Can we isolate deformation due to tectonic and volcanic origin? - New results from deformation monitoring at Mayon volcano, a collaborative project EOS-PHIVOLCS

Dannie Hidayat[1], Eduardo Laguerta[2], Ramses Valerio[2], Christian Clarito[2], Alejo Baloloy[2], Sergio Marcial[1], Teresito Bacolcol[2]

[1]Earth Observatory of Singapore, Nanyang Technological University, Singapore, [2]Philippines Institute of Volcanology and Seismology, Philippines

E-mail: dhidayat@ntu.edu.sg

Mayon is an openly-degassing volcano with low seismicity dominated mostly local and regional tectonic earthquakes. A research collaboration between Earth Observatory of Singapore-NTU and Philippine Institute of Volcanology and Seismology (PHIVOLCS) aims to understand the mechanisms, timing, rates, and other details of magma supply and degassing at Mayon. Deformation monitoring using tiltmeters has been done at Mayon since 1999. We are comparing the tilt data of 1999-2001 and the past one year. In the earlier period, there was a much higher rate of seismicity and frequent strombolian to vulcanian explosions. The tilt signals also showed significant inflation and deflation prior to and following a few explosions with some hints of signal due to local tectonics during pauses between eruptions. On the other hand, seismicity and deformation following the latest eruption in 2009 has been much lower. Regional seismicity has dominated seismic records, and tilt data reflect mainly tectonic deformation. A method to separate deformation due to regional tectonics and magma intrusion is tested on Mayon tilt data assuming an active NW-SE trending fault. The preliminary result is that after removal of tectonic signal, there is still slight inflation of Mayon during the period 2011-2012. However, understanding exactly where deformation (including fault slip) is occurring and how it is partitioned between tectonic and volcanic origins will need additional data such as GPS. We are developing a time series of tilt and GPS data to understand the volcano-tectonic interaction at Mayon Volcano.

Spatial and temporal tilt maxima of an ascending Mogi source

Martin Hensch[1], Torsten Dahm[2], Matthias Hort[3]

[1]Icelandic Meteorological Office, Iceland, [2]GFZ Potsdam, German Research Center for Earth Sciences, Germany, [3]University of Hamburg, Germany

E-mail: martin@vedur.is

Joint seismological and deformation analyses are of great importance for studying the dynamics of magmatic processes at active volcanoes. While InSAR only provides informations about the present state of deformation and longterm variations at volcanic systems, high resolution GPS and especially tilt measurements can deliver valuable insights into ongoing short term magma accumulation processes and magma movements.

This study analyses temporal variations of tilt maxima, measured at the Columbo submarine volcano, north of Santorini (Aegean Sea, Greece), during an earthquake swarm in July 2006. Microearthquakes of the swarm have been relatively relocated using the data of an amphibian network of land- and ocean bottom seismometers. By investigating event densities over time, an ascent of the main seimic cluster with velocities of around 15 cm/s has been observed. Simultaneous, ocean bottom tiltmeters deployed on a profile over the volcano were showing increasing tilt radial to the earthquake cluster, i.e. uplift of the epicentral region. For larger epicentral distances, the maximum of the tilt signal was reached at an earlier point than on tiltmeters closer to the source, before retreating rapidly. This time shift can not be described by a volume source at a fixed location, but rather reflects the dependency of the wavelength of the deformation signal on the varying depth of the source.

Using the simplified model of an upwards migrating Mogi source, time shift and amplitude changes between the observed maxima could be reproduced numerically and analytically. The timing of the observed tilt maximum at a certain epicentral distance is depending on the initial depth and ascent velocity of the source. This temporal maximum differs from the spatial maximum of the whole tilt field due to the exponential increase of the amplitude for decreasing source depths, i.e. the tilt amplitude temporarily increases further although the spatial maximum has already passed the tiltmeter. The temporal maximum can be calculated as the envelope of tilt functions by deviating the Mogi equations with respect to depth and epicentral distance. Subsequently, the ascent velocity of the source can be determined by using the time shift between the temporal maxima on tiltmeters at varying distances. For our observations at Columbo, the obtained results are in good agreement with the vertical migration velocity of the seismic cluster.

Can InSAR contribute to volcano early warning systems?

Nicolas d Oreye[1], Alicia Arjona[2], Sergey Samsonov[3], Benoit Smets[2], Francois Kervyn[4]

[1]National Museum of Natural History, Luxembourg, [2]European Center for Geodynamics and Seismology, Luxembourg, [3]Canada Centre for Remote Sensing, Canada, [4]Royal Museum for Central Africa, Belgium

E-mail: ndo@ecgs.lu

InSAR is known to be efficient to produce high-resolution ground deformation maps. Providing that a SAR sensor acquires enough data in a given geometry, the displacement of each coherent pixel can be monitored over an extended period of time. However these InSAR time series methods often do not permit contributing to an early warning system as they rely on the revisiting period of the satellite, which typically ranges from week to month. Namely, if InSAR detects a possible pre-eruptive signal, the eruption might come too soon before a second acquisition may confirm it and discriminate it from an atmospheric artifact.

Perspective offered by these time series methods can be improved if enough data acquired under different geometries can be combined in a common time series. This is hardly achievable with only one satellite. We present here a novel Multidimensional Small Baseline Subset (MSBAS) methodology for integration of multiple InSAR data sets for computation of 2D or 3D time series of deformation (Samsonov and d Oreye, GJI2012). The approach combines all possible SAR data acquired with different acquisition parameters, temporal and spatial sampling and resolution, wave-band and polarization. The method has 4 main advantages:

1) It achieves combined temporal coverage over an extended period of time when data from many different sensors with different temporal coverages are available;

2) Temporal resolution increases since it includes the combined sampling from all data sets, which helps to observe signal in more details and improves the quality of post-processing (i.e. filtering);

3) 2 or 3 components of ground deformation vector are computed, which helps in interpretation of observed ground deformation and further modeling and inversion;

4) Various sources of noise (i.e. atmospheric, topographic, orbital, thermal...) are averaged out during the processing improving S/N ratio.

The technique was successfully applied to study ground deformation in Virunga Volcanic Province (VVP, DRCongo). Using ERS, ENVISAT, Radarsat2, ALOS and TerraSarX SAR data, we identify long-term deformation of Mt. Nyamulagira and deformations associated to its most recent eruptions. The method also reveals the first unambiguous pre-eruptive deformations in the VVP. They are detected about 15 days prior the onset of the 2010 eruption by 3 successive images acquired by 3 different sensors in different geometries while the seismic precursors only started less than 1 hour before the lava outburst. These pre-eruptive signals are of about the same amplitude and spatial extent as the atmospheric noise and therefore cannot be identified on individual differential interferograms.

Providing that enough SAR data is available with a short latency, and with the help of automated processing and trend change detection algorithms, MSBAS method opens new opportunities for very high-resolution ground deformations studies and possibly for contributing to early warning systems.

Deformation sources at a divergent plate boundary: interplay between volcano deformation, geothermal processes, and plate spreading in the Northern Volcanic Zone, Iceland.

Vincent Drouin[1], Karsten Spaans[2], Sigrun Hreinsdottir[1], Benedikt Ofeigsson[3], Freysteinn Sigmundsson[1], Erik Sturkell[4], Rikke Pedersen[1], Amandine Auriac[1], Andy Hooper[2], Pall Einarsson[1], Theodor Theodorsson[5]

[1]Nordic Volcanological Center, Institute of Earth Sciences, University of Iceland, Iceland, [2]University of Leeds, United Kingdom, [3]Icelandic Meteorological Office, Iceland, [4]University of Gothenburg, Department of Earth Sciences, Sweden, [5]Landsvirkjun, Iceland

E-mail: vjp1@hi.is

Iceland is a subearial part of the Mid-Atlantic Ridge, where the divergent plate boundary between the North-American and Eurasian Plates can be studied. The Northern Volcanic Zone (NVZ) of Iceland, divided into volcanic systems, is particularly well suited to study interplay between volcanoes, geothermal areas, and plate spreading as the zone is relatively simple and accommodates the full spreading of the plates (18.6 mm/yr in a direction of 105 degrees according to NUVEL-1A predictions). The most recent volcanic activity in the area was the Krafla rifting episode 1975-1984. Extensive crustal deformation studies have been carried out in the NVZ; we report the results of recent GPS and Interferometric Synthetic Aperture Radar (InSAR) studies focusing on Krafla and Theistareykir volcanic systems at the northern part of the NVZ. A GPS survey in 2012, more extensive than previous measurements, with over 121 stations measured was evaluated together with data from 2010 and 2011 to generate a velocity field for 2010-2012. Three continuous GPS stations have been installed in the area 2011-2012, complementing one previous station. The 2010-2012 GPS velocities can be compared to earlier GPS results, and complementary analysis of InSAR images. The plate spreading is the most significant signal visible with an E-W velocity of about 12 mm/yr over a 30 km wide area. Earlier studies have shown that the Krafla caldera uplifted during 1984-1989 under the influence of a shallow magma chamber in its center and then subsided. Since 1995, the maximum subsidence in Krafla has shifted from directly above the shallow magma chamber towards an array of boreholes (geothermal exploitation) in Leirbotnar. Similar subsidence has been observed around another array of boreholes in Bjarnaflag, 7 km further south. In the 1990s, an uplift was detected at edge of the geodetic network in Krafla. Recent InSAR studies have shown that this deformation took place over a very large area east of Theistareykir with both E-W horizontal as well as vertical displacements. Velocities calculated from the 2010, 2011 and 2012 GPS campaign results show an ongoing pressure decrease in Krafla caldera. The subsidence in Leirbotnar and Bjarnaflag caused by geothermal exploitation is still continuing. However, the broad deformation area east of Theistareykir seems to have changed in shape, with an uplift concentrated on a smaller area situated on the plate boundary. ERS, Envisat, and TerraSAR-X images have been acquired over the NVZ areas of interest for InSAR studies. By combining InSAR and GPS data, an enhanced spatial and temporal resolution of the deformation history within the area is achieved. The planned expansion of geothermal utilization and new power plants in the area may produce additional deformation signals. Continuous monitoring for the upcoming years may deliver information on further magmatic activity as well as the effects of geothermal exploitation on the volcanic systems.

Investigating the source mechanisms of deflation-inflation events at Kilauea Volcano, Hawai‘i

Jessica H Johnson[2], Kyle R Anderson[1], Michael P Poland[1], Asta Miklius[1]

[1]Center for the Study of Active Volcanoes, University of Hawaii at Hilo, USA, [2]U.S. Geological Survey-Hawaiian Volcano Observatory, USA

E-mail: jessica.helen.johnson@gmail.com

The summit of Kilauea Volcano, Hawaii, is characterized by frequent cyclic deflation-inflation ("DI") events that are best recorded on tiltmeters, reflecting pressure perturbations in the shallow magma plumbing system. Most DI events begin with quasi-exponential deflation at the summit, that lasts 8-80 hours, followed by inflation that is initially rapid but wanes over the course of 12-48 hours as the net deformation approaches pre-event levels. This gives the tilt time series a V- or U-shaped appearance, depending on the onset deflation rates. DI events are also manifested at the Puu Oo eruptive vent on Kilauea’s east rift zone, about 20 km along the rift from the summit. The tilt change at Puu Oo usually lags behind summit deformation by approximately 30-200 minutes. DI tilt events have become more common since the onset of Kilauea’s summit eruption in March 2008, increasing from about 5-15 per year before 2008 to more than 100 in 2012. DI events often occur back-to-back and follow similar patterns, suggesting that the causal mechanism is repetitive and non-destructive. DI events also seem to be less frequent during times of increased summit inflation rate, suggesting that an increase in pressurisation rate or magma supply impedes the mechanism of DI events.

We construct multiphysics finite element models (FEMs) to simulate pressure changes and deformation to link the observations to the physical magmatic processes that drive DI events. The FEMs allow us to investigate realistic 3D model configurations including topography, distributions of rheological properties, and multiple deformation sources. Crucially, the models also allow for temporal variation of fluid flow and subsurface pressurization, which will provide insights into the unique patterns of tilt at Kilauea. Preliminary results suggest that the exponential shape of DI events may be a manifestation of the pressure changes within the magma reservoir due to restriction of flow into the chamber, causing episodic supply. Two possibly inter-related mechanisms have been suggested to explain the restriction of magma flux: (1) blockage and subsequent clearing of the transport pathway that feeds the shallow summit magma system and conduit to Puu Oo, and (2) convective overturns caused by replacement of degassed magma with gas-rich magma.which could be due to either a blockage or a convective overturn.

Monitoring recent geodynamical activity at Campi Flegrei, Italy

Roberto Scarpa[1], Francesca Bianco[2], Paolo Capuano[1], Mario Castellano[2], Luca D'Auria[2]

[1]Dipartimento di Fisica, Universita' di Salerno, Italy, [2]Osservatorio Vesuviano, Istituto Nazionale di Geofisica e Vulcanologia, Italy

E-mail: Roberto.Scarpa@sa.infn.it

After some centuries of subsidence, following the last Monte Nuovo 1538 eruption, the Campi Flegrei caldera has shown unrest episodes of activity since at least 1950. The first uplift episode dates back in the period 1950-1952 and amounted to 73 cm, without any report or record of seismic activity. In the period 1970-1972 and during 1982-1984 two strong inflation episodes occurred, the first accompanied by moderately low seismicity, with only few events felt by residents, whereas the second has been accompanied by relatively intense swarms of VT earthquakes, reaching up to magnitude 4. The seismic activity caused alarm in the population and a spontaneous nightly evacuation of part of the city of Pozzuoli (44.000 residents). Since this last episode, subsidence has been recorded for several years, interrupted by some small mini-uplift episodes, with a duration of several weeks, all accompanied by seismic swarms of low magnitude VT events. In recent years some high sensitivity instruments have been installed to detect slow earthquake transients and other mechanical/temperature low intensity precursory signals. Since late 2004 another moderate uplift is occurring at very small rate, amounting to about 1-2 cm/yr, showing the occurrence of clear LP events. This uplift is different from the past mini-uplifts due to its duration. This work summarizes all seismic and ground deformation data and models proposed to interpret these phenomena, suggesting possible scenarios for detecting precursors of future eruptive activity in the area.

The 2009-2013 uplift at Campi Flegrei caldera, Italy: does continuous GPS monitoring demand a predominant source different from that of the major 1982-1984 unrest?

Antonella Amoruso[1], Luca Crescentini[1], Prospero De Martino[2], Francesco Obrizzo[2], Ilaria Sabbetta[1], Umberto Tammaro[2]

[1]University of Salerno, Department of Physics, Italy, [2]Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Vesuviano, Italy

E-mail: lcrescen@unisa.it

Campi Flegrei (CF) is one of the most active volcanic systems of Southern Italy. It is a resurgent caldera located 15 km west of Naples inside the Campanian Plain, a graben-like structure at the eastern margin of the Tyrrhenian sea. Several eruptions have occurred during historical times, the last one in 1538.

CF periodically experiences notable unrest episodes which include seismic swarms, increases in the degassing activity and ground deformations. The 1970-1972 and 1982-1984 uplift episodes produced a cumulative vertical displacement of more than 2.5 m at the town of Pozzuoli. About 15000 shallow earthquakes (maximum magnitude 4) occurred during the 1982-1984 unrest. The ground has generally subsided between 1984 - 2000 at decreasing rate. During and after the subsidence phase, uplift episodes occurred in 1989, 1994, 2000, 2006. After partial recovery of the 2006 episode, the ground is generally uplifting at an increasing rate. From 2011 cumulative uplift is about 14 cm.

Osservatorio Vesuviano, department of Istituto Nazionale di Geofisica e Vulcanologia, is in charge of monitoring CF. Ground deformations are monitored by means of classical (e.g. leveling and tiltmetry) and satellite (e.g. GPS and SAR) techniques. Eleven GPS sites of the NeVoCGPS (Neapolitan Volcanoes Continuous CGPS) network are located inside CF. The oldest stations have been active since thirteen years and the newest since 4 years. Data processing is performed by the Bernese Processing Engine of the Bernese GPS software version 5.0.

Here we have used GPS data from 2009. At first, we have cross-compared the time series of the three displacement components (Eastward, Northward, vertical) of each station to search for possible time variations in the horizontal displacement direction and vertical-to-horizontal ratio. Then, the time series of the different stations have been compared with each other to search for local anomalies. Both tests have given negative results. In other words, the deformation pattern depicted by GPSs remains constant during the whole test period.

We have also compared the GPS time series with deformation data related to the 1982-1984 unrest. The latter data set originates from leveling and triangulation (EDM and angular) surveys; horizontal displacements are given with respect to a local coordinate system whose origin coincides with a reference triangulation monument and whose y-axis points toward a second one. Since GPS horizontal displacements radiate from a common center, we have searched for a roto-translation capable to make the 1982-1984 horizontal displacements radial. We have found that both (2009-2013 and 1982-1984) radiating centers and displacement (vertical and horizontal) patterns coincide within uncertainties, suggesting a common predominant source.

Physics-based modeling at Kīlauea Volcano, Hawai‘i: Constraining magma supply and storage rates, primary melt volatile content, and reservoir volume

Kyle Anderson, Michael Poland

USGS Hawaiian Volcano Observatory, USA

E-mail: kranderson@usgs.gov

Kīlauea Volcano has been intensively studied for more than a century, yet many of its fundamental properties remain poorly resolved, including the volume of magma storage beneath the summit (estimates vary from 0.08 to more than 200 km^3), the deep magma supply rate (0.06 to 0.19 km^3/yr), and the rate at which magma accumulates in the rift zones. These properties are often estimated using only a single type of observation to constrain a simple model which fixes other parameters to assumed values; this approach does not make use of all available data, does not account for uncertainties in assumed parameters, and produces results which are not always physically consistent with one another.

Physics-based models of volcanic systems can be used to relate a wide range of observations and physical properties to one another in a coherent system. Using such a model, an observation of ground deformation for instance might better inform not only an estimate of the magma reservoir location, but also of the volatile content of melt in that reservoir.

In this work we develop a physical model of magma supply, storage, and eruption at Kīlauea Volcano which is capable of predicting CO_2 and SO_2 emissions and ground deformation. We constrain the model using observations from different time periods in the ongoing Pu‘u ‘Ō‘ō–Kupaianaha eruption to estimate magma supply rate, magma storage rate, and primary melt volatile content. We also look for changes associated with an inferred surge in magma supply to the volcano during 2003-2007. Inversions are performed using a Bayesian technique which yields probability distributions for all estimated parameters. When possible, we compare results to independent estimates from the literature. This work can be considered a first step towards the development of more realistic physics-based models of Kīlauea’s magma plumbing system with which to better interpret and utilize the remarkable diversity and quantity of geological and geophysical observations available at the volcano.

Absolute gravity variation at Sakurajima volcano from April 2009 through January 2011 and its relevance to the eruptive activity of Showa crater

Shuhei Okubo[1], Takahito Kazama[2], Keigo Yamamoto[3], Masato Iguchi[3], Yoshiyuki Tanaka[1], Yuichi Imanishi[1], Wenke Sun[4], Mamoru Saka[1], Atsushi Watanabe[1], Shigeo Matsumoto[5]

[1]Earthquake Research Institute, the University of Tokyo, Japan, [2]Graduate School of Science, Kyoto University, Japan, [3]Disaster Prevention Research Institute, Kyoto University, Japan, [4]Graduate University of Chinese Academy of Sciences, Japan, [5]Sumiko Consultants Co., Ltd, Japan

E-mail: okubo@eri.u-tokyo.ac.jp

We describe continuous absolute gravity measurements performed from April 2009 through January 2011 at Sakurajima volcano. The results clearly show significant gravity variations of as large as 30 microgal during the observation period. Hydrological simulations reveal that about half of the gravity change is attributable to groundwater disturbance. After correcting for this disturbance, the observed variations in gravity can be divided into 5 separate phases. Phase 2 is a period with few eruptions, which extends from April to late June 2009 when an abrupt 10 microgal gravity decrease was observed. During the succeeding phase 2, from July 2009 to May 2010, gravity oscillated about a mean value with an amplitude of 5 microgal, while the monthly number of explosions at Showa crater dramatically increased from 50 to about 150. In phase 3, which was a transient quiescent period, gravity increased by as much as 10 microgal in a single month. This was followed by phase 4, during which there was a steady gravity decrease until November 2010. During the final phase 5, gravity remained almost constant until at least January 2011. These five phases are closely linked to the eruptive activity at Showa crater. In fact, excellent correlations are found among the records of absolute gravity, ejected weight of volcanic ash, ground tilt, and infrasound air shock amplitude. The gravity data are transformed into changes in magma head height using a simplified line mass model.

Insights into the cyclic eruptive behavior of Mount Etna during 2011: geophysical and geochemical constraints

Domenico Patane[1], Alessandro Aiuppa[2], Marco Aloisi[1], Boris Behncke[1], Andrea Cannata[1], Mauro Coltelli[1], Giuseppe Di Grazia[1], Salvatore Gambino[1], Sergio Gurrieri[3], Mario Mattia[1], Giuseppe Salerno[1]

[1]Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo - Sezione di Catania, Italy, [2]DiSTeM, Universita di Palermo, Italy, [3]Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Palermo, Italy

E-mail: cannata@ct.ingv.it

Since the second half of the 1990s, the eruptive activity of Mt. Etna has provided evidence that both explosive and effusive eruptions display periodic variations in discharge and eruption style. In this work, a multiparametric approach, consisting of comparing volcanological, geophysical and geochemical data, was applied to explore the volcano's dynamics during 2009-2011. In particular, temporal and/or spatial variations of seismicity (volcano tectonic earthquakes, volcanic tremor, long period and very long period events), ground deformation (GPS and tiltmeter data) and geochemistry (SO2 flux, CO2 flux, CO2-SO2 ratio) were studied to understand the volcanic activity, as well as to investigate magma movement in both deep and shallow portions of the plumbing system, feeding the 2011 eruptive period. After the volcano deflation, accompanying the onset of the 2008-2009 eruption, a new recharging phase began in August 2008. This new volcanic cycle evolved from an initial recharge phase of the intermediate-shallower plumbing system and inflation, followed by (i) accelerated displacement in the volcano's eastern flank since April 2009 and (ii) renewal of summit volcanic activity during the second half of 2010, culminating in 2011 in a cyclic eruptive behavior with 18 lava fountains from New South East Crater (NSEC). Furthermore, supported by the geochemical data, the inversion of ground deformation GPS data and the locations of the tremor sources are used here to constrain both the area and the depth range of magma degassing, allowing reconstructing the intermediate and shallow storage zones feeding the 2011 cyclic fountaining NSEC activity.

How do volcanic rift zones relate to flank instability? Evidence from collapsing rift at Etna and its relationship with the nearby Pernicana Fault System

Joel Ruch[1], Susi Pepe[2], Francesco Casu[2], Valerio Acocella[1], Marco Neri[3], Guiseppe Solaro[2], Eugenio Sansosti[2]

[1]Dipartimento Scienze, Universita Roma Tre, Roma, Italy, [2]National Research Council (CNR-IREA), Napoli, Italy, [3]Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania, Italy

E-mail: jruch@uniroma3.it

Rift zones, characterized by repeated dike emplacement, are expected to delimit the upper portion of unstable flanks at basaltic volcanoes. We use nearly two decades of InSAR observations excluding wintertime acquisitions, to analyze the relationships between rift zones, dike emplacement and flank instability at Etna. The results highlight a general eastward shift of the volcano summit, including the NE and S rifts. This steady-state eastward movement is interrupted or even reversed during transient dike injections. Detailed analysis of the NE Rift shows that only during phases of dike injection, as in 2002, does the rift transiently becomes the upper border of the unstable flank. The flank's steady-state eastward movement is inferred to result from the interplay between magmatic activity, asymmetric topographic unbuttressing, and east-dipping detachment geometry at its base. This study documents the first evidence of steady-state volcano rift instability interrupted by transient dike injection at basaltic volcanoes. We further use three decades of available geodetic data (leveling, InSAR with ERS-ENVISAT and CosmoSkyMed data) and seismic data, from 1981 to 2012, to analyze the E flank motion in the area of the Pernicana Fault System (PFS), structurally connected to the NE Rift and marking the lateral boundary of the unstable flank. We observe an overall temporal and spatial relationship between dike intrusion along the NE Rift, seismic activity and surface fracturing along the PFS.

This research has been partially performed within the frame of Italian Space Agency (ASI) and Japan Aerospace Exploration Agency (JAXA) bilateral cooperation. CSK data have been provided by ASI and JAXA within the SAR4Volcanoes project (ASI agreement n. I/034/11/0).

Linking geodesy and petrology - The influence of cooling, crystallisation and re-melting on the interpretation of geodetic signals

Luca Caricchi[1], Juliet Biggs[2], Catherine Annen[2], Susanna Ebmeier[2]

[1]Section of Earth and Environmental Sciences, University of Geneva, Switzerland, [2]School of Earth Sciences, University of Bristol, United Kingdom

E-mail: luca.caricchi@unige.ch

Deformation of volcanic edifices is typically attributed to the movement of magma within the volcanic plumbing system but a wide range of magmatic processes are capable of produce significant volume variations. In order to understand the evolution of magmatic systems prior to eruption and properly interpret monitoring signals, it is necessary to quantify the patterns and timescales of surface deformation that processes such as crystallisation and degassing can produce. We show how the combination of petrology and thermal modelling can be applied to geodetic observations to identify the processes occurring in magmatic reservoir during volcanic unrest.

Thermal modelling in combination with petrology was used to determine the timescales and volumetric variations associated to cooling, crystallization and gas exsolution. These calculations can be performed rapidly and highlight the most likely processes responsible for the variation of a set of monitoring parameters.

This modelling was applied to a time series of geodetic data spanning the period between the 1997 and 2008 eruptions of Okmok volcano, Aleutians, examining scenarios involving crystallisation, degassing and re-melting of a crystallizing shallow magmatic body. The geodetic observations are consistent with the injection of a water-saturated basalt, followed by minor crystallization and degassing, while other scenarios are not compatible either with the magnitude or rate of the deformation signals.

Active monitoring at Active Volcano - Performance of ACROSS at Sakurajima volcano, Japan.

Koshun Yamaoka[1], Hiroki Miyamachi[2], Masato Iguchi[3], Toshiki Watanabe[1], Takahiro Kunitomo[1], Hiroshi Yakiwara[2], Ryoya Ikuta[4]

[1]Graduate School of Environmental Studies, Nagoya University, Japan, [2]Faculty of Science, Kagoshima University, Japan, [3]Disaster Prevention Research Institute, Kyoto University, Japan, [4]Faculty of Science, Shizuoka University, Japan

E-mail: kyamaoka@seis.nagoya-u.ac.jp

First test on the monitoring of volcanic activity with continuous-operatable seismic source has started at Sakurajima volcano, Japan. This paper reports the methodology to estimate the performance of the source-receivers system before deployment. It also reports the actual performance of the source using the data of existing seismic stations in and around Sakurajima volcano.

We deployed seismic sources, named ACROSS (Accurately Controlled Routinely Operated Signal System) in Sakurajima volcano in March of 2012. Two sources are deployed in the northwestern frank of Sakurajima volcano with a distance of 3.6km from the main crater. With some preliminary test, we have started a test of continuous operation from 12 June to 18 September, 2012 with single frequency of 10.01Hz and frequency modulation between 10-15Hz. The first test was successfully finished with minor trouble even if this is the first opportunity to deploy the source in the remotely located volcano. The sources are in operation now with frequency modulation of 5-10 and 10-15 Hz.

Before the deployment we assessed the feasibility of monitoring of magma transport in Sakurajima with ACROSS system using existing datasets. For the assessment two issues are posed, one is whether we can obtain transfer function with enough signal-to-noise ratio (SNR) in Sakurajima, and the other is how we can detect the change in subsurface structure by using ACROSS signal under the realistic structure of the volcano.

Signal-to-noise ration (SNR) were estimated as a function of the stacking length and the soruce-receiver distance. With the distance-dependent attenuation model that is established in the Tokai area for the ACROSS source, we estimate the distance-dependent attenuation relation in Sakurajima volcano for the ACROSS source. By comparing the relation with the noise level in Sakurajima volcano we can estimate the time period that is necessary to obtain enough SNR. The result shows that ACROSS signal can be recorded with SNR of more than 10 within the distance of 5km if signal have been recorded for one month. The estimated distant-dependent attenuation relation is almost consistent with the real observation.

Wave propagation is numerically calculated with the 3D velocity and attenuation structure model, that is established based on the refraction experiment in and around Sakurajima volcano. With the model we calculated the wave propagation from a single force exerted at the planned source site, and compare it with the calculation in different model in which a low-velocity body is placed beneath the summit. The results show that the maximum change will be observed at an opposite region with respect to the summit. The analysis of the real monitoring data is now underway to reveal the source of temporal variation of the monitoring.

The BENTO Box: Development and field-testing of a new satellite-linked data collection system for volcano monitoring

Diana C. Roman[1], Alberto Behar[2], Matthew J. Fouch[1], Angelica Munoz[3], A. Jeff Sutton[4]

[1]Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, USA, [2]School of Earth and Space Exploration, Arizona State University, USA, [3]Instituto Nicaraguense de Estudios Territoriales, Nicaragua, [4]USGS Hawaiian Volcano Observatory, USA

E-mail: droman@dtm.ciw.edu

Currently it is impossible to monitor all of Earth's hazardous volcanoes for precursory eruption signals. The primary constraint is the high cost of deploying monitoring instrumentation (e.g., seismometers, gas sensors), which includes the cost of reliable, high-resolution sensors, the cost of maintenance (including periodic travel to remote areas), and the cost/difficulty of developing remote data telemetry. Our goal is to develop an integrated monitoring system and an associated monitoring strategy that will allow identification of restless volcanoes through widespread deployment of robust, lightweight, low-cost, easily deployable monitoring/telemetry systems. Ultimately, we expect that this strategy will lead to more efficient allocation of instrumentation and associated costs.

Towards achieving this goal, we have developed the BENTO (Behar's ENvironmental Telemetry and Observation) box. These portable, autonomous, self-contained data collection systems are designed for long-term operation (up to 12 months) in remote environments. They use low-cost two-way communication through the commercial Iridium satellite network, and, depending on data types, can pre-process raw data onboard to obtain useful summary statistics for transmission through Iridium. BENTO boxes also have the ability to receive commands through Iridium, allowing, for example, remote adjustment of sampling rates, or requests for segments of raw data in cases where only summary statistics are routinely transmitted. Currently, BENTO boxes can measure weather parameters (e.g., windspeed, wind direction, rainfall, humidity, atmospheric pressure) and volcanic gas (CO2 and SO2) concentrations.

In the future, we plan to develop BENTO boxes for seismic, atmospheric pressure/infrasound, other gases (e.g., halogens), tilt, and temperature. We are currently field-testing BENTO boxes equipped with gas and meteorological sensors ('BENTO 1') at Telica Volcano, Nicaragua; and Kilauea Volcano, Hawai'i. We plan to deploy a third gas BENTO prototype at Etna Volcano, Italy in June of 2013. Together, the data from these three BENTO boxes and previously established volcano monitoring instruments are allowing us to test and refine sensor deployment strategy. 'BENTO 2', currently under development, will be compatible with high data rate sensors, including seismic, tilt and infrasound. We expect this prototype development to be complete by mid-2013.

Development of risk-free observation tools at active volcanoes using unmanned Helicopter

Takao Ohminato[1], Takayuki Kaneko[1], Takao Koyama[1], Minoru Takeo[1], Takatoshi Yanagisawa[2], Yosiaki Honda[3], Takeshi Hashimoto[4]

[1]Earthquake Research Institute, University of Tokyo, JAPAN, [2]JAMSTEC, JAPAN, [3]CEReS, Chiba University, JAPAN, [4]Hokkaido University, JAPAN

E-mail: takao@eri.u-tokyo.ac.jp

Observations at active volcanoes using unmanned vehicles are very important from various viewpoints. From a scientific point of view, it is important to conduct observations in the close vicinity of active vent where no scientist can approach without risking his/her life. From a view point of volcano hazard mitigation, reinstalling monitoring sensors is indispensable to maintain observation networks around an active volcano when existing monitoring stations are damaged by the intense activities of the volcano. Installation of volcano monitoring sensors using unmanned vehicle is the only way to recover damaged stations without spending any risk of human lives.

We started a project in which risk-free volcano observation tools are developed. When this project started in 2005, we adopted using unmanned autonomous helicopter RMAX-G1 manufactured by Yamaha-Motor Co., Ltd., but at that time, there was essentially no know-how to use the helicopter for volcano observations. We spent first several years in developing an aeromagnetic survey system using this helicopter with a cesium magnetometer. This system has gradually been improved and has been applied to Izu Oshima, Sakurajima, Kirishima, and Tarumae. These observations have revealed changing magnetization structures of these target volcanoes with high-resolution. We also started developing observation modules that require direct ground contact such as seismic and GPS observation modules. We had to develop a winch that is attached underneath the helicopter and is used to install sensors in the target area near active volcanic vents. Earthquake observation modules and GPS modules were designed so that they satisfy the requirements for helicopter installations. These modules have to be light weight, compact size, and solar powered. We have been maintaining seismic observations at Sakurajima summit area since 2009, and GPS observations at Sakurajima and Kirishima since 2011.

Through these experiences, valuable know-hows necessary to conduct volcano observations using an unmanned helicopter have been gradually but steadily accumulated. For example, the ground coupling of the seismic or GPS modules installed by the helicopter is poor due to the way they are installed on the ground. Albeit the imperfect ground coupling, seismic signals recorded by the modules are as good as well installed sensors if we remove high frequency resonance noise.The location errors of the GPS in horizontal and vertical components are 1cm and 3cm, respectively.These error amplitudes are smaller than the amplitudes of the deformation signals expected for the stations in the close vicinity of the source.

In the presentation, we will start with brief review of the development of this tool. We will then introduce some results obtained by the helicopter observations. Finally, we will briefly mention future perspective of volcano observations using unmanned vehicles.

Volcano monitoring using ultraviolet cameras: two case studies from Volcan de Colima, Mexico and Volcan Villarrica, Chile

Kelby Hicks[1], Nial Peters[1], Yves Moussallam[1], Kayla Iacovino[1], Nick Varley[2], Clive Oppenheimer[1]

[1]Department of Geography, University of Cambridge, United Kingdom, [2]Centre of Exchange and Research in Volcanology, Faculty of Science, University of Colima, Mexico

E-mail: kh471@cam.ac.uk

Ultraviolet cameras can yield high temporal resolution (1–3 Hz) images of volcanic plumes suitable for measurements of SO2 flux. This data rate offers better possibilities for integrating SO2 emission rate time–series with other geophysical, geodetic or geochemical data. Such a multiparameter approach is valuable for recognizing and understanding eruption precursors and thereby supports monitoring and forecasting efforts. For the mildly degassing activity typical, at present of Volcan de Colima and Volcan Villarrica, the ability of the UV camera to measure immediately above the emission source substantially limits the effects of eddy development, which can bias measurements made by narrow field–of–view spectrometers (i.e., COSPEC, Flyspec and DOAS approaches). Additionally, detailed quantitative study of the atmospheric interactions surrounding degassing and explosion events is possible via processing SO2 absorbance maps as a continuous series of images similar to time–lapse video.

To illustrate the capabilities of UV cameras and data synergies, we present measurements from two contrasting volcanoes: Colima (andesite) and Villarrica (basalt to basaltic andesite), the former renowned for dome-building and Vulcanian eruptions, and the latter for persistent degassing through a small lava lake. A dual-camera system based on two EnviCAM 1 UV cameras, with filters centered at 310 and 328 nm, was used in the investigation. We identify variations in gas output on minute–hour–day timescales and consider the origins of this variability.

Systematic re-analysis of waveform data from the Hawaiian Volcano Observatory seismic network, 1992 to 2009

Robin S Matoza[1], Peter M Shearer[1], Guoqing Lin[2], Cecily J Wolfe[3], Paul G Okubo[4]

[1]Scripps Institution of Oceanography, UC San Diego, La Jolla, California, USA, [2]Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida, USA, [3]Hawaii Institute of Geophysics and Planetology, University of Hawai'i at Manoa, Honolulu, Hawaii, USA, [4]Hawaiian Volcano Observatory, U.S. Geological Survey, Hawaii Volcanoes National Park, Hawaii, USA

E-mail: rmatoza@ucsd.edu

The analysis and interpretation of seismicity from mantle depths to the surface plays a key role in understanding how Hawaiian volcanoes work. We present results from a comprehensive and systematic re-analysis of waveforms from 130,902 seismic events recorded by the USGS Hawaiian Volcano Observatory (HVO) permanent seismic network from January 1992 to March 2009. We have produced a comprehensive multi-year catalog of high-precision relocated seismicity for all of Hawaii Island using waveform cross-correlation and cluster analysis. The 17 years of relocated seismicity exhibits a dramatic sharpening of earthquake clustering along faults, streaks, and magmatic features, permitting a more detailed understanding of fault geometries and volcanic and tectonic processes. Our relocation results are generally consistent with previous studies that have focused on more specific regions of Hawaii. The relocated catalog includes crustal seismicity at Kilauea and its rift zones, seismicity delineating crustal detachment faults separating volcanic pile and old oceanic crust on the flanks of Kilauea and Mauna Loa, events along inferred magma conduits, and events along inferred mantle fault zones. Our cross-correlation and filtering parameters were optimized for high-frequency seismicity (volcano-tectonic and tectonic earthquakes); we are now working to produce a separate relocated catalog optimized for long-period (0.5-5 Hz) events. We are also estimating spectra systematically from every event recorded at every station to aid with event classification and to analyze spatial variations in Brune-type stress drop of shear-failure earthquakes.

Hypocenter determination of B-type earthquakes using the envelope correlation method: an application to Miyakejima volcano, Japan

Higashi Uchida[1], Takeshi Nishimura[1], Hisashi Nakahara[1], Hitoshi Yamasato[2], Eisuke Fujita[3]

[1]Geophysics, Science, Tohoku University, Japan, [2]JMA, Japan, [3]NIED, Japan

E-mail: higashi@zisin.gp.tohoku.ac.jp

B-type earthquakes with emergent onsets of P and S phases are frequently observed in active volcanoes, and it is difficult to locate them by traditional phase picking. Recently, we analyzed 1,049 B-type earthquakes occurring at Miyakejima volcano, Japan from August 2010 to April 2011, and succeeded in locating 18 % of the observed 1,049 B-type earthquakes by stacking the waveforms of earthquake families to read the P- and S-wave onset times (Uchida et al., 2012). However, the hypocenters of the rest of B-type earthquakes still remain unknown.

In this study, aiming to locate all of the B-type earthquakes at Miyakejima, we apply the method of Obara (2002), which was used for non-volcanic deep tremors on the subducting plate, to the seismograms observed at nine stations located within 4 km of the summit. At each station, we compute a RMS envelope from 4 - 8 Hz band-pass-filtered three-component seismograms, and measure the differential travel times between stations by taking cross-correlations of the envelopes. We assume that the envelope is composed of S-wave traveling with the velocity of 1250 m/s, as in Uchida et al. (2012).

To assess the applicability of the method to B-type earthquakes, we determine the hypocenters of individual events in each of the four earthquake families (L1, L2, H1, and H2) by applying the envelope correlation method, and compare the resultant hypocenters with those obtained from phase picking of the stacked waveforms (hereinafter referred to as "stack-and-pick hypocenters"). As a result, we found that the epicenters located by the envelope correlation almost coincide with the stack-and-pick epicenters, and the differences are about 0.5 km. On the other hand, the method sometimes yields large error in depth. For example, the hypocenters of family L1 and L2 cluster in the depth range of 1 km, respectively. While the cluster of L1 includes the stack-and-pick hypocenter, that of L2 shifts 1 km shallower than the stack-and-pick hypocenter. In the case of H1 and H2, their hypocenters spread over the depth range of 2 km. The inconsistency in the depths is probably due to the difficulties in measuring the S-wave travel times from the envelopes. To improve the accuracy of the depths, we need to consider the envelope broadening by scattered waves, surface waves and/or reflection phases.

We then apply the envelope correlation method to all of the observed 1,049 B-type earthquakes, of which about 80 % had never been located, and successfully locate them in an automated way. As a result, we found that 97 % of them are located within a 1.5 km diameter centered on the southern part of the summit caldera, where continuous fumarolic gas emission occurs. Those hypocenters are distributed at the depths shallower than 3 km. Our study shows the usefulness of the method as a tool to monitor volcanic earthquakes which are difficult to locate by phase picking.

Microseismicity results from the Volcanic Risk in Saudi Arabia (VORISA) project, northern Harrat Rahat, Al-Madinah, Kingdom of Saudi Arabia

Catherine Lewis Kenedi[1], Mohammed F. Abdelwahed[2], Marcos Alvarez[1], Essam M. Aboud[2], Jan M. Lindsay[1], Mohammed R. Moufti[2], Talal A. Mokhtar[2]

[1]University of Auckland, New Zealand, [2]King Abdulaziz University, Saudi Arabia

E-mail: katelk@auckland.ac.nz

Since April, 2012, an 8-station borehole seismic research array has been recording microearthquakes in northern Harrat Rahat. This recently active monogenetic volcanic field lies southeast of Al-Madinah, Kingdom of Saudi Arabia, and is being evaluated for volcanic hazard. The goal of the seismic array is an improved understanding of the local geology and structure by locating and analysing microearthquakes. We report on the following: (1) The location of and instrumentation in the array, (2) A new seismic velocity model using a genetic algorithm method, (3) Microearthquakes located around the city of Al-Madinah, and (4) Local tremor activity.

The array has a total aperture of 17 km with station spacing at 5 to 10 km. The seismometers are housed in 2-Hz, 3-component borehole sondes. Sensor depths range from 107 to 121 m. The data acquisition system at each stand-alone station consists of a Reftek 130-01, 6-channel, 24 bit data logger which records at 250 samples per second. Local temperatures reach extremes of 0 degrees - 50 degrees C, so the battery and recorder are contained in a specially designed underground vault. We can locate local microearthquakes of M-1. All stations show a very high signal to noise ratio. The tremor is seen sporadically throughout the recording period with at least one period of concentrated activity.

The VORiSA seismographs are operated in collaboration between King Abdulaziz University in Jeddah, Kingdom of Saudi Arabia, and the Institute of Earth Science and Engineering, University of Auckland, in New Zealand.

How ambient is ambient noise?

Kathleen F McKee, Gregory P Waite, Joshua P Richardson

Michigan Technological University, United States

E-mail: kfmckee@mtu.edu

Villarrica is an open-vent stratovolcano located in the southern Andes of Chile characterized by strombolian style eruptive activity. Campaigns were conducted from March to October 2010 and February to April 2011 with 8 broadband and 6 short-period stations, respectively. Although these data are dominated by tremor and superposition of closely-spaced events related to bubble-bursting at the surface of the lava lake, the high frequencies should be sufficiently scattered at distances of several km from the summit to be considered ambient noise. We removed the instrument response, normalized with an RMS method, whitened the spectra, and filtered from 1 to 10 Hz where the background noise was high. Hour-long auto- and cross-correlations were computed and the respective functions stacked by day and total time. To track temporal changes we stretched a 24 hour moving window of correlation functions from 90% to 110% of the original and compared them with the total stack. There was an average decrease in relative arrival time from the auto-correlation functions (ACF) during the 2010 array of 0.13%. Cross-correlations from station nearest the summit, to the other stations show comparable decreases. This decrease was interpreted as a velocity increase and attributed to the closing of cracks in the subsurface due either to seasonal snow loading or regional tectonics. In addition to the long-term decrease in relative arrival time across the stations, there are short-term excursions on the same order lasting several days. We compared long-term trends in 1) the time lags between arrivals from discrete seismic and infrasound events (seismic-infrasound lag SIL) and 2) the infrasound tremor frequency with the relative arrival time changes at Villarrica. The relative delay times are correlated with changes in SIL and anti-correlated with the infrasound frequency, which suggests 1) the position of the lava lake changes and 2) the changing source position may explain the short-term variations in relative delays. When evaluating the short-term changes in the ACF interferometrically, we found a better fit using static shifts, than linearly increasing shifts (stretching), supporting the model for variable lava lake levels, rather than short term changes in velocity.

Diking-faulting interaction and interpretation of moment tensor solutions

Eleonora Rivalta, Francesco Maccaferri, Luigi Passarelli

GFZ-Potsdam, Germany

E-mail: rivalta@gfz-potsdam.de

Full moment tensor inversions are a useful tool for the understanding of the dynamics of faulting during volcanic crises. However, it is generally difficult to interpret the sometimes puzzling results of such inversions in volcanic contexts. Here we present a series of forward models of the interaction of faulting with diking, and of the resulting change in the moment tensor. The sudden elastic change in dike geometry associated with faulting will interact with the seismic waves radiated from the fault and will result in a cumulative effect. We find that the fault orientation extracted from the seismic moment appears rotated with respect to the true orientation of an angle that depends on the geometry of the interaction and may be up to 25 degrees. We also find that the presence of pure double couple solutions or of CLVD and isotropic components depends on the compressibility of the magma. Gas-rich, very compressible magma will be associated to isotropic components, while DC and CLVD will result from the interaction of faulting with gas-poor magma. CLVD components may have a physical meaning of geometrical change in the dike associated to interaction with the faulting.

Applying UV cameras for SO2 detection to distant or optically thick volcanic plumes

Christoph Kern[1], Cynthia Werner[2], Tamar Elias[3], A. Jeff Sutton[3]

[1]USGS Cascades Volcano Observatory, USA, [2]USGS Alaska Volcano Observatory, USA, [3]USGS Hawaiian Volcano Observatory, USA

E-mail: ckern@usgs.gov

Ultraviolet (UV) camera systems represent an exciting new technology for measuring two dimensional sulfur dioxide (SO2) distributions in volcanic plumes. The high frame rate of the cameras allows the retrieval of SO2 emission rates at time scales of 1 Hz or higher, thus allowing the investigation of high-frequency signals and making integrated and comparative studies with other high-data-rate volcano monitoring techniques possible. One drawback of the technique, however, is the limited spectral information recorded by the imaging systems. Here, a framework for simulating the sensitivity of UV cameras to various SO2 distributions is introduced. Both the wavelength-dependent transmittance of the optical imaging system and the radiative transfer in the atmosphere are modeled. The framework is then applied to study the behavior of different optical setups and used to simulate the response of these instruments to volcanic plumes containing varying SO2 and aerosol abundances located at various distances from the sensor. Results show that UV radiative transfer in and around distal and/or optically thick plumes typically leads to a lower sensitivity to SO2 than expected when assuming a standard Beer-Lambert absorption model. Furthermore, camera response is often non-linear in SO2 and dependent on distance to the plume and plume aerosol optical thickness and single scatter albedo. The model results are compared with camera measurements made at Kilauea Volcano (Hawaii) and a method for integrating moderate resolution differential optical absorption spectroscopy data with UV imagery to retrieve improved SO2 column densities is discussed.

New developments in UV imaging for the monitoring of volcanic SO2

Jean-Francois Smekens[1], Michael R. Burton[2], Amanda B. Clarke[1], Georgina M. Sawyer[3]

[1]Arizona State University, Tempe, AZ, USA, [2]Istituto Nazionale di Geofisica e Vulcanologia, sezzione di Pisa, Italy, [3]Laboratoire Magmas et Volcans, Universite Blaise Pascal, Clermont-Ferrand, France

E-mail: jsmekens@asu.edu

SO2 monitoring is a common technique at many volcanic centres. Recently, automated networks of scanning spectrometers have led to great improvement in frequency and accuracy of measurements. Simultaneously a new instrument has been proposed to acquire 2D images of volcanic plumes in the UV spectrum. This imaging technique (hereafter referred to as UV camera) provides additional contextual information, as well as a quantitative way of determining plume velocity from a single remote location, without relying on weather reports. These advantages are to be balanced with a loss of spectroscopic information when using bandpass filters, leading to reduced precision in the measurements. Following on the work of Kantzas et al., we have designed, built and begun testing a UV imaging system, along with corresponding acquisition and processing software, that combines two CCD cameras equipped with UV filters and a USB2000+ spectrometer.

The cameras acquire simultaneous images of the drifting plume at two different wavelengths. The 310nm filter captures the absorption of UV light by the SO2 molecules present in the plume, while the 330nm filter captures a reference image subject to the broader effects of other gas species and aerosols. The USB2000+ spectrometer is used as a spot check to calibrate the images, acquiring high-resolution spectra in the range 280-400nm. Comparing the SO2 retrieval from the USB2000+ with those from the corresponding pixels in the calibrated image allows us to guarantee the accuracy of our calibration, and to estimate the effects of light dilution resulting from scattering of UV photons between the plume and the instrument.

We have tested the instrument at the Navajo Generating Station, the largest coal burning plant in the American Southwest, located near Page, AZ. Preliminary data have also been acquired at Stromboli volcano, Italy and Semeru volcano, Indonesia.

The eruptive activity of Sakurajima Showa crater, Kyushu, Japan

Koji KATO[1], Masanao SHIMOMURA[1], Hiroaki INABA[1], Shinichi MATSUSUE[2], Takayuki SAKAI[3], Yoshiaki FUJIWARA[3], Tomoyuki KANNO[3], Jun FUNASAKI[3]

[1]FUKUOKA District Meteorological Observatory, Japan, [2]KAGOSHIMA Local Meteorological Observatory, Japan, [3]Japan Meteorological Agency, Japan

E-mail: funasaki@met.kishou.go.jp

The Sakurajima is an andesitic volcano located on the southern rim of the Aira caldera in Kyushu,Japan and is known to be one of the most active volcanoes in Japan.Large eruptions accompanied by substantial lava effusion occurred in 1471-1475,1779,and 1914(Taisho eruption). Among them,during Taisho eruption lava flow effused from one of the fissures on the eastern flank of the volcano connected Sakurajima with Osumi-peninsula. Showa crater located at the eastern flank of the volcano began to erupt in 1939,and then the eruptive activity gradually increased and in 1946 lave effusion occurred. The total volume of lava amounts to about 0.2km3. However,the eruptive activity has declined after that. In 1955,Explosive activity at the Minamidake crater has begun,and the annual number of explosions exceeded 100 from 1972 to 1988. The explosions were accompanied by strong air shocks,and volcanic bombs reached the residential area at a distance of approximately 3km. However,the explosive activity has declined from 2000.

On the other hand,Showa crater resumed eruptive activity in June 2006,after 58 years of interval. Although the eruptive activity started with small phreato-magmatic eruption,on 3 February 2008 an explosive eruption occurred for the first time since the restarting of the activity.After that,eruptive activity gradually increased,such as repeated explosive eruptions, volcanic bombs reaching at a distance of about 2km, and very small-scale pyroclastic flows. The amount of magma moved to magma chamber located beneath Minamidake gradually increased, too. The total number of explosions at Showa crater since 2008 exceeded 3000 by 2012. Although eruptions requiring evacuation have not occurred yet,it is expected that eruptive activity of Sakurajima will become violent near future.

Japan Meteorological Agency (JMA) began issuing Volcanic Warnings and Volcanic Forecasts on 1 December 2007 to mitigate the effects of volcanic disasters. In addition, the warnings and forecasts are accompanied by one of five Volcanic Alert Levels based on the disaster mitigation measures required in the target area. Each level corresponds to the action to be taken. Volcanic Alert Levels are applied to major volcanoes through coordination of evacuation planning at local Volcanic Disaster Management Councils.

The Volcanic Alert Level of Sakurajima had been Level 2 since the system was put in place on 1 December 2007. On 3 February 2008,JMA issued a Volcanic Warning at Sakurajima, raising the Volcanic Alert Level from Level 2 to 3 because the volcanic activity was expected to become more active. Since then, in response to the activity JMA has issued Volcanic Warnings with Volcanic Alert Level,Sakurajima is classified as Level 3 as of January 2013.

The 2011 eruptive activity of Shinmoedake volcano, Kirishimayama, Kyushu, Japan

Koji KATO[1], Masanao SHIMOMURA[1], Hiroaki INABA[1], Shinichi MATSUSUE[2], Hitoshi YAMASATO[3], Takayuki SAKAI[3], Yoshiaki FUJIWARA[3], Tomoyuki KANNO[3], Jun FUNASAKI[3]

[1]FUKUOKA District Meteorological Observatory, Japan, [2]KAGOSHIMA Local Meteorological Observatory, Japan, [3]Japan Meteorological Agency, Japan

E-mail: funasaki@met.kishou.go.jp

Shinmoedake volcano is one of the Kirishimayama volcanoes group located southern Kyushu, Japan and the previous magmatic eruptions occurred in 1716-1717. This time, small phreatic eruptions which repeatedly ocurred in 2008 and 2010 were followed by magmatic eruptions in 2011. The 2011 eruptive activity started with a small phreatomagmatic eruption on 19 January 2011. On 26 January, purely magmatic activity began with subplinian eruptions, effusive activity inside the summit crater and frequent explosive eruption. With these eruptions, large amounts of tephra-fall and shockwaves damaged municipalities located around Shinmoedake. During the subplinian eruptions and lava growth between 26 January and the beginning of February, deflation of the magma chamber beneath north-west of Karakunidake caused by magma movement to Shinmoedake was observed by tiltmeters. Although eruptions including explosive ones had occurred repeatedly since then, the eruptive activity had gradually declined since March 2011, and then has ceased on 7 September 2011. Besides, seismic activity had also declined during March 2012, and in May 2012, had reached pre-eruption levels. As for magmatic activity, since the beginning of February inflation caused by magma supply to the magma chamber had been detected by GEONET again, but had declined during December 2011 and has almost stopped on January 2012.

For the sake of the disaster mitigation of the 2011 Shinmoedake eruptive activity, Japan Meteorological Agency (hereinafter JMA) issued various information, including the Volcanic Alert Level corresponding to the countermeasures of the local governments. JMA was unable to raise the Volcanic Alert Level before the initial subplinian eruption because of a lack of clear precursory signals. And then, after the start of the magmatic eruption, JMA raised the Volcanic Alert Level from Level 2 to 3 and widened the target area in response to the eruptive activity. To the contrary, tilt changes and an increase in seismicity probably caused by magma intrusion beneath Shinmoedake were often observed about 60 hours in advance of eruptions which had repeatedly occurred since the beginning of February 2011.

Taking into account geodetic, seismic, and infrasonic data observed during the subplinian eruptions, we conclude it was after magma eruptions started that a large amount of magma in the magma chamber located at northwest of Karakunidake moved to Shinmoedake. This result indicates that it is difficult to predict the subplinian eruptions with sufficient lead time. The 2011 Shinmoedake eruptive activity underscores the importance of detection and correct interpretation of magma movement with which to anticipate eruptive phenomena quickly and to mitigate the impacts of volcanic activity.

In this presentation, we provide an overview of the 2011 eruptive activity of Shinmoedake and discuss application of the Volcanic Alert Level for the 2011 Shinmoedake eruption.

Best practice volcano monitoring in New Zealand.

Craig A Miller, Arthur D Jolly

GNS Science, New Zealand

E-mail: c.miller@gns.cri.nz

An approach to achieving best practice volcano monitoring through a review of New Zealand's volcano monitoring capability as established under the GeoNet project is presented. A series of benchmark, consultation and station performance studies were undertaken to provide a comprehensive review of volcano monitoring in New Zealand and to establish plans for future improvements in capability. The USGS NVEWS method was applied to benchmark the built instrumentation networks against recommendations for instrumentation based on a volcanoes threat level. Next, a consultative study of New Zealand's volcanology research community was undertaken to canvas opinions on what future directions GeoNet volcano monitoring should take. Once the seismic network infrastructure was built, a noise floor analysis was conducted to identify stations with poor site noise characteristics. Noise remediation was implemented by either re-locating the site or placing sensors in boreholes. Quality control of GPS networks is undertaken through the use of multipath parameters derived from routine processing. Finally the performance of the monitoring networks is assessed against two recent eruptions at Mount Tongariro and White Island.

Activity monitoring of the volcano Kizimen using remote methods, eruption in 2010–2012

Irina Nuzhdina

Kamchatkan Branch of Geophysical Survey RAS, Russia

E-mail: irina@emsd.ru

Kizimen is one of the poorly known active volcanoes in Kamchatka. The volcano is similar to Unzen in Japan according to their characteristics. Tephrachronological study shows several catastrophic eruptions in evolution of Kizimen volcano. Thus there is a hypothesis, that it has the potential to produce a Mount St. Helens style eruption. There is very few information about previous weak and moderate eruptions of Kizimen. The last known one was in 1927-1928. Three seismic stations were installed in the vicinity of the Kizinen volcano in 2003-2011. Nearest station KZV is located 2.6 km from top at the slope of volcano. Video observation of volcano began in July 2011. Kamchatkan Branch of Geophysical Survey monitors a volcanic activity of Kizimen volcano using three remote methods:

1) Seismic monitoring is a leading method. Processing and interpretation of the data from automatic telemetric seismic stations.
2) Video observation.
3) Satellite observation. Data from AVO (Alaska Volcano Observatory).

It is very important to prevent the population and administration, ministry of the emergency situation about the possible eruption in proper time. The purpose of this work is a reducing the risk from volcano hazards and providing safety of air travel across the North Pacific.

Last seismic activity at the volcano began in April 2009. Successful short-term prediction (time and size) of strong explosive eruption was made using seismic data. First strong explosive event with 10 km ash plume height was on December 12, 2010. Eruption of Kizimen with ash plumes, pyroclastic and lava flows continues till present time.

The Domerapi project. Dynamics of an arc volcano with extruding lava domes, Merapi (Indonesia): from the magma reservoir to eruptive processes

J. P. METAXIAN[1], S. SURONO[2], C. MARTEL[3], F. BEAUDUCEL[4], K. KELFOUN[5], P. LESAGE[1], S. WIDIYANTORO[6], J. S. PALLISTER[7], J. P. TOUTAIN[8], P. JOUSSET[9]

[1]ISTerre, CNRS, Université de Savoie, IRD R219, 73376 Le Bourget du Lac, FRANCE, [2]CVGHM, Jalan Rancabentang No.26 Bandung 40142, West Java, INDONESIA, [3]ISTO, UMR 7327 - CNRS/Université d'Orléans, 45071 Orléans, FRANCE, [4]IPGP, Sorbonne Paris Cité, Univ Paris Diderot, UMR 7154 CNRS, 75005 Paris, FRANCE, [5]LMV - UMR 65245, rue Kessler, 63000 Clermont-Ferrand, FRANCE, [6]Bandung Institute of Technology - Jalan Ganesha 10, Bandung, INDONESIA, [7]VDAP USGS Cascades Volcano Observatory 1300 SE Cardinal Court Vancouver, WA 98683, USA, [8]IRD, Graha Kapital 1, Lantai 2, S 205 Jalan Kemang Raya 4 Jakarta 12730, INDONESIA, [9]Helmholtz Center GFZ, Telegrafenberg, 14473 Potsdam, GERMANY

E-mail: jean-philippe.metaxian@ird.fr

Volcanoes are complex systems that transfer magma from deep storage zones to the surface through a set of dykes and conduits. At each level, numerous coupled phenomena modify the chemical and physical properties of the magma and the state of the surrounding medium, producing geophysical and geochemical signals that may be detected at the surface. In the case of andesitic volcanoes, magma reaches the surface as lava flows, domes that may destabilize gravitationally or explosively to form pyroclastic flows that travel many kilometers along the flanks of the volcano or via vertical explosive columns of fragmented magma. These different eruptive styles generate drastically different human, structural and environmental impact.

In order to improve our understanding of these magmatic processes and their interplay with eruptive dynamics, DOMERAPI project proposes a multi-disciplinary approach that involves and integrates petrological, geochemical and geophysical methods. This strategy is quite appropriate to understand complex dynamic systems where any individual technique would give only a narrow and limited perspective. DOMERAPI includes analysis of existing data, but also designs new and novel field observations and innovative laboratory experiments. As a major objective, results obtained by different disciplines will be integrated in numerical conduit flow models and interpreted in terms of physical processes, to assist in eruption forecasting and eruptive scenario definition on volcanoes forming lava domes.

This project is focused on Merapi, a target exceptionally challenging after the paroxysmal eruption of October-November 2010. Such a project provides the opportunity to investigate the transition between moderate and violent explosions related to dome growth and collapse and the longterm impacts of such an event on dome-forming type volcanoes. To reach that goal, the permanent monitoring system will be implemented with a dense multiparametric network of sensors, making Merapi one of the best monitored volcanoes in the world. The results will have major implications for understanding magmatic processes, volcano monitoring, hazard assessment and risk reduction on other explosive island-arc volcanoes.

This cooperative project brings together Indonesian, French, American and German research teams that are highly specialized in their own field, such as in volcano monitoring, experimental petrology, physical volcanology, geophysical structure imaging or numerical modeling of magmatic processes.

DOMERAPI project began in 2013 and will last 4 years. It is funded by the french Agence nationale de la Recherche. We will present the scientific objectives of the project, the first experiments initiated in the field and results of petrological and geophysical studies of the 2010 eruption.

MaGCAP-V: Windows-based software to analyze ground deformation and geomagnetic change in volcanic areas

Keiichi Fukui[1], Shinobu Ando[5], Kenji Fujiwara[3], Sadayuki Kitagawa[4], Kazuya Kokubo[2], Shin'ya Onizawa[2], Takayuki Sakai[3], Toshiki Shimbori[2], Akimichi Takagi[2], Tetsuya Yamamoto[2], Hitoshi Yamasato[3], Akira Yamazaki[3]

[1]Kakioka Magnetic Observatory, Japan, [2]Meteorological Research Institute, Japan, [3]Japan Meteorological Agency, Japan, [4]Morioka Local Meteorological Observatory, Japan, [5]Ministry of Education, Culture, Sports, Science and Technology, Japan

E-mail: kfukui@kakioka-jma.go.jp

MaGCAP-V is Windows-based software to evaluate volcanic activity from ground deformation and geomagnetic changes observed at volcanoes. That has been developed by Meteorological Research Institute, Japan Meteorological Agency since 2000. Recently, we can use many kinds of advanced technology for volcano monitoring, such as dense GNSS networks, distance measurements by using automated EDM, borehole tiltmeters installed near the crater, InSAR technique, precise gravity observations, geomagnetic observations by using the Overhauser magnetometers. And the development of a convenient analysis tool is required to interpret the volcanic activities from these various kinds of data. In order to meet this requirement, MRI started to develop MaGCAP-V in 2000. Over the past ten years, JMA has adopted these technologies and has operated the monitoring system consist of seismometers, monitoring camera, infrasonic microphones, borehole tiltmeters, and GNSS network at 47 active volcanoes in Japan. Furthermore, JMA has routinely carried out the repeated GNSS and geomagnetic observations at the summit areas of active volcanoes since 2000. These geodetic and geomagnetic data are analyzed by JMA using MaGCAP-V. The estimated source models are used to evaluate the volcanic activities and reported to the Coordinating Committee for Prediction of Volcanic Eruption.

Overview of MaGCAP-V

Observation data: 1) GNSS data, 2) displacements (including leveling data), 3) tiltmeter data, 4) EDM data, 5) InSAR data, 6) strainmeter data, 7) gravity change, 8) magnetic total intensity.

Auxiliary data: 1) Hypocenter data, 2) Gridded digital elevation data for modeling and drawing the topography, 3) Vector data (e.g., shorelines or faults).

Data visualization: 1) Time series plot, 2) Space distribution plot on map and cross sections (marks, vectors, and bars style plots at observation points or colored distribution map, contour map), 3) Overlay plots with any combination of plot styles and kinds of observations.

Source model: 1) Mogi, Okada, and spheroidal source model (Sakai et al, 2008) for ground deformation, 2) Gravity change due to Mogi and Okada model, and the mass movements for gravity data, 3) Thermal demagnetization in sphere, column, conical, box, and spheroidal for geomagnetic data, 4) Piezo magnetism for geomagnetic data, 5) Sources for the combined analysis using different kinds of observations, 6) FEM-DB model for ground deformation. FEM-DB is a data set of ground surface displacement vectors calculated by 3D finite element method for various pressure sources. A source model is selected from the models in DB or interpolated from the DB.

Method to determine optimum sources: Grid search or inverse analysis.

Semi-automatic analysis: Semi-automatically execute the process of modeling and creating of image files.

Pressure source inferred from long-term volcanic deformation observed by GPS in Izu-Oshima

Tetsuya Yamamoto, Shin'ya Onizawa, Akimichi Takagi

Meteorological Research Institute, Japan Meteorological Agency, Japan

E-mail: tyamamot@mri-jma.go.jp

In Izu-Oshima, one of the most active volcanoes in Japan, GPS observation has been conducted since 1990s to detect volcanic deformation, and the data shows a continuous inflation of the volcano edifice indicating magma accumulation. Onizawa el al. (2012) investigated the long-term deformation by the GPS displacement data and analyzed the inflation using a spherical pressure source in a homogeneous semi-infinite earth, namely the Mogi model. Here we carried out further analysis using the finite element method (FEM).

Based on the result of Onizawa et al., the horizontal components of the observed displacements were found almost similar to the values expected by the Mogi model which pressure source was located beneath the northern part of the summit caldera at 6.7km depth. For vertical component, however, the observed and extected values were different in a part. The vertical displacement (uplift) by the Mogi model was estimated to be largest just above the pressure source, though the observed uplift at a corresponding location was smaller than the surrounding area.

In order to investigate this difference, we carried out further analysis by the FEM considering the topography of the volcano, the underground structure and a pressure source of not simple shape; all those were not accounted in the Mogi model. In the finite element models a prolate spheroidal source elongated vertically was utilized, assuming axisymmetric underground structure and topography. The models were characterized by two source parameters, the aspect ratio of the spheroid and the depth of the source. Searching in the parameter space, we found that the displacement expected by the FEM was most similar to the observed one when the source depth was about 4km and the aspect ratio was larger than 3. The observed feature of the uplift was realized by this model as well. Compared with the case of the Mogi model, the source depth was shallow significantly and the change of source volume was only about a half. It shows such analysis by the FEM is useful for a precise investigation of a magma plumbing system of the volcano.

Restart of magma accumulation after the 2010 eruption at Merapi Volcano, Indonesia detected by GPS observation

Takahiro Ohkura[1], Masato Iguchi[2], Muhamad Hendrasto[3], Umar Rosadi[3], Nurnaning Aisyah[3]

[1]AVL,Kyoto University, Japan, [2]SVO, DPRI Kyoto University, Japan, [3]Center for Volcanology and Geological Hazard Mitigation, Indonesia

E-mail: bonkura@aso.vgs.kyoto-u.ac.jp

Merapi Volcano in Central Java, Indonesia is one of the most active volcanoes in the world. This volcano has erupted intermittently since 16th century based on historical records and often caused pyroclastic flows due to collapse of lava domes called "Merapi-type".

In October 2010, an explosive eruption occurred at the summit and destroyed the old lava dome formed in the eruptive activity of 2006 and a new crater was opened at the summit. And pyroclastic flows continuously occurred through the summit crater during the period of November 3 - 5.

In this paper, we report a ground deformation detected by GPS observation which we deployed after the eruptive activity of 2010 at Merapi volcano as an activity of a project "Multi-disciplinary Hazard Reduction from Earthquakes and Volcanoes in Indonesia" under SATREPS supported by JST, JICA, RISTEK and LIPI.

We have started GPS observation in December 2010 around Merapi volcano. We installed 3 stations around the summit, which are 2-5km apart from each other and these stations are located 27-32 km north from the base station, BPPTK (former Merapi Volcano Observatory located in Yogyakarta city). Each station around the summit is equipped with a dual-frequency GPS receiver (Leica GR10). Continuous observation with a sampling rate of 1second is performed at all stations. We also installed a Wireless LAN system between each station and BPPTK where other type of GPS receiver (Leica GRX1200) was installed for the reference. We applied a PPP (precise point positioning) using GPS analysis software, GIPSY-OASIS II ver. 6.1.2. In the analysis, JPL precise ephemeris is used, and dairy coordinates are calculated with single receiver ambiguity resolution.

As a result of this analysis, extensions were detected in the baseline between BPPTK and the stations located at the northern foot of the volcano with a rate of 1cm per year. And a contraction was detected between BPPTK and the southern station of the volcano with a rate of 1cm per year. The baselines among the summit stations showed expansion with a rate of 1-2 cm per year. These results suggest an expansion of volcanic edifice.

Assuming a Mogi source beneath the summit, the depth and the volume change of the source were determined with a grid search method using baseline change between March and December 2011. The obtained depth is 3-3.5km below sea level with an inflation volume of 5-8x$10^5 m^3$.

This depth almost coincides the lower limit of the volcanic (VTA) earthquakes during 1991 obtained by Ratdomopurbo et al. (2000, JVGR). And obtained inflation rate (about 1x$10^6 m^3$) is almost same as the magma production rate during 1890-1992(Siswowidjoyo, et al. 1995, Bul. Volc.). We can conclude that it is highly possible that magma accumulation has already started for the next eruption.

The Pernicana and Trecastagni faults: the most active structures dissecting Mt. Etna volcano (Sicily) studied by multidisciplinary ground deformation measurements

Alessandro Bonforte[1], Gianpiero Aiesi[1], Giuseppe Brandi[2], Francesco Calvagna[1], Salvatore Consoli[1], Giuseppe Falzone[1], Angelo Ferro[1], Salvatore Gambino[1], Francesco Guglielmino[1], Giueppe Laudani[1], Francesco Obrizzo[2], Giuseppe Puglisi[1], Benedetto Saraceno[1]

[1]Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo, Italy, [2]Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Vesuviano, Italy

E-mail: alessandro.bonforte@ct.ingv.it

The complex interaction between regional stress, gravity forces and dike-induced rifting, seems to have a role in the eastward movement of the Mt. Etna eastern flank. In this context the Pernicana and the Trecastagni-Tremestieri Fault systems seem to identify the northern and southern boundaries of the unstable sector.

The Pernicana fault system forms a left-lateral shear zone that dissects the north-eastern flank of Etna. The kinematics of this system is related to shallow seismic crises (M $\approx$ 4.0) occurring along the western segment. The eastern segment, ESE trending, is only affected by aseismic creep with purely left-lateral displacement.

The Trecastagni fault is a NNW-SSE tectonic structure on the lower southern flank, characterized by evident morphological scarps and normal and right-lateral movements damaging roads and buildings. This fault is affected by continuous dynamics with episodic accelerations accompanied with shallow seismicity.

The dynamics of these faults has been analysed by a multi-disciplinary approach with terrestrial (levelling across both faults and extensometers record on the Trecastagni fault) and satellite (InSAR data and GPS surveys) ground deformation data.

The levelling route on Mt Etna is 150 km long and consists of 200 benchmarks. Part of the levelling route crosses the Pernicana fault, at an altitude of 1400 m asl. A new levelling network has been installed across the Trecastagni fault and it showed a mean vertical slip rate of about 1 cm/y and episodic acceleration on short segments of the fault, with displacements of almost 3 cm.

The monitoring of the Trecastagni fault is also performed by two continuous wire extensometers and a system for periodic direct measurements across the fault in its central and north-central sectors. The two stations measure the relative displacements perpendicular to the fracture, evidencing an opening of about 2-3 mm/y.

Both faults show clear traces on SAR interferograms and time series. InSAR data allows tracking the path of the Pernicana fault with a rate of about 2-3 cm/y. The Trecastagni fault shows a main vertical kinematics, at a rate of about 4 mm/y, with a minor E-W component.

The dense GPS network is measured periodically and has more than seventy benchmarks. Two GPS sub-networks lie across the eastern segment of the Pernicana fault. The first one was installed in April 1997; the second one was measured for the first time in July 2002 upgrading an EDM network. The aim of these networks is to detail the structural framework and displacements along the aseismic sector of the fault.

Integration of this wide spectrum of geodetic data allows strongly constrained ground deformation pattern to be defined and modeled. Furthermore, the very long time series available on the Pernicana fault, allows its behavior to be investigated in time and its role and relationships in the framework of flank instability and eruptive activity to better understood.

25 years of GPS measurements at Mt. Etna

Giuseppe Puglisi, EtnaGPS Team

Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo, Italy

E-mail: alessandro.bonforte@ct.ingv.it

GPS (Global Positioning System) monitoring has been performed on Etna volcano since 1988, making this volcano one of those with the longest records of GPS data. The first order network, measured at least once every year in accurate static mode, was progressively augmented from 9 benchmarks in 1988 to about 80 benchmarks nowadays. Through the quarter of a century, improvements concerned also technological aspects. The most important was the evolution towards a network of permanent stations, which now collect GPS data continuously on 25 selected sites, at very high rate (up to 10 Hz), spurred the development of specific approaches for data processing. However, Etna has also proved an optimum testing ground of new surveying approaches in order to optimize geodetic fieldwork. Several methodological developments related to kinematic surveys and to the correction of tropospheric delays were made.

The use of GPS for monitoring ground deformations at Mt. Etna considerably improved our knowledge of the dynamics of the volcano, its main structural features and plumbing system, producing more that 30 papers on international journals and specific books. The analysis of GPS data allowed, for instance, to infer the location of magma reservoirs acting during the last two decades, identifying a pressure zone beneath the western flank at a depth ranging from 2 to 9 km, studying several shallow intrusions related to the recent eruptions, quantifying the flank dynamic of Mt. Etna and modeling detachment surfaces beneath the eastern and southern flanks. At a local scale (e.g. in the summit areas and across the Pernicana fault), displacements have been also identified and modeled.

EtnaGPS Team: Aloisi M. (1), Bonaccorso A. (1), Bonforte A. (1), Briole P. (2), Bruno V. (1), Calvagna F. (1), Campisi O. (1), Cannavo' F. (1), Cantarero M. (1), Consoli O. (1), Consoli S. (1), Gambino S. (1), Guglielmino F. (1), Mattia M. (1), Nunnari G. (3), Palano M. (1), Patane' D. (1), Pellegrino D. (1), Puglisi B. (1), Pulvirenti M. (1), Rossi M. (1), Ruegg J.C. (4), Velardita R. (1)

1) Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo, Catania, Italy

2) Ecole Normale Superieure, Paris, France

3) Dip. Elettrico Elettronico e dei Sistemi, Universita' di Catania, Catania, Italy

4) Institut de Physique di Globe, Paris, France

Analysis of Volcanic earthquake swarm in Gede Volcano, Indonesia base on seismicity and focal mechanism

Ahmad Basuki[1], Dannie Hidayat[2], Iyan Mulyana[1]

[1]Center for Volcanology and Geological Hazard Mitigation, Geological Agency, Indonesia, [2]Earth Observatory of Singapore, Singapore

E-mail: ahmad_b@vsi.esdm.go.id

Gede volcano is an active strato-volcano in Indonesia. It was very active in 1747-1748 and produced a devastating eruption and lava flow. In 1890, a pyroclastic flow destroyed a wide area near the volcano. The last eruption was occurred in 1957, when the height of plume reached 3000 m above the crater. Since the installation of the first seismometer at Gede, there have been swarms of earthquakes that occurred every 2-4 years with almost the same amount of total energy. The last two swarms were detected in November-December 2010 and February-March 2012. The volcano monitoring system has been improved by adding five seismic stations and two tiltmeter stations to locate volcanic earthquakes and deformation source. The hypocenter determination in 2011 showed that the volcano tectonic earthquakes were located under Gede Volcano, and also North- and South of the volcano. The earthquakes occurred along a SW-NE trending strike-slip fault which may be connecting the Cimandiri and Lembang faults. Focal mechanisms and tilt vectors in 2011 also suggested strike slip movement. However, when a VT earthquakes swarm occurred in February - March 2012, hypocenters were elongated E-W beneath the Gede crater. Tiltmeter data showed inflation shortly prior to the increasing seismicity, and focal mechanisms indicated normal faulting. Apparently, tectonic movement of the fault was interrupted by magma intrusion beneath Gede in February-March 2012.

Active monitoring at active Volcanoes -Monitoring temporal change of transfer function in Sakurajima volcano, Japan

Hiroki Miyamachi[1], Koshun Yamaoka[2], Masato Iguchi[3], Hiroshi Yakiwara[1], Takahiro Kunitomo[2], Toshiki Watanabe[2], Ryoya Ikuta[4]

[1]Faculty of Science, Kagoshima University, Japan, [2]Graduate School of Environmental Studies, Nagoya University, Japan, [3]Disaster Prevention Research Institute, Kyoto University, Japan, [4]Faculty of Science, Shizuoka University, Japan

E-mail: kyamaoka@seis.nagoya-u.ac.jp

We have deployed an active seismic source at the northwestern flank of Sakurajima volcano to monitor the temporal variation of seismic propagation property on which the volcanic activity may influence. The source, named ACROSS (= Accurately Controlled Routinely Operated Signal System), started its routine operation from 18 September, 2012 and is still in operation at the moment of the abstract submission. We are operating two rotational vibrators in the site that is 3.6 km to the northwest of the Minamidake crater of Sakurajima. The sources are operated with a frequency modulation, in which the modulation period is 50 seconds and the frequency range is 5 to 10 Hz and 10 to 15 Hz for each of the sources, to produce broad frequency range of signal.

The vibrator produces a force with a rotation of an eccentric mass around an axis. The vibrator is designed to switch its rotation direction in every two hours, so that we can synthesize a linear vibration of any direction that is perpendicular to its rotational axis, which has two degrees of freedom. As each seismic station has three component signals, we can obtain 6 components of transfer function for each source-receiver pair.

The signal from the ACROSS source is routinely monitored with more than 20 permanent seismic stations in and around Sakurajima volcano. Four temporal seismic stations are also deployed to increase the spatial coverage of monitoring. The signals that are recorded at the seismic stations are deconvoluted with the source function to obtain the transfer function between the source and the receivers. The transfer function is clearly obtained even for the stations on the other side of the summit, which will enable us to monitor the temporal variation of the seismic propagation property beneath Sakurajima. The transfer function so obtained will be shown in the poster presentation to discuss the temporal variation of seismic characteristics beneath Sakurajima.

Seismic source determination on volcanoes: lessons from high resolution field experiments

Christopher J. Bean[1], Ivan Lokmer[1], Louis DeBarros[2]

[1]University College Dublin, Ireland, [2]Geoazur-Universite Nice Sophia, France

E-mail: chris.bean@ucd.ie

Determining the locations, mechanisms and source time histories of volcano seismicity are key goals towards a better understanding of volcano processes. This is especially true of shallow low frequency events which may hold the key to dynamic interactions that are the immediate preludes to eruptions. Whilst it is clear that knowledge of the velocity structure of the edifice is important for the absolute location accuracy of seismic events, what is not so obvious is the role that knowledge of the velocity structure plays in determining the mechanism and source time history. A seismogram is the convolution of the source with the path and the instrument response. The volcanic edifice can exhibit extreme mechanical heterogeneity which can lead to very strong path effects for seismic frequencies as low as 0.5 Hz, and perhaps lower. In the near surface this mechanical heterogeneity is poorly constrained and can lead to strong but unknown path effects. This makes the details of the source difficult to determine. Using very high resolution temporary networks we investigate this problem in detail.In-depth field data analysis is complemented by full wavefield numerical simulations in quasi-realistic edifice models in order to calculate numerical Green's functions and to test source locations algorithms. Using this approach is it possible to separate some artefacts from real effects, leading to more robust source locations and models. However we still suggest that the general lack of (difficult to determine) detailed velocity models which include strong spatial derivatives not normally seen in tomography velocity models, and especially in the near surface where velocity coverage is poor, is hampering detailed quantification of shallow volcano seismic sources.

A ray-tracing study for wind effects in middle-distance infrasound propagation

Makiko Iwakuni[1], Mie Ichihara[2], Giorgio Lacanna[3], Minoru Takeo[2], Masato Iguchi[4], Maurizio Ripepe[3]

[1]Japan Weather Association, Japan, [2]Earthquake Research Institute, University of Tokyo, Japan, [3]Earth Science Department, University of Florence, Republic of Italy, [4]Disaster Prevention Research Institute, Kyoto University, Japan

E-mail: iwakuni_01@jwa.or.jp

Infrasound has become an important component of observation for volcanic activity. At present, infrasound observations for volcanoes are concentrated in two distinct scales: close to the volcano in less than 10 km, or in hundreds or thousands of kilometers away. Observations and studies of infrasound in the middle-distances are very few. Infrasound signals induced by explosive eruptions of Sakurajima are often observed clearly at the dense network of well-calibrated infrasound sensors, which Earthquake Research Institute installed around Kirishima volcano, about 40 km to NNE of Sakurajima volcano. The variations are considered to be caused by changes in the atmospheric structures and possibly in the radiation patterns of infrasound generation. This study focuses on the wind effect to understand the middle-distance infrasound propagation variations.

We have been analyzing more than one thousand signals of Sakurajima explosions from July, 2011 till now. Temporal stations were installed in various distances and directions from Sakurajima. The variation of waves among the network is numerically investigated using a finite differential method, in 2-D with a correction of geometrical spreading and taking account of the topography and the profile of atmospheric temperature (Lacanna et al., 2012, AGU). Observed variations are easily explained by the effect of topography. On the other hand it is hard to explain observed variations in winter by 2-D simulation even considering large variable in atmospheric temperature. To evaluate the degree of wind effect, we tried to simulate the ray-paths by using two kinds of models. One is taking account of the wind effect as a moving medium and the other is taking account of the wind effect as the modification of temperature (medium traveling waves is static). In close-distance station both models showed similar ray-paths. On the other hand, two models sometimes showed different ray-paths in middle-distance stations. Next, although infrasound waveforms observed in the north and east directions were sometimes very similar regardless of distances, signals recorded at a station 43 km to SSW were quite different and much weaker than those at similar distances in NNE, the stations at Kirishima. Sound propagation is increased by wind toward the down-wind direction and inverse layers of effective sound speed are formed. These inverse layers were frequently formed in the direction of Kirishima but rarely to the south during the analyzed period. The inverse layers prevent upward propagation of infrasound and confine waves to increase the observed amplitudes. When the inverse layers were not clear or lower than Kirishima peaks, the wave amplitudes were distinctly reduced behind the peaks. In this way, wind effect is significant in the middle-distances. In order to obtain quantitative information of the source, we need atmospheric data with better resolutions in time and space.

Relationship between infrasound pressure and possible flight distance of volcanic bomb

Akimichi TAKAGI[1], Toshiki SHIMBORI[1], Tetsuya YAMAMOTO[1], Takashi YOKOTA[1], Yoshiaki FUJIWARA[2], Yoshihiko HASEGAWA[2], Akira SUGAI[2], Sei IIJIMA[2], Koji KATO[3], Shingo UTSUNOMIYA[4], Masaki NAKAHASHI[4], Masato IGUCHI[5]

[1]Meteorological Research Institute, Japan, [2]Japan Meteorological Agency, Japan, [3]Fukuoka District Meteorological Observatory, Japan, [4]Kagishima Local Meteorological Observatory, Japan, [5]Kyoto University, Japan

E-mail: atakagi@mri-jma.go.jp

We propose a method to estimate flight distances of volcanic bomb by using infrasound records. Ballistic bombs ejected from a volcano crater cause damage to the resident area instantly. It is important to detect the flight-bombs distance from the crater. Volcanoes are often hidden by clouds, so it is necessary to get the detecting method by not using visual observations.

At many active volcanoes in Japan, air-shock observation has been carried on for several decades in order to detect eruptions. Especially at Sakurajima volcano, having been repeated Vulcanian eruptions, many sensors are installed. Pressure changes caused by eruptions have been recorded for more than half a century by the microbarometer installed by Kyoto University at Harutayama, 2.7 km northwest from Minamidake crater. In addition, the five sensors of the infrasound microphone are located by the Japan Meteorological Agency (JMA). We investigated the relationship between flight distance of ballistic bomb and infrasound pressure recorded by microphones. 148 Vulcanian eruptions, occurred at the Showa crater from 2011 to 2012 with flight-bomb distances of over 0.7 km, were analyzed.

Most commonly, amplitude of infrasound pressure recorded at every site are not to be same, even if they are considered the distance attenuation. Therefore we need to estimate site correction factors of infrasound pressure caused by explosions, using pressure changes recorded at JMA's microphone sites in reference to pressure changes measured by the microbarometer at Harutayama. By using these correlation factors, we calculated the pressure changes normalized to a 1 km distance from the Showa crater. Then an empirical relationship between the possible maximum flight distances of ejection bomb and corrected normalized pressure changes is obtained as below,

$D_{max} = 9 P_n$

where D_{max} is the maximum possible flight distance of bomb, in meter, and P_n is the corrected normalized pressure change, in Pascal. This relationship can be applied to Vulcanian eruptions at other volcanoes, for example of Asamayama and Shinmoedake volcanoes, in Japan.

PRECURSOR TO ERUPTION OF LOKON VOLCANO - NORTH SULAWESI, INDONESIA DURING 2011 - 2012

Kristianto Kristianto, Nia Haerani, Ahmad Basuki, Farid Ruskanda Bina, Ferry Rusmawan

Geological Agency of Indonesia - Center for Volcanology and Geological Hazard Mitigation, Indonesia

E-mail: kris@vsi.esdm.go.id

Lokon volcano has erupted many times since 1829. It has short interval of 1 until 8 years between eruption, and long interval of 64 years. Eruption character of Lokon volcano precede by phreatic eruption for several months and continue with short periode of magmatic explosions. Eruption produces mostly ash and ejected glowing material around the crater. In 1991 a pyroclastic flows about 1 km from the crater.

The eruptive activity of Lokon volcano in 2011 began with small phreatic eruption on February 22 and repeated on June 26. The explosions frequency was getting higher in July 2011. The main explosion on July 17, produced a 3000 until 5000 dark ash column and ejected glowing material that burned the bush around the crater. Hundreds of explosion earthquakes recorded everyday during June 2011 till June 2012. In July 2012, the explosion stopped but the seismicity remains high. August 2012, explosions continue and getting higher in the middle of September 2012. Till first week of October 2012, explosions activities ongoing with explosion column maximum of 2000 m high. During first week of December 2012, the explosions occured every two days and produced 2000 - 4000 m high of dark ash column.

Precursor of each explosion always showed increasing number of shallow volcanic earthquakes (VB type), surface burst earthquakes (hembusan type) and increasing amplitude of volcanic tremor. Those things indicate fluid pressurized before the explosion, supported by inflation and SO2 flux reduce approaching the explosion.

Monitoring of Lokon volcanic activity supported by scientific data gained from five seismic stations, three CGPS sites, periodical gas measurement and continuous visual observation from Lokon volcano observatory by CCTV. One tiltmeter station deployed in October 2012 as complementary. January 2013, the alert level of Lokon volcano is still in level III (SIAGA) from four highest level that standardized by CVGHM.

Volcanic process of the 2011 Shinmoedake eruption inferred from extensometer records

Ken'ichi Yamazaki[1], Masahiro Teraishi[1], Kazuhiro Ishihara[2], Shintaro Komatsu[1], Koji Kato[3]

[1]Disaster Prevention Research Institute, Kyoto University, Japan, [2](retired), Japan, [3]Fukuoka District Meteorological Observatories, Japan Meteorological Agency, Japan

E-mail: kenichi@rcep.dpri.kyoto-u.ac.jp

The Shinmoe-dake, one of volcanic cones of Kirishima volcanic group in Japan, erupted in January 2011. The activity was characterized by three sub-Plinian eruptions and a subsequent lava effusion and accumulation at the summit crater, between 26 and 31 January, 2011. Ground deformation in association with these activities was monitored by GPS and tiltmeters by several institutions. The deformation source was estimated from analysis of GPS data to be located 7 km northwest of the volcano. In addition, it has been observed by vault-housed extensometers at Isa-Yoshimatsu Observatory (ISA) placed approximately 18 km away from the summit of the crater. We inspected the time series of strain data at ISA to clarify more detail process of the subsurface volcanic activity.

Significant changes of 10^{-7} in strain are recorded at the time of three sub-Plinian eruptions on 26 and 27 January, and during lava effusion from 28 through 31 January. We estimated locations and sizes of deformation sources by using strain data at ISA, assuming horizontal position of sources to coincide with that estimated from GPS. Estimated depths of volume changes corresponding to three sub-Plinian eruptions and following lava extrusion are 7.2, 7.0, 7.6 and 8.3 km, respectively. Estimated changes in volume corresponding to these events are 1.25, 1.59, 0.94 and 5.25×10^{6} m^3, respectively. The ratio of the sum of volume change due to three eruptions to that of lava effusion is 0.7 and total of volume change is 9.02×10^{6} m^3, which are smaller than those estimated by other means.

In addition, the extensometers recorded minute strain changes of the order of 1×10^{-9} several hours prior to each of sub-Plinian eruptions. The magnitudes of the pre-eruption strain changes are about 1% of the magnitudes of co-eruption changes in strain. Temporal changes in these pre-eruption changes suggest that a gradual expansion and following quick contraction occurred beneath Shinmoe-dake. Gas and ash emission was observed during contraction phase. Although accurate estimation of locations and sizes of these deformations is difficult, calculations considering reading errors indicate that the deformation source is approximately on the same direction to the magma chamber from the ISA, and its depth is shallower than the estimated depth of those associated with sub-plinean eruptions and lava effusion. Pre-eruption deformations are also recorded by a borehole tiltmeter of the Japan Meteorological Agency at 1.5 km away from the crater of Shinmoe-dake. Analysis of the tilt data also suggests that the depth of the pre-eruption deformation source is shallow. These results propose a hypothesis that a portion of magma stored in the chamber moved upward as a forerunner of main ejection of magma, and it is ejected from the surface of the ground before sub-Plinian eruptions.

Monitoring the 2011 dome growth at Colima Volcano using Digital Image correlation

Jacqueline Salzer[1], Thomas Walter[1], Legrand Denis[2], Breton Mauricio[3], Reyes Gabriel[3]

[1]GFZ Potsdam, Germany, [2]Universidad Nacional Autonoma de Mexico, Mexico, [3]Universidad de Colima, Mexico

E-mail: salzer@gfz-potsdam.de

The current dome at Colima began growing in 2007, but the steep slopes and explosive nature of the volcano limit the possibilities for monitoring it directly. However, measuring deformation in the region of the crater as well as getting accurate estimates of the volume of material being extruded is important to determine the rate of the ongoing eruption and the stability of the dome. The number of explosive activity as determined in seismic data was very high in early 2011, but decreased significantly by June 2011 and remained low since then.

Here we report on a video camera system installed by the University of Colima volcano observatory to monitor the dome growth. We have analysed the optical camera data obtained between February and June 2011 using spatial digital image correlation techniques. By determining the optical flow we show that the velocity of dome extrusion varies strongly on a daily basis, reaching up to 3m/day, and systematically decreased over the 5-month period analysed. Deformation was barely above the detection threshold of 30cm/day in the weeks prior to June 21st 2011, when a significant explosion occurred, removing part of the dome. The potential links between the stagnation of dome growth and the explosion will be discussed.

Evolving Multi-Parameter Monitoring Network in Mayon Volcano, Philippines

Ma. Antonia V Bornas[1], Hiroyuki Kumagai[2], Christopher Newhall[3], Dannie Hidayat[3], Yuta Maeda[2], Takahiro Ohkura[4], Bo Galle[5], Eduardo Laguerta[1], Alejo Baloloy[1], Ramses Valerio[1], Rudy Lacson[1], Melquiades III Figueroa[1], Ramil Vaquilar[1], Christian Clarito[1], Erickson Fajiculay[1]

[1]Philippine Institute of Volcanology and Seismology, Philippines, [2]National Research Institute for Earth Science and Disaster Prevention, Japan, [3]Earth Observatory of Singapore, Nanyang Technological University, Singapore, [4]Aso Volcanological Observatory, Kyoto University, Japan, [5]Chalmers University of Technology, Sweden

E-mail: mariton.bornas@phivolcs.dost.gov.ph

Mayon is the most active Philippine volcano, having erupted 49 times since its first recorded activity in 1616. Its gamut of eruptive behavior spans small but hazardous hydrovolcanic eruption (e.g. 1993), quiet lava effusion (e.g. 1993, 2006 and 2009) and explosive pyroclastic flow-forming (e.g. 1928, 1984, 2000-01) and deadly Plinian (e.g. 1814) eruptions. In the past two decades, a combination of seismic, geodetic, gas, hydrologic and visual observation techniques have been employed with variable successes. Nonetheless, constraining the long- to short-term behavior of Mayon's magmatic system that contributes to highly precise eruption warning services remains a challenge.

In partnership with the Philippine Institute of Volcanology and Seismology (PHIVOLCS) Japan- and Singapore-based institutions have been developing multi-parameter monitoring systems in Mayon in support of enhanced eruption warning and volcanic systems research. The evolving network to date consists of a 16-station distribution of seven broadband seismographs, five tiltmeters, two infrasonic sensors, nine continuous GPS, two infrasonic sensors, two scanning mini-DOAS, two hydrologic sensors, six soil CO2 sensors, six all-weather stations and one microbarograph. Most seismic, tilt and GPS data are currently transmitted in real-time via spread-spectrum transceiver (SST) or GSM telemetry to Mayon Volcano Observatory (MVO) for archiving, processing and retransmission in near-real-time via satellite and DSL links to the PHIVOLCS Main Office (MO). All stations are targeted for SST telemetry by sometime 2013, enabling individual systems to be fully integrated in MVO and MO operations and other applications, such as automatic earthquake source location programs.

Data from the enhanced multi-parameter network are hoped to shed light on the dynamics and timescales of, among others, magmatic recharge, degassing, convection and eruption; magmatic and hydrothermal forcing of ground deformation and near to distal seismicity; and tectonic contribution to overall unrest. The integrated methodologies are ultimately expected to provide highly-constrained warning criteria for the next eruption, which can subsequently be reformulated into the five-tiered Alert Level Scheme for the eruption crisis response guidance of local disaster authorities.

A new double-difference location method for LP event families: the ability to image structures within volcanoes.

Megan Zecevic, Thomas S Eyre, Louis De Barros, Ivan Lokmer, Christopher J Bean

Seismology Laboratory, School of Geological Sciences, University College Dublin, Ireland

E-mail: megan.zecevic@ucd.ie

Long Period (LP) volcano seismic events have been observed at many volcanoes around the world. Swarms of LP events are often recorded prior to or during volcanic eruptions, and can be used to provide an insight into a volcano's internal dynamics. Within these swarms numerous recorded LP events can have almost identical waveforms, thus it can be assumed that these events have both similar source locations and source mechanisms; these events can be grouped together into families. An accurate source location is crucial in order to further understand the source processes involved in producing LP events, however locating these events can be difficult due to their emergent onset and poorly differentiated P- and S-waves. In this study we present a location method, an extension to the double-difference location technique, which can simultaneously determine the absolute location of a family of LP events and the relative source locations of each event within the family in order to image structures within the volcano. The location method has been tested on a synthetic dataset which was produced using 3D full-waveform simulations for a strongly heterogeneous, layered velocity model of a volcano, including topography, with a seismic network of 13 instruments realistically distributed around the edifice of the volcano. In order to create a family of LP events, the source locations of each synthetic event are slightly different, with the sources lying along a sloping, planar structure. When implementing the location technique we assume an unknown homogeneous velocity model, which we chose as the velocity structure is often poorly constrained due to the highly heterogeneous nature of volcanoes or even unknown. The location method was able to obtain an absolute location which was offset only by 40 m horizontally and 70 m vertically from the true source location, but what is most impressive is the ability of the method to accurately obtain the relative source locations and hence almost perfectly reconstruct the sloping, planar structure on which the LP events were originally located. The method will also be tested on real families of LP events recorded at volcanoes where other location techniques have been applied, in order to compare the methods and the corresponding results.

Seismicity of New Tolbachik Fissure Eruption

Sergey Senyukov, Svetlana Droznina, Irina Nuzhdina, Valentina Garbuzova, Tatyana Kozhevnikova, Oxana Sobolevskaya, Zoya Nazarova

Kamchatkan Branch of Geophysical Survey RAS, Russia

E-mail: ssl@emsd.ru

The Great Tolbachik Fissure Eruption (GTFE) took place in the southwestern sector of Plosky Tolbachik Volcano in 1975–76. Earthquake swarm before this eruption was strong, 200 events were located with local magnitude from 3.0 to 5.0 in 10 days. Kamchatkan Branch of Geophysical Survey RAS began a real–time seismic monitoring of Plosky Tolbachik Volcano in November 1996. In contrast to the previous eruption precursor seismicity before current eruption was relatively weak. All earthquakes had local magnitude less than 2.5. The frequency of events per day began to increase gradually in September, 2012. Earthquake number increased rapidly on November 26, 2012. Earthquake hypocenters were generally only to depths of 10 km, and most were initially located below the main summit of Plosky Tolbachik, before migrating to the southern flank and the present main eruptive vent. New major Tolbachik Fissure Eruption began at 05 hours 15 minutes UTC on November 27, 2012 with shallow seismic events with local magnitude 4.0 and strong continuous spasmodic volcanic tremor. New fissure is located between Northern Vent of GTFE and the crater of Plosky Tolbachik. Current powerful explosive–effusive eruption is continuing to present time and is accompanied by strong volcanic tremor.

Constraining melt storage and transport beneath Nabro volcano, Eritrea using seismic anisotropy

James OS Hammond[1], Mike Kendall[2], James Wookey[2], Jo Hamlyn[3], Berhe Goitom[4], Derek Keir[5], Ghebrebrhan Ogubazghi[4]

[1]Imperial College London, UK, [2]University of Bristol, UK, [3]University of Leeds, UK, [4]Eritrea Institute of Technology, Eritrea, [5]National Oceanography Centre, Southampton, UK

E-mail: j.hammond@imperial.ac.uk

Seismic anisotropy, the variation of seismic wavespeed with the direction of propagation, is often observed beneath volcanoes. It can highlight dominant fracture orientations, show regions of preferential melt alignment and can even highlight changes in strain during periods of unrest. Thus it is a useful technique in understanding how melt is stored and transported beneath a volcano.

In this study we utilise shear-wave splitting to constrain seismic anisotropy beneath Nabro volcano, Eritrea, the site of a large eruption in June 2011. This eruption, the first in the historical recorded emitted significant sulphur into the atmosphere and resulted in a ~15km long lava flow, showing the potential for these large caldera systems to erupt without warning. We use two months of seismic data recorded at 8 broadband seismic stations deployed in the months following the June 2011 eruption. In total we record 548 splitting results from earthquakes accurately located not beneath the volcano and the surrounding regions.

Initial results show that anisotropy increases for raypaths that travel directly beneath the volcano (~5% anisotropy) compared to those raypaths that sample the region outside the volcano (~1% anisotropy). Fast directions show more northwest-southeast orientations outside the volcano, but are much more variable beneath the volcano itself. These results suggest that the presence of magma in the upper crust may enhance anisotropy beneath Nabro.

The large dataset, covering a wide spatial and depth range means that we have numerous crossing raypaths beneath the volcano. As a result we are uniquely placed to use newly developed shear-wave splitting tomography techniques. We plan to invert the dataset for a number of anisotropic domains that will constrain the dominant anisotropic mechanisms beneath the volcano. These inversions will highlight differences between the strain field inside and outside the caldera and can highlight regions of preferential melt orientation, possibly indicative of magma transport.

Strain recording using a new fiber-optic Bragg-grating sensor

Olivier Coutant[1], Mikhael Demengin[2], Etienne Le Coarer[2], Stephane Gaffet[3]

[1]ISTerre, Universite de Grenoble, CNRS, France, [2]IPAG, Universite de Grenoble, CNRS, France, [3]LSBB, Universite de Nice, CNRS, France

E-mail: olivier.coutant@ujf-grenoble.fr

Strain recordings from tiltmeters or borehole volumetric strainmeters on volcanoes reveal extremely rich signal of deformation associated with eruptive processes. The ability to detect and record signals of the order of few tens of nanostrain is complementary to other monitoring techniques, and of great interest to monitor and model the volcanic processes.

Strain recording remains however a challenge, for both the instrumental and the installation point of view. We present in this study the first results of strain recordings, using a new fiber-optic Bragg-Grating (FBG) sensor. FBG sensors are known for many years and used as strain gauges in civil engineering. They are however limited in this case to microstrain capability. We use here a newly developped interferometer named SWIFTS whose main characteristics are i) an extremely high optical wavelength precision and ii) a small design and low power requirements allowing an easy field deployment. Our FBG sensor use a 3cm long Bragg network, and could ultimately present an alternative to larger sensors. We present the first results from the recording obtained in the low noise underground laboratory at Rustrel, south of France.

The campi flegrei deep drilling project: initial results from gas monitoring site surveys and drilling mud gas monitoring during the 500 m pilot hole drilling

Renato Somma[1], Thomas Wiersberg[2], Jorg Erzinger[2], Alessandro Fedele[1], Claudia Troise[1], Giuseppe De Natale[1]

[1]Osservatorio Vesuviano INGV, Italy, [2]Deutsches GeoForschungsZentrum, Germany

E-mail: renato.somma@ov.ingv.it

Situated in the Campanian region (Italy), the Phlegraean Volcanic District is a densely populated active volcanic area, including the Campi Flegrei caldera, the islands of Procida and Ischia, and a number of submerged volcanoes. The understanding of mechanisms for volcanic unrest and eruptions of large calderas is crucial to mitigate volcanic hazards and to evaluate the influence of volcanic activity on the global environment. The Campi Flegrei Deep Drilling Project (CFDDP) was born to tackle these questions by scientific drilling of a 500 m pilot hole and a 3-4 km deep main hole.

The drilling of a pilot hole was successfully executed in late summer 2012 and late fall 2012, interrupted by three months of operational stop. In the first phase, a 12 ¼inch hole was drilled to 222 m below ground level. In the second phase, the hole was deepened to 434 m (8 ¼inch borehole diameter) and finally reached a depth of 501 m with 6 inch diameter. The hole was logged and cased at the end of each phase with exception of the lowermost 80 meter, where a slotted liner was installed to permit fluid flow from the formation into the well for future fluid and gas monitoring. Cuttings were separated from the drilling mud at the shale shakers, analysed in a field laboratory and sampled for further measurements. Two core runs at 438 m and 500 m yield only poor recovery.

On-line gas monitoring was carried out to gain new insights into the evolution of the fluid regime (drilling mud gas monitoring) and to understand the interplay between deep circulating fluids and volcanic/seismic processes. The only formation-derived gas extracted from the drilling mud during pilot hole drilling was CO_2 with concentrations lower than 0.1%. Preliminary data evaluation suggests that CO_2 concentrations vary with different lithology. The low gas concentrations identified by scientific mud gas monitoring and by commercial mud logging are most likely caused by heavy drilling mud that impedes the flow of gas from the formation into the drilling mud. In the future, water and gas will be sampled from the pilot hole by a modified U-tube technique.

Prior to drilling, two long-term gas monitoring site surveys were executed from January-Mai 2009 and from May-July 2012 at a Pisciarelli fumarole field at the eastern outer flank of the Solfatara volcano, 3.2 km away from the CFDDP drill site. The average composition (air-corrected) of fumarolic gas is as follows: CO_2 (98.4 vol.%), H_2S (0.24 vol.%), N_2 (1.13 vol.%), CH_4 (65 ppmv), H_2 (0.089 vol.%), and He (7.3 ppmv). Long-term and diurnal variations in the gas composition have been identified. Stable isotope and noble gas isotope analysis are planned on all types of gas samples.

Precursory anomalies before Karymsky seismo-volcanic crisis on January 1-2, 1996 in Kamchatka by multi-scale seismicity and hydrogeochemical data

Vadim Saltykov, Gennadiy Riabinin, Yulia Kugaenko, Nadezhda Kravchenko

Geophysical Survey of Russian Academy of Sciences, Kamchatkan Branch, Russia

E-mail: salt@emsd.ru

Karymsky seismo-volcanic crisis (KSVC) is the series of paroxysmal seismic and volcanic events occurred in Kamchatka East Volcanic Belt on January 1-2, 1996: summit eruption of Karymsky volcano, freatomagmatic eruption in the lake in the Academia Nauk caldera, a significant earthquake swarm with largest event on January 1, 1996 with Mw=6.8 (Karymsky earthquake, the most strong crust earthquake recorded in Kamchatka during time of instrumental observation).

Significant hydrogeochemical anomalies and anomalies in parameters of seismicity in different levels of energy were detected before KSVC. In addition, swarms of weak low-frequency earthquakes (LFE) were detected under Karymsky volcano during last 8-9 months before KSVC.

Hydrogeochemical anomalies were markedly observed in the variations of water composition in two boreholes (N1 with the depth 600 m and N2 with the depth 2540 m) at the distance near 125 km from KSVC. Observations at borehole N1 revealed the impulsive increase (duration of about 15 days) of the concentration of calcium-, sulfate- and sodium-ions and the impulsive decrease of hydrocarbonate-ions concentrations. Similar variations of these parameters were observed prior to other large earthquakes. On the contrary, measurements in borehole N2 showed long-standing changes (up to 4 months) in concentration of hydrocarbonate-ions and ions of Ca, sulfate, Cl and Na. However alternatively to the variations observed at N1, the concentration of hydrocarbonate-ions increased and the concentration of other ions decreased.

As a multi-scale seismicity we use earthquakes of Kamchatkan regional seismic catalog and microseismicity (lowamplitude seismic noise with the frequency band within first decades of Hz). We calculated the spatial distribution of RTL parameter and Z-function for detection of dynamics of seismic process. For microseismicity analysis the original method, based on seismic noise response to tidal influence was used. Precursory seismic quiescence, detected by two independent methods (RTL and Z) are synchronous in time and demonstrate spatial agreement. Duration of detected anomaly is about 4 years.

Anomaly in seismic noise response to tidal influence was detected on the distance about 140 km from Karymsky earthquake epicenter. Duration of anomaly is about 1 month. Parameters of anomaly detected before crust Karymsky earthquake are differ from ones for subduction earthquakes 1992-2012 attended with similar effects.

Anomalies in hydrogeochemical data, seismic noise and LFE were detected in real time before KSVC. Seismic quiescence by RTL parameter and Z-function were found retrospectively.