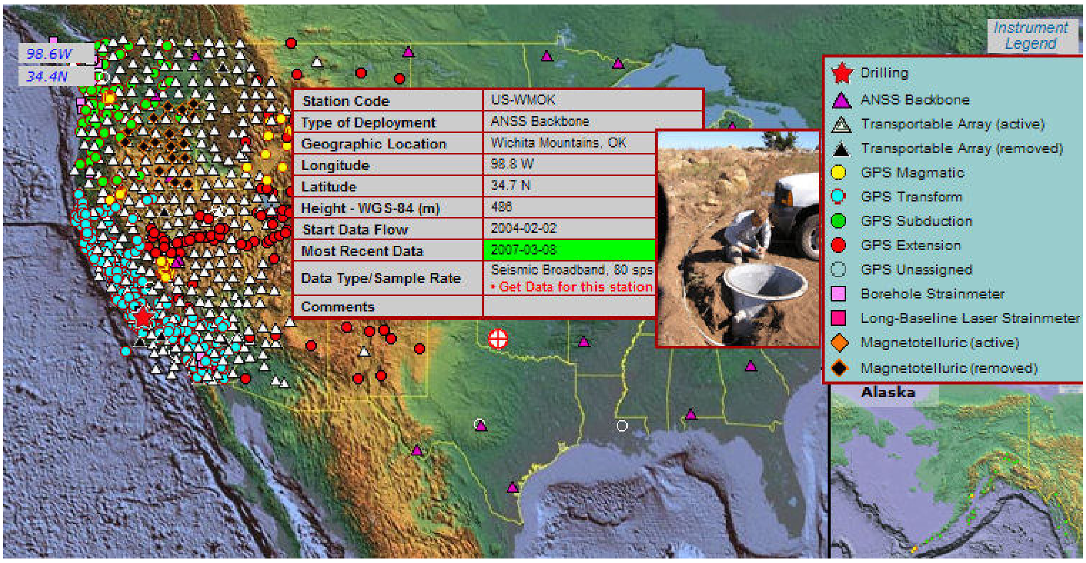

Figure 1.6: EarthScope Information System showing instrument (seismic and GPS) locations and station information **(EarthScope, 2006)**

It provides a foundation for fundamental and applied research throughout the US that contributes to the mitigation of risks from geological hazards, the development of natural resources, and the public's understanding of the dynamic Earth. GPS, seismic, strain, drilling and LIDAR data are being collected and stored every day. And they require high capacity computing environment to be analysed so that grid applications are trying to cope with this data deluge. Grid network environment was developed to solve large scale computation problems while Web was developed to meet the need for communication between computers (Figure 1.7). Grid technology can solve the computational problems of Earth science. Grid is 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 **(Grid Infoware, 2008)**. Researchers working to solve many of the most difficult scientific problems have long understood the potential of such shared distributed computing systems **(Sun, 2008)**. At the beginning, grid technology has limited potential as a basis for future-generation grids, which will need to be scalable and interoperable to meet the needs at a global-scale. Now, there is considerable overlap between the goals of grid computing and the benefits of Web services. Grid applications include collaborative visualization of large scientific datasets, distributed computing for computationally demanding data analyses, and coupling of scientific instruments with remote computers and archives **(Foster et al., 2002)**. So today's grid technology can be classified into three types:

- Computational grids for computationally-intensive operations.
- Data grids for sharing and management of large amounts of distributed data.
- Equipment grids for using equipments remotely and analyzing the data produced.

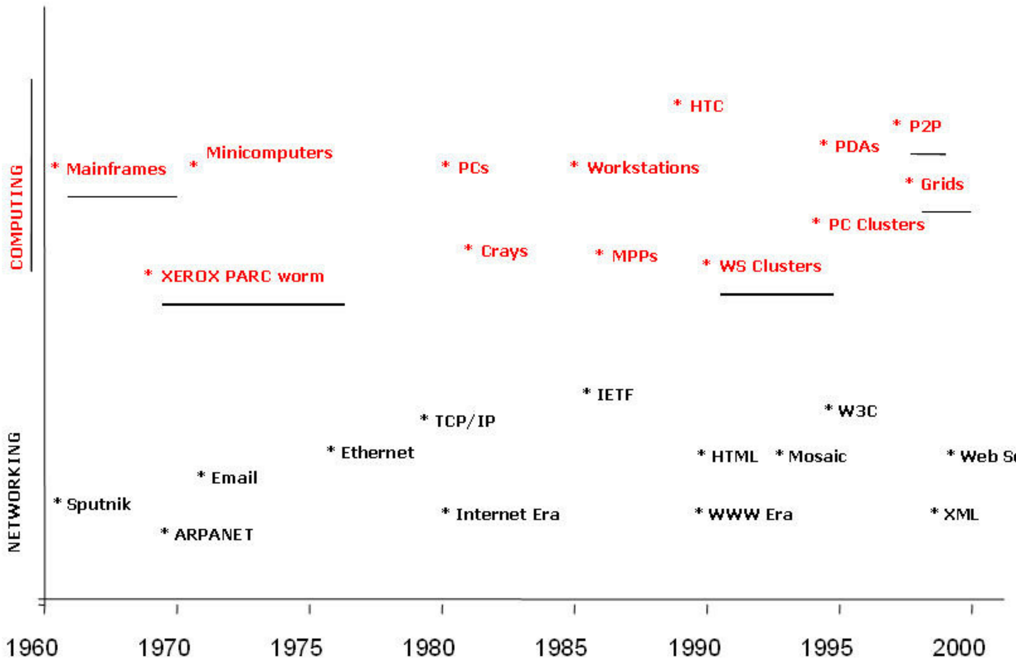

Figure 1.7: Evolution of network and computer technologies **(Akcan et al., 2005)**

Today, the Grid exists as a number of groups who are building experimental and production grid infrastructures for their own purposes. These groups are called virtual organizations because they are groups of organizations that are using the Grid to share resources for specific purposes. Examples of these VOs are the EU DataGrid, NASA Information Power Grid, NSF Alliance and NPACI Technology Grids, iVDGL, NSF TeraGrid, and apGrid. These virtual organizations are largely independent and aren't linked together for shared use (**Globus, 2006**). The TeraGrid project provides integrated resources and services operated by some of the nation's supercomputing centers. TeraGrid resources are integrated through a service oriented architecture in that each resource provides a service that is defined in terms of interface and operation. TeraGrid resources are interconnected by a dedicated optical network, with each resource provider site connecting at either 10 Gigabits per second or 30 Gigabits per second. TeraGrid users access the facility through national research networks (Internet2). There are roughly 4,000 users at over 200 universities.

Earth science (a.k.a. Geoscience), is a term for the sciences related to the Earth. Geoscientists study physical and chemical processes in the Earth. They work with people, data, information, and technology. Earth sciences are a discipline that is strongly data- and compute-intensive. There are duplicative efforts on data collection and tool creation which cause waste of labour and time. Building mechanisms which are capable to share data and tools is the key for the next generation of Earth science research. These platforms must include databases, networks, visualization, analytical tools, computational resources, and so on. There are a lot of efforts in Earth sciences such as data collection from field observations and sensors, database creation, software development, data integration, and data management. And each of them has its own various problems. The need is to provide access to all of existing resources and support interoperability among them by using information technologies. One of the most important projects in the US, which uses these technologies, Geospatial One-Stop which is one of 24 E-Government initiatives sponsored by Government budget. The portal of this project (geodata.gov) was designed for communication and sharing of geographic data and resources. It includes metadata records, links to live maps, features, and catalog services, downloadable data sets, images, clearinghouses, map files, and more. Three major institutions of the US; USGS, NOAA, and NASA, which collect data from land, sea and the space, are creating virtual organizations on the Internet to work together by sharing expertise, tools, information and facilities. This initiative is called as the Federation of Earth Science Information Partners. It brings together partners to develop models and tools that make Earth observation information more useful and accessible across many different communities. They have over 50 Web-GIS applications about data analysis and visualization in geosciences.

Today, scientists in the US and Europe are creating cyberinfrastructures in the field of Ocean, Atmosphere and Earth sciences. Cyberinfrastructure, which is also called as e-Science, is the coordinated aggregate of software, hardware and other technologies, as well as human expertise, required to support current and future discoveries in science and engineering. NSF is making an important investment in cyberinfrastructure development across all the sciences, at a level of $800 million per year in its current budget. One of them is GEOscience Network project **(GEON, 2005)**. The San Diego Supercomputer Center is the lead player. Others participants are USGS, Pennsylvania State University, and San Diego State University. The total budget of this project is $11.25 million. 82 people work on this 5-year project. GEON is developing cyberinfrastructure for integrative research to enable transformative advances in Geoscience research and education. The term cyberinfrastructure describes the new research environments that support advanced data acquisition, data storage, data management, data integration, data mining, data visualization and other computing and information processing services over the Internet. In scientific usage, cyberinfrastructure is a technological solution to the problem of efficiently connecting data, computers, and people with the goal of enabling derivation of novel scientific theories and knowledge. GEON is inherently a distributed system, since the scientists - who are users as well as providers of resources (e.g., data, tools, and computing and visualization capabilities) - are themselves distributed. GEON was designed as an equal collaboration between Information Technology and Geoscience researchers, with the goal of developing an enabling IT platform to facilitate the next generation of Geoscience research. GEON is based on a service-oriented architecture with support for intelligent search, semantic data integration, visualization of 4D scientific datasets, and access to high performance computing platforms for data analysis and model execution via the GEON Portal **(GEON, 2005a)**. Figure 1.8 displays the overall system architecture of GEON.

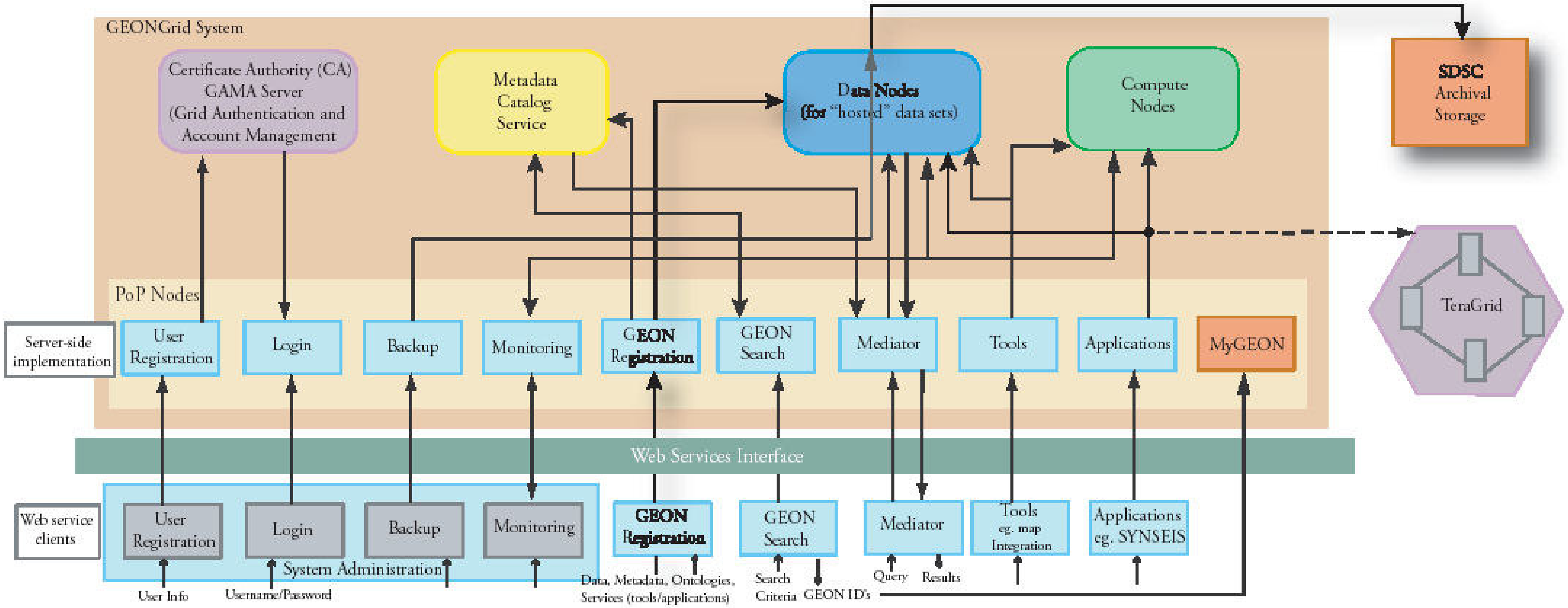

Figure 1.8: System architecture of GEON (**GEON, 2005a**)

SYNSEIS is one of the GEON products and based on a service-oriented architecture, where each sub-component in the system is implemented as a Web service. This approach also supports multiple usage scenarios for each component, since researchers can re-use components in different contexts. GEON Cyberinfrastructure provides:

- Authenticated access to data and Web services
- Registration of data sets, tools, and services with metadata
- Search for data, tools, and services, using ontologies
- Scientific workflow environment and access to HPC
- Data and map integration capability
- Scientific data visualization and GIS mapping

GEON uses ontologies for searching data and tools. Ontology is a data model that represents a domain and is used to reason about the objects in that domain and the relations between them. Ontologies are machine-operational specifications of the meaning of terms and relationships between terms. They provide an organizational structure for classifying data so that they can be discovered by computers. Ontologies are used in the semantic web. Humans are capable of using the Web but a computer can not do the same thing. Semantic Web makes web pages understandable by computers so that they can search websites and perform actions. The development in the semantic web could substantially enhance the automatic knowledge discovery from multi-source diverse geospatial data and information. The goal of the emerging semantic web services is to provide the mechanisms to organize the information and services so that human queries may be correctly structured for the available application services in order to automatically build workflows for specific problems, which means that is, automatically determine the correct relationships between available and characterized data and services to generate the process models and convert them to executable workflows to provide the answers to what-if questions **(Di, 2004)**. GEON also uses scientific workflows to register and discover resources. Similar to ontologies which are about gluing the vocabulary and interlinking) data, scientific workflows are about gluing components such as web services, scripts, and external tools. Workflow is the operational aspect of a work procedure: how tasks are structured, who performs them, what their relative order is, how they are synchronized, how information flows to support the tasks and how tasks are being tracked. GEON publishes geospatial data and processes as Web Services and composes them using a scientific workflow approach.

Cyberinfrastructure is also called e-Science, and the United Kingdom has a major e-Science initiative which is similar to GEON. The UK e-Science programme comprises a wide range of resources, centres and people including the NeSC which is managed by the Universities of Glasgow and Edinburgh (**NESC, 2006**). The goal is to enable better research in all disciplines. The method is to develop collaboration supported by advanced distributed computation. The 5-year budget is 213 million pounds. The core team composes 73 people in this project. The term e-Science is used to describe computationally intensive science that is carried out in highly distributed network environments, or science that uses immense data sets that require grid computing. Figure 1.9 shows the idea of e-Infrastructure behind these projects and initiatives.

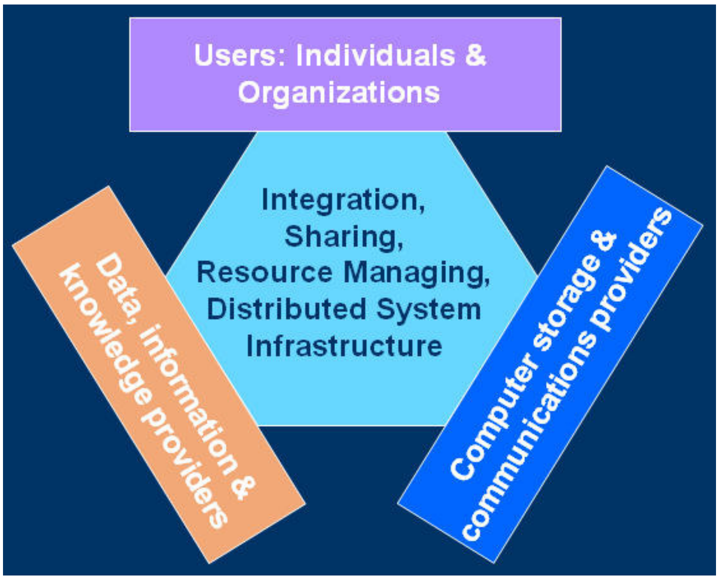

Figure 1.9: E-Infrastructure (Adapted from **Atkinson, 2005**)

Another important project is the Globus Alliance which is a community of organizations and individuals developing fundamental technologies behind the Grid and supported by the US Department of Energy, NSF, NASA, DARPA, IBM, and Microsoft. The Globus Toolkit is an open source software toolkit used for building Grid systems and applications. SCEC uses Globus software to visualize earthquake simulation data. Scientists simulate earthquakes by calculating the effect of shock waves as they propagate through various layers of a geological model. SCEC simulations cover a very large space with very high resolution and can generate up to

40 terabyte of data per simulation run **(Globus, 2006)**. Another project from SCEC, Community Modeling Environment, comprises 53 researchers from the fields of Earth Science and IT. They are developing a geophysics and IT collaboratory that will perform seismic hazard analysis and geophysical modeling. They are using grid computing and Web services technologies. If one people tried to develop, it would last 96,725 days. This number shows the importance of collaboration among different disciplines. This 5-year project has been awarded $10 million from NSF.

Another project, the Consortium of Universities for the Advancement of Hydrologic Science, is an organization representing more than 100 US universities. CUAHSI receives support from the National Science Foundation to develop infrastructure and services for the advancement of hydrologic science and education in the US. HIS of CUAHSI is a geographically distributed network of hydrologic data sources and functions that are integrated using web services so that they function as a connected whole. The goals are to unite the nation's water information, to make it universally accessible and useful, and to provide access to the data sources, tools and models that enable the synthesis, visualization and evaluation of the behavior of hydrologic systems **(CUAHSI, 2006)**. It is a geographically distributed network of hydrologic data sources and functions that are integrated using Web services. It is a two-year project and 12 people work on it.

The use of distributed systems has increased in recent years and it is expected that all systems will be distributed systems in the future. A distributed system can be defined as one in which the hardware and software components in networked computers communicate and coordinate their activities only by passing messages, e.g. the Internet **(Baru, 2006)**. Figure 1.10 displays the distributed system models.

In the early days, distributed applications used ad hoc methods to manage the systems. Then numerous standards have been developed over the years to ease the deployment and the maintenance. Today, the key technologies in distributed systems are service-oriented architecture, Web services, and grid computing. Service oriented technology can support strongly Earth sciences. It has evolved as a practical, cost-effective solution for uniting information distributed between critical applications over operating system, platform, and language barriers that were previously impassable.

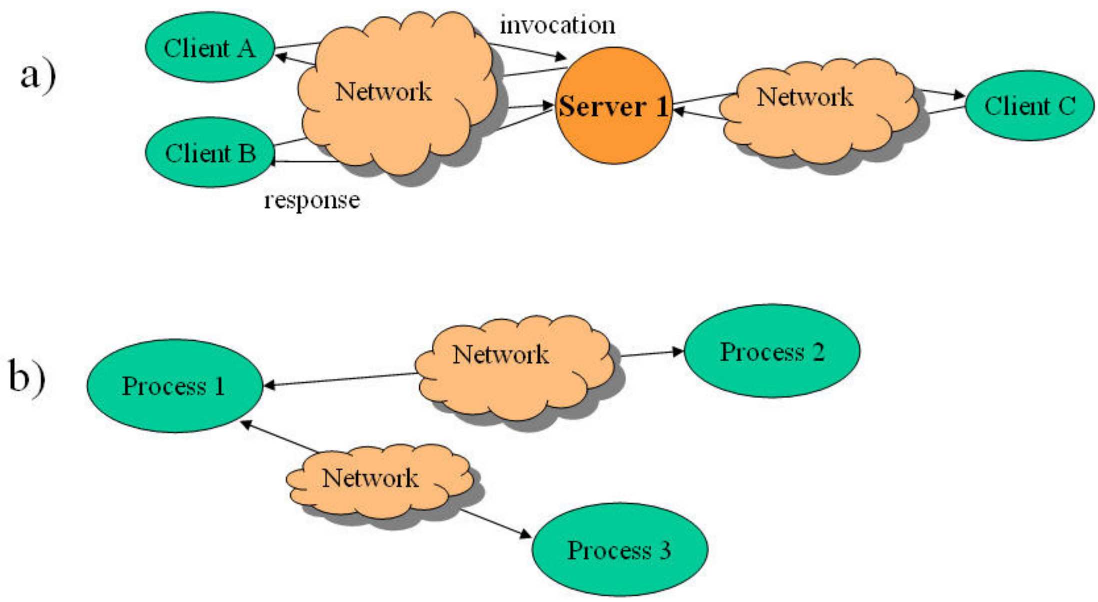

Figure 1.10: Distributed system models (**a:** client-server; **b:** peer-to-peer)

1.5 Definition of the Problem and Motivation

Since this field requires a collaboration of computer scientists and Earth scientists, and also financial investment, unfortunately there are no such these projects in our country. In Turkey, NEMC of KOERI of BU has approximately 120 seismic stations, and is continuing to install for covering the entire nation more densely. Also a national project, **CORS-TR (2006)**, is installing over 100 of continuously operating GPS stations that will be covering the entire nation in two years with an average station spacing of 100 km. This amount of data will provide significant challenges to the Earth sciences community. These data can only be analyzed by utilizing IT resources. There is a need to speed up the discovery process in scientific research.

The access statistics of NEMC's waveform data request system between May 16, 2005 and Jan 16, 2006 are shown in Figure 1.11 and Figure 1.12. The center has huge earthquake data which in the size of 3 terabytes per year. In addition to this, the duration of data storage is 5 years and the number of data request from the center is 1500 times per year. This does not mean only that there is so much data but also there is a need for geoscientific data management using the current information technology for efficiently use of them.

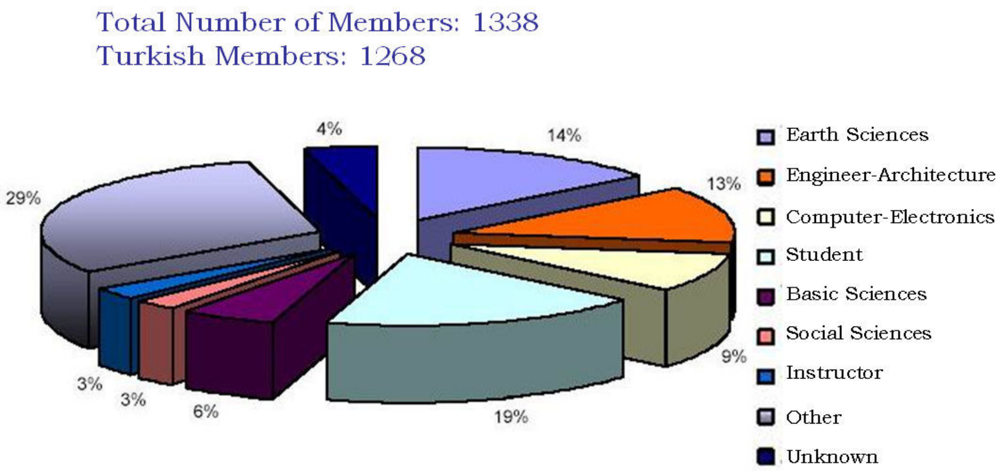

Figure 1.11: Percentage of the users from different professions **(Barbarosoğlu, 2005)**

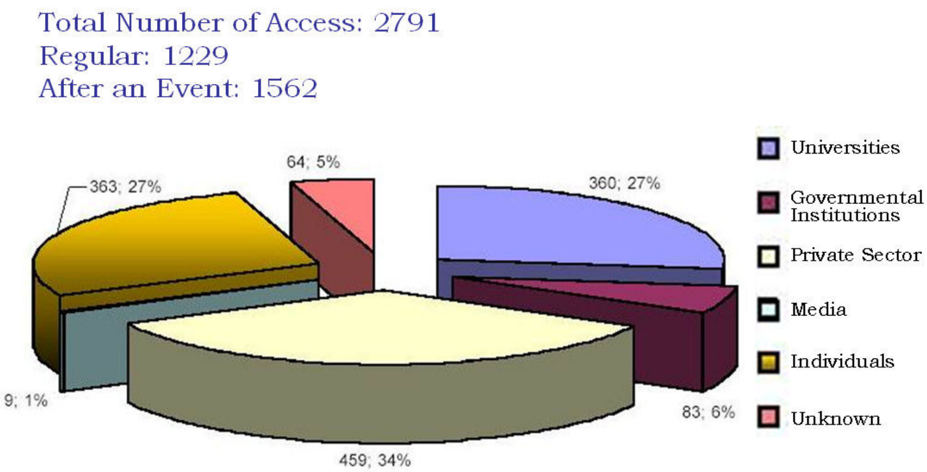

Figure 1.12: Percentage of the users from different institutions **(Barbarosoğlu, 2005)**

During this study, an institution-wide survey was realized to obtain information on how geoscientists currently acquire, store, and disseminate geoscientific information. Thus, the lifecycle of the geoscientific data (such as field data collection, analysis, visualization, and storage) was identified. Requirements and suggestions from potential end-users on software user interface, access methods, data availability, and data formats were obtained. The most of the potential users were interested in taking advantage of data management systems, both in their departments as well as in a multi-organization system. Also, they expressed that they can contribute their data to the system for use by others. They suggested that all the data should be made available to the data contributors and the tools must be shared among scientists. They also agreed that a web-based system using a standard web browser would be convenient. This survey shows that a study needs to be initiated with the collaboration of the geoscience institutions to create a system for integrating, modernizing, and expanding earthquake studies.

Geoscientific data from earthquake studies in Turkey is stored and processed using various softwares. Furthermore a big amount of these data are available in different forms and projections. They come from various resources and they do not have a datum defined. And each scientist tries to create own tool to analyse them. However, the common platform can provide easy access to geospatial data and tools for internal and external users of them. The studies of recent crustal movements are based on analyses of repeated geodetic measurements, and their combination with results of geophysical and geological investigations. Earthquake researches are often interdisciplinary or multidisciplinary in character. It is obvious that a single data producer can not produce useful datasets and information without integrating data from others. One scientist's results can be another's data. The current projects in Turkey do not take advantage of information resources that are available through existing spatial data infrastructure services and networks, and therefore unknowingly create redundant capabilities. However, information technologies allow scientists to create appropriate solutions to meet the requirements of interdisciplinary Earth science projects which have multiple goals. Implementing information technology resources in Earth sciences is a challenge issue. The importance of geospatial technology is increasing rapidly and the geospatial data associated with this technology is extremely large. Also there is a large community of users who need access to these data and tools. Accessing geospatial data and tools now means more than file transfer or downloading capability. New technologies make it possible to access complex datasets and tools via network links.

In a broader sense, the main objective of this study is to provide optimal use of tools that exist, and develop necessary IT infrastructure applicable to Earth sciences community. The problem solved in this research is to bring calculations and analysis to desktops of researchers, students, decision-makers, and educators. This system basically aims to enable linking and sharing multidisciplinary Earth science data, tools and software, and provides a wide range of users (scientist, educators, policymakers, and public) access to the system. The applications of the system provides opportunities for Earth science people to compute and study Earth science data for better understanding of earthquakes. The system was built using a service-oriented architecture for reusability and interoperability of each components. Figure 1.13 explains the process of Web services interaction.

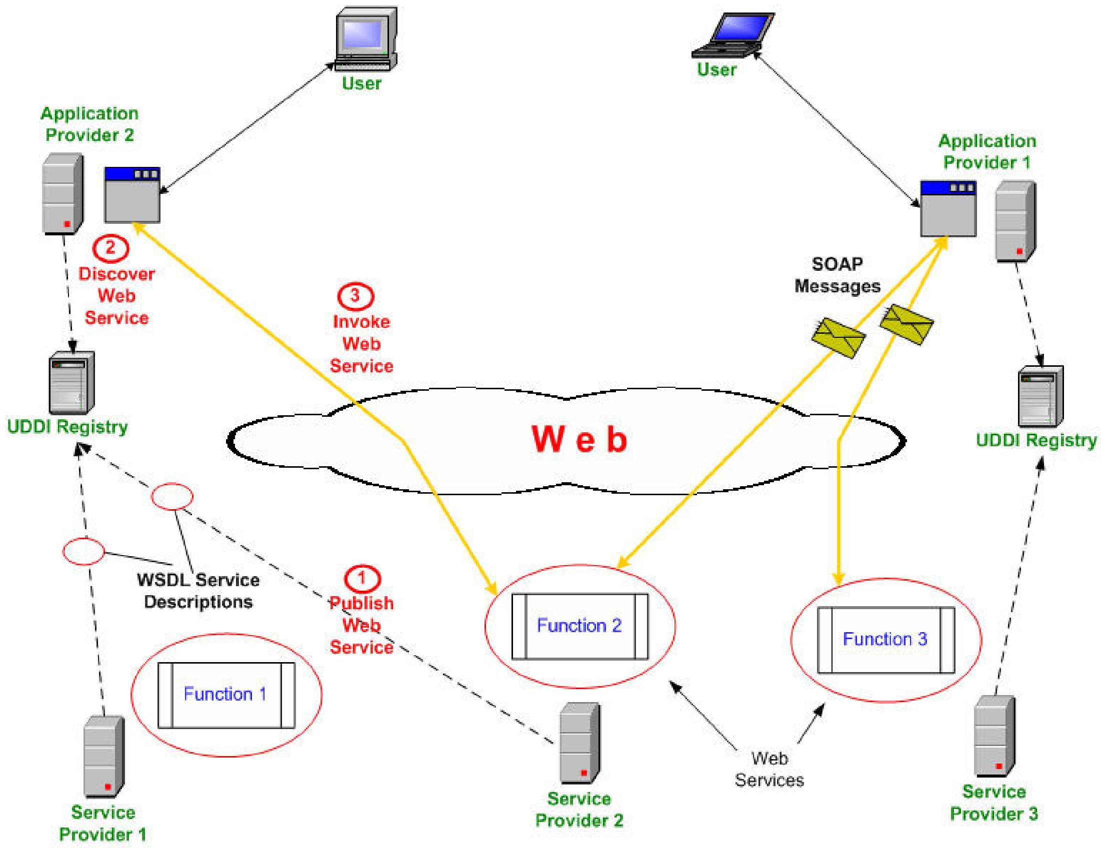

Figure 1.13: Web services and related standards **(Sinha, 2006)**

The idea of a Web service of service-oriented architecture developed from the evolution of the Internet and it is based on existing standards such as XML, HTTP, SOAP, UDDI and WSDL. In the present study, the developed system brings the complex strain analysis procedure (which gives opportunity to understand seismic hazard) to a level that can be used by anyone efficiently and effectively by using Web services approach.

2. CASE STUDY: STRAIN ANALYSIS AS A TOOL FOR SEISMIC HAZARD ASSESSMENT IN TURKEY

2.1 Definition of Terms

The magnitude of an earthquake reflects how much strain was released. Strain accumulates on a fault due to the relative motions on either side of the fault. The fault is locked due to friction and does not move. As strain reaches a critical level the fault over comes the frictional resistance and slips so that the strain is released. Once the fault slip has stopped, strain accumalation begins again. When the critical level is reached again, relaxation occurs and the earthquake cycle is repeats. This concept, known as the theory of Elastic Rebound, was developed by Henry Reid in 1910. Earthquakes are most dramatic part of a seismic cycle occuring on segments of the plate boundary over hundreds to thousands of years. During interseismic stage, most of the cycle, steady motion occurs away from fault but fault is locked, though some aseismic creep (a movement which occures when the fault moved slowly without generating an earthquake) can occur on it. Immediately prior to rupture is a preseismic stage, that can be associated with small earthquakes (foreshocks) or other possible precursory effects. Earthquake itself is coseismic phase, during which rapid motion on fault generates seismic waves. During these few seconds, meters of slip on fault catch up with the few mm/yr of motion that occurred over hundreds of years away from fault. Finally, postseismic phase occurs after earthquake, and aftershocks and transient afterslip occur for a period of years before fault settles into its steady interseismic behavior again **(Stein, 2006)**.

Understanding of the kinematics and dynamics of crustal deformation in plate boundary zones is the main goal of Earth scientists. Dynamics is concerned with the motion of plates under the action of forces, and kinematics is concerned with the motions of plates without being concerned with the forces that cause motion. While kinematic studies are aimed at obtaining velocity and strain rates which provide us to estimate deformation areas using fault slip rates, earthquake moment tensors, and geodetic data; dynamic studies are aimed at the investigation of the driving forces of crustal deformation. The aim is to understand the relationship between long-term and short-term deformations and the interpretation of the results in terms of seismic hazard.

The interaction of tectonic plates is responsible for the formation of ocean basins, the uplift of mountain ranges and the rifting of the continents. These plate motions are the cause of earthquakes, and have the devastating effects on the populations that live along plate boundaries. Although the kinematics of plate motions are well known, there are still unanswered questions regarding the forces acting. Answering these questions requires the collection of seismic, geodetic and other geophysical and geological data at multiple scales and time. Plate motions are described by the geographic coordinates of the rotation pole (Euler pole) and the angular velocity (Figure 2.1). Plate kinematic models describe the velocities of points at the Earth's surface due to the plate tectonic motions. They are either derived geophysically from sea floor spreading rates, transform fault and earthquake slip azimuths (e.g. NUVEL-1, NNR-NUVEL-1, NUVEL-1A, NNR-NUVEL-1A), or from geodetic space techniques like VLBI **(Herring et al., 1986)**, SLR **(Christodoulidis et al., 1985)** and GPS (e.g. APKIM, ITRF 2000).

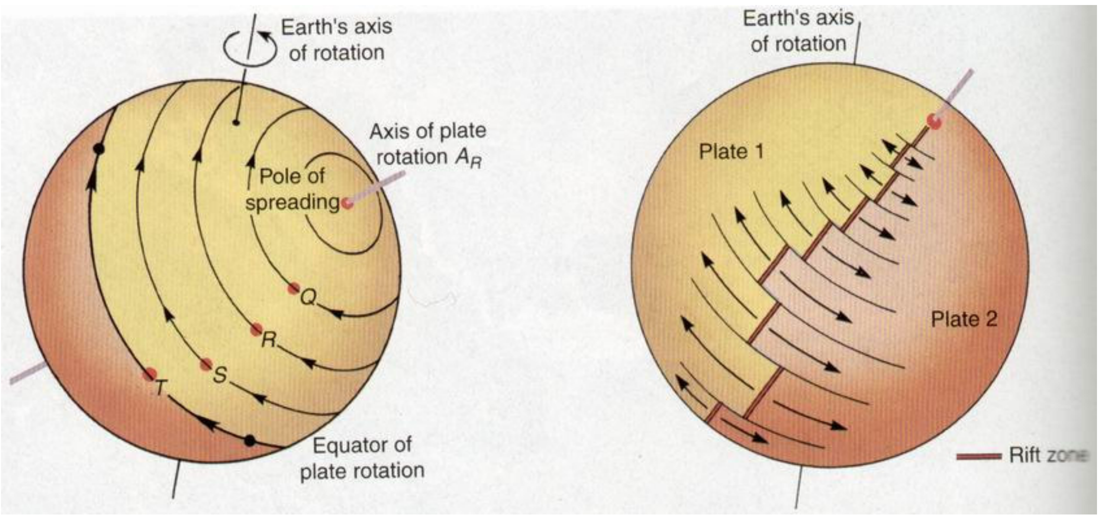

Figure 2.1: Euler pole **(Hamblin and Christiansen, 2001)**

According to **Goldfinger and Christie (2007)**, measurement of plate motions can be done both by geologic rates:

- Spreading rates
- Seismic moment estimates on faults

- Geologic rates from offset features
- Fault, transform, and ridge geometry
- Paleoseismology
- Paleomagnetics

and by direct measurement of rates and strains:

- Focal mechanisms
- Earthquake slip vectors
- GPS
- VLBI
- SLR
- Strain meters
- Satellite Interferometry
- Trilateration
- Offset features, seismic or creep

2.1.1 Crustal Strain

Crustal deformation can be observed as relative movement of the points on the Earth's surface. As a consequence of continental plate movement, the Earth's surface near active faults deforms before, during and after earthquakes. In order to understand how Earth crust responds to plate tectonic forces, the concepts of stress and strain should be examined. Stress is expressed as the force per unit area at a particular point. However it is difficult to measure stress in Earth crust. But the effects of past stress can be observed. Strain is the change in shape while an object is undergoing stress. Similar to stress, strain is referred to Normal and Shear strain, and Compressional and Extensional strain to indicate the orientation of the strain with respect to some direction. The terminology is a little confusing, but it may be expressed that stress is the force that causes deformation or strain **(Monroe and Wicander, 2005)**. In other words, whereas stress describes how much force is acting on an object, strain describes how much effect the applied stress has on an object. The relationship between stress and strain is illustrated in Figure 2.2. Stress and strain can be formulized as follows:

$$stress = force / area \quad \textbf{(2.1)}$$

$$strain = change\ in\ size / original\ size \quad \textbf{(2.2)}$$

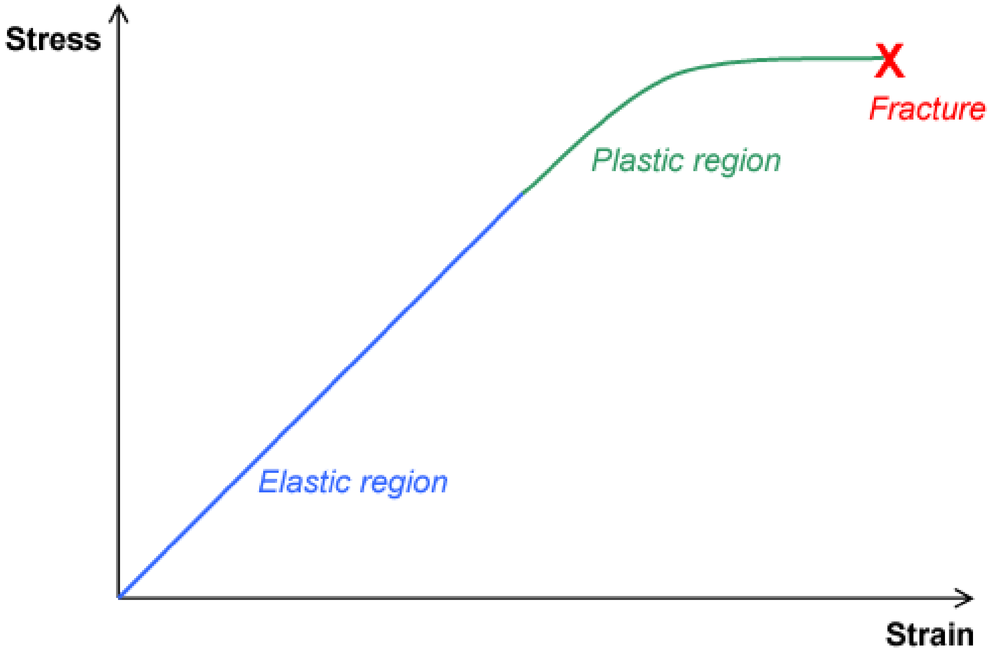

Figure 2.2: The relationship of stress to strain showing linear elastic region, nonlinear plastic region, and fracture

Three types of deformation are elastic deformation, plastic deformation and rupture deformation. Elastic Deformation occurs when a body is deformed in response to a stress, but returns to its original shape when stress is removed. In plastic deformation, stress is applied to a solid body and deformation occurs. When stresses are removed, a portion of the strain remains. That portion of the solid body that is deformed has experienced plastic strain. In rupture deformation, visible fractures form. During deformation, Earth crust changes in size and shape. Deformation and strain are closely related terms but they are not the same. Deformation describes the collective displacements of points in a body. It describes the complete transformation from the initial to the final geometry of a body. Strain describes the changes of points in a body relative to each other. The displacement field can be subdivided into three components as distortion, rotation, and translation. Each component can be described by a vector field and their sum gives the total displacement field. Importantly, a change in the order of addition of these vector components affects the final result. Deformation, therefore, is not a vector entity, but a second-order tensor. When the rotation and distortion components are zero, there is only a translation. And this translation is called rigid-body translation. When the translation and distortion components are zero, there is only rotation of the body. This component is called as rigid-body rotation. When translation and rotation are both zero, the body undergoes distortion and this component is described by strain. So, strain is a component of deformation and therefore not a synonym. Deformation describes the complete displacement field of points in a body relative to an external reference frame. Strain, describes the displacement field of points relative to each other **(Marshak, 2004)**. In brief, deformation describes the complete transformation from the initial to the final geometry of a body, and can be broken down into 4 main components **(Rey, 2006)** (Figure 2.3):

- Translation (movement from one place to another)
- Rotation (spin around an axis)
- Distortion (change in shape)
- Dilation (volume change can be positive or negative, as the volume increases or decreases, respectively)

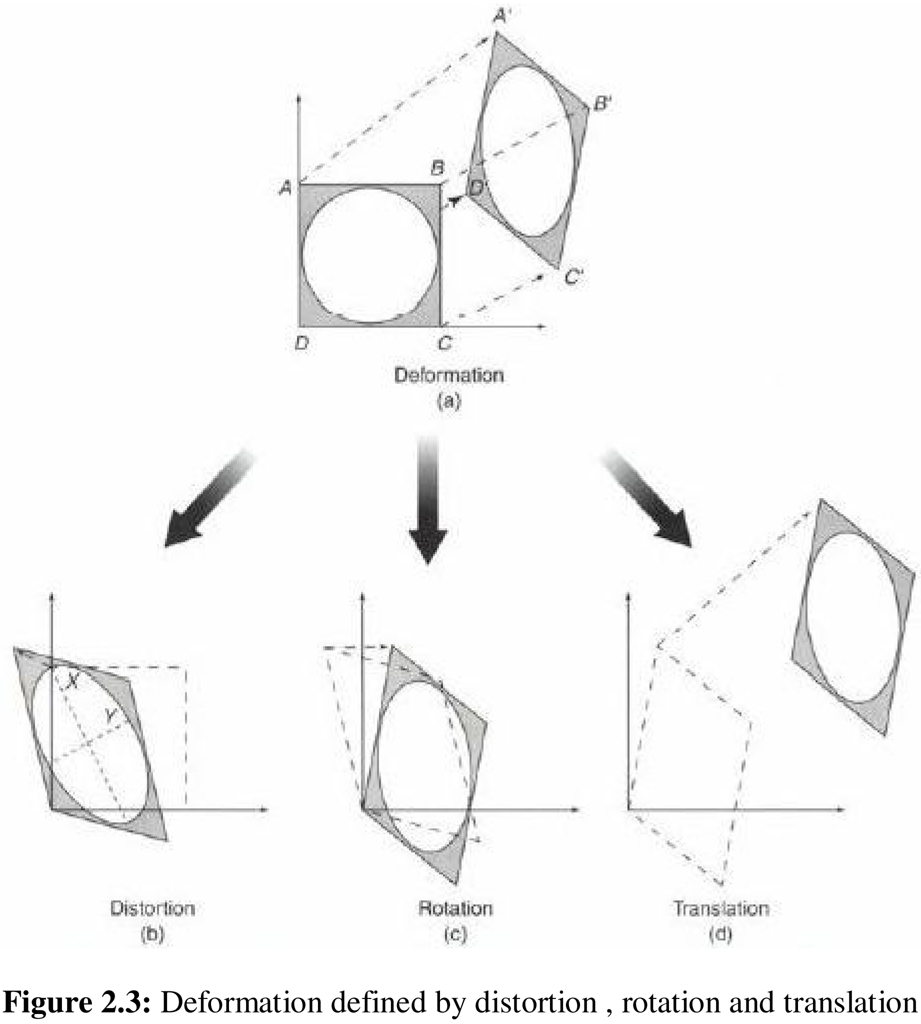

Figure 2.3: Deformation defined by distortion , rotation and translation

Strain can be homogeneous or heterogeneous (Figure 2.4). Homogeneous strain results when any two portions of a body which were similar in form and orientation before strain, are still similar in form and orientation after the strain. As a consequence, straight lines remain straight, parallel lines remain parallel, and planar surfaces remain planar. In two dimensions, circles will become ellipses, and in three dimensions spheres will become ellipsoids. Strain is heterogeneous when it varies across the surface of an object. Changes in the size and shape of small parts of the body are proportionately different from place to place. As a consequence, straight lines become curved, planes become curved surfaces, and parallel lines generally do not remain parallel after deformation. This implies the presence of a strain gradient.

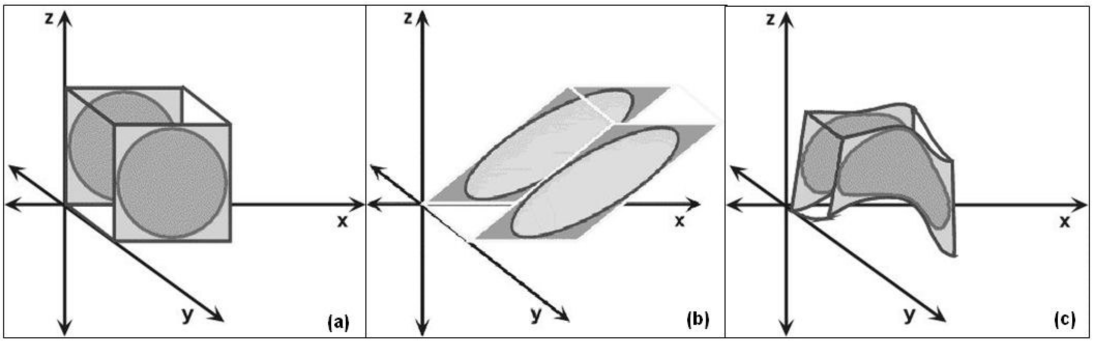

Figure 2.4: Original body **(a)**, homogeneous strain **(b)**, heterogeneous strain **(c)** **(Reish and Girty, 2006)**

Analyzing a heterogeneously strained body requires to break it down into homogeneous portions. Therefore a deformed body is divided into grids that are small enough for the deformation to be described as locally homogeneous (Figure 2.5).

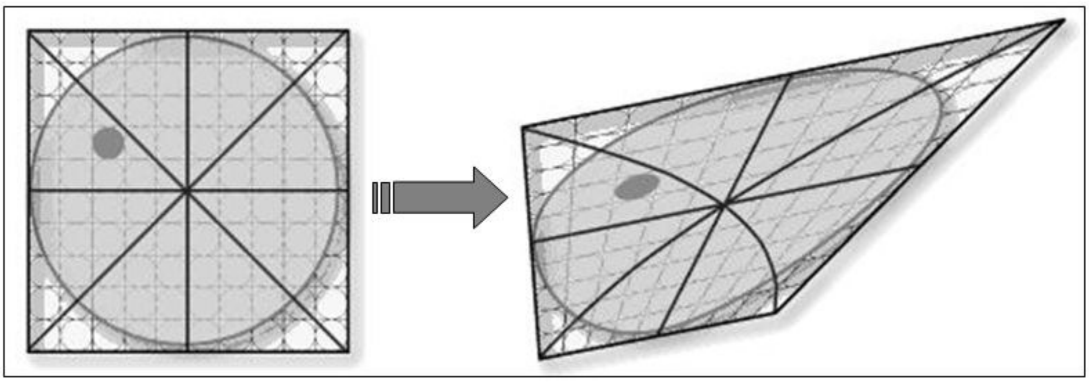

Figure 2.5: Squares which the strain conditions are approximately homogeneous **(Rey, 2006)**

Strain expresses the relationship between the original solid body with deforming one. In fact, strain is very similar to affine transformation used in Geodesy. Determination of crustal and structural deformations, geodetic network analysis, and deformation analysis of cartographic projections are in the scope of strain in Geodesy (**Demir, 1999**). Strain can be studied in any dimension like 1-D (Figure 2.6), 2-D, or 3-D. By imagining a solid rod in a 1-dimensional coordinate system (0,x) and taking two points like A and B, very close to each other, it can be expressed that A's coordinate is x, B's coordinate is x+dx. When a traction P is applied in the x-direction at the end of the rod, it elongates, and points A and B will be displaced. These displacements can be assumed as infinitesimal. The amount of displacement depends on the position of the point along the rod. The closer to the place where the force is applied, the larger the displacement is. Therefore, B is displaced slightly more than A. The displacement at A is noted u(x), the displacement at B is noted u(x+δx) (**Calais, 2006**).

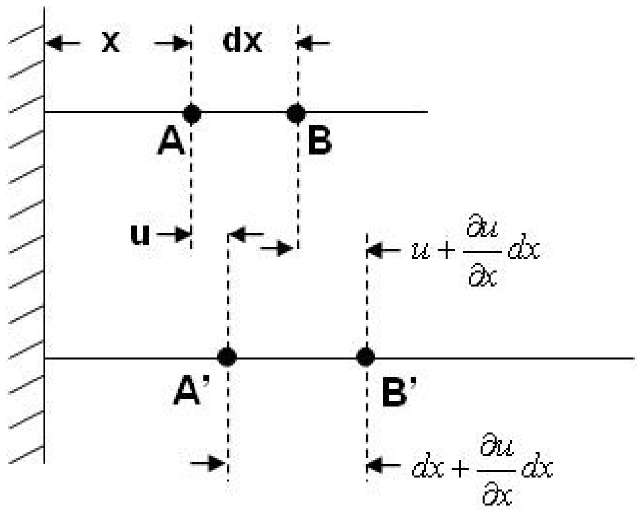

Figure 2.6: One-dimensional strain

Because the displacement δx is infinitesimal, it can be written:

$$u(x+\delta x)=u(x)+\frac{\partial u}{\partial x}\delta x \qquad \textbf{(2.3)}$$

Strain is defined as the change of length which is divided by the original length. Therefore:

$$e_x=\frac{\Delta L}{L}=\frac{A'B'-AB}{AB}=\frac{(dx+\frac{\partial u}{\partial x}dx)-dx}{dx}=\frac{\partial u}{\partial x} \qquad \textbf{(2.4)}$$

This shows that strain is the spatial gradient of the displacement. Similarly, strain rate is the spatial gradient of velocity. By integration, it can be written:

$$u = e_x x \tag{2.5}$$

A similar derivation can be done for 2 or 3 dimensions. In 2-D, strain can be defined as the rate of coordinate changes through axis to the original coordinates.

$$u = e_{xx} x + e_{xy} y$$

$$v = e_{yx} x + e_{yy} y \tag{2.6}$$

which is often written in tensor form:

$$u_i = e_{ij} x_j \tag{2.7}$$

$$e_{ij} = \begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{bmatrix} \tag{2.8}$$

E_{ij} is the displacement gradient tensor and it describes the displacement of any point in the body. Displacements combine strain and a rigid body rotation. Tensor theory states that any second-rank tensor can be decomposed into a symmetric and an anti-symmetric tensor. Therefore, it can be written:

$$e_{ij} = \frac{1}{2}(e_{ij} + e_{ji}) + \frac{1}{2}(e_{ij} - e_{ji}) \tag{2.9}$$

$$e_{ij} = \varepsilon_{ij} + \omega_{ij} \tag{2.10}$$

Here, ε_{ij} is the symmetric part of strain tensor which means $\varepsilon_{ij} = \varepsilon_{ji}$. And ω_{ij} is the anti-symmetric part of strain tensor which means $\omega_{ij} = -\omega_{ji}$. From here, the general displacement model is

$$u_i = \varepsilon_{ij} x_j + \omega_{ij} x_j + \mathrm{t} \tag{2.11}$$

This formula shows the relationship between strain and velocity. Displacement of a body is formed by rotation and strain components. Here, t represents the displacement (or translation) of all points in solid body and it is ignored in the case relative position does matter. Although a reference system is needed to define translation and rotation, defining strain, which is caused by the relative displacements in the body, is independent from reference system **(Demir, 1999)**. The lines that are perpendicular before and after strain are called the principal strain axes. Their lengths define the strain magnitude. In two dimension, two lines form the axes of the strain ellipse. The principal axes of strain ε_1 and ε_2 are given by:

$$\varepsilon_1, \varepsilon_2 = \frac{1}{2}(\varepsilon_{xx} + \varepsilon_{yy}) \mp \sqrt{\frac{1}{4} \quad (\varepsilon_{xx} - \varepsilon_{yy})^2 + \varepsilon_{xy}{}^2} \qquad \textbf{(2.12)}$$

with directions θ and $\theta + (\pi / 2)$, with θ given by:

$$\tan(2\theta) = \frac{2\varepsilon_{xy}}{\varepsilon_{xx} + \varepsilon_{yy}} \qquad \textbf{(2.13)}$$

ε_1 and ε_2 can be positive or negative. In graphical illustration, these values are pointed by arrows.

There are different kinds of methods to obtain strain parameters. Geodetic methods of repeated determination of position are used to obtain and monitor strain accumulation and analysis. Importantly, determination of the small regions in which the strain is assumed as homogeneous affects the results. In this study, strain from geodetic velocities and also from seismic data is obtained.

2.1.2 Earthquake History and GPS Geodesy for Strain Determination

With the current advanced technologies, we can detect the recent tectonic movement and the seismic activity on the Earth. The systematic study of active tectonics is of considerable importance, not only because of its significance in global and regional tectonics, but also because it is precisely in these zones that destructive earthquakes occur, with great loss of life and property. It is the knowledge of the location and size of past earthquakes that confirms major tectonic structures that are known to be active, reveals new ones, allows the estimation of strain rates and of the regularity or clustering of seismic activity, and provides the means to assess earthquake hazard for design purposes (**Ambraseys and Finkel, 1995**). Figure 2.7 shows the locations of earthquake record stations of NEMC (approximately 109) to monitor seismic activity over the country.

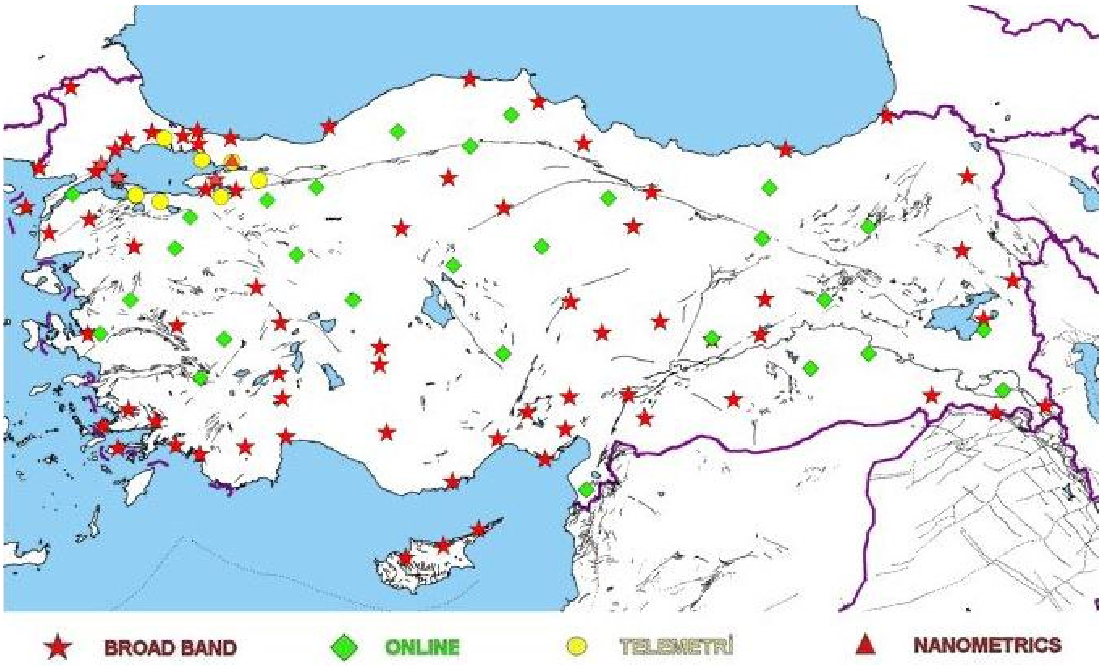

Figure 2.7: Locations of NEMC's seismic stations **(KOERI NEMC, 2007)**

Geodetic measurements of deformation provide an indirect measure of the rate of seismic productivity of a region. The objective of geodetic measurements is the determination of three components of position (latitude, longitude and height). Their temporal derivatives are commonly used to describe plate motions (two horizontal and one vertical velocity) and several spatial derivatives provide details of tectonic processes (strain, tilt and rotation). These derivatives are rarely measured directly. What is measured instead, are positions (latitude, longitude and height) and/or spatial separations (distance, relative elevation, angular separation) and these are repeated after an elapsed time to determine average velocities that are commonly assumed linear in time **(Bilham, 2000)**. The study of monitoring horizontal crustal movements on the western part of NAFZ has started by Geodesy Department of KOERI, Bogazici University in 1990. Three geodetic control networks were established in Iznik, Sapanca, and Akyazi regions in order to monitor crustal displacements. The first period observations were performed by using terrestrial methods and these observations were repeated annually until 1993 by using total-station and electromagnetic distance-meter instruments. Since 1994 GPS measurements have been carried out at the temporary and permanent points in the area and the crustal movements are being monitored (Figure 2.8).

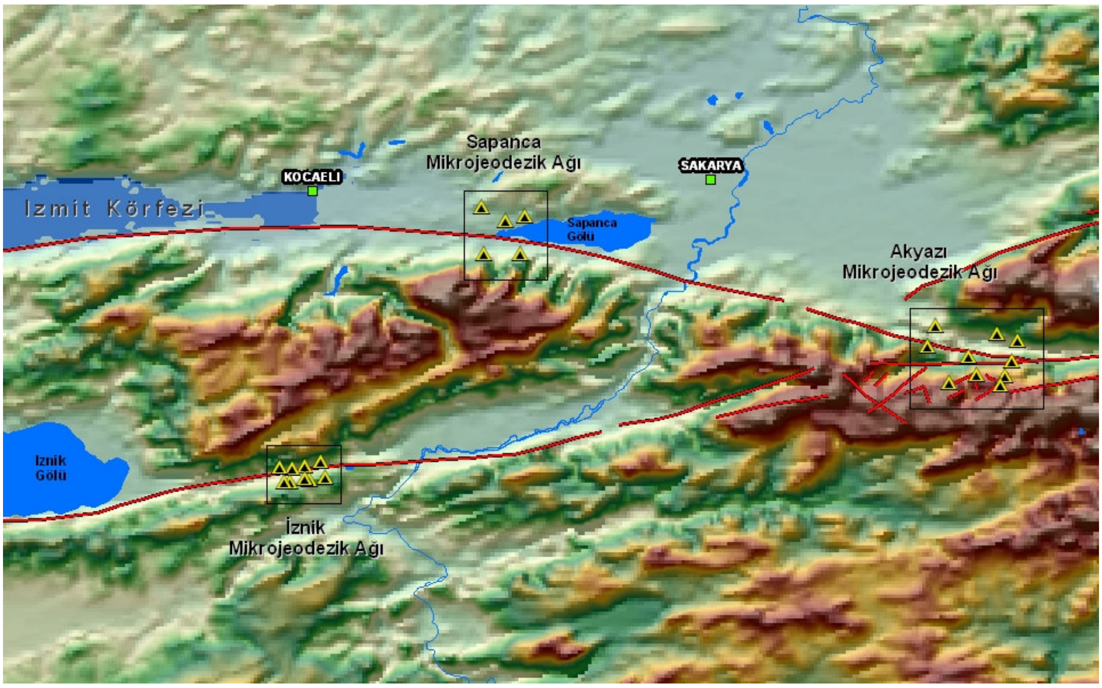

Figure 2.8: Microgeodetic Networks by Geodesy Department of KOERI of Bogazici University

The GPS technique has taken increasingly progress during the 1990s. The satellite constellation was completed. The GNSS (IGS) service formally began on 1 January 1994. RINEX format is widely used. This widespread availability of GPS geodesy has resulted in a number of significant findings related to deformation of the Anatolian plate. Researchers have learned more about the deformation processes in the past decade using GPS techniques. Continuous and accurate information of relative position is one of primary needs for the analysis of crustal deformation. The information is essential to refine the regional crustal deformation models and even to make long-term earthquake predictions in the region. GPS is the tool that can provide this kind of information. Through recent advances in GPS techniques, it is now possible to detect regional-scale crustal deformation and to provide direct evidence for seismological studies. In recent years, the success of GPS applications in geodynamics is remarkable. The GPS applications for monitoring crustal motion are mainly in three fields:

- global and continental plate motion and deformation analysis,
- regional crustal motion analysis,
- local monitoring of deformation and subsidence **(Shen, 2004)**.

One of the main advantages of using GPS technology for deformation measurements, as opposed to terrestrial geodetic techniques, is the ability to determine absolute displacement vectors, including rigid-body motions (rotations and translations), as well as internal deformation (strains) **(Dixon, 1991)**. The advent of space geodesy makes it possible to measure present day plate movements **(Gordon and Stein, 1992)** and to test the velocities estimated from NUVEL-1 plate velocity model **(DeMets et al., 1990)**. The origin of ITRF 2000 is defined by the Earth center of mass sensed by SLR and its scaleby SLR and VLBI, and it combines unconstrained space geodesy solutions that are free from any tectonic plate motion model **(Altamimi et al., 2002)**. The ITRF 2000 and APKIM 2000 results show in general a good agreement, there are, however, several discrepancies which exceed the 95% confidence. The comparison with NNR NUVEL-1A (No-Net-Rotation: motion of each plate with respect to the weighted average of all of the Earth's plate velocities) shows in particular large discrepancies of the Asia plate which obviously does not belong to Eurasia **(Drewes and Angermann, 2001)**. In practice, the geophysical kinematic model NNR NUVEL-1A is frequently used. This model, however, is a model describing the motions of rigid plates over the last millions of years and is not necessarily valid for present day motions **(Goldfinger and Christie, 2007)**. In the 1980s the international geodetic community began to define terrestrial reference frames that were realized by positions and velocities of a global network of stations estimated from a combination of space geodetic methods. The proliferation of global geodetic stations provided by the Global Positioning System and the accuracy of space geodetic positioning have evolved to the point where discrepancies began to appear between geodetic velocities and velocities predicted by the geologic models. Plate tectonic theory is an idealization and does not describe broad zones of plate boundary deformation. Recent work has attempted to develop more refined models of deformation that combine the motions of rigid plates and deforming zones **(Prawirodirdjo and Bock, 2004)**. GPS data from crustal deformation monitoring studies is being used to estimate the velocities and strain rates.

Earthquakes are sudden motions in the Earth caused by the sudden release of slowly accumulated strain. Seismic hazard assessment depends on the ability to understand where strain in the Earth's crust is accommodated and how much of this strain is accommodated seismically. So strain rate maps can be used to visualize the present-day deformation of Earth's crust. These maps are derived from the velocity model but show more directly how much stretching, squashing and shearing is taking place in different parts of the crust. Instead of showing the velocity itself, the strain rate maps show the difference in velocity from place to place. Where the velocity changes slowly from place to place, there is little deformation occurring. Where the velocity changes rapidly from place to place, there is a lot of deformation occurring. Geodesy is one way to measure the amount of crustal strain, other sources such as fault slip rate determination are not used in this thesis study.

2.2 Method for Obtaining Strain and Velocity Field

The method, which was developed by **Haines and Holt (1993)** in order to estimate a strain rate and velocity model, is followed to carry out this research. This method was then upgraded by **Haines et al. (1998)** and **Beaven and Haines (2001)**, and applied in various regions **(Holt and Haines 1995; Shen-Tu et al. 1999; Kreemer et al. 2000)**. A bicubic Bessel interpolation is used to expand a model rotation vector function which is obtained by a least-squares minimization, that is a best fit, between the model and the geodetic velocities. A comprehensive overview of the methodology can be found in **Haines et al. (1998)**. Geodetic velocities are the changes in location of campaign-based GPS sites. These data are used as input data into a strain rate model which then calculated strain on a 0.5 x 0.5 degree array over the study region. A spline interpolation technique was applied in which model velocities are fitted to observed GPS velocities, and those are then interpolated to derive a continuous velocity gradient tensor field which implicitly defines the strain rate tensor everywhere.

The finite element method is used in this method. Different from closed mathematical models, FEM is an open solution in which a complex structure is broken into many small simpler components or finite elements. Each of the elements has nodes at each corner and at each midpoint. At these nodes, each element is attached to another. Within each separate element, a simple displacement field is assumed and the continuity of these fields enforced within the interpolation.

Spline interpolation uses low-degree polynomials in each of the intervals, and chooses the polynomial pieces such that they fit smoothly together. The resulting function is called a spline. If the function has more than one variable, the method can be multivariate interpolation. This method includes bilinear interpolation and bicubic interpolation in two dimensions, and trilinear interpolation in three dimensions. A bicubic spline is a special case of bicubic interpolation. With this method, the value of a function at a point is computed as a weighted average of the nearest samples in a rectangular grid. Two cubic interpolation polynomials, one for each plane direction, are used. Bicubic interpolation results in an interpolating function which is continuous, has continuous first partial derivatives, and has continuous cross derivatives everywhere. The cubic spline method is applied to the important problem of interpolating values at equispaced points with irregularly distributed observations. For locations where no data exist, spatial interpolation and smoothing of the point estimates provide estimates over a continuous area. The process of smoothing and interpolation can be achieved essentially by different techniques. Smoothing a data set is to create a function that attempts to capture important patterns in the data, while leaving out noise. Many different algorithms are used in smoothing. Kernel smoothing is used to obtain a smooth estimate of a univariate or multivariate probability density from an observed sample of observations **(Bailey and Gatrell, 1995)**. In kernel estimation, a three-dimensional floating function visits every cell on a fine grid that has been overlaid on the study area. Distances are measured from the center of the grid cell to each observation that falls within a predefined region of influence known as a bandwidth. Each observation contributes to the density value of that grid cell based on its distance from the center. Nearby observations are given more weight in the density calculation than those farther away. Selecting an appropriate bandwidth is a critical step in kernel estimation. The bandwidth determines the amount of smoothing of the point pattern. The bandwidth defines the radius of the circle centered on each grid cell, containing the points that contribute to the density calculation. In general, a large bandwidth will result in a large amount of smoothing and low density values, producing a map that is generalized in appearance. In contrast, a small bandwidth will result in less smoothing, producing a map that depicts local variations in point densities. Using a very small bandwidth, the map approximates the original point pattern.

In this study, the model grid is continuous in longitudinal and latitudinal directions and covers the study area, Turkey, between 30°N and 45°S and between 20°W and 45°E. The model is calculated on a regular grid. A regular grid is a grid that has a regular topology and a regular geometry. A regular topology means that each element in the grid can be addressed by index (i, j) in two dimensions. Each grid point in the grid can be addressed by coordinates (x[i, j], y[i, j]) in 2D. Each grid area is 0.5° x 0.5° in dimension whether an area is considered to be deforming or not is based primarily on seismicity occurrence (**Ambraseys, 1995; the Global CMT Catalog, 2006; KOERI Earthquake Catalog, 2006**). Grid size can be choosen smaller or bigger than this value. Totaly 1500 grid areas, 1081 of them are the grid areas which cover the deforming regions of Turkey, all other areas are considered to be rigid. The rigid areas EU, AF and AR plates. So 34 grids for AR rigid block, 135 for AF rigid block and 250 for EU rigid block (Figure 2.9). The extent of the rigid blocks are based on the seismicity.

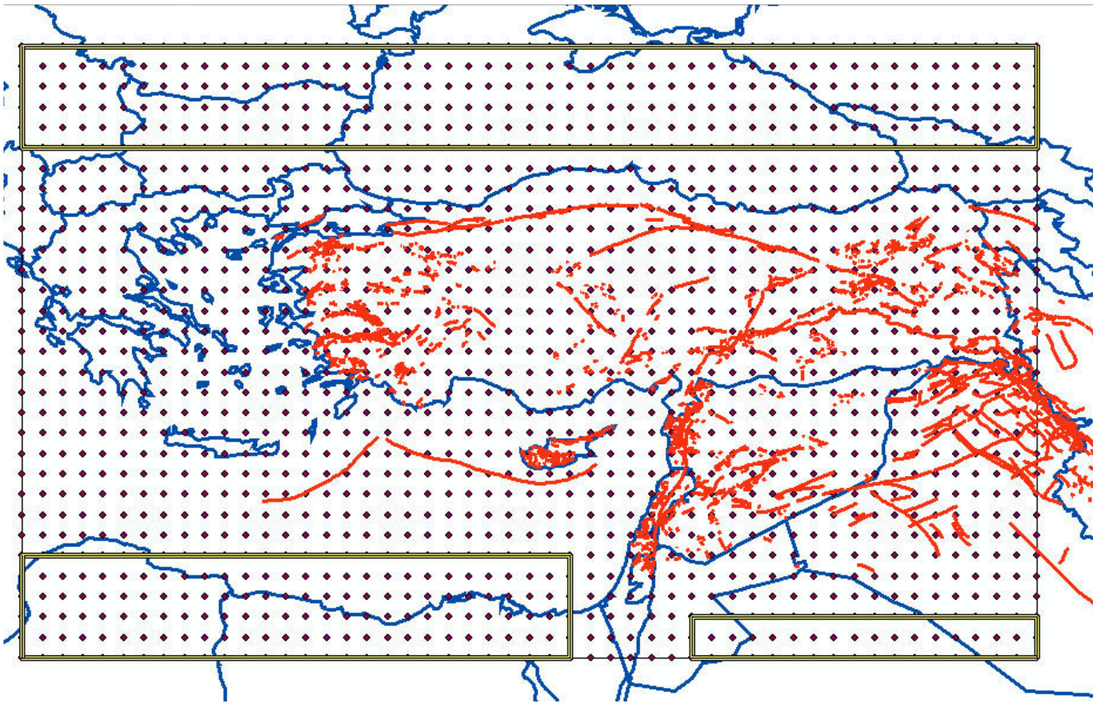

Figure 2.9: Grid geometry for the study area

Here, rigid blocks refer to rigid bodies which is the idealization of a solid body of finite size in which deformation is neglected. In other words, the distance between any two given points of a rigid body remains constant in time regardless of external forces exerted on it. Rigid bodies have meaningful rotations, so they have both linear and angular velocitites. Angular velocity describes the speed of rotation and the orientation of the instantaneous axis about which the rotation occurs.

In this thesis study, a least-squares fit to 66 geodetic velocities obtained during GPS campaigns in Marmara region between 2002 and 2005 by Geodesy Department of

KOERI. One of the main advantages of this methodology is that an unlimited number of geodetic studies can be combined. The model velocity field provides a best fit to the observed vectors that have been rotated into a single model frame of reference **(Kremer and Holt, 2000)**. For regions that are not densely sampled with geodetic observations, the interpolation of geodetic velocities can be highly non-unique in describing the regional strain rate field **(Kreemer et al., 2000b; Beavan and Haines, 2001)**. However, the design of the strain rate covariance matrix can place a priori constraints on the style and direction of the model strain rate field. Information about the style and direction of expected strain rate is inferred from the principal axes of the seismic strain rate field, which is obtained through a **Kostrov (1974)** summation of seismic moment tensors in each grid area. Seismic moment tensors are used only from shallow events (less or equal 30 km) in the Global CMT catalog (between January 1976 - May 2006) (Figure 2.10).

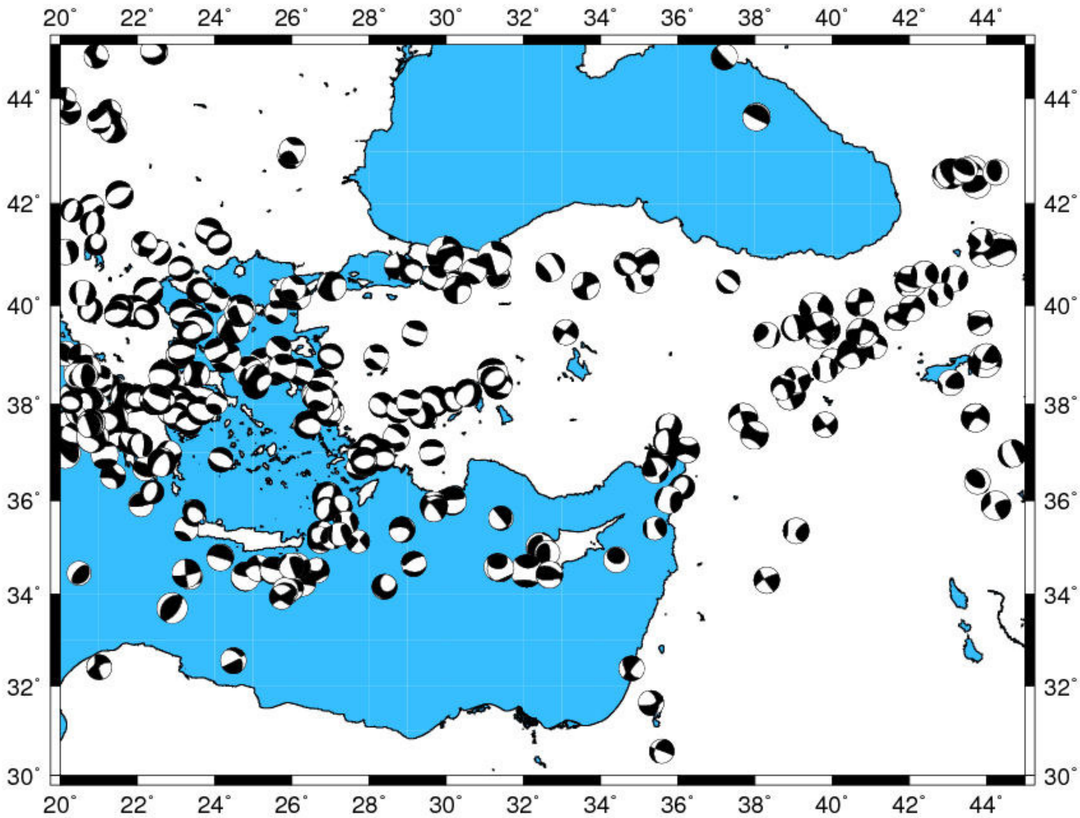

Figure 2.10: Earthquake Focal Mechanisms (Beachballs) with M > 5.0 from Global CMT catalogue

It should be noted that only the style and direction of the model strain rate field is constrained using the direction and style of the seismic strain rate field, not the magnitude. Also, constraints on the style and direction of the model strain rate field do not significantly affect the fit of the model velocities to the observed velocities. Moreover, including constraints on the style and direction of the model strain rate field results in a solution that is as consistent as possible with regional seismotectonics, while providing more stability in the model strain rate field from one grid area to another **(Kreemer et al., 2000b)**.

Knowledge of long-term (timescale that are less than the period which plate motions change but greater than several seismic cycles) seismic strain rates is essential for determining the seismic hazard of a region. In probabilistic seismic hazard analyses, the region of interest is divided into sesimic source zones in which seismicity is assumed to be homogenously distributed. For each source zone a magnitude-frequency seismicity distribution is determined, and an estimate of long-term seismic hazard analyses is done. However, for some regions, the strain rate fields are not compatible with other strain rate data such as geodetically inferred. So it is preferable to use all consistent available data. That is different types of data can be used and integrated for hazard analysis purposes **(Jenny, 2004)**. Focal mechanism solutions enable to determine orientation of fault plane where an earthquake occurs and to gain information on state of stress in the lithosphere. It is done with the analysis of distribution of compressional and dilational first arrivals from an earthquake. Although focal mechanisms provides information on the geometry of seismic zones, and on the style and localization of permanent deformation, they are available since the start of CMT catalog. So it may be seen an incomplete sampling of seismic cycle of larger events. On the other hand, geodetic measurements record complete deformation (seismic and aseismic). Elastic deformation can be distinguished from permanent deformation with GPS. However, dense distribution of GPS data are not available for many regions **(Kreemer, 2000)**. In this study, GPS data provide velocity gradient tensor field while mechanisms of moderate-sized earthquakes are used to help for constrain on the direction and style of strain in localized zones.

2.2.1 Using Seismic Data

Focal mechanism solutions from Global CMT catalog are used to obtain a model of the seismic strain rate and velocity field. Seismic data contains solutions for approximately all events with magnitude $M_w > 5$ within a time period of 30.5 years (from 1976/1/1 to 2006/06/31). Since the lithosperic deformation is studied, events with a depth less than 30 km are used. Using moment tensors from earthquakes between 1976 and 2006, the horizontal velocity gradient tensor field associated with the seismic deformation in Turkey is determined.

According to **Haines and Holt (1993)**, the horizontal velocity field u(r) for the spherical Earth expressed as

$$u(\hat{x}) = rW(\hat{x}) \times \hat{x} \qquad \textbf{(2.14)}$$

where r is the radius of the Earth and $\hat{x}$ is the position vector on the Earth's surface. This method allows for the combination and comparison of different data types **(Jenny, 2004)**. It determines $W(\hat{x})$ at the nodes of a rectangular grid using bi-cubic spline interpolation. These values are obtained from least-squares inversion between observed and predicted values of strain rate and velocity. Depending on the data distribution on the study region, smoothing between neighbouring grid cells is required. No smoothing takes no account of how the strain rates are distributed in neighbouring rectangles, in which the strain rates may be significantly higher or lower. In the case of seismic data inversion, strain rates are estimated from Kostrov summation (1974):

$$\bar{\dot{\varepsilon}}_{ij} = \frac{1}{2\mu VT} \sum M_0 m_{ij} \qquad \textbf{(2.15)}$$

where μ is the shear modulus, V is the cell volume (the grid area times the seismogenic thickness), T is the time period of the earthquake record, M_0 is the scalar seismic moment, and m_{ij} is the unit moment tensor. Shear modulus is taken as $3.5 \times 10^{10}\, Nm^{-2}$, and seismogenic thickness is 30 km. These chosen values affect the magnitude but not the style of the estimated strain rates.

The strain rate field (Figure 2.11) has an agreement with the region tectonics and the past studies. It can be seen that the largest seismic strain (strike-slip) rates are along the NAFZ, east of Marmara Sea and eastern Turkey.

The velocity field (Figure 2.12) obtained from seismic moment tensors inferred from event with $M_0 < 1 \times 10^{20}$ Nm is consistent with known relative plate motions.

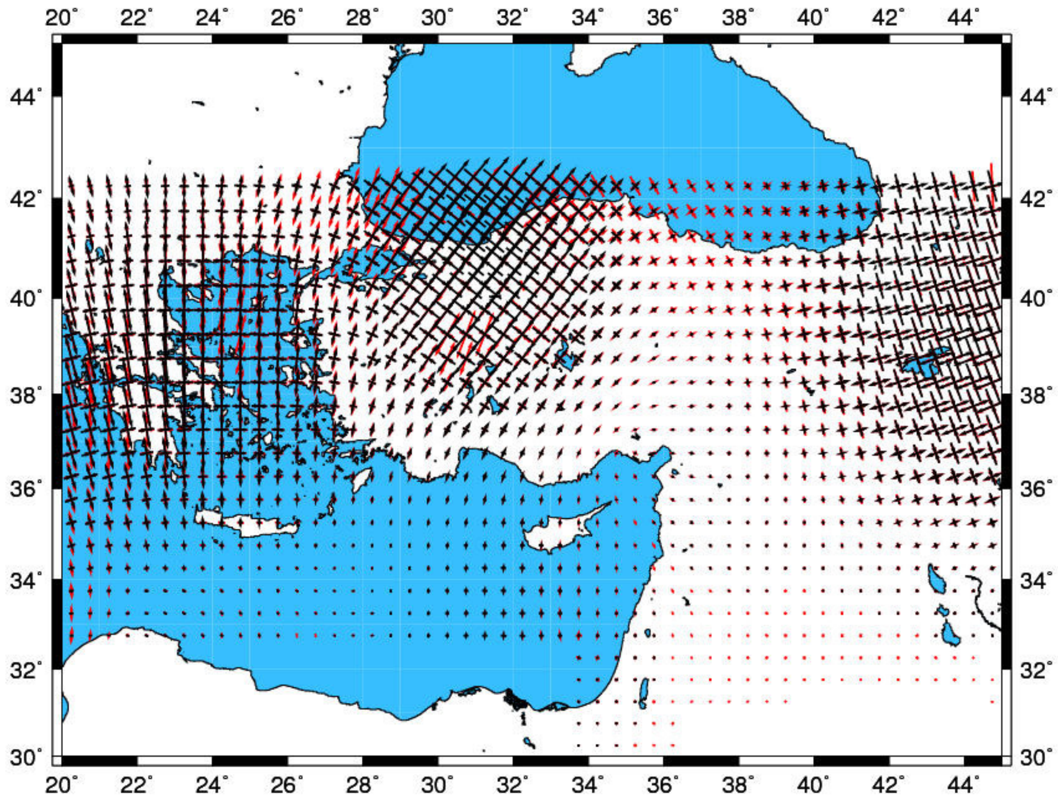

Figure 2.11: Observed (red axes) and model (black axes) strain rate field from an inversion of seismic strain tensors inferred from moderate-sized earthquakes

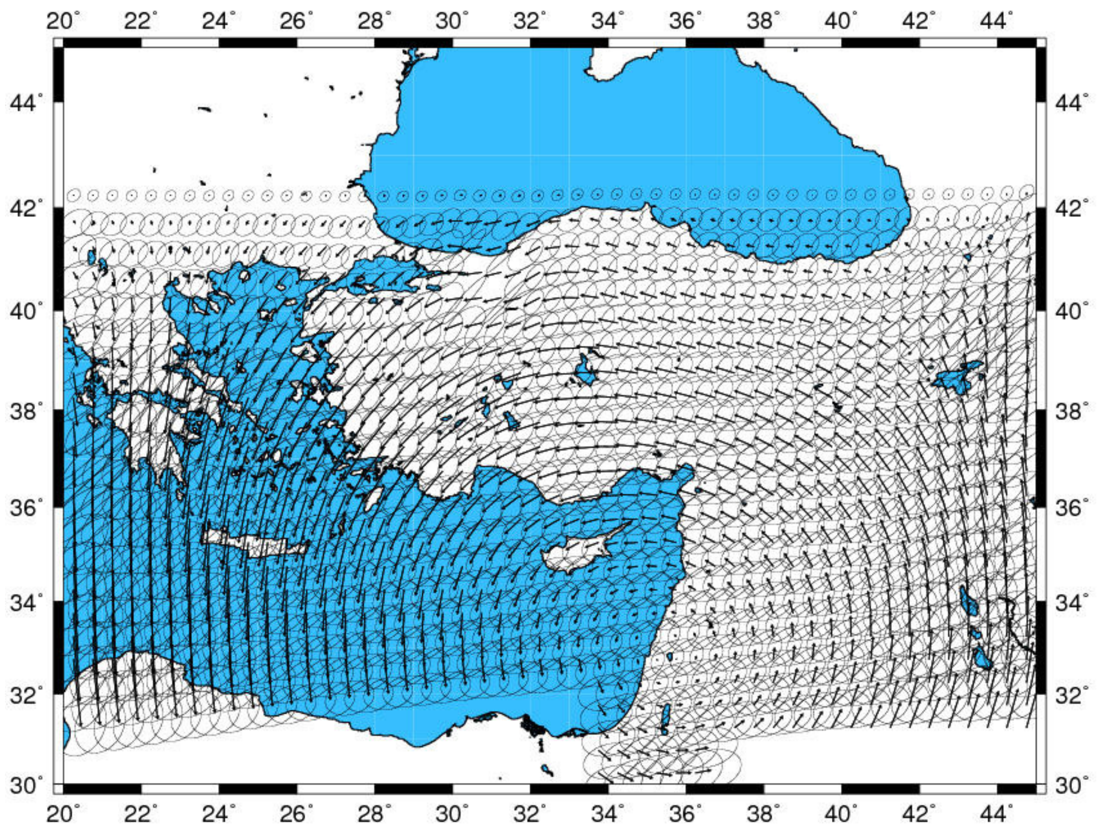

Figure 2.12: Velocity field relative to Eurasia from seismic inversion

2.2.2 Using GPS Data

In this case of inversion, observed strain rates are not used. GPS velocities are matched while no apriori constraints are placed on the style and direction of the model strain rate field. Importantly, the GPS data coverage in the region affects to define a reliable long-term strain rate field **(Kreemer, 2000)**. The geodetic deformation field is dominated by right-lateral strike-slip deformation along the NAFZ and its prolongation in the Aegean. The geodetic strain rate field (Figure 2.13) is much smoother than the seismic strain rate field. It reflects the differing characters of long-term tectonic and short-term seismic strain rates **(Jenny, 2004)**. Figure 2.14 displays the velocity field obtained from fitting GPS velocities. GPS data comes from GPS campaigns performed in Marmara region by Geodesy Department of KOERI of BU.

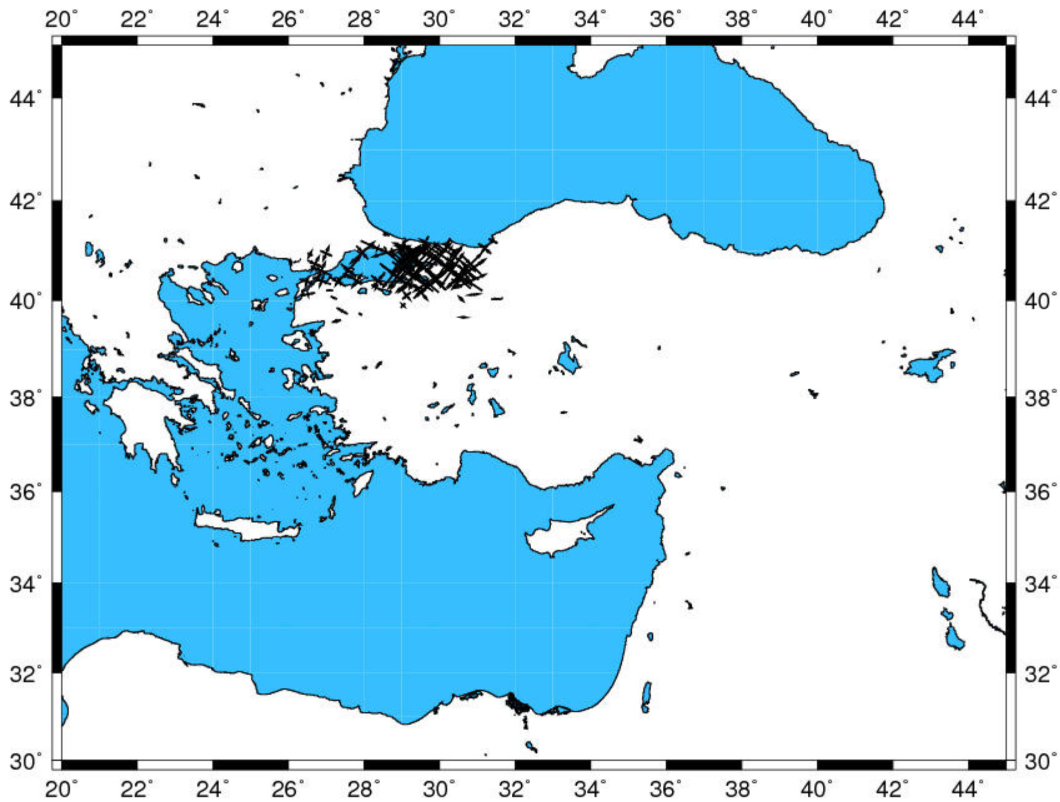

Figure 2.13: Strain rates obtained from fitting GPS velocities

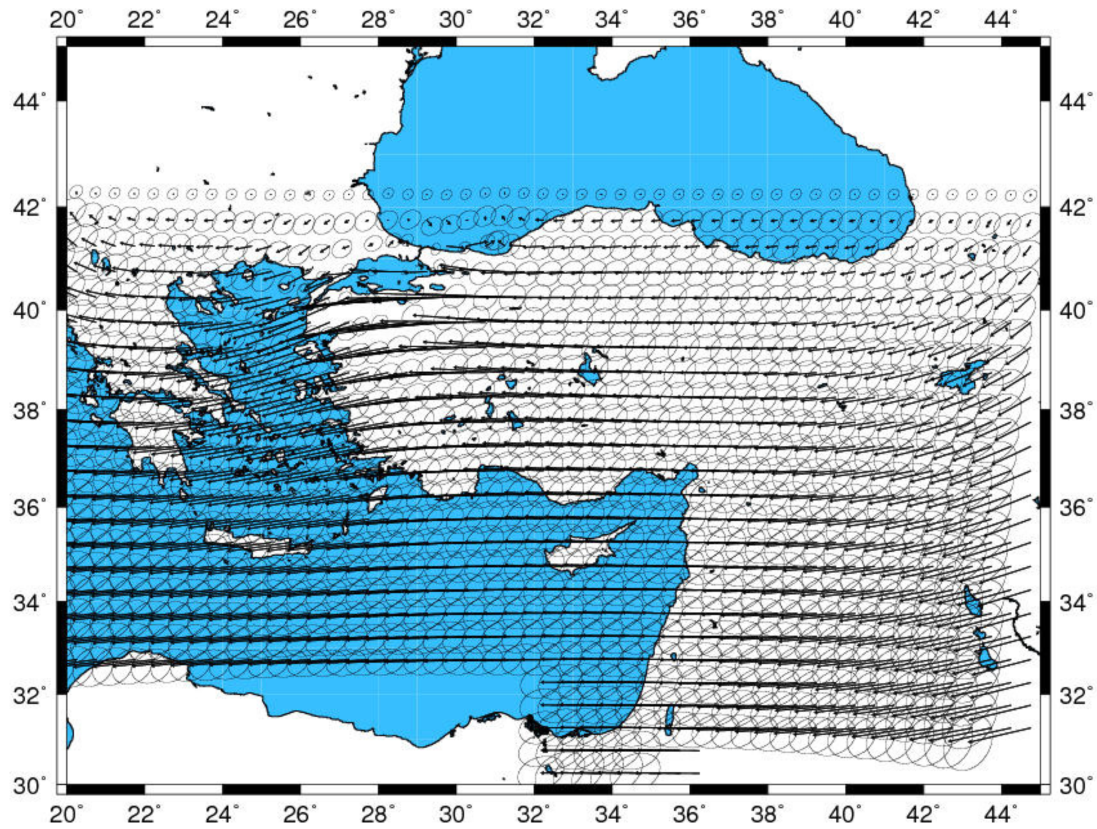

Figure 2.14: Velocity field relative to Eurasia from GPS only inversion

2.2.3 Using GPS Data With Constraints From Seismicity

Here, only the direction and relative magnitude of the principal axis of strain rate are constrained a priori. Whether the strain rates are compressional or extentional is defined by GPS data. The model strain rate field (Figure 2.15) and velocity field (Figure 2.16) obtained from bicubic Bessel interpolation of GPS velocities with a priori constraints on the style and direction from earthquakes with $M_0 < 1 \times 10^{20}$ Nm are produced in this inversion.

Assessment of strain accumulation throughout Turkey or in specifically targeted areas can be obtained by using geodetic and seismic data. Determination of strain accumulation can identify areas of high seismic hazard in Turkey. In order to improve the understanding of the relationship between strain accumulation and seismic hazard assessment, integration of geodetically derived data from regional and national networks with the existing seismic catalogue is needed.

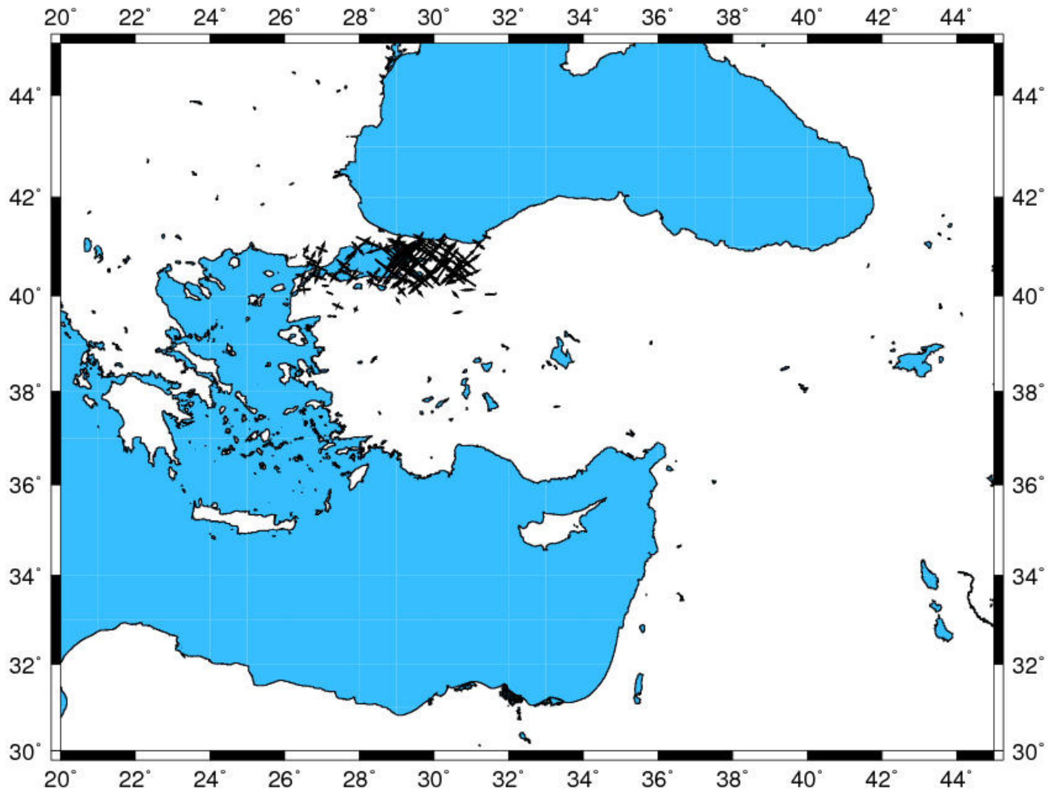

Figure 2.15: Strain rates obtained from fitting GPS velocities with constraints from seismicty

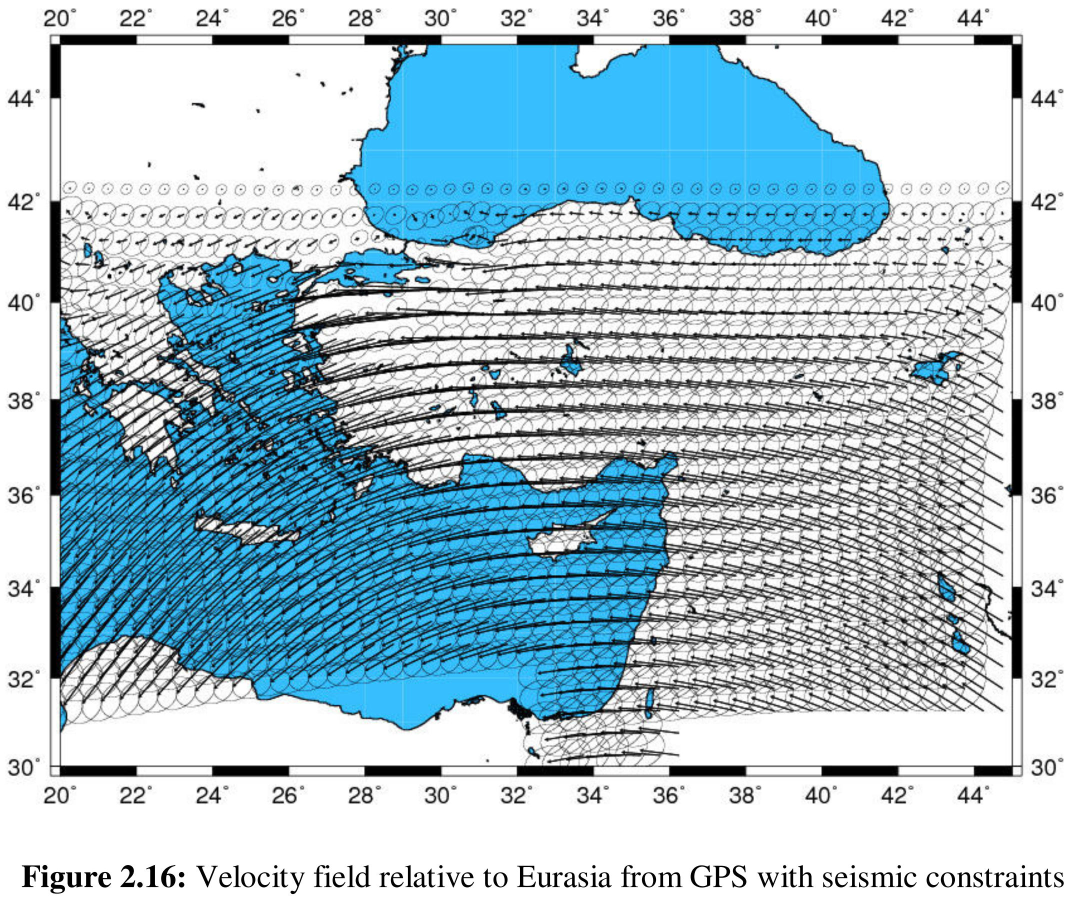

Figure 2.16: Velocity field relative to Eurasia from GPS with seismic constraints

3. DESIGN AND IMPLEMENTATION OF A WEB-GIS APPLICATION

Data alone does not make a geospatial information infrastructure. It consists of organizations, users, technologies, standards and metadata. In Turkey, it is not easy to constitute and maintain a policy in the field of Earth science data management. Various projects in these fields have been conducted for years in the world. And now there is an increased awareness of the need for multipurpose and interdisciplinary projects in our country. In Earth science studies, scientist works on one aspect of the problem. For comprehensive understanding of earthquakes, scientists must put all of data and tools together. The solution is to combine the information technology with the science of studying earthquakes. This increases the scientific understanding of seismic hazard and awareness of seismic hazard in the general public, it also improves emergency response as an outreach. Informatics, which is defined as the science of information, the practice of information processing, and the engineering of information systems, make it possible to reuse the functionality of existing systems. The key Informatics areas such as management of geospatial information, web services, portals, and webmapping which involved in this study are defined under different subtitles.

3.1 Definition of Information Technology Resources

3.1.1 GIS

3-D is essential in Earth sciences. Large-scale scientific investigations and evaluation of natural hazards require the construction of highly integrated 3-D models of the Earth. The construction, editing, and visualization of 3-D models are major technical challenges. GIS is an ideal tool to play a key role in meeting these challenges.

In the history of GIS, it has been evolved from Geographic Information System to Geographic Information Services. In the 1980's GIS was Geographic Information System; in the 1990's, Geographic Information Science was the preferred phrase; and now the trend is toward Geographic Information Services. GIS has benefited from the same improvements in the information technology (i.e. faster processing, increased bandwidth, greater storage capacity, mobile technologies, and real time networks) and has moved to workstations, then PCs, and now the Web.

The power of GIS comes from the ability to relate different information in a spatial context and to reach a conclusion about this relationship. Today, scientists recognize that the atmosphere, the land, and the ocean, are coupled. And they need GISs and other resources to analyse the relationships among them. However, GIS will not work unless the combination of compute, data, networking, visualization, and other resources. So geoscientists and computer scientists need to work together to design comprehensive GIServices applications which make time for doing science.

Over the last 20 years, a phenomenon has evolved in the software industry. It is called as open source. To best understand the concept of open source, its opposite (closed source) should be considered first. A typical computer program can take one of two forms: source code or compiled executable. The source code of a program are written using computer language but can not be run by the computer since the code is intendend to be read by programmers. They are translated (compiled) into a form that can be executed by a computer. Then it is named as executable or binary program. For example, Microsoft Internet Explorer is an executable program. Users can use the program but they are not allowed to see the source code, and can not make changes in the program. It should be noted that open source does not mean free, and the all free computer programs are not open source. The main advantage of open source software is free (or low-cost) availability. Source code availability makes users to modify it and to redistribute modifications and improvements.

In 1980s, GNU Project and the Free Software Foundation was launched. The goal was to build a free operating system. Another improving was BSD Unix. The aim of this effort was to make Unix hackers around the world help to debug, maintain and improve the system. In 1990s, Linus Torvalds (a student of computer science in Finland) implemented a kernel (responsible for communication between hardware and software components) for Unix operating system. And it was named as Linux. In 1998, the publicly available source code of Netscape was the starting point to understand the importance of open source software by big companies around the world. Then, the Open Source Geospatial Foundation was created to support and build the highest-quality open source geospatial software. Today, many open source projects are continueing to be produced. This advancement in the software industry has also affected GIS development. GIS industry has been undergoing a revolution, and it has evolved from closed systems to open systems. There is an impressive increase in free and open source and low-cost commercial GIS packages. GRASS, JUMP, and Quantum GIS are widely used open source desktop GIS programs, and MapBender, MapBuilder, GeoTools, UMN MapServer and OpenLayers are the examples of open source Web mapping tools. Nevertheless, there are still expensive commercial GIS softwares such as ArcGIS, MapInfo and free ones such as Map Maker Gratis. Figure 3.1 shows the commercial GIS software used in the industry.

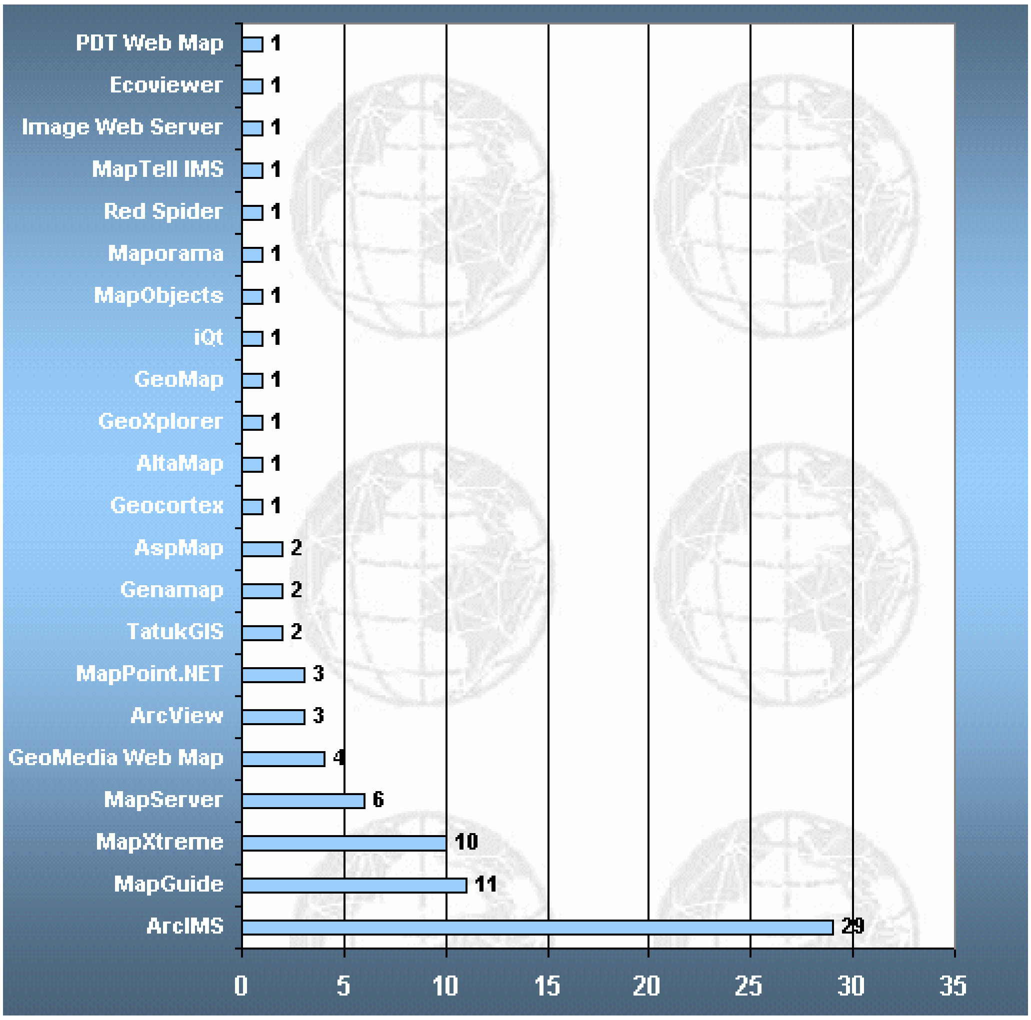

Figure 3.1: Commercial GIS packages **(Directions Magazine, 2006)**

Besides, there is a vast increase in Web-based applications including spatial data (i.e. Yahoo Maps, Mapquest, Microsoft Virtual Earth, Google Earth and NASA's open source World Wind) and public awareness of GIS technology. Web-based spatial information browsers have dramatically impacted the way people discover, share and visualize geographic information and affected the development of GIS and its interface with public users. As computer technology and instrument technology involved in geospatial data improve, new approaches continue to affect the future of GIS.

3.1.2 Web Services

SOA is basically a collection of services which communicate with each other. This communication can involve either simple data passing or some activity. Service oriented architectures are not new. The previous implementations of SOA are DCOM (by Microsoft) and ORB (based on CORBA Specifications - Java). They are very complex and they have no standard interchange format **(Memon, 2006)**. So the new implementations are called Web services. The implementation of SOA in the web environments is called Web services. A Web service can be defined that a programmable application which is accessible using standard Internet protocols. Web services can be any piece of code that is available over the Internet, so that other applications can invoke it and utilize its functionality (Figure 3.2). Reuse of existing tools, lower cost of maintenance and reduced impact of change are the most important benefits of Web services Web services can be written in any language.

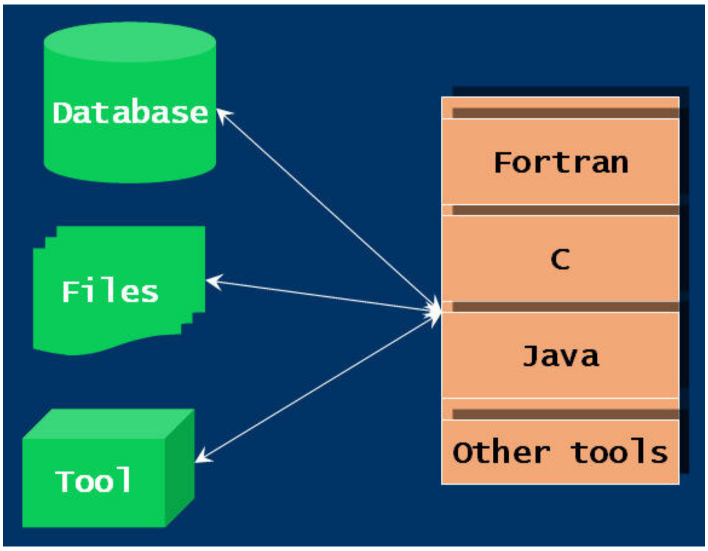

Figure 3.2: Web services are independent from platform and programming language

SOA is an architectural style whose goal is to achieve loose coupling among interacting services. Figure 3.3 illustrates a simple service interaction cycle, which begins with a service describing itself through a registry service. A potential client or another service queries the registry to search for a service that meets its needs. The registry returns a list of suitable services, and the client selects one and passes a request message to it by using any mutually recognized protocol. And the service responds with the result of the requested operation.

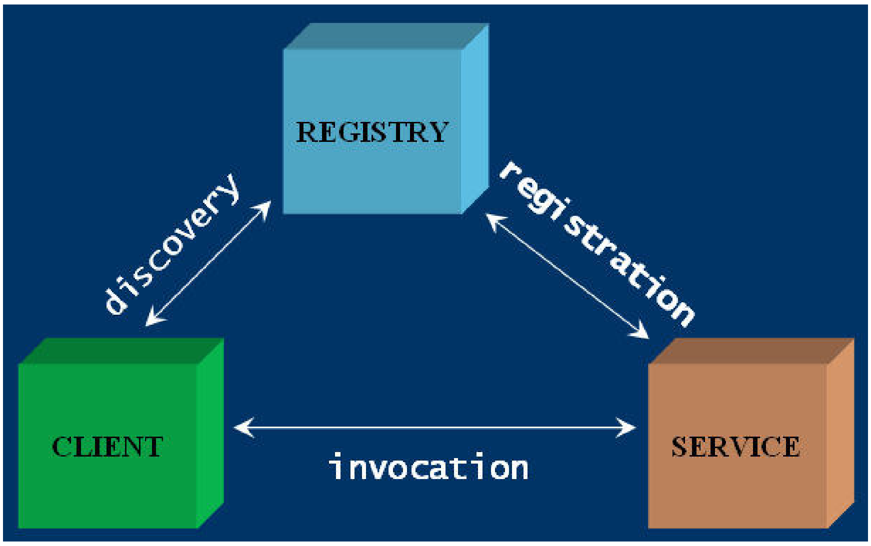

Figure 3.3: Web services interaction cycle

Web services standards such as SOAP (messaging), WSDL (metadata) and UDDI (metadata) enable system-to-system integration. SOAP is a simple XML-based communication protocol to let applications exchange information over HTTP. It is a protocol for accessing a Web Service. XML is a mark-up language for exchanging data and is basically another version of HTML. A markup language combines text and extra information about the text XML provides a mechanism to describe the structure and organization of data, and an XML file can contain the data too. SOAP connects two fields "application middleware" and "Web publishing" that were previously unrelated. SOAP is platform and language independent. It is simple and extensible. WSDL is an XML-based language for describing Web services and how to access them. WSDL is also used to locate Web services. UDDI defines a SOAP-based Web service for locating WSDL-formatted protocol descriptions of Web services. A sample of XML code pertaining to an earthquake record is presented below.

<?xml version="1.0"?> <table> <record> <lon> 29.265E </lon> <lat> 36.650N </lat> <magnitude> 3.0 </magnitude> </record> </table>

A Web browser provides a human-oriented interface to information and services. When a user requests a Web page, the request is handled by a remote Web server, which returns the information in HTML form. Web services, on the other hand, are distributed software components that provide information to applications rather than to humans. The information is structured using XML, so that it can be parsed and processed easily. Figure 3.4 shows the relationships among SOA-related terms.

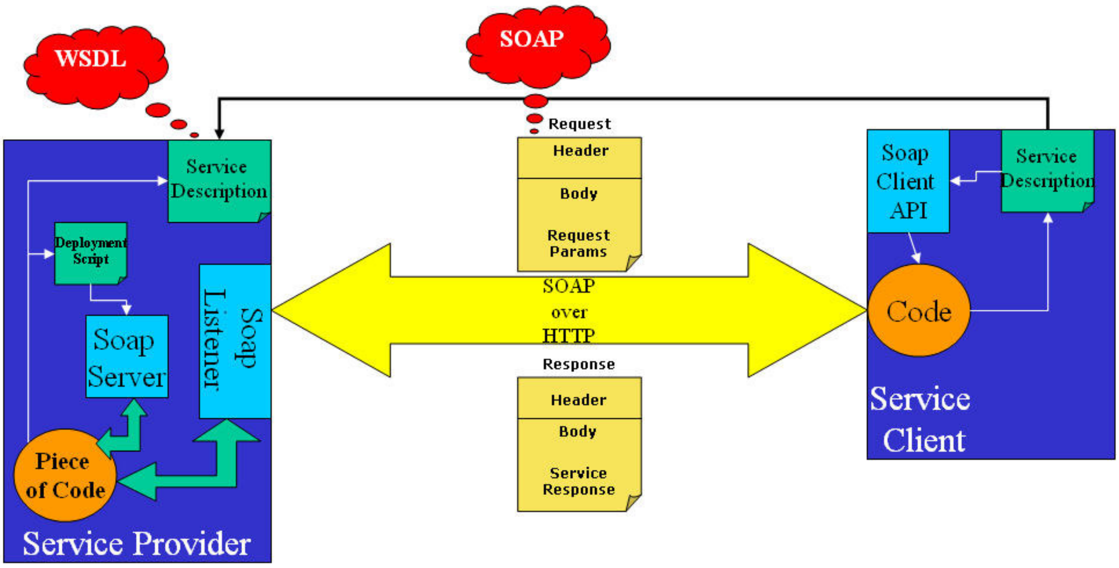

Figure 3.4: Accessing a Web service using SOAP **(Memon, 2006)**

W3C is responsible for the architecture and standardization of Web services. According to the **W3C (2006)**, a Web service is a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface that is described in a machine-processable format such as WSDL. Other systems interact with the Web service in a manner prescribed by its interface using messages, which may be enclosed in a SOAP envelope. These messages are typically conveyed using HTTP, and normally comprise XML in conjunction with other Web-related standards. Software applications written in various programming languages and running on various platforms can use Web services to exchange data over computer networks like the Internet in a manner similar to inter-process communication on a single computer. This interoperability (for example, between Java and Python, or Microsoft Windows and Linux applications) is due to the use of open standards.

3.1.3 Portal Frameworks

Web portals are sites on the Web that provide personalized capabilities to their users. They are designed to use distributed applications and various numbers and types of middleware to provide services from different sources. A portal framework provides a standard interface which is independent of programming languages or platforms. Scientific application portals are entry points for accessing online resources such as data and tools. Different sections of the portal (a.k.a. portlets) provide different functionalities. Portlets are pluggable user interface components that are managed and displayed in portals. The behaviour of the portlets is similar to that of servlets (small programs that runs on the servers and equivalent to CGI, but they are more powerful and more efficient) in many ways, i.e. both portlets and servlets are Java-based Web components, managed by a container, used to generate dynamic content and interact with Web clients via a request/response paradigm. Unlike servlets, portlets have additional features and limitations **(Akram, 2005)**. Today, major online scientific projects involving grid computing and web services (e.g. GEON, SCOOP, CHRONOS, P-GRADE) from the fields of Bioinformatics and Earth Sciences, use portals as an interface for managing data and using applications with a single login and password. Some of the key features of these projects' portals include personalized user information, tools for collaboration with other users, automatic storage of data in supercomputers, and workflows.

Two of the major open source (and free) portals are Gridsphere (Java-based, available for Linux and Windows operating systems) and DotNetNuke (.NET-based, Microsoft platform). The GridSphere portal framework provides an open-source portlet based Web portal. GridSphere enables developers to quickly develop and package third-party portlet web applications that can be run and administered within the GridSphere portlet container **(GridSphere, 2006)**. Gridsphere has a big user community, and it is used by many online science projects. It has both windows and linux releases. Gridsphere portal framework required Apache Ant (1.6.5), Apache Web Server (2.0.48) and JDK (1.4.2_12) installations. The impressive user interface of Gridsphere portal is displayed in Figure 3.5. GridSphere supports different type of authentication mechanisms, by default it is username and password.

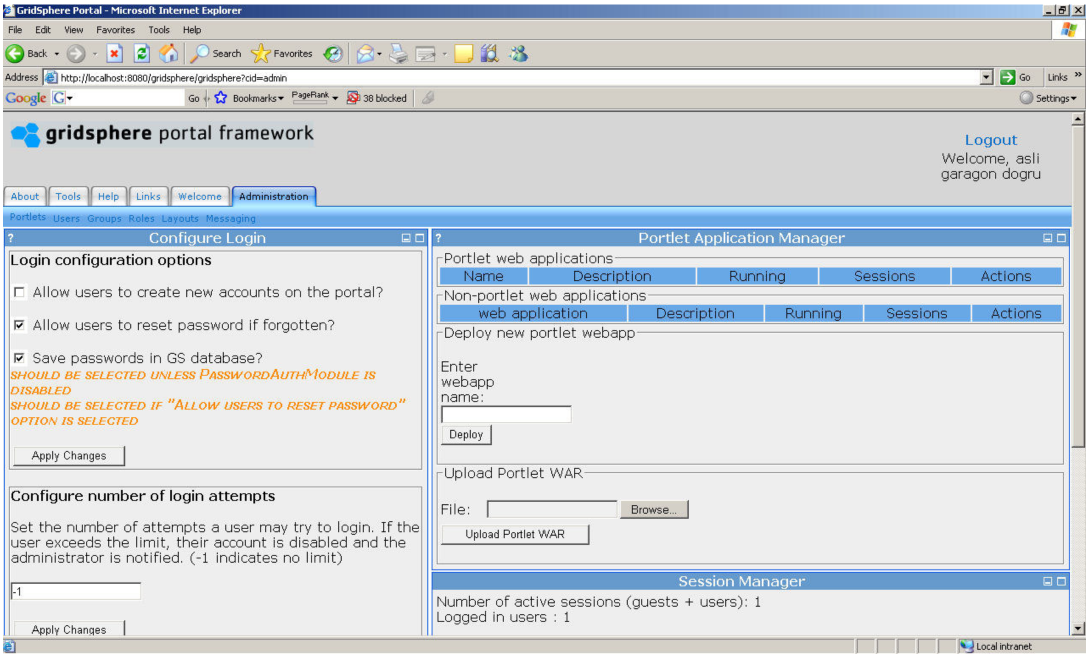

Figure 3.5: Gridsphere portal runs on Windows XP operating system showing portlet manager

DotNetNuke (Figure 3.6) is built on a Microsoft ASP.NET platform. It provides automated content management capabilities and tools to maintain a dynamic and truly interactive data-driven web site. The remarkable characteristics of DotNetNuke (DNN) can be summarized as follows **(DNN, 2006)**:

- Versatile. DotNetNuke is an open source web application framework ideal for creating, deploying and managing interactive Web, intranet and extranet sites.
- User-Friendly. DotNetNuke is designed to make it easy for users to manage all aspects of their projects. Site wizards, help icons, and a well-researched user interface allow universal ease-of-operation.
- Powerful. DotNetNuke can support multiple portals or sites off of one install. In dividing administrative options between host level and individual portal level, DotNetNuke allows administrators to manage any number of sites – each with their own look and identity - all off one hosting account.
- Feature-Rich. DotNetNuke comes loaded with a set of built-in tools that provide powerful pieces of functionality. Site hosting, design, content, security, and membership options are easily managed and customized through these tools.
- Supported. DotNetNuke is supported by its core team of developers and a dedicated international community. Through user groups, online forums,

resource portals and a network of companies who specialize in DNN, support is always close at hand.

- Easily Installed. DotNetNuke can be up-and-running within minutes. One must simply download the software from DotNetNuke.com, and follow the installation instructions. In addition, many hosting companies offer free installation of the DotNetNuke application with their plans.
- Localized. DotNetNuke includes a multi-language localization feature which allows administrators to easily translate their projects and portals into any language. And with an international group of hosts and developers working with DotNetNuke, familiar support is always close at hand.
- Open Source. DotNetNuke is provided free, as open-source software, and licensed under a standard BSD open source license agreement. It allows individuals to do whatever they wish with the application framework, both commercially and non-commercially, with the simple requirement of giving credit back to the DotNetNuke project community.
- Cutting-Edge. DotNetNuke provides users with an opportunity to learn best-practice development skills (such as module creation, module packaging, debugging methods, etc) all while utilizing cutting-edge technologies like ASP.NET 2.0, VWD, Visual Studio 2005 and SQL Server 2005 Express.
- Extensible. DotNetNuke is able to create the most complex content management systems entirely with its built-in features, yet also allows administrators to work effectively with add-ons, third party assemblies, and custom tools. DNN modules and skins are easy to find, purchase, or build. Site customization and functionality are limitless.
- Recognized. DotNetNuke is a trademarked name, and a brand widely recognized and respected in the open source community. With over 340,000 registered users and a talented team of developers, DotNetNuke continues to evolve its software through participation, real world trial, and end-user feedback.

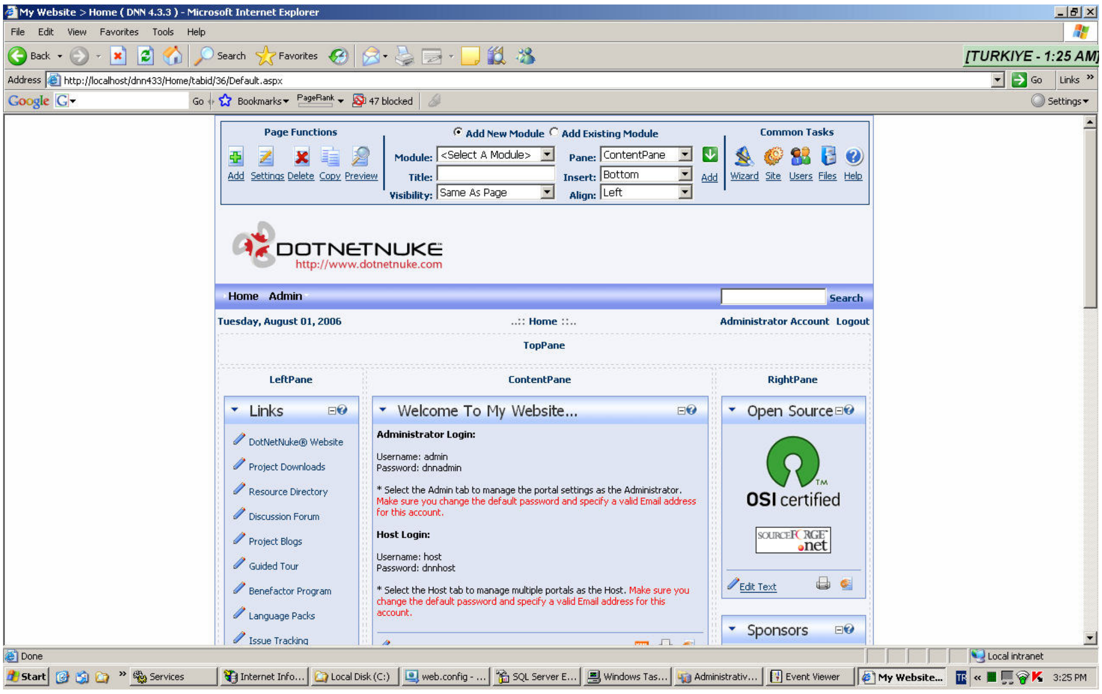

Figure 3.6: DotNetNuke portal runs on Windows operating system showing module properties

DNN 4.3.3 required MS IIS 5.1 (Figure 3.7), MS .NET Framework 2.0 and MS SQL Server 2000 installations. SQL Server 2005 Express Edition can also be used but it does not have an interface so that it is hard to use. Creating virtual directory on IIS, arranging file permissions, and creating database are important for the installation of DNN. Application protection for virtual directory must be medium.

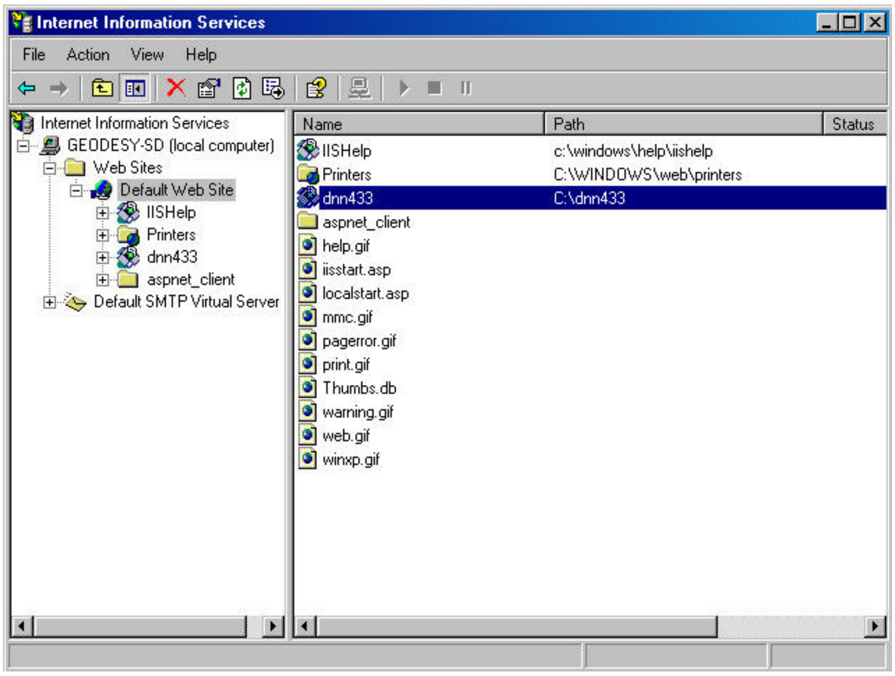

Figure 3.7: Creating a virtual directory on IIS

SQL Server 2000 Developer Edition is installed in mixed mode. And then a database is created in SQL server for DNN using Enterprise Manager (Figure 3.8). Microsoft SQL Server is a relational database management system (RDBMS) produced by Microsoft. Its query language is a variant of SQL (Transact-SQL). It offers a variety of administrative tools to ease the burdens of database development, maintenance and administration.

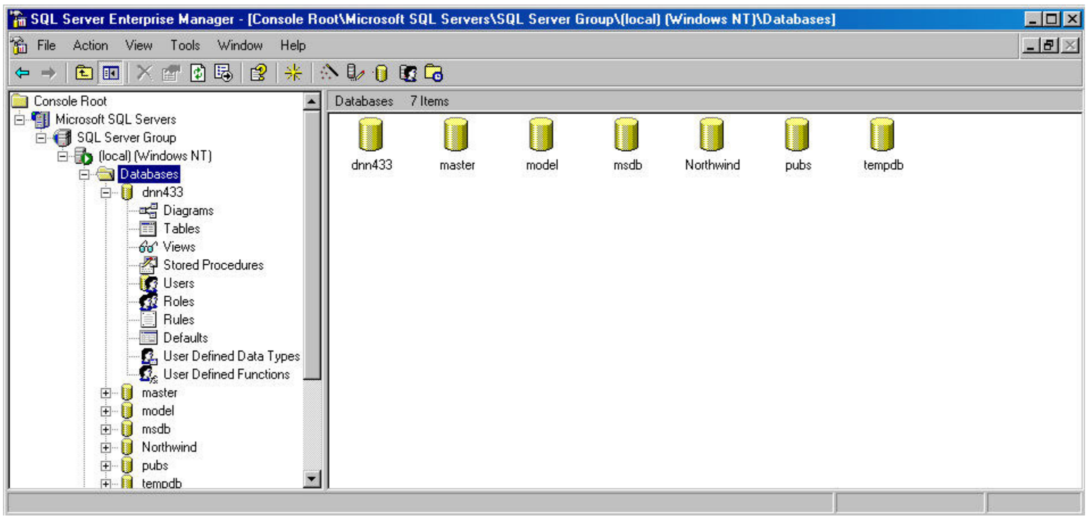

Figure 3.8: Creating a database and users in an SQL server

Enterprise Manager is the main administrative console of SQL Server. It provides a graphical view of all of the SQL Server installations on the network. Although this graphical interface is a good one, Aqua Data Studio 4.7 software can also be used for controlling databases (Figure 3.9). Aqua Data Studio is a database query tool and administration tool that allows developers to easily create, edit, and execute SQL scripts, as well as browse and visually modify database structures. Aqua Data Studio provides an integrated database environment with a single consistent interface to all major relational databases. It supports all operating systems, it is provided freely by AquaFold.

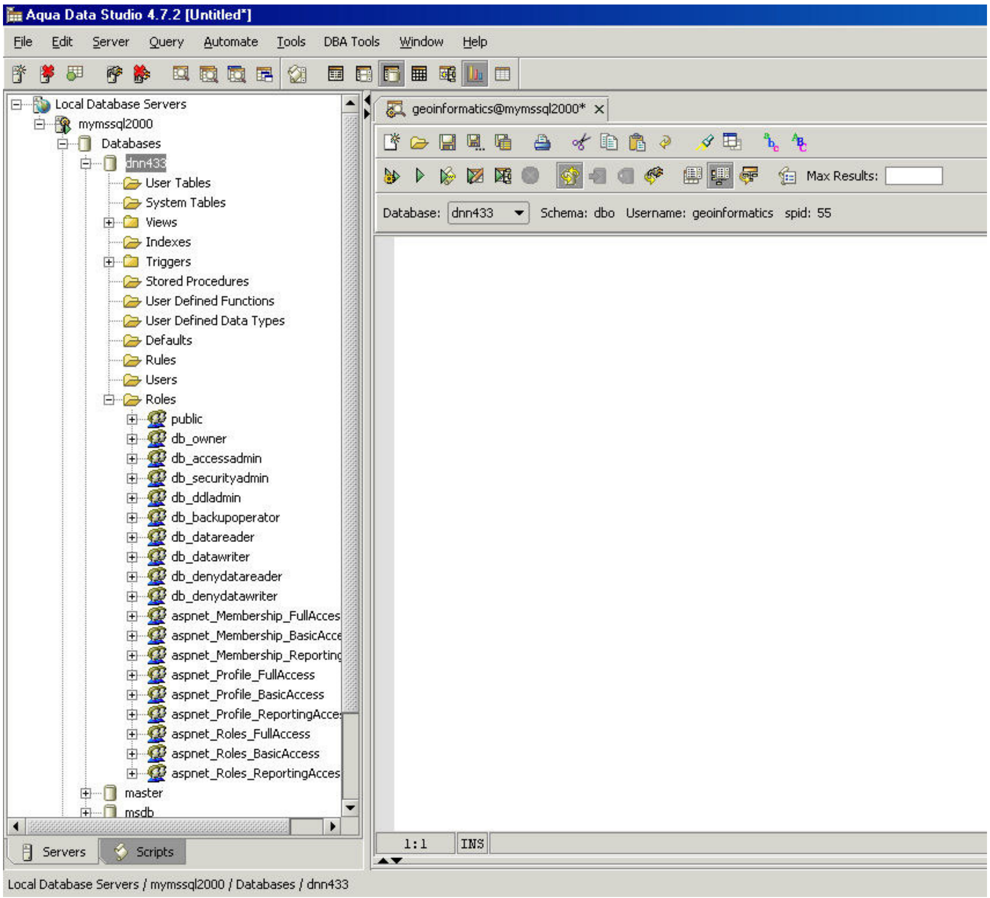

Figure 3.9: Aqua Data Studio screenshot showing schema browser to understand the structure and dependencies of the database

Visual Web Developer 2005 Express can be used for programming environment (Figure 3.10). Visual Web Developer Express is an easy-to-use development tool to build dynamic Web applications with ASP.NET 2.0. It has reusable controls and codes to reduce the time needed for creating interactive Web applications. To create dynamic web sites with ASP.NET, Microsoft .NET Framework and Visual Web Developer 2005 Express Edition are needed. They are provided free by Microsoft. The Microsoft .NET Framework is a component of the Windows operating system. It provides the foundation for next-generation applications, including ASP.NET web applications.

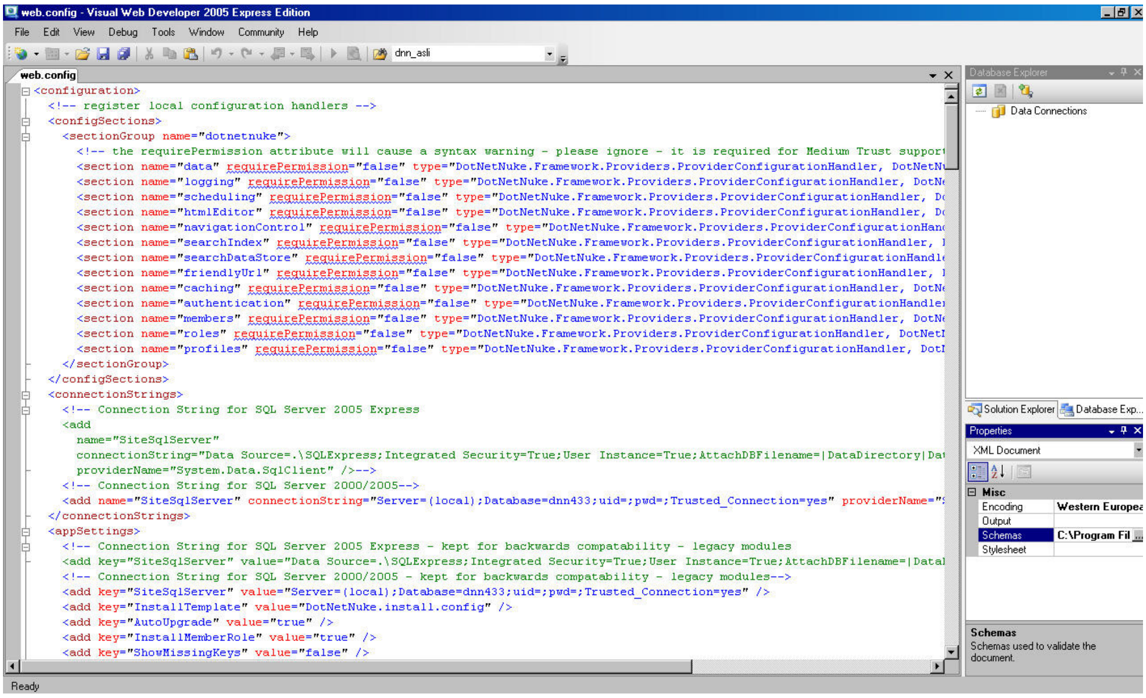

Figure 3.10: Visual Web Developer 2005 Express Edition screenshot displaying web.config file for adjusting DNN configuration settings

ASP.NET is a server-side Web technology platform with many layers and capabilities. ASP.NET is used to create Web pages (with aspx extension) and Web services. ASP.NET takes an object-oriented programming approach to Web page execution. Every element in an ASP.NET page is treated as an object and run on the server. Following displays a samle of ASP.NET codes:

```
<%@ Page Language="VB" codePage="28599" %> <script runat="server">
sub Page_Load(obj as object, e as eventargs)
dim number As integer
For number=1 to 10
Response.Write (number & "<br>")
Next
end sub
</script> <html> <head> <meta http-equiv="Content-Type" content="text/html;
charset=iso-8859-9"> </head> <body> </body> </html>
```

ASP.NET combines unprecedented developer productivity with performance, reliability, and deployment. It provides developers easy programming model, and supports more than 25 .NET languages including VB.NET, C#, and JScript.NET. It also makes exposing and calling XML Web Services simple. Figure 3.11 shows the code writing environment in ASP.NET.

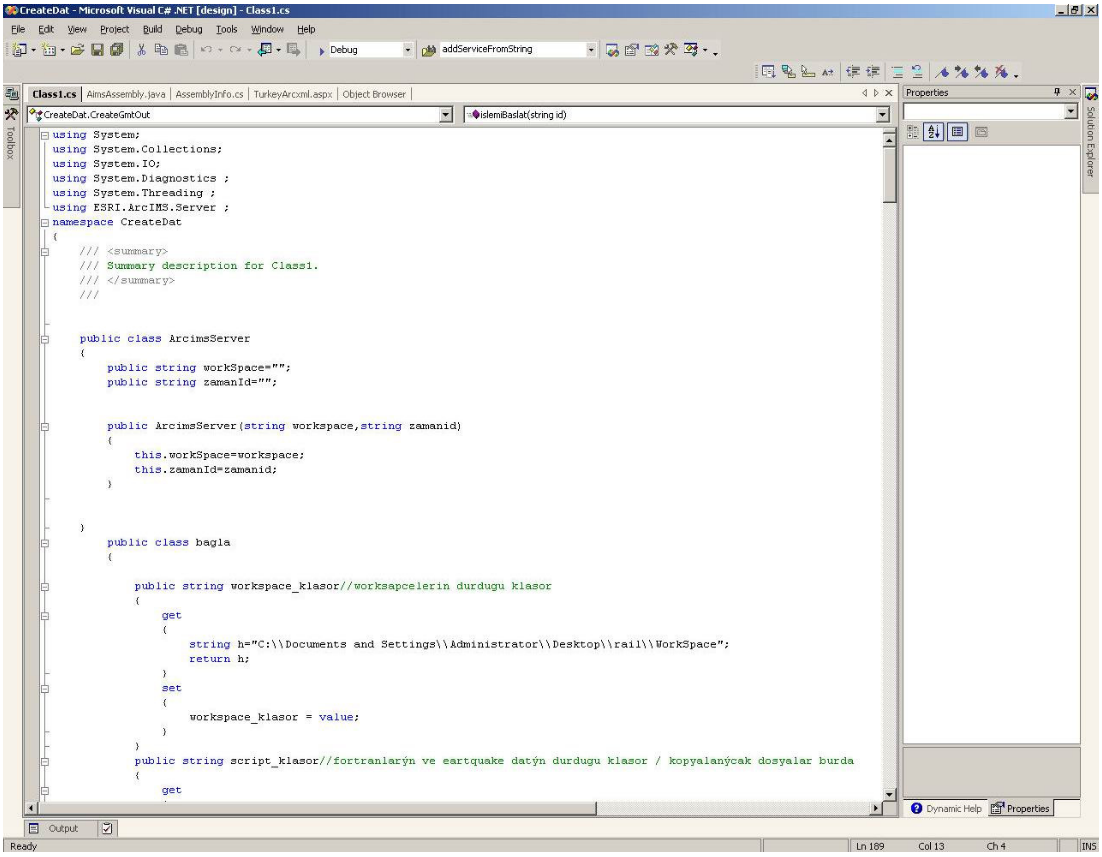

Figure 3.11: ASP.NET development environment

Seperate from DotNetNuke, there are also other open source portals and commercial ones like IBM's Websphere. Every portal has its own pros and cons. DotNetNuke comes with so many ready to use portlets while Gridsphere comes with the extensible architecture, and JSR 168 (Portlet Specification which standardises the interoperability of between portlets and portlet containers) and WSRP (aims to define standards for interactive Web services to make portlets hosted by different geographically distributed portal frameworks accessible) standards support. However, Gridsphere requires advanced computer programming skills. Though portlets can be developed in different languages, Gridsphere portlet programming can also be done using JSP. JSP is a Java technology for generating HTML, XML dynamically. Originally, the Web consisted of static HTML pages. In an interactive Web service, the pages contain forms with information to the server, and the reply is generated dynamically. JSP (resembles ASP/PHP) and Servlets (resembles Perl/C/VB CGI scripts) are Java-based technologies for making interactive Web services (**Moller and Schwartzbach, 2006**). Servlets are server-side extensions. A sample of JSP codes to create node numbers automatically according to input parameters by the users for gridding the study area in order to calculate strain rates is as follows.

```
<html> <head><title>number of nodes</title></head> <body>
<%-- nodenumber calculator --%>
<%
String value1 = request.getParameter("value1");
String value2 = request.getParameter("value2");
String value3 = request.getParameter("value3");
String value4 = request.getParameter("value4");
String value5 = request.getParameter("value5");
double value1double = Double.parseDouble(value1);
double value2double = Double.parseDouble(value2);
double value3double = Double.parseDouble(value3);
double value4double = Double.parseDouble(value4);
double value5double = Double.parseDouble(value5);
double firstterm = ((value1double - value2double)/value5double) + 1;
double secondterm = ((value3double - value4double)/value5double) + 1;
double nodenum = (firstterm * secondterm) + 1;
%>
Node number is: <%= nodenum %> <br> </body> </html>
```

In this study GridSphere 2.1.5 and DotNetNuke 4.3.3 portal frameworks were experienced and compared. Finally, a portal-based web interface was created by using ASP.NET.

3.1.4 Webmapping

Web-based GIS provides real-time access to geospatial databases online and equip users with GIS query, analysis, and visualization tools. There are various numbers of tools for serving web maps. Two of web mapping tools are experimented during this study. The one is commercial ArcIMS 9.1 and the other one is open source UMN MS4W 2.0. ArcIMS (Figure 3.12) is a Web Map Server produced by ESRI. It is a GIS that is designed to serve maps across the Internet. Interactive maps served with ArcIMS include maps with layers that can be turned on and off, or with features containing attributes that can be queried. A web browser is just needed by the user, and the database is maintained on the server side. ArcIMS uses ESRI's ArcXML to receive and respond to requests from the client. The data behind ArcIMS is usually stored in Shapefile format or an RDBMS database.

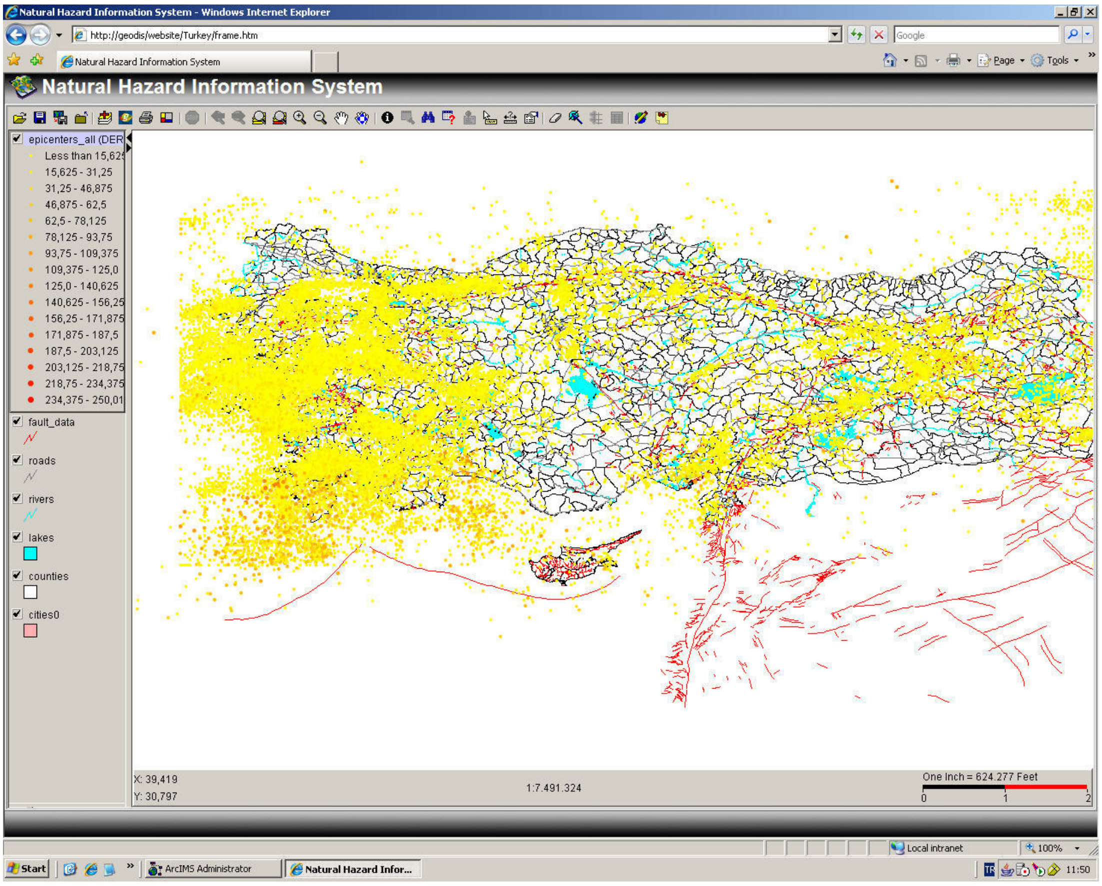

Figure 3.12: Data in ArcIMS environment

MapServer (Figure 3.13), which was developed by the University of Minnesota, is an open source internet map server. UMN MapServer is a CGI-based application for delivering dynamic GIS via the Web. The package also contains a number of stand alone applications for building maps, scalebars and legends offline. Access to the development environment of MapServer is possible with a number of different programming languages.

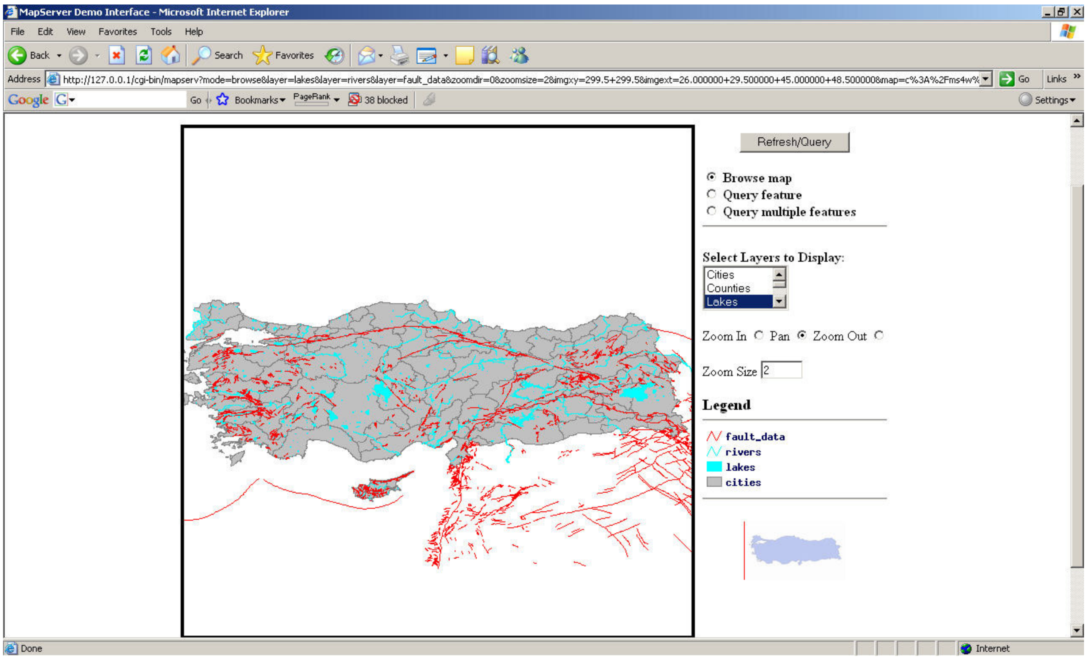

Figure 3.13: Web interface by Minnesota MapServer to publish data with GIS functions

A piece of code from MapServer to add GIS layers to the project and publish them is as follows:

```
LAYER
NAME fault_data
TYPE LINE
STATUS OFF
DATA fault_data
CLASS
NAME 'fault_data'
TEMPLATE "fault_data.html"
COLOR 255 0 0
END
HEADER "fault_data_header.html"
FOOTER "fault_data_footer.html"
END # fault_data
```

Figure 3.14 displays the architecture of MapServer configuration. It has both windows and linux releases. The main features are:

- Advanced cartographic output
- Support for popular scripting and development environments (PHP, Python, Perl, Java, and C#)
- Cross-platform support (Linux, Windows, Mac OSX, and Solaris)

- A multitude of raster (TIFF/GeoTIFF and many others via GDAL) and vector data formats (ESRI shapfiles, PostGIS, ESRI ArcSDE, Oracle Spatial, MySQL and many others via OGR)
- OGC web specifications
- Map projection support and on-the-fly map projection **(MapServer, 2006)**.

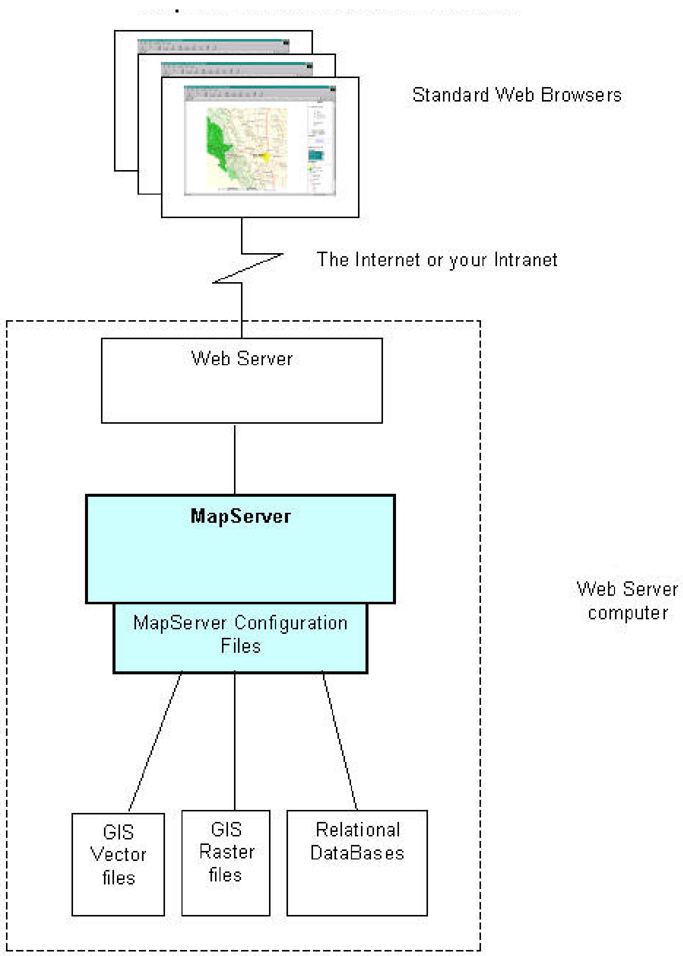

Figure 3.14: MapServer architectural overview **(MapServer, 2006)**

MS4W package already has Apache HTTP Server 2.0.58. ArcIMS requires Web Server (Apache 2.0.48), Servlet Engine (Apache Tomcat 5.0.28), Tomcat Connector Mod_jk2, and JDK 1.4.2_06 installations. A typical single computer configuration for ArcIMS is shown Figure 3.15.

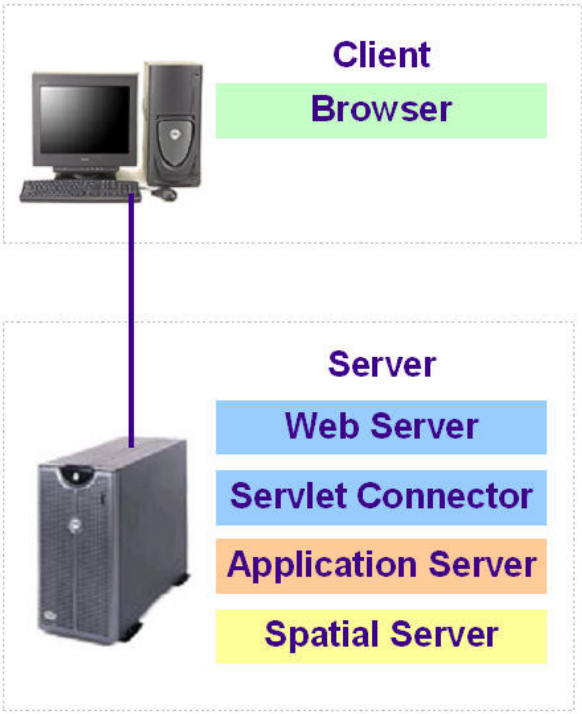

Figure 3.15: ArcIMS install on one machine **(ESRI, 2006)**

Developing custom applications using standard Web development environments, sharing data, and implementing GIS portals are the important features of ArcIMS software. ArcIMS 9.1 and MapServer 4.8.3 were evaluated in this study. ArcIMS was found more appropriate and used in this study.

3.2 Design and Development

This study was divided into a short-term and a long-term objectives. The short-term objective is to develop a prototype web-based system that is capable of being expanded to a larger system that links multiple datasets and tools. The long-term objective is to extend the prototype system and develop more Web services and portal framework for efficient access to data and tools. In this study, geodetic and geophysical data, software packages and scientific applications were compiled and a Web-GIS has been developed.

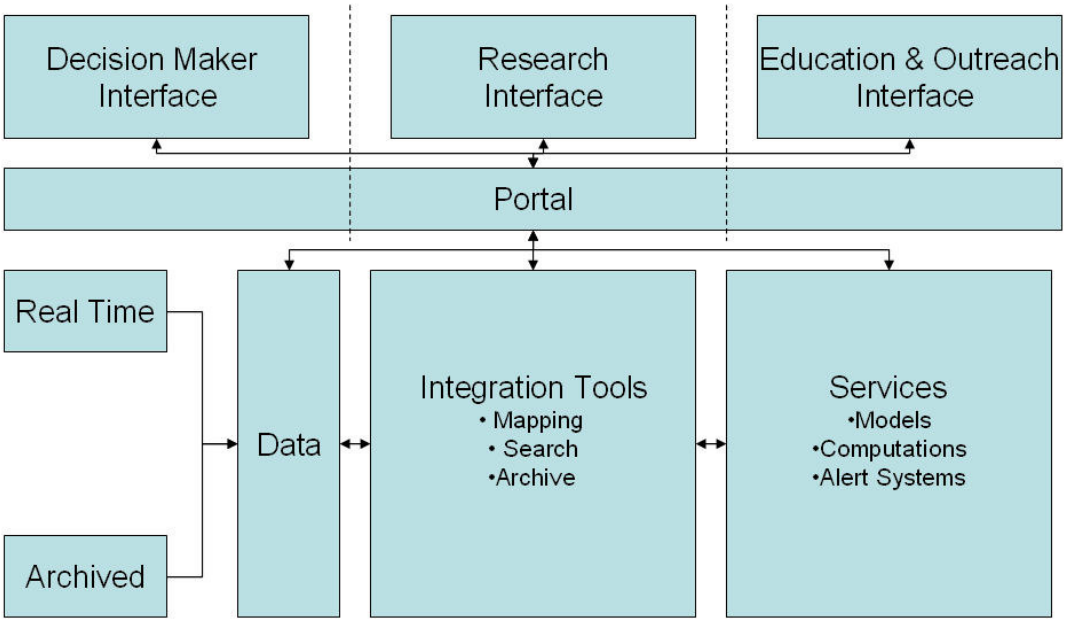

Figure 3.16: Overall approach and system architecture

The concept and implementation emerged from the needs of the scientific communities and decision makers. This system integrates data and tools from data- and labour-intensive, multidisciplinary Earth sciences and provides users from different levels (geoscientist, educator, decision-maker and public) to access it. It enables people, who want to work on earthquake hazard, to reach and use geoscientific data, as well as the computations and analysis environment by user-friendly interface and interaction. The scope of the study covers obtaining and processing Earth science data and tools, and integrating them in a GIS environment using information technologies, and then transmitting them to mass users via the Internet. Figure 3.16 displays the architecture of the system.

This study integrates data, tools, software and users for earthquake studies. The system is made up of three main components: Services, Integration tools, and data. The services provide users computations and models. The integration tools are analysis and display tools. Access to real-time and archived datasets from data sources regarding Earth sciences, and the ability to render this information in useful and meaningful ways to the wide range of users are the important part of the system.

3.2.1 Code Development

Sparse Programs were developed (by Holt and Haines) to determine estimates of continuous horizontal velocity and strain rate fields, inferred from seismic, geodetic and geologic data (see Chapter 2). They consist of over 20 open source fortran programs which run on Linux operating system. Depending on the inversion type, Sparse has various input files. The input files are ASCII and data that the files include must be in a specific order, and these input files needed to be created manually. They may have over hundreds of lines. Furthermore, these files depend on the area of interest, data and method used. These initial files include data pertaining to geometry, earthquakes and GPS. In addition, programs need some other input files which created during the run process. The geometry file is to create a rectangular grid for the area of interest (Turkey). A sample of the content of the geometry file is as follows.

```
50  30 4
0 0 3 0 3
 30  20
1 0 3 0 3
 30  20.5
2 0 3 0 3
 30  21
3 0 3 0 3
 30  21.5
```

Header line has the maximum number of knotpoints in X direction, maximum number of knotpoints in Y direction and number of rotation value while other lines include the number of X coordinate, number of Y coordinate, and three indeces (number of rotation value, index for xy derivatives of rotation value, index for xy derivatives of latitude-longitude). The knotpoints of the grid are the points where x and y have integer values. The model is calculated on a regular grid structure, which each grid area is in 0.5x0.5 degree size (50 grids between 20 < longitude (E) (X) < 45 and 30 grids between 30 < latitude (N) (Y) < 45). So the total number of grid areas is 1500 and the number of deforming grid areas is 1081. In other definition, the total number of knotpoints is 1581 and the number of deformation points is 1053. The results are velocities at 1581 points and strain rates at 1081 points. The number of rigid blocks is 3, and it is assumed that rigid plates are not deforming. 34 grids cover AR rigid block, 135 grids cover AF rigid block, and 250 grids cover EU rigid block in the study. Sparse program assigns "rotation value numbers" in a specific order to the deformation points. In order to explore this structure and to analyse rectangular grid ArcGIS was used (Figure 3.17). The geometry file consists 3,163 lines in case of

0.5x0.5 degree size grid area for the study area so that a program was written to create geometry data file automatically.

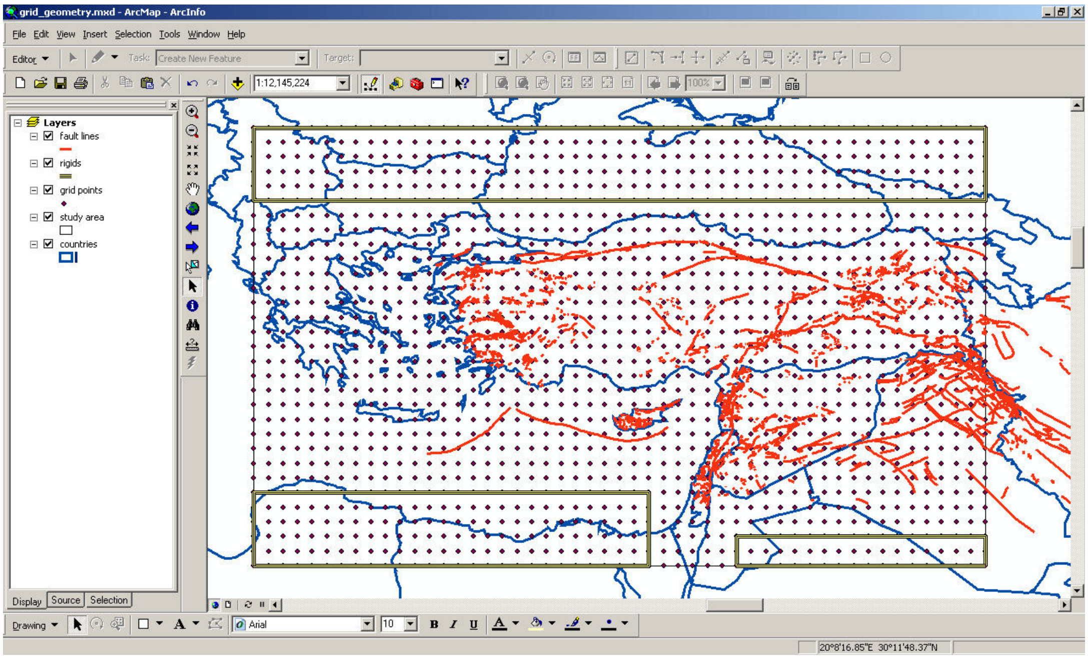

Figure 3.17: Rectangular grid geometry for the study area in a GIS environment showing deforming and non-deforming areas with data

For the creation of the earthquake focal mechanisms input file (Figure 3.18), a program was written and a C program, which assigns number of rotation values to the GPS points, was used for the creation of the GPS input file (Figure 3.19). Earthquake focal mechanisms data were selected according to below criteria from Global Seismology Centroid Moment Tensor catalog (Table 3.1).

Table 3.1: Search criteria used in CMT catalog

Start date	1/1/1976
End date	31/06/2006
Latitude	between 30^o-45^o
Longitude	between 20^o-45^o
Depth	< 30 km

This catalog contains solutions for events with magnitude about and greater than 5.5. There are 275 earthquakes which match these criteria. $M_0<1x10^{20}$ earthquakes were used, and the August 17 earthquake was excluded since it decreases the strain rates. Thus earthquakes input file includes 274 earthquakes in a time span (duration) of 30.5 years.

earthquakes.dat

36.99	20.13	5.37E+18	-1.84	-0.71	-0.95
38.88	43.96	4.16E+19	2.61	-2.85	2.93
37.58	39.82	9.38E+16	8.52	-8.76	-2.98
40.39	33.62	6.09E+17	-3.05	2.49	5.37
41.46	23.85	2.60E+17	-0.17	2.4	0.85
41.23	44.03	2.77E+17	2.58	-2.8	-0.43
39.85	23.19	5.70E+17	0.13	5.21	-1.1
40.73	23.13	1.07E+17	-0.06	1.05	-0.1
39.60	23.58	2.71E+18	0.07	2.57	0.71
43.65	38.04	4.48E+17	-0.31	-1.4	-0.86
30.54	35.59	5.89E+16	2.55	-2.12	3.01
34.38	24.80	1.52E+18	-0.08	0.09	0.15
37.58	26.40	5.97E+17	-0.84	5.45	0.85
38.46	26.77	1.20E+17	-0.32	1.19	0.28
39.44	29.19	1.15E+17	-0.36	1.16	0.53
35.29	26.75	3.20E+17	1.47	0.55	-1.44
37.06	36.24	1.47E+17	1.19	-1.68	-0.3

Figure 3.18: Earthquake input file containing latitude, longitude, moment (in newton-meters), m_{xx}, m_{yy}, and m_{xy} values of focal mechanism solutions

Global CMT catalog uses dyne-cm unit. 1 dyne-centimeter is equal to 1e-007 newton-meter. Sparse coordinate system for moment tensor components is different from this catalog and also from **Aki and Richards (2002)**. Conversion is needed for both notation and direction of the axis (mxx= mpp, myy= mtt, mxy=-mtp).

```
GPS_raw.dat

31.4390 40.9370 1.0100 5.6300 0.8700 0.8200 -0.0320 YIGI_GPS MARMARA
31.4170 41.2010 7.4200 5.2300 4.3500 3.0800 -0.0760 ALAP_GPS MARMARA
31.1980 41.0450 7.0500 9.7700 3.0800 2.6500 -0.0930 AKKO_GPS MARMARA
30.9160 40.1180 -24.8100 2.1900 0.9700 0.8200 -0.0630 CMLN_GPS MARMARA
30.8270 40.7350 -9.6200 2.4900 0.9400 0.8800 -0.0670 KDER_GPS MARMARA
30.8040 40.3860 -23.0000 2.2500 1.0700 0.9400 -0.0520 TEBA_GPS MARMARA
30.7610 40.5890 -17.7300 0.7800 1.1000 1.0500 -0.1030 AGOK_GPS MARMARA
30.6800 40.5380 -22.7900 1.2000 0.9800 0.8800 -0.0830 AGUZ_GPS MARMARA
30.6370 39.6580 -24.3800 -0.3500 0.8100 0.8100 -0.1180 ESKI_GPS MARMARA
30.5700 40.0280 -23.3400 -0.6500 0.9100 0.7600 -0.0480 MHGZ_GPS MARMARA
30.4620 40.4780 -25.0100 0.8200 0.9300 1.0800 -0.0730 DGCT_GPS MARMARA
30.4530 40.3510 -25.3200 2.1500 0.9000 0.7600 -0.0510 SEYH_GPS MARMARA
30.4050 40.8800 4.7600 1.1900 1.1200 1.3400 -0.0800 CALT_GPS MARMARA
30.3250 40.6120 -22.2500 -1.6300 0.8800 0.9600 -0.1070 SEFI_GPS MARMARA
30.3030 40.7850 0.7900 5.8300 0.8500 0.7900 -0.0470 KAZI_GPS MARMARA
30.2940 41.0480 7.8800 -0.8100 0.6600 0.6700 -0.0940 KANR_GPS MARMARA
30.2290 41.1870 5.4000 2.4800 1.6700 1.8300 -0.0290 KFKT_GPS MARMARA
30.1340 40.6900 -20.7300 1.0800 1.8300 1.7500 -0.0910 SMAS_GPS MARMARA
29.9730 41.0340 4.4800 -1.4100 1.1000 0.7800 -0.0560 AKCO_GPS MARMARA
29.9620 40.8460 4.7100 0.9800 0.4000 0.4100 -0.0380 UCG2_GPS MARMARA
29.9290 40.4250 -24.6400 -1.8900 1.9900 1.6300 -0.0620 IUCK_GPS MARMARA
29.9080 40.4380 -23.3100 -3.0900 1.1600 1.1000 -0.0970 IGAZ_GPS MARMARA
29.6810 40.3620 -23.4900 -1.4200 0.8200 0.7600 -0.0670 DERB_GPS MARMARA
29.6230 41.1790 4.0400 0.3700 0.6300 0.6700 -0.0630 SILE_GPS MARMARA
29.5850 40.6670 -14.2900 -1.9600 1.1000 1.2600 -0.0610 OLUK_GPS MARMARA
29.5390 40.9800 3.4100 -3.4600 0.6800 0.7500 -0.0380 OVCT_GPS MARMARA
29.5140 40.1640 -22.0000 -0.2400 1.3700 1.4200 -0.0290 HMZA_GPS MARMARA
29.4510 40.7870 -1.1500 0.8000 0.2900 0.2600 -0.0370 TUBI_GPS MARMARA
29.3720 40.5660 -20.1600 -1.1600 0.3200 0.3100 -0.0390 DUMT_GPS MARMARA
29.3620 41.0170 3.7900 -2.9000 0.6700 0.7400 -0.0570 KRDM_GPS MARMARA
29.3210 40.8660 2.8200 -2.2200 1.0200 1.1800  0.0140 IBBT_GPS MARMARA
29.3100 40.9270 0.4200 -1.6000 2.1000 2.4300 -0.0290 HART_GPS MARMARA
29.2880 40.4850 -21.6400 -2.7700 0.5500 0.5900 -0.0430 KUTE_GPS MARMARA
```

Figure 3.19: GPS input file containing longitude, latitude, E_{vel}, N_{vel}, standard deviations of E and N, CC, and the names of the stations and the project

In order to inverse GPS data with seismic constraint (seismic style and direction) to obtain strain rates and velocity field, two files, one from seismic inversion and the other from GPS inversion, needed to be combined. In order to be able to do that, a Java program was written. In addition to these input files, Sparse programs give output files as ASCII files. For instance, in order to draw velocity error ellipses, the diagonal values in the variance-covariance matrices from Sparse programs must be used (following some mathematical calculation). The first and second values in the diagonal of the matrices are the standard errors of east and north velocities, and the third one is corelation coefficient. And this has to be done for each of inversions. A sample of variance-covariance matrices obtained from Sparse programs is as follows.

no. 1 LAT.= 30.00000 LONG.= 20.00000
0.65244146E-01 -0.35264134E-01 0.24350502E+00
-0.35264134E-01 0.65459771E-01 -0.37096604E+00
0.24350502E+00 -0.37096604E+00 0.28188015E+01

For analysing output files as a whole and getting the strain and velocity results, visualisation of these files are absolutely needed. In order to do this, GMT program **(Wessel and Smith, 1995)** which is widely used in the Earth science, was used.

GMT is an open source collection of about 60 UNIX tools, which was developed by SOEST of University of Hawaii. It allows users to manipulate (x,y) and (x,y,z) data sets (including filtering, trend fitting, gridding, projecting, etc.) and produce EPS illustrations ranging from simple x-y plots through contour maps to artificially illuminated surfaces and 3-D perspective views in black and white, gray tone, patterns, and 24-bit color. GMT supports 30 common map projections, and comes with support data such as coastlines, rivers, and political boundaries. Nevertheless, GMT can read the ASCII files in a specific form (for strain crosses, input file columns must include respectively long, lat, eps1, eps2, azimuth of eps2 values; and for velocity arrows and ellipses, columns must include long, lat, eastward velocity, northward velocity, uncertainty of eastward velocity, uncertainty of northward velocity, correlation between eastward and northward components, station name) and then draw the maps. In order to convert Sparse outputs to GMT inputs, a program, which can convert matrix form data to a one line form, was written.

Here, the problem is that the calculation process of Sparse programs and the other codes created during this study is pretty much complex. There are over 30 programs to be able to use this method and to see the results obtained. Furthermore, each researcher who wants to use these algorithm has to develop own tools. There is so much redundancy of development efforts and little interoperability among these tools. Interaction among different tools requires extensive recoding for every effort. So the solution is to wrap these tools as Web services which are accessible to the scientific community worldwide. A wrapper is a design pattern where a piece of code allows classes to work together that normally could not because of incompatible interfaces. There were some modifications done to Sparse for study purposes. These modifications were primarily to increase portability and IO performance. There were a number of places where the codes require user interaction. These codes were removed, and such input parameters were arranged by user interface. The steps of this process are (Figure 3.20):

- Recoding the fortran codes to remove user interaction in the codes
- Compiling them in Windows OS
- Batch file scripting to run all programs as one program
- Creating Web service
- Connecting the application to ArcIMS

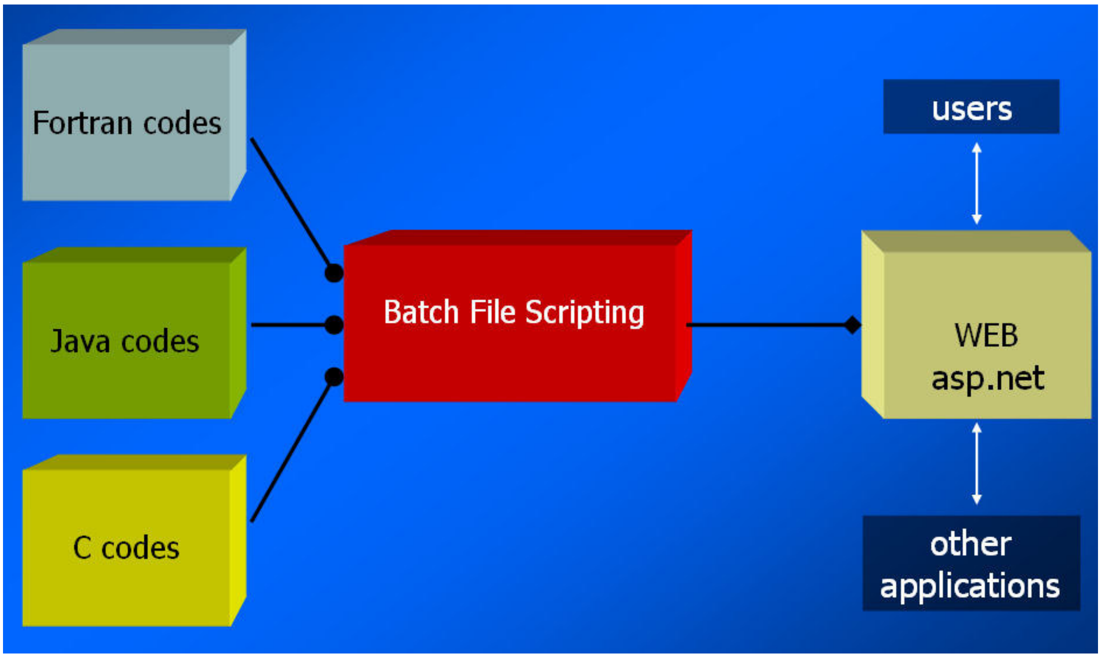

Figure 3.20: Running scientific tools as Web services

In the system according to entered parameters, input files are created, some files are renamed and stored as a different format. The parameters are

- algorithm type
- data type
- coordinates of the area of interest
- grid size

3.2.2 Server Side

After entering the parameters, at the server side, each request is given a unique id number according to the time the request arrived at the web server. Then input files are created and stored in the workspace. The application runs the programs and output files are created. GMT is executed for each line in those files including strain and velocity information. GFW files are created for georeferencing strain and velocity images in ArcIMS environment. Batch files which run GMT creates PS files. Then ImageMagick program converts PS files to GIF files.

ImageMagick is a software to create, edit, and compose bitmap images. It can read, convert and write images in a variety of formats. The functionality of ImageMagick is typically utilized from the command line. ImageMagick is free software delivered as a ready-to-run binary distribution or as source code. It runs on all major operating systems **(ImageMagick, 2007)**. GMT is also a command line program and GMT scripts can run with data from outside the script. In the application, for each request ArcIMS's ArcXML file is created dynamically and GIF images are embedded into ArcXML file as a layer. ESRI.ArcIMS.Server.dll is to provide a connection between the client and ArcIMS Application Server.

ArcIMS is an integrated approach for creating, distributing, and maintaining GIS maps on the Web. ArcIMS brings GIS to the Web by providing the ability to generate maps on the fly and also integrate data from different sources for display, query, and analysis. An ArcIMS service is a fundamental component of ArcIMS and a requirement for publishing maps on the Web. These services can be created and managed by using ArcIMS. There are four main ArcIMS services available in a typical ArcIMS installation. These are image, feature, metadata, and ArcMap image (Figure 3.21).

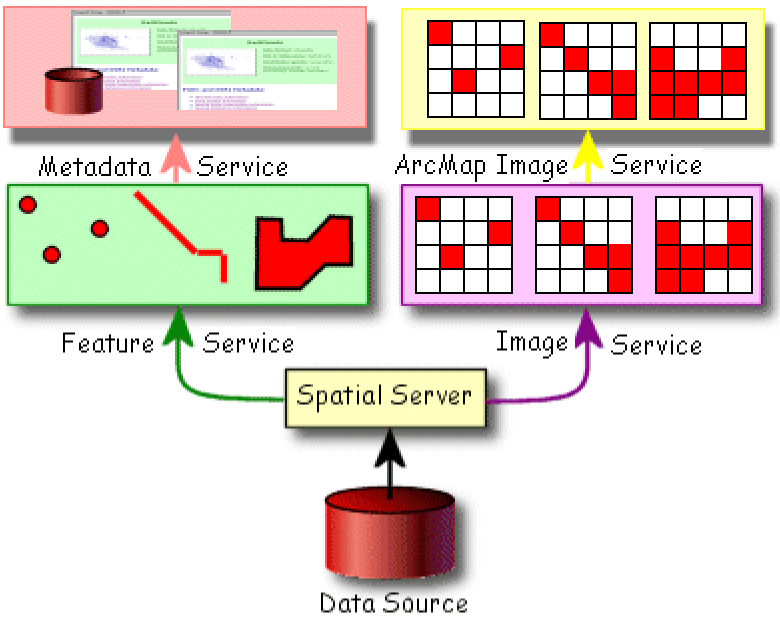

Figure 3.21: Four primary types of services supported by ArcIMS **(ESRI, 2006)**

In order to create these services, a map configuration file (with axl extension) must be created first. The map configuration file is a text file that stores information about map design. This file is written in ArcXML, which is an XML used specifically for creating Web-based products. ArcIMS Author is for creating AXL file, the Administrator creates and starts ArcIMS Services, and the Designer is for creating the look of the web site.

ArcIMS operates on a client/server architecture. The server processes requests, creates and runs ArcIMS services, and manages the Web site. Data sources managed by the server can include both database and file-based sources. The ArcIMS server-side architecture includes many components. ArcIMS needs a Web server that can be extended to run Java code, either built-in or by using a servlet engine. A Web server is a computer that delivers Web content over the Internet. A Web server has an IP address and a domain name. The address is a name or number that uniquely identifies a computer on the Internet, and is referred to as an URL. Any computer can be converted to a Web server by installing Web server software and connecting it to the Internet. There are many Web server software applications, including open source (such as Apache) and commercial packages (such as Microsoft). In this study, Apache Web Server 2.0.48 was used. The Apache web server was developed in 1995 at the National Center for Supercomputing Applications at the University of Illinois **(Apache, 2006)**. According to statistics on web servers provided by Netcraft, in August 2002 an Apache web server was employed on over 60 percent of all the web servers examined. Apache web servers can run under Linux or Windows operating systems. In brief, Apache is one of the most popular open-source HTTP Servers, and it is powerful and secure.

ArcIMS installation also needs a servlet engine installation. Servlet engines extend Web servers with a common API and allow them to process Java code. A servlet is a Java program that runs on a Web server and responds to requests. Servlets are similar to applets, except they work on the server side of the architecture. In this study, Apache Tomcat Servlet Engine 5.0.28 was used. Tomcat is a web container which provides an environment for Java code to run in cooperation with a web server. It includes its own HTTP server internally as well. Tomcat is a cross-platform open source product running on any operating system that has a Java Runtime Environment. J2SDK 1.4.2_06 was also installed in a Windows Server 2003 machine for ArcIMS. The J2SE SDK supports creating J2SE applications. Apache handles the request for static pages (including HTML, JPEG, and GIF files) while Tomcat handles requests for dynamic pages (JSPs or servlets) (Figure 3.22)

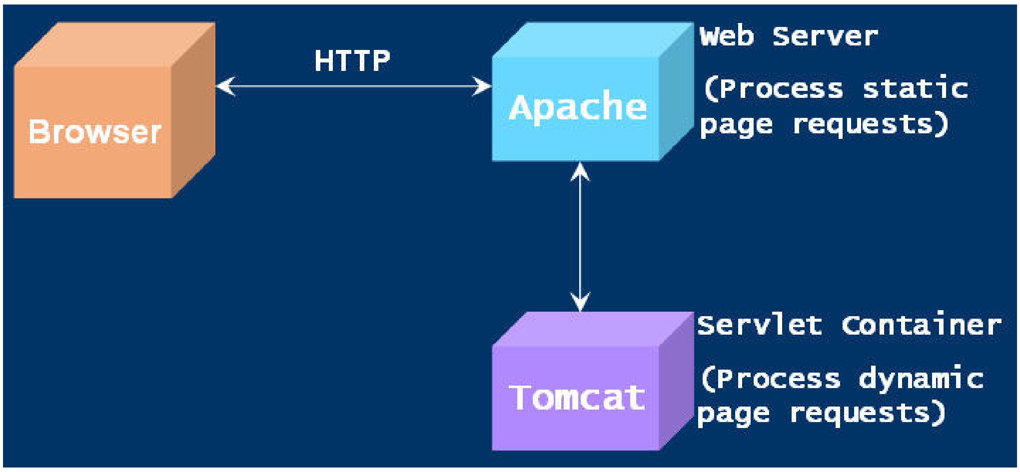

Figure 3.22: Apache and Tomcat work together to handle all HTTP requests

ArcIMS is dependent on the operating system for networking. A port is a logical connection place using the Internet protocol (TCP/IP). Port numbers are from 0 to 65536 and ports from 0 to 1024 are reserved for use by certain privileged services. Web servers listen on port 80 and wait for other hosts to connect. Tomcat Servlet Engine uses port 8080. Each of the ArcIMS processes has a listening port with numbers higher than 5000. These are unusual port numbers for avoiding conflicts with other software. ArcIMS can display any of data type (i.e. vector and raster). However, it only allows users to query on simple data types such as point, polyline, and polygon. Furthermore, it provides a dynamic environment for static data, not for dynamic data which is created at runtime. Contrarily, GMT can present dynamic data created at runtime as static maps. However, GMT does not provide a GIS environment, it is just a visualization tool for spatial data. So, an integration between ArcIMS data and GMT images was performed. GMT images are created and then embedded into ArcIMS environment (Figure 3.23).

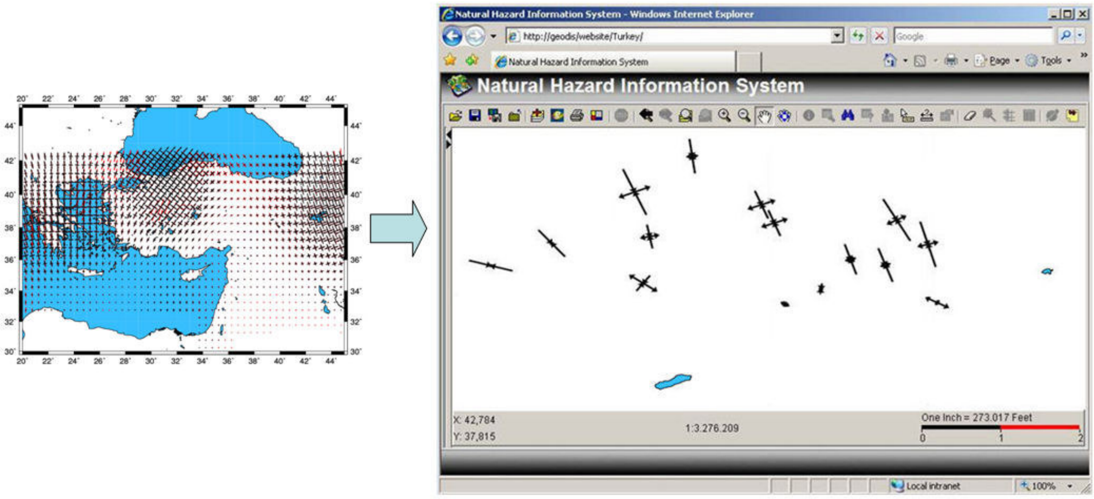

Figure 3.23: GMT images embedded into ArcIMS

To show end product map, following function was created.

```
private string GetMap(string servis,string host,double xMin,double yMin,double
xMax,double yMax){
string serviceName=servis;
string hostName=host;
int serverPort=5300;
int iWidth=814;
int iHeight=599;
ESRI.ArcIMS.Server.ServerConnection conn=new
ESRI.ArcIMS.Server.ServerConnection (hostName,serverPort);
ESRI.ArcIMS.Server.Xml.AxlRequests axlRequest=new
ESRI.ArcIMS.Server.Xml.AxlRequests ();
System.Xml.XmlDocument axlResponse=new System.Xml.XmlDocument ();
conn.ServiceName=serviceName;
string sAXLText =null;
sAXLText = "<?xml version=\"1.0\" encoding=\"UTF-8\"?><ARCXML
version=\"1.1\">";
sAXLText = sAXLText + "<REQUEST><GET_IMAGE><PROPERTIES>";
sAXLText = sAXLText + "<IMAGESIZE width=\"" + iWidth + "\" height=\"" +
iHeight + "\"/>";
sAXLText = sAXLText + "<ENVELOPE minx=\"" + xMin.ToString () + "\"
miny=\"" + yMin + "\" maxx=\"" + xMax + "\" maxy=\"" + yMax + "\" />";
sAXLText = sAXLText + "<LEGEND display=\"true\" />";
sAXLText = sAXLText + "</PROPERTIES>";
sAXLText = sAXLText + "</GET_IMAGE></REQUEST></ARCXML>";
axlResponse.LoadXml(conn.Send(sAXLText));
string imageURL="";
if (axlResponse.GetElementsByTagName("OUTPUT").Count == 1){
System.Xml.XmlNodeList nodeOutput =
axlResponse.GetElementsByTagName("OUTPUT");
imageURL = nodeOutput[0].Attributes["url"].Value;
}return imageURL;}
```

Codes of the application can be found in appendices part of the thesis. Figure 3.24 displays the overall system configuration and identifies the components. The user uses the interface to access the service which is implemented as a .NET program running on a web server. Work flow of the system can be summarized as follws.

- Client makes a request to Web server
- Input files for Sparse programs are created and stored in a workspace with unique id (GeometryDatDosya method)
- Sparse programs are copied into the workspace and run (FortranOutLariniYaratServisBaslat method)
- This method also creates GmtVeGfw class and triggers VelocityCiktilari and StrainsCiktilari methods. These methods have BatOlusturExecuteEt and GfwDosyaOlustur functions. They create GMT batch files in a loop, execute them, and build GFW files.
- Then XmlVeServis class, which triggers ArcxmlOlustur ve ArcimsServisiYaratVeServisiBasla methods, is created under FortranOutLariniYaratServisBaslat method.
- ArcimsServisiYaratVeServisiBaslat method displays website as ArcIMS interactive map including GMT images with archived Shape files.

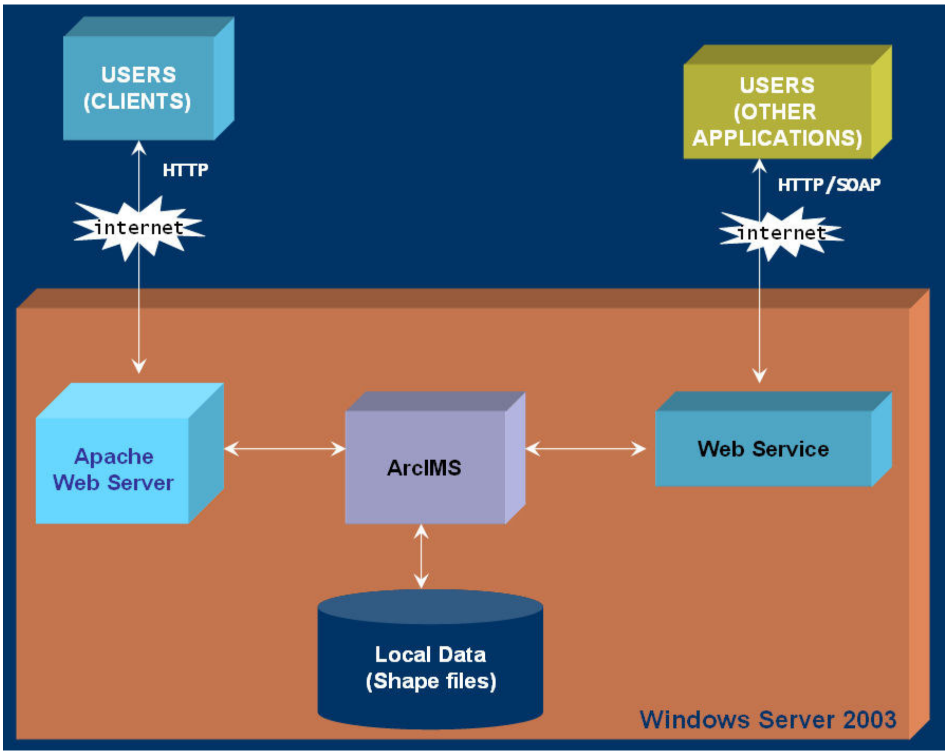

Figure 3.24: Overall system

3.2.3 Implementation of User Interface

Over 1000 lines of program (Java, ASP.NET) have been developed during this study. User interface was created using ASP.NET. A piece of code to send user request to the application is as follows.

```
private void Submit_Click(object sender, System.EventArgs e){
CreateDat.geometryDat a=new CreateDat.geometryDat ();
string zamanID=a.GeometryDatDosya (double.Parse
(this.max_latitude_t.Text),double.Parse(this.min_latitude_t.Text),double.Parse(this.
max_longitude_t.Text),double.Parse(this.min_longitude_t.Text),double.Parse(this.gri
d_size.Text ));
if (zamanID!=""){
string yeniServis="";
CreateDat.HaritaVeServis b=new CreateDat.HaritaVeServis ();
b.islemId=zamanID;
b.FortranOutLariniYaratServisBaslat(ref yeniServis);}}
```

The system interface has many functions. It includes a brief information part about the system, frequently asked questions section where the users of the system can find descriptions of terms and additional information, a newsletter section which is a periodic publication of system related news, a messaging part for communication among users, and a contact information page for the user feedback and inqueries. Services of the system are under the title of "Strain and Velocity Calculation" part. Inversion methods can be reached using "Seismic Only", "GPS Only", and "GPS with Seismic Constraints" interfaces. Archive section is for users' application history storage and search. Screenshots from the system are displayed on Figures 3.25, 3.26 and 3.27.

A typical user request on the system for a given region (i.e. lat/long extent, grid size), return strain map with accompanying data. Within user interface, several components are provided such as an interactive mapping tool.

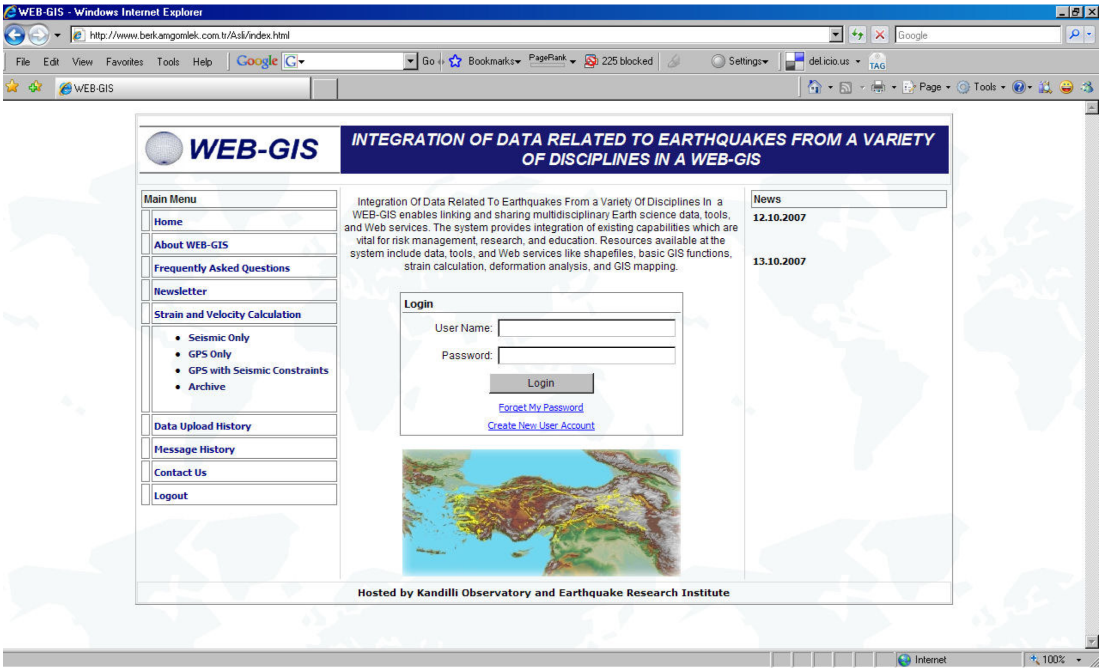

Figure 3.25: Enter point of the system

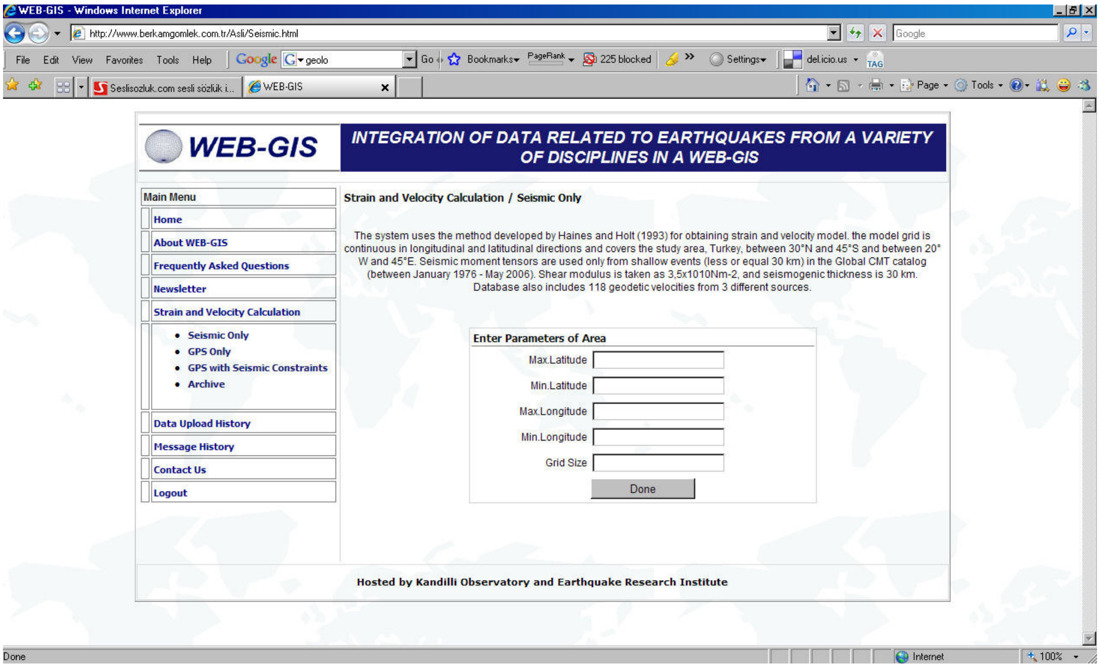

Figure 3.26: Strain and velocity calculation page using seismic data

If users have GPS data and would like to upload them to the system, they are directed to the upload section. If they are not willing to share their own data with other users, they can use private section of the file type. Data upload history section is to see the available file uploads to the system.

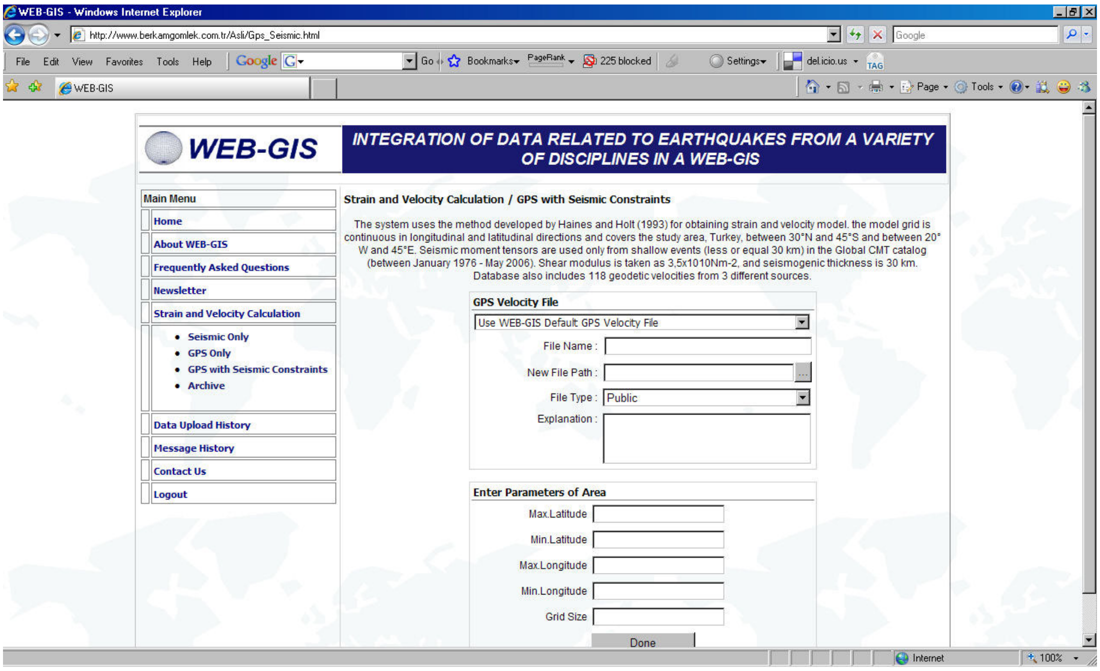

Figure 3.27: Strain and velocity calculation page using GPS data

3.3 Data and Storage

Depending on the purposes, any Earth science data can be used in the study. Archived data such as geographic (cities, roads, rivers, etc.) and geological (faults), are currently integrated in the study. Focal mechanisms data is updated periodically. Demographic data will be added in the scope of the future implementations. GPS velocity data are related to Marmara region of the country which involves strike slip faulting. The area has a high seismic hazard and risk because of the region's tectonics. GPS data from various sources can be currently uploaded into the system. And the integration of real-time GPS data from continuous GPS stations will be studied in the context of the future applications. In addition, real-time geophysical data (earthquakes including latitude, longitude, magnitude, depth, and time information) are ready to be integrated into the study (Figure 3.28 and 3.29).

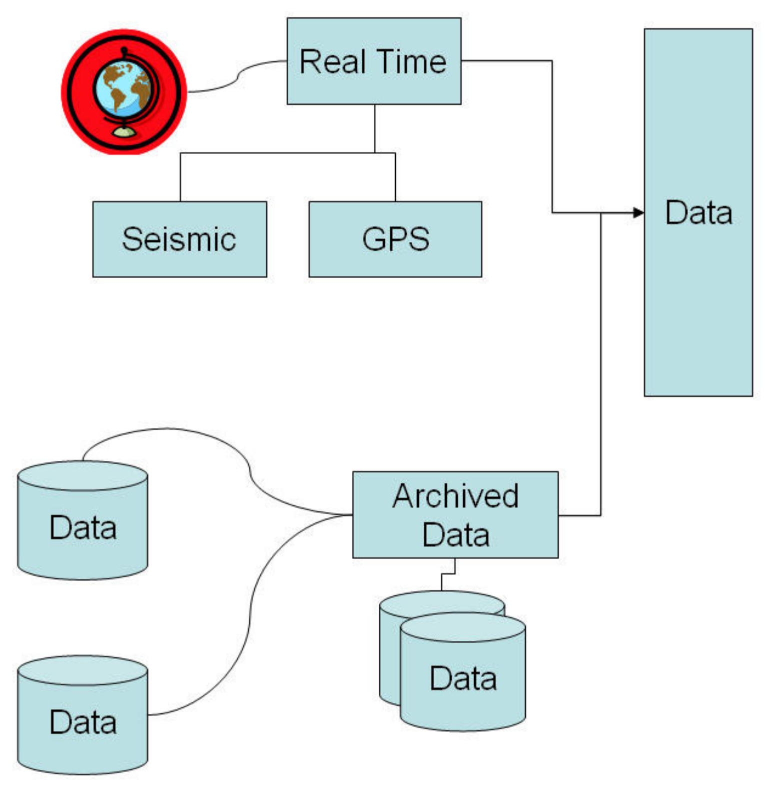

Figure 3.28: Archived and real time types of data

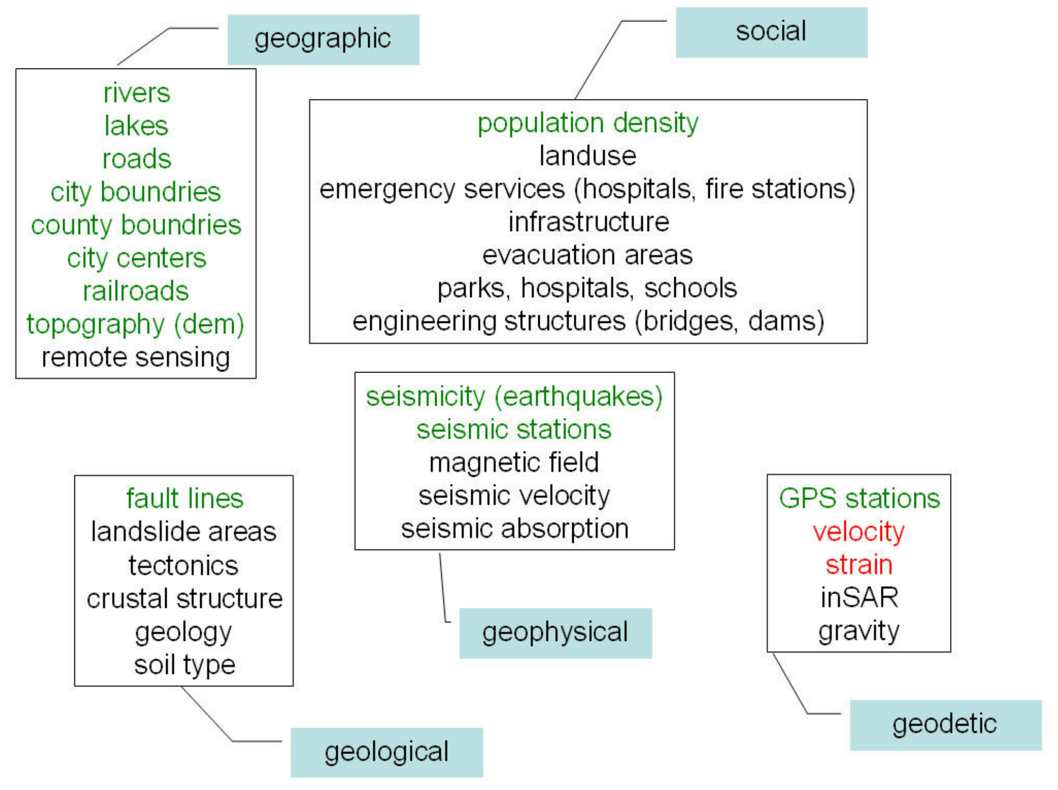

Figure 3.29: Red color-data at runtime, green color-data available, and blue color-data continued to be gathered

GPS data consists of the information related to 66 GPS points including longitude and latitude values, eastward velocities, northward velocities, uncertainties of eastward velocities, uncertainties of northward velocities, and corelation between eastward and northward components. Figure 3.30 shows the velocity arrows and ellipses used in the study.

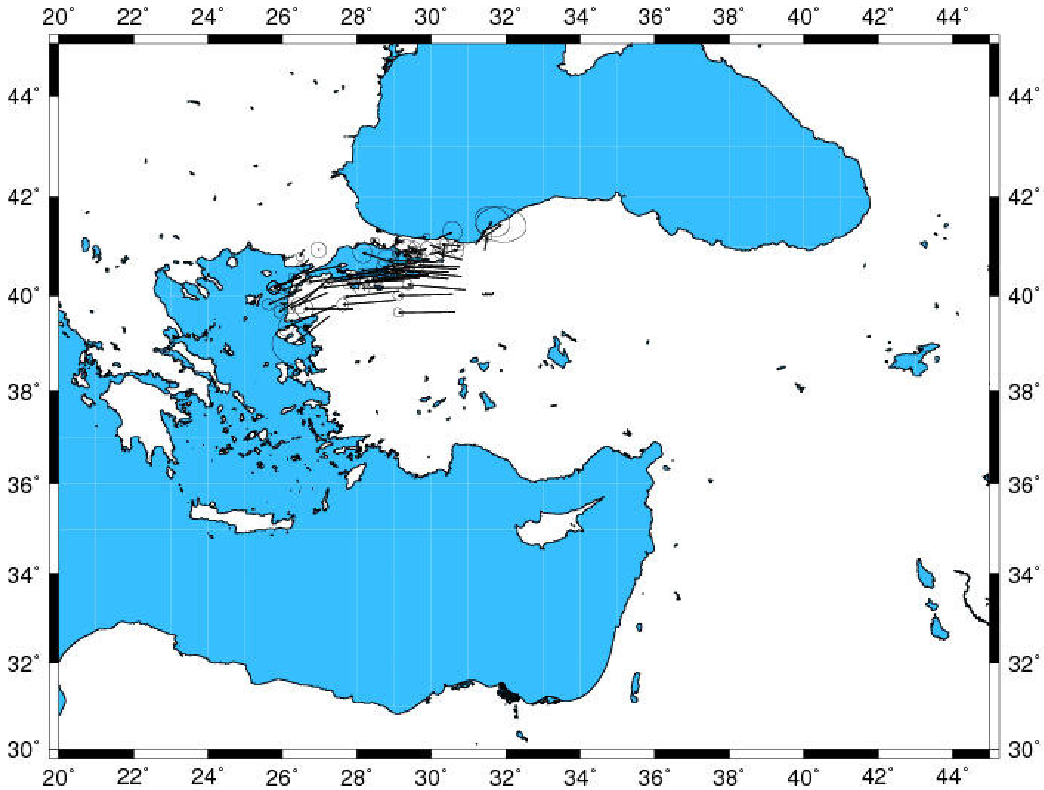

Figure 3.30: GPS velocity data (Eurasia-fixed reference frame)

66 GPS velocities come from GPS campaigns performed between the years of 2003 and 2005 in Marmara region by Geodesy Department of KOERI of BU (Figure 3.31). These campaigns were performed by a collaborative project among BU, MIT, TUBITAK, GCM, and ITU.

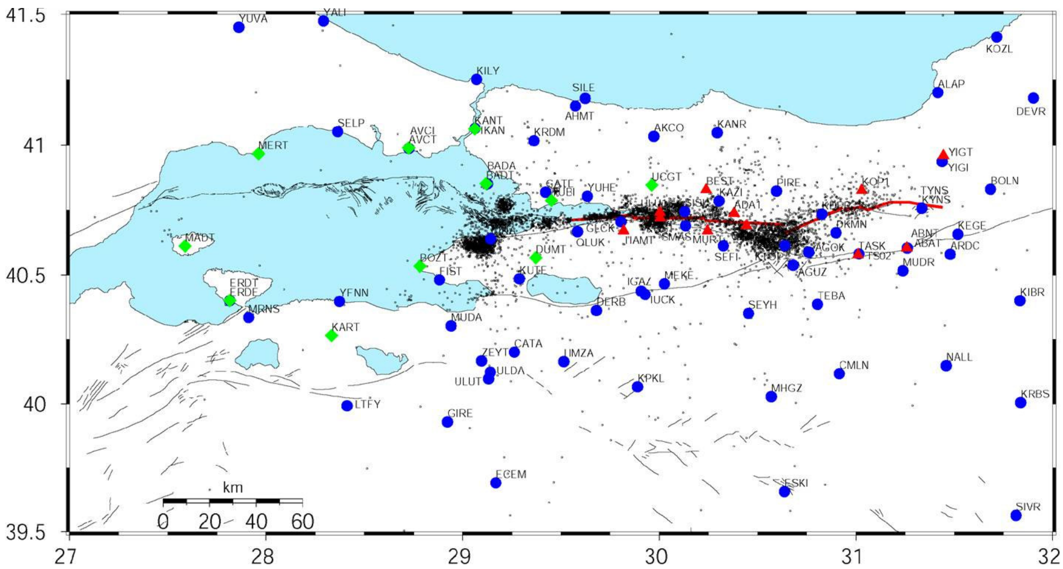

Figure 3.31: Campaign-based GPS network in Marmara region

Since the study is an open-end one, any kind of data, which contributes valuable information, can be added into the system. As new datasets are being added, new applications become possible, which require new features to be added to the server. This loosely coupled development model generates many innovative applications.

4. POTENTIAL IMPACT OF THE STUDY

Natural hazards become natural disasters when they affect people, the structures that they build. Natural disasters injure and kill people, damage or destroy property, weaken the societal infrastructure. Scientific analysis of hazard and disaster data is needed before, during, and after a natural disaster to understand its effect and dimension and to determine how best to respond to existing and potential losses and how to aid with recovery activities **(USGS, 2008)**. From the geophysical point of view, disaster management includes the several geophysical topics to investigate the physical properties and to use physical techniques for land use planning and natural disaster risk estimation studies. According to **ORCHESTRA (2007)** project's reports, which is an integrated project partly funded by the European Commission's 6th framework program, recent disaster events have highlighted the urgent need to consolidate information from disparate information systems to support citizen protection and security issues, and disaster and emergency management operations. Disaster risk management activities involve multiple organisations at various administrative levels, each having their own systems and services. One of the most urgent and important challenges governments are facing is to get these systems to work together and share information to allow proper data analysis and resource management, both being critical elements of disaster risk management. ORCHESTRA is designing and implementing the specifications for a service oriented spatial data infrastructure for improved interoperability among risk management authorities in Europe, which will enable the handling of more effective disaster risk reduction strategies and emergency management operations. ORCHESTRA will not only deliver technical results such as the services and applications, but also aims to bring together and consolidate the risk management community. This is being done by integrating the results and recommendations of previous and current European and national projects and initiatives, thus harmonising the technical underpinning of risk management. Specific goals of ORCHESTRA are

- To design an open service-oriented architecture for risk management

- To develop the software infrastructure for enabling risk management services
- To deliver an infrastructure integrating spatial and non-spatial services for risk management
- To validate the ORCHESTRA results in a multi-risk scenario
- To provide software standards for risk management applications **(ORCHESTRA, 2007)**

This thesis study has been inspired from the necessity of such this project needed to be initiated with the collaboration of the Earth science institutions and decision-makers to create a system for integrating, modernizing, and expanding earthquake related studies. Distribution of accurate information and analysis facilities related to earthquakes is vital for decision makers as well as for scientists. Over the last years, relevant institutions in the world have been investing heavily in new technologies and methodologies to improve disaster management. As a result of these efforts, some key points are identified as follows.

- Lack of a common terminology
- Lack of technical interoperability, accessibility and availability of data, information and software
- Lack of involvement of disaster risk management stakeholders

This study is considered to meet the needs of the second matter. It is known that data management in many fields of Earth sciences in Turkey is still in a period of transition. Information technologies which allow geospatial data to be integrated with other resources for efficient and effective risk management will bring new areas. To provide information anywhere through the Internet and to make it accessible by decision-makers, resource managers, educators, and the general public outweigh the effort required to produce it. So this system provides integration of existing capabilities, tools and data which is vital for research, risk management, and education. The following benefits have been identified for end-users.

- Share data which are in heterogeneous formats and which comes from multiple source types
- Integrate, process, model the data and transform it into useful information.
- Use current technological solutions while enabling technical interoperability for data and application

- Enable rendering of knowledge in a Web-GIS environment

Information already exists but there are numerous obstacles to accessing it, and the necessary methods for integrating it from a variety of sources for use in decision-making are presently inadequate. It is therefore important to expand from the concept of a single user/single data provider to the concept of multiple users/multiple data providers. Computer linking via the internet provides the perfect tool for enabling access and transfer of the required information and applications among the decision-makers.

4.1 Benefits at Decision Making Level

Earthquake hazard estimation is the most effective way for Earth scientists to reduce earthquake losses. For the public, earthquake prediction means short-term prediction. Such prediction must specify the time, place, and magnitude of the earthquake. This type of prediction is not possible. But the investigation of crustal strain (long-term prediction) can provides strategies for effective earthquake risk reduction. Especially when these information are used with seismicity data. This surely requires taking advantages of the recent advancements in Earth sciences, computers, and communication technologies. Long-term prediction of earthquakes is very important for development of building design, strengthening existing structures, and land-use planning. The main reasons for damages after an earthquake occurred are inadequate quality of design and construction of the buildings, inappropriate construction material usage, poor workmanship and allowance of constructions on active faults by local authorities. Another point the recent 1999 Kocaeli earthquake illustrated was that the efficiency of the government and other official organizations in dealing with disasters of this scale should be improved. So, the products of this study can be informative to decision makers. This study will bring economic and social benefits. Earthquake hazards cause an enormous cost to the society in terms of loss of life and property. As highlighted in the UNDP reports Turkey as the third country according to the number of deaths as a result of earthquakes. After 1999 Kocaeli earthquake, economic loss is 20 billion YTL and the socio-economic impact is tremendous considering the number of people affected by this disaster. It is clear that substantial savings could be made with better understanding of the events and improved prediction, which would help to mitigate the risks. Relying on data and on-line services will support the preparation of strategies for disaster management and planning to cope with natural multi-hazard events. This contributes to the reduction of the resulting economic losses and to the development of a more secure country. In order to reach these results in disaster cycle, building a bridge between scientists and decision makers and including "end-users" from the land use planning are necessary as well as scientific research (Figure 4.1).

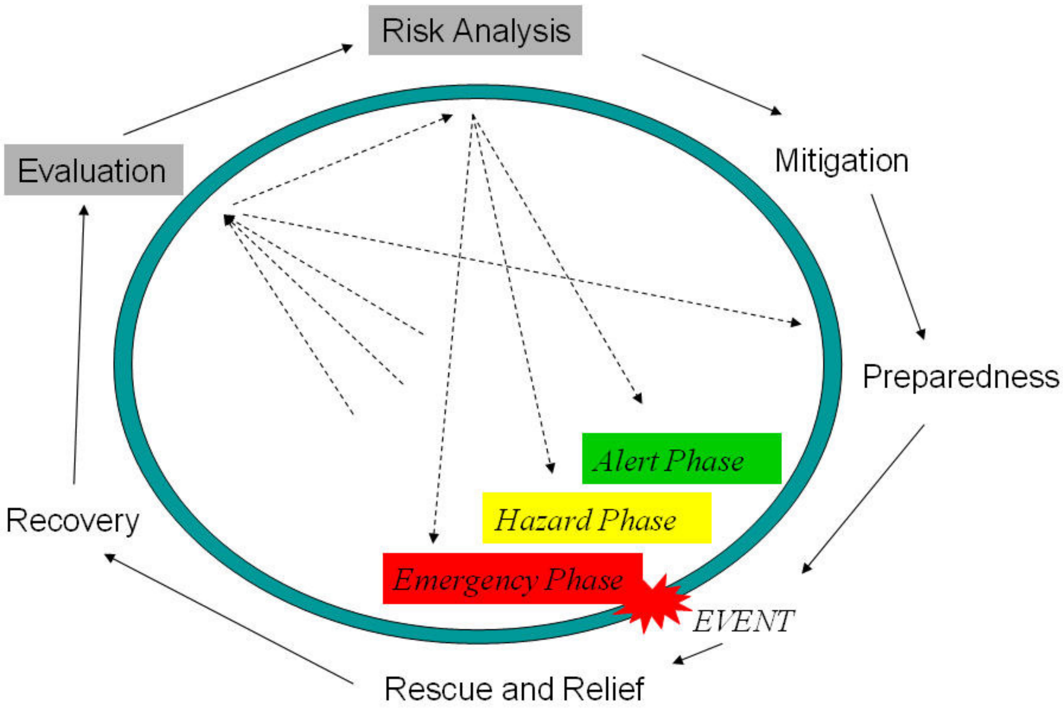

Figure 4.1: Disaster cycle

In this study, GIS is used to visualize temporal changes and spatial variations in some data layers. It means graphically displaying a variable, such as strain, that synthesises the available data for understanding by all users. GIS analysis improves hazard assessment by answering questions such as "Which faults has increased activity?". It also improves risk management by answering questions such as "Which areas are vulnerable to an earthquake?". The integration of Earth science data with socio-economic data as different layers in the same GIS provides taking the step from hazard assessment to risk management. So this system can maximise the interaction between scientists and land-use planners, which will lead to improvements in risk management. It will provide better maps of the hazard, which will inform decision-makers attempting to develop strategies for mitigating risk.

Seperate from strain analysis, other applications can be and must be integrated into this study such as Coulomb stress, tsunami modeling, or landslides. Because they are inter-related. Earthquakes can trigger landslides and tsunamis, and landslides can trigger tsunamis. Disaster prevention and loss mitigation has three major steps. Understanding geophysical processes by visualising data and applying models is the first step in tackling "multi-risk". The second step is considering the relationships between hazards. Usually considered separately in risk analyses, these hazards must be analysed together. This requires bringing together the data associated with each hazard into a single GIS. This will provide "multi-hazard" maps which is the second step in tackling "multi-risk". The third step in assessing risk is to evaluate the vulnerability to a given hazard. These three steps can identify areas that are too hazardous. To deliver scientific results to decision makers will develop methodologies for managing the risk. The long term goal of this study is to improve hazard assessment and risk management by understanding the interactions between natural hazards.

4.2 Benefits at Scientific Level

Application of this study, strain analysis procedure, which is a tool for seismic hazard assessment, is brought to a level that can be used by anyone efficiently and effectively. It provides an opportunity for the Earth science community to compute and study Earth science data for better understanding of earthquakes. In a narrow sense, an earthquake is a sudden failure process, but in a broad sense, it is a long-term complex stress accumulation and release process occurring in the Earth's crust. Scientific understanding of earthquakes is vital. As the population increases, urban development and construction works expand on areas susceptible to earthquakes. With a greater understanding of the causes and effects of earthquakes, it may be possible to reduce the damage and loss of life from this destructive phenomenon.

There is an overflow in all of the branches of science today, especially in Earth sciences. The most important thing here is the harmonisation of data. Because the harmonisation of data in GIS layers is one step on the road from "discovery to inter-operability". And the best way to harmonise data sets is to share them and to work on them together. Scientists have to make harmonised and quality geographic information available for the purpose of formulation, implementation, monitoring and evaluation of community policy-making. Harmonising methodology is also vital for assessing vulnerability. As such IT studies increase in the field of Earth science, better methodologies will be continued to be produced **(Ergintav, 2007)**.

Computer and communication technologies have revolutionized education, especially education of Geomatics. They extend learning process in two primary forms. One of these includes any kind of educational process. The Internet is beyond its original intension now. It provides access to up-to-date source material and creates opportunities to collaborate students, scientists and professionals around the world. The second is lifetime after the educational process. Today, it is possible to make conventional GIS over the Internet sharing various data and tools for the use of the whole world. Web-GIS applications become education tools for the public learn about the importance of GIS for understanding of the Earth. With the rapid advancement of the computer technology and Internet environment, various activities are going on related to the Earth science. The Internet has been a very important medium for the exchange of information besides its many other functions and services. The use of this medium as a learning environment is obvious. The information technology grows rapidly, there will be innovative applications. So this study also has a high potential to be used in educational environments allowing students to experiment with data and tools, and make their own analysis over the Internet.

5. CONCLUSIONS

There are an increasing number of applications using spatial data on the web. Some of them are Earth sciences applications including GIS and web-mapping implementations from major institutions in the world such as US Geological Survey, Geosciences Network, The Incorporated Research Institutions for Seismology, and European-Mediterranean Seismological Centre. They have capabilities and limitations, too. In general, applications include interactive maps showing location of the earthquakes, seismicity of the region, seismic hazard and earthquake density, GPS sites, their displacement history and also some geophysical data. Most of these applications are for earthquake monitoring. This study went a step further than earthquake monitoring and created an application which calculates strain by GPS velocities and focal mechanisms data and retrieves maps on the Web using IT tools. The outcomes of the study can be summarized as follows:

- This study shortened the time for obtaining the results from the strain analysis algorithm developed by **Haines and Holt (1993)** and visualizing them in a dynamic and interactive environment on the Internet (Chapter 3, Section 2).
- In order to apply this algorithm, a number of FORTRAN programs run in the background. Furthermore, a bunch of programs for creating input files and using output files with visualization software were developed (Chapter 3, Section 2 and Appendix 1).
- In fact, there are so many complexities and it takes too much time to get results for evaluation of strain accumulation. But with this study, a complex strain analysis procedure was brought to a level that can be used by anyone efficiently and effectively. A visualized, easy-to-use, interactive, data and computation accessible environment was built to work on strain analysis (Chapter 3, Section 2.3 and Appendix 2).
- This study created an IT infrastructure to enable multidisciplinary Earth science research by using existing tools and integrating them. Therefore, it

increased the speed of the scientific discovery process. The faster analysis results in the faster interpretation and discovery in Earth science.

- The application was developed as an Internet based system that brings together data, tools, computations and users in a single efficient framework to be used for determination of strain field. The framework of the study is based on the service-oriented architecture using Web service approach. It means that the modules of the application were written in various programming languages, and run on different computers over the Internet. This allowed some parts of this application to be used by other applications and users over the Internet (Chapter 3, Section 2.2 and Appendix 3).

- This thesis study does not only plot strain arrows onto the map using GMT program but also calculates strain field using scientific programs in Windows platform over the Internet. In Earth science field, there are just a few applications using Web service approach. An example is the web application of GEON project. GEON creates cyberinfrastructures for geosciences using the same approach. GEON's Synseis application, which enables earthquake simulation using waveform data from real and virtual stations, is based on SOA. Being based on the web service approach is the similarity of this application with this thesis study. The difference is that this thesis study enables calculation and visualization of strain field on the Web. GEON application just plots the earthquake focal mechanisms onto the interactive map on the Web using GMT program. This does not include any calculation.

- In this study, a portal based architecture was adopted in the user interface and service oriented architecture in the middleware. Portal-based structure provided a single point of access to the system. It also provided a dynamic environment and interactive capabilities. The architecture is flexible and scalable. Since reusability of components was provided, it minimized the need for new coding. Furthermore, Web service of the system supports any communication protocol. It reduced the data volume and computing resources at the user side (Chapter 3, Section 2.3).

- The functional requirements of the study were the various information technologies. So the key concepts, relationships and benefits of information technologies were introduced. This study also investigated how IT can bring benefits to the integration and distribution of data and tools for users who need efficient ways of passing spatial data and tools to and from different locations. It explained how spatial information and tools can be disseminated to the users with low technological requirements by using information technology. The study included many types of data and algorithms from the field of the Earth sciences, computers, GIS, networking and databases (Chapter 3, Section 1).

- In the study, several software tools were used for processing input data, storing them, and presenting on the web. Most of these software were open source programs. This study showed the usability of open source software in Earth science studies. And there is no current single open source tool provides all of these capabilities (Chapter 3, Section 1.3).

This system will continue to be developed. In its current form, it is a functional system for calculating strain and analysis of outputs. Moreover, its infrastructure is ready to be used for other applications in Earth science community. It is expected that this study will pioneer the development of such projects in Earth sciences. Since this study is an example of Open GIS, it will be opened to more data.. The word “open” emphasizes the community-driven nature of this study. The study required integrative information technology platform and it was beyond capability of one person. Therefore, there is a need for bridging between Earth science and Computer science. Earth sciences need information technologies to solve data related problems. The Earth scientists and IT professionals need to work together to formalize the different characteristics of geospatial data and information, and to design comprehensive Web services applications.

REFERENCES

Akcan, B., Konuş, K. Y., Temizsoylu, O., Yüksek Başarımlı Bilgi İşlem Kaynakları, *Akademik Bilişim*, Gaziantep Üniversitesi, Şubat 2005.

Aki, K. And Richards P. G. , 2002. Quantitative Seismology, University Science Books, New York, USA.

Akram, A., Chohan, D., Wang, X. D., Yang, X., Allan, R., A Service Oriented Architecture for Portals Using Portlets, *UK e-Science All Hands Conference*, 2005.

Aktuğ, B. and Kılıçoğlu, A., 2006. Recent Crustal Deformation of Izmir, Western Anatolia and Surrounding Regions as Deduced From Repeated GPS Measurements and Strain Field, Journal of Geodynamics, **41**, 471–484.

Altamimi, Z., Sillard, P., Boucher, C., 2002. ITRF2000: A New Release of The International Terrestrial Reference Frame for Earth Sciences Applications, Journal of Geophysical Research, **107**, 2214.

Ambraseys, N.N. and Finkel, C.F., 1995. The Seismicity of Turkey and Adjacent Areas, A Historical Review, 1500-1800, Eren Yayıncılık, İstanbul.

Apache, 2006. Apache Software Foundation Home Page, May 2006, <http://www.apache.org/>.

Atkinson, M., Learning from e-Science: Grids and e-Infrastructure, Keynote for EGEE, September 26, 2005.

Avedal et al., 2000. JSP, Wrox Press, USA.

Babylon, 2006. Online Dictionary, February 2006, <http://www.babylon.com/>.

Bailey, T. C. and Gatrell, A. C. 1995**.** Interactive Spatial Data Analysis, Reading, Massachusetts: Addison-Wesley Publishers.

Barbarosoğlu, G., The Administrative Activity Report of KOERI (2003-2005), İstanbul, 2005.

Barka, A. and Reilinger, R., 1997. Active Tectonics of the Eastern Mediterranean Region: Deduced From GPS, Neotectonic and Seismicity Data, Annali di Geofisica, **XL**.

Baru, C., 2006. Distributed Software Systems: Cyberinfrastructure and Geoinformatics, *Cyberinfrastructure Summer Institute for Geoscientists*, August 14-18, San Diego Supercomputer Center, CA, USA.

Başbuğ, B., 2006. The Mandatory Earthquake Insurance Scheme in Turkey, Middle East Technical University, Department of Statistics, Ankara.

Beavan, J., and Haines, J., 2001. Contemporary horizontal velocity and strain rate fields of the Pacific-Australian plate boundary zone through New Zealand, Journal of Geophysical Research, **106**, 741-770.

Bertram, L., 2006. Scientific Workflows, *Cyberinfrastructure Summer Institute for Geoscientists*, August 14-18, San Diego Supercomputer Center, CA, USA.

Bilham, R. and Gaur, V. K., 2000. Geodetic Contributions to the Study of Seismotectonics in India, Current Science, **79**, No. 9, 10.

Calais, E., 2006. Geodetic Measurements of Active Crustal Motions Lecture Notes, Purdue University, USA.

Chappell, D. and Jewell, T., 2002. Java Web Services, O'Reilly, USA.

Christodoulidis, D. C., D. E. Smith, R. Kolenkiewicz, S. M. Klosko, M. H. Torrence, P. J. Dunn, 1985. Observing Tectonic Plate Motions and Deformations from Satellite Laser Ranging, Journal of Geophysical Research, **90**, 9249–9263.

CORS-TR, 2006. Continuously Operating Reference Stations Project Home Page, June 2007, <http://cors-tr.iku.edu.tr>.

CUAHSI, 2006. The Consortium of Universities for the Advancement of Hydrologic Science, Home Page, July 2006, <http://www.cuahsi.org/>.

DeMets, C., Gordon, R. G., Argus, D. F., Stein, S, 1990. Current Plate Motions, Geophysical Journal International, **101**, 425-478.

Demir, C., 1999. Investigation of Horizontal Crustal Motion and Strain Accumulation in Western Part of North Anatolian Fault, *PhD Dissertation*, Yıldız Technical University, Istanbul, Turkey.

Di, L., Distributed Geospatial Information Services-Architectures, Standards, and Research Issues, *XXth ISPRS Congress*, Istanbul, Turkey, 12-23 July 2004.

Directions Magazine, 2006. The Worldwide Source for Geospatial Technology - Directions Magazine Home Page, February 2006, < http://www.directionsmag.com/>.

Dixon, T. H., 1991. An Introduction to the Global Positioning System and Some Geological Applications, Reviews of Geophysics, **29**, 249-276.

DNN, 2006. DotNetNuke Portal Framework Home Page, June 2006, <http://www.dotnetnuke.com/>.

Drewes, H. and Angermann D., 2001. The Actual Plate Kinematic and Crustal Deformation Model 2000 (APKIM2000) as a Geodetic Reference System, *IAG Scientific Assembly*, Budapest, September 2-8.

EarthScope, 2006. Project Home Page, February 2006, <http://www.earthscope.org/>.

Eclipse, 2006. Open Development Platform Home Page, June 2006, <http://www.eclipse.org/>.

Ergintav, S., 2007. Personal Interview, September 2007.

ESRI, 2006. Virtual Campus Notes, May 2006, < http://training.esri.com/>.

Foster, I., Kesselman, C., Nick, J., Tuecke, S., 2002. The Physiology of the Grid: An Open Grid Services Architecture for Distributed Systems Integration. Open Grid Service Infrastructure WG, *Global Grid Forum*, June 22.

Gantz, J., 2007. The Expanding Digital Universe, A Forecast of Worldwide Information Growth Through 2010, An IDC White Paper.

GEON, 2005. GeoScience Network Project Home Page, December 2005, <http://www.geongrid.org/>.

GEON, 2005a. Cyberinfrastructure for the Geosciences, Annual Report.

Global CMT Catalog, 2006. Global Centroid Moment Tensor Project, May 2006, <http://www.globalcmt.org/>.

Globus, 2006. The Globus Alliance Home Page, February 2006, <http://www.globus.org/>.

Gordon, R. G. and Stein, S., 1992. Global Tectonics and Space Geodesy, Science, **256**, 333-342.

Goldfinger, C. and Christie, D., 2006. Plate Tectonics Lecture Notes, Oregon State University, USA.

Grid Infoware, 2008. Grid Computing Info Centre Home Page, April 2008, <http://www.gridcomputing.com/>.

GridSphere, 2006. Gridsphere Portal Framework Home Page, June 2006, <http://www.gridsphere.org/>.

Fawcett, N. and Ridge, T., 1997. Java A Practical Guide, Butterworth-Heinemann, Great Britain.

Haines, A.J. and Holt, W.E., 1993. A Procedure to Obtain the Complete Horizontal Motions Within Zones of Distributed Deformation From the Inversion of Strain Rate Data, Journal of Geophysical Research, **98**, 12,057-12,082.

Holt, W.E. and Haines, A.J., 1995. The Kinematics of Northern South Island New Zealand Determined From Geologic Strain Rates, Journal of Geophysical Research, **100**, 17991-18010.

Haines, A.J., Jackson, J.A., Holt, W.E., Agnew, D.C., 1998. Representing Distributed Deformation by Continuous Velocity Fields, *Institute of Geological and Nuclear Sciences science report*, 98/5, Wellington, New Zealand.

Hamblin, W.K. and Christiansen E.H., 2001. Earth's Dynamic System Systems, Prentice Hall, USA.

Harold, E. R. and Means, 2002. W. S., XML in A Nutshell, , O'Reilly, USA.

Herring, T. A., Shapiro, I. I., Clark, T. A., Ma, C., Ryan, J. W., 1986. Geodesy by Radio Interferometry: Evidence for Contemporary Plate Motion, Journal of Geophysical Research, **91**, 8341– 8347.

Herring, T.A., 1997. GAMIT/GLOBK Kalman Filter VLBI and GPS Analysis Program; Version 4.1. Massachusetts Institute of Technology, Cambridge.

ImageMagick, 2007. ImageMagick Home Page, February 2007, <http://www.imagemagick.org>

Jackson, J. and McKenzie, D., 1988. The Relationship Between Plate Motions and Seismic Tremors, and the Rates of Active Deformation in the Mediterranean and Middle East, Royal Astronomical Society Geophysical Journal, **93**, 45-73.

Jenny, S.,Goes, S., Giardini, D., Kahle, H., 2002. Earthquake Recurrence Parameters From Seismic and Geodetic Strain Rates in the Eastern Mediterranean, Geophysical Journal Int., **157**, 1331-1347.

Kiratzi, A. A., 1993. A Study on The Active Crustal Deformation of The North and East Anatolian Fault Zones, Tectonophysics, **225**, No. 3, 101-203.

KOERI Earthquake Catalog, 2006. Bogazici University, Kandilli Observatory and Earthquake Research Institute, National Earthquake Monitoring Center, Waveform Data Request System, May 2006, <http://barbar.koeri.boun.edu.tr/sismo/zKDRS/bilgi.htm>.

KOERI NEMC, 2007. Bogazici University, Kandilli Observatory and Earthquake Research Institute, National Earthquake Monitoring Center Home Page, February 2007, <http://www.koeri.boun.edu.tr/sismo>

Kostrov, V.V., 1974. Seismic Moment and Energy of Earthquakes, and Seismic Flow of Rocks, Izv Acad. Sci., USSR, Phys, Solid Earth, English Translation, 1, 23-44.

Kreemer, C., Holt, W.E., Goes, S., Govers, R., Active Deformation in Eastern Indonesia and the Philippines From GPS and Seismicity Data, Journal of Geophysical Research, **105**, 663-680, 2000.

Lambeck, K., 1988. The Slow Deformation of the Earth, Clarendon Press, Oxford.

Ludaescher, B., 2006. Scientific Workflows, *Cyberinfrastructure Summer Institute for Geoscientists*, August 14-18, San Diego Supercomputer Center, CA, USA.

MapServer, 2006. University of Minnesota Map Server Home Page, June 2006, <http://ms.gis.umn.edu/>.

Marshak, S., 2004. Essentials of Geology, Thomson Books.

McKenzie, D. P., 1970. Plate Tectonics of the Mediterranean Region, Nature, **226**, 239-243.

Meade, B.J., Hager, B.H., McClusky, S.C., Reilinger, R.E., Ergintav, S., Lenk, O., Barka, A., Ozener, H., 2002. Estimates of Seismic Potential in the Marmara Sea Region from Block Models of Secular Deformation Constrained by Global Positioning System Measurements, Bulletin of the Seismological Society of America, **92**, No. 1, 208-215, February.

Memon, A., 2006. Web Services Overview, *Cyberinfrastructure Summer Institute for Geoscientists*, August 14-18, San Diego Supercomputer Center, CA, USA.

Moller, A. and Schwartzbach, M. I., 2006. An Introduction to XML and Web Technologies, Addison Wesley.

Monroe, J. S. and Wicander, R., 2005. Physical Geology: Exploring the Earth, Thomson Books.

Morales, M. and Lorena, A., 2002. Urban Disaster Management, ITC Publication Series, **96**.

NESC, 2006. National e-Science Centre Home Page, February 2006, <http://www.nesc.ac.uk/>.

ORCHESTRA, 2007. Open Architecture and Spatial Data Infrastructure for Risk Management Project Home Page, July 2007, <http://www.eu-orchestra.org>

Prawirodirdjo, L. and Y. Bock, 2004. Instantaneous Global Plate Motion Model from 12 Years of Continuous GPS Observations, Journal of Geophysical Research, **109**, B08405.

Reilinger, R., Toksoz, N., McClusky, S., Barka, A., 2000. 1999 Izmit, Turkey Earthquake Was No Surprise, GSA Today, **10**, No. 1, January.

Reish, N.E. and Girty G.H., 2006. Visualizing Stress and Strain: Using Visual Basic 6.0 to Provide a Dynamic Learning Environment, San Diego State University Department of Geological Sciences, February 2006, <http://www.geology.sdsu.edu/visualstructure/vss/htm_hlp>

Rey, Patrice F., 2006. Lecture Notes, January 2006, <http://www.geosci.usyd.edu.au/ users/prey>.

Schmidt, C., 2000. Earthquakes in Turkey, March 2006, <http://www.facworld.com/>.

Seber, D., Vallvé, M., Sandvol, E., Steer, D., Barazangi, M., 1997. Middle East Tectonics: Applications of Geographic Information Systems (GIS), GSA Today, **7**, No. 2, February.

Shen, C., 2004. A Method for Processing Data From a Regional Continuous Crustal Deformation GPS Monitoring Network, Geodesy and Geomatics Engineering, UNB, Technical Report, No. 221.

Shen-Tu, B., W. E. Holt, A. J. Haines, 1999. The kinematics of the western United States estimated from Quaternary rates of slip and space geodetic data, Journal of Geophysical Research, **104**, 28927-28955.

Sinha, A. K., Malik, Z., Rezgui, A., Dalton, A., Lin, K., 2006. A Cyberinfrastructure Framework for Discovery, Integration, and Analysis of Earth Science Data, *Cyberinfrastructure Summer Institute for Geoscientists*, August 14-18, San Diego Supercomputer Center, CA, USA.

Siwen, B., Dongsheng, J., Xianfeng, Z., Framework of Basic Theory in Digital Earth, Institute of Remote Sensing Application, Chinese Academy of Sciences, Beijing, 100101.

Sun, 2008. Sun Grid Technology Home Page, April 2008, <http://www.sun.com/software/grid/>.

Şaroğlu, F., Emre, Ö., Kuşçu, I., 1992. Turkish Active Faults Map, Directoriate of Mineral Research and Exploration, Ankara, Turkey.

Şengör, A.M.C., Burke, K., Dewey, J., 1980. Tectonics of the North Anatolian Transform Fault. In: A.M. Isikara And A. Vogel (Eds), Multidisciplinary Approach to Earthquake Prediction, Freidr. Vieweg And Sohn, 3-22.

Şengör, A.M.C. and Yılmaz, Y., 1981. Tethyan Evolution of Turkey: A Plate Tectonic Approach. Tectonophysics, **75**: 181-241.

Taymaz, T., Jackson, J., McKenzie, D., 1991. Active Tectonics of the North and Central Aegean Sea. Geophysical Journal International, **106**: 433-490.

Turcotte, D.L. and Schubert, G., 1982. Geodynamics: Applications of Continuum Physics to Geological Problems, John Wiley and Sons, New York, USA.

Tüysüz, O., 1990. Tectonic Evolution of a Part of the Tethyside Orogenic Collage - The Kargi Massif, Northern Turkey. Tectonics, **9**: 141-160.

USGS, 2008. United States Geological Survey Home Page, April 2008, <http://www.usgs.gov/>.

W3C, 2006. World Wide Web Consortium Home Page, February 2006, <http://www.w3.org/>.

Wessel, P. and Smith, W.H.F., 1995. New Version of the Generic Mapping Tools Released, EOS 76, 329.

CURRICULUM VITAE

Education

1999 – 2002 Master of Science in Geodesy and Photogrammetry Engineering, Istanbul Technical University, Istanbul. (Grade: 3.50/4)

1993 – 1999 Bachelor of Science in Geodesy and Photogrammetry Engineering, the Faculty of Civil Engineering, Istanbul Technical University, Istanbul. (Grade: 73,67/100)

Professional Experience

2001 – Present, Research Assistant at Bogaziçi University, Kandilli Observatory and Earthquake Research Institute, Department of Geodesy, Istanbul, Turkey.

2001 – Present, Research Assistant (Part time) at Bogaziçi University, Civil Engineering Department, Istanbul, Turkey. (CE 200 – Surveying Course)

2000 – 2001, Surveying Engineer at Kadikoy Municipality, Research-Planning-Coordination Department, Istanbul, Turkey.

1997 – 2000, Surveying Engineer at Cemre Inc., Istanbul, Turkey.

Personal Details

Date of Birth: 07 December 1976

Date of Place: Istanbul

Marital Status: Married