

GRANT PROGRAMME

Project title:

Monitoring Taal volcano unrest in Philippines based on a joint Electromagnetic and multi-disciplinary educational **EMSEV-PHIVOLCS** program

Contact Name, Institutional Affiliation & E-mail address: Name, Institutional Affiliation and E-mail address of Project Principal Participants:

| EMSEV Inter- Association (ElectroMagnetic Studies of Earthquakes and Volcanoes) | |
|---|---|
| Jacques Zlotnicki, Chairperson | Yoichi Sasai, IAVCEI Liaison member |
| CNRS-France | Tokyo Metropolitan Government |
| (UMR6524-Clermont-Ferrand Observatory, France) | The Disaster Prevention Division |
| Email: <u>Jacques.zlotnicki@wanadoo.fr</u> | Email: <u>yosasai@zag.att.ne.jp</u> |
| Toshiyasu Nagao, EMSEV Secretary | Renato Solidium, PHIVOLCS Director |
| Tokai University, Shimizu | The Philippines Institute of Volcanology and Seismology |
| Forthquake Prediction Research Center | PHIVOI CS |

Earthquake Prediction Research Center Email: nagao@scc.u-tokai.ac.jp

Email: renato_solidum@yahoo.com

Introduction

Among the Natural Hazards occurring in the Philippines, the volcanic eruptions may involve large pyroclastic flows, base surges and violent phreatic explosions. Economy requests progressive occupation of volcanoes flank where agriculture is expanding. Therefore, dense populations are living on volcanoes, even in restricted areas where volcanic risks are high (gas emission, possible flank collapse, geothermal activity, etc.).

Taal volcanic complex, located at 60 km from Manila capital, is composed of a large prehistoric caldera filled by Taal Lake. The active volcano rises in the middle of the lake, and its crater (called Main Crater Lake, MCL) is filled by an acidic lake. About 9,000 inhabitants occupy the island, and several tens of thousands people live along the inner rim of the prehistoric caldera. Aquaculture, agriculture and tourists guiding on Taal are the main resources of the local population.

Since 1572, Taal has erupted 33 times killing more than 1,500 people. Phreatomagmatic, plinian, or phreatic eruptions have occurred, some of them with pyroclastic surges. Since the last 1965-1976 eruption, seismic swarms, cycles of ground deformation, geysering activity, and opening of fissures are observed.

The Philippine Institute of Volcanology and Seismology (PHIVOLCS) which is responsible for monitoring the volcano and for delivering reliable information, regularly issues an alert 1 on a scale of 5 during several weeks or months (alert 2 would mean the evacuation of children and elderly people).

PHIVOLCS-EMSEV Cooperation

After a joint EMSEV-PHIVOLCS meeting held in 2003 in Manila, it was commonly decided to focus on the understanding of Taal activity and the volcanic hydrothermal system, and on the development of electromagnetic (EM) and other geophysical monitoring systems. In 2004, an PHIVOLCS-EMSEV agreement was signed in which teaching of new PHIVOLCS scientists to EM methods was included.

In 2005, an international EM team composed of Japanese, French, and Filipinos scientists began common field works. 5 to 10 PHIVOLCS including scientists, engineers and technicians constitute the core of an PHIVOCS EM team. Since then, one to two joint campaigns are done each year including magnetic, electric, and soil degassing surveys, and installation of continuous EM stations (see 2005, 2006, 2007, 2008 EMSEV annual reports; http://www.emsev-iugg.org/emsev/).

Objectives and work plan

♦ Tasks

The understanding of the volcanic structure and the hydrothermal system, the sources of thermal and fluid transfers, the role of inner acidic and warm lake (MCL) on the volcano dynamism led us to define the following tasks:

- Imaging the hydrothermal system and the relationships between the different geothermal fields,
- Imaging the volcano and the geological interfaces (i.e. regional faults) by EM methods,
- Characterization of thermal and fluid transfers by EM and geochemical methods,
- Morphology and activity of the Main Crater Lake (bathymetry, water temperature, degassing),
- Monitoring the hydrothermal activity by magnetic, electric, and soil degassing repeated surveys,
- Continuous monitoring the volcanic activity by multi-parametric stations (magnetic, electric, ground temperature, seismicity, Radon emission),
- Monitoring water level and temperature of Main Crater Lake,
- Development of a real time telemetry system with data reception at the local observatory; visualization and data transfer by internet link.

• Teaching EM methods

During field works, a particular attention is done to educate EM-PHIVOLCS team to the methods which are applied. EM-PHIVOLCS team is advised to make measurements by him.

Before each field work, a meeting is organized at PHIVOLCS which updates the level of knowledge of the volcano, clarify the present volcanic activity, and defines precisely the content of the fore coming campaign. At the end of the campaign, a meeting and/or a report is done with PHIVOLCS direction.

• Dissemination of results

- Scientific results are regularly presented at international meetings, and published in international journals (see references below). Some results are now presented by PHIVOLCS team in International meetings (AOGS-2009; Alanis et al., 2009).

- Results have to be integrated in the hazards map and evacuations plans updated. Reports and public meetings done by PHIVOLCS will contribute to inform inhabitants living on Taal Island, and Local Authorities on the risks.

Past observations (2005 - 2008)

On volcanoes which display hydrothermal/magmatic unrests, electromagnetic (EM) methods can be combined with geochemical (GC) methods. The integration of these methods allows us to image in detail hydrothermal systems, to find out possible scenarios of volcanic unrest, and to monitor the on-going activity with a better knowledge on the sources of heat, gas emission, and fluid transfers. Since 1572, 33 phreatic to phreatomagmatic eruptions have occurred on Taal volcano, some of them causing several hundred casualties. Considering the time delay between two consecutive eruptions, there is a 90% probability that Taal volcano should have already erupted Moreover, sporadic but sometimes intense, seismic crises are observed since 1992.

A strong and large scale hydrothermal system stands on the volcano and is periodically re-activated. Commonly applied since 2005, combined EM and GC methods give an accurate description of the hydrothermal activity and heat discharge (Harada et al., 2005, 2008; Zlotnicki et al., 2008, 2009). EM methods, as magnetic and self-potential, map the hydrothermal system and locate the source of thermal and fluid transfers at depth, while soil degassing and thermal imageries clearly point out the location of the most active areas where thermal discharges take place. GC methods also specify the origin of the gas and fluids escaping from faults, fumaroles, and geothermal areas. Between 2005 and 2009, no continuous large change in the hydrothermal activity takes place, in spite of sporadic seismic swarms and surface activities which could lead to sudden phreatic explosions. The heat discharge of the volcano is estimated to 17 MW. Combined EM and GC methods are now integrated in the monitoring of the slow unrest of the volcano.



Figure 1. Topographic map of Taal volcano (14°N, 121°E). The Surface activity is mainly located in the white bordered rectangular.

2008-2009 Work

Repeated surveys

As for previous years and each campaign, EMSEV-PHIVOLCS EM teams re-survey characteristic magnetic benchmarks, self-potential (SP) and ground temperature profiles, as well as CO_2 soil degassing when this equipment is available. The benchmarks and profiles are located inside and outside the hydrothermal system, and across the major active fissures. These simple methods are easy to

perform in a short time span by PHIVOLCS and give valuable information on the spatial extent and the strength of the thermal state of the volcano, the hydrothermal system, the thermal fluxes, the origin of the degassing, and the long term evolution with time.

Some major results can be outlined from these observations (Zlotnicki et al., 2009; Toutain et al., in preparation):

- Seismic activity enhances thermal fluxes in the active fissures located outside the northern crater rim; those which could be submitted to a flank collapse in the crater,
- $-CO_2$ fluxes and concentrations, ground temperature and fluxes measurements suggest that the main area for volatile transport takes place in the northern part of the Main Crater. Magmatic source could be located there, at a depth of a few kilometres,

- No spatial extension of the hydrothermal system is observed between 2005 and 2009. Only local expansion of the hydrothermal activity has been observed during the last years when seismic swarms were more intense and escorted by geysering activity in the Main Crater Lake (2007),

- Changes in the amplitude of SP anomalies, ground temperature and CO₂ concentrations are observed above active fissures during renewal of seismic activity.



Figure 2. Upper Left (11 and 14 Jan. 2005) and right (28 Feb. 2009): From top to bottom: Ground temperature, CO₂ soil degassing, Self-potential (SP) data, and topography along p4 survey crossing the northern active fissures opened during 1992-1994 seismic crisis. Bottom: Comparison between total magnetic and SP surveys along p4 survey (Jan. 2005)(After Harada et al., 2005; Zlotnicki et al., 2009).

IUGG grant

Bathymetry of Main crater lake

Up to 2008, the knowledge of the bathymetry, thermal and degassing activity of the Main Crater Lake was poor. IUGG grant allowed us to buy a rubber boat and to start the study of the features and the activity of the lake. A geomagnetic and topographic survey of the Main Crater Lake (MCL) was conducted to identify the eruption mechanism of the volcano. A mound at the lake bottom was found near the northern part of MCL, which was not present at the 1986 survey. Called mound M, it was formed between 1986 and 2008 during a period of new fumarole activity, which started on the northeastern shore of MCL in the early 1990's. A geomagnetic survey found no Total Magnetic Field (TMF) anomaly corresponding to the mound, which implies that mound M is non-magnetic. The site coincides with the location of a high-temperature area detected by the ASTER satellite imaging (A. Bernard, personal communication) and by surface water temperature surveys made in 2008 and 2009 (see hereafter). The mound M might contain chemicals (chloride or sulphide) deposited from volcanic gas.



Figure 3. Bathymetric map made by Ramos (1986) [left] and the one newly measured by the present study (Sasai et al., 2008) [right]. The most apparent difference between the two is the appearance of a shallow 'mound' on the right, which is indicated by dotted circle (Sasai et al., 2009).

• Surface temperature of Main crater lake

During the bathymetry mapping, surface temperature of MCL was measured at 1 m depth. The objective was to find the location of the most active thermal areas, their connections with opened vents of fissures at depth. Water temperature surveys were done in 2008 and 2009. Both mappings show that thermal activity mainly stands in two areas. One is along a narrow band following the south rim of MCL, and the other extends in the northern part of the lake.

The northern thermal anomaly is elongated in the N.NW-S.SE direction, and could correspond to active fissures and/or aligned vents at the bottom of the lake. Further experiments will be done to evaluate if this thermal anomaly could also be the result of the regional N.NW-S.SE fault cutting the volcanic edifice.

The temperature of the thermal area changes with time exhibiting changes in the hydrothermal activity. This thermal anomaly which extends over some hundreds of metres is also well observed by thermal Aster imaging (A. Bernard, personal communication).



Figure 4. Upper cartoon: 1 m depth surface temperature of Main Crater Lake in March 2008 (Left) and March 2009 (Right). Bottom Left cartoon: Enlargement of the temperature anomaly located in the northern part of MCL (Zlotnicki et al., IAGA-2009).

• Continuous monitoring: Real time multi-parametric stations

In order to monitor more accurately the volcanic activity EMSEV teams have installed two stations located inside ('MCL') and outside ('DAK') the crater. These stations record the electric field along different directions, the ground temperature in several spots, the RMS seismic activity and the Radon emission.

The data are sampled every two seconds and sent to Buco local observatory located outside the volcanic island. A radio-transmission relay was set in operation on the top of the northern crater rim for transmitting data from the crater. At the observatory, a daily routine was integrated on a PC computer. Recently, an internet link became available, and data can now automatically be sent to PHIVOLCS headquarter in Manila and to French EMSEV team in charge of this network.



Figure 5. Upper left: 2009 Real time multi parametric stations DAK and MCL located outside and inside the crater, respectively. Upper right: Data reception at Buco local observatory. Bottom: Internet link between Buco observatory and detail data processing centres.

• Continuous monitoring: Total magnetic field

Two continuously-recording proton magnetometers were set up at two geothermal areas on Volcano Island in the immediate vicinity of the two telemeter multi-parametric stations (KAK and MCL), one on the eastern shore of MCL (MCE) and the other on the northern slope of Daang Kastila (DKT). The sampling interval is 1 minute.

Recordings of TMF variations obtained over two years on Volcano Island show excellent stability and precision for monitoring the volcanic activity. However, there happened some instrumental troubles during early half of 2009, and these defects were finally recovered in November, 2009. It turned out that TMF showed 1 nT decrease at MCE after the summer of 2009, when large typhoons assaulted the Philippines causing heavy rain fall. The observed decrease in TMF at MCE may reflect the cooling of shallower part of the underground rocks which had been heated during the 2005-2006 activity.



TMF Changes in Taal Volcano

Date (Dec. 2007 - Dec. 2009)

Figure 6. Changes in the TMF differences among MCE, DKT and MUT during the period from December 2007 to December 2009. Daily means of simple differences are plotted. TMF values at MUT were disturbed owing to resettlement of magnetometer during the first half of 2008. The decrease in TMF did occur at MCE as shown in the curves during the latter half of 2009.

• Continuous monitoring: High sampling multi-parametric stations

In parallel to the real time network, two complementary stations located at the same spots as the telemeter stations were progressively installed in order to study short time magnetic and electric signals related with seismicity. These stations will also allow us to perform continuous magnetotelluric soundings based on data processing of the magnetic and electric fields.



Figure 7. Schematic representation of the parameters recorded on the field at DAK and MCL spots.

Continuous monitoring: Water temperature and level of MCL

The understanding of the hydrothermal activity and of the relationships between the ground water transfers (recharge of the hydrothermal system, transfers between the Crater Lake and the lake surrounding the island, evaporation, etc) requests the installation of a water temperature and pressure gauge. Therefore a self-recording sensor was installed along the cliff of the islet located in MCL. Data which are sampled every fifteen minutes are collected by boat during field campaigns. A second pressure gauge was set at the local observatory for taking care of the barometric pressure changes.

2009-2010 prospective

• Field campaigns

Two field campaigns are scheduled in 2010. One will follow EMSEV-PHIVOLCS workshop in February and the second field work will be scheduled in October-November 2010.

For both campaigns repeated surveys will be performed and new electric/magnetic profilings will be achieved. Continuous stations will be completed by missing sensors, as a seismometer in DAK station.

Continuous efforts will be done for educating more deeply PHIVOLCS colleagues in EM methods applied to volcano monitoring. Effort will also be done in the knowledge of data processing and interpretation. PHIVOLCS EM team could already be ready to perform by itself SP and magnetic surveys on other volcanoes in Philippines.

Specific new tasks

- Imaging the hydrothermal system by resistivity soundings,
- Imaging the volcano structure and the hydrothermal system by magnetotelluric soundings
- Mapping the water temperature of the floor of Main Crater Lake,

- Setting of three continuous GPS-EM stations in the frame of a JICA program (Japan),

Data processing

A telemetry system is now running on Taal volcano. Although the internet link has to be secured, automatic data transfers to PHIVOLCS and EMSEV partner are scheduled every day. Therefore, data can be processed by PHIVOLCS EM team at the local observatory, as well as at PHIVOLCS headquarter. Observations should be included in the routine processes done by the Volcano monitoring group.

EMSEV teams will work with PHIVOLCS EM team on data processing, on data visualization, and on signal recognition.

EMSEV-PHIVOLCS Workshop

A second joint EMSEV-PHIVOLCS workshop will be organized in February 2010. The scope is: "Following the first Workshop held in 2003 for initiating Seismic and Electromagnetic Monitoring in Asian Countries, this second workshop will highlight techniques and methodologies for monitoring active volcanoes with the application to Philippines and other Asian volcanoes. Topics will focus on advanced multi-methodological methods based on electromagnetic and other geophysical methods for understanding volcanic structures and monitoring awaking volcanoes and hydrothermal/magmatic unrests. A particular attention will be paid to volcanic hazards, public information and risk management in highly populated volcanic areas. The five years cooperation between EMSEV and PHIVOLCS on Taal volcano will be exploited for educating young scientists to field work."

The main topics of the Workshop are:

- Volcanic risks in Asian countries
- Volcanic risk assessment, education, information and education
- Historical activity of volcanoes in Asian countries: Exiting precursory phenomena?
- -Advanced electromagnetic methodologies for imaging volcanoes
- Electromagnetic and other geophysical methodologies for monitoring hydrothermal/magmatic systems
- Satellite observations
- -Data processing and modelling

- Special session on Taal volcano: historical eruptions, structure, hydrothermal activity and magma injection, what to monitor and how, real time monitoring and processing, risk mapping, predictability

After the end of the IUGG grant (November 2010), EMSEV will do his best for organising a final workshop between the teams involved in the project.

Participation to International meetings

Members of the EM teams have programmed to participate to the following scientific events.

- -EGU, Vienna (April 2010)
- -CoV6, Tenerife (May 2010)
- AOGS, Singapore (August 2010)
- -EMSEV workshop (October 2010)
- -IUGG 2011

• Risk mitigation

EM and geochemical mappings have already highlighted a key issue. Every day, some hundreds of tourists climb the volcano along a trail crossing the northern active fissures opened during the 1992-1994 seismic crises. But, the sector located between these fissures and the view point located along the crater rim may collapse in case of large eruptive activity. Now, PHIVOLCS has advised Local Authorities of this possible scenario.

Another issue is the thermodynamical equilibrium of the hydrothermal/volcanic system which can be rapidly annihilated giving rise to an eruptive event following a process as: 1) an increase of magmatic fluids and heat in the hydrothermal system, 2) a collapse of the hydrothermalized northern crater rim of MC, 3) a seismically-induced response of the hydrothermal system, and 4) self-sealing processes leading to a closing system with subsequent pressure built-up.

During the past years, cycles of activity have been observed, with inflation and deflation of the ground surface, seismic swarms, local geysering activity, and transient changes in the hydrothermal activity (fumaroles, bubbling in MCL, thermal activity, etc.). These events can start within a few days or

less. Because of the proximity of the magma below the crater, the presence of the 45 M^3 of water of MCL, the activity could give rise to sudden violent phreatic to phreatomagmatic explosions followed by a possible larger activity. This scenario is the most difficult activity to monitor and to predict.

Budget

Financial support from IUGG and Associations is used to facilitate PHIVOLCS EM team to field campaigns and local expenditures. The foreign teams provide equipment and other materials.

An IUGG grant was obtained for 2009 and 2010.

PHIVOLCS supports Filipinos participants to the cooperation.

French Embassy in Philippines (Ministry of Foreign Affairs) is supporting French team.

Tokai University, Earthquake Prediction Research Centre is supporting Japanese team.

References

- M. Harada, Julio P. Sabit, Y. Sasai, Paul K. B. Alanis, Jr. Juan M. Cordon, Ernesto G. Corpuz, J. Zlotnicki, T. Nagao and Jane T. Punongbayan, 2005. Magnetic and Electric Field Monitoring of Taal Volcano, Philippines. Part I: Magnetic Measurements, Japan Acad. Sci., 81, B, 261-266.
- J. Zlotnicki, Y. Sasai, J.P. Toutain, E.U. Villacorte, A. Bernard, Julio P. Sabit, Juan M. Gordon Jr, Ernesto G. Corpuz, M. Harada, J.T. Punongbayan, H. Hase and T. Nagao, 2008. Combined Electromagnetic, geochemical and thermal surveys of Taal volcano (Philippines) during the period 2005-2006. Bull Volcanol., doi: 10.1007/s00445-008-0205-2.
- Y. Sasai, M. Harada, J.P. Sabit, J. Zlotnicki, Y. Tanaka, J.M. Cordon Jr., S. Uyeda, T. Nagao, J.S. Sincioco, 2008, Geomagnetic and topographic survey of the Main Crater Lake in Taal Volcano (Philippines): preliminary report, J. Geography, 117, 894-900 (in Japanese with English abstract).
- M. Harada, Y. Sasai, J. Zlotnicki, Y. Tanaka, H. Hase, J.P. Sabit, J.T. Punongbayan, J.M. Cordon Jr, E.U. Villacorte, E.G. Corpuz, and T. Nagao, 2008. Monitoring of volcanic activity of Taal volcano (Philippines) by electromagnetic methods, Bull. Inst. of Oceanic Res. and Dev., Tokai University, 29, 9-28, 2008 (in Japanese with English abstract).
- J. Zlotnicki, Y. Sasai, J.P. Toutain, E. Villacorte, PHIVOLCS team, P. Yvetot, F. Fauquet, A. Bernard, 2009. Electromagnetic and Geochemical methods applied to investigations of Hydrothermal/magmatic unrests: Examples of Taal (Philippines) and Miyake-jima (Japan) volcanoes, Physics and Chesmistry of the Earth, 34, 394-408. doi:10.1016/j.pce.2008.09.012.