APPLICATIONS OF REMOTE SENSING FOR THE EVALUATION AND MITIGATION OF VOLCANIC HAZARDS: SPECIFIC EXAMPLES AND RECOMMENDATIONS

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Abstract

A substantial percentage of the Earth's population lives in areas vulnerable to the negative impacts of future volcanic activity These impacts vary from the nuisance of light ashfall to the potential for catastrophic devastation of areas presently inhabited by tens of millions of people. Remote sensing technologies offer great promise for mitigation of future risk in two ways: lives can be saved in the short term by the prediction of impending hazardous activity and by the monitoring of eruptions in progress, and risk to life and property can be lessened in the long-term by the identification of areas and populations most at risk and by subsequent wise land planning. Examples of remote sensing applications in Hawaii, Italy and the Philippines are given.

1. Volcanic hazards - the reality of the threat

Society's interest in volcanic hazards waxes and wanes as a function of the elapsed time since the last major eruption. Following major eruptions (such as Krakatau in 1883, Mont Pelée in 1902, Mount St. Helens in 1980, or Mt. Pinatubo in 1991), the world focuses its attention (and governmental funding) on volcanic hazards for a few months or years, and then interest swiftly dies away as attentions move to the next current event. But, the hazards themselves (actual volcanic events) do not lessen, and the volcanic risks (the number of people and value of property threatened) increase with time.

Tom Simkin of the Smithsonian Institution, the world's foremost keeper of volcano statistics, has published an extremely useful summary of the nature of volcanic activity on the Earth (Simkin,1993). He shows that the rates of volcanic activity have remained relatively constant over the past several thousand years, on average 55-70 volcanoes erupt each year on land (the number of submarine eruptions must be far greater) Most of these eruptions are small or occur in sparsely populated areas, and are not of major social concern. Larger eruptions occur infrequently, but have killed several hundreds of thousands of people in historical time. The threat of truly catastrophic eruptions, which have the potential to produce millions of casualties, also remains very real. The threat to humankind increases with time since, in Simkin's words:

"Human populations grow dramatically while volcanism shows no sign of slowing down, ensuring that volcanic hazards will be a continuing problem for the future"

In order to protect growing populations in volcanic areas and to minimize future loss of life, new scientific techniques must be applied to volcanic hazards research and mitigation efforts. The improving capabilities of remote sensing technology hold vast promise for these endeavours. This paper briefly discusses some thoughts on how to apply remote sensing capabilities to the real world of hazards mitigation - a world which unfortunately is far-removed from the academic, industrial, and military communities in which the technical expertise resides.

2. Hazards mitigation strategies - long-term vs short-term

Once a potentially dangerous volcanic eruption has begun, responsible authorities are pretty much at the mercy of the mis-behaving volcano; mitigation efforts are mostly focused on evacuating those in danger -- one reacts to the volcano's actions and one's efforts are mainly directed at saving lives. Attempts at controlling the course of the eruption itself, mainly to protect property by diverting lahars (volcanic mudflows) or lava flows, are feasible under some circumstances, although questions of cost, property rights and philosophy (e.g. Should Man attempt to control Mother Nature?) make the issue of volcano control controversial. Emergency mitigation efforts are short-term in the sense that they are implemented after eruptions have begun or after signs of volcanic unrest have been detected. The capabilities of remote sensing are most commonly applied to these short-term efforts to protect the lives of those who are threatened.

Short-term mitigation of volcanic hazards is expensive, however, as it is always more difficult to save the lives and property of those who have already moved into hazardous areas than it is to prevent unwise developments in the first place. Discouragement of development in unsafe areas, or modification of that development to allow co-existence with potential volcanic activity, is the goal of *long-term* hazards mitigation. A long-term perspective on volcanic hazards will not lessen the volcanic hazards, but it can dramatically lower the volcanic risk. It is much less expensive to plan for volcanic hazards rather than to react to them. Unfortunately, a truth of human nature is that we and our governments spend most of our efforts reacting to crises rather than planning for them, so that it will be an uphill struggle for those who take long-term views.

3. Remote sensing capabilities - the potential

Long term applications

Long-term hazards mitigation efforts must be based on assumptions about future behaviour, and such assumptions are best derived from studies of past volcanic activity. In volcanology, study of past eruptive behaviour is the only basis on which to make forecasts of long-term future behavior. Studies of volcano histories involve three basic needs: 1) accurate geologic maps showing the distribution of the products of past eruptions, 2) information on how these products formed and the stratigraphic relations between them, and 3) the obtaining of ages of the mapped units in order to understand the frequency of past activity Remote sensing tools can be used for each of these studies, primarily as an aid to careful field investigations.

Aerial photography has been a standard geological mapping tool for over half a century, but recent utilization of infra-red photography has depicted features not visible in conventional wavelengths. Digital remote sensing of thermal infra-red radiation from young volcanic rock surfaces in Hawaii using the airborne NASA TIMS sensor (Thermal Infra-red Multispectral Scanner) showed that relative ages of flows can be determined from different spectral patterns. Although age determination by TIMS imagery is impossible in vegetated, ash-covered, and older terrains, however, it may be well suited to arid, young volcanic areas Results in 1993 in Kamchatka suggest TIMS may also be of use in mapping age relations in snow-free arctic areas.

Landsat TM images have proven useful in evaluating gross geologic structure for "first-cut" volcanic hazards studies. Satellite-derived imagery is particularly useful for reconnaisance mapping of volcanoes which are not easily accessible, and for assessment of vegetation anomalies which may be best viewed outside the normal visual spectrum of conventional aerial photography. In addition, TM data have been used to detect and measure thermal features associated with lava flows, lava lakes and fumaroles, and to estimate thermal flux. Several orbital systems now available are capable of obtaining the data needed to generate low-cost topographic maps of all the world's volcanoes, either by stereo photogrammetry or radar interferometric techniques. Such maps can be used to identify volcanoes with potential slope-failure hazards, and where sufficiently accurate, as baseline data to detect future physiographic changes.

Short-term applications

Remote sensing, from orbital or airborne platforms, has already been proven as a means of obtaining unique monitoring data and holds great promise for the detection of volcanic unrest in remote areas, where communications are poor and opportunities for conventional aircraft observations are few. Repetitive observations can detect changes of thermal or topographic (deformation) changes which would likely not be noticed by human observers. During actual eruptions, satellites have the potential to provide invaluable assessments of the areas affected and threatened by on-going activity, and in cloud-covered areas can provide monitoring capabilities (through radar imagery) of threatening activity which may be impossible to detect during poor weather. Satellite monitoring of tephra plumes is already a capability, and excellent progress has been made towards linking remotely-sensed plume-monitoring information with the international aviation community to give real-time warnings to aircraft in flight. Satellites are now routinely being used to make quantitative measurements of eruption plume heights, particle density, and SO_2 contents.

TIMS data (mentioned above for its utility in studies of long-term volcano behavior) is perhaps even more useful for studies of short-term and on-going activity. Flown by aircraft, the TIMS system can provide detailed images which depict distribution of thermal anomalies (such as buried lava tubes and shallow magma bodies) and which can assess changes in volcanic heat distribution through repetitive surveys. Studies at Etna show that TIMS can detect SO_2 plumes, though not with the quantitative precision of satellite systems

Monitoring activities are restricted by the 16-day repeat cycle of Landsat, by cloud cover and by the current high cost of the data. Hence only a few volcanoes have been studied in this way.

4. Remote sensing capabilities - the realities

The remote sensing community is mostly composed of academic researchers, who commonly publish statements such as "If anomalous thermal changes are noted, local authorities will be contacted". In reality, few of the remote sensing experts who are able to obtain and interpret the anomalous data know who the "responsible authorities are", fewer know how to actually contact them, and almost none speak a common technical language to converse with those who must make actual emergency decisions. Remotely sensed data are only obtained infrequently, and is rarely looked at with any degree of urgency (unless alerted to a specific problem area). Most hazards assessments have been made after the fact, long after the disaster has occured.

An exception was during the Pinatubo eruption of 1991, where excellent remote sensing resources were made available by the U.S. Air Force, because of the severe threat to major U. S. military bases Cooperation between the Air Force and on-site volcanologists from the Philippines and the United States was excellent, and timely warnings (based largely on seismic monitoring and field observations) enabled several tens of thousands of threatened residents to be evacuated from dangerous areas before the paroxysmal eruption began. But even here, where state-of-the-art technology was brought to bear in monitoring of the eruption, communications between those who collected the remote-sensing data and those who needed to act on the information broke down at critical times. As an example, the weather radars at Clark Air Force Base provided excellent data on ash plume heights during large explosions, and a sophisticated meteorological staff could produce exact predictions of the expected distribution of ash drift. A link from the on-site observers at Clark AFB and the Manila Air Traffic Control authorities proved elusive to establish, and was reliably in place only months after the largest and most dangerous plume-forming events. It finally required the personal commitment of a single individual who met extensively with the data-collectors and the data-users, made the effort to bring the two teams together, and who taught them enough about each others work so that a common language could be spoken. Although no aviation accidents occured, several million dollars of damage was caused to aircraft which inadvertantly flew into ash clouds downwind from Pinatubo. A moral is that *COMMUNICATION DOES NOT COME EASILY* between people who speak different languages - even if they have a linguistic common ground. This is especially true of the remote sensing community - they do not speak the language of the "Operations" people who must make emergency decisions.

Another example of failed communications, with terribly tragic results, involved the 1985 eruption of Ruiz Volcano in Colombia. The break-down of communications between Civil Defense authorities and those who obtained and evaluated traditional monitoring data illustrates the communications problem well, even though remote sensing technologies did not play a role in the outcome of this particular eruption. Ruiz gave over a year of warning before it erupted in November, 1985, and volcanologists from around the world came to install monitoring systems and to assist Colombian agencies evaluate hazards for the expected eruption. It was recognized that volcanic mudflows (lahars) represented the most serious threat to life, and a very accurate map of threatened areas was published in October. This map showed that the city of Armero, located far to the east of Ruiz, lay directly in the potential path of distructive lahars. When the eruption began on November 13, sirens were eventually sounded in the city of Armero, but confusion reigned and some authorities urged citizens to not "pay attention to false alarms". More than six hours elapsed from the beginning of the eruption to the time when the lahars poured into the city, but few had heeded the conflicting evacuation warnings on that rainy night, and more than 20,000 people needlessly lost their lives in Armero alone.

Had remote sensing technologies been in place, more accurate warnings could perhaps have been made, but would it have made any difference? Probably not, because credible comunication channels between the scientific community and the threatened populace, via emergency authorities, were not in place, and no one knew what to believe nor what to do when time had run out.

Another problem of current remote sensing technology is that the systems in use or proposed for volcanic hazard mitigation are planned for Earth-orbiting platforms which can obtain imagery of particular volcanoes only during polar orbital passes, which take place only at intervals of several days to weeks. This may one day provide early-warning information, yet may not be frequent enough during fast-changing eruptive crises. The need exists for continuous monitoring of threatening volcanoes during times of actual eruptive crisis, yet such capabilities (from mobile spacecraft in geo-synchronous orbits) do not exist in the civilian world.

5. A call for action

Remote sensing technologies have great potential to assess volcanic hazards, to give early-warning of restless volcanoes, to observe the onset and course of eruptions by monitoring the advance of lava flows, lahars and distibution of volcanic gases, and to aid in rapid assessment of impacted areas and planning of emergency relief.

But these capabilities will not be effective unless communications channels are established and continually maintained between the scientific organizations which collect and interpret data, the national emergency services agencies responsible for acting on the information provided, and ultimately with the populations at risk. The above statement calls for effective channels between organizations, and of course this is needed, but "channels between organizations" by themselves are commonly limited to bureaucratically required paperwork , the Memoranda of Understandings and such. What is needed are *"people channels"* , people-to-people linkages between responsible individuals in different agencies who personally know each other. These individuals should speak the common languages required to disseminate credible hazards information rapidly down the chain of command to the people who must eventually evacuate threatened areas, perhaps on short notice in the middle of a stormy night.

People-to-people relations must be established between those who collect remote sensing data and those who are expected to use it. Scientists in their laboratories have a moral responsibility to see how their data are used - it is not enough to merely collect the data, to present it at scientific meetings, and to assume one's job is done. If your data have the potential to save lives, you must make an effort to see that they reach the right hands and are understood.

These problems are becoming increasingly important as the remote sensing capabilities become ever greater and as real-time monitoring of potentially destructive volcanoes becomes a reality. The day will come when a computer monitor in someone's laboratory will show clearly that eruptive activity is impending at some far-away volcano, and that lives are in jeopardy. If this turns out to be your computer, what will you do - will the channels to communicate a credible warning to those in need be in place?

6. Acknowledgements

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Discussion

Sir John Knill asked about second order impacts from eruptions, particularly famines. Tambora is the classic example in which the global aerosol loading caused the "year without a summer" and triggered the Irish potato famine. Prof. Wadge (NUTIS) raised the question of who should have responsibility for monitoring volcanoes generally (perhaps 1000 worldwide), particularly in cases such as El Chichon in Mexico. Dr. Lockwood cited efforts to monitor ash clouds on behalf of aircraft by the ICAO but agreed there was a need for a more general geophysical coordination organisation to perhaps take on such a role. Could Russian military hardware be used for volcano monitoring? asked Dr. Harris (U. of North London). It is true that ex-military data and hardware are now available, though operational costs are still high. Mr. Lodge (ESYS) and Dr. Francis (Open University) both argued that communications between scientists and authorities is often poor and credibility of warnings low The answer is to work towards operational systems in which even non-experts become confident. Professor Coppock (Carnegie Trust) urged us to look at remote sensing as part of the whole issue of environmental management.