Remote Sensing for Hazard Mitigation and Resource Protection in Pacific Latin America

Gregg Bluth (PI); John Gierke, Bill Rose, Essa Gross (Co-PI's)

Sponsored by the National Science Foundation's Office of International Science and Engineering (OISE)

The ultimate goal of integrating research with education is to encourage cross-disciplinary, creative and critical thinking in problem solving and foster the ability to deal with uncertainty in analyzing problems and designing solutions. Remote sensing provides an ideal setting for engaging a broad range of engineering and science students in developing these qualities. Although remote sensing has great potential and is commonly used in research for characterizing, monitoring, and exploring large regions in a cost-effective manner, it has not met with much acceptance in terms of practice, especially in the developed world due to a lack of proof or confidence.

Though much of the developing world has the potential to gain significantly from remote sensing techniques in terms of public health and safety and, eventually, economic development, they lack the resources required to advance the development and practice of remote sensing. Both developed and developing countries share a mutual interest in furthering remote sensing capabilities for natural hazard mitigation and resource development, and this common commitment creates a solid foundation upon which to build an integrated education and research project. This will prepare students for careers in science and engineering through their efforts to solve a suite of problems needing creative solutions: collaboration with foreign agencies; living abroad immersed in different cultures; and adapting their academic training to contend with potentially difficult field conditions and limited resources.

This project makes two important advances: (1) We intend to develop the first formal linkage among geoscience agencies from four Pacific Latin American countries (Guatemala, El Salvador, Nicaragua and Ecuador), focusing on the collaborative development of remote sensing tools for hazard mitigation and water resource development; (2) We will build a new educational system of applied research and engineering, using two existing educational programs at Michigan Tech: a new Peace Corp/Master's International (PC/MI) program in Natural Hazards which features a 2-year field assignment, and an "Enterprise" program for undergraduates, which gives teams of geoengineering students the opportunity to work for three years in a business-like setting to solve real-world problems This project will involve 1-2 post-doctoral researchers, 3 Ph.D., 9 PC/MI, and roughly 20 undergraduate students each year.

The intellectual merits include:

-Satellite-based techniques will monitor precursory ash and gas emissions, thermal and topographic changes at active volcanoes over many months to improve understanding of precursory processes that can warn of impending hazards.

-Remote sensing methods will be used to facilitate the first systematic groundwater investigations of this kind in these countries.

-Long-term field assignments facilitate research with longer-than-usual timeframes, allowing continuity and consistency from local perspectives during potentially rapidly changing natural hazard crises, and establishing a strong social component to the science/engineering studies.

-Development of stable monitoring programs for gas emissions, water resource development, topographic and land cover changes - all with strong field validation components.

Outreach and broader impacts include:

-This project builds upon the individual projects, many funded by NSF, to build a stable collaboration and sharing of resources, personnel and experience among MTU, the USGS, and agencies in Guatemala, El Salvador, Nicaragua and Ecuador.

-The project reinforces a strong graduate level program in volcanological hazards, with the ability to generate many high quality Ph.D. candidates from this program. Merging academic coursework and field research gives the participants a unique combination of technical training and practical, international experience in real hazard mitigation and resource development.

-Develop improved outreach methods for hazard mitigation and resource protection. Extended field activities will allow for closer collaboration with affected communities.

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1. Research Plans and Objectives

Research rationale

Remote sensing offers the ability to monitor and explore large regions with relatively low cost and few personnel, both in the U.S. and abroad. It is the only practical approach to monitor large-scale natural processes and human impacts on our landscape and natural resources. However, we need to build confidence in our methods and define practical limitations for earth science applications. Remote sensing tools developed at Michigan Tech and elsewhere need to be tested in active regions over significant time periods and over a range of environmental and geological conditions. Pacific Latin American countries face many natural hazards and threats to resources, but are limited by economic constraints, such that trained personnel and technical resources are rarely adequate to develop and sustain appropriate programs in hazard mitigation and resource development and protection. Our proposed partnership serves both sides by bringing together these diverse groups to develop and validate remote sensing applications.

The key components of our research plans focus on a series of collaborative volcanic and hydrogeologic studies:

-Forecast activity of open vent volcanoes. Some volcanoes feature relatively mild activity from repetitive ashfalls, dome extrusions or fountaining, punctuated by more hazardous events including structural collapses, lahars, pyroclastic flows and violent explosions. Consistent and careful examination of background activity through satellite and ground-based studies of thermal changes, ashfalls, flow extrusions, and gas emissions can shed light on the timing and magnitude of the more threatening events.

-Development of efficient volcanic gas monitoring programs using satellite remote sensing. We have developed a suite of satellite methods using both ultraviolet and infrared sensors, which are capable of determining sulfur dioxide gas emissions from the active pacific Central American volcanoes. Regular gas flux observations can help determine optimum monitoring frequency, as well as derive relationships with seismic and thermal monitoring.

-Develop a satellite-based program of topographic monitoring. We propose to use satellite (ASTER) topographic mapping capabilities for determination of lava and lahar flow volumes and distribution and to identify regions of sediment accumulation. These data will serve as a baseline for future activity.

-Satellite characterization and monitoring of land use/land cover. Satellite sensors (Landsat, SPOT, ASTER) will be used for land use and land cover monitoring, initially for water resource protection. Combined with topographic studies, these efforts will also help determine the location of past slope failures in the volcanic soils and help define regions of high susceptibility to future slope failure. Ash and debris deposits on the flanks of active volcanoes can be monitored for prediction of future slope failures.

-Development and application of remote sensing tools for water resource exploration. Landsat and SPOT will be used in conjunction with topographic studies (ASTER) to help locate lineaments and surface expressions of fracture traces, indicators for groundwater access. Ground-based, geophysical remote sensing (EM geophysics) will be used as the most efficient means of defining local water tables.

Education rationale

International education plays a crucial role in developing a stronger U.S. workforce of culturally and environmentally experienced scientists and engineers. The standard educational path favors abundant classroom and laboratory work, while a lack of time, proximity to field sites, and locally-based infrastructure all conspire to confine educational pathways to a few options. This can produce graduates who lack critical-thinking skills, creativity, and the ability to collect, evaluate, and apply information from a variety of sources. Field studies give participants a chance to become immersed in the subject and culture, make connections across disciplines, and deal with uncertainty. The practical needs of a region provide a framework within which to apply the methods learned in classical coursework, but the best students will learn to adapt and develop new methods based on local environmental conditions and needs. An international infrastructure, which we develop through this proposal, has the ability to establish consistent, long-term field programs in regions of frequent activity and clear need, and help students apply their education within the context of active research and education exchanges.

The key components of our education plans focus on extended field experiences and the benefits derived from closer working relationships with local agencies and local populations, and the diverse, high quality participants attracted to these graduate and undergraduate programs:

-Develop better scientists and engineers by engaging students in their undergraduate and graduate careers through meaningful research and engineering projects. Efforts to involve students in long-term, practical projects in which they become an active part of the community, are designed to increase retention and the overall number of students who select earth science professional careers. International field experience will benefit earth science and engineering careers, which produces U.S. workers better prepared to deal with major natural threats in this country (e.g., hurricanes, depletion of natural resources, sporadic volcanic activity), as well as the capability to serve the international community.

-Development of sustained monitoring programs using U.S. participants. Long-term commitments using well-trained scientists and engineers are needed in order to determine and disseminate accurate baseline activity at many Central American volcanoes. Much of the data collected by the local hazard and geoscience agencies are not published or disseminated; the simplest solution is to develop web-based data repositories, which are accessible by the widest range of users.

-Develop more effective outreach methods of natural hazard mitigation. A major advance is possible through the development of hazard maps through long-term community involvement. In hazard crises, this is the rarely possible, yet hazard education is most effective when developed over time with the local populations. To do this we need researchers with long-term relationships with the communities at risk.

-Use our Latin American geoscience education programs to attract minority, female applicants and ultimately increase their numbers in the geosciences and engineering fields. Our current experience is that the Peace Corps and volcanology programs attract many more (high quality) female than male applicants; we will use these programs as means to attract more Hispanic American students into the geosciences.

2. Background

This project is based upon five main components to develop a new system of engineering and science education experiences. These components consist of Pacific Latin American hazard and earth science agencies and the USGS; remote sensing and educational methods; MTU Peace Corps Master's International Program; MTU Enterprise Program; and on-going research, student exchanges, and collaborative efforts by Michigan Tech in Latin America.

Hazards Agencies

Guatemala's INSIVUMEH (*Instituto Nacional de Sismología, Vulcanología, Meteorología, E Hidrología*) is a scientific and technical agency that works with both the private sector and the government. The agency's responsibilities include the monitoring and research of natural hazards, and the development and maintenance of a hazards database. The organization operates instrument networks for monitoring volcanic activity - principally through seismic stations. INSIVUMEH consists of approximately 100 scientists/engineers, technicians and staff, and is directed by Eddie Sanchez, an engineer. The two staff volcanologists are Oto Matías and Gustavo Chigna.

CONRED (*COordinadora Nacional para la REduccion de Desastres*) is concerned with overall disaster mitigation. The group works in developing and implementing disaster reduction strategies, which include many aspects of volcanogical hazards, both primary (ash falls, lava and debris flows) and secondary (flooding, mudflows and relocation). This agency is responsible for hazard education and emergency response planning. CONRED, with a staff of seventeen, is led by an Executive Secretary, Hugo Hernández. The Emergency Management Department, led by Ovidio García works most closely with volcanic activity in Guatemala.

CIICT (*El Centro de Investigaciones en Ingeniería Civil y Ciencias de la Tierra*), a part of the *Universidad del Valle* in Guatemala since 1991, works towards increasing research activity and the understanding of the natural disasters common in Guatemala, including floods, lahars, and earthquakes. Concentrating on improving earthquake-resistant construction materials and design, as well as the mitigation of natural hazards, work done at CIICT complements Civil Engineering and Earth Science coursework taught at the Universidad del Valle.

In El Salvador, following a tragic civil war and a series of natural disasters, the government called for the reorganization of agencies dealing with natural hazards. A new agency called SNET (*Servicio Nacional de Estudios Territoriales*), created in 2001, aims to centralize and prioritize monitoring and mitigation efforts in the country. The Geology division is headed by Carlos Pullinger (M.S., MTU 1997). SNET intends to involve the academic community in hazards efforts.

Nicaragua's INETER (*Instituto Nicaraguense de Estudios TERritoriales)*, founded in 1981, is headed by Dr. Wilfried Strauch. As the country's technical and scientific organization that generates and disseminates information on Mapping, Meteorology, Hydrology, Geology, and Seismology, the organization also conducts and assists scientific studies and monitoring efforts that support natural hazard mitigation. The agency organizes an annual workshop on volcanic gasses that draws volcanologists from all over the world.

Ecuador's *Instituto Geofísico Escuela Politécnica Nacional*, maintains a real-time monitoring program of the country's volcanoes and active seismic regions. Dr. Pete Hall, in charge of the volcanology sector since 1983, has over 30 years experience studying Ecuador's volcanoes, serves as a volcanological consultant to the United Nations, and participates in both national and international projects assessing natural hazards. The staff of 32 is responsible for dissemination of hazard information associated with volcanism, tectonism, and associated secondary effects, through the creation and distribution of hazard maps, publications, and daily maintenance of a comprehensive web-page.

The USGS/OFDA Volcano Disaster Assistance Program (VDAP) was created in 1985 by the USGS and OFDA (Office of U.S. Foreign Disaster Assistance). VDAP's main mission is to "reduce eruption-caused fatalities and economic losses in developing countries." VDAP is a highly mobile unit which can respond quickly to volcanic activity, and is able to quickly assess the situation with appropriate monitoring, hazard mapping, and communication strategies. It is comprised of a small core group of scientists at the USGS Cascades Volcano Observatory (CVO) in Vancouver, Washington and a large group of contributing scientists from CVO and other USGS offices. They are equipped with a cache of portable volcano-monitoring equipment ready for rapid deployment. Our main contact with VDAP is through Dr. Jim Vallance, an MTU alumni and adjunct faculty in the Geology Department.

Relevant Remote Sensing Research

The numerous technological advances focused on forecasting volcanic events have been largely aimed at interpreting the many physical and chemical processes initiated when a magma body begins to rise towards the surface, for example, changes in gas emissions, surface deformation, gravity, seismicity, surface temperatures, electric fields, acoustic signals (e.g., Sparks, 2003). Secondary hazards such as lahars, ash falls and debris flows create additional concerns, which again require close monitoring and preparation for hazard-prone regions. A wide array of satellite remote sensing tools are available for use on volcanic, seismic and slope hazards (Francis, 1994; the main satellite sensors used in this proposal are described in Table 1). Many remote sensing approaches to groundwater exploration and protection have been developed, but to date have not been employed in Central America.

Harris et al. (2003; 2004) used the Enhanced Thematic Mapper, in combination with ground-based thermal measurements, to measure the velocity of the Santiaguito, Guatemala block flow and derive an extrusion rate of the active Caliente dome. This relatively cool, slow-moving flow produces hazards by stream damming and emplacing large amounts of easily transported material close to distal communities. The extrusion rate is a key parameter for many other investigations of the potential hazards at Santiaguito, such as rockfalls, stability of the upper flanks, generation of pyroclastic flows and the liklihood for future large eruptions. Kerle and van Wyk de Vries (2001) developed a methodology for determining slope stability using a combination of SPOT and radar with field studies on the 1998 slope failure at Casita volcano, Nicaragua. This work illuminated the pre-slide deformation of the volcano edifice, which produced an unstable flank that was triggered by intense rainfall from Hurricane Mitch.

Stevens et al. (2004) generated a method of DEM construction at 10 m resolution from ASTER data, in addition to simultaneously generating land surface maps from the two visible and one near-infrared channel. Ganas et al. (2001) combined Landsat Thematic Mapper with a 20 m DEM to locate seismic traces for the 1999 Athens, Greece earthquake. Fu et al. (2004) used ASTER data to map the 2003 Bam, Iran fault in three dimensions; most significantly, they identified a restraining fault bend and a topographic-high marking a “stepover” displacement, interpreted as a likely location for future events.

Hotspot detection has many applications for volcano monitoring and wildfire detection. The University of Hawaii (http://www.higp.hawaii.edu/goes/) maintains an automated detection system featuring GOES data (Harris et al., 2002). Pergola et al. (2004) applied an automated thermal detection scheme for Mt. Etna and Stromboli volcanoes, based on AVHRR.

The detection of silicate ash clouds using infrared sensors is fairly robust, based on the methods of Prata (1989) and Wen and Rose (1994); multisensor retrievals of ash, sulfate and ice are relatively routine nowadays (Rose et al., 2000; Guo et al., 2004a; McCarthy et al., 2004; Gu et al., 2005), particularly from the AVHRR, GOES, HIRS, and MODIS sensors.

Satellite measurement of volcanic SO_2 emissions is well established in the ultraviolet (Bluth et al., 1993; Carn et al., 2003). More recently two infrared methods have been developed that take advantage of SO_2 absorption at 8.6 microns (Realmuto et al., 1994) and 7.3 microns (Prata et al., 2003). Guo et al. (2004) applied both ultraviolet and infrared methods to derive a new estimate of SO_2 emissions from the 1991 Pinatubo eruption. Watson et al. (2004) has demonstrated the capability of MODIS to perform multi-species retrievals of ash, aerosols and SO_2. The recent launch of the OMI sensor (which appears to be the best sensor for daily monitoring of SO_2) provides exciting new prospects for robust detection of relatively low level emissions from Central American volcanoes (htttp://toms.umbc.edu).

Lahars and debris flows can be mapped with respect to their likely extents through a GIS method (Iverson et al., 1998) that uses digital topography, an advanced numerical modeling approach, and field observations to predict the distribution of future hazardous deposits around the volcano. In 2001, Steve Schilling of the USGS visited MTU and provided the LAHARZ code and instruction on its usage. Two of our students have used LAHARZ extensively during their thesis research to help generate lahar hazards maps for Tungurahua Volcano in Ecuador (Sorenson, 2003) and Atitlán, Guatemala (Haapala et al., in review).

Besides general geologic maps, no specific geological or hydrogeological information exists for sighting water wells. Sander et al. (1997) demonstrated the use of lineament analysis for groundwater exploration in sedimentary rock aquifers in Ghana. They used Landsat TM and SPOT imagery data and conducted three types of reproducibility tests. Lineaments classified as more hydrologically significant showed a reproducibility of up to 90% and they advocate the use of lineament mapping. Taylor et al. (1999) concluded in their economic analysis that using a combination of imagery (lineament mapping) and surface geophysics enhances the probability of success for drilling wells in regions where productive zones are concentrated in sparse fracture zones.

Based on the literature in volcanic terrains, electromagnetics and resistivity surveys best characterize subsurface structural features that suggest productive zones for water development. Chen (1999) employed transient electromagnetic (TEM) surveys along the southwest coast of Taiwan to evaluate groundwater potential by delineating different geohydrologic units based on their geoelectric signal. A significant result of this work was its use in conjunction with well data to resolve ambiguities. Grgich et al. (2004) used surface geophysics (resistivity, EM, GPR) to characterize flow paths in a karst system. Aubert et al. (1984) used resistivity and magnetic surveys for groundwater exploration in France. Lee (1994) used electromagnetics, seismic refraction, and resistivity in complementary fashion to delineate potential fracture zones in sedimentary rocks. His surveys attempted to delineate near-vertical, water-bearing fractures. Lluria (1990) employed controlled source audio-frequency magnetotellurics (CSAMT) for delineating fracture zones because if its capability to penetrate very deep and its relative insensitivity to cultural interferences. Robineau et al. (1997) used audiomagnetotellurics (AMT) and time domain electromagnetic (TDEM) techniques to reveal a major paleoalluvial drainage system buried under recent lava flows and to delimit sectors with different hydrogeological characteristics. The TDEM was better suited for shallower resistivity structures, while the AMT was better for deeper detecting deeper layers. Jansen and Taylor (1998) summarized case studies in the Midwest where fracture-trace analyses in conjunction with surface geophysics delineated fracture zones in bedrock aquifers.

Table 1. Satellite sensors featured in this project

Sensor	*Relevant Characteristics*	*Project Applications*
ASTER – Advanced Spaceborne Thermal Emission and Reflection Radiometer	3 channels in visible and near-infrared, with 11 more infrared; 15-90 m spatial and 16 day temporal resolution	Generation of 10 m resolution digital elevation models; topography; land cover; ash and SO_2 plumes
AVHRR – Advanced Very High Resolution Radiometer (3 currently in operation)	4-6 channels in visible and infrared; 1.1 km spatial and 2-12 hour temporal resolutions, owing to multiple sensors	Volcanic ash clouds; surface thermal monitoring of the surface
GOES – Geostationary Operations Environmental Satellite	5 channels in visible and infrared; 1-8 km spatial and 15 minute temporal resolutions	Volcanic ash clouds; thermal monitoring of the surface
HIRS – High Resolution Infrared Radiation Sounder	1 visible and 19 channels in infrared; 20 km spatial and daily temporal resolution	Volcanic ash, ice, aerosol, and SO_2 clouds
Landsat ETM+ - Enhanced Thematic Mapper Plus	3 visible and 4 infrared (1 broadband); 30 m spatial and 16 day temporal resolution	Land surface features: vegetation, soil/rock
MODIS – Moderate Resolution Imaging Spectroradiometer	36 channels in visible and infrared, 250-1000 m spatial and 2 day temporal resolution	Volcanic ash, ice, aerosol, and SO_2 clouds
OMI – Ozone Monitoring Instrument	740 channels in the ultraviolet, 13 km spatial and 1 day temporal resolution	Volcanic ash, aerosol, and SO_2 clouds
SPOT – Systeme Pour l'Observation de la Terre	2 visible, 1 infrared and 1 panchromatic band, 20 m spatial and 26 day temporal resolution	Land surface features: vegetation, soil/rock
TOMS – Total Ozone Mapping Spectrometer	6 ultraviolet channels; 39 km nadir and 1 day temporal resolution	Volcanic ash, aerosol, and SO_2 clouds

Relevant Education Studies

In "Shaping the Future of Undergraduate Education", Ireton et al. (1996) explained how merging active research with education provides students with problem-solving and critical thinking skills. The Workshop Report on "Integrated Research in Risk Analysis and Decision Making in a Democratic Society" (National Science Foundation, 2002) stressed the need for multidisciplinary research including engineering, information sciences, natural sciences, and social sciences. Although scientific and technical advances have significantly improved risk and analysis and hazard mitigation practices, there is a gap between scientists and policy-makers; essentially a lack of integration across physical and social sciences. They concluded that experience was needed across the board: for undergraduate, graduate and postdoctoral scholars, as well as mid-career faculty, these were vital to foster cross-disciplinary training, and closer networks and partnerships as part of the training process. Geoscience education must expand beyond the traditional coursework to prepare students for diverse, related careers in law, business, engineering and education (Correll and Bishop, 1997).

Huntoon et al. (2001) focused on student learning in field situations precisely because field work requires students to think holistically through discovery-based and inquiry-based learning (Correll and Bishop, 1997), relating different technical and social skills to new and sometimes relatively unknown situations. Students in traditional curricula often come to feel that their education is composed of series of unrelated elements, increasing frustration and reducing motivation. Although students in a technically rigorous program will graduate possessing the knowledge and skills required to purse careers successfully, at risk is the enthusiasm for life-long learning, and ability to adapt to new situations that characterize excellent researchers and educators (Rutherford and Ahlgren, 1990). There are relatively few cases in which "reformed" education and its measured effectiveness have been presented to the geoscience community (e.g., Orion et al., 1997; Huntoon et al., 2001). Although methodologies for assessing geoscience curricula are widely available (e.g., National Research Council, 1996), a need exists for documentation of how well procedures work in actual course settings.

Field studies promote many of the main points of "Evaluating and Improving Undergraduate Teaching" (National Research Council, 2003). Better understanding results when students are trained to apply their knowledge in new situations around a framework of major concepts and disciplinary principles. Overall learning is enhanced when students are involved in socially supported interactions. Likewise, "How People Learn" (National Research Council, 2000) stressed the importance of engaging students while learning, as a means to provide a deeper understanding and improved retention. Organization becomes a major part of learning when dealing with unfamiliar situations; while in the field, students must learn how to adapt their basic experience to best deal with new situations and constraints.

Dym et al. (2005) reviewed many aspects of research into engineering design education principles. Design systems can develop essential skills for engineers: recognizing the context of a dynamic system, reasoning with uncertainty, making estimates, and conducting experiments to test their system designs. Project-based learning must also occur on an international and intercultural scale to develop deeper understanding of design systems. Machotka and Spodek (2002) noted that less than 3% of American students studying abroad were engineering majors, yet cite numerous ABET criteria and the Bush administration itself strongly encouraging such experiences for engineers. They provide numerous cross-cultural awareness issues and logistical aspects of engineering "study-abroad" programs, for example the need for preparatory academic programs and cultural preparation for the host countries. A good example of international experience has been documented in the Ambae Volcano region, Vanuatu (Cronin et al., 2004), showing that more useful and meaningful maps and mitigation plans result when communities are actively involved with the process of identifying hazards.

Peace Corps Master's International Program in Natural Hazards

In Fall 2004, we began a new graduate education effort together with the U.S. Peace Corps (http://www.geohazards.mtu.edu/) in selected Latin American countries (Guatemala, El Salvador, Nicaragua and Ecuador). This program is the only Peace Corps Master's International program in Geosciences. The program's scope includes earthquakes, volcanic hazards, slope stabilities, landslides, debris flows, droughts, floods and water resource management. It also provides indirect linkages such as the impacts of these events on infrastructural elements like community development, environmental education, transportation, health, sanitation and water quality. The program aims to reduce economic and social vulnerability to hazards in Latin America by incorporating the results of hazards research into local-level cultural systems.

The program is designed for ten new students each year, meaning that at full capacity there will be 30+ students in the program, with the majority in the field. This first year, despite a lack of funding during the critical recruiting season, we attracted more than 60 serious inquiries, and seven students have enrolled in the program, thanks to NSF support (see Results of Previous NSF Support).

The program begins with two coursework-intensive semesters at Michigan Tech. During this period the students work with the Peace Corps and the Latin American agencies to develop appropriate assignments, based on the local community and hazard agency needs, Peace Corps program availabilities, and the student's expertise. During the following two years the students do their field assignments with the Peace Corps. After this time, the students return to Michigan Tech to complete either a Master's Report or Thesis. The program emphasizes a substantial social component in natural hazards work, significant multicultural foreign practical experience, and long-term direct contact with active natural hazards. This program is also designed for the retention of the best of these students into the Ph.D. program; with two solid years of field experience, this program will produce some of the best trained candidates in the country.

Enterprise Program and Aqua Terra Tech (ATT)

Beginning in the Fall of 2000, Michigan Tech introduced the "enterprise" curricula to foster leadership and entrepreneurship among students during their education, to better prepare them for professional careers (Stone *et al*., 2004). The Enterprise Program (http://www.enterprise.mtu.edu) is a new curriculum that gives teams of students from different disciplines the opportunity to work for approximately three years in a business-like setting to solve real-world problems. The Enterprise Program attempts to meet private industry's need for scientists and engineers who not only have technical competence but also understand the practical application of skills and knowledge (Creed et al., 2002, NSF, 1996), including the following attributes: (1) effective communication skills and team-based, problem-solving approaches; (2) awareness of global markets and competition; (3) an appreciation of societal and cultural influences on solving real-world problems; (4) experience in environmental issues, ethics, and professional responsibilities; (5) independent problem-solving (resourcefulness) and critical-thinking skills; (6) a pervasive business sense; (7) management skills; and (8) a realization of the importance of life-long learning.

Michigan Tech developed the Enterprise program to provide our undergraduate students a curriculum that allows them to practice their chosen discipline in a project setting starting in their second year of college and continuing through graduation. ATT is one of the MTU Enterprises, and it is the only one involved in areas of geological, hydrological, and environmental engineering. Co-PI Gierke serves as the advisor of this unique multidisciplinary group of undergraduate students. They currently perform hydrological characterization and modeling for the purpose of developing quantitative understanding of local water resources to enable the development of effective protection plans. For example, ATT conducts geophysical surveys to characterize the hydrogeology of the watershed and performs water-level testing in wells. ATT uses the collected data to develop and test a computer model of the watershed hydrology.

Students majoring in civil, environmental, and geological engineering typically join in their sophomore year of study and participate through graduation. Annually, ATT recruits new members to replace those who are graduating and satisfy needs for addressing various project tasks. The ATT enterprise has grown to 25 members since starting up in the Fall 2000 semester.

Michigan Tech's Presence in Latin America

January of 2005 marked the sixth consecutive year of (largely NSF and USGS-supported) field studies in Central America by a broad-based group of volcanologists and geophysicists, led by Michigan Tech. These field efforts are the combined work of U.S. and international universities and organizations with interests in Central America. The work includes many ground-based, geophysical field studies in conjunction with satellite remote sensing. The university contingent works closely with the local volcanological and hazard mitigation agencies, with all benefiting from the sharing of manpower, resources, technical and field expertise (Bluth and Rose, 2002). These efforts have been mainly led by co-PI Bill Rose, whose research in Guatemala, El Salvador, Nicaragua and Ecuador goes back 35 years. However, despite our long-term commitment to Latin American studies, the field efforts themselves have been by necessity relatively short-term, typically only a matter of 1-2 weeks in length.

A significant aspect of our recent work in Central America has been the ability to support Latin American students in degree programs at Michigan Tech. Carlos Pullinger (El Salvador) completed a Master's degree in Geology, in 1997, working under co-PI Rose on the Santa Ana complex in El Salvador. After returning to his home country, Carlos became the head of the Geology division of SNET. Demetrio Escobar completed a Master's degree in 1993 on San Miguel volcano in el Salvador (again funded by PI Rose). Escobar is back in El Salvador, working in the geology division of SNET. Oto Matías (INSIVUMEH, Guatemala) completed a B.S. degree in Geology at Michigan Tech (co-advised by Rose and Bluth); his senior research project focused on Landsat Thematic Mapper evaluation of Pacaya lava flow areas. Currently, Rudiger Escobar Wolf (CONRED, Guatemala) has been accepted into the

Master's program on a research assistantship starting Fall 2005. Escobar Wolf will be working on Santa María volcano, in a study of it's eruptive history, co-advised by Rose and Dr. Jim Diehl at Michigan Tech.

Michigan Tech has maintained a research presence in Pacific Latin America for almost four decades, and particularly so in the past 6 years. We have forged important long-term relationships with the hazard and geoscience agencies in this region, and most importantly have developed a trust that we take very seriously. We have never attempted a coordinated, long-term effort. This proposal is significantly different because we now have the means, through the Peace Corps Master's International and undergraduate Enterprise program in geoengineering, to provide significant levels of sustained support simultaneously throughout Pacific Latin America. Thus we feel that this is the ideal time to develop a coordinated effort among the various countries, focusing our efforts in remote sensing to improve the regional capabilities in hazard mitigation and resource protection.

3. Research Tasks

The tasks will be flexible by necessity, because of the countries' changing needs (e.g., due to volcanic activity, meteorological and seismic events), the regional Peace Corps constraints, and student recruitment interests. We anticipate that on an annual basis we will maintain 3 senior faculty, 1-2 post-docs, 3 Ph.D., 9 PC/MI students, and 20 undergraduate Enterprise students. It is unlikely that these will divide evenly among the various topics covered in the proposal; for example, this year the majority of Peace Corps students have chosen volcanological projects.

For a project of this scope, with essentially 20-30 students working simultaneously, it is impossible to list every sub-project here. Can we find enough projects for the estimated 50 graduate and 100 undergraduates in the 5-year project? We have no doubt that there are more projects than students – besides the many active volcanoes, steep slopes, constant seismic threats, hazard mapping, needs for securing clean drinking water, and education and outreach, most of these projects will require repetitive measurements each year, and positions will be filled by subsequent student researchers. Below we briefly describe a set of initial projects, and describe a generic timeline for typical volcanic, land surface, and hydrological studies (other volcanic studies are listed in greater detail in Bluth and Rose, 2002). Obviously, the volcanic studies in particular are dependent on current activity levels; were those to change, we would modify the projects accordingly. These timelines would essentially repeat annually for the Master's and undergraduate Enterprise participants, as each year a new set of students would arrive. The post-doctoral scientists and Ph.D. students will provide year-to-year continuity and cohesion amongst the various projects.

The project work is organized into three phases (outlined in Table 2). These phases form a repetitive annual cycle, with specific plans in an ensuing year building on the prior experiences. The Preparation and Planning Phase will occur at MTU, prior to the field work, and will span all of Fall semester. We are tentatively planning to travel in mid December and early January (dry season runs from October through March). The Data Analysis and Synthesis phase would occur over Spring semester. The students who will actually be traveling in a given year will be assisted by their fellow Enterprise students, some of whom will be traveling the following year, in both the preparation and data analysis aspects. So even though only 12 students per year will visit the field sites (~60 total over the project period), some 8-13 other students will be participating in the project in various activities each year.

Table 2. Annual project phases.

Project Phase	*Volcanological Hazards and Gas Monitoring*	*Landslide Hazard Assessment & Prediction*	*Resource Development & Protection*
Preparation & Planning	Social & Cultural Elements and Communication in Spanish		
	Travel Logistics	Travel Logistics	Travel Logistics
	Volcanology	GIS Analysis of Surficial Features	Lineament Characterization
	Remote Sensing Applications	Review Geology & Topography	Review Geology & Topography
	Remote Sensing Fundamentals	Development/Refinement of Landslide Model	Prepare Geophysical Equipment and Survey Procedures
	GIS and Applications	Field Work Planning	Field Work Planning
	Field Work Planning		
Field Work	Field Reconnaissance	Field Reconnaissance	Field Reconnaissance
	Surface Mapping of ash, lahar deposits	Geophysical Surveys	Geophysical Surveys
	Ground truth - thermal measurements	Soil Sampling	Water Quality Sampling
	Ground truth – gas measurements	Land Cover Sampling & Mapping	Water Sample Analyses
Data Analysis & Compilation	Satellite Data Acquisition and Storage	Geophysical Data	Geophysical Data
	Data and Image Processing	Mechanical Strength of Soils	Water Quality Data
	Review of Ground-measurement Results	Landslide Model Development & Testing	Hydrological Model Development & Testing

Sediment volumes and topographic changes - Santiaguito Volcano, Guatemala. The dacitic Santiaguito lava-dome complex has been growing episodically at the base of the Santa María crater since 1922, accompanied by almost continuous minor explosions and periodic lava extrusion, larger explosions, pyroclastic flows, and lahars (Rose, 1987). Hazards generated by Santiaguito activity are mainly directed towards the south, affecting western Guatemala's rich agricultural region and disrupting major ground transportation routes. The near-constant output of pyroclastic material is transported, sometimes catastrophically, downstream through several major river channels during the rainy season, producing major topographic and surface hydrological changes. The volume of sediments and the migration of these sediments downstream can be determined and monitored through remote sensing together with field measurements (Bluth and Rose, 2002). We propose to develop a time-series of ASTER-generated DEM's, focusing particularly on the pre- and post- transport during the rainy season. This will aid in understanding sediment transport behavior, and relate the timing of the transport to the volcano's eruptive activity (e.g., extrusion rates).

Satellite gas flux measurements - Masaya Volcano, Nicaragua. Masaya, located just 20 km S of Managua, is one of Nicaragua's most unusual and active volcanoes; it has erupted at least 19 times since its description by Spanish explorers in 1524. The most recent eruption was in 2002. Masaya is an unusual basaltic volcano because it has had explosive eruptions. Three times during the past 100 years, Masaya has emitted large amounts of sulfur dioxide gas. In 1981, sulfur dioxide was released from Santiago Crater at a rate of 500,000 tons per year; however, normally it maintains a fairly persistent, low-level emission of SO_2. The site is ideal for coordination of ground-based and satellite-based retrievals of SO_2 and thermal measurements (e.g., Bluth and Rose, 2002). Here we plan for simultaneous measurements using a combination of field spectrometers during satellite overpasses of OMI and MODIS sensors (gas) and AVHRR (thermal) during the course of a months-long field season. Our main research objectives are validation of satellite SO_2 retrievals and thermal signals, and the use of these sensors in tandem to monitor changes in volcanic activity.

Eruption forecasting – Reventador and Tungurahua volcanoes, Ecuador. Reventador volcano, approximately 70 km E of Quito, began erupting in November 2002 after a 26-year period of repose. The eruption, which produced pyroclastic flows, ash and gas clouds, was unusual because it had virtually no seismic precursors. The combination of low altitude sulfur gases detected as far as Quito, pyroclastic flows that reached highways, and ashfall in surrounding towns, resulted in the evacuation of 3000 people. Intermittent activity has continued at Reventador, including pyroclastic flows and lahars from remobilized material and ash and gas emissions. Reventador is particularly challenging to monitor directly because of its remote location, and because of the Andean geography develops thick cloud cover over the summit.

Tungurahua volcano, located 140 km south of Quito, is one of Ecuador's most active volcanoes. Its most recent eruption occurred in 1999, and its activity presents a severe threat to the town of Baños, located at the base of a large channel leading from its upper flanks. Activity in the form of seismicity and ash and gas emissions continues to cause concerns, both because of problems caused by remobilization of ash and debris on its flanks, and the potential of developing into another large eruption.

We propose to use satellite observations of gas and ash emissions, and to measure changes in activity to forecast future activity. To calibrate the satellite data, measurements must be taken and corroborated with field observations. Subsequently, the satellite data archives can be used to characterize the precursory events and changes to help predict future activity.

Satellite data for monitoring SO_2 fluxes – all countries. Currently a number of volcanoes in the Pacific Latin America region are capable of producing measurable SO_2 from either current or very recent activity: Santiaguito, Fuego, Pacaya (Guatemala); Santa Ana, San Miguel (El Salvador); Masaya (Nicaragua); Tungurahua, Cotopaxi, Reventador, Guagua Pichincha (Ecuador). For routine monitoring capabilities, the OMI sensor appears to be the most appropriate because of its relatively fine spatial resolution and daily coverage. Larger events will be analyzed as they occur from less robust sensors (HIRS, MODIS, AVHRR). Routine ground-based measurements from COSPEC and DOAS will validate the satellite retrievals. The OMI sensor uses essentially the same processing software as the TOMS, which we have tested and used in Remote Sensing workshops already. Many individual studies of SO_2 emissions have already been performed; however, very few studies have persisted beyond a few weeks of measurements; therefore, we propose to determine SO_2 fluxes from both single volcanoes and on a regional basis with a much greater degree of certainty than any previous effort.

Earthquake traces and slope failure prediction – El Salvador. In 2001, El Salvador suffered two major earthquakes (7.6 and 6.6 respectively) 13 January and 13 February, triggering more than 500 landslides. One of the most damaging occurred in Las Colimas, a suburb of San Salvador, killing 450 people, injuring 1200, and burying or destroying parts of the Pan American highway (Evans and Bent, 2004). This proposal will combine ASTER-generated DEMs, image processing of Landsat ETM+ and SPOT data, with field surveys to characterize the slopes of this region of El Salvador. SNET has generated a GIS database focused on particular slide-prone (clay-rich) volcanic soils, and intends to incorporate slopes and land cover data from satellites. These new remote sensing data, used to map the slope failure patterns, expand the imagery database with surface parameters, will aid in investigating indicators of slope failure and thus improve seismic/slope hazard map accuracy.

Lineament mapping and geophysics for water resources – Nicaragua. With rapidly depleting water resources, many communities in Nicaragua look to developing groundwater as a potable water resource. However, expertise and necessary equipment are lacking. Our primary activities to facilitate this exploration include field reconnaissance, geological mapping, field geophysical surveys, and water quality analyses. Prior to geological mapping, SPOT and Landsat imagery will enable us to delineate surface expressions of fracture lineaments. After locating potential well sites, students will perform electromagnetic surveys to aid in aquifer characterization.

4. Education tasks

This project focuses on three educational objectives: (1) The integration of research and education will develop better scientists and engineers by engaging students in their undergraduate and graduate careers through meaningful research and engineering projects; (2) The project promotes the development of more effective outreach methods of natural hazard mitigation and resource management; (3) The project structure creates an ideal setting for implementing sustained monitoring programs abroad.

The project will include international research experiences on the undergraduate, graduate, post-graduate and faculty levels. The undergraduate component entails the participation of MTU's Enterprise group, Aqua Terra Tech (ATT). The students take a suite of courses specifically designed to prepare them to perform hydrological characterization and modeling to develop an understanding of local water resources. 12 members of ATT (juniors and seniors) will participate in a field trip to a site in Latin America to perform ground-truthing of remote sensing data, field reconnaissance, geological mapping, and field geophysical surveys. The end products are development of effective protection and resource management plans. Students chosen to travel abroad will be required to take additional courses devoted to learning the Spanish language, and about regional culture, history, and politics.

At the Master's level, students begin with a year on campus at MTU with courses in geologic hazard and mitigation, geological sciences and engineering, and Latin American language and culture. Concurrently, they develop project ideas and begin communicating with the local Peace Corps and geoscience agencies. The second and third years are spent in the field, as part of the Peace Corps program. While in the field, they will be required to maintain regular contact with a member of one of the hazard agencies mentioned above, to encourage the exchange of ideas, knowledge, and technical expertise. Though these students' primary responsibilities will be to carry out their field research for the earth science aspects of their degree, as a Peace Corps volunteer the international component will offer ample exposure to social science issues.

While the undergraduate and Master's level students will cycle through the program, with new students added each year, work done by three Ph.D. students will add a more continuous dimension to the project. A likely scenario will be two students emphasizing in volcanology and one in hydrogeology following a traditionally-structured Ph.D. program (Table 4), with field work opportunities (two weeks to three months in duration) in Latin America. We anticipate that their dissertations will include a large international component, from collaboration with our foreign counterparts. Additionally, these students will be involved in the project by providing guidance for the Master's students' projects

The project success relies on effective mentoring by the MTU and foreign institution professors. In addition to the advisory role that professors assume, they will also serve as mentors to students at all levels (National Academy of Sciences, 1997). Two barriers that commonly impede students from completing a higher education degree are 1) insufficient academic preparedness and 2) lack of understanding of the nature of studies. In this particular program mentors may discover a third barrier: overcoming challenges students encounter during extended field work abroad. In moving overseas, students will experience many changes that, from time to time, may shift the focus of their lives from high-level research and education to simply functioning. As mentors, the professors will maintain regular contact with students and keep tabs on motivation, frustrations, and interest level. Monitoring student progress will ensure students complete their field work and degree in a timely manner.

Students will develop skills valuable to their future career. A standard curriculum gives students disparate opportunities to develop skills in problem solving, time management, project planning, communicating, conducting research, presenting results, and possibly publishing. The proposed project offers even more opportunities, and under a set of conditions that will better prepare them for careers. Student participants will deal with issues particular to cross-cultural collaborations – such as culture and language barriers, inadequate resources/materials, uncertainty, unfamiliar environments, changing expectations, and challenges in working with diverse groups. Students who successfully overcome these obstacles will be better prepared for their careers.

5. Potential Impacts of Project Research

Support strong international collaborative research and education. This project builds on our many years of individual collaborative efforts with the various agencies, to develop a truly collaborative effort among the four Latin American countries, the USGS and Michigan Tech. We cannot stress enough the importance of maintaining an active research presence, for continuation of research directions and sustained interagency collaborations. The result will be vastly superior to the individual efforts, because we will be sharing the combined resources and expertise of many experienced scientists and educators. The implementation of remote sensing/GIS into routine monitoring and management will make the most efficient use of limited personnel and resources in this developing region of the world.

Support high quality research and education. This project features numerous long-term field studies, which are crucial to developing, validating, and applying effective remote sensing tools for hazard mitigation and water resource management; this type of effort has not been possible in the past. The ability to place graduate students into regions where they have two years of field work will produce higher quality theses, with much more thorough understanding of both the geological and social/cultural needs. The extended stays of the PC-MI students will allow for greater community comfort and personal relationships to grow, thus allowing for a freer exchange of knowledge between all those involved.

Provide international research experiences for U.S. students and faculty that will prepare them to work in the global research community. This program will support 1-2 post docs, 3 Ph.D., 9 Peace Corps Master's International, and 20 undergraduate students per year. They will benefit from long-term field campaigns which could not be obtained through standard academic programs, nor from the typical research proposals. The doctoral and post-doctoral research will require significant international collaboration throughout the four Latin countries. The Peace Corps participants who spend two years in the field will have a vast amount of experience and knowledge of the region, it's geology and culture, which will give them a decided advantage in career options.

Engage resources across a U.S. institution that will contribute to strong international partnerships. Michigan Tech will make much more focused and efficient use of teaching and research resources, engaging faculty from Geology, Geophysics, and Geological Engineering (natural hazards, volcanology, hydrogeology, remote sensing), Environmental Engineering (resource engineering), Forestry (Remote Sensing, GIS), Humanities (Latin Culture and Language). This project is sponsored by MTU's Remote Sensing Institute (PI Bluth, Director), a consortium of faculty and graduate students from nine different departments on campus.

Develop new collaborative models for international research and education. The scope of this project is quite large, as we fully expect this program to dominate our department's efforts for the next decade. The project will be sustainable through this period because a large portion of our departments faculty, resources, and coursework will respond to increased student demands for technical and cultural training. This project combines graduate and undergraduate education into meaningful applications and international experience, and develops a truly international collaboration through the sharing of resources among the project partners.

Raise the profile of international collaborative research and education within the U.S. research and education community. The MTU PC/MI program is already attracting national interest, and this project will help the program build to its fullest extent. The geoengineering Enterprise program will attract many more students as the word of this program is disseminated. We have experience in hosting international Remote Sensing workshops and publishing multidisciplinary volumes; these efforts serve to build the profile of the collaborative efforts through nationally recognized and respected dissemination pathways.

6. Management Plan

The research and education responsibilities are outlined in Table 3. We include the principal players, their affiliations, primary project responsibilities and advisorial roles for each. Note also that the post-doc researcher is a split position. Table 4 describes the project timeline, based on the research tasks outlined in section 3.

Travel logistics. The PIs collectively have a wealth of experience in travel to these countries in many of the activities outlined in this proposal. Although foreign travel logistics are rarely straightforward, planning for field work, vehicles, drivers, accommodations (including home stays), health issues and insurance, travel safety, weather conditions, shipping equipment, National holidays, and collaborating with foreign counterparts are all activities the PIs are experienced in planning and executing. Dr. Bluth has worked in volcanic studies extensively in Guatemala since 2001. Dr. Gierke and Ms. Gross are both familiar with water resource issues in Boaco, Nicaragua and traveled there last December. Dr. Rose has traveled to Guatemala every year since 1968 and has made countless trips to El Salvador and Nicaragua, as well as many visits to Ecuador for his volcano studies. Graduate students have accompanied the PIs on almost all of these trips and even a few undergraduate students have gone to some of the sites. Travel logistics will be somewhat more efficient for this project as it will be the first formal agreement between MTU with these agencies. First and foremost in the planning is safety for the participants in the field. Where necessary, security personnel are arranged through the foreign counterparts, as we have done in the past using either military or local police. All MTU participants traveling as part of this project will either have appropriate health insurance or appropriate short-term insurance will be obtained for them prior to the trip.

Assessment. This project will establish a new set of collaborative relationships with and among foreign groups and institutions in order to advance specific research and education objectives in areas of remote sensing pertaining to natural hazards and water resources. The project evaluation plan will encompass three aspects: (1) advancement in remote sensing techniques and their application in Pacific Latin America, (2) effectiveness of a new collaborative arrangement among researchers in Guatemala, El Salvador, Nicaragua, and Ecuador, and (3) impact of the international research and educational experiences on U.S. student (graduate and undergraduate) participants. To date, the PIs have project evaluation experience primarily with the educational aspects, using various assessment approaches to gauge the educational impacts (Frechtling, 2002; Manduca et al., 2002; Olds et al. 2005). An external evaluator that is able to assess the advancements made in the remote sensing techniques and their applications and the significance of the collaborations will be contracted for the project duration. Another

Table 3. Primary responsibilities for educational and research activities.

Person/Point of Contact	*Affiliation(s)*	*Primary Project Leadership Responsibilities*	*Student Advising*
Dr. Bluth	GMES[1], RSI[2], MTU	PI/PD, Volcanoes, Landslides & Remote Sensing	Ph.D., PC/MI, & URAs[3]
Dr. Gierke	GMES, Enterprise, SFI[4], MTU	Co-PI, Landslides & Water Resource Development/Protection	Ph.D., PC/MI, ATT[5] & URAs
Dr. Rose	GMES, RSI, MTU	Co-PI, Volcanoes & Remote Sensing, Hazard Communication	Ph.D., PC/MI, & URAs
Ms. Gross	GMES, MTU	Co-PI, Intercultural Interactions & Communications, Resource Protection	Intercultural Interactions
Post-Doctoral Researcher 1	GMES, RSI, MTU	Remote Sensing	Ph.D., PC/MI & URAs
Post-Doctoral Researcher 2	GMES, RSI, MTU	Modeling	Ph.D., PC/MI, ATT & URAs
Dr. Vallance	VDAP[6], USGS	Sharing Data & Hazard Mapping Tools	
Mr. Matias	INSIVUMEH[7], Guatemala	Gas Measurements, Field Stations, Hazard Mapping, Hydrological Studies	PC/MI
Mr. Galicia	CONRED[8], Guatemala	Field Logistics in Guatemala, Geographical Information Systems (GIS)	PC/MI
Dr. Castellanos	Universidad del Valle, Guatemala	Remote Sensing, Field Station	M.S., URAs
Dr. Strauch	INETER[9], Nicaragua	Remote Sensing, AVHRR Ground Station, Hydrological Studies	PC/MI
Mr. Pullinger	SNET[10], El Salvador	Remote Sensing Stations, Hydrological Studies, Slope Stability	PC/MI
Dr. Hall	Instituto Geofisico, Ecuador	Seismic Stations, Hazard Mapping, Geologic Mapping, Gas Measurements, Thermal Imagery, Lahar Warning Systems	PC/MI

[1]Geological & Mining Engineering & Sciences (GMES) Department, Michigan Technological University (MTU); [2]Remote Sensing Institute (RSI), Michigan Technological University (MTU); [3]Undergraduate Research Assistants (URAs); [4]Sustainable Futures Institute (SFI), Michigan Technological University (MTU); [5]Aqua Terra Tech (Undergraduate) Enterprise (ATT), Michigan Technological University (MTU); [6]Volcano Disaster Assistance Program (VDAP), U.S. Geological Survey (USGS); [7]Instituto Nacional de Sismología, Vulcanología, Meteorología, E Hidrología (INSIVUMEH); [8]Coordinadora Nacional para la Reduccion de Desastres (CONRED); [9]Instituto Nicaraguense de Estudios Territoriales (INETER); [10]Servicio Nacional de Estudios Territoriales (SNET)

evaluator will be tasked to develop the assessment plan for the educational aspects. For the educational assessment plan, a similar approach as taken by Huntoon et al. (2001), which built off of the Teaching goals Inventory (Angelo and Cross, 1993) and the national Science Education Standards (National Research Council, 1996), will be used. This uses an outcome-based approach (e.g., determining measurable changes in participant knowledge or perspective), to investigate the effectiveness of the project methodologies (Orion et al., 1997; Olds et al., 2005). Prior to beginning the field work planning and preparation, students will complete a pre-project assessment (e.g., Huntoon et al., 2001): a questionnaire that will gauge the students' level of knowledge of the work to be completed in the field, their lower and higher order cognitive skills, problem solving ability and confidence, attitudinal survey, and perceptions and interest in working internationally. Likewise, at the end of the program, an identical questionnaire will be administered to serve as the post-project assessment. A comparison of these surveys annually will allow for a thorough short-term investigation of the project's success. To evaluate the success of the project in the long-term, an on-going assessment will be completed by evaluating the participants at the end of the academic year and further on, as part of ongoing assessment practices in the College of Engineering at MTU, by tracking students' career choices and/or decision to seek higher education. The first two project years will focus on assessing the educational impacts and the significance of the collaborations. The advancement of remote sensing techniques and applications will undergo regular assessment starting in year 3.

Table 4. Project timeline.

Project Activity & Participant Involvement		***Year 1***			***Year 2***			***Year 3***			***Year 4***			***Year 5***		
		Fall	*Sprg*	*Sumr*	*Fall*	*Sprg*	*Sumr*	*Fall*	*Sprg*	*Sumr*	*Fall*	*Sprg*	*Sumr*	*Fall*	*Sprg*	*Sumr*
Volcanological Remote Sensing																
SO_2 Monitoring	Compile Existing Data	■	■		■	■		■	■		■	■		■	■	
	Perform Retrievals	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Field Sampling		■			■			■			■			■	
Volume & Topographic Changes	Compile Existing Data	■			■			■			■			■		
	Generate DEMs	■	■		■	■		■	■		■	■		■	■	
	Field Validation		■	■		■	■		■	■		■	■		■	■
Gas Flux Validation	Ground-based Spec.		■	■		■	■		■	■		■	■		■	■
	Validation of OMI		■	■		■	■		■	■		■	■		■	■
Eruption Forecasting	Gas & Ash Emission Data	■			■			■			■			■		
	Compile Seismicity	■			■			■			■			■		
	Relate to Lahar & Volcanic Activity		■	■		■	■		■	■		■	■		■	■
Landslide Hazard Mapping & Prediction	Landsat & ASTER Data	■									■					
	Slope & Vegetation Anal.		■									■				
	LAHARZ Modeling			■	■								■	■		
	Sampling & Mapping					■	■								■	■
	Sample Testing						■	■								■
	Model Development				■	■								■	■	
	Model Testing						■	■								■
Ground-water Development & Protection	Landsat & SPOT Data	■			■			■			■			■		
	Map Lineaments	■			■			■			■			■		
	Plan Surveys	■			■			■			■			■		
	Field Geophysical Surveys		■	■		■	■		■	■		■	■		■	
	Data Analysis		■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Conceptualize Model		■	■		■	■		■	■		■	■		■	
	Apply Models			■	■		■	■		■	■		■	■	■	■
	Dev. Recommendations				■			■			■			■		■
MI/PC Cohort 1	Geohazards Courses	■	■													
	PC Assignment				■	■	■	■	■	■						
	Return/Defend										■					
Cohort 2	Geohazards Courses				■	■										
	PC Assignment							■	■	■	■	■	■			
	Return/Defend													■		
Cohort 3	Geohazards Courses							■	■							
	PC Assignment										■	■	■	■	■	■
Cohort 4	Geohazards Courses										■	■				
	PC Assignment													■	■	■
Cohort 5	Geohazards Courses													■	■	
ATT Enterprise & URAs	Recruitment		■			■			■			■			■	
	Intercultural Interactions	■			■			■			■			■		
	Field Work Planning	■			■			■			■			■		
	Field Work		■	■		■	■	■	■	■		■	■		■	■
	Data Analysis				■	■		■	■		■	■		■	■	
PhD Student Research	Courses	■	■								■	■				
	Project Formulation	■									■					
	Research Plan Develop.		■									■				
	Research			■	■	■	■	■	■				■	■	■	■
	Dissertation Completion								■	■						
Post-Doctoral Research Associates	Recruitment	■							■							
	Project Formulation		■							■						
	Research Plan Develop.		■							■						
	Research			■	■	■	■	■	■		■	■	■	■	■	■

Recruitment. Recruitment of appropriate students for this work will not involve extra effort than we currently expend, as we currently receive and accept more applicants for our graduate programs than we can support. We will certainly have sufficient applications of qualified Ph.D. and PC/MI students. The ATT Enterprise continues to experience growth in student numbers and this project will only serve to attract more members. Both the PC/MI and Enterprise Programs are self selective for the types of students that are appropriate for this kind of work, as students in both programs are the type that seek out challenging projects that define the limits of a persons capabilities. Without even targeted recruiting efforts, ATT has already had 4 Spanish-speaking students join in the last 2 years. At the graduate level, women students outnumber male, and ATT is gender balanced. The selection of graduate applicants follows the standard departmental review procedures, which includes a committee evaluation of an application packet that consists of a standard form, statement of purpose, transcripts, GRE and TOEFL (if applicable) scores, and three letters of reference. Currently the ATT Enterprise selection involves an interview with the advisor, Dr. Gierke, but due to its rapid growth, policies for application and review are under development and will follow those that are used in industry.

7. Resources for International Activities

Existing MTU Peace Corps programs: There is a vibrant Peace Corps presence on the MTU campus. The first MI program was developed in Forestry, in 1996. It currently has about 30 students, with 10 on campus and 20 on their field assignments. An second program in Environmental Engineering was begun in 1998 (which also maintains roughly 20 students in the field, and 10 on campus).

Language and cultural training programs developed for the PC/MI program (http://geohazards.mtu.edu): GE5001 Intercultural Communication of Hazards; HU2293 Spanish Language and Culture Transition; HU3293 Spanish for Special Purposes; CE5993 Field Engineering in the Developing World; FW5770 Rural Community Development Analysis and Planning.

MTU's Remote Sensing Institute (RSI): a consortium of faculty and graduate students from 9 departments on campus. RSI maintains a computer network, a seminar series, a Remote Sensing minor program and supports graduate students and travel through its own budget.

International Remote Sensing workshops: MTU has hosted two such workshops, in 2001 and 2003 (Rose, 2003) with a third planned for summer 2006. MTU personnel have recently played prominent roles, as instructors for volcanic cloud analysis, for three other international remote sensing workshops, in Argentina (2002, 2004) and Nicaragua (2004).

USGS Volcano Disaster Assistance Program (VDAP): We maintain a solid connection with the VDAP program through Dr. Jim Vallance, a graduate of co-PI Rose (also a non-USGS VDAP member) and an adjunct faculty of our department at Michigan Tech. This group has helped us enormously both with expertise and field support for Central American studies.

8. Value of Partnership to MTU international programs and goals

This project would provide an enormous contribution in the following ways to the University's seven main strategic goals (http://www.mtu.edu/stratplan/): ***Learning***, by providing an outstanding and relevant learning environment; ***Scholarship***, by expanding our research activities; ***Size and Composition***, developing a diverse student body and faculty; ***Enrichment***, by providing diverse student experiences; ***Administration***, providing sound technological framework; ***Outreach***, by supporting economic development and public outreach; and ***Image***, by building the MTU reputation nationwide. MTU's International Programs and Services are committed to "meet the changing needs of a global, technological, diverse, and environmentally sensitive society." This project addresses those needs through our collaborative efforts, and the guidance of students through situations where they must apply their academic knowledge to problems which affect people directly and significantly; this is a strategy which is rarely addressed through U.S.-based education, because the problems faced here are so vastly different from developing nations.

9. Foreign Institutions Involved and Specific Contributions of Each

INSIVUMEH, Guatemala: expertise in volcanology, seismology and hydrology; GIS data for use in hazard maps; limited GIS and remote sensing experience; computer systems and data storage facilities; COSPEC for SO_2 measurements; field logistical support (vehicle); field observatory stations at Pacaya, Fuego, and Santiaguito volcanoes.

CONRED, Guatemala: several engineers with remote sensing workshop experience; GIS equipment; field logistical support (vehicle, driver, support staff).

Universidad del Valle, Guatemala: remote sensing computer laboratory and storage facilities; university labs and classrooms for workshops; field and lab assistance; field stations at Atitlán volcano.

INETER, Nicaragua: variety of earth science and remote sensing expertise; hosts annual remote sensing workshops; computer facilities; installed satellite ground station for AVHRR data

SNET, El Salvador: expertise in volcanology, hydrogeology and slope stability studies; limited field and lab assistance; facilities to set up remote sensing stations.

Instituto Geofisico, Ecuador: 14 volcanoes under observation, some with seismic stations; experience with satellite thermal imagery, geologic mapping, hazard mapping; ground-based COSPEC, GPS, thermal imagery, lahar warning systems; computer facilities; field logistical support.

10. Mechanisms for Sustainable Collaboration

We have already sustained a fairly long-term commitment to Central America; co-PI Rose has worked in Central America, particularly Guatemala, annually for over 35 years. However, the scope of this project goes beyond individual efforts. We have a vested interest in the region through our own students (Pullinger, Matías, Escobar, and currently Escobar Wolf), which is developing a solid base of support. The projects themselves are designed to build upon repetitive measurements of gas emissions, ashfalls, topography, thermal, which we anticipate will be incorporated into the standard monitoring methodologies. The student infrastructure at MTU, with the Peace Corps MI and Enterprise programs, facilitate a consistent source of student interest, and this is an area which we believe will drive our departments academic direction for many years. The Peace Corps programs at MTU have maintained a consistent level (the maximum, actually) for nearly a decade. As this project progresses, we will be able to contribute to the existing INETER-hosted workshops in a major way. This is crucial, because it is centered in the region; the regional interest in remote sensing is growing, and we simply hope to foster this interest to help the region develop their own collaborations and applications of remote sensing. Secondly, our past work in the region has culminated in large publications of collaborative efforts. We have published a volume on El Salvador hazards (Rose et al., 2004), have a second volume in progress on Central American hazards; an appropriate third effort would feature Remote Sensing as the focus.

11. Results from Prior NSF Support

SGER – Support for exploratory initial year of campus work for Master's International students in Geological Natural Hazards; Award EAR-0451447; $95,030 from 9/1/04 - 8/31/05; W.I. Rose and G.J.S. Bluth. This proposal provides support for 10 graduate students in a new Peace Corps/Master's International (PC/MI) Natural Hazards program at Michigan Tech, and is the first of its kind in the Geosciences. The program includes a two-year Peace Corps field assignment in either Guatemala, El Salvador, Nicaragua or Ecuador. The NSF funding is meant to allow exploratory evaluation of the recruitment potential of this program, and to assess the potential of Peace Corps collaboration with Earth Science curricula in Natural Hazards. The program is designed to emphasize a substantial social component in natural hazards work, multicultural foreign practical experience, and to facilitate long-term direct contact with active natural hazards. This funding began after the Spring 2004 recruiting season; however, we still attracted six excellent students starting Fall 2004; another began Spring 2005. All of the PC/MI students began investigating potential field sites during their first term at MTU; co-PI's Gierke and Gross visited Boaco last December to establish relationships with the local water agencies and plan future research and engineering directions. Placement procedures have already occurred for three of our existing PC/MI students; one will be performing hazard education and monitoring at Cotapaxi volcano, Ecuador in conjunction with the Instituto Geofisico; another at Fuego volcano, Guatemala with INSIVUMEH; and the third (Co-PI Gross) will be in water resources in the Boaco region of Nicaragua. Currently we have 8 new students accepted into the program for Fall 2005, from universities nationwide.

US-El Salvador-Guatemala Collaborative Research: Volcanic Hazard Mitigation Award # 0118587; $60,000 from 5/01-5/04; W.I. Rose and J.W. Vallance. This project funded field research visits by U.S. scientists to work with Guatemalan and Salvadoran professionals to help build infrastructural capability for volcanic hazards mitigation in both countries, and for travel of Central American professionals to the U.S. The project sponsored work on volcanic caldera lake chemistry, volcanic hazards of Ilopango caldera, hazard studies of San Miguel Volcano, comprehensive studies at Santiaguito, and continuing work at Pacaya and Fuego. The project was also supported by $85K from USAID which included scholarships for two Central American professionals, Otoniel Matías, who completed his B.S. in Geology at Michigan Tech in 2002, and Demetrio Escobar, who received his M.S. degree in 2003. A report to the geophysical community was published in Eos (Bluth and Rose, 2002) and the main outreach project was a Geological Society of America Special Paper with 40 scientific papers about physical and social aspects of natural hazards in El Salvador (Rose et al., 2004).

Geology of Utah's National Parks and Monuments: Education Materials for Earth Science Courses. Award # 9950213; $428,131 from 7/15/99 to 6/30/03; J.E. Huntoon, G.J. Bluth, and W.A. Kennedy. Funds were used to develop, evaluate, and disseminate three components of an introductory earth science multimedia laboratory (http://www.ehr.nsf.gov/PIRSWeb/Doc/9950213.htm). This project developed CD-ROM based activities that integrate the components of a field course taught in the National Parks and Monuments of southeastern Utah. The course and the CD incorporate a variety of teaching methods to communicate fundamental geologic principles and concepts. The materials target lower division undergraduate students and K-12 teachers. The multimedia laboratory is designed to help university undergraduates and secondary school earth science teachers to understand information using an earth system approach. The content of the multimedia laboratory encourages problem-solving on the part of users and the ability to integrate information from a variety of sources. Quantitative and qualitative assessment vehicles, including diagnostic learning logs, pre-test/post-test attitude surveys, and an instrument to measure higher-order cognition were used by students and teachers who participate in the project to determine the materials success at teaching basic geologic concepts. Project dissemination included 6 publications and 7 presentations; tangible products include a CD-ROM "virtual" field course, extensive lesson plans, rock samples, and an instructional video detailing some of the field techniques used by students and teachers in this course (Bluth and Huntoon, 2001). Project participants included undergraduate students, pre-service teachers, in-service teachers, minorities, and graduate students. The major research and education activities were tested in part by the PI's during the field-based version of the course (Huntoon et al., 2001). Based on participant assessments, the project consistently produced a significant (>20%) increase in scores on technical skills, scientific concepts, and open-ended concepts.

Volcano-atmosphere interactions: the first week; Award # EAR 0106875; $259,000 from 5/01/01-4/30/03; W.I. Rose. The focus of our project was to apply all of our current methods for satellite-based sensing of volcanic clouds to two recent eruptions, the February 2000 Hekla event and the February-March 2001 eruption of Cleveland. Advances in satellite retrievals enable us to get quantitative estimates of SO_2 (three different methods), ash, ice and sulfate for volcanic clouds during periods lasting from hours to days, mapping of the 2D positions of volcanic clouds, and the separation of ash and SO_2. Tangible results from this project were six major publications: (1) A comprehensive paper in the AGU Volcanism/ Climate volume about the February Hekla eruption, including results from many satellite-based volcanic cloud sensors and research aircraft validations (Rose et al., 2003). This is the most robust data set ever analyzed to assess the first few days of stratospheric residence of a volcanic cloud; (2) A paper about MODIS results on volcanic clouds (Watson et al., 2004).; (3) Development of a forward model of radiative transfer of volcanic clouds is completed (Watson et al., in review); and (4) Demonstration of a new scheme for atmospheric corrections of IR ash size and mass retrievals (Yu et al., 2002). In addition, this project has supported the doctoral research of Colleen Riley (2002), who studied the fallout of fine ash from earth's atmosphere and Song Guo (2004) who re-evaluated remote sensing data for the 1992 Pinatubo eruption, the largest of the satellite era (Guo et al., 2004a; 2004b).