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" Characterization of volcanic regimes using continuous seismic data... and possibly more! "

BOOK OF ABSTRACTS

Seismic and Volcano Seismic monitoring in Nicaragua

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History. The history of the Nicaraguan seismic network in Nicaragua started in 1968 when accelerographs were installed in Managua. These equipments recorded the disastrous Managua earthquake in 1972. In 1975, a telemetric seismic network was installed in Western Nicaragua (http://www.ineter.gob.ni/geofisica/boletin/1975/03-06/index.html). Recording was on 16mm photographic film (develocorder). This network worked fairly well until the mid 1980ies when it degraded substantially. In 1992, a new development was initiated. A central digital recording (SEISLOG) and analysis (SEISAN) unit was installed, seismic stations were recovered and new sites were opened. Soon it became the largest seismic network in Central America. In the last years the network was greatly upgraded and extended utilizing funding from several projects.

Seismic stations are now mostly of digital type with a 24-bit digitizers and a local processor which organizes digital recording on hard disk and data communication. The network counts with 16 broad band stations (2 STS-2, 14 Trillium), 50 short period stations, 2 small seismic arrays (experimental), and 20 digital accelerographs.

Data Communications. In Western Nicaragua, especially in the volcanic chain, a wireless digital communications network was put in place to serve the monitoring and early warning system. Most seismic stations are connected via wireless communication, WAN, LAN or INTERNET to INETER´s Monitoring and Early Warning Center. An important progress was the extension of the network towards the Central and Atlantic regions of Nicaragua

The Monitoring and Early Warning Center at INETER works on a 24x7 base and processes all registered seismic events in near real time. In case of strong seismic events, volcanic unrest or the possibility of tsunami occurrence an information or warning message is sent by email, and fax a few minutes after the event was detected to more than 70 institutions in Nicaragua and Central America. Seismic recordings, hypocenter data, epicenter maps and fast information messages are published in near real time on the web site of INETER. .

For the Registration and processing of seismic network data a hardware and software system was configured. for the automatic registration of seismic events, automatic preprocessing and interactive final processing. Earthworm software under Windows OS is used for the registration of the digital data stream coming in permanently, in real time from the seismic stations. In total, the system records more than 150 channels with sampling frequencies of 20, 50 or 100 Hz. Main parts of the recording and data processing system are doubled to have the redundancy necessary to guarantee the performance of the seismic data center in case of failure of a hardware or software component or during maintenance of parts of the system. That means, that two identical data streams are transmitted from each of the Nicaraguan seismic stations to feed the two Earthworm systems.

Data recording of all data is continuous and stored in a ring buffer for about 3 days. For broad band stations and one seismic station at each active volcano the continuous data stream is archived permanently in Miniseed format. For other stations only detected events are stored permanently, in Seisan format. Many data channels are bandpass filtered to improve seismic event detection. The total of seismic stations is divided in different groups and detection schemes are used to perform detection according the characteristics of the various station groups of the network and the seismicity expected in different parts of the monitored area. Final locations and magnitude determinations are obtained by interactive processing carried out by the seismologist on duty using SEISAN software on SUN Workstations (SOLARIS). RSAM and SSAM is calculated continuously for seismic stations located near the active volcanoes to be used for eruption prediction.

Volcano-seismic monitoring. Many seismic stations are installed in the Nicaraguan volcanic chain to be used for volcano monitoring and eruption warning. Each of the 6 active volcanoes has at least one broad band station and some additional short period stations near the crater area. Volcanoes Cerro Negro and Telica count now with dense local networks of 10 or 6 stations, respectively. In 2008 a local network will be installed at Concepción volcano. Many of the not active volcanic complexes have also at least one station installed to detect the possible reawakening of activity. A small seismic array is in development at Cerro Negro volcano for volcano monitoring.

Virtual regional network. Around 50 stations from other Central American countries, North and South America and the Caribbean region are recorded in real time. Seismic data from Nicaraguan stations are transmitted to several institutions in Central America as well to IRIS(USA), GEOFON (Germany) and Puerto Rico Seismic Network (PRSN) which serves as a node for the emergent tsunami warning system for the Caribbean Sea. These data are of importance for the rapid information about large earthquakes in and near Central America and for tsunami warning.

A small seismic array with 5 sensors is installed at INETER´s headquarters in Managua for experimenting with array methods for local and regional monitoring and fast processing of strong earthquakes.

A Regional seismic array at the Nicaraguan Atlantic coast is to be installed in the Eastern part of Nicaragua**.** INETER has acquired the equipment for the installation of 8 short period sensors and the communications network. The objective is to improve the seismic monitoring of the Atlantic region of Nicaragua and of the Caribbean Sea. The array will also help to improve the capacity of the national and regional tsunami warning system with fast epicenter determinations. The array will be installed until the end of 2008.

A mobile seismic network with 15 stations **is acquired by** INETER, in cooperation with the local private company GEONICA, This equipment is intended to be used for temporal studies on local seismicity, for aftershock monitoring and crustal structure investigations. This network will be operating in a first temporal project at the end of 2008. **Tsunami warning system.** After the destructive tsunami which struck, in 1992, the Pacific coast of Nicaragua INETER worked on tsunami disaster prevention and the development of a tsunami warning system. Actually Nicaragua counts with tsunami hazard maps on different scales for the Pacific coast. The Nicaraguan tsunami warning system is based on INETER ´s seismic monitoring system and communications facilities of the Nicaraguan Civil Defense. Several projects were executed with local administrations, governmental institutions, NGO´s, for hazard mapping, determination of tsunami evacuation routes, installation of tsunami signs, and execution of evacuation exercises in schools located near the beach. INETER promoted the development of a regional tsunami warning system for Central America. **Central American cooperation.** In 2007/2008 INETER supported the installation of 5 digital seismic stations in Honduras in cooperation with UNAH and COPECO.

New local seismic networks and disaster prevention measures at volcanoes Cerro Negro and Telica, Nicaragua.

Emilio Talavera , INETER, Nicaragua

In 2006-2008 local seismic networks were installed at Cerro Negro and Telica volcanoes, Nicaragua. The stations are of digital type and data transmission is continuously to INETER´s monitoring center in Managua. The networks are part of an Early Warning System for the prevention of volcanic disasters which also includes communications systems with the population living near the volcanoes. The installation of the networks is part of projects which were realized in cooperation with CARE. Another local seismic monitoring network will be installed at Concepción volcano, Ometepe Island in Lake Nicaragua, in 2008 and 2009.

Volcanic Hazard Maps in Nicaragua.

Angélica Muñoz, INETER Nicaragua

In the last years, comprehensive hazard maps were elaborated for the active volcanoes in Nicaragua. The data used for these maps are available in INETER´s GIS on Georisks and can be used for further investigations.

Temperature monitoring at volcanoes Cerro Negro, Telica and Masaya.

Julio Alvarez.INETER

Temperature measurements are carried out monthly in the crater areas of the active volcanoes in Nicragaua, San Cristóbal, Telica, Cerro Negro, Momotombo, Masaya, Concepción. Additionally in some fumaroles areas and hot springs of other volcanoes as Mombacho, Cosigüina, in Tipitapa. Data aree published in the Monthly Bulletin and are correlated with other data obtained from the volcano to be used for eruption prediction.

Geographical Information System (GIS) on Geo-Risks in Nicaragua and Central America

Wilfried Strauch, BGR, Project on Geo-Risks

INETER´s Geophysical Department, in cooperation with national and international institutions (eg. long term cooperation on GIS Disaster mitigation and development with Bundesanstalt für Geowissenschaften und Rohstoffe, BGR, Germany) , has developed and applied a Geographical Information System on Geo-Risks in Nicaragua. A data base was created which includes information on dangerous geological and hydro-meteorological phenomena on one side and elements under risk on the other side; geographical information, air and satellite photos were integrated. Volcano hazard related data cover a mayor part of the data base.

A multidisciplinary group was formed in which geologists, seismologists, volcanologists, informatics specialists, from Geophysical department learned to develop and use the GIS for the realization of the daily work, for project work and to respond requests from the government, emergency commission, or the population. The generation and publication of high quality maps is a central task of this group.

The GIS is pretended to interact in real time with the monitoring and early warning system. A map server (ArcIMS software) presents in real time seismic epicenters and other geological phenomena together with maps, air photos, satellite images, population density and other information.

The GIS infrastructure and its data bases were already utilized in numerous projects. Besides its main routine task - monitoring and early warning of the dangerous phenomena - INETER/Geophysics works intensely with projects dedicated to 1) the further development of the monitoring and early warning system, 2) on the mapping of geologic hazards, vulnerability and risks in Nicaragua, 3) on the further development of the Georisks GIS. Since 1997, INETER/Geophysics has carried out supervised or participated in more than 60 projects, most of them in cooperation with foreign institutions, or financed by foreign funds and/or from the Government of Nicaragua.

Most of the projects are related to the prevention and mitigation of disaster for large parts of the Nicaraguan population. Some projects have a strong social component. E.g. in the project in execution together with the Nicaraguan Institute of House Construction in Rural Areas (INVUR) and local administrations there were investigated the natural hazards in more than 90 sites. These sites are located mainly in rural areas throughout Nicaragua, where local administrations proposed to construct new houses. Up to now, these studies made sure for more than 7,000 families that their new homes will be build in safe areas. (www.ineter.gob.ni/geofisica/proyectos.html)

Seismic Activity of the volcano San Cristobal, Nicaragua during its eruption in April 2006.

Virginia Tenorio, INETER, Nicaragua

The San Cristobal volcano, 12.70 º N, 87.02 º W, Elevation: 1745 meters above sea level is a strato-volcano, located 150 km north of Managua The volcano entered the April 21, 2006, into a new stage of eruptive activity. The volcano's seismic tremor was increased from 10 units (base value), reaching 400 units RSAM, remaining on until April 22, oscillating between 380 and 440 units RSAM, with short episodes of 700 units RSAM. From the morning of day 22, there was observed a small column of gas, steadily. On the afternoon of April 23 there occurred the first freato-magmatic explosion. This and following explosions were small and the small amount of ash that fell in towns to the east of the volcano was tolerable by the people. After two days, the seismic tremor of the San Cristobal volcano was no longer almost continuous but very pronounced in periods of about an hour. In each period, there was a stage with up to 800 RSAM tremor and high peaks up to 1500 units. The high tremor phases lasted about half an hour and were accompanied by explosions in the crater. Then volcano went quiet for half an hour. Then began another period with strong tremor and explosions. This process continued until the end of April with amplitudes RSAM diminishing and the explosions in the crater becoming less prominent. INETER intensified the visual observations and revised the system of seismic monitoring stations, weather stations, high-precision GPS and Web cameras in the area. MiniDOAS profiles were conducted to determine the amount of gases produced by the volcano. We analyzed the behavior of the historical San Cristobal and geological data on eruptions occurred in the volcano. The result was that the behavior of the volcano was controlled by an interaction of magma in the volcano with water tables. Due to the low intensity of the phenomena and the absence of other strong indications it was concluded that there was no excessive danger to the public, at this moment, but it was felt that in the coming weeks the following could occur: 1) Increased occurrence of lahars during the rainy season, the cast and material deposited on the flanks of the volcano. 2) Continuation of the progress of the magma to the surface that caused the freato-magmatic phenomena, and within a few weeks or months, a magmatic eruption larger of which the observed activity was only premonitoring episode. Therefore, INETER intensified monitoring for the volcano and presented these considerations to the System for Prevention, Mitigation and Attention to Disasters (SINAPRED). In response to these recommendations, SINAPRED defined the level of "green alert" for the municipalities of Chinandega, Chichigalpa and El Viejo, from the day on April 26, 2006, staying in place for four weeks. Fortunately, the volcano did not enter into mayor activity, but remained relatively quiet.

Analysis of the Seismic Activity of the Colima Volcano, using RSEM, BLNSS and Correlation Functions, from 2004 to 2005.

Arámbula-Mendoza, R[1]., Valdés-González, C[1]., Lesage, P[2]., Varley, N[3]., Reyes-Davila, G[4].

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The Colima volcano is the most active of Mexico, during the last years has show effusive and explosive eruptions. The cycle eruptive from 2004 to 2005 was a period of great activity, this stage beginning from March to September of the 2005, several vulcanian explosions with the generation of pyroclastic flows occurred as a result of the destruction of a lava dome created in September of the 2004. We have analyzed the eruptive activity of Colima volcano for this period, using a continuous seismic analysis, RSEM (Real-time Seismic Energy) and BLNSS (Base Noise Level Seismic Spectrum). Likewise we have done analysis of long period events (LP's), with functions of correlation to find if exist families that proceeded to the explosions.

We found that there are families that exist just before the explosions and that can serve as precursors, likewise observed that there are events that are not affected by these explosions. We also obtained the inverse values of RSEM and compared our results to the FFM (Material Failure Forecast Method), to determine the time of occurrence for each explosion. The analysis of the data analyzed on this work correspond to records from a permanent short-period station (Soma, EZV4), located 1.7 km away from the crater.

Application of Self Organizing Maps to the characterization of volcanic regimes

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L. Barbui (University of Udine, Italy)
P. Malisan (University of Udine, Italy)
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The characterization of regimes at an active volcano starts from a phase of data reduction, when spectral, dynamical and/or stochastic parameters can be computed on successive time windows which duration determines a new time scale, that typically goes from seconds to hours. The resulting parameter vectors (also called feature vectors) can then be used to try to automatically classify the different phases of the volcanic activity, possibly also looking for precursors. This classification can be done using many possible approaches, most of them using "machines" than have to be trained before they can be applied to classify data. The training procedure can in turn be supervised or unsupervised. In this talk we present the approach of Self Organizing Maps (SOM for short), an example of unsupervised machine, together with case studies of application to volcanic tremor recorded at Raoul Island and Ruapehu volcanoes in New Zealand.

Configuring an automatic volcanological observatory able to operate in unattended areas: the example of Deception Island, Antarctica

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One of the major problems in installing a volcanological observatory to operate in isolated areas is the power supply energy and its maintenance. This also affects and reduces the chance of real-time data transmission. However, the possibility to get indication of the current status and possible changes of the volcanic activity may be done by transmitting a set of reduced information obtained by means of an automatic analysis. The selection of the appropriate parameters may be sufficient to dispose of enough information to forecast and provide alert levels. As a continuation of the studies initiated in 1986, a system designed in the MNCN-CSIC to operate in Deception Island (Antarctica) will be installed in short.

Monitoring the activity of the Teide volcano (Tenerife island, Spain) through the analysis of continuous seismic data.

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The reawakening of the Teide volcano in 2004 suggested the installation of several seismic stations, operating in continuous mode. This allowed the application of different techniques of time series data analysis. The results show that analysis of the background seismic noise in the surroundings of the volcano not only allows forecasting the occurrence of tectonic (volcanotectonic??) events but also the tectonic events have a clear influence in the variation of the background noise characteristics.

Mid-Atlantic rift volcano Askja in Iceland: seismic observations

Heidi Soosalu, Janet Key, Robert S. White, Páll Einarsson and Steinunn S. Jakobsdóttir

Askja is one of the active volcanic systems along the north Iceland rift. It has a caldera complex and a transsecting fissure swarm. The latest major, explosive and caldera-building eruption of Askja occurred in 1875 and the latest minor eruption in 1961. Geodetic and gravimetric data point to a dual magma chamber system at Askja: a shallow one centred at ~3 km depth and a deep one at ~16 km. Small-scale (magnitude < 3) upper-crustal seismicity, at < 8 km depths, is well documented within the Askja caldera and the surrounding area. Our unexpected discovery is persistent lower-crustal seismicity, at 13–27 km depth, at the roots of the Askja system and in the vicinity. Earthquakes are small in size (magnitudes < 2), occur typically in swarms lasting a few minutes, and have distinctly different waveforms to the ordinary upper-crustal earthquakes. We interpret the lower-crustal earthquakes to be caused by magma movement from beneath Askja, along its fissure swarm towards the northeast.

We have run temporary seismic networks at Askja since the summer 2005, during the accessible field season in July-August. The episodic nature of Askja seismicity has prompted us to install a longer-term network. A 5-station trial network in winter 2007-2008, equipped with several solar panels and large batteries is now expanded to a 15-station network, planned to be run until end-summer 2010.

Deep crustal seismicity beneath Askja volcano, central Iceland: interpretations and future work.

J. Key, H. Soosalu, R.S. White, J. Drew, P. Einarsson and S.S. Jakobsdottir

Lower-crustal earthquakes in the region surrounding Askja volcano on the plate spreading boundary in central Iceland were first discovered with a temporary network of broadband seismometers operated during summer 2006. Subsequent deployments in summer 2007 and winter 2007/2008 have found that this activity in ongoing, with more than 350 such events now recorded. They are located at depths of 13 – 27 km, in the normally aseismic zone well below the brittle-ductile boundary in the region. They are distinctly different in appearance to the well documented shallow earthquakes in the area, with more emergent P- and S-phases and a lower frequency content. The majority occur in a region extending 10 km to the NE of the Askja caldera; a second cluster is located a further 25 km to the NE on the same SW-NE trend. A third cluster is located halfway between the volcanic systems of Askja and Kverkfjöll and is possibly related to a cluster of seismicity beneath Upptyppingar mountain that started in February 2007.

These events have been located using both hand-picked first arrivals and additionally by a new detection and location program developed at the University of Cambridge and these locations are compared. Initial work on fault plane solutions for the deep events will also be shown.

The lower-crustal events are interpreted as melt related, caused by the high strain rates generated at the tips of propagating dykes. Askja has been deflating for the last 30 years after the last eruption in 1961 and this could be the first sign of new activity at Askja.

Large scale deformation in Lastarria volcano and associated seismicity

D. Legrand., J-L Froger, D. Remy, S. Bonvalot, G. Gabalda

InSAR data on Lastarria volcano, Northern Chile, show a persistent two large ground inflations, one of about 40km length and a velocity of about 2.5 cm/yr and another of about 6 km length located on the Lastarria volcano from March 2003 to May 2005. In may 2006, one broad-band seismic station has been install for 2 weeks in order to check if these deformations were associated with seismic signals. These deformations are related with a persistent seismicity of different characteristics of about 10 events / hour that is classified and study.

Seismicity of Kluchevskoy volcano within 1999-2007. Spatio-temporal analysis of the earthquakes.

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There was carried out spatio-temporal analysis of the Kluchevskoy volcano earthquakes within 01.01.1999-31.12.2007. B-value and a seismic energy center were investigated for the seismic precursor study of the eruptions in terminal crater. Lifting of seismic energy center was fixed before all three terminal eruptions of Kluchevskoy volcano from depth ~30 km to crater. Such lifting can be a good seismic precursor before terminal eruption of this volcano.

Moment tensors for Very Long Period signals at Etna Volcano, Italy

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Very long period signals (10 s - 30 s) have been observed at Etna Volcano, Italy, in conjunction with long period events (0.5 Hz - 5 Hz). They are only recorded at the broadband stations nearest to Etna's craters, ECPN, EBEL, EPDN and EPLC. Although the signal-to-noise (S/N) ratio for these signals is in general only poor to fair, they seem to recur, and can be classified into two families. To improve the S/N ratio, we crosscorrelated (correlation > 0.95) the causally bandpass filtered (0.033 - 0.16 Hz) VLP signals, and then for each component and family, stacked them. 194 members contributed to the stack for Family I and 87 members for Family II. During the stacking process we retained absolute timing among components and between the four stations, as well as the absolute signal amplitudes. The difference between Families I and II is clear in the stacks: Family I begins with positive and Family I
I with negative ground motion on the Z component. Nonetheless, particle motion is similar for both families. The ground motion is much larger at ECPN and EPDN, respectively to the SW and NE of the active craters, and radially polarized. This suggests that a crack-type model may best represent the source of these signals. We determined full moment tensors for the two representative waveform sets, using synthetic Greens functions calculated for a homogeneous halfspace (vp=2.0 km/s, vs=1.2 km/s). Since the periods are very long and the source presumably close to the stations, heterogeneity and velocity variations will have relatively little effect. We search through a grid on a 250 m spacing to determine the point source location and the full moment tensor solution (DC, CLVD and ISO) with the best variance reduction. For both families,
the source region with the highest variance reduction lies approximately beneath the active craters, at an altitude of approximately 2500 m below the altitudes of the stations. The solutions are very similar for Families I and II with sources that are 60% and 70% isotropic (ISO), respectively. The remaining energy seems to be fit rather arbitrarily by double-couple (DC) and compensated-linear-vector-dipole (CLVD) depending on the source location. Most likely this is an attempt by the inversion to fit the remaining relatively high level of noise.

Seismic array analysis of Tornillo-like signals recorded in a non- volcanic area of Italy

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With the scientific purpose to monitor the micro-seismicity in the Central Apennines, we recently deployed in Eastern Tuscany (Casentino) a temporary 12 element seismic array, composed exclusively of 3-component seismometers. During the one month of registration we recorded an unexpected high rate of local micro-seismicity with up to 180 events per day.
Waveforms surprisingly resembled volcano-seismic events rather than tectonic earthquakes. Distinct P and S-phases with a sharp onset are missing. Seismograms show an emergent onset followed after a few seconds by a weakly attenuated monochromatic coda, similar to "Tornillos" known from active volcanoes like e.g. Galeras. More than 5000 Grapillos (Gas-Related APenninic Tornillos) have been recorded during the one month recording period, showing all similar amplitudes but irregular temporal occurrence. Locations of the Grapillos were determined by automated f-k analysis. Wavefronts reach the array from NW (306°) with a slowness 20 s/deg (v_{app}~5.32 km/s), corresponding to an epicentre location 13 km NW respect to the array centre. Source locations seem to remain rather stable for the entire duration of the array installation.
At the end of the experiment some of the array stations were used to set up a small network around the epicentral area. Classical hypocentral determination - using exclusively first onsets - confirmed the epicentres found by f-k analysis and determine for the Grapillos a distinct focal depth of ca. 4 km.
Concerning the origin of the unusual seismic events geothermal and volcanic activity can be excluded "a priori". However, in the nearly situated Upper Tiber Valley many cold CO_2 springs (Mofettes) can be observed on the surface since decades. Pulsation and transients in gas flux have been observed at known Mofettes and are possibly caused by tectonic transients. However, in the epicentral area currently no gas Mofettes are known. We speculate, that the origin of the "Tornillo"-like seismic signals could be related to transients in an unknown CO_2 reservoir inside the upper crust.

Preliminary Insights Into a Continuous Seismic Data Set Recorded in 2008 at Yasur Volcano (Vanuatu)

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We present preliminary observations from a temporary seismic network which we operate since January 2008 around Yasur volcano. The volcano is located in the southern part of the Vanuatu arc, on the island of Tanna. It has a permanent strombolian activity which is at a relatively high level since the installation of the network, with commonly several explosions per minute. Our network includes up to 22 stations. Twelve antennas were first installed in January, each including up to 7 short period sensors: one 3-component and 6 single-component vertical sensors. In May, 10 broadband stations equipped with 30 s Guralp CMG-40 seismometers were added. The experiment is still ongoing. The network records an intense seismic activity with thousands of short period transients per day, as well as a strong very long period seismicity below 1 Hz. We present here mostly results about the short period transients. According to video recordings, most of these signals are directly related to the strombolian explosions. Fewer signals are not accompanied by any surface activity. The explosion quakes mostly contain frequencies below 4-5 Hz and often include a short higher frequency acoustic phase. We scanned the 5 months of continuous data available until now with several pre-defined master events and show that a large part of the transients can be grouped into families of similar events. This result suggests the explosive activity is characterized by the presence of dominant modes of resonance of the conduit in response to the gas slug ascents causing the explosions. These modes were apparently affected by the occurrence of a M=7.3 earthquake on April 9 about 50 km

offshore of the island. While the earthquake did not significantly change the surface morphology of the volcano nor the intensity of the eruptive activity, it apparently caused significant changes to the resonance of the conduit as no similar family of explosion quakes is observed both before and after the earthquake.

Seismic monitoring of Tungurahua volcano: 1989-2008

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Tungurahua volcano is one of the most active volcanoes in the Northern Andean Volcanic Zone with 70 eruptions in the last 3,000 years. In July 1989, a short-period telemetered seismic station was installed on the volcano flanks. A low-level seismic activity was found using this station (15 local events mainly volcano-tectonic events per month). Monitoring capabilities were enhanced with the addition of 4 telemetric stations in January 1993. In April 1994, an important increase volcanic tremor began in Tungurahua volcano. Waveforms showed dominant frequencies in the range of 1.4-2.2 Hz over distances upto 6 km from the crater. Several long-duration high-frequency cigar-shape signals were also detected, although there was not evidence for an imminent eruption.

In late 1998 and during 1999 increasing seismicity and fumarolic activity were observed. In October 5 1999, the first explosion of a new eruptive period occurred in Tungurahua. It was followed by a significant explosive activity in November-December 1999. Since the sizable eruptive activity in late 1999 ended Tungurahua exhibited four eruptive cycles that preceded the climatic eruptions of July 14-15, 2006 (VEI=2); August 16-17, 2006 (VEI=3). Starting July 2007, a new explosive cycle reaching more than 300 explosions ended with a moderate eruption on February 5-6, 2008. Minor eruptive episodes occurred between May and August 2008.

Four different types of infrasound signals have been observed at Tungurahua volcano during nine years of non-steady eruptive activity: Explosions, Infrasound tremors, Roars, and Chugs. More than 20,000 explosions events have been identified using air-coupled waves on seismograms. Using infrasound microphones, they show impulsive waveforms that usually are followed by ash columns and ballistic fragments. Pressure histories of these events show a sharp impulse followed by a slow rarefaction lasting about 4-5 s. Infrasound tremors accompanied major Tungurahua eruptions (July 14-15, 2006; August 16-17, 2006; February 5-6, 2008) and moderate eruptive episodes in 2007 and 2008. Spectra of infrasonic tremors display peaks in the range of 0.5 to 2 Hz. Roars signals are short-duration spindle-shaped waveforms with broad spectral content. Roars have been related to non-impulsive degassing and puffing from the vent. Although barely seen in andesitic volcanoes, clear episodes of chugging events have been recorded in Tungurahua. These events followed large explosions in the aftermath of the July 14-15, 2006 eruption and also they appeared after moderate infrasound tremors in June 2008. At stations close to the vent, they exhibit pulsing waveforms with up to six overtones and frequency gliding effect. At farthest stations, chugging infrasound records look like tremor events, showing significant signal degradation with distance.

Currently a network of 10 seismic stations (4 broad-band plus 6 short-period), 3 infrasonic sensors, 2 tiltmeters, 2 GPS receivers, COSPEC, DOAS, and a FLIR camera, are monitoring Tungurahua volcano.

Unrest of Turrialba volcano (Costa Rica): analysis and multidisciplinary interpretation of seismic observations.

Martini, F., and the Volcano Monitoring Group,
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Turrialba is a basaltic-andesitic stratovolcano, 3340 m a.s.l., in the Cordillera Volcánica Central in Costa Rica. Since the last eruption in 1864-1866, volcanic manifestations were limited to low temperature fumarolic degassing (continuous since 1980) through its Central and West craters. From 1996 onward, its activity has been progressively increasing, with the occurrence of several seismic swarms. An increment in the number of fumaroles and level of degassing has been observed at the occurrence of each seismic swarm. New fumaroles have appeared in both Central and West craters (the latter now being the most active), and in the fracture system in between, showing sulfur deposits and progressively increasing degassing levels. Recently, fumaroles and new cracks have been appearing on the external flanks, and strong degassing has been observed as far as 1.3 km SW of the summit, along a major tectonic fault.
The maximum seismic activity to date was recorded in mid 2007 with swarms of up to thousands volcano-tectonic-type of events/day. This peak in seismic activity has marked an important change in the seismicity patterns as well as geochemical, geodetical and field observations. Since late 2007, gas-driven events have dominated the seismicity, sometimes followed by

episodes of harmonic tremor. Temperatures measured at fumaroles in the bottom of the Western crater have increased from 90° to 280° C in recent months, while pH of fumarolic condensates at the same crater has decreased to values as low as 0,55 and their solute concentrations have largely increased. Changes in the fumarolic gas composition, isotopic composition of the condensates as well as in rainwater samples collected in the surroundings of the volcano have been showing a progressively higher magmatic signature, possibly interacting with a shallow hydrothermal system. Since late 2007, SO_2 flux measured with mini-DOAS has increased two orders of magnitude (1 ton/day in 2002 to 740 tons/day in January 2008). The enhanced gas discharge at Turrialba volcano has caused significant interference on troposphere O_3 measurements at 2-3 km altitude ~50 km W from the volcano. Geodetical data have shown an inflationary trend in the crater area.
In this work, we present a summary of the activity of the volcano and the data collected over the last decade and the initial results obtained from analysis of the seismic data, with a particular emphasis on the changes occurred over the last 2 years. Integrating the geochemistry, geophysical, geodetical, and field data available, we present an interpretation of the seismic observations and the current status of the volcano.

Multi Method Approach for the Remote Monitoring of Arenal Volcano (Costa Rica)

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In the past few years, efforts have been made to combine multiple geophysical methods for the remote monitoring of explosive volcanic activity, in hope to gain better insight on the eruptive dynamic mechanisms. Several field campaigns have been carried out on Arenal volcano (Costa Rica) to study its eruptive activit. Datas of February 2004 and 2005 included ground-based Doppler Radar measurements (VOLDORAD, OPGC) of velocities and power backscattered by particles inside volcanic jets/plumes, along with broad-band seismic records (UCR, LGIT). From 2005 to 2007, acoustic (UCR, LGIT) and seismic data were recorded continuously. We present hereafter the preliminary correlations sketched between the different geophysical signals.
"Seismo-Radar Analysis" has been designed during July and August 2008 to visualize both seismic and radar data on a unique graphical interface, and calculate basic parameters for both data types. Preliminary observations indicate that radar signals (hence when ash is ejected) are accompagnied by 3 types of seismic signals: high frequency signal, harmonic tremor, and / or LP event/explosion quake. The first type seems to be systematically present, beginning a few seconds after the radar signal onset and lasting up to more than 2 minutes, with frequencies well staggered between 4Hz and 25Hz. Such signals are thought to be generated by either strong degassing / ash emission, or rock falls near the summit region. Harmonic tremor and LP events on the other hand do not seem indispensable for ash emission as radar signals are not systematically accompanied by them. Further investigation with quantitative parameters is ongoing in order to better characterize each event and attempt classifications.
During almost two years, we registered simultaneously (on the same station) seismic and acoustic signals. The idea is firstly to identify the different acoustic signals and then to establish the correlation between the two types of datas (seismic and acoustic) in order to better classify the seismic signals of the Arenal and better understand the mechanisms that rule the volcano. For exemple, the acoustic signal can help characterize the source of the of the tremor, and then give more constraints for source modelling.

Degassing through permeability in volcanic systems

A. Collinson and J. Neuberg

The volume of gas dissolved and subsequently exsolved greatly influences the degree of explosiveness of a volcanic eruption. There is a marked contrast between the behaviour of a volcano in an open system compared to one which is closed. It is therefore essential to understand degassing, to appreciate the volumes of gas lost and where. Previous studies by a variety of scientists have led to the accumulation of data via field evidence, from both active and fossil volcanoes (Stasiuk et al., 1996); laboratory experiments (Moore et al., 1994); and conceptual modelling, in which Darcy's Law has become increasingly applicable (Eichelberger et al., 1986; Edmonds et al., 2003). Of particular interest for this study, is the effect different permeabilities and pressure gradients (atmospheric, lithostatic, hydrostatic) have on the degree and pattern of the gas flux. Gas loss is modelled using a finite element approach which allows the specification of boundary (pressure) and subdomain (permeability) conditions. The modelling involves the use of equations which are solved simultaneously: A partial differential equation is derived by combining the equations for mass conservation, ideal gas law and Darcy's Law, and solved for the pressure gradient. This pressure gradient is then used within Darcy's Law to determine the gas flux. This method permits the modelling of many different situations to demonstrate how various volcanic characteristics affect the gas loss. Such features include: cracks within the dome; regions of different permeability within the wall rocks and dome; and anisotropic permeability gradients within the conduit.

Constraining magma properties through low-frequency volcanic earthquakes

Paddy Smith

Low-frequency volcanic earthquakes are considered a key part of volcanic monitoring, as they are one of the few available tools that can link surface observations directly to internal volcanic processes. Our model for their generation on the Soufrière Hills Volcano, Montserrat, is brittle fracturing of the magma at the conduit walls, which provides the seismic trigger mechanism, followed by conduit resonance. The attenuation of seismic waves in a viscous magma is highly dependent on the properties of the attenuating material, in particular the viscous friction, controlled by the melt viscosity, gas content and diffusivity. Therefore we can use the seismicity to infer information about these magma properties.

In this study we begin by demonstrating that the apparent attenuation of the coda of the recorded seismic signals should be considered a combination of effects from the intrinsic attenuation of the material and the radiative energy loss of the resonating system. We then employ a two-dimensional viscoelastic finite-difference model, with the attenuative behaviour of the magma parameterized by an array of Standard Linear Solids. By examining the relationship between the amplitude decay of the synthetic low-frequency events, the intrinsic attenuation of both the magma and surrounding medium and the elastic parameter contrast across the conduit wall, this research explores the links between the amplitude decay of the coda and magma properties.

Stress models of volcano-tectonic earthquake triggers

Dulce Bracamontes

Among the various types of seismic signals linked to volcanic processes, volcano-tectonic (VT) earthquakes are probably the earliest precursors of volcanic eruptions. Two seismological observations, regarding the use of VTs, seem to be crucial in the diagnoses to forecast volcanic eruptions: i) the spatio-temporal evolution of the hypocentres where the presence of distal VTs plays an important role, ii) the occurrence of VT earthquakes with rotated fault-plane solutions (FPS) which indicate a ~90° rotation with respect to the regional stress field. To understand the physical mechanisms behind the generation of VTs, it is needed to comprehend the behavior of rocks under different states of stress and strain. Several analytical models of geological structures such as cracks, dikes and magmatic intrusions have been published regarding their elastic response. By means of these analytical models, an analysis of how the regional and local pressure effects interact to generate failure in the surrounding rocks is presented. Also, the Coulomb failure criterion is used to test whether the VT earthquakes of Soufrière Hills volcano that have been shown to experience a change in their FPS, could have been generated by the intrusion of magma at depth.

Research of temperatures of the thermal anomalies of Kamchatkan active during the 2006-2007 years using the AVHRR (NOAA 16-17) satellite data, with the purpose of determination of their eruption precursors

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There are 29 active volcanoes in Kamchatka peninsula. The Kamchatka Branch of Geophysical Survey of RAS (KF GS RAS) is conducting a monitoring of active volcanoes with the purpose of volcanic danger estimation. One of the sections of observations is the satellite monitoring of thermal anomalies and ash plums. They are based on a treatment and interpretation of satellite data information of AVHRR sensor NOAA 16 and 17.
The reception of information is carried out by the Kamchatka center of connection and monitoring. Research Laboratory of Seismic and Volcanic Activity of KF GS RAS had begun a processing of AVHRR sensor data since September 2002. We used the ReadHRPT program and published the results in Internet (http://www.emsd.ru/~ssl/monitoring/main.htm). Due to the help of Institute of Space Researches (reformat program "FRAME") and Alaskan Volcano Observatory (ENVI 4.0 program) we have begun to measure the thermal anomalies temperatures in October 2006.
The quantity of pixels, their orientation in relation to the tops of volcanoes and maximal temperature are determined in each thermal anomaly. The parameters of the anomalies are measured on volcanoes and pyroclastic flows, and temperature of the background level is estimated on the contiguous laying surface.
The results of all conducted works are using as an additional parameter for the seismic monitoring for the forecast of Kamchatka volcanoes eruptions.
The got information is compared with seismic, visual and video data. It allows us to trace the process of preparation of volcano to eruption more correctly.
It was set as a result of researches, that before eruptions of the Sheveluch, Klyuchevskoy and Bezymianny volcanoes is observed appearance and growth of temperature (or only growth) of thermal anomaly in the period of time from one to a few weeks before eruption. The thermal anomaly of Karymsky volcano is observed only in periods of eruptions.

Implantation of the National Geographic Institute's Volcano Monitoring Network in the Canary Islands

Domínguez Cerdeña Itahiza Francisco

After the 2004 Tenerife's seismo-volcanic crisis, IGN held the responsibility of volcano monitoring in Spain, given its experience in geophysical and geodetical monitoring. The primary concern was the design of a multiparametric volcano monitoring system for the island of Tenerife, nowadays in the process of implantation. This project will be expanded to the rest of the Canary Islands, with some modifications so it will be adapted to them. We present the state of the monitoring network.
This talk will be focused on the seismic network with special interest in the recent improvement of instrumentation and the development of new software of analysis. We also present the first results obtained from the improvement of the seismic network included in the monitoring system. We report the presence of some conspicuous monochromatic seismic signals observed in the island of Tenerife.

Seismic Activity Index (SAI) of Tungurahua Volcano

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The Seismic Activity Index (SAI) is a measure of the seismic activity around the Tungurahua volcano that takes into account volcano tectonic, long period, hybrid, explosions and tremor events, integrating them in a single value. Currently this value is being used to follow the changes of behavior of the volcano. These changes are detected using levels of state that have been defined statistically. The general procedure compares the seismicity of the 1999-2005 period with the current activity, therefore it is considered as a reference period. The experiences of the last eruptions on July 14, 2006; August 16, 2006 and February 6, 2008 that included pyroclastic flows, have shown significant changes of the SAI. Other minor crises without pyroclastic flows but related to periods of ash emissions also show changes of the SAI. At short term, around two weeks, the behavior of the SAI has been used to forecast new changes, some times associated to an increasing activity. Studying the levels of the reference period, a threshold that separates eruption processes with or without pyroclastic flows has been defined. The SAI and its physical interpretations could be used to evaluate the volcanic threat, as a function of time, define early alerts, guide plans and take decisions.

Microseismicity survey along the Volcanic Chain of El Salvador.

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This research involves focal mechanisms, 'a' and 'b' values and quality factor Q, of the seismic events registered since 1983 to 2006 by the Geotecnico and the Servicio Nacional de Estudios Territoriales (SNET) of El Salvador. The data base was classified in seismic swarms, so for each swarm the parameters "a", "b" and Q are calculated. About focal mechanisms, they are built for the main event of each swarm.
The parameter 'b' shows differences between the swarms happened in the western and central region with respect to the group in the eastern region. The "b" values are within the range of 1.29 and 1.58. These results point that the geological conditions in both regions are different. The quality factor Q will be determined in function of frequency, in the range of 2-16 hertz, with focal depth between 0-25 km. and with the Aki and Chouet model of propagation and generation of coda waves.
After determining the parameters mentioned above, it will be made a study of the evolution in time of this parameters, as a comparison of the values among regions.

Predicting explosive eruptions at Bezimianny volcano (Russia, Kamchatka)

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Bezymianny volcano is located in Kamchatka, Russia (55° 58' N, 160° 35' E, 2869 m). The last catastrophic eruption was on March 30, 1956, after 900-1000 years of quiescence. Since 1956 the volcano has had 1-2 eruptions per year with ash plume height up to 15 km above see level.
Seismic precursors were registered before some eruptions from 1956 to 1994, but no eruptions were predicted officially using seismic data. The Kamchatka Branch of Geophysical Surveys (KBGS) Russian Academy of Science began processing volcanic earthquakes in 1992. During 1996-1999, seismic monitoring was improved significantly: 1) new telemetered stations were installed, 2) seismic data were converted to digital format, 3) custom seismic processing software was written.
KBGS began monitoring the activity of Kamchatka volcanoes in 2000 (http://www.emsd.ru/~ssl/monitoring/main.htm) using real-time seismic, visual (or video) and satellite (NOAA, AVHRR) data. 7 eruptions of Bezymianny volcano were recorded and investigated from February 2000 to February 2004. As a result of this experience, in May 2004, an algorithm for eruption prediction was established. 6 out of 7 eruptions were successfully predicted within 1-7 days using this algorithm during 2004-2007 in real time. It was also determined that successful prediction at Bezymianny depends on activity at nearby Kluchevskoy volcano.

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