Generating a Database of Seismic Events and the Probability That They Were Caused by Precipitation Using Acoustic Debris Flow Data Gathered at Mt. St. Helens

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Abstract— **Mt. Saint Helens gained notoriety in 1980 for its cataclysmic eruption on March 27 with the major collapse of the dome. Since this major eruption, the mountain had remained relatively quiet. However, in 2004 an increase in activity and dome building caused a renewed interest in volcano research. In 1982 the United States Geological Survey placed debris flow monitoring systems, called Acoustic Debris Flow (ADF) monitors, at several locations near the crater of Mt. St. Helens to further study the potential use of debris flow data. The data was collected by the Cascades Volcanic Observatory (CVO). Also located on the mountain is a machine called a Tipping Bucket that calculates precipitation. The CVO has asked the research team to generate a database of seismic events based on the data collected by the ADF monitors. This research project hopes to generate a database of seismic activity for Mt. St. Helens for the year of 2004 and to calculate a probability of whether the activity correlates with precipitation. The project will analyze the data using Excel and will determine what constitutes as a seismic event, as opposed to background noise and create a database cataloging each event, its duration, its peak activity, and whether or not there was a correlating precipitation event.**

I. INTRODUCTION

Mt. St. Helens was discovered on May 1972, while Royal Navy Commander George Vancouver and the officers of "HMS Discovery" were surveying the Northern Pacific Coast. Vancouver named the mountain after the British diplomat Alleyne Fitzherbert, Baron St. Helen on Oct. 20, 1972. For many years it was considered the world's most beautiful volcano, due to its amazingly symmetrical shape and snow-capped peak. The earth is ever changing however, and the mountain awoke in 1980 with fatal results.

II. MT. ST. HELENS GEOLOGIC HISTORY

Mt. St. Helens is part of the Cascade Mountain range, located on the mid-northwestern edge of North American continent. The area started as an accreted portion of the pacific tectonic plate that collided with the North American continental plate during the Middle Eocene. Marine basin sediments later covered the accretion. The first cascade volcanoes began erupting in the Late Eocene as the Juan de Fuca plate pushes into the North American plate.

The first eruption and growth of Mt. St. Helens, a composite volcano, began approximately 40,000 years ago. Since then there have been four recognized stages of eruption divided by periods of dormancy. Each stage contains several periods of eruptive activity of varying lengths. The eldest stage is the Ape Canyon stage, calculated at having started 50,000 years ago to 36,000 years ago. These were the first confirmed deposits from Mt. St. Helens. This stage is marked by pumice rich dacite and fall out deposits, as well as pyroclastic flows and lahars deposits.

A dormant period of 15,000 years ensued. It was broken around 20,000 years ago by the Cougar Eruptive Stage that lasted until 18,000 years ago. This sequence included an avalanche deposit similar to the one produced by the 1980 cataclysmic eruption. Another 5,000 years of dormancy followed.

Between 13,000 and 10,000 years ago the Swift Creek Eruption Stage saw activity. This stage was dominated by large volumes of tephra being deposited. Pumiceous pyroclastic flows were also noted, but these gave way to later lithic pyroclastic flows. Mt. St. Helens saw another period of 5,000 years of dormancy.

The latest stage, the Spirit Lake Stage, began around 3,900 years ago and continues through today. After the third eruptive period within the stage, the Castle Creek Period, viscous silica, in the form of dacite, began to alternate with mafic lavas, like basalt and andesite.

The present period of eruptions began in 1980. March of that year saw many earthquakes in the area signaling magma movement under the volcano. On the 27th of March a minor eruption created a small crater on the summit. Surveys begun in April showed the creation of a bulge on the north flank of the volcano due to magma intrusion. The bulge continued to grow until the morning of May 18th, when the catastrophic explosion of 1980 began. The collapse of the dome led to the largest debris avalanche in recorded history. It traveled north through Spirit Lake and over the top of Johnston ridge. Additional westward debris flow moved down the North Fork Toutle River. This reduced the pressure holding back the thermal and magmatic system, allowing a lateral blast of pyroclastic material, causing the devastation of the vegetation and wildlife for twelve miles along an arc of 180° in front of the blast zone. Major lahars were generated by the melting of snow and ice by heat released from the blast, devastating everything in their paths.

While the major explosion occurred on May 18 of 1980 several other eruptions took place that year, some with pyroclastic flows. In the following years two other explosions, both relatively minor, but powerful enough to generate lahars flowing at least ten miles, occurred; one in 1982 and one eruption in 1984. There has been dome growth since 1980 as well. The year 1986 saw dome growth, but there has been more recent growth as well.

Mt. St. Helens is currently active. It resumed dome growth in October of 2004, which has continued to the present. Steam bursts and ash fallout are relatively common occurrences. On January 16, 2005 a minor eruption, venting at the north end of the currently growing dome, destroyed three of the monitoring systems placed on the volcano by the Cascades Volcanic Observatory. Most recently, as of the writing of the paper, there has been another minor explosion on March 8, 2005.

III. EFFECTS OF THE 1980 CATACLYSMIC ERUPTION

Washington State's early economy relied heavily on the land—especially timber, farming, and fishing—and the region used the Columbia River for economic purposes. During the time the Grand Coulee Dam was completed in 1940, it was the largest man-made structure in the world. In the 20th century Mount St. Helens was known for its beautiful scenery, wildlife, and leisure activities. Its landscape was dominated by dense forests, clear streams, and lakes. Many residents depended on the fisheries of these waters for recreational activities and livelihood.

The effect of the1980 eruption was far reaching. It has been estimated that: eight million tons of tephra entered several lakes and river systems. Eruptions and mudflows altered the composition of the Cowlitz River watershed by flooding the nearby rivers with sand and silt from the Cowlitz, Toutle, and Columbia Rivers. Condominiums on the Cowlitz River came within a foot of being flooded, the Columbia River was clogged with debris and sediment, and its shipping lanes were blocked. The eruption dumped vast amounts of vegetation into Spirit Lake including a million logs, raising the lakes level by 200 feet. In May 1982, President Regan, out of concern for the rising water, asked the Corps to develop a plan that would stabilize and maintain the lakes elevation. By November the Corps had a system in place that allowed water to be transported to the North Fork Toutle River. More importantly, lives were lost during this explosion. During the months of the initial outbursts, the general public took warnings and the designation of the mountain and its surroundings as a dangerous Red Zone lightly. Some of the logging companies in the area also refused to shut down claiming to know the mountain. State officials urged the residents of the area to abandon their homes and warned people not to hike in the area. Harry Truman, an 84 year old innkeeper, along with other residents refused to move away.

Post eruption erosion, sedimentation, and the potential for floods and debris avalanches have presented very costly problems. Millions of dollars have been spent to aid in the restoration of areas affected during the 1980 eruption. It has been estimated that 1.1 billion dollars was lost as a result of timber, civil work, and agricultural losses. Additional funds have been lost due to loss of tourism, restoration efforts, and personal property loss. Timber, one of the regions principle resources, was affected the most. Weyerhaeuser Company lost approximately 60,000 acres of trees. Logging camps, buildings and equipment were also lost or damaged.

Several legal, health, and environmental concerns arose as a result of the Mount St. Helens eruptions. After the eruption FEMA provided the public with guidance on the procedures to be followed in order to minimize personal injury, loss of life, and property damage during an eruption. Medical services reported an increase in the number of patients that experienced respiratory and eye symptoms. An increase of bronchitis was also reported in the area. Natural water sources and man made ponds were contaminated by ash, causing a short supply of clean water for livestock in the region.

Governmental agencies at the state and local level have been established in support of efforts to protect and or minimize the effects of another eruption of this magnitude. The International Volcanic Health Hazard Network was created in February 2003 to determine the health effects of volcanic emissions. John Spellman, Governor of the state of Washington, established the Mt. St. Helens Coordinating Council to support efforts of accessing necessary long and short-term response, relief, recovery, and reconstruction. The Cascade Volcanic Observatory was designed to monitor the volcano and predict future activity. The observatory monitors seismic disturbances, gas emissions, temperature, elevation changes, water levels, sediment flow rates, and magma movement. This data is disseminated to the public, the media, and respective agencies.

As a result of the eruptions, in August 26, 1982, President Ronald Regan and the U.S. Congress designated an 110,000-acre area surrounding the volcano as Mount St. Helens National Monument, for research, recreation, and education. Inside the monument the environment is left to respond naturally to the disturbance in order for scientist to get a better understanding of volcanic processes, how ecosystems respond to catastrophic disturbances and enhance our ability to predict future eruptions. One of the data gathering tools implemented since 1982 was an Acoustic Debris Flow monitoring system. It is hoped that data gathered from this monitor will be instrumental in predicting future eruptions and potentially hazardous lahars flows.

IV. METHODOLOGY

In order to receive debris flow data from the Cascades Volcano Observatory it was necessary that we familiarize ourselves with a volcanic terrain of Mt. St. Helens, and the surrounding region. To accomplish this, the ONR research team under Dr. Lloyd Mitchell was required to travel to the Pacific North West in order to become acquainted with the regional culture and topography. The students were able o travel extensively throughout the region gained a lot of knowledge about the history of the Mt. St. Helens volcano and its surrounding region.

During the orientation trip access to Mt. St. Helens itself was restricted due to the recent occurrences of seismic activity. Our proximity to the mountain was limited to a range of about five miles from the mountain. Due to our limited access we could not perform the data collection ourselves, however we were fortunate enough to witness the end of a steam emission on the afternoon of march 17. the steam emission occurred at one o'clock pm and reached a height of just over five stories

The Acoustic Flow Monitors, which were the sources for the Quantitative data we used for our project, is one of several pieces of equipment distributed throughout the slopes of Mt. St. Helens equipped to measures ground vibration. Vibration recorded where transferred to an electronic spreadsheet depicted in millivolts, over a range of 0-5 volts, this information was used to create files for Mt. St. Helens debris flow. The AFM sensor is comprised of two parts the first is a seismic sensor known as a geophone. The second part of the AFM array is a precipitation meter known as a tipping bucket. The geophone is buried in the ground in locations near the existing paths of debris flow to measure activity along these lines of high activity. The tipping bucket is located at a peripheral location in the vicinity of the geophone in order to record relevant rain data. The AFM units have been in place since the early eighties, though the data files which have amassed since then have remained untouched and are still in the form raw unprocessed data.

The CVO was not able to access all of the data for this time period due to the differing organizational practices of the preexisting systems. The data that was available was sent to the ONR research team via e-mail in its raw form use Microsoft Excel as a medium. After all the available data was received from CVO, it was modified by our team members into useable information. The data files consisted of each month in the years 2000-2004. The initial spreadsheets were labeled as Month_Year.csv (for comma separated values). The files had a total of ten columns; the first column gave the date and time tag. The second column was the station identifier number, which was the number 1 for every case. The third and fourth columns were low gain and high gain vibration data respectively from the same sensor. These two output signals contain an electronic signal. This is done to allow the AFM alert transmissions to be triggered by a threshold set using the low gain signal, so that a large event is required to trigger the alert; and allow us to use the high gain signal record to do more detailed analysis of the data. The fifth and sixth columns are not data. The seventh and eighth columns are again low and high gain vibration data from a second sensor that was installed closer to the stream channel. The ninth columns represent battery voltage and the tenth column is the number of tips from a tipping bucket rain gage. Each .01 inch of rain causes one tip, or up count in the number displayed in that column. This was useful in plotting up alongside data to show whether there was significant rainfall that correlated with an event.

After we were able to assign values to the raw data, the next step was to label the columns and to group the years with the months that were provided for that year. In order to sort for events and patterns with in the data graphs for each month had to be created. While creating the graphs we noticed several instances in which data was missing or incongruent, in some of these occurrences, months, days, or minutes, were missing from a given year. Other problem that occurred within data occurred in the form of typos within the spreadsheets. The month in which this occurred often would not display correctly when graphed, because of this some of the years were with held from the data base until these anomalies could be corrected.

When the data analysis was complete we began to work towards our goal of forming the seismic events data base for Mt. St. Helens. Due to time restraints we had to limit the range of time that we would use for our database. We used the occurrence of documented seismic events in the fall of 2004 as a determining factor for our selection of that year for our subject material. Graphs were compiled for the year 2004 on a weekly scale this allowed us to closely examine each of the seismic events according to the low gain 1 readout. We designated a minimum threshold of 100 millivolts and as the signature of a seismic event that was not background noise. This information is preliminary research that will be used in the future try to determine the cause of the recorded seismic activity. See "Fig. 1" above for an example.

One of the possible causes is precipitation, and this would be indicated by an increase in the number of tips recorded by the tips bucket. We then calculated a probability for rain generated seismic events based on the number of seismic events that correlated with an increase in tip count. There were several problems with this data as well. One reason is that in the winter months the tip bucket may freeze and thus will not record precipitation. Also, the tip bucket does not tip properly when the precipitation is in the form of snow. Snow may cause an incorrect read in another way if the snow melts in the tip bucket at a later date and then cause a tip when there is no current precipitation. The tip bucket itself seems to go through long periods during non-winter months in which it reads no precipitation. This we have determined to be a malfunction because the area is one of high precipitation and a period of a year with almost no rainfall recorded does not seem likely.

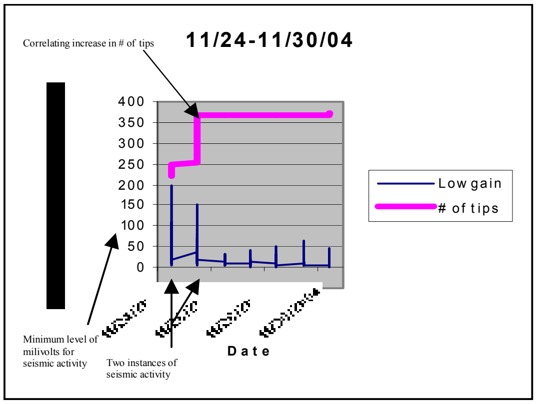

FIGURE I. DIAGRAM OF SAMPLE GRAPH WITH SET INDICATORS

V. RESULTS

For the year 2004 we determined that 157 instances of seismic activity occurred. Using 157 as our base number, and calculating the total number of instances where rainfall correlated with the seismic activity we determined that there is A 80.2% probability that a seismic event will have been generated by rainfall and a 19.7% chance that the event was not caused by rainfall. However, this again is preliminary research for a future, much more involved project. In order to determine the exact cause of each seismic event wind activity data, tectonic seismic data, and river level data will be needed in addition to the database created by the ONR research team. The database provides a date and start time for each event, its duration, whether or not there was a correlated increase in tip number, and the peak millivolts generated by the event. It is hoped that this data will be instrumental in the prediction of volcanic induced hazards.

VI. RECOMMENDATION FOR FURTHER RESEARCH

It is the recommendation of this research team that a future project be organized to compile a database of the remaining debris flow data from the years preceding 2004, as well as any data gathered after the date of this project. This more extensive data base could then be used by the Cascades Volcanic Observatory, or another organization to determine the cause behind each of the registered seismic occurrences. In order to continue the examination of the debris flow data information will be needed on wind patterns and weather condition during the time and duration of the study. Additional information on seismic events and precipitation will be needed to determine the validity of the debris flow data that we have received to this point.

In addition to the completion of the database it is also recommended that a network of monitors be established on the slopes of Mount St. Helens to replace those lost in the 2004 explosions, and to increase the accuracy of the data collected. Data collected from sources at varying orientation to the crater will allow for better isolation and negation of background noise, thus improving the quality of quantitative data.

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Date/Time	Low Gain1	Tips
1/1/2004 0:01	5	2227
1/1/2004 0:16	10	2227
1/1/2004 0:31	10	2227
1/1/2004 0:46	7	2227
1/1/2004 1:01	5	2227
1/1/2004 1:16	7	2227
1/1/2004 1:31	7	2227
1/1/2004 1:46	8	2227
1/1/2004 2:01	12	2227
1/1/2004 2:16	7	2227
1/1/2004 2:31	5	2227
1/1/2004 2:46	6	2227
1/1/2004 3:01	7	2227
1/1/2004 3:16	7	2227
1/1/2004 3:31	5	2227
1/1/2004 3:46	16	2227