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Volcanic Activity: Processing of Observation and Remote Sensing Data (VAPOR)

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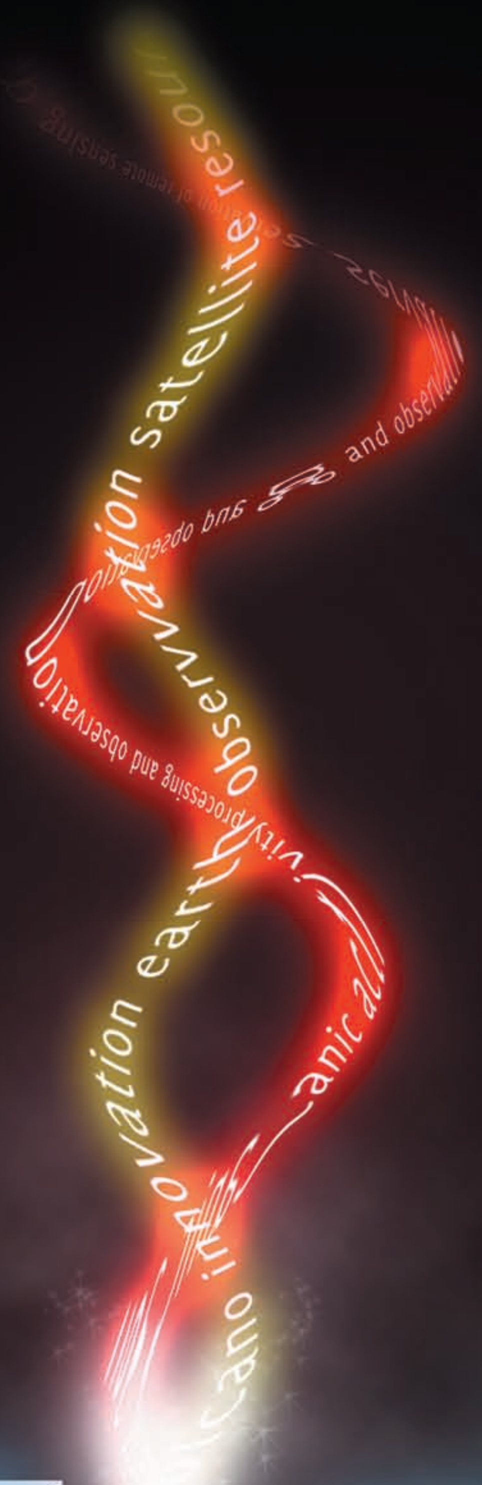

VAPOR

[Volcanic Activity: Processing of Observation and Remote Sensing Data]

Final Report

Volcanic **A**ctivity: **P**rocessing of **O**bservation and **R**emote Sensing Data

An Integrated Framework for Early Warning and Hazard Tracking of Volcanic Activity on Earth

Final Report

International Space University
Space Studies Program 2008

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Abstract

The ISU SSP 2008 Team Project Volcanic Activity: Processing of Observation and Remote Sensing Data (VAPOR) has established the following mission statement:

> To define an integrated framework for early warning and hazard tracking of volcanic activities on Earth using space-based and terrestrial resources

Early warning is defined as monitoring and reporting on the risk of an eruption during the period from the first sign up to the point of the eruption. Hazard tracking is defined as monitoring and reporting on lava flows, ash plumes, gas emissions, lahars, and pyroclastic flows during and post eruption.

The main deliverable for this project is the VAPOR Integrated Data-sharing and Analysis (VIDA) framework. VIDA is a framework for the implementation of a system capable of integrating data from global providers, standardizing that data, processing it into useful information, and disseminating both data and information to the end-users. Providers would include ground-based, air-borne, and space-based Earth observation sensors that collect data on the precursors and indicators of volcanic activity. End-users could include decision makers at various levels of government, emergency crews, aviation authorities, the scientific community, and populations at risk from volcanic hazards. In addition to the technological challenges, this report considers the governance, policy and law issues, the business and financial aspects, and the potential societal benefits associated with such a system.

The design and implementation of a VIDA system is well beyond the scope of this project. Instead, this project has conducted the preliminary work of identifying and assessing the need for this system and establishing a set of top-level requirements that such a system would need to satisfy. In order to move the VIDA framework to the design stage, the users must verify the system requirements. Implementation of a framework like VIDA requires coordinated efforts between data providers, data processing organizations, the companies that store produced information products and finally the companies that distribute them.

Faculty Preface

Volcanoes are one of nature's most amazing phenomena, credited for both triggering life on our planet Earth and being responsible for several of the extinction level events registered on the geological record. For these reasons volcanoes have inspired both wonder and fear for centuries. Mythological creatures and deities are present in diverse cultures, endowed with responsibility (and accountability) for volcanic activity and consequences. Examples include Vulcan, who in Roman mythology is the god of fire, responsible for manufacturing tools and weapons for the other gods in his workshop at Olympus. In Hawaiian mythology, Pele is the goddess of fire, lightning, dance, volcanoes, and violence. Agni is a Hindu and Vedic deity, he is the god of fire, messenger between gods and man, and accepts sacrifices through fire. In the Mesoamerican Aztec mythology, Chantico was the goddess of volcanoes and fires in the family hearth.

This international, intercultural, and interdisciplinary fascination for volcanoes has been deeply embedded in the human spirit for centuries, and this summer it has captured the interest of forty (40) intelligent and enthusiastic students of the International Space University Space Studies Program. The students come from different academic and professional backgrounds, from cultures and countries as diverse as the mythologies: Austria, Canada, China, Colombia, France, Georgia, Germany, India, Ireland, Israel, Italy, Japan, Spain, Turkey, and the United States of America. This remarkable group has studied volcanic phenomena and the human response to it without preconceptions and from a multidisciplinary vantage point. They have performed a gap analysis that identified three main areas that could benefit from creative thought and innovation. Further, they develop a framework listing a set of actions and requirements to integrate space-borne, airborne, terrestrial sensor data, human-, and computer-based expert and knowledge systems to provide early warning and response information to multiple interested parties in near-real-time.

This report synthesizes information about the current understanding of volcanoes and their effects, of disasters and technologies deployed in mitigating consequences, and of the applicable policy and legal context. Innovative recommendations are offered that are capable of having a significant impact on the space, geophysics, disaster risk management, and aviation sectors. This exemplary work is characteristic of the intentions of the ISU; the team have competently met and surpassed expectations.

We commend this work to the reader, and look forward to its impact.

Barcelona, Spain – August 2008

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Student Preface

The World Bank makes a very clear distinction between disasters and natural phenomena. Natural phenomena are events like volcanic eruptions. A disaster only occurs when the ability of the community to cope with natural phenomenon has been surpassed, causing widespread human, material, economic or environmental losses. By these definitions, volcanic eruptions do not have to lead to disasters.

On November 13, 1985, the second most deadly eruption of the twentieth century occurred in Colombia. Within a few hours of the eruption of the Nevado del Ruiz volcano, 23,000 people were dead because no infrastructure existed to respond to such an emergency. José Luis Restrepo, a Colombian geology student, recalled:

"We didn't hear any kind of alarm, even when the ash was falling and we were in the hotel. We turned on the radio. The mayor was talking, and he said not to worry, that it was a rain of ash, that they had not reported anything from the Nevado, and to stay calm in our houses... When we went out, the cars were swaying and running people down, there was total darkness, the only light was provided by cars. We were running and were about to reach the corner when a river of water came down the streets. We turned around screaming towards the hotel, because the waters were already dragging beds along, overturning cars, sweeping people away. We went back to the hotel, to a three-story building with a terrace, built of cement and very sturdy. Suddenly, I heard bangs, and looking towards the rear of the hotel I saw something like foam, coming down out of the darkness. It was a wall of mud approaching the hotel, and sure enough, it crashed against the rear of the hotel and started crushing walls. And then the ceiling slab fractured and the entire building was destroyed and broken into pieces. Since the building was made of cement, I thought it would resist. But the boulder-filled mud was coming in such an overwhelming way, like a wall of tractors, razing the city, razing everything. Then the university bus, that was in a parking lot next to the hotel, was higher than us on a wave of mud and on fire. It exploded, so I covered my face, thinking this is where I die a horrible death."
[Scarth, 1999]

Six years later, the 1991 eruption of Mount Pinatubo in the Philippines was the largest volcanic eruption in the 21st century to affect a heavily populated area. Because the volcano was monitored, early warning of the eruption was provided and thousands of lives were saved.

Despite these improvements, some communities still face danger from volcanic events and volcano-monitoring systems still require further development. There remain clear gaps in monitoring technologies, in data sharing, and in early warning and hazard tracking systems.

A global volcano-monitoring framework such as the VIDA framework can contribute to filling these gaps. VIDA stands for "VAPOR Integrated Data-sharing and Analysis" and is also the Catalan and Spanish word for 'life'. The ultimate goal for this project is to help save the lives of people threatened by volcanic hazards, while protecting infrastructure and contributing to decision support mechanisms in disaster risk management scenarios.

The VAPOR Team would like to dedicate this report to all the victims of volcanic eruptions in the hopes that our proposal can be used to develop a comprehensive system that may one day save lives. We hope that one day the natural phenomena of volcanic eruptions will not become disasters.

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List of Acronyms

3D	Three Dimensions
A	
ADRC	Asian Disaster Reduction Center
ADRRN	Asian Disaster Reduction and Response Network
AFM	Acoustic Flow Monitor
AJAX	Asynchronous JavaScript and XML
ATC	Air Traffic Control
ATCs	Air Traffic Controllers
AVHRR	Advanced Very High Resolution Radiometer
B	
BNSC/DMC	British National Space Centre / Disaster Management Centre
BRGM	Bureau de Recherches Géologiques et Minières
BSCW	Basic Support for Cooperative Work
C	
CANERM	Canadian Emergency Response Model
CBERS	China-Brazil Earth Resources Satellite
CENAPRED	Centro Nacional de Prevención de Desastres
CEOS	Committee on Earth Observation Satellites
CFP	Call For Participation
CONAE	Comision Nacional de Actividades Espaciales
COSI-Corr	Co-registration of Optically Sensed Images and Correlation
CNES	Centre National d'Etudes Spatiales
CNSA	China National Space Administration
CRED	Centre for Research on the Epidemiology of Disasters
CSA	Canadian Space Agency
CVS	Control Version System
D	
DEMs	Digital Elevation Models
DEISA	Distributed European Infrastructure for Supercomputing Applications
DInSAR	Differential InSAR
DMCii	Disaster Monitoring Constellation International Imaging Ltd.
DRC	Democratic Republic on the Congo
DUE	Data User Element
E	
ECLAC	UN Economic Commission for Latin America and the Caribbean
EDM	Electronic Distance Measure
EM-DAT	Emergency Events Database
EPA	US Environment and Protection Agency
ESA	European Space Agency
ESRI	Environmental System Research Institute
EU	European Union
EULA	End-user licensing agreement
F	
FAA	US Federal Aviation Administration
FEMA	US Federal Emergency Management Agency
FFM	Failure Forecast Method
G	

GDACS	Global Disaster Alert and Coordination System
GEM	Global Earthquake Model
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GIS	Geographic Information System
GMES	Global Monitoring for Environment and Security
GML	Geography Markup Language
G-POD	Grid Processing On Demand
GPS	Global Positioning System
GRASS	Geographic Resources and Analysis Support System
GSI	Geographical Survey Institute
GVO	Goma Volcano Observatory
GVP	Global Volcanism Program

H

HAZPAC	Hazards of the Pacific
HEWS	Humanitarian Early Warning Service
HYSPLIT	HYbrid Single-Particle Lagrangian Integrated Trajectory

I

IASC-SWG	Inter-Agency Standing Committee Sub-Working Group
IAVW	International Airways Volcano Watch
ICAO	International Civil Aviation Organization
ICEO	IEEE Committee on Earth Observation
ICSMD	International Charter: Space and Major Disasters
IEEE	Institute of Electrical and Electronics Engineers
IFRC	International Federation of Red Cross and Red Crescent Society
IGOS	Integrated Global Observing Strategy
INGV	Istituto Nazionale di Geofisica e Vulcanologia
INPE	Instituto Nacional de Pesquisas Espaciais
InSAR	Interferometric Synthetic Aperture Radar
IPRs	Intellectual Property Rights
ISDR	International Strategy for Disaster Reduction
ISO	International Standards Organization
ISRO	Indian Space Research Organisation

J

JAXA	Japan Aerospace Exploration Agency

M

MACUV	Measurement of Atmospheric Composition in Ultraviolet
MEDIA	Modèle Eulérien de Dispersion Atmosphérique
MMS	Multimedia Messaging Services
MODIS	Moderate Resolution Imaging Spectroradiometer
MWO	Meteorological Watch Office

N

NAME	Nuclear Accident Model
NGO	Non-governmental Organization
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice To AirMen
NRC	National Research Council

O

OGC	Open Geospatial Consortium
OMI	Ozone Monitoring Instrument

P

PDA	Personal Digital Assistant
PDC	Pacific Disaster Center
PHIVOLCS	Philippine Institute of Volcanology and Seismology

R

Radar	Radio Detection And Ranging
RAT	Robust AVHRR Techniques
RDF	Resource Description Framework
RSS	Really Simple Syndication

S

SAR	Synthetic Aperture Radar
SAVAA	Support to Aviation for Volcanic Ash Avoidance
SBAs	Societal Benefit Areas
SBAS	Satellite-Based Augmentation System
SDSU	San Diego State University
SIGMET	SIGnificant METeorological Information
SMS	Short Message Service
SWOT	Strengths, Weaknesses, Opportunities and Threats

T

the Charter	the Charter On Cooperation To Achieve The Coordinated Use Of Space Facilities In The Event Of Natural Or Technological Disasters
TOMS	Total Ozone Mapping Spectrometer

U

UAV	Unmanned Aerial Vehicle
UN	United Nations
UN OCHA	United Nations Office for the Coordination of Humanitarian Affairs
UN OOSA	United Nations Office for Outer Space Affairs
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNGA	United Nations General Assembly
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management
US	United States of America
USFS	United States Forest Service
USGS	United States Geological Survey

V

VAACs	Volcanic Ash Advisories Centers
VAFTAD	Volcanic Ash Forecast Transport And Dispersion
VAPOR	Volcanic Activity Processing of Observation and Remote sensing data
VEI	Volcanic Explosivity Index
VIDA	VAPOR Integrated Data-sharing and Analysis

W

WGCV	Working Group on Calibration and Validation
WGE	Working Group on Education, training and capacity building
WGISS	Working Group on Information Systems and Services
WIPO	World Intellectual Property Organization
WOVO	World Organization of Volcano Observatories

X

XML	Extensible Markup Language

List of Units

°C	degrees Celsius
gu	gravity unit
Hz	hertz
km	kilometer
km/hr	kilometers per hour
km^3	kilometers cubed
m	meter
mm	millimeter
nm	nanometer
nT	nanotesla
pH	power of hydrogen
Ω	ohm

Keywords Glossary

Ash plume	Ash plume is a cloud containing fine-grained fragments (less than 2 mm in diameter) of volcanic rock blasted into the air after an explosion or carried upward by hot gases during an eruption.
Early warning	For the purpose of this report, early warning is defined as monitoring and reporting on the probability of a volcanic eruption during the period from the first sign of a possible eruption (as provided by existing monitoring systems) up to the point of the eruption.
Geographic Information System (GIS)	A GIS is a system (both hardware and software) for acquisition, storage, analysis of data, and display of geographically referenced information allowing users to view and interpret data in a way that can reveal relationships and patterns among several sources.
Hazard tracking	Monitoring and reporting on volcanic hazards, such as lava flows, ash plumes, gas emissions, and pyroclastic flows during and after eruption.
SWOT analysis	SWOT Analysis is a method used to evaluate the Strengths, Weaknesses, Opportunities, and Threats of a project It helps to identify internal and external factors that create or destroy value.
The Charter	The Charter On Cooperation To Achieve The Coordinated Use Of Space Facilities In The Event Of Natural Or Technological Disasters
VIDA	VIDA is a framework for the design of a system capable of integrating data from global providers, standardizing that data, processing it into useful information, and disseminating both data and information to the end-users.
VIDA end-users	End-users could include decision makers at various levels of government, aviation authorities, emergency crews, the scientific community, and populations at risk from volcanic hazards.
VIDA providers	Providers would include ground-, air-, and space-based Earth observation sensors that collect data on the precursors and indicators of volcanic activity.
VIDA system	System adhering to the VIDA framework.
Volcanic hazards	Lava flows, tephra, pyroclastic flows, lahars, landslides, and gas emissions.
Volcano monitoring technologies	Awide variety of instruments and sensors used to provide primary data, algorithms and modeling techniques, and systems such as GIS used to produce valuable information regarding volcanic risks and hazards.

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Chapter 1

Introduction

Volcanic eruptions are one of Earth's most dramatic and violent agents of change. Notorious eruptions in the past, such as Krakatoa, Mount (Mt.) Pinatubo, and Mt. St. Helens as shown in Figure 1-1, have demonstrated the devastating impact volcanoes can have on landscapes and communities. Some of the major hazards that result from a volcanic eruption are lava flows, ash plumes, and pyroclastic flows. These can have severe consequences for the surrounding areas by displacing, injuring or killing people, and by destroying habitats and infrastructure.

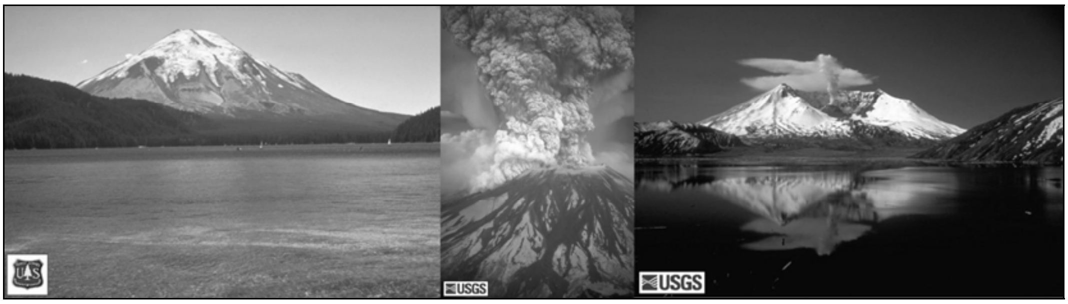

Figure 1-1: Mount St. Helens before, during, and after the 1980 eruption [Tilling, 1990]

1.1 Impacts of Volcanic Activities

The most important effects of volcanic eruptions are the human casualties. There are over 1500 active volcanoes (excluding undersea volcanoes) around the world [ESA, 2004]. Some of these volcanoes are in populated areas, posing a significant threat to the safety of human lives. Since the beginning of the 20th century, the two largest volcanic disasters in terms of fatalities were the 1902 eruption of Mont Pelée in French Martinique and the 1985 eruption of Nevado del Ruiz in Colombia, causing 30,000 and 23,000 deaths respectively. However, the number of people affected by volcanic events, for example requiring immediate assistance during a period of emergency, must also be taken into account. In 1991 the eruption of Mt. Pinatubo in the Philippines killed approximately 600 people, but affected more than one million [EM-DAT, 2008].

The rich fertile soil around volcanic sites attracts a large number of people [The Geography Site, 2006b], leading to the development of local and national economies in close proximity to volcanoes. An estimated 500 million people live near an active volcanic site [ESA, 2004]. Since the period between eruptions can vary significantly, up to thousands of years in some cases, the consequences of an eruption are mostly unacknowledged [Hawaiian Volcano Observatory, 2008]. Table 1-1 shows estimated values of the social and economic impact of past volcanic eruptions.

The financial impact of volcanic eruptions varies depending on the location and intensity of the event. The economic impact includes damage to agriculture, natural resources, industry, tourism, trade, and infrastructure such as transportation, communication networks, power, and water facilities. An estimation of the economic damage in different regions is also provided in Table 1-1. It is important to realize that the impact of volcanic eruptions on the regional and national economy persists for several years after the event.

Table 1-1: Volcanic damage from 1900 to 2006

Continent	Number of Events	Killed	Homeless	Affected	Total Affected	Damage US$ (000's)
Africa	15	2,213	180,710	318,800	500,353	9,000
Americas	69	67,841	35,680	1,082,150	1,123,587	2,808,697
Asia	80	21,456	97,900	2,565,980	2,668,287	696,549
Europe	11	783	14,000	12,200	26,224	44,300
Oceania	20	3,665	46,000	202,391	248,422	400,000

[Salichon, 2007]

A rising concern is the effect ash plumes can have on aircraft even at long distances – up to thousands of kilometers – from the actual eruption site. In the case of Mt. St. Helens, ash accumulation and poor visibility caused the closure of several airports in eastern Washington State and the cancellation of more than a thousand commercial flights [Tilling, 1990]. Ash plumes are a direct threat to the human and financial aspects of air travel.

1.2 Present Challenges

Despite a recent increase in enthusiasm and support for Earth observation, such as the Global Monitoring for Environment and Security (GMES), monitoring systems for volcanoes still require further development. Volcano hazards require accurate and near-real-time transfer of data to interested parties to help prevent or limit the effects of an event. Currently, ground-based observation techniques have helped scientists gain a deeper understanding of many phenomena associated with an eruption. Meteorological satellites provide information on volcano hazards and have aided in the tracking of ash plumes. The launch of new X-band Synthetic Aperture Radar (SAR) satellites and other Earth observation missions (*e.g.* the 'Sentinel' series), as well as the development of advanced instrumentation and analysis such as Interferometric SAR (InSAR) is slowly increasing the ability to identify and track hazards using space-based assets. However, even with the improved ability to identify hazardous areas and to warn of impending eruptions, communities still face imminent danger from volcanic events.

There remain clear gaps in the existing monitoring technologies, in data sharing, and in early warning, hazard tracking, and disaster management systems. The revisit time of remote sensing satellites is often inadequate in providing rapid notification of volcanic activity. The Volcanic Ash Advisory Centers (VAACs), as well as the many individual volcano observatories use various data formats, different modeling tools, and do not necessarily transfer data effectively between them. Furthermore, a near-real-time database of volcanic hazards and relevant geophysical data near volcanic sites does not yet exist.

Volcano monitoring and early warning systems in developing nations are insufficient or non-existent. The Charter On Cooperation To Achieve The Coordinated Use Of Space Facilities In The Event Of Natural Or Technological Disasters (the 'Charter') is an important mechanism to aid relief efforts in the event of volcanic eruptions, that suffers from delays in response time, in data availability and delivery.

1.3 Project Mission Statement and Scope

'Volcanic Activity: Processing of Observation and Remote sensing data' (VAPOR) is the name adopted for this project, and reflects the selected scope. The VAPOR project is primarily focused on the important gap in data access, collection, and sharing. To that end, the mission statement for this project is:

> ***"To define an integrated framework for early warning and hazard tracking of volcanic activities on Earth using space-based and terrestrial resources."***

This mission statement includes the terms 'early warning' and 'hazard tracking'. Early warning is defined as monitoring and reporting on the probability of an eruption during the period from the first sign of a possible eruption (as provided by existing monitoring systems), up to the point of the eruption. The development of a long-term monitoring system is not considered a part of this project. Hazard tracking is defined as monitoring and reporting on volcanic hazards, such as lava flows, ash plumes, gas emissions, and pyroclastic flows during and after an eruption.

1.4 Deliverables

The main deliverable for this project is the *VIDA framework*. VIDA stands for "VAPOR Integrated Data-sharing and Analysis," and is also the Catalan and Spanish word for 'life'. The ultimate goal for this project is to help save the lives of people threatened by volcanic hazards, while protecting infrastructure and contributing to decision support mechanisms in disaster risk management scenarios.

VIDA is a framework for the design of a system capable of integrating data from global providers, standardizing that data, processing it into useful information, and disseminating both data and information to the end-users. The actual design, selection of data, and the proposed standardization are all beyond the scope of this project. Providers would include ground-based, air-based, and space-based Earth observation sensors that collect data on the precursors and indicators of volcanic activity. End-users could include decision makers at various levels of government, aviation authorities, the scientific community, emergency crews, and populations at risk from volcanic hazards. Such end-users would obtain data and information through a variety of means including the internet via web-based tools, Geographic Information Systems (GIS) tool interfaces, specific network–based interfaces, mobile platforms, *etc.* By disseminating information in near-real-time, such a system adhering to the VIDA framework – herein referred to as a 'VIDA system' – could provide advanced warnings to end-users, enabling them to avoid the effects of volcanic activity. Such a system could allow end-users to track volcanic hazards, enabling them to mitigate their effects.

Not only would a VIDA system present a technological challenge, it would also have implications on policy, law, economics, society and education. Policy and law issues include governance, data collection and standards, licensing, and liability. Societal and educational issues include the potential benefits of such a system and local community awareness of volcanic hazards. Economic aspects include possible stake holders, funding, and business opportunities. The aforementioned framework is *not* the system itself. The design and implementation of a VIDA system is well beyond the scope of this project. Instead, this project has conducted the preliminary work of identifying and assessing the need for this system, researching the expectations of the end-users, and establishing a set of top-level requirements that such a system would need to satisfy.

1.5 Report Purpose and Outline

The scope and deliverables provided in sections 1.3 and 1.4 drive the main purpose of this report: to define the VIDA framework and provide a useful starting point and a reference source for future designers of a volcano early warning and hazard tracking system.

Figure 1-2 illustrates both the content of this report, and the process through which it was developed. Important process steps that fall outside the scope of this project are shown as hatched blocks. These show awareness of the context required to develop a framework with regard to the needs of end-users and are highlighted as steps for further research. Each element of Figure 1-2 within the scope of this report is identified with the corresponding chapter number, while those elements contained as appendices are labeled by 'App.'.

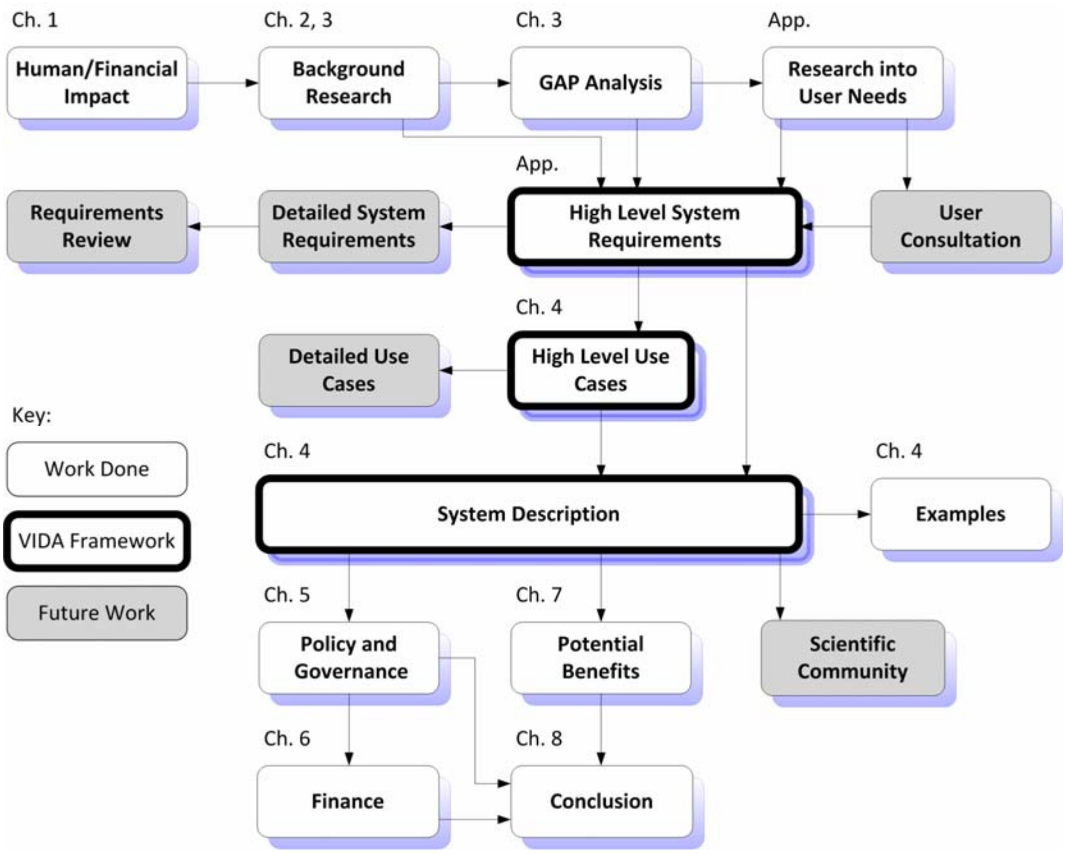

Figure 1-2: Report content and development of the VIDA framework

This Introduction provides an overview of the human and financial impacts of volcanoes and establishes the motivation for this project. Chapters 2 and 3 present the background research conducted during this project and establish a context for the report. In Chapter 2, volcanoes are described in greater detail, along with descriptions of the many hazards associated with them. The concept of the multi-hazard is presented, as hazards seldom occur in isolation, one often induces another.

Chapter 3 begins with a survey of existing systems and examines the volcano monitoring technologies that are employed on the ground, in the air, and in space. The survey of the existing systems, programs, and organizations addressing the challenge of volcano monitoring include existing coordination and management systems like the Global Earth Observation System of Systems (GEOSS), warning systems like the Global Disaster Alert and Coordination System (GDACS), and the various volcano observatories.

This background research provides the input to a gap analysis, which is presented at the end of Chapter 3; several gaps were already identified earlier in this Introduction. The gap analysis justifies the need for a VIDA system and supports research into the needs of potential end-users. Both the gap analysis and the identified user needs provide enough information to develop a list of high-level system requirements. These requirements can be viewed as a stand-alone document and are given in Appendix A.

In Chapter 4 the high level system requirements are used to define high-level use cases for a VIDA system and its overall description. Emphasis is placed on how such a system could leverage enabling technologies. Four examples of how a VIDA system would interact with data providers and end-users are presented. Chapter 4 is thus the main deliverable of this report; it *is* the framework. The expectation is that a designer could take the information in this Chapter, with Appendix A and cited references, and design a system for volcano early warning and hazard tracking. This objective is consistent with the project goals established at the outset.

The remaining chapters of this report address legal, political, economic, and societal implications of the VIDA framework. Chapter 5 addresses the questions of how data is obtained from the providers, how such a system would be run and by whom, are also addressed. It also outlines liability and copyright issues with the data sharing. Chapter 6 addresses the question of whether such a system would be financially viable and justifiable. The results of a stakeholder analysis are presented, followed by a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis, and a risk assessment along with a cost estimation using a comparative method. Finally, Chapter 7 returns to the societal motivations for a volcano early warning and hazard tracking system. It shows how a VIDA system will help international aid organizations and how such a system can be used as an educational tool.

As shown in Figure 1-2, several blocks (each representing elements of the system definition process and/or the present project) have not been addressed. These are the next steps in the development of a volcano early warning and hazard tracking system. Direct consultation with end-users is needed to derive more detailed system requirements and use cases, and the requirements need to be reviewed before the system can be designed. Chapter 8 concludes the report with recommendations for these next steps.

References, bibliography, and appendices may be found at the end, in support of the material given throughout the main body of this report.

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Chapter 2

Volcano Fundamentals

To define a framework to improve early warning and hazard tracking of volcanic eruptions, the physics of volcanoes including what causes them, where they occur, and what hazards they pose must be addressed. This Chapter introduces plate tectonics, the types of volcanoes, the hazards associated with volcanoes, and the timeline of an eruption.

2.1 Structure of Earth

In a simplified way, the solid Earth is composed of three principal layers: the core, the mantle, and the crust [Harris, 2001].

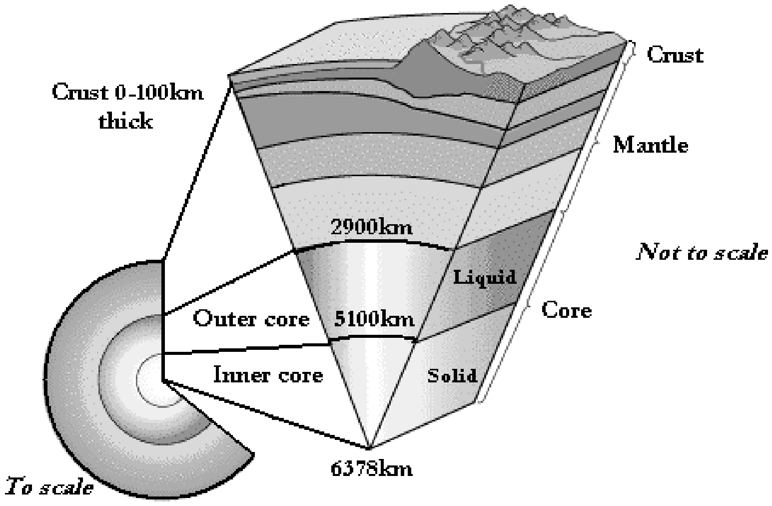
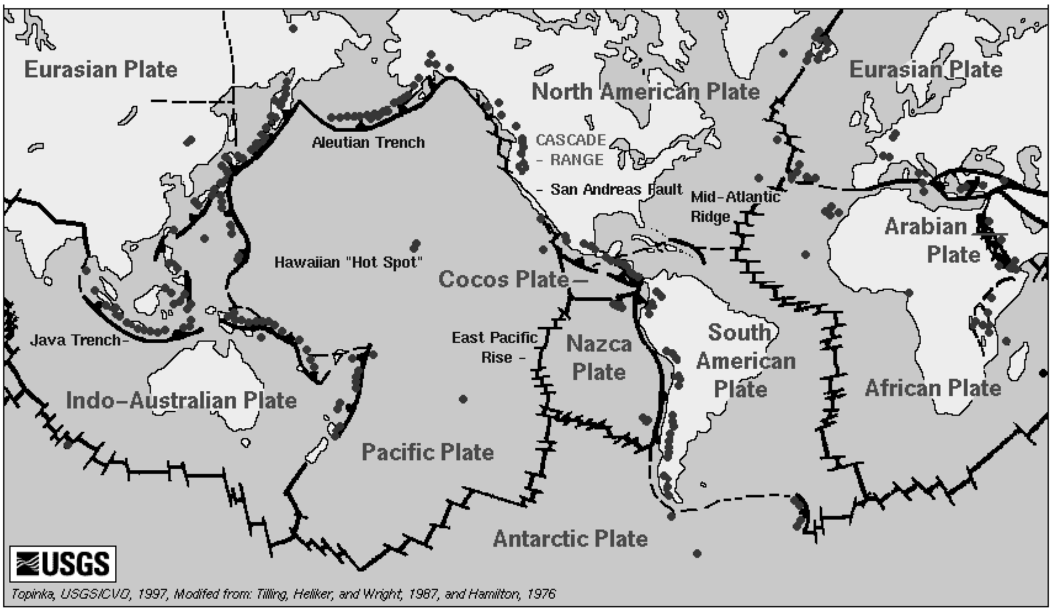


Figure 2-1: Earth's composition
[USGS, 1999b]

The center of Earth is composed of a solid inner core surrounded by a liquid outer core. Rotation of Earth causes spinning of the outer core liquid that creates Earth's magnetic field [USGS, 2000b]. Surrounding the core is the mantle, the largest layer of the earth [Brown, 1992]. The mantle is extremely hot but most of mantle material stays solid because the pressure at this depth is so high that the material cannot melt. The external layer of Earth is called the crust and is composed of continental and oceanic plates. The oceanic plates are 7 to 8 km thick and the continental plates, on average, are 35 km thick [Fowler, 2005].

2.1.1 Plate Tectonics and Volcano Production

The lithosphere, composed of the outer crust and the uppermost solid mantle, is divided into plates. These plates drift very slowly over the mantle. This motion is called plate tectonics and is the result of surface cooling and lithosphere subduction [Green, 2005]. The activity at the boundary between some of these plates causes the solid mantle material to melt, producing magma. A volcano is any place on Earth where magma from the mantle makes its way through the outer crust to the surface. Figure 2-2 shows the locations of the plates and the general locations of volcanoes on Earth; the lines indicate the plate boundaries and the dots indicate volcanoes [Harris, 2001].



Topinka, USGS/CVO, 1997, Modified from: Tilling, Heliker, and Wright, 1987, and Hamilton, 1976

Figure 2-2: Plate boundaries
[Topinka, 2003]

The interaction between different plates can typically occur in one of three ways as shown in Figure 2-3: a transform plate boundary (shown on the left), a divergent plate boundary (shown in the middle), or a convergent plate boundary (shown on the right). The plate boundaries are narrow and are characterized by seismic and volcanic activity [Sandwell, 2005]. However, transform plate boundaries rarely produce volcanic activity [Harris, 2001].

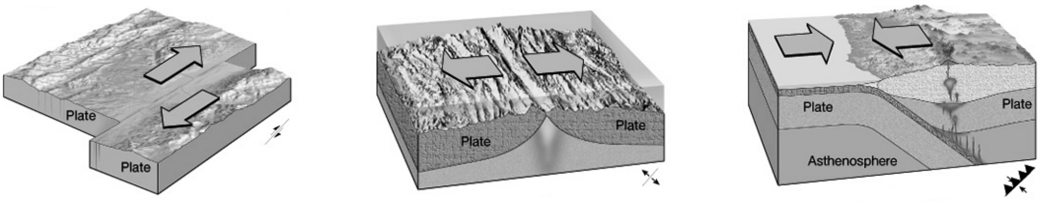


Figure 2-3: Types of plate boundary interaction
[Pompa, n.d.]

When two plates move away from each other it is called a divergent plate boundary. At a divergent plate boundary, the plates separate, allowing magma from the mantle below to fill the space between the plates. The magma cools and hardens forming ocean or continental ridges. This process is called spreading center volcanism [Harris, 2001].

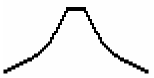
When two plates collide it is called a convergent plate boundary. At a convergent plate boundary, subduction may occur where one plate is pushed under the other plate. This normally causes formation of trenches in the ocean floor. Water from these trenches is forced into the mantle material of the upper plate lowering its melting point and forming magma. This process is called subduction zone volcanism. If subduction does not occur at a convergent plate boundary, volcanoes will not be produced but the crust will be forced up and form mountains [Harris, 2001].

Intraplate volcanic activity occurs when magma is formed under the middle of a plate but this is far less common than spreading center volcanism and subduction zone volcanism at plate boundaries. Intraplate volcanic activity is caused by unusually hot mantle material at a specific location called ‘hotspot’: when a plate moves over the hotspot, volcanoes are created (*e.g.* Hawaiian volcanoes) [Harris, 2001].

2.1.2 Volcano Types

Despite a unique history of eruptions, all volcanoes can be divided into three main types according to the following criteria: eruptive patterns and general forms. Characteristics of each type are summarized in Table 2-1 [Camp, 2006].

Table 2-1: Form and composition of main volcano types

Volcano Type	Volcano Shape		Eruption Type
Scoria Cone		Small, steep, straight slopes and large summit crater	Strombolian – eruptive columns of pasty lava ejected a few hundred meters into the air
Shield Volcano		Broad, gentle slopes and flat summit	Hawaiian – effusive emission of lava flows
Stratovolcano		Gentle lower slopes that rise steeply near summit; small summit crater	Plinian – highly variable and highly explosive (most dangerous type)

2.2 Volcano Hazards

The eruptive products of volcanoes are "highly variable and largely dependent on the composition, viscosity, and gas content of the erupting magma" [Camp, 2006]. Hazards include lava flows, tephra, pyroclastic flows, lahars, landslides, and gas emissions.

2.2.1 Lava Flows

Lava flows are masses of magma that pour out of the volcano during an eruption. Both moving lava and the cooled solidified deposit are referred to as lava flows. Because of the wide range in viscosity, the effusion rate (*i.e.* volume of lava produced over a given amount of time), the characteristics of the erupting volcano, and the topography over which the lava travels, lava flows can be of different shapes and sizes. Lava flows can travel tens of kilometers from an erupting volcano. When thermally isolated by a channel or lava tube on steep slopes, they can reach speeds of over 30 km/hr but they typically travel at speeds less than 1 km/hr [USGS, 2000b].

Although a lava flow moves at relatively low speeds, everything unable to get out of its path will be knocked over, surrounded or buried. The intense heat from the lava can melt or burn materials relatively close to it. If the lava flow encounters water, the water can "boil violently and cause an explosive shower of molten spatter over a wide area" [USGS, 2000b].

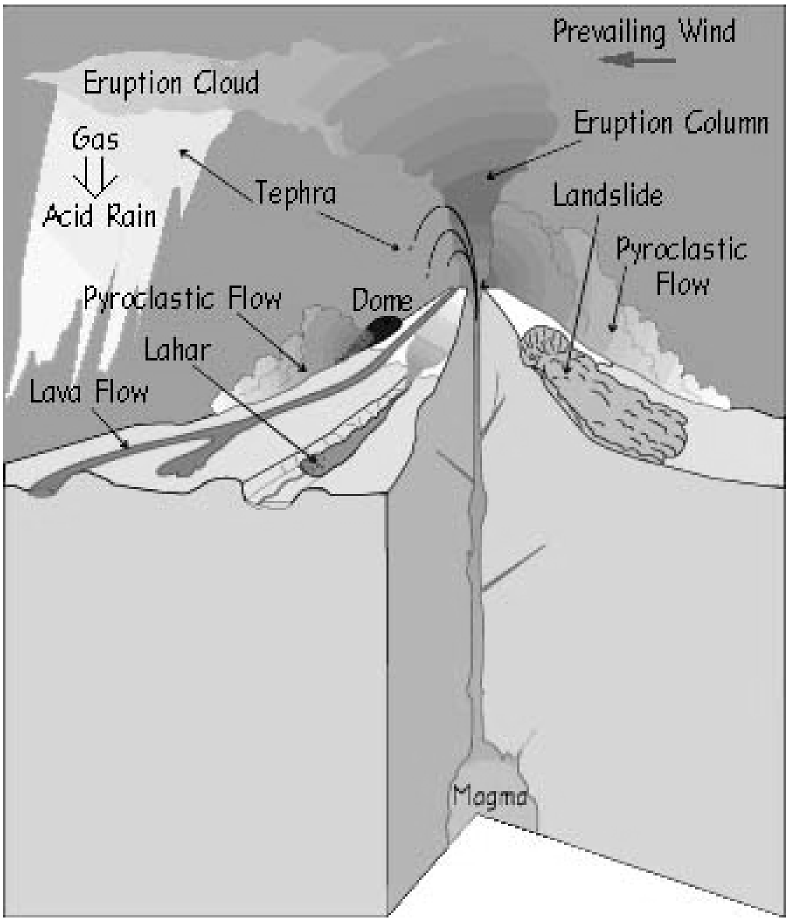


Figure 2-4: Volcano hazards
[USGS, 2000b]

2.2.2 Tephra

Tephra are fragments of volcanic rock and lava that are blasted into the air for up to 10 km [Hogan, 2007] by explosions or carried upward by hot gases during an eruption. Tephra are classified on the basis of size as follows [USGS, 2000b]:

- **Ash:** very fine-grained fragments of less than 2 mm in diameter. When carried upward by hot gases, they form ash plumes and ash clouds that can rise tens of kilometers into the atmosphere and travel for hundreds or thousands of kilometers downwind from a volcano.
- **Lapilli:** gravel-size fragments between 2 mm and 64 mm in diameter. The bigger they are, the shorter period of time they can remain in the air. Therefore, they can still be hot liquid when they hit the ground [Camp, 2006].
- **Blocks and Bombs:** fragments bigger than lapilli. Blocks are solid fragments with angular shapes; bombs are lava fragments that are semi-molten and become more aerodynamic when airborne. These can still be hot liquid when they hit the ground. Both blocks and bombs typically fall back to the ground on, or close to the volcano [Camp, 2006].

Figure 2-5 contains a visual representation of the different types of tephra: ash and lapilli on the left, and bombs on the right.

Figure 2-5: Different sizes of tephra
[USGS, 2003]

2.2.3 Pyroclastic Flows

A pyroclastic flow is a fluid-like mixture of solid fragments and hot gases that quickly move down the side of a volcano. These flows are heavier than air and move much like a snow avalanche. They are intensely hot (generally between 200°C and 700°C), contain toxic gases and move at high speeds often over 100 km/hr [Camp, 2006]. The extreme temperatures can cause fires, destroying forests, crops, and buildings. People can die or be seriously injured from burns and inhalation of hot gases that pyroclastic flows contain [USGS, 2000b].

Figure 2-6: Pyroclastic flow on the Mayon Volcano, Philippines
[USGS, 2003]

2.2.4 Lahars

In Indonesian 'lahar' means volcanic mudflow. It is a mixture of tephra and water that looks like wet concrete, but can move as fast as streams of normal water [Camp, 2006]. They can be produced by the heat from the volcano melting large amounts of ice and snow, by the disruption of crater lakes or by intense rainfall during or after the eruption [Martí, 2005]. Lahars can carry boulders of more than 10 m in diameter and can vary from hot to cold, depending on how they were produced [Camp, 2006]. Lahars and pyroclastic flows are the deadliest volcano hazards [Martí, 2005].

2.2.5 Landslides

Landslides are masses of rock and soil that fall or slide under the force of gravity. Volcano landslides can be triggered by intrusion of magma into a volcano, explosive eruptions, earthquakes beneath or near a volcano, or intense rainfall. They can be more than 100 km^3 in size and reach speeds of more than 100 km/hr. These factors explain their immense destructive power: a large landslide can bury valleys with tens to hundreds of meters of rock debris or can dam streams to form lakes [USGS, 2000b].

2.2.6 Volcanic Gases

Gases constitute around 1% to 5% of the total magma weight, 70% to 90% being water vapor. The remaining gases include sulfur dioxide (SO_2), carbon dioxide (CO_2), as well as some amounts of "nitrogen (N), hydrogen (H), carbon monoxide (CO), sulfur (S), argon (Ar), chlorine (Cl), and fluorine (F)" [Camp, 2006]. In combination with hydrogen and water they can produce toxic products of volcanic activity (*e.g.* hydrochloric acid (HCl), hydrogen fluoride (HF), sulfuric acid (H_2SO_4) [Camp, 2006].

The destructive effects of volcanoes are usually caused by lava flows, lahars or pyroclastic eruptions. However, volcanic gases are also dangerous as their emission in large quantities can be fatal due to their toxicity and high temperature. In rare cases, they can kill thousands of people. For example an outburst of Lake Nyon, a crater lake in Cameroon, killed 1746 people [Brown, 1992].

2.2.7 Multi-hazards

The hazards described in sections 2.2.1 to 2.2.6 are not discrete hazards. They can be triggered directly by a volcanic eruption, but also by the occurrence of other hazards. The volcano hazards can also initiate floods, tsunamis (large sea waves), earthquakes, and storms. It is also possible that these natural phenomena can trigger volcanic eruptions. The hazards that result from the interaction between volcano hazards and other natural phenomena are called multi-hazards.

Some examples of multi-hazards include:

- Landslides that reach a lake or ocean can cause waves or tsunamis.
- A lake formed by a landslide or lava flow that has dammed a stream may eventually drain catastrophically and generate lahars and floods.
- Landslides may decrease pressure on the volcano magmatic and hydrothermal systems, which can generate explosions, pyroclastic flows, and earthquakes [USGS, 2000b].
- When Krakatoa exploded in 1883, the eruption produced a series of tsunamis that swept over the coastal areas of Java and Sumatra killing over 36,000 people [the Geography Site, 2006a].
- Forest fires were ignited by lightning during the eruption of Mount Saint Helens in 1980 [Thompson, 2007].

2.2.8 Supervolcanoes and Global Risks

The term 'supervolcano' has no well-defined scientific meaning but is used to describe volcanoes that have violently erupted in the past. It is generally agreed that an eruption with a Volcanic Explosivity Index (VEI) of 7 or 8 is considered a supervolcano. These explosions produced large amounts of volcanic tephra, which led to long lasting changes to weather patterns around the globe. Yellowstone is a prime example of a supervolcano with an eruption that occurred 600,000 years ago releasing about 1,000 km^3 of material [USGS, 2000b]. In comparison Mt. St. Helens and Mt. Pinatubo released 1 km^3 and 10 km^3 of material respectively during their most recent eruptions [USGS, 2000b].

The probability of an eruption of a supervolcano has been estimated as once every 100,000 years. The main potential consequence of such an eruption is the volcanic winter that could last as long as 7 years. It could cause global climate changes and block out large amounts of incoming solar radiation [Leggett, 2006]. With the decrease in sunlight, vegetation would be killed by sudden hard freezes and the human death toll has been estimated to reach one billion [Leggett, 2006].

2.3 Eruption Timeline and Monitoring

To discuss the effects of a volcanic eruption, the actions to be taken, and the tools to be used, it is important to define the timeline of an eruption. For this purpose, the timeline is separated into four phases: long-term monitoring for scientific purposes, monitoring for early warning purposes, hazard tracking and response, and recovery.

Long-term monitoring for scientific purposes is defined as the continued observation of a volcano to detect any changes that could indicate an increase in volcanic activity that may signify an upcoming eruption. This monitoring is performed over many months and years and will continue indefinitely. It is conducted before, during and after an eruption. Note that long term monitoring is outside the scope of this report.

Monitoring for early warning purposes is defined as the continued monitoring of a volcano for the purpose of detecting when an eruption will occur in order to initiate appropriate action. It begins when there is an increase in volcanic activity that may signify an upcoming eruption and ends either at the point of eruption or when the volcanic activity decreases to previous levels.

Hazard tracking is defined as continuous monitoring of a given hazard for changes in its magnitude and direction. It begins from the point of hazard detection until it is unlikely to cause any further injury or damage. Response is defined as the reaction taken to the hazards to preserve lives and to prevent or mitigate damage to land and property. This phase normally lasts from several hours to several days after an eruption.

Recovery is defined as the actions taken to re-establish the lives of affected populations and the infrastructure that supports returning them to the pre-eruption state. There is no distinct point at which response transitions to recovery, but the recovery phase can last for many years.

2.4 Conclusion

The hazards of volcanoes vary and are significant. Distinct volcanic hazards can also interact, forming multi-hazards. With the potential loss of life and damage to property, it is important to monitor these hazards and ensure that the right people are informed in a timely manner to prevent loss of life and mitigate the effects of the hazards. The existing systems and organizations that monitor and respond to volcanic hazards are discussed in the next Chapter.

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Chapter 3

Existing Systems and Gaps

Many organizations are already actively involved in hazard tracking and early warning systems. To propose any recommendations regarding improvement of early warning and hazard tracking systems, it is necessary to understand these existing systems. The term 'system', in this context, encompasses international groups, regional groups, and Geographic Information Systems (GIS). The research of current systems and technology presented in this Chapter leads into a gap analysis that identifies areas where improvements would benefit volcano monitoring and hazard tracking.

3.1 International Integration Initiatives

Several organizations provide Earth observation data and information internationally. These groups include Global Monitoring for Environment and Security Initiative (GMES), Group on Earth Observation (GEO), Integrated Global Observing Strategy (IGOS), and the Charter. Some of these organizations are still being developed and all are fairly new, emerging in the course of the last ten years. Nevertheless, they are now key players in integrating ground-, air-, and space-based Earth observation capabilities to provide useful information and services in a more efficient and timely manner. The following sections highlight some of the important features of each of the organizations.

3.1.1 Group on Earth Observation

GEO is coordinating the effort to implement the Global Earth Observation System of Systems (GEOSS). GEO is a voluntary partnership of international organizations and governments. GEOSS, when established, will aim at improving connection between data providers and the users to enhance the relevance of Earth observation to the activities covered. Issues of focus include disasters, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity [GEO, 2008b]. GEOSS is discussed further in section 5.1.2.

3.1.2 Global Monitoring for Environment and Security

GMES is an initiative led by the European Commission in collaboration with the European Space Agency (ESA). GMES will be the European contribution to GEOSS (see section 3.1.2) services which are expected to be operational by the end of 2008 [European Commission, 2007]. The aims of GMES are to compile the use of multiple sources of data, provide rapid and high quality information, as well as provide services and knowledge to decision makers concerning environment and security [Liebig, 2007].

3.1.3 Integrated Global Observing Strategy

IGOS is a partnership that pursues the goal of providing a framework that harmonizes of the interests and activities of space- and ground-based systems for global Earth observations [IGOS, 2004]. It is meant to address the needs of policy makers, as well as the scientific community. The goal of IGOS is to build an overall strategy to coordinate environmental observations in order to improve the monitoring capability as well as data availability [IGOS, 2004].

In 2001, IGOS started a Geohazards Initiative. This initiative addresses the information needs for predicting and monitoring geophysical hazards including volcanoes [IGOS, n.d.]. Since 2005 this initiative is also part of the GEO coordination process and is represented in all four committees established by GEO to implement GEOSS [Salichon, 2007].

3.1.4 The Charter

The Charter is a group of space agencies that came together to provide access to space resources for those affected by natural or man-made disasters. It serves as a mechanism to provide information to rescue and civil protection agencies, as well as defence and security bodies for use in crisis management [The Charter, 2000].

ESA and *Centre National d'Etudes Spatiales* (CNES) initiated the Charter in July 1999. It was originally intended to be a temporary solution for countries without advanced space technologies to gain access to space-based assets in times of emergencies. The Charter was declared operational in November 2000, and current membership has expanded to include the Canadian Space Agency (CSA), National Oceanic and Atmospheric Administration (NOAA), the United States Geological Survey (USGS), the Indian Space Research Organization (ISRO), the Argentine *Comision Nacional de Actividades Espaciales* (CONAE), the Japan Aerospace Exploration Agency (JAXA), the British National Space Centre (BNSC), the Disaster Monitoring Constellation International Imaging Ltd. (DMCii), and the China National Space Administration (CNSA) [The Charter, 2008].

3.2 Regional and National Organizations

International organizations coordinate the efforts between different national actors, such as space agencies. They help to prevent the overlap of space capabilities from different countries and to streamline the process of Earth observation. In addition to their efforts, regional and national organizations have a role in volcano monitoring and hazard tracking. They have some advantages over global monitoring and response groups. For example, these organizations can quickly transfer data from volcanic sites to response units, have a lower management load and can retrieve near-real-time *in situ* measurements allowing effective response actions. They are also responsible for 'ground truthing' of space data and ensuring the accuracy of space-based technology. These organizations include local volcano observatories, government relief agencies, and the local offices of humanitarian organizations like the Red Cross and Red Crescent Movement.

Volcano monitoring organizations and observatories are normally the first to trigger an alarm regarding possible eruptions and usually work closely with local governments. They are important players with dual roles as data providers and as links to local governments. While this scheme works in most locations, it is important to note that not all regions have extensive *in situ* monitoring capabilities. Table 3-1 contains a very brief list outlining some regional organizations involved in volcano monitoring. This list was narrowed from a compiled table of more than 130 organizations in order to focus on the major players by region and to demonstrate the wide range of monitoring capabilities. For example, the Democratic Republic of the Congo (DRC), unlike larger, economically stable countries, is unable to perform extensive monitoring due to regional instabilities. For countries such as this, global services are most useful in providing information such as digital elevation maps, vegetation change monitoring, ash plume tracking, and more.

Table 3-1: Organizations for volcanic eruption early warning and hazard tracking

Region	Country	Description
North America	US	• The USGS operates the Volcano Hazards Program to provide information on potentially active volcanoes in the US. The web-based interface for this program displays a Google Maps-based view of every volcano within the US and its territories, along with a color-coded hazard level [USGS, 2008b]. • The Federal Emergency Management Agency (FEMA) is concerned with response to an eruption event, and its website provides information on how to prepare for the harmful effects of an eruption, as well as what to do in the event of an eruption [FEMA, 2006].
Central and South America	Mexico	• The *Centro Nacional de Prevención de Desastres* (CENAPRED) is responsible for monitoring volcanoes in Mexico. Daily updates on the activity of volcanoes are posted on the agency's website, along with risk maps that show which areas are in danger of being affected by an eruption, and to what degree, as well as evacuation routes [CENAPRED, 2008].
Asia and the Pacific	Japan	• The Geographical Survey Institute (GSI) is a national organization that conducts basic surveys for mapping, and provides data for disaster prevention. They also utilize ground based GPS receivers throughout Japan to get information about crustal movements and deformation throughout the country [GSI, n.d.].
	The Philippines	• Philippine Institute of Volcanology and Seismology (PHIVOLCS) is a governmental agency that monitors natural disasters and mitigates hazards arising from geotectonic phenomena, particularly volcanic eruptions and earthquakes. It aims at formulating up-to-date and comprehensive disaster preparedness plans for volcanic eruptions and earthquakes that can affect the human environment [PHIVOLCS, n.d.].
Europe	Italy	• The *Istituto Nazionale di Geofisica e Vulcanologia* (INGV) gathers all scientific and technical institutions operating in geophysics and volcanology to create a permanent scientific forum in Earth sciences. INGV cooperates with universities and other national public and private institutions, as well as with many research agencies worldwide and is devoted to 24-hour countrywide seismic surveillance, real-time volcanic monitoring, early warning, and forecast activities [INGV, 2008].
Africa	DRC	• Goma Volcano Observatory (GVO) is a small observatory building located in Goma, a city near Nyiragongo and Nyamuragira volcanoes. There is little done to monitor them because of the political unrest in the country, the dangers of the Ebola virus, and the dangers of volcanic hazards caused by their regular eruptions [Allard, 2002].

3.3 Information Providers and Networks

On an operational basis, different systems gather data to produce information that is then disseminated via the Internet using mostly web-based services. Some organizations such as GDACS address hazards from multiple natural phenomena, while others such as the Global

Volcanism Program (GPV) are focused on hazards from one natural phenomenon. This section briefly presents some of the main information providers and networks dealing with volcano monitoring and hazard tracking to show how information is currently relayed.

3.3.1 Global Disaster Alert and Coordination System

GDACS is a joint initiative of the United Nations Organization (UN) and the European Commission. They provide a web-based system which automatically alerts registered users of potentially disastrous events all around the world. Alerts provided by GDACS are not meant to be authoritative and are generated automatically without human verification.

GDACS offers a platform for those involved in emergency response to exchange information and coordinate efforts. Its near-real-time alert service is currently only available for earthquakes and tsunamis. GDACS offers a daily newsletter for all natural phenomena monitored, including volcanic eruptions. The volcano information provided by GDACS is based on the weekly bulletins of the GVP [GDACS, 2008].

3.3.2 Global Volcanism Program

The GPV is run by the National Museum of Natural History at the Smithsonian Institute in Washington, D.C. It contains a database of all volcanoes that have been active in the last 10,000 years. Together with the USGS Volcano Hazards Program, it provides a weekly report that shows changes in volcanic activities. It takes into account news reports, reports from external observers, and changes in the alert level by VAACs (see section 3.3.5). The GPV also provides a monthly Global Volcanism Network bulletin containing a summary of volcanic activities [Smithsonian Institute, n.d.].

3.3.3 Relief Web

Relief Web is an information portal about humanitarian emergencies including natural disasters provided by the UN Office for the Coordination of Humanitarian Affairs (UN OCHA). It helps to improve worldwide communication and coordination in disaster response. It is continuously updated and contains information useful in case of a humanitarian crisis. This information includes, but is not limited to, situation reports, maps, and background information as well as documents related to policy issues such as coordination and security. This information is produced by the UN, Non-Governmental Organizations (NGOs), media reports, and scientists [Relief Web, 2008].

3.3.4 GlobVolcano

GlobVolcano is a project run by ESA as a part of the Data User Element (DUE) program. It provides an Earth observation based information service for volcanic observatories and other users with a focus on prevention and early warning. The information service includes deformation mapping by SAR, surface thermal anomalies, volcanic gas emission (SO_2), plumes, and cloud characteristics (volcanic ash) [GlobVolcano, 2008].

3.3.5 Volcanic Ash Advisory Centers

Ash clouds and SO_2 gas emission are serious threats to aircraft. An encounter can cause severe damage such as surface abrasion, cabin air contamination, and even complete engine failure [USGS, 2000a]. In 1987, safety concerns led the International Civil Aviation Organization (ICAO) to create the International Airways Volcano Watch (IAVW), an international framework for issuing ash cloud warnings to aircraft [Servranckx, 2005]. This led to the creation of nine VAACs tasked to monitor volcanic hazards within assigned airspace as shown in Figure 3-1. For this they use different technologies, including meteorological satellite imagery. Official ash cloud warnings are issued as Significant Meteorological Information (SIGMET) by the Meteorological Watch Offices (MWOs) who are close collaborators with the VAACs [Servranckx, 2005]. The warnings are also sent to control centers that then use Notices to AirMen (NOTAM) to warn their pilots about potential hazards and to communicate modified air routes [Elrod, 2008].

3.3.6 World Organization of Volcano Observatories

World Organization of Volcano Observatories (WOVO) is dedicated to the observation and monitoring of volcanoes. This organization maintains open communication between observatories around the world, collecting a database of monitoring data. In the time of an eruption WOVO is responsible for notifying the local authorities and the public directly of potential volcanic hazards [WOVO, n.d.].

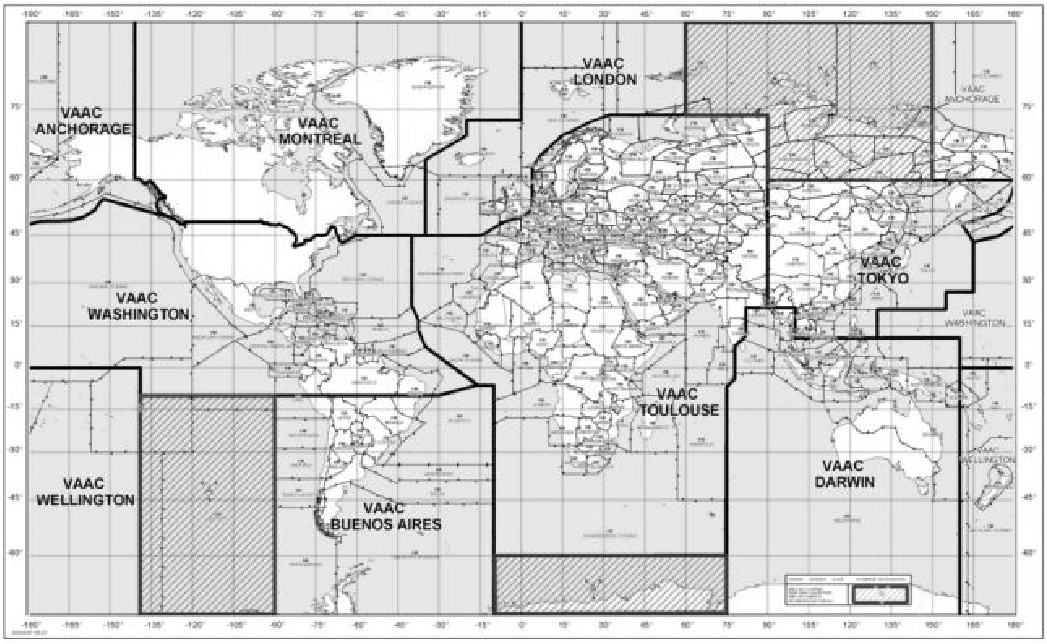

Figure 3-1: VAAC territories
Areas with hatchlings are not monitored [Darwin VAAC, 2008]

3.3.7 Humanitarian Early Warning Service

Humanitarian Early Warning Service (HEWS) is a partnership project of the Inter-Agency Standing Committee Sub-Working Group (IASC-SWG) on Preparedness and Contingency Planning developed by the World Food Program. It is a global multi-hazard watch service to support humanitarian preparedness and the monitoring of volcanoes, storms, floods, seismic activity, tsunami, locusts, El Niño, and severe weather. It issues early warning messages and alarms through its website, HEWSWeb. This includes systematic early warning by displaying graphics, maps, and simple messages for managers and decision makers. It aims to establish a better link between early warning and preparedness actions among partners. Seismic activity data is frequently updated but the volcano related section is not [IASC, 2008].

3.4 Existing Technology

All the organizations, information providers, and networks rely on technology to be able to gather data and process it into useful information. To monitor volcanoes, a wide variety of instruments are used to provide primary data that support analysis of risks and hazards. Measurements come from the sensors and are then processed to extract valuable information using algorithms and modeling techniques. This section gives an overview of the sensors, algorithms, and GIS used for volcano monitoring.

3.4.1 Sensors

The sensors used for monitoring can be classified into three categories: ground-, air-, and space-based. Table 3-2 presents the most commonly used sensors: ground-based and air-borne sensors provide local information, whereas space-based sensors can capture global features. Early warning and tracking systems use a combination of these sensors to improve their overall accuracy. Figure 3-2 shows a typical deployment of monitoring sensors in the vicinity of a volcano.

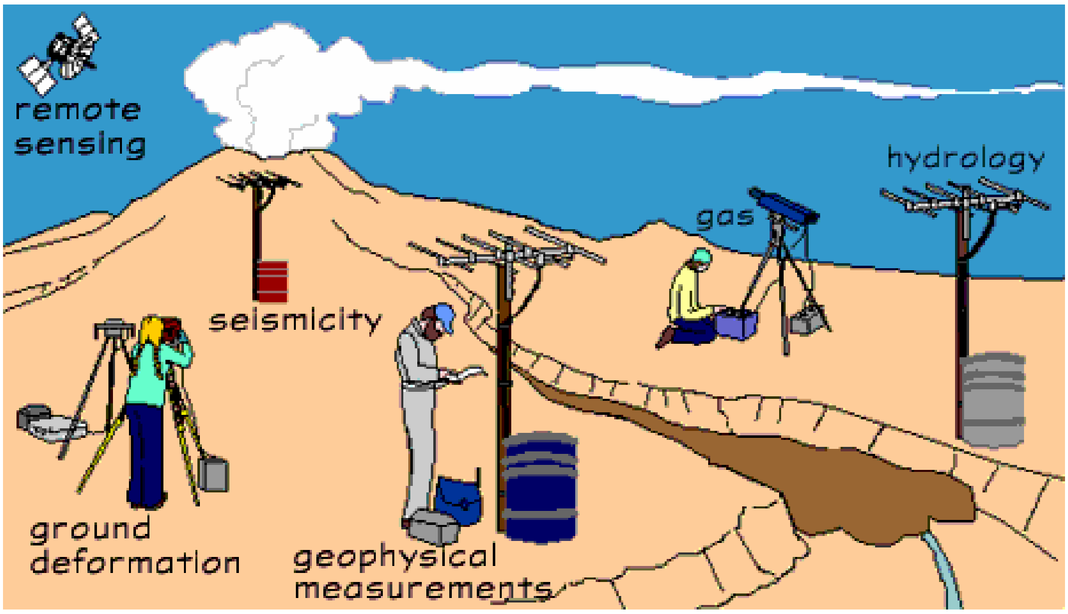

Figure 3-2: Typical deployment of volcano monitoring sensors [USGS, 2004b]

3.4.2 Algorithms and Modeling Techniques

Several attempts to automatically process and combine data from ground-, air-, and space-based sensors have already been made by different research groups and analysis centers. Data processing algorithms are important because they enable fast and automatic data processing. By studying these, it is possible to understand the strengths and weaknesses of each technique. The importance of having a human in the process to verify the final output before measures such as evacuations are undertaken should be considered, as there are number of uncertainties in the current programs. Nevertheless, these algorithms and modeling techniques are a crucial first step in helping turn data into useful information in a timely manner. Examples of algorithms and VAAC modeling techniques are provided in Table 3-3 and Table 3-4, respectively.

3.4.3 Geographic Information Systems

GIS is a system (both hardware and software) for acquisition, storage, and analysis of data and display of geographically referenced information. It allows the user to view and interpret data in a way that can reveal relationships and patterns among several sources. The output can be displayed in different forms such as maps, globes, and graphs. GIS technology is an expansion of cartographic science, enhancing the capabilities of more traditional methods using computers.

Table 3-2: Most commonly used sensors for volcano monitoring and hazard tracking

Existing Technologies	Sensor Types	Description
Ground-Based*	Seismometer	Measures seismicity related to magma movements and eruptive phenomena.
	Electronic Distance Measure (EDM)	Measures distances between the instrument and a remotely located reflector.
	Global Positioning System (GPS)	Measures position to allow for ground deformation and movement calculations.
	Tiltmeter	Measures ground tilt near active volcanoes.
	Borehole strainmeter	Measures crustal deformation near active volcanoes. Strainmeters are installed at the bottom of boreholes.
	Spectrometer	Analyzes gas samples from the active craters or by ground-based remote sensors to determine chemical composition.
	Magnetometer	Measures the intensity of the local magnetic field for comparison with previously measured data.
	Gravimeter	Measures long and short-term gravity changes due to ground and magma movement.
	Acoustic Flow Monitor (AFM)	Measures ground vibrations in the frequency range of 10-300 Hz.
	Hydrological sensor	Measures changes in water level and composition around volcanic sites.
	Electric field sensor	Measures electric field around volcanic sites.
Air-Based	SAR, InSAR, and Differential InSAR (DInSAR)	Used to generate Digital Elevation Models (DEMs) of the crater and surrounding area. Provides an unobstructed view of a volcano even if it is covered by smoke.
	Thermal Imaging	Measures thermal signatures of active volcanoes, lava flows, and hot spots.
	Laser Altimetry	Is used to measure time varying topographical changes around the volcanic regions.
Space-Based	Thermal Infrared Sensor	Measures the changes in surface temperatures in volcanic regions, track volcanic ash plumes, and estimate the spectral attenuation of infrared terrestrial radiation from volcanoes to quantify emissions.
	Ultraviolet sensor	Measures ultraviolet backscattering and absorption bands to provide critical information of the tephra.
	SAR, InSar, and DInSAR	Are used to generate DEMs of wide areas or on global scale. InSAR and DInSAR are used to monitor relative changes in landforms [Kobayashi, 1999].

*[USGS, 1999c, 2000c, 2001]

Table 3-3: Examples of algorithms

Algorithm	Function/Capability
Failure Forecast Method (FFM)	Ground deformation or seismic energy release is used as an input to forecast material failure within volcanoes using physical laws. Failure time is forecasted from the inverse relationship between time and a proxy for strain rate.
Mogi Model	Models volcanic sources allowing for the interpretation of the deformations based on a model of a pressure source buried in an elastic half-space.
Robust Advanced Very High Resolution Radiometer (AVHRR) Techniques (RAT)	Is used to improve the automatic detection of volcanic hotspots and thermal anomalies; potentially can be used to detect low-level thermal anomaly and to identify early pre-eruptive thermal anomalies.
NOAA AVHRR plume detection	Improves automatic detection of volcanic hotspots and thermal anomalies; is based on a multi-image approach, statistical measures for pixels separation, and contextual information for pixels corresponding to plumes.
IAVW	Uses remote sensing data to perform surface based observations, pilot reports, and dispersion model output.
Co-registration of Optically Sensed Images and Correlation (COSI-Corr) Software Package	"Allows for automatic and precise ortho-rectification, co-registration, and subpixel correlation of satellite and aerial images" [Leprince, 2008].

Table 3-4: Summary of VAAC models

VAAC	Model	Function/Capability
London	Nuclear Accident Model (NAME)	Atmospheric dispersion model used to forecast the dispersion of the ash up to 48 hours in advance.
Toulouse	*Modle Eulerian de DIspersion Atmospherique* (MEDIA)	Computes drifting due to winds, dispersion by turbulence, washing by precipitations, sedimentation by gravity.
Montreal	CANadian Emergency Response Model (CANERM)	3-dimensional numerical transport and dispersion model that calculates advection and diffusion and simulates wet and dry depositional processes.
Washington	Volcanic Ash Forecast Transport and Dispersion (VAFTAD)	Volcanic ash model that runs on output from various models employing a three-dimensional grid Eulerian formulation.
Darwin	HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT)	Computes simple air parcel trajectories and performs complex dispersion and deposition simulations.

According to the Environmental Systems Research Institute (ESRI), one of GIS leading system developers, a GIS can be understood in three different ways. First, GIS a database that incorporates and integrates information from several geographic and socio-economic sources (known as a geo-database). Second, GIS is a set of maps that presents information in layers that can be overlapped showing interactive features, trends, and relationships suitable to be displayed on a map. GIS has also the capability to support queries, analyses, and editing of the information. GIS is not only capable of answering the question "where" but also "what" and "what if". Third, GIS is a set of software tools for transforming information from existing datasets to derive new geographic information [ESRI, n.d.].

Examples of GIS software include ArcGIS, Geographic Resources Analysis Support System (GRASS), and Miramon. ArcGIS is created by ESRI, while GRASS is free and open source software. An interesting project that emphasizes the usefulness of GIS for monitoring natural hazards is the database 'Hazard of the Pacific' (HAZPAC) [Bemis, 2002]. It was created by the Crowding the Ring Initiative that was set up in 2002. HAZPAC is a useful and educational tool since it can combine information regarding hazards and infrastructures.

Examples of its capabilities are depicting air routes, population density, and major shipping lanes with respect to volcano locations in a single map.

3.5 Gap Analysis

This gap analysis is derived from the survey of the existing systems and technology presented in the previous sections. Gaps in technology, aviation safety, and the Charter were identified as being the most crucial and are discussed in this section.

3.5.1 Technological Gaps

Several important gaps regarding current monitoring capabilities, instrumentation, temporal and spatial coverage, and software have been identified. Since all technological resources rely on the existence and availability of useful data, some issues regarding data are also addressed. No measurement by itself can provide a definitive conclusion relating to volcanic activity.

Data

Issues that need to be improved include incompatible data formats, restricted circulation of data, the necessity to calibrate acquired data, and a lack of ground truth verifications. Standards for catalogues of data should be proposed and digitized inventories of existing volcanic related information should be progressively created and updated. Access to the data catalogues should also be facilitated and networks of data created [Anderson, 2008].

Monitoring capability

Significant gaps in the capability to monitor potentially active volcanoes remain and need to be addressed. Nineteen volcanoes in Alaska and the Mariana Islands that represent a significant threat to air traffic, lack the ground sensors necessary for near-real-time ground-based monitoring. Furthermore, many dangerous volcanoes are only monitored at a minimal level with regional networks of sparsely spaced seismometers [USGS, 2005]. Failing to monitor the early stages of volcanic activity can result in the loss of crucial and timely information needed to forecast the behavior of volcanoes. This can result in both human and infrastructure losses.

Ground-based sensors

Ground-based networks have been identified as sparse, as in the case of seismic and deformation networks. Although wireless integration networks exist in some volcanic regions, such networks have not yet been systematically deployed for all volcanoes on a global basis. There is a strong need for detailed maps of the surface of volcanic regions but high-resolution digital topographic mapping is not being done. The necessity for better topographic maps may be met with satellite data, but not in areas of low relief.

Air-based sensors

The reliability of volcanic activity predictions could be improved with frequent air-borne SAR and laser altimetry operations. However, these are carried out only over limited regions. The detection of anthropogenic contaminants in ash plumes would require expanded airborne hyperspectral capability [Simpson, 2000]. The integration of local ground measurements and InSAR or advanced InSAR data should be carried out.

Space-based sensors

No single satellite sensor is able to identify and track all volcanic hazards. In particular, volcanic ash clouds can be very difficult to track. The main limitations are due to the presence of meteorological clouds, ambient moisture, or substantial amounts of ice obscuring volcanic hazards. There are no satellites in operation to specifically monitor volcanoes, instead meteorological satellites are being used. Satellites have a limited ability to detect small-scale events due to their spatial resolution power. Satellite sensors working in the visible spectra have a reduced capability of monitoring volcanoes at night. As well the detection of toxic compounds in ash plumes would require expanded space-based hyperspectral capabilities.

Temporal resolution as well as continuous monitoring is a current drawback due to the few satellites devoted to civilian applications. This was the case for Total Ozone Mapping Spectrometer (TOMS) data; it was limited due to infrequent observations. TOMS instruments performed daytime observation of the stratosphere, but only the Anchorage VAAC had a direct TOMS downlink. The last TOMS instrument on board the Earth Probe satellite was decommissioned in 2005 [MACUV, n.d.]. The Ozone Monitoring Instrument (OMI) on board the Aura spacecraft has taken over collecting ozone data. Subsets of collocated AVHRR satellite imagery are required to carry out time series analysis.

GIS software

One of the most significant gaps of GIS is the lack of complete integration between GIS and remote sensing data formats, which requires standardization. Other gaps include the level of data exchange, the geometric registration of multi-angle images acquired by airborne multispectral scanners, the matching of cartographic representation, parallel user interfaces, and the compatibility of geographic abstraction [Mesev, 2007]. In order to move towards the integration of data, algorithms, techniques, and organizations that use GIS with remote sensing data, greater computer processing power is required. Errors in data propagation should be reduced, as well data structure compatibility should be improved. Issues such as data availability, costs, standards, and organizational infrastructure should be addressed [Mesev, 2007].

There is also a need to dynamically update GIS databases. Information stored in a static GIS cannot be relied on after a natural phenomenon has occurred to track hazards. In the previously presented HAZPAC interactive map, the information has not been updated since 2002. A tool that maintains an up-to-date GIS database would be an important asset when an eruption occurs, to plan any evacuations or civil response design in accordance with the topology within the hazardous area.

3.5.2 Gaps Identified for the Aviation Sector

Even following the creation of the VAACs, which have global responsibility for the prompt detection of airborne volcanic ash and for notifying the aviation community, aircraft encounters with ash clouds have not been eliminated. The aviation sector is concerned about accurate early warning and ash cloud tracking to minimize losses. Unreliable and false detection of ash plumes is another major problem for forecasters during the early stages of the eruption that is most critical to aviation safety. Below the main challenges identified for the aviation industry are summarized.

Timely information

In 2008 ESA analyzed aviation needs to support volcanic ash avoidance. Current hazard warnings emitted through VAACs take between 1 and 1.5 hours to get to the pilots from the moment a volcano starts emitting ash. However, it takes as little as five minutes before the ash cloud reaches flight altitude [ESRIN, 2008]. An ideal system would thus provide ash cloud location and altitude within this five minute window to allow immediate avoidance measures. Unfortunately, accurate detection of volcanic ash within five minutes is difficult to be achieved due to limitations in the simulation models with regards to particle size, shape, and plume opacity. Unpredictable atmospheric motions may also keep larger particles in the ash cloud aloft much longer than expected.

Effects of ash clouds and aerosols on aircraft

The strategy for ash clouds is currently total avoidance [Ellrod, 2008]. Flights are re-routed or even cancelled in order to prevent encounters. This is a safe way to proceed since structural damage has been recorded even in low gas and ash concentration clouds [ESRIN, 2008]. Minimum tolerable concentrations remain unknown. More research is needed to better understand the effects of ash clouds and aerosols on aircrafts and passengers. To achieve this, more data would be needed on ash and gas concentrations. Only certain VAACs have access to SO_2 and other aerosol measurements [ESRIN, 2008].

Disparity in VAAC tools

Table 3-4 shows that every VAAC runs its own detection and forecasting model based on different meteorological data and inputs. An analyzed of the different outputs obtained for the same eruption from various algorithms used by different VAACs was performed [Witham, 2007]. The results were very similar although small differences were noted. For example, the London system is more likely to overestimate a small eruption than other VAAC's systems. The type of output maps are also hard to compare since they differ from one facility to the other. There is a need to improve and potentially standardize the parameters and thresholds used by all the different VAAC models to ensure consistency [Witham, 2007].

There is a requirement for a stand alone, robust volcanic ash retrieval algorithm for satellite data [Simpson, 2000]. Some attempts to automatically detect ash plumes have been carried out. For instance, Craig Bauer, Lead Techniques Development Forecaster for the Anchorage VAAC, tried to set up an automatic scan for volcanic ash detection derived from AVHRR T4–T5 imagery in the late 1990's. He encountered problems due to false indicators of ash in the atmosphere. This work showed that cumulonimbus clouds and some cirrus features make it difficult to reliably detect volcanic ash [Simpson, 2001].

Communication gap

Communication gaps were analyzed in a study on disaster risk management for the Ruapehu volcano eruption in New Zealand, 1995. A survey questionnaire to all involved organizations showed that communication problems were perceived as an important issue [Paton, 1998]. More specific problems such as lack of clear responsibility for coordination and inadequate communication within the agencies involved were also identified.

3.5.3 The Charter Gap Analysis

The Charter has achieved a great deal of success given that it has only been in effect since 2000. However, there are a number of issues that it currently faces. These concerns include timeliness of activating the Charter, data delivery, data availability, formatting, and language continuity. Activation of the Charter is defined as "mobilization of space and associated ground resources to obtain data and information on a disaster" [The Charter, 2008].

Delays in activating the Charter

Delayed responses can greatly intensify the severity of the impacts of a natural event. According to the Charter's 2006 annual report, the average response time of the Charter is almost two days, [The Charter Executive Secretariat, 2008]. However, in the case of volcano eruptions that have lead to the activation of the Charter, the average time is over 6 days. Figure 3-3 shows delays of activation following a volcanic disaster, using the activation data provided by the Charter annual reports and website. For example, a deadly volcano occurred in Ecuador in January 2008 and the Charter was not activated until 16 days after the eruption started [The Charter Executive Secretariat, 2008].

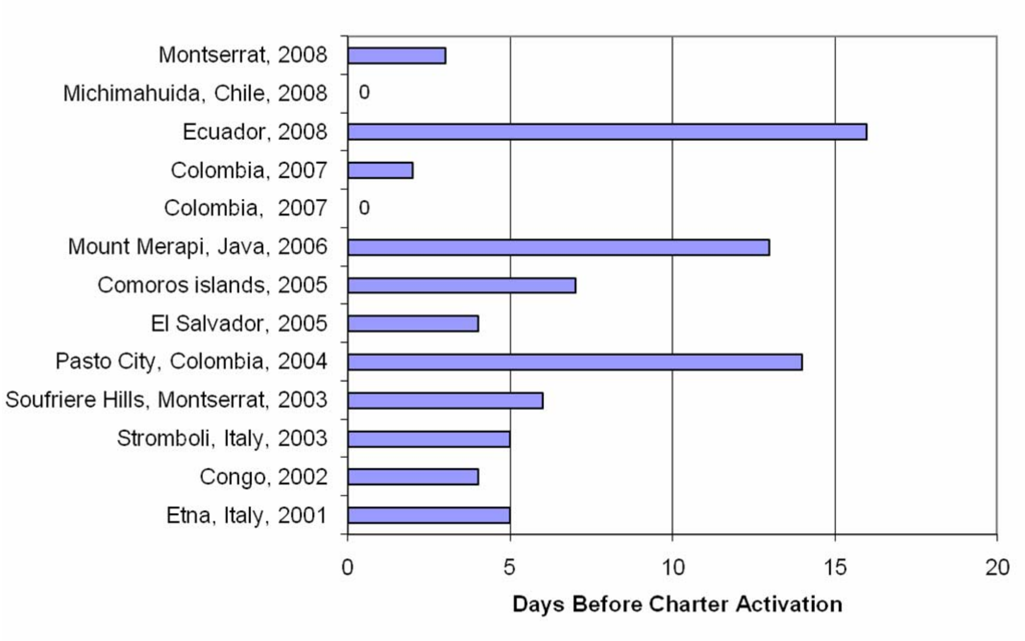

Figure 3-3: Days before activation of the charter following a volcanic eruption

The lengthy process of activating the Charter contributes to delays. First, an Authorized User must call the On Duty Operator and submit a request form to activate the Charter. After the request is made, an On Duty Operator confirms the identity of the Authorized User. Next, the operator relays the information to an Emergency On-Call Officer who reviews the request with the Authorized User. Then, they together formulate an acquisition plan based on available space resources. Finally, a Project Manager is selected to assist the user throughout the process of data acquisition and delivery [The Charter, 2008]. For example, during the 2006 floods in Ethiopia, it took three days before a Project Manager was officially designated [The Charter Executive Secretariat, 2008].

Given the complexity of the process there are many opportunities for activation to be delayed. Authorized Users, as well as Cooperating Bodies, are the only entities authorized to request the services of the Charter [The Charter, 2008]. This means that those who are first aware of an event have to rely on authorized users to start the process for them. Commercial entities, such as airline companies, are unable to initialize the charter.

Reactive nature of the Charter

Given the process that must take place in order to activate the Charter, it currently acts reactively rather than proactively. Although the Charter has been activated twice in advance of a natural phenomenon, this practice is far from the norm [The Charter Executive Secretariat, 2008].

Delays in data delivery

In order for the Charter to have a positive impact on the situation, the relevant data must be successfully delivered to the right people in a timely manner. Unfortunately this is sometimes not the case, for instance during the Stromboli Volcano eruption in Italy in April 2003, shipment issues led to a 12-day delay of data [The Charter Executive Secretariat, 2004].

Data format problems

The Charter has also faced problems with data formatting. For example, during the volcanic eruption in El Salvador in October 2005, the project manager had difficulty downloading the image data [The Charter Executive Secretariat, 2006]. Similarly during the floods in Ethiopia in October 2006, the Radarsat-1 system provided data that was not compatible with the data delivery system, leading to delays [The Charter, 2008]. In addition, the system for downloading and delivering the information had many stations, service offices, and actors involved for a single call, leading to delays in providing this information to the project manager [The Charter Executive Secretariat, 2008]. Another more basic communications problem is the lack of an official language for the Charter framework, this can lead to difficulties in using the data and products.

3.6 Conclusion

For complex problems such as volcano monitoring and hazard tracking, getting useful information in a timely manner to the right people is a challenge. With new existing global initiatives such as GMES, IGOS or GEOSS, there is a trend towards developing integrated systems to provide global services to a wide variety of users. These initiatives have their foundations in large databases, networks, and technologies already available today. However, there are still obstacles to producing a truly efficient early-warning system for eruptions and volcanic hazard tracking. Some difficulties are technical, since predictions and hazard identification methods are not yet completely reliable and others are related to organization coordination. Improving communication and data sharing should definitely be addressed in order to achieve a global strategy in volcano monitoring and hazard tracking. The principal existing gap identified has been the lack of an integrated framework for all available data. The framework for a global cooperative, communicative, and participative system, the implementation of which would contribute to solving these issues is introduced in the next chapter.

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Chapter 4

VIDA Design Framework

The previous chapter identified gaps in the existing systems and networks used for early warning and hazard tracking of volcanic eruptions, such as GDACS, ReliefWeb, and GlobVolcano. For instance, GDACS (see section 3.3.1) lacks authoritative information, is initially only based on automatic alerts and is not capable of near-real-time warnings for volcanic events. The information on volcanoes is based on weekly reports and is shared via daily newsletters. Moreover, even though the scientific community is the main data provider, GDACS does not provide them with any valuable information. GlobVolcano (see section 3.3.4) uses only satellite data and provides it to the scientific community and public users. However, it does not integrate data from ground-based sensors with the space-based platforms.

To address these gaps, this chapter will describe the *framework* for a new system – VIDA – that will collect and provide uniform access to relevant Earth observation data, as well as information services.

This chapter begins with a brief summary of the high-level requirements for a VIDA system; the details are given in Appendix A. These requirements are based on research into end-user needs, as well as on the survey of technology and the gap analysis in Chapter 3. These requirements in turn form the basis for a description of a VIDA system. This chapter identifies several use cases for the system and provides four examples of interactions with a VIDA system. The requirements, system description, use cases, and examples form the design framework for a VIDA system, which is the main deliverable for the report.

4.1 High-Level System Requirements

The high-level requirements for a VIDA system are classified into four categories: end-user, early warning, hazard tracking, and core system requirements. The requirements for early warning and hazard tracking are defined independently, because they represent tasks that the system is supposed to carry out separately. This section will provide a brief overview of the system requirements. A detailed description can be found in Appendix A.

For the **end-user requirements**, the system shall be capable of providing information to at least five classes of end-users: the aviation community, private citizens, emergency crews, authorities, and the scientific community. The information provided to each end-user should allow them to plan, make decisions, and take appropriate actions. It should be noted that the end-user requirements have been written according to reference documents and not in coordination with any specific end-user. Consultation with end-users is a necessary next step before the implementation of the VIDA framework.

For the **early warning requirements**, a VIDA system shall be capable of collecting and analysing data about the precursors of volcanic activities such as thermal flux, gas emissions, hydrological changes, geomagnetic changes, seismic activity, and ground deformation.

For the **hazard tracking requirements**, a VIDA system shall be capable of accessing data that can be used to track hazards associated with volcanic activity including pyroclastic flows, lahars, lava flows, landslides, and ash plumes.

For the **core system requirements**, a VIDA system shall be capable of collecting, processing, storing, and delivering data coming from different sources. All the data provided will be transformed by the system into a standardized, documented, and open format. To allow the system to expand in the future, it will be flexible, extendable, and scalable.

4.2 Description of a VIDA System

The Earth observation community has access to a large amount of data, information, and methods for processing, but one of the main problems is that the end-user has to deal with many different data formats and different ways to collect and to process them.

The VIDA framework outlines a system that will provide uniform storage and easy access to Earth observation data and information. Such a system will provide uniform access to services that allow the end-user to process this data, as well as advanced computing facilities for creating useful information. The aim of the VIDA framework is not to develop new computing, storing, or data providing facilities, but to integrate existing Earth observation technologies, computing, and storage facilities in a uniform fashion.

Figure 4-1 presents a general overview of the architecture of a VIDA system. It is composed of three different layers. The first layer is the **interface layer** and contains the interface tools that are employed by end-users to interact with the system. These can be web-based tools on web-enabled devices (*e.g.* desktops or mobile phones), GIS-based tools, broadcast tools for early warning, or other specific tools to interface with governmental organizations.

The second layer is the **access layer**. It provides access to the services of the system and is responsible for creating the content that is sent to the users through the interface tools. This layer is composed of the **content provider**, the **service provider,** and the **notification server**. The content provider creates the content requested by the user via an interface tool. One of the important features of the system is that it is able to select different degrees of detail and complexity of information, depending on the user's needs and technical skills. It allows many different users to access the information in a straightforward manner. For instance, the crew of an aircraft only needs to know how ash plumes are moving in the airspace and how they can avoid them. Scientists, on the other hand, require data that has as much detail as possible to study volcanoes. The service provider implements the different functionalities provided by the system. This component coordinates access to the resources managed by the VIDA system. The notification server is responsible for providing notifications to users concerning specific set of events that are detected by the system.

The third layer is the **processing layer** and contains the external systems and architectures that provide uniform input that is integrated into the overall VIDA framework. This layer standardizes and unifies specific data formats and specific access procedures for other systems. It is composed of the **data provider**, the **knowledge provider**, the **storage provider**, and the **computing provider**. The data provider ensures uniform access to the external systems that provide raw data. For example, the external data providers can include organizations such as USGS and ESA. The knowledge provider uses various mechanisms to create information from the raw data. To do this, capabilities of other systems (*e.g.* the NASA Distributed Active Archive Centers and the ESA Earth Observation Service) will be used as well. These mechanisms can be specific tools, methods, or algorithms for data processing. The computing provider and storage provider supply computing and storing facilities to the system and end-users. Similar to the previous components, these providers unify access to the infrastructures.

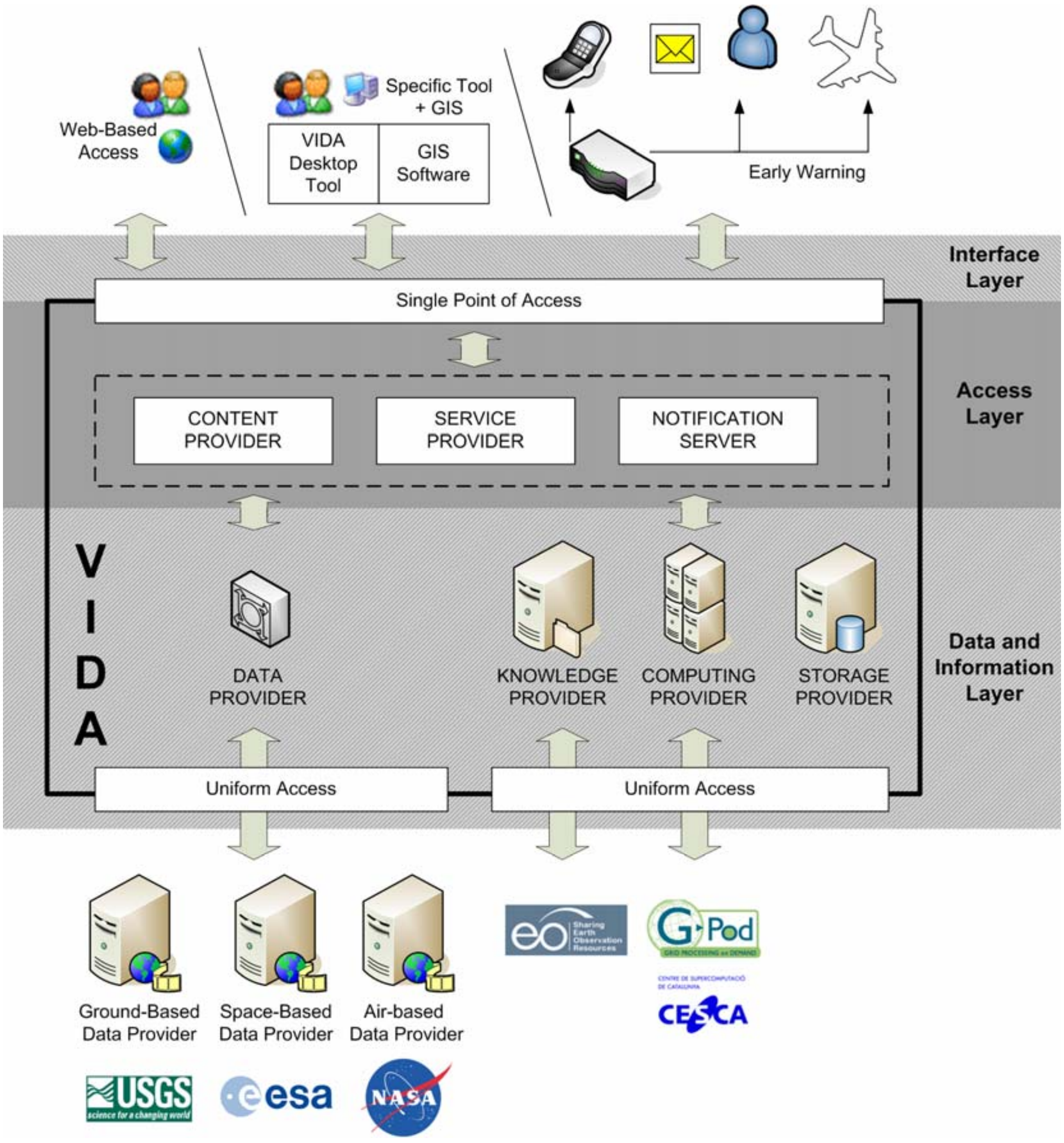

Figure 4-1: Architecture of a VIDA system

4.2.1 Enabling Technologies

The VIDA framework is intended to leverage enabling technologies that are becoming more important and widely used. They can be classified in three different areas: communication interfaces, computing and modeling services, and collaborative work tools.

Communication interfaces, part of the first layer in Figure 4-1, provide content to the user in a very dynamic and flexible way. They specify what information is delivered and how it is delivered. The VIDA framework can take advantage of technologies like RSS feeds, blogs [Avesani, 2005], Multimedia Messaging Services [Sevanto, 1999], and AJAX [Jeon, 2007] tools. Furthermore, the framework can use novel infrastructures and protocols to transmit the information. For example, the Satellite-Based Augmentation System (SBAS) [Bonnet, 2004] can be used to broadcast small packets of information concerning early warning and hazard tracking.

Existing computing and modeling services can be integrated into the third layer of the VIDA framework. These technologies create knowledge and provide computing power. Examples include ESA's computing and data provider Grid Processing on Demand (GPod) [ESA, 2008a], the computing infrastructure of the Distributed European Infrastructure for Supercomputing Applications (DEISA) project [Catlett, 2002], and the TERAGRID project

[Andrews, 2006]. The VIDA framework could also integrate other service providers such as the ESA Service Support Environment that provides generic service for process Earth Observation raw data.

Collaborative work tools promote interaction between VIDA users. These are Web 2.0 technologies that facilitate the dynamic flow of knowledge. The VIDA framework can incorporate wikis, portfolios [Siddiqi, 2000], twitters, and Basic Support for Cooperative Work (BSCW) [Appelt, 1996].

In order to integrate these technologies, the VIDA framework can use standard web technologies and data formats like eXtensible Markup Language (XML), XML Schemas, Resource Description Framework (RDF), and open standards such as the OpenGIS Geography Markup Language (GML) [OGC, 2008a].

Communication and computing technologies are continuously evolving. Incorporating these technologies into the VIDA framework means that such a system will also evolve, allowing more effective dissemination of early warning and hazard tracking information.

4.3 General Use of a VIDA System

The foregoing section described the architecture of a VIDA system. This section provides a discussion of how end-users interact with such a system, and the general use of the system, that is common to all users.

4.3.1 Common User Access

Users will be able to access a VIDA system through user-specific connections and will be able to manage their user profiles and the characteristics associated with their accounts. They will be able to manage files, including functions such as creating, moving, copying, and deleting files or directories. They will be able to request access to specific services, software tools, specific data from a particular provider, and resources such as computing services or storage capacity. They will be able to retrieve a list of services available to them, including technical description, available data quota, and instructions on how to use them. Depending on the user profile, they will be able to access different types of data and resources including the semantics of the data (such as a satellite thermal infrared image), the format of the data (such as an XML based format), and the sensor used to gather the data (such as MODIS).

4.3.2 Administration of VIDA

A VIDA system will provide a web-based application to manage the user accounts, including the ability to create or delete a user account, and to grant or deny specific user privileges. These features will allow managers to permit specific users to access specific services, data, and resources. Managers of the system will have access to the status of the different services provided by VIDA using a web-based interface. This will provide information about the status of the different computing, data, and knowledge providers.

4.3.3 Alarms and Hazard Warnings

A VIDA system will provide an interface that can automatically trigger alarms when volcanic activity is anticipated or volcanic hazards are detected. Authorized users will specify conditions that lead to an alarm being triggered for a given volcano, depending on its location. They will also be able to override the system to either cancel a false alarm or issue an alarm not triggered. The information provided with the alarm will depend on the type of user.

If a user identifies a potential hazard that has not been already identified by the system or by other users, they will have an interface via a web-based tool to introduce the hazard and request its integration into the system. The user will have to describe the identified hazard.

The system will provide the ability to include visual information about hazards. Some users will be authorized to review these entries and delete them if they are not valid.

4.3.4 Callbacks on specific monitoring information

The users will be able to subscribe/unsubscribe to different kinds of events that will be triggered when a volcanic event is impending. These callbacks could be done through Really Simple Syndication (RSS), Short Message Service (SMS), or email. The user will be able to specify the characteristics of the event (*e.g.* specify different levels of confidence, time of notification, and geographic locations concerned).

4.4 Use Cases for a VIDA System

A VIDA system will provide different levels of services and privileges depending on user groups. Table 4-1 shows a summary of these services available for each of the different user groups. Each of the users contained in the table is explained below.

4.4.1 Local Communities and Individual Users

The main goal of the functions provided to local communities and individual users is to reduce their risk to hazard exposure by providing updated information concerning volcanic eruptions. A VIDA system will allow access to a set of predefined forecasting information provided in near-real-time. Through a user-friendly web-based application, the user will have access to visual information of different hazards in the specified area including the evolution of each of the detected hazards over time. The information concerning the hazard will include generic information specifically composed for non-expert users.

Once an alarm is triggered, the users will be able to track the impact of a hazard on specified areas. For instance, a VIDA system will provide areas and locations at higher risk, possible changes on the topography, or possible routes of entry and evacuation. To provide this information, the system will use forecasting models to create knowledge about how a given hazard may behave. For example, it could estimate the flow of ash plumes using satellite images and wind information coming from weather forecast providers. Forecasts will be accompanied by a level of confidence measure.

4.4.2 Authorities

The main goal of the functions given to the authorities is to provide them with sufficient information for decision-making purposes. The term “authority” includes three levels of users: local governments, national governments, and international organizations. Personnel authorized to access the VIDA system will be chosen within each organization. The functionalities designed for different authorities will be characterized by different levels of details, depending on the area controlled by the specific entity. Authorities will interface with the system via a desktop web browser.

A VIDA system will provide mechanisms to apply forecasting models or other models to data from a suitable sensor to create useful information about how a given hazard may behave and how different areas may be affected. Models will be predefined within the system so that users only deal with the final information and avoid interfacing with complex simulation models. This function will also allow generating damage scenarios to get information such as: specific maps with the general outline of the affected area, estimate of the population, infrastructures likely to be affected, and general estimates of the damage. Two types of data will support this function: pre-event data for planning purposes and near-real-time data during the volcanic events for hazard tracking and response actions.

When an alarm is triggered, the user will be provided with detailed information about the identified hazard including who has triggered the alarm, if it is an early warning alarm, the level of confidence, and forecasting information (*e.g.* direction and velocity of ash plumes).

By default, the system will provide all the information available on hazardous events in progress. This will also include information related to human safety risks.

A VIDA system will allow authorities to introduce and publish information to the system concerning the different *in situ* data that they collect, mainly related to population density and infrastructure. This information can be introduced manually or using a specific tool.

Table 4-1: Services provided to the different user groups

	Local Communities / Individual Users	**Authorities**	**Emergency Crews**	**Aviation Community**	**Scientific and Educational Community**
Passive (only visualization)					
Access to Hazard Information	X	X	X	X	X
Access to Alarms	X	X	X	X	X
Access to Experts Information				X	X
Access to Experts Network					X
Access to Processing Capabilities					X
Active (those with inputting rights)					
Provide Hazard Warnings	X	X	X	X	X
Callbacks on specific monitoring information	X	X	X	X	X
Updating System Data		X	X	X	X
Editing Recommendations				X	X
Activating Alarms				X	X
Defining Research Groups					X

4.4.3 Emergency Crews

The main goal of the functions given to emergency crews is to enable them to acquire sufficient information to be able to respond effectively. Emergency crews include organizations such as fire departments, police, non-governmental organizations (NGOs), and hospital staff members. The functions will be accessible to the users by means of a web browser interface accessible via desktop browser or a mobile device. Utilizing the VIDA framework via mobile devices can enable emergency management to be more effective by providing an information link between the control center and the ground personnel.

A VIDA system will provide both forecast and monitoring information for identified volcanic hazards. The information will be provided based on the needs of the emergency crews. This can be done, using an interface like a desktop GIS tool or a simplified web-based GIS. The system will provide forecast information about the detected hazards to identify how a given hazard may behave and how the different areas may be affected. This tool will allow the user to perform such activities as estimating the vulnerability of the population, comparing knowledge of past volcanic episodes by examining several eruption scenarios in a potentially hazardous area, and to access hazard predictions.

When an alarm is triggered, the user will be provided with detailed information about the identified hazard: a representative image of the hazard detected, identification of the risk level of the affected areas, access to possible routes of entry and evacuation, topography of the terrain, seismic activity, direction of lahars and lava flows, gas emissions, ground deformation, and access to information related to ash clouds, hotspots, and landslides. Moreover, information about who has triggered the alarm, the level of confidence, forecasting information, and other details will also be provided. VIDA will allow emergency crews to introduce and publish new information to the system concerning the different *in situ* data that they can collect.

4.4.4 Aviation Community

The main goal of the functions provided to the aviation community is to give them sufficient information to avoid hazards, primarily ash plumes. These functions will provide monitoring and early warning. In this area there are two different users: the crew of the aircraft and the ground segment - *i.e.,* air traffic controllers (ATCs).

The aircraft crew will have access to early warning information concerning ash cloud hazards. This information can be provided by using beacon and satellite connections. Near-real-time satellite images of ash clouds crossing aircraft routes will be processed to provide the crew with information regarding cloud position, velocity, level of hazard intensity, *etc.* The system will also be able to provide weather forecasting information concerning the hazard. Users will have access to recommendations on how to interpret the data provided by the tool and confidence of the reliability of such information, depending upon whether the provided information is based on forecasting models or based on near-real-time data.

A VIDA system will provide an interface that will issue alarms when an ash plume that can affect the aircraft has been detected. This alarm will provide detailed information about the identified hazard: who has triggered the alarm, the level of confidence, forecasting information, and relevant information about the ash cloud. In the event that the crew identifies a potential ash plume hazard that has not been already identified by the system, they will be able to provide this information to other aircrafts and the ground segment. The system assumes that the aircraft already have a communication channel to exchange information with other aircraft and ATCs.

The ATC will have access to a set of specific tools and web-based tools that will provide several functions. Some of these functions are shared with the crew members, such as access to hazard information and alarms. In this scenario the ATC users will have a global view of the whole airspace, using GIS software and specific system tools. They will be able to select the areas about which they want to get information.

In case the ATC identifies a potential hazard that has not been already identified by the system, they will have a web interface to introduce the information related to the hazard and request its integration into the system. The system will allow users to introduce and publish information to the system concerning the different routes and other *in situ* information available to them. This information can be introduced manually, or may be provided automatically by aircraft sensors or images. The user will be able to provide recommendations to the crews of different aircrafts.

A VIDA system will provide an interface to automatically generate reports and information. The ATC, using, for example, a web-based interface, will be able to select which data has to be included in the report and which procedures have to be applied to the data.

4.4.5 Scientific and Educational Community

The main goal of the functions available to the scientific and educational communities is to provide them with all the data required to further their understanding of volcanoes and to facilitate communication with relevant authorities. These functions will be accessible to users that have expertise in the early warning and monitoring systems, who will have access to all content and extended information.

Whenever a hazardous event in a specific location is detected by the system, the scientific community in the area (*e.g.* local volcano observatory members) will be notified and all the available information about hazards will be automatically sent to them. Expert users will also receive notifications about new sensors and data sources.

To facilitate the coordination among the different researchers, the system will allow for the creation of research groups consisting of experts from different countries. In each group the users will have access to collaborative and communication tools to coordinate their work. The users will have a set of tools that will allow communication among scientific and educational users.

In addition, users will have a set of collaborative existing frameworks that facilitate the interaction between the different organizations belonging to the system (volcano observatories, space agencies, universities *etc*.). These frameworks will allow users to share data, knowledge, and procedures. Technologies that will be available to users are: Wikis, Portfolios [Siddiqi, 2000], Knowledge Map Tools (IHMC, Mind Maps, FreeMind, and Belvedere), Concurrent Version Systems (CVS), and BSCW Collaborative Platform [Appelt, 1996].

A VIDA system will provide scientific and educational users with specific interfaces to create data analysis experiments, and use computational and storage resources. It will enable them to define workflows of tasks and to specify when the output of one task is needed as an input for another task. The system will provide mechanisms that apply forecasting and other models to useful data. This will create knowledge about how a given volcanic event may develop. In this scenario, the user will have to specify which models and data should be used and will have to deal with the complexity of using such models. Therefore, this user should know how complex models behave, what data they require, as well as how to interpret their outputs. To access this function the user will have a specific VIDA tool. This tool will be available in a web-based interface.

Scientific and educational community users will be able to provide warning alarms after they analyze available data. The system will allow the researchers to introduce data and information into the system. They will be able to store raw data and processed information.

4.5 Interaction Examples

The preceding user case descriptions highlighted all interactions with a VIDA system. This section presents specific interaction examples that illustrate the utility of a VIDA system.

4.5.1 Interaction with the Charter

One of the goals of a VIDA system is to improve information flow between all the entities involved when a volcanic event happens, including the Charter. The flow diagram in Figure 4-2 shows a possible interaction between the Charter and the proposed VIDA system. The system can act both as a user of the Charter and as a knowledge provider. Once a volcanic event occurs, the Charter can be activated in two different ways: by an Authorized User through the VIDA system or by a VIDA administrator that will act as an Authorized User. When the Charter is activated, the VIDA system will provide information to the on-duty operator, the emergency on-call officer, and the program manager, and will deliver value added information directly to the local authorities and emergency crews on the ground.

A VIDA system can help authorities make the decision to activate the Charter in advance of volcanic events, since data will already be available to forecast the event. This way, the process of assigning a project manager and gathering data will already be taking place if and when the volcanic event occurs. By activating prior to a potential event, the Charter would add further value to the disaster management process, taking on a new role as an early warning mechanism.

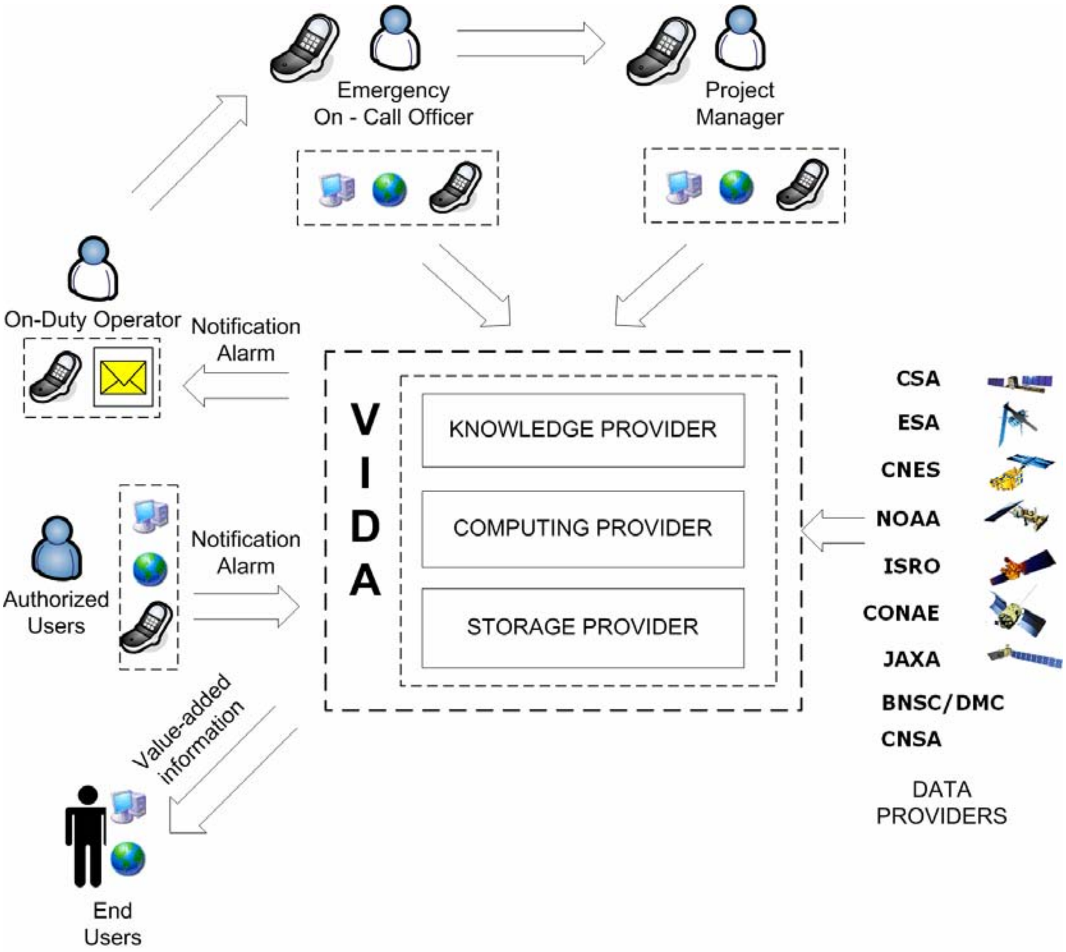

Figure 4-2: Interaction between the Charter and VIDA system

4.5.2 Local Community and Individual User example

A simple example of interaction between a VIDA system and a local community or individual user is described in Figure 4-3. The information, as described in section 4.4.1, is provided to the local user at two different levels: near-real-time information, and monitoring and forecast information.

The top of the diagram shows schematically the data acquisition, both from ground stations and from space assets. The provided data are converted by the VIDA system into an open source standard; this is value added data. At this point the knowledge provider can interact with the user at different levels.

The bottom left of the diagram shows the early warning alarm issued by the notification provider of the VIDA system. The early warning alarm can be communicated by SMS, e-mail, or RSS, as well as through a web portal. The information has a defined scope to allow local authorities to make an informed decision on how the local population should react given the impending volcanic event.

On the bottom right, the VIDA system knowledge provider interacts with the user by means of different technologies (web-based, specific tool interfaces, *etc.*) and supplies information useful to follow ongoing volcanic activity and anticipate possible hazards. The information accessible is in the form of images and maps of the area of interest, as well as information provided by other users of the system (*e.g.* the scientific community).

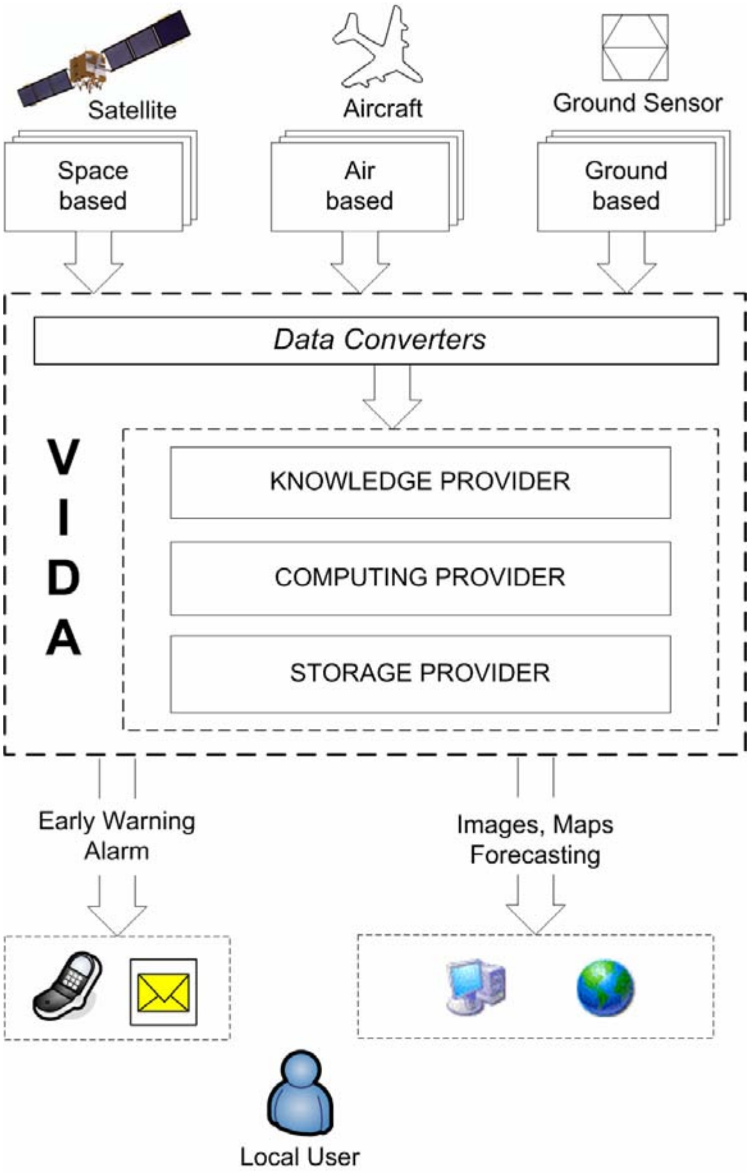

Figure 4-3: Interaction between VIDA and user from local community

4.5.3 Scientific and Educational User example

A VIDA system will provide the scientific and educational communities with a set of different services and tools, as shown in Figure 4-4. According to the defined framework, the scientific community will interact with the VIDA system in two different ways: as an end-user with access to all the services and tools available, and as a data provider, introducing into the system data that will be available to the whole scientific community. Different tools and services provide the user with different types of information: near-real-time information, monitoring information, and forecast information.

The VIDA system will include a notification service to provide the scientific community in areas surrounding volcanoes (*e.g.* volcano observatories) with an early warning alarm about a detected hazard by means of SMS technology, e-mail, or RSS services. All the available data related to this hazard will be automatically sent to them. They will also have access to a communication tool with the identification of the relevant authorities. The scientific community will have access to GIS and web-based tools to interact with other users sharing data and knowledge, to visualize the data, and to conduct interactive experiments with other scientists.

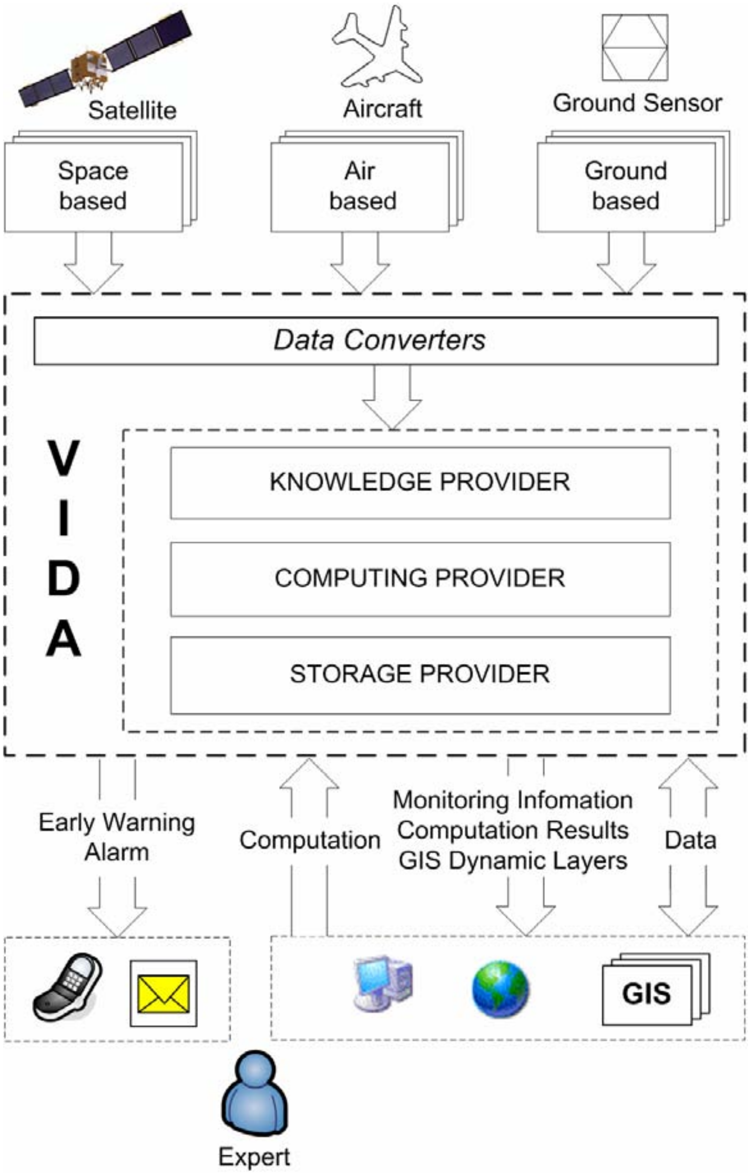

Figure 4-4: Interaction between VIDA and the scientific community

4.6 Summary

This chapter has presented the VIDA design framework - a starting point from which future system designers can develop a VIDA system capable of collecting, standardizing, and sharing information about volcanic activity with many different end-users. This design framework includes high-level system requirements, a system description, use cases, and specific user interaction examples.

The challenges to implementing a VIDA system are not just technical. The following chapters discuss the political and financial implications of a VIDA system.

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Chapter 5

Governance, Policy, and Law

For a system to be successful it must have a governance structure that oversees its functions and it must comply with relevant policies and laws. This chapter will discuss the governance, policy and law issues that should be considered in the design of a system that adheres to the VIDA framework.

5.1 Governance

This section discusses the governance structure for a VIDA system, including the consortium under which such a system could be set up. It will also discuss the potential integration of the system under the umbrella of a global Earth observation system, such as GEOSS described in Chapter 3, and the advantages of such an integration.

5.1.1 VIDA Governance

A volcano early warning and hazard tracking system adhering to the VIDA framework is best conducted in a global context. Similarly, the ultimate goal of GEOSS is to be a global and flexible network providing information to decision makers [GEO, 2008a]. Integration of a VIDA system into GEOSS would ease a VIDA system's ability to obtain data and would minimize redundancy of multiple similar systems. To integrate into the global GEOSS network, a VIDA system organization would need to be established.

A VIDA system would initially be established by a consortium that would be, at least initially, publicly funded. Public funding is justifiable given the humanitarian benefits. This consortium would be comprised of government agencies and satellite companies that specialize in earth observation, meteorology and hazard tracking. Initialization of a VIDA system would require the consortium to establish and administer the VIDA framework during a two year pilot project.

If a VIDA system prototype were to be established, governance would fall to a private entity called, for the purpose of this report, VIDA Co. VIDA Co. would be governed by a decision-making body called the Council. The Council could consist of volcanologists, stakeholder representatives and remote sensing experts. They would govern the functioning of the VIDA system by vetting end-user requirements, ensuring the requirements are being met and determining which volcanoes fall under the repository of the system. The Council would be responsible for periodically making system improvements and would conduct an annual meeting with end-users to discuss system operation, system updates, user needs, and potential improvements.

In addition, the Council would be tasked with writing end-user agreements. Several types of agreements will need to be written depending on the type of user or provider. These agreements would state the conditions of use for the system including a condition detailing that the data would be used only for monitoring and disaster risk management of volcanic disasters. Data providers and end-users would have to sign this agreement before becoming a cooperating entity or end-user of VIDA Co.

Under the Council, a management team would oversee and operate the daily workings of VIDA Co. The management team would administer the process of obtaining end-user requests and granting licenses. In addition, the management team would monitor the use of the data and restrict user access if inappropriate conduct were to become evident. An information technology and system engineering team would design the physical infrastructure and ensure that it functions correctly.

5.1.2 Integration within GEOSS

Once a recognized corporation, VIDA Co. could adopt the GEOSS framework and following a successful installation, could submit a proposal for integration in the overall GEOSS system structure. A summary of how this would be accomplished can be found in Figure 5-1. Once GEOSS is implemented, it will support nine Societal Benefit Areas (SBAs): disasters, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity [GEO, 2008a]. A VIDA system could potentially be integrated under the societal benefit area of disaster mitigation.

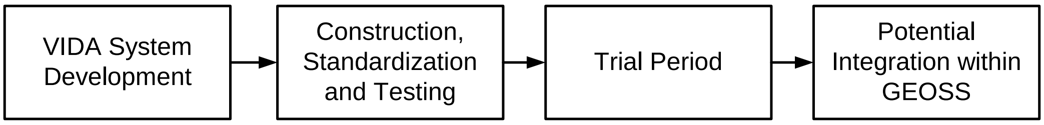

Figure 5-1: Flowchart illustrating potential integration of VIDA within GEOSS

If incorporated, VIDA Co. would also be able to maintain its own governance structure because GEOSS itself does not have a hierarchical structural system. GEOSS will consist of existing and future Earth observation systems that will be "supplementing but not supplanting their own mandates and governance arrangements" [GEO, 2005]. The overall GEOSS structure is being built by the Group on Earth Observations (GEO) on the basis of a ten year implementation plan, which runs from 2005 to 2015 [EPA, 2008]. GEO is open to all UN Member States, as well as the European Community. Currently, GEO has seventy-four Member States plus the European Commission, as well as forty-six participating organizations [GEO, 2007]. GEOSS can thus be described as an inter-institutional mechanism for ensuring the necessary level of coordination, strengthening and adding value to the existing Earth observation systems [GEO, 2005].

On the 26th of June, 2008 GEO issued its Call for Participation (CFP) in the GEOSS System Pilot Architecture [GEO, 2008c]. A VIDA system could potentially participate in a later phase of the GEOSS Pilot Architecture Project within the area of disaster management by registering VIDA Co. as a GEOSS component and implementing the GEOSS system interoperability arrangement.

By becoming a GEOSS component, the VIDA system would gain an international infrastructure in which crucial data from different sources would be interconnected and standardized to serve the public good. If embedded within GEOSS, VIDA Co. could process raw GEOSS data pertaining to volcanoes, integrate it into predictive models and forward data to stakeholders, policy makers, and public and private entities [GEO, 2007].

5.2 Data Policy Considerations

The key role of any governance body applying the VIDA framework to a system would be to consider data policy issues including data sharing restrictions and interoperability. This section will discuss how data can be collected and standardized - two necessary components for the implementation of a system adhering to the VIDA framework.

5.2.1 Data Collection

In addition to a functioning governance system, it is essential that a system applying the VIDA framework acquire enough data to serve its purpose. The success of implementing such a system would depend on the amount of free data accessible from data providers. This may be complicated since various nations have data policy and data sharing restrictions. Certain nations may prefer to maintain control over their data rather than share it due to national security, commercial confidentiality or financial considerations. Data providers would be more likely to overcome these complications if the effectiveness and societal benefits of a VIDA system were proven. The Council would be responsible for outreach to data providers to promote the rationale and benefits of the system.

A model that could be used to convince data providers to provide free data would be the *de facto* data policy, adopted by the Brazilian *Instituto Nacional de Pesquisas Espaciais* (INPE) in the late 1990's. The goal of this policy is to make all remote sensing data received by INPE available for free on the Internet, including the resulting maps, and software for image processing and GIS [Ferreira, 2008]. International recognition of the importance of providing free data has grown since this policy was enacted. In 2007, China and Brazil agreed to deliver China-Brazil Earth Resources Satellite (CBERS) data free of charge to African countries, in a partnership which included Italy, South Africa and Spain [Ferreira, 2008]. From April 2004 until January 2008, more than 350,000 CBERS images have been delivered to governmental and NGOs, educational institutions, and the private sector [Ferreira, 2008]. The USGS is currently working to provide end-users with increased electronic access to any Landsat data. As of July, 2008, newly acquired Landsat 7 data are being distributed by the USGS over the Internet free of charge [USGS, 2008a]. It is expected that by February 2009, any archived Landsat data will be processed automatically to a standard product recipe free of charge and staged for electronic retrieval [USGS, 2008a]. This movement toward sharing data can continue to expand facilitating the implementation of a framework, such as VIDA, that relies on free data.

5.2.2 Data Interoperability and Standards

Once the data has been provided, it must be standardized to meet the needs of end-users. Several international organizations are involved in the definition of standards for interoperability. These standards are necessary for system implementation, including those using the VIDA framework. Data standards for integration within GEOSS would also need to be considered.

Most of the international agreements on interoperability and standards for Earth observation were created as a result of the development of GEO, which, as mentioned, is constructing GEOSS [GEO, 2008a]. The main international organizations involved in the definition of standards for geospatial information are the Institute of Electrical and Electronics Engineers (IEEE), the International Standards Organization (ISO), the Open Geospatial Consortium (OGC), and the CEOS. These groups define standards for sharing geospatial data, services and systems across different platforms all over the world. During the implementation of a VIDA system it would be necessary to consider the ISO, OGC and CEOS standards to assure the proper operation and interoperability of this system.

The first standard that would need to be considered is that of the IEEE, specifically the committee in charge called the IEEE Committee on Earth Observation (ICEO) established in 2004. ICEO provides expertise in information technologies associated with Earth observation to support GEO's needs in the development of GEOSS [ICEO, 2008].

Another standard that would need to be followed is the ISO, which also collaborates with GEOSS through the definition of standards for data sharing and protocols in the geospatial community. Within the ISO, Technical Committee 211 is responsible for setting international standards on digital geographic information aiming to establish a set of standards for information concerning or related to Earth. These standards specify geographic information, methods, tools, and services for data management, acquiring, processing, analyzing, accessing, presenting, and transferring such data in digital and electronic form between different end-users, systems and locations [Liping, 2006].

Additionally, OGC standards would need to be considered. OGC works on standards definition for sharing geospatial data and services across different systems and platforms [OGC, 2008b].

The final organization involved in standardization activities to consider would be CEOS. For a VIDA system to integrate this organization's standard, it must participate in CEOS working groups. These working groups include the Working Group on Calibration and Validation (WGCV), the Working Group on Information Systems and Services (WGISS) and the Working Group on Education, Training and Capacity Building [CEOS, 2008].

The VIDA framework would also need to address specific standardization needs at the end-user level, including the aviation sector, emergency aid crews, political decision makers, scientific communities and private citizens. See Table 5-1 for a summary of the current existing or required standardizations for the different user groups.

Table 5-1: Standardization for end-users

End-User	Standard
Aviation Sector	The implementation of geospatial data is in its infancy. Agencies such as the US Federal Aviation Administration (FAA) are leading on-going standardization activities [NRC, 2004].
Emergency Aid Crews	Safety protocols and data standards need to be defined. This is an on-going activity at an international level.
Political Decision Makers	International standardization exists and as a result proprietary data formats and communication protocols are adopted at the local and national level.
Scientific Communities	Scientific community users utilize ISO rules to aid in the definition of the data formats, communication protocols, and interfaces.
Private Sector	Standard data formats and protocols exist since these end-users employ web-based technology.

The components and services of a VIDA system must be registered in the GEOSS Component Registry and the Service Registry to include the system within GEOSS. These registries will provide a formal listing and description of all the Earth observation systems, data sets, models, and other services and tools [GEO, 2008d]. Standards and protocols will interlink the various components and will facilitate the integration of data and information from various sources [GEO, 2008d]. Decision-makers, managers and other users of Earth observation data and information will have access to the components and services listed on the Registry, thus creating a GEOSS common infrastructure [GEO, 2008d].

5.3 Legal Implications

A variety of legal systems exist that would impact the functioning of a VIDA system, including international, national and private law. Issues involving licenses and liability would also prove crucial to the viability of the VIDA system.

5.3.1 Relevant International Law

While no specific treaty deals exclusively with remote sensing from space, the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (The Outer Space Treaty), declares the "freedom of use and exploration" of outer space [UNGA, 1967]. As a result, it can be argued that remote sensing satellites are free to collect data on any portion of the Earth from space. On January 22, 1987, the United Nations General Assembly (UNGA) adopted the UN Principles Relating to Remote Sensing of the Earth from Outer Space (UN Principles) in the form of a non-binding Resolution [UNGA, 1986]. Under these UN Principles, remote-sensing activities must be carried out for the benefit and interest of all countries and in accordance with international law [UNGA, 1986]. However, since the UN Principles are not a binding source of international law, enforceable regulation of remote sensing activities is carried out on a national level.

5.3.2 National Law

Although national laws regarding remote sensing vary widely from country to country, they must be considered in the development of a VIDA system. One issue that might prevent the VIDA framework from properly functioning is the so-called "shutter control". This is when a government bars remote sensing satellite operators from sensing certain areas or from disseminating acquired data and information derived from it. Shutter control could occur when a government chooses to shut down satellite operations for national security reasons. All existing national laws regarding remote sensing activities give national governments with remote sensing capabilities the right to carry out shutter control. For example, in the United States, the Land Remote Sensing Policy Act requires private space-based remote sensing systems to be licensed by the US Government [US Congress, 1992]. Presidential Decision Directive 23 requires these licensees to limit data collection and/or distribution by the system to the extent necessitated by the given situation during periods when national security or international obligations and/or foreign policies may be compromised [US Government, 1994]. Although shutter control is rarely practiced, the fact that countries have the capability to shut down satellite operations could prove problematic in the future, and therefore must be considered in the development of a VIDA system.

Moreover, attention should be paid to the delivery of sensitive remote sensing data to entities prohibited by national statutes. Restrictions in national remote sensing acts will inevitably influence data flow.

5.3.3 Private Law

Since the VIDA framework includes commercial providers, carries on commercial activities and works with copyrighted material, application of this framework to a system would involve private law. To make the procedure of gaining data required for a VIDA system functional, data protection must be addressed. Some national space laws (*e.g.* Law of Russian Federation on Space Activities), national data policies (*e.g.* Indian Remote Sensing Data Policy), and corporate data policies (*e.g.* SPOTImage general license, Eurimage licensing conditions, ESA ENVISAT Data Policy) refer to existing national and international copyright regimes as governing the protection of remote sensing data. According to copyright laws, some creative effort is needed in the production of a piece of work. However, remote sensing data does not qualify under this law [Guibault, 2002]. Furthermore, ideas, processes, methods of operation, *including data* are not protected by copyright laws [WIPO, 1996].

A VIDA system is intended to gain the participation of both commercial remote sensing companies and government data providers. However, data received from commercial remote sensing companies (*e.g.* GeoEye and DigitalGlobe) and government subsidized data (*e.g.* Landsat and ENVISAT) must be treated differently. The commercial remote sensing data are gained through commercial operations, while government data are subsidized. In addition, the principles of access to and often use of these two types of data are different. Further complicating this issue, within the category of government subsidized data, different states have distinct approaches in regulating access and use issues. For example, the US has state and federal open record laws [Dansby, 1991]. In addition, the US information policy at the federal level is based on the following principles: freedom of access to and re-use of information, no government copyright and information at the cost of reproduction and delivery [Weiss, 1997]. However, the majority of European Union (EU) Member States have systems that operate with closed access to commercially valuable government GIS records [Onsrud, 2004]. For instance, in the United Kingdom, the Ordnance Survey, as a Crown Corporation, is responsible for dissemination of topographic maps and has the right to establish prices for its products and services as the copyright holder [Ordnance Survey, 2008].

In the EU, remote sensing datasets have an extra layer of protection under the Database Directive on the legal protection of databases. According to this directive under article 7, the database-maker has the right to prohibit unauthorized extraction or re-utilization of the substantial parts of the database. Article 11 states that the protection is granted to only those databases created in Europe which results in denial of protection of databases made elsewhere.

Dissemination of information facilitates the exchange of knowledge, furthers awareness, benefits “downstream creators”, and ultimately fosters the generation of social welfare gains [Okediji, 2006]. This is exactly what the VIDA framework aims to accomplish in the sphere of early warning and hazard tracking of volcanic events. From a global perspective, if the goal of achieving welfare within society is to be pursued to its logical conclusion, there is a need to recognize a legitimate claim and interest in accessing data. Furthermore, access to information should be recognized as a right, by virtue of the public interest in it. Therefore, the relationship between VIDA and its data providers should be based on this ideal to freely access data needed to achieve its aims.

5.3.4 Licensing

In the development of a VIDA system, licensing schemes would have to be developed to enable the system to take on value-added activities regarding the licensed data, as well as to disseminate the processed information. Full and open access to available data resources would be a key principle for the VIDA framework. Such open access would ensure that value-added activities are properly conducted and the necessary information is delivered to those in need.

Licensing mechanisms represent private regulation of rights regarding access to data and information. It can include copyright, other intellectual property protection regimes and elements of trade secret or confidentiality laws. Content of the license depends on the source of data (private or public) and the category of use (research or commercial). Licensing conditions restricting access to a single application or a specific purpose are common in many projects.

Standard End-User Licensing Agreements (EULAs) set strict conditions of data access and use. For example, technological protection measures the use of digitized products that are otherwise available for end-users of hard copies. It normally includes the following: Intellectual Property Rights (IPRs) and reservation of ownership, specification of the type of the license granted, scope of use, terms and termination, limited warranties and disclaimers, exclusive remedies, limitations of liabilities, and infringement indemnities. The license is limited and non-exclusive, permitting only internal use of the data products and value-added products containing licensed imagery, developed by the end-user (*e.g.* SPOTImage license). The licensors generally control the distribution and dissemination of data.

During the development of a VIDA system, two types of licenses should be developed: one for the incoming data with data providers and the other for the outgoing information with system end-users.

5.3.5 Liability issues

Since a VIDA system will provide information services for the purpose of early warning and hazard tracking of volcanic eruptions, no liability for the damage that the use of information provided may cause will be attached. This is because the system will serve humanitarian purposes and the information within this use will be provided for free. To ensure that the information is produced with the highest level of care and accuracy, a Code of Conduct for VIDA system personnel, as well as strict specifications with regard to the indicators used to process the data should be introduced.

5.4 Conclusion

Governance, policy, and law issues are critical in the implementation of a framework such as VIDA and must be considered throughout the planning process. Once A VIDA system implemented, the governance body of VIDA will need to continue to monitor these issues as policies and laws evolve to ensure that the system continues to comply.

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Chapter 6

Business and Financial Aspects

While the previous chapter discussed the governance of a VIDA system, this chapter addresses the issue of financing. It begins by investigating the economic impact of volcanic events. It outlines the strengths, the weaknesses, and the costs of a system adhering to the VIDA framework and then identifies possible business opportunities, stakeholders, and risks. The system referred to in this section is a hypothetical system assuming that all high-level requirements of the VIDA framework are met. All monetary amounts are in US dollars unless otherwise specified.

6.1 Economic Impact

Depending on the location of the volcanic eruption and the intensity of the event, the financial impact can vary widely. A financial regional estimation impact for the 20th century was provided in Table 1-1. In the 1970s, the UN Economic Commission for Latin America and the Caribbean (ECLAC) developed a method for disaster evaluation. It has been strengthened and customized for different areas of the world and the World Bank has also conducted assessments using it [CRED, 2004]. It is now considered a global standard. The financial impact of an event contains several aspects such as damages to infrastructure (transportation, communication networks, power facilities, water), destruction of natural resources and agricultural lands, as well as the effects on industry, tourism, and trade.

The eruption of Mt. St. Helens was the most economically destructive volcanic eruption in the United States. At the request of the US Congress, the International Trade Commission estimated the cost at \$1.1 billion [Tilling, 1990] (representing more than \$2.8 billion in 2008 dollars). In Colombia, the eruption of Nevado del Ruiz cost the country an estimated \$1 billion − about 20% of the country's Gross National Product for the year 1985 [SDSU − Department of Geological Sciences, 2006].

The impact of a volcanic eruption on regional and national economies persists for several years after the event. The authors of the Socioeconomic Impacts of the Mt. Pinatubo Eruption study estimated that "damage to crops, infrastructure, and personal property totaled at least 10.1 billion pesos (\$374 million) in 1991, and an additional 1.9 billion pesos (\$69 million) in 1992." They also stated, "in addition, an estimated 454 million pesos (\$17 million) of business was foregone in 1991, as was an additional 37 million pesos (\$1.4 million) of business in 1992" [Mercado, 1999]. The financial benefits of monitoring Mt. Pinatubo are further outlined in section 6.7.

Collateral financial impact of volcanic eruptions also includes air travel. In the case of Mt. St. Helens, ash accumulation and poor visibility caused the closures of several airports in eastern Washington State and the cancellation of more than a thousand commercial flights [Tilling, 1990]. During the 1995-1996 eruptions of Mt. Reuapehu in New Zealand, the value of cancelled flights alone was \$2.4 million [GNS Science, n.d.].

In a 2002 report, the Japanese government estimated that a future Mt. Fuji eruption could cost up to $21 billion. While experts try to determine the likelihood of such an eruption, many volcanologists believe it is really a question of timeframe, not likelihood [Earth Island Institute, 2007].

6.2 Stakeholder Analysis

In this analysis, the major potential stakeholders, along with their interests, were identified. Table 6-1 summarizes this, and presents how a VIDA system can address those interests.

Civil aviation companies have an interest in protecting their aircraft and passengers from accidents and damage due to ash plumes. More rapid access to and distribution of data would help to mitigate the hazards. The academic community and the volcanology community would benefit greatly from a system that integrates data from ground-based and space-based sensors. A VIDA system would also allow easy and efficient data sharing, and ultimately provide access to a much wider base of information. Governments, particularly of countries with volcanoes, are also identified as stakeholders. They may be the primary source of funding, and their major interest is the protection of their citizens. They are also interested in economic development and industrial growth. Therefore, spin-off and spin-in potential would be important. Remote sensing data processing companies would be interested in business opportunities, while insurance companies would be interested in risk assessment and mitigation, as well as claims verification. Finally, the World Bank is identified as a stakeholder due to its mandate to assist during and after natural hazards. A process that increases efficiency of response would be of interest to them.

Table 6-1: A Summary of VIDA stakeholders

Stakeholders	Interests	How a VIDA system can meet these interests
Civil Aviation	Security of people, cost reduction of aircraft assets	Faster access to ash plume information
Space Agencies	Ownership of assets, data providers	Decreased processing time of data through automation
Geosciences Union, Academic Community, Volcano Observatories	Scientific knowledge	Data integration of a wide variety of sources
UN, Governments	Security of people, economic growth	Information to decision makers enabling them to reduce loss of life in the time of a disaster; spin-off potentials; licensing agreements to generate revenue
Remote sensing data processing companies	Business opportunities	Increases business opportunities for data distribution
Insurance Companies, World Bank	Cost estimation, claims verification	Contribution of dynamic data to risk assessment

6.3 SWOT Analysis

The **strengths** and **weaknesses** of a VIDA system were assessed by evaluating its ability to meet the needs of the stakeholders. This allowed for the identification of potential **opportunities** and **threats**. The full SWOT analysis can be found in Appendix B. The major strengths of the system are the rapid access to information, the data sharing capabilities, and the scalability of the system. The major weaknesses are cost, size, and complexity of the system. The most important opportunity was the potential for saving lives, however scientific, research, and business opportunities were also identified. The major threat to the success of the system was identified as lack of funding, or interrupted funding, as this would lead to gaps in data acquisition and impair the functionality of the system. Changing political regimes within countries around the world has been identified as the leading source of potential funding issues.

6.4 Risk Analysis

The SWOT analysis was followed by a risk analysis, which also identified the cost of a system, along with the related lack or interruption of funding, as the major risks. Scaling a VIDA system to the needs of the stakeholder can partially mitigate this risk. For example, a system utilizing only free satellite data, with limited geographic and near-real-time scope would be significantly less expensive than a global system with multiple data sources. Nevertheless, it is expected that initial development and start-up costs would be significant.

Access to data is another significant risk. A well-defined and rigorous security plan would need to be clearly established and implemented in order to give confidence to countries that shared data would only be used for acceptable purposes. Losing this credibility would have a large negative impact on the system.

False alarms are the final major risk identified in the analysis. If a VIDA system incorrectly activates an emergency response scenario, the cost and liability may be significant. Therefore, the final decision to activate any emergency response must be made by a human end-user. This would increase the lag time for an emergency response, but would be a necessary safeguard.

6.5 Cost Analysis

An accurate cost analysis of a system applying the VIDA framework is unrealistic without having a tailored system design. However, for cost estimation purposes, the system can be compared to Google Earth, Global Earthquake Model (GEM), and GEOSS. Google Earth provides maps and satellite images for regions all around the world, and is used by over 400 million people [McIntyre, 2008]. It is similar to VIDA in the sense that it must accept, store, and output various forms of satellite data. It utilizes very complex software that provides multiple features including the 3D rendering of buildings and swoop navigation. The approximate cost of running and maintaining Google Earth is upwards of $150 million annually [McIntyre, 2008]. However, the total amount of Google Earth users, both commercial and public, is significantly larger then the amount of users expected to be involved with a VIDA system.

GEOSS, as was explained in Chapters 3 and 5, is a system being built by GEO. Its goal is to develop a comprehensive, coordinated, and sustained Earth observation system in order to improve Earth monitoring, increase understanding of Earth processes, and elevate prediction capabilities of Earth's behavior. While funding for a program of this magnitude is substantial, a limited amount of cost will be allocated to the system itself. Most of the system's resources are being provided by either national and international mechanisms or voluntary contributions [GEO, 2005]. This system is a prime example of how international government cooperation is essential for global systems.

GEM aims to be a global, open-source model for seismic risk assessment. GEM will be integrating science and engineering into hazard, risk, and economic modules. In addition to assessing earthquake risk, the system will also raise awareness, promote mitigations and insurance use, and stimulate risk transfer. The projected start-up costs of this system are approximately $50 million over the next five years. Sources of this funding include both public and private institutions [GEM, 2008].

A VIDA system would be able to function similarly to systems like GEOSS and GEM. Funding for a VIDA system would be required from both the public and private sector, similar to GEOSS and GEM. The VIDA system is intended to be scalable to meet the needs and budget of the funding organization, therefore rough cost estimates are difficult. However, the estimated cost of a fully functional system with global coverage may be similar to that of the GEM. Additional costs must be assumed for obtaining near-real-time data from satellites and air-based resources, as well as costs associated with standardizing multiple-source data. With this in mind a start-up cost of $10 million to $15 million per year for the next five years has been estimated. This results in a total start up budget of $75 million. Once established the annual cost to operate and maintain the system will depend on the number of sites monitored as well as the number and cost of data sources.

6.6 Funding and Business Opportunities

It is expected that funding would come from one or more governments from developed nations that are willing to participate in an international collaborative project. It is also foreseeable that a private company such as an international insurance agency or tourism company could fund a VIDA system. However, the full humanitarian benefits as focused on in this report lend themselves better to a government-run system, and as such, are investigated here. The costs and benefits of private ownership should be the subject of future research.

The participating members would be responsible for the initial development phase and the maintenance of a VIDA system. They would also participate in the financing steps of collecting, processing, and sharing data and information for the different users identified in section 4.4. Once established, a VIDA system would likely have a source of funding and functionality within GEOSS. While the public would have free access to a limited amount of data, specialized companies that want to derive a product from the VIDA system could obtain a license to access and manipulate the greater database. Revenues will be generated from these license agreements and spin-off potentials.

Spin-off potentials exist in software development for many markets, including civil aviation, insurance, tourism, real estate sales and development, risk mitigation, and more. Specialized software companies would be able to develop better tools for forecasting and tracking other hazards, as well as generate natural hazard simulations. Insurance companies could be interested in having access to these and other products to evaluate the risk from volcanic activities. Software could also be developed to meet the specific needs of the civil aviation industry, tracking and predicting ash plumes and suggesting alternate flight paths. Tourism companies and real estate companies could also develop or change business strategies based on information derived from a VIDA system.

While a VIDA system is currently intended to address hazards from volcanoes, it is capable of being expanded to be beneficial in other situations. The system could include data to support other types of hazards, the transport sector, water resource monitoring and management, air quality monitoring, biodiversity conservation, public health, the development of energy sources, agriculture, and management and protection of terrestrial, coastal and marine ecosystems. All of these areas provide platforms for future revenue from licensing agreements and spin-offs.

Different humanitarian organizations could be interested in such a system to improve their operations management and their intervention efficiency during an emergency and during the reconstruction phase. Another area of opportunity involves the educational potential of a VIDA system. Organizations such as UN Educational, Scientific and Cultural Organization (UNESCO) could use such a system as a tool to promote and educate people about volcano hazards. It is intended that the system would provide programs and data to these types of organizations for free, since part of the mandate of VIDA is to improve hazard monitoring and response. Therefore, revenues would not be directly generated from these activities. However, promoting the capabilities of VIDA to a larger audience, and promoting a standardized system may assist in strengthening existing markets, and establishing future markets.

6.7 Mount Pinatubo Example

The eruption of Mount Pinatubo that occurred on June 15th 1991 is a good example of the benefits of monitoring volcanic activity. The USGS and PHILVOLCS observatories forecasted the eruption, allowing early evacuation that ultimately saved at least 5,000 lives. It further prevented property losses valued at more than $250 million [USGS, 2005]. Military equipment from the US bases in the area was moved to secure areas, which prevented between $200 and $275 million in damages. Similar actions undertaken by commercial airlines saved between $50 and $100 million in damage to aircrafts. Tracking of the ash clouds allowed for both military and commercial aircraft trajectory corrections. The total amount of money spent, including previous studies, putting in place an emergency plan and the actual evacuation operation, was evaluated to be $56 million. The monitoring and forecasting costs were significantly less than the money saved.

6.8 Results of Financial Analysis

It is likely that VIDA will not be a standalone system, but instead an integrated component of a larger program such as GEOSS, and require both public and private sources of funding. In addition to the obvious benefits this system will provide to humanity, it is conceivable to begin implementation of a VIDA system from a business and financial standpoint.

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Chapter 7

Potential Benefits of a VIDA System

Implementation of the VIDA framework will have substantial benefits for society as a whole. The motivation for developing a system for early warning of volcanic eruptions and tracking of their hazards is ultimately to save lives, but numerous educational benefits also exist. This chapter discusses some of the ways in which a VIDA system could support the international emergency management framework, and explores its educational potential.

7.1 Impact on International Organizations

Often the responsibility to support those affected by the hazards caused by volcanic eruption falls to international organizations. The work they do relies on the information they have about a given emergency situation. The needs of different international organizations vary widely; therefore the integrated system proposed by the VIDA framework could support them by providing different types of data in a timely manner. Previously, the Charter was given as an example of an international organization that could benefit from a VIDA system. This section will focus on the benefit of other organizations.

7.1.1 Aid Organizations

Organizations like the International Red Cross and Red Crescent Movement regularly mobilize to bring aid to regions affected by volcanic hazards, but they cannot do it alone. Aid organizations require detailed maps of an affected region, not only to determine where survivors might be located, but also to understand the evolving nature of the hazards resulting from the initial eruption. When Mount Karthala erupted in 2005, thousands of villagers were forced to leave their homes because the ash plume had contaminated their water supply [The Charter Executive Secretariat, 2008]. Images generated within a VIDA system could have shown aid workers how the ash plume was propagating, thereby allowing them to better organize the evacuation process.

The UN Platform for Space-Based Information for Disaster Management and Emergency Response (UN-SPIDER) has been envisioned as a web-based knowledge portal for emergency management. While the system is not yet operational, the VIDA framework would be of prime use to SPIDER, which would in turn help the aid organizations whose activities are critical to the disaster and relief management cycle.

7.2 Impact on Regional and National Emergency Management Agencies

As was described in Chapter 3, regional approaches to monitoring and responding to volcano hazards vary widely. Some countries have a stronger infrastructure for emergency management than others, but every agency could benefit from the implementation of the VIDA framework. Depending on the particular situation it is likely that the information needs will differ, but these differences can be accommodated if a centralized framework such as the one proposed herein is implemented.

The USGS Volcano Hazards Program provides detailed information on volcanic hazards in the US and its territories [USGS, 2008b]. The web-based interface is a great asset for those living within the US; however it could be improved by the existence of a VIDA system. Updates to the website could come more regularly, and the information that feeds the website would be much richer. Currently, the program relies on US monitoring capabilities [USGS, 2008b], and VIDA would greatly increase that existing knowledge base.

In contrast to the US, Chile does not have a volcano early warning system in place [Edronkin, 2008]. Whereas some countries would draw upon information from a VIDA structure to support their established systems, Chile could use it as the foundation for its national system. The South Andes Volcano Observatory would obviously be a key element to any early warning system the government chooses to establish, but the higher level of coordination and data processing provided by the VIDA framework could be its critical component.

In the Asia Pacific region, there are many organizations that would greatly benefit from the implementation of the VIDA framework. The Asian Disaster Reduction Center (ADRC), the Asian Disaster Reduction and Response Network (ADRRN), and the Pacific Disaster Center (PDC) focus on reducing the effects of natural hazards by increasing communication and availability of various information products. Because of their regional nature, these organizations can be limited in the amount or quality of data or information available to them, and access to services provided by a VIDA framework could increase their capacities. Apart from this, VIDA could help to greatly increase the efficiency of Sentinel Asia – a voluntary initiative to share disaster data in the region using web-based GIS tools – that currently is limited to using data from a Japanese Aerospace Exploration Agency (JAXA) satellite.

7.3 Education and Outreach

Research into education about volcanoes has shown that many resources exist all over the world, primarily on the Internet. Some websites, such as that of the USGS Volcano Hazards Program [USGS, 2008b] are very exhaustive in their information about volcanoes, while others like the ESA Kids Portal [ESA, 2008b] are very minimal. ESA does have the advantage of making their information available in as many as six languages on its websites [ESA, 2008b], but few other organizations even attempt this level of diversity. Despite the risks posed by eruptions, little has been done to standardize volcano education efforts. For this reason, attention should be given to improvement of the educational framework surrounding volcano hazard management.

7.3.1 Potential Educational Benefits of VIDA

Information gathering and sharing is the crucial benefit of a VIDA system. It would incorporate useful data and provide various information products that would contribute to a better knowledge of volcanoes and the hazards they can cause. The open and uniform standard framework is particularly helpful to the educational field: to acquire personal knowledge, to educate those active in relevant national entities, or to support international frameworks in their activities. Functions that the VIDA framework defines allow educators and students to obtain relevant information on a range of subjects, including basic volcano geology and the hazards of eruption events.

The UN Educational, Scientific, and Cultural Organization (UNESCO) is the UN specialized agency for education. In its Medium Term Strategy 2008-2013 document (the Strategy), UNESCO states that the mobilization of science knowledge and policy for sustainable development, and the contribution to disaster preparedness and mitigation constitute its strategic program objectives. Considering that "natural events, such as …volcanic eruptions …are increasingly resulting in disastrous consequences for humankind", UNESCO "will seek to harness knowledge and technology and promote education for building effective capacities to foster prevention and reduce vulnerability" [UNESCO, 2008]. The Strategy declares that education and information systems will lay the basis for interdisciplinary platforms to manage disaster risks [UNESCO, 2008]. Data sharing principles of VIDA would help to achieve these objectives, at least within the field of volcanology, early warning, and hazard tracking, as it would improve efficiency of information search and delivery, thereby contributing to disaster preparedness and mitigation.

7.3.2 Future Educational Efforts

While it is beyond the scope of this report, the authors feel that a VIDA system could prove to be a valuable educational tool, and further work should be done to leverage its educational possibilities. The mission of the UN International Strategy for Disaster Reduction (ISDR) is to create of disaster resilient communities throughout the world by promoting increased awareness [UN-ISDR, n.d.]. Their current world disaster reduction plan is targeted at educating children about the risks of natural hazards [UN-ISDR, 2007]; interfaces that the VIDA framework defines, would support this effort.

ISDR has targeted school children as the primary audience of their campaign and has developed various activities that bring disaster education into the regular curriculum [UN-ISDR, 2007]. If implemented, the VIDA framework could support this initiative by acting as an information resource. ISDR curricula could be developed on topics ranging from basic volcano geology and geophysics to the hazards of eruption events by making use of a VIDA system tools. It has often been shown that engaging students in specific activities can better support their learning [Ronan, 2001], and tools that will be available through a VIDA system foster this process. Furthermore, a VIDA system could provide information needed to increase general awareness of the volcanic hazards, which could improve actions in the event of an eruption.

It is likely that, if implemented, a VIDA system will be most beneficial as an educational tool in countries with a strong Internet infrastructure. For instance, it could complement a website operated by US FEMA that presents disaster information and educational games for the benefit of young children [FEMA, n.d.]. For the countries without such a system in place, VIDA's capability to meet the needs of different users could be used as a helpful framework. It should be noted that in developing parts of the world, schools are one of the few places to be equipped with an internet connection, so the internet-based educational framework discussed in this chapter would still be appropriate.

7.4 Summary

Implementation of the VIDA framework could increase the ability of both national and international organizations to obtain useful information that integrates space, airborne and terrestrial data, depending on their needs and the field of expertise. A VIDA system could become a useful educational tool. Information this system would generate and disseminate could support primary school hazard education, university level research, and professional training. Many governments and international organizations have made attempts at educating a large segment of their population about the hazards of volcanoes, and a VIDA system could facilitate and improve these projects.

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Chapter 8

Conclusion

Volcanoes are an extremely complicated natural phenomenon. Volcanic eruptions are the result of the interactions of many different processes, some of which the scientific community only now begins to fully understand [Sparks, 2003]. The methods used to characterize, and eventually predict behavior of a given volcano require a lot of data. This data can come in many different forms from an array of sources, sometimes with varying degrees of processing. In response to the need for a centralized, user-friendly repository of volcano monitoring data, the VIDA system framework has been defined. Within a VIDA system users from around the world will be allowed to access useful information from ground-, air-and space-based assets. The information products of a VIDA system will be of relevance not only to the scientific community, but to governmental agencies, airline industry, emergency relief agencies, and educators as well.

8.1 The VIDA Framework

VIDA is a framework for the design of a system capable of integrating data from global providers, standardizing that data, processing it into useful information, and disseminating both data and information to the end-users. They would obtain data and information through web-based, GIS tool-based, and network-based interfaces. By disseminating information in near-real-time, a VIDA system could provide advanced warnings to end-users, enabling them to avoid the hazards of volcanic activity. In the same way, such a system could allow end-users to track volcanic hazards and to mitigate their effects.

There exists a multitude of Earth observing satellites, volcano observatories, and *in situ* sensors that could provide important data, but the task of sifting through it to produce information and knowledge is a challenging one. According to the VIDA framework the outputs received by interested parties will be standardized not by a new hardware, but by integrating existing ones.

Many organizations have done important work to create a universal, user-friendly data access system. One challenge that almost all of these systems have struggled with is the formatting of data. If standard formats for specific data types (such as InSAR images) could be agreed upon, then emergency management agencies around the world would know what sort of information to expect when they call for help. The gap between data, and information and knowledge can sometimes be large, and a VIDA system could provide for an interface to help bridge it. By providing a repository of easily accessible data that is commonly understood, a VIDA system could become an invaluable tool for furthering knowledge about volcano phenomena.

8.2 The Threat of Ash Plumes

As was described in Chapter 3, ash plumes represent a real threat to aircraft. The region of air space surrounding Alaska is one of the most heavily traveled in the world, yet Alaska contains some of the world's most active volcanoes. Despite the substantial attention that has already been given to this matter, fundamental issues still cannot be solved in a timely manner. In the event of a volcanic eruption, how quickly can a commercial aircraft be notified of an ash plume and then be re-routed? Given a specific eruption event, what percentage of aircraft utilizing specific airspace will need to be grounded? Because of the environmental implications of ash plumes created by volcanoes, much study has been done and all that data would be accessible through the application of a VIDA system. The elegance of this system is in its ability to address the interests of a wide range of end-users, not just concerns of a limited technical audience. In the case of risks ash plumes pose for aircraft, a VIDA system might represent a way to reduce the time delay between volcanic eruption and aircraft notification, and could certainly help to provide deeper understanding of the behavior of ash plumes.

8.3 Additional Benefits

There are many examples of large data repositories throughout the world, and often the distinguishing feature of these repositories is the manner in which they are used. It has already been stated that information products generated by a VIDA system can play an important role in our understanding of the nature of volcanoes, which will in turn support better knowledge of the precursors to an eruption event. Of equal importance, however, is the potential for the data to be used beyond the volcanology community.

The data that will be accessible in this framework could help developing nations better understand how to manage land use near a volcano, or could be used to educate school children about basic geophysics. Many countries with volcanoes develop emergency action plans, but then let those plans fall out of date. Because a VIDA system would continually be updated by Earth observation data, countries could draw upon those products to update and improve their emergency response scenarios. In many ways, the data collected by a given satellite or observatory would increase in value due to their access to a VIDA system, because the audience with the ability to access that data would increase substantially.

The basic structure of the VIDA framework allows for it to be expanded and used to monitor and track other natural events such as: earthquakes, tsunamis, hurricanes, tornados, and forest fires. The integration of different ground-, air-, and space-based sensors can allow for a centralized warehouse for collected information. Tailored user interfaces can enable different experts to extract the information pertaining to their specialty. They would also be able to see how the data from their area of interest is dependent on other natural processes on Earth. This can allow for the creation of more robust algorithms in order to understand and create more accurate models of Earth dynamics.

8.4 Implementation Challenges

The development, analysis, and dissemination of volcano data products cannot occur without numerous organizations incurring costs. Many consortia that produce products similar to those a VIDA system would produce, (such as the Charter) do so on a ‘best-effort’ basis, and the member organizations are under no obligation to produce their products if it is not fiscally feasible. A major risk to successful implementation of the VIDA framework is finding a continuous and reliable funding source. The system defined by the VIDA framework would not be sustainable if, after an initial investment period, funding was then lost, and those relying on its products were left without assistance.

Another substantial implementation challenge is that of governance. The framework defined in this report could bring substantial benefits to many organizations throughout the world. Also, proper data formatting must be considered a high priority in order to meet the users’ need for timely information. A consortium of interested government agencies and remote sensing organizations has successfully governed similar systems, and that same model could be applied to this framework.

Provided that funding can be secured and governance of the system can be settled upon, the next major challenges will be collection and standardization of data and dissemination of the information products. Standardization will require particular attention, because the goal set out by the VIDA framework is to provide users with easily accessible and useful information. Many international organizations have taken on the challenge of developing international standards, and a VIDA system could closely follow the lead of these groups. Proper data formatting must be considered a high priority in order to meet the users' need for timely information

The VIDA framework is intended to leverage enabling technologies that are becoming more widely used. They can be classified in three different areas: communication interfaces, computing and modeling services, and collaborative work tools. A VIDA system can use novel infrastructures and protocols to transmit information such as RSS feeds, blogs, and MMS. Integrating computing and data providers such as ESA's GPOD, DEISA, and TERAGRID projects serve to strengthen the system. The utilization of collaborative work tools, such as wikis, portfolios, and twitter, will facilitate the dynamic flow of knowledge. Communication and computing technologies are continuously evolving. Incorporating these technologies into the VIDA framework means that such a system will also evolve, allowing more effective dissemination of early warning and hazard tracking information.

8.5 Future Work

As has been stated, VIDA is only a framework. Substantial work must be done in order for this concept to move from paper to reality, but the work is feasible. Implementation of a framework like VIDA requires coordinated efforts between data providers, data processing organizations, the companies that store produced information products, and finally, the companies that distribute them. Interested parties must be educated about the VIDA system framework as a whole, and work must be done to encourage interaction between these groups.

User requirements have been proposed in this report, but there was not enough time to have those requirements vetted by the interested parties. The system requirements, as they have been defined, must be verified by end-user in order to move the VIDA framework into the design phase. There have been many instances in the history of global initiatives that did incorporate the needs of end-users properly; the VIDA framework is intended to meet the needs of its potential end-users.

A chief concern of many organizations within the UN is to educate populations around the world who are at risk of being affected by natural phenomena such as volcanoes. Numerous tools have been developed to support these educational goals, and a VIDA system could be one of them. The VIDA framework, as defined, provides a clearinghouse of data from a wide range of sources, and information produced should be distributed as widely as possible. Additional work should be done to develop a web-portal or some other form of mass data distribution by which larger communities can benefit from the products.

The novelty of the VIDA framework is its unification of already existing technologies and its ability to expand to include other natural phenomena. Such a system would contribute to the process of transforming the immense amount of data already being gathered into knowledge that can be used by decision makers to save lives. It is hoped that the VIDA framework will prevent natural events, such as volcano eruptions, from becoming disasters.

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Appendix A

High-Level System Requirements

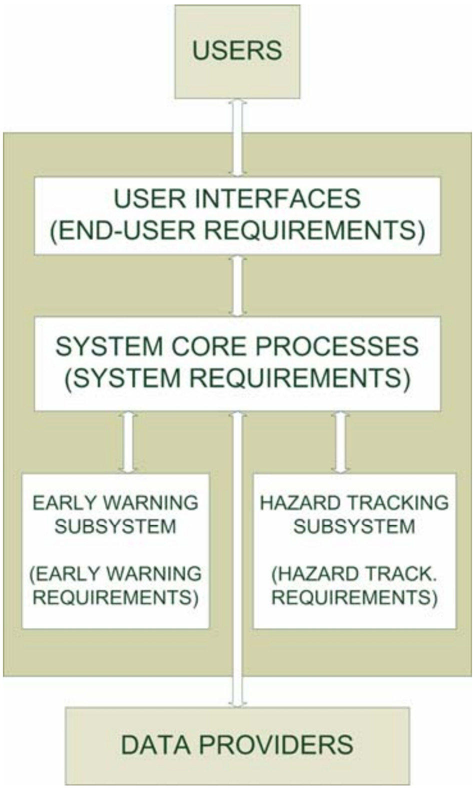

Figure A-1: System requirements breakdown

In light of the gaps identified in Chapter 3, this appendix strives to outline the requirements for a VIDA system. These requirements will be classified into four categories: end-user, early warning, hazard tracking, and general system requirements (core processes). A suggested system outline can be seen in Figure A-1, where these requirements groups are illustrated.

The system core processes block can be considered the brain of the system It shall be capable of collecting, processing, and delivering data from different sources to satisfy end-user requirements. The data providers block represents all data sources, such as space agencies, volcano observatories, and research groups. This is the main input to the system in terms of data, and bidirectional communication between the system core processes and data providers is needed to guarantee information flow. Functional requirements represent different tasks that the system shall be able to carry out, so it is necessary to distinguish between early warning subsystem requirements and hazard tracking subsystem requirements. Finally, the user-interfaces block represents different communication technologies needed to deliver information to different end-users. Note that the end-user requirements have been written according to reference documents and not in coordination with any specific end-user. As was noted in Chapter 1, user consultation is a necessary next step before the implementation of a VIDA system.

Requirements relating to the end-user are prefaced with a 'U'; requirements relating to early warning are prefaced with an 'E'; requirements relating to hazard tracking are prefaced with an 'H'; requirements relating to the general system requirements are prefaced with an 'S'. Additional comments and clarifications are italicized.

End-User Requirements

U. The system shall provide information to at least five classes of end-users:

Aviation User Requirements

U.1. The system shall promptly notify air traffic control centers of the magnitude of potential and current ash plumes.

- U.1.1. 'Promptness' shall be considered as less than five minutes of volcanic activity [ESRIN, 2008; Hufford, 2000].
- U.1.2. 'Magnitude' shall include location and height of the ash plume, particulate density, and composition (*e.g.* mixed ash and ice, mixed ash, and liquid water aerosols) of the ash plume, visibility through the ash plume (horizontal and vertical boundaries), the direction and velocity of ash plume regions, and the temperatures inside the ash plume [ESRIN, 2008].
- U.1.3. 'Potential' shall include event probability forecasts of ash plumes, direction, and velocity forecasts of ash plumes.
- U.1.4. 'Current' shall include tracking and monitoring of ash plumes with a quality figure of merit of the tracking and monitoring accuracy.
- U.1.5. Notifications shall be directed through existing national assets in the affected areas, including VAACs and national weather agencies, unless unavailable.

  These are analogous to weather reports/forecasts received by air traffic control centers and airlines.

Private Citizen Requirements

U.2. The system shall provide information about volcanic activity to private citizens through a web-based platform that is updated as the information becomes available, at least every 12 hours, with a goal of hourly updates. [Davey, 2003]

- U.2.1. The system shall provide the location of volcanic activity.
- U.2.2. The system shall provide a description of the intensity and types of volcanic activity.
- U.2.3. The system shall provide a safety risk estimate based on the nature of the hazard, consistent with current international protocols (*e.g.* used by USGS, ICAO, INGV, PHIVOLCS, VAACs).

  This should be on a scale, such as from one – negligible or minimal possibility of physical danger, to ten – high possibility of hospitalization and/or death.
- U.2.4. The system shall provide safety risk estimates as a gradient function of the radius from the volcanic activity based on the nature of the hazard(s) and consistent with international protocols.

  For example, zero to 50m has a safety risk estimate of eight, while >25 km has a safety risk estimate of one.
- U.2.5. The system shall make available information about the possible hazards associated with the volcanic activity in question.

  Hazards include but are not limited to landslides, earthquakes, dangerous aerosols (e.g. SO_2, sulfuric acid), lava flows, pyroclastic clouds, mobility restrictions (unable to leave/get to the area via plane, train, car), lahars and volcanic ash.

Emergency Crew Requirements

U.3. The system shall provide information about volcanic activity to emergency crews via mobile platforms (radio, portable satellite phones) or web-based platforms that do not solely rely on ground infrastructures [European Commission, 2007].

U.3.1. The system shall meet all requirements under U.2.

U.3.2. The system shall provide the location of the population and areas in greatest risk that require immediate rescue/evacuation to emergency crews via mobile/web-based devices, updated by the minute.

U.3.3. The system shall make available maps of possible routes of entry and evacuation via mobile/web-based devices, updated by the minute.

U.3.4. The system shall make available topographic maps and changes.

U.3.5. The system shall make available up-to-date information on infrastructure.

Infrastructure includes, but is not limited to roads, bridges, railways, air and sea ports, medical facilities, and water and electricity plants.

U.3.6. The system shall provide information regarding potential and current locations of humanitarian assistance operations.

U.3.7. The system shall make available:

U.3.7.1. Disaster scenarios based on simulated events and on estimations of the population vulnerability.

U.3.7.2. Knowledge of past volcanic episodes, potentially hazardous areas, different types of eruptions, and hazards, as presented previously.

U.3.8. The system shall provide a multi-dimension map to emergency crews via mobile/web-based devices containing, but not limited to:

U.3.8.1. Safety risk estimates as a function of area/location, hazard warnings and description as a function of area/location, prioritization of areas that need rescue/evacuation, areas that should be avoided or are too dangerous for rescue, types of hazards in the area in question.

U.3.8.2. Topography and its influence on prospective development of hazards influenced by topography (*e.g.* lava flow routing, low altitude airborne ash routing around/over significant terrain).

U.3.8.3. Possible entry/evacuation routes.

U.3.9. The system shall make known potential volcanic activities to emergency crews so that they are prepared (in terms of resources and man-power) for a disaster scenario.

Authority Requirements

U.4. The system shall provide information regarding volcanic activity to local, national, and international authorities to aid in disaster risk management and response.

U.4.1. The system shall make available requirements under U.3 as needed.

U.4.2. The system shall provide updated and detailed maps including security zones for the population (*e.g.* refuge locations).

U.4.3. The system shall provide simulated damage scenarios with probabilities of occurrences to identify the current weaknesses in the response mechanisms.

U.4.4. The system shall provide risk and vulnerability maps.

U.4.5. The system shall address the risk of volcano-triggered tsunamis.

U.4.5.1. The system shall identify locations at risk of volcano-triggered tsunamis.

U.4.5.2. The system shall be capable of issuing early warning information about volcanic eruption to tsunami monitoring stations.

U.4.6. The system shall be able to allow information exchange and sharing between the different international actors involved in disaster risk management and emergency management (local governments, the UN and its agencies, NGOs such as the International Red Cross and Red Crescent Movement) [IFRC, 2007].

System development and design activities will include active solicitation of local requirements from potential end-users, with special attention to volcanic hazards, notification formats, and notification requirements.

Scientific Community Requirements

U.4.7. The system shall make available volcano-related raw data and processed information to academic and scientific communities for research, system analysis and model validation.

U.4.8. The system should enhance mutual awareness between the space agencies and the volcano observation community [Salichon, 2007].

U.4.9. The system shall facilitate the task of attaining relevant imagery in the event of a major episode of volcanic activity.

U.4.10. The system shall be able to accept data streams from multiple satellites and other platforms to:

- U.4.10.1. Provide finer temporal resolution.
- U.4.10.2. Reduce obscuration by clouds and moisture [Tralli, 2005].
- U.4.10.3. Increase observational capability of satellites at night [European Commission, 2007].

U.4.11. The system shall provide access to both raw data and processed information.

U.4.12. The system shall provide documented and open data access interfaces.

Early-Warning Functional Requirements

E. The system shall have access to data that can be used to forecast volcanic eruptions shortly before they occur and promote the early warning of individuals at risk from volcanic hazards. The system shall have access to devices confirming the occurrence of an eruption, or its imminent onset.

E.1. The system shall have access to data on the various precursors of volcanic eruptions.

E.2. The system shall have access to data on associated changes in thermal flux (positive or negative) from potential eruption sites (*e.g.* summit and flank craters, fracture networks, fumarolic systems, volcanic lakes, groundwater temperature and level).

E.3. The system shall have access to data on gas emissions.

E.3.1. The system shall have access to data regarding "sulfur dioxide, water vapor, and CO_2 variations" [Bobroski, 2007; ESRIN, 2008; Julian, 1998].

Variations in SO_2, water vapor, and CO_2 concentration have been found to be predictive indicators for impending volcanic activity.

E.4. The system shall have access to data regarding vegetation changes [Julien, 2006].

E.4.1. The system shall have access to data on "surrounding crop and vegetation health" [Houlié, 2006].

Pre-eruptive volcanic activity can alter water source availability, cause toxic gas emissions, acid rain from SO_2, soil acidity, etc. All of this can have measurable effects on vegetation.

E.5. The system shall have access to data regarding hydrological changes [Barclay, 2006].

E.5.1. The system shall have access to data on "pH readings, ice and water volume, humidity, and temperature of lakes or rivers surrounding volcanoes" [Barclay, 2006; Rowe, 1992].

Hydrological changes can be associated with volcanic precursors such as subterranean thermal and gas emissions that can influence pH readings of surrounding bodies of water.

E.6. The system shall have access to data regarding underground magma flows.

E.6.1. The system shall have access to data regarding the presence and/or flow of magma (sensors would include geomagnetic, geo-electric, and gravimetric measuring devices) [Johnston, 1997; Williams-Jones , 2002; Currenti, 2007; Ueda, 2005; Rymer, 2000].

E.7. The system shall have access to data regarding geomagnetic changes [Johnston, 1997].

E.7.1. The system shall have access to geomagnetic measurements with a precision of 0.1 nT within +/- 15 nT of background range [Lagios, 2006].

E.8. The system shall have access to data regarding geo-electric changes.

E.8.1. The system shall have access to geo-electric measurements with a precision of 0.1 Ω between 0.1 Ω and 10000 Ω [Bryant, 2005; Elming, 1997].

E.9. The system shall have access to data regarding gravitational changes.

E.9.1. The system shall have access to gravimetric measurements with a precision of 0.3 gu between -300 and 500 gu [Bryant, 2005; Elming, 1997].

Tectonic plate shifts and changes to magma reservoirs can affect geomagnetic, geoelectric, and gravitational measurements that are informative in volcanic activity forecasting.

E.10. The system shall have access to data regarding ground deformation.

E.10.1. The system shall be capable of continuously monitoring ground deformations by processing data from GPS ground receivers in fixed locations (*e.g.* network of 12 or more GPS receivers in the neighboring area of the volcanoes) [Fernandez, 2005; Trota, 2006].

E.10.2. The system shall be able to provide at least centimeter accuracy of the vertical component by means of improved algorithms and techniques for GPS positioning. [Currenti, 2007; Trassatti, 2008].

E.10.3. The system shall have access to ground deformation data (from tiltmeters, extensometers, theodolites) and shall be capable of combining its data with GPS data [Fernandez, 2005; Rymer, 2000; Ueda, 2005].

E.10.4. The system shall be able to integrate geodetic observations from GPS and InSAR (where available) in order to compute high resolution DEMs [Vassilopoulou, 2002; Pavez, 2006; Tralli, 2005].

GPS and InSAR allow accurate tracking of ground deformation and elevation changes due to subterranean volcanic activity.

E.10.5. The system shall be extendable so as to incorporate data from future satellite-based sensors.

Having the ability to integrate data from many data-gathering sources including future satellite-based sensors will aid in the forecasting capabilities of the system.

E.11. The system shall have access to data regarding seismic activity [Aki, 2004].

E.11.1. The system shall have access to seismic data related to volcanic tremors (*e.g.* sustained seismic signals) during both quiescent and eruptive stages.

E.11.2. The system shall be able to conduct spectral analysis of seismic data to discard other sources and path/site effects.

E.11.3. The system shall be able to identify dramatic amplitude increases in seismic data.

E.11.4. The system shall have access to acoustic signal data [Helffrich, 2006; Seyfried, 1999].

Seismic activity data is important in the understanding of the subterranean arrangement of the volcanic activity progression.

Hazard Tracking Functional Requirements

H. The system shall have access to data that can be used to track hazards associated with volcanic activity.

H.1. The system shall have access to data indicating occurrences of pyroclastic flows.

H.1.1. The system shall have access to data pertaining to lava domes, including height, temperature, location, and volume [USGS, 1999a].

With the correct data, the system will be able to identify growing lava domes that might collapse and induce a pyroclastic flow.

H.1.2. The system shall have access to data that supports the prediction of volcanic ash fountain collapse [USGS, 1999a].

H.1.3. The system shall support pyroclastic flow prediction.

Data about previous pyroclastic flow deposits and up-to-date elevation maps of volcanic sites will help in predicting lava flow.

H.2. The system shall aid in the tracking of lahars.

H.2.1. The system shall have access to data that can indicate the formation of a lahar and its flow velocity [Lockhart, 2003; Lavigne, 2000].

H.2.1.1. The system shall have access to the data from trip wires to indicate lahar formation. [Lockhart, 2003]

H.2.1.2. The system shall have access to data from different acoustic flow monitor sensors at different locations around volcanic sites to measure the lahar flow velocity [Lavigne, 2000].

H.2.2. The system shall have access to data including satellite and airborne images that indicates the direction of lahars.

H.2.3. The system shall have access to data that indicates the status of crater-lake dams on volcanoes.

The breakout region of the dam would help in forecasting the direction of the lahar flow.

H.2.4. The system shall incorporate rainfall forecasting. [Lavigne, 2000].

Rainfall is also a major trigger factor for lahars. Rain forecast information would be helpful in assessing the probability of lahar formation if an eruption occurs and also assess the magnitude of the lahar.

H.2.5. The system shall have access to data that indicates ash cloud position, velocity, density, SO_2 concentration, and temperature [Watson, 2004; Seftor, 1997].

H.2.5.1. The system shall have access to data from satellite-based systems such as AVHRR channels and systems based on split-window technique [Watson, 2004].

H.2.5.2. For SO_2 detection, the system shall have access to data from satellite based 340 nm and 380 nm channels (*e.g.* OMI) [Seftor, 1997].

H.2.5.3. The system shall have access to data available from *in situ* high altitude platforms and unmanned aerial vehicle (UAV) [Pieri, 2003].

H.2.6. The system shall predict ash plume location and its direction [Searcy, 1998; Univ. Of Alaska Fairbanks, 2008].

H.2.6.1. The system shall use 3D dispersion models based on satellite and ground sensors to predict ash plume location and direction. [Searcy, 1998].

H.3. The system shall have access to data indicating hot features, including lava flow, lava tubes, hotspots, fumaroles, and summit craters.

H.3.1. The system shall have access to data from previous lava flows and up to date elevation maps of the volcano site [Tralli, 2005].

The data from previous lava flows and elevation maps would be helpful in predicting lava flow route.

H.4. The system shall have access to data indicating landslides and debris flows, including snowmelt-driven flows [Temesgen, 2001].

H.4.1. The system shall allow future expansion to include landslide models and monitoring data.

H.4.2. The system shall have access to data from satellite images that indicate land deformation, which could be a precursor to landslides.

Core System Requirements

S. To satisfy end-user requirements for volcano monitoring, early warning, and hazard tracking activities, the system will be capable of collecting, processing, and delivering data from different sources. To achieve this, requirements are described in the following order: 'Data Acquisition', 'Data Storage', 'Data Processing', 'Data Delivery & System Interface', and 'System Extendibility & Scalability'.

The provided data will be transformed into a standardized, documented, and open format by the system regardless of its origin and provider. The provided data will be archived within the system. Pre-existing external databases will be enriched by feeding them the processed information. To let end-users to interact with the system correctly, easily, and efficiently, end-users will be provided with guidelines, procedures, and help files.

Data Acquisition

S.1. The system shall translate provided data into a standardized, documented, and open format, regardless of its origin and provider.

This will help to unify procedures for data processing, data storage, and data dissemination throughout the system and its subsystems.

Storage

S.2. The system shall be capable of archiving provided raw data.

The raw data, obtained from data providers, will be archived within the system for further processing.

S.3. The system shall be capable of storing converted data for further retrieval by subsystems.

S.3.1. The raw data shall be converted to an XML-based format and saved within the system.

S.4. Processed information shall be used to augment pre-existing external databases (*e.g.* GIS).

Doing this will allow external GIS databases to remain up-to-date.

Processing

S.5. The system shall possess a 'Monitoring Mode', during which data is received from providers and processed.

In this mode, the system will receive data from data providers and process it to analyze volcanic activities.

S.6. The system shall change state from 'Monitoring Mode' to 'Early Warning Mode'. The triggers and thresholds for this state change will be specific for each country and volcano, which will be determined by the end-user.

S.6.1. The system shall be capable of establishing baseline information and identifying quantifiable, statistically meaningful deviations from the baseline in order to start the early warning processes.

S.6.2. The system shall establish threshold values for specific events, precursors, and hazards from the information stored and processed, to identify input deviations and initiate early warning processes.

S.7. The system shall change state from 'Early Warning Mode' to 'Hazard Tracking Mode'. The triggers and thresholds for this state change will be specific for each country and volcano, which will be determined by the end-user.

S.7.1. The system shall be capable of establishing baseline information and identifying quantifiable statistically meaningful deviations from the baseline in order to start the hazard tracking processes.

S.7.2. The system shall identify the deviations in the data input that indicate precursors (seismic activity, gas emissions, *etc.*), events (eruptions), and hazards connected with the event (lahars, landslides, tsunami, storms, *etc.*). The system shall be able to find indicators or critical data to identify collateral hazards.

S.8. When deviations in the data streams with respect to baselines become more frequent (indicating volcanic activity), the system shall redistribute resources automatically in order to collect more raw data from the data providers and meet the demand for more information from the end-users.

The system shall be capable of adapting its resources to handle the increasing amount of data produced during an event, by increasing incoming, internal and outgoing data flows, and processing capacities.

S.9. The system shall assure data reliability and integrity.

S.9.1. The system shall have an embedded procedure that is able to assure integrity and reliability of the input data.

S.10. The system shall provide a means of minimizing the false alarm rate.

S.10.1. When the system identifies a quantifiable statistically meaningful deviation in one data stream with respect to the baseline, it shall be crosschecked against data coming from different data providers.

S.10.2. The system shall use human intervention to achieve an acceptable false alarm rate in the absence of reliable algorithms.

To reduce risk of false positive alarms and increase probability of event detection, the system will use human oversight monitoring and intervention when necessary.

Delivery / Interface

S.11. System will provide guidelines, procedures, and help files to let end-users interact with the system correctly, easily, and efficiently.

S.12. The system shall provide clear information about itself and the features available to the end-user.

S.13. The information shall be made accessible through at least three different interfaces: internet, a specific analytical tool, and a network for early warning.

S.13.1. The network for early warning shall include mobile telephony, broadcast networks, and satellite-based systems to guarantee data accessibility.

S.14. The system shall have an embedded authentication system in order to recognize, identify, and differentiate end-users connected to the system without ambiguity.

S.15. Output information disseminated via internet and analytical tools shall be in a standardized, documented, and open format.

S.15.1. Any information disseminated from the system to any end-user will be formatted following the rules stated in S.15.

S.16. The status of 'data providers interacting with the system', 'communication times', and 'progress of computations' shall be displayed by the system and be visible to all end-users.

The system shall display the status of the system process to improve monitoring and controllability.

Extendibility and scalability

S.17. The system shall offer the ability to define groups of routine procedures that will process data in a workflow manner.

'Routine procedures to analyze concrete aspects of data' means that authorized categories of end-users can use the system for data processing.

S.18. The system shall be extendable so as to integrate new knowledge providers and new computing capabilities.

S.18.1. The system shall be flexible to extend and enhance it by integrating new providers for data input and data processing and computing.

S.19. The system shall be scalable to accommodate increasing demand for the monitoring of new volcanoes.

S.20. The system shall be flexible to extend the number of monitored items for early warning and hazard tracking in terms of processing capability and new monitoring items.

S.21. The system shall be scalable to accommodate increasing processing demands.

Closing Comments

This list of requirements is by no means an exhaustive list of requirements for such an early-warning and hazard tracking system, but rather a high level consolidated list on which the preliminary design of such a system can be founded. The requirements presented in each of the four categories are idealistic, but achievable with current spaced-based and terrestrial technologies and resources. It is encouraged that the development or fine-tuning of any early warning and hazard tracking system related to volcanic activity should strive to satisfy these requirements.

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Appendix B

SWOT Analysis Results

This appendix outlines the results of the SWOT analysis done for identified VIDA stakeholders. This analysis first identifies the strengths and weaknesses of the VIDA system in relation to stakeholder needs as identified in Table 6-1. Then, the list of strengths is used to identify possible opportunities, while the list of weaknesses is used to identify possible threats and risks.

Civil Aviation

The civil aviation industry would be interested in improved ash plume detection and tracking, in particular, more rapid data dissemination. The strength of the VIDA framework is that it addresses this need. However, because VIDA establishes a new design, it lacks the credibility of previous successes. Furthermore, the possibility of false alarms, leading to the unnecessary re-routing of planes, remains. The threats are then smaller less-complex ground-based systems that may be more cost effective for the industry. There is also the possibility that the time requirements to be effective for planes may be too short for the VIDA system to achieve.

Strengths	Weaknesses
• Short response time • Increased accuracy • Increased temporal resolution due to multiple sources • Improved access time to data • Scalable to meet different users (ATCs and pilots) • Global coverage • Improved ash prediction	• Possibility of false alarms from system errors • Novel system, no previous experience • Lots of data that needs to be converted to useful information in a short time • Time lag from acquiring data and delivering information • Limited coverage with existing infrastructure • Overall structure is very big
Opportunities	**Threats**
• Need for volcanic eruption warning system • Need for volcanic hazard warning system (focusing on ash plumes) • Potential to integrate with other systems	• Competition with other data providers (non-space based) • Time window for data delivery to aircrafts is very short

Academics

The academic sector would be interested in data archives, access to new data and new projects, so again, there is an opportunity for a VIDA system. The weaknesses of VIDA for this sector include the cost of the system and potential issues with identifying and protecting IPRs. Also, without access to previous data archives the system would take a few years to compile a useable data archive.

Strengths	Weaknesses
• Implementation of new technology • Data sharing • Barter (less costs) • Creating a community • Joint projects	• Lower reliability • Less financial support • Patent rights • Need time to build up archive
Opportunities	**Threats**
• New projects and publications • Future consultants / employees • Publicity for academic institution • Conferences	• Confidentiality issues • Intellectual property • Cost

World Bank

The World Bank would be interested in the ability of VIDA to save human lives and to encourage economic growth and hazard response capabilities in developing countries. There may be funding opportunities available for VIDA, however the complexity and cost of the system maybe a threat, particularly with competition.

Strengths	Weaknesses
• Save lives • Global • Scalable • Improved disaster response – resolution	• Complexity • Cost • Lack of credentials
Opportunities	**Threats**
• Financial aid • Developing economies • Improved emergency response to humanity	• Competition from GEOSS

Space Agencies

While space agencies are generally government bodies, they are listed separately from governments as stakeholders due to their particular involvement and interests in the space industry. Their interests would be developing space technologies, having access to information to assist with launching and re-entry of spacecraft, and developing research capabilities. There are therefore opportunities for collaboration in new projects, as well as public awareness. However, this was ultimately not considered crucial for space agencies to meet their mandates, so the cost of the system may be a threat.

Strengths	Weaknesses
• Commercial spin-offs • Faster access to data may assist with situational awareness, and launch and reentry decision support • Data overlay • Free information • Unique – new research paradigm • Compartmentalization of data handling	• Political conflict • Size of system • Lack of control • Security
Opportunities	**Threats**
• Future collaboration between agencies • New space related projects • Launch & reentry condition analysis and decision support • Public recognition	• Costs • Conflict of interests • Nice to have, not a need

Governments

Governments have been identified as the major potential source of funding for VIDA. There are several strengths, and the largest opportunity for VIDA is the potential to save human lives. Governing VIDA as an international collaboration would maximize the humanitarian potential, and still allow for development of profit generating spin-offs. Weaknesses identified include the need for security of data for reasons of national defense, the possibility of false alarms and the resulting liability. A major threat is the continual change in governments, which can disrupt the continuity of funding.

Strengths	Weaknesses
• Faster response • Temporal resolution • More information • Disaster response coordination • Identification of escape routes for disaster response teams • Save insurance money and reduce damages • Spin-offs, value added • Public relations • Standardization • Scalable • Large amounts of data	• Limited near real time images available • Security • Liability • False alarms
Opportunities	**Threats**
• Save lives • Save money • Support industries • Economic growth • Emergency and disaster response – cascade effect • Exchange of information	• Start up costs • Legal issues • GEOSS • Rights in data • Funding - lack of guarantee, continuity

Remote Sensing Companies

Remote sensing companies would be most interested in developing new markets and profit potential. The opportunities exist for spin-offs, value-added services, and increasing public awareness of their capabilities. Some companies may see the new technology of VIDA as a threat, with negative impact on their profit.

Strengths	Weaknesses
• Public image • New customers • Technology push • Produce, develop, sell configurable software • Access to larger datasets • Handling, storage, processing, standardization of data • Flexible, scalable	• Cost – change paradigm • Credibility
Opportunities	**Threats**
• Business opportunities • Money • New markets – global • Public image	• Legal issues and liability • GEOSS • Unknown impact on competition – income loss • Rights in data

Insurance Companies

Insurance companies would be interested in reducing damage, money paid out in claims, and making better risk estimates. There is an opportunity for VIDA since such a system is capable of providing large quantities of useful data. The possible risks involve the size and complexity of the system, which may exceed the needs of an insurance company, and the possibility that a false alarm may result in new claims or liability. Insurance companies would be interested in archive data, so unless the system started with access to an archive, it may take a year or two for a enough data to be compiled.

Strengths	**Weaknesses**
• Data • Save Lives • Reduce Damage • Verification of claims • Save money • Scalable • Global	• Take time to build up a data archive • Do not need massive archive • Complexity, size, cost • False alarms – novel claims
Opportunities	**Threats**
• Data archiving • Save money • Reduce risk • Don't pay out	• Legal issues – precedence of claim verification • Competition


VAPOR

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