



**UNION GEODESIQUE ET GEOPHYSIQUE INTERNATIONALE  
INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS**

## **2009-2010 GRANT PROGRAMME**

**Project title:**

### **Monitoring Taal volcano unrest in Philippines with joint Electromagnetic and multi-disciplinary educational EMSEV-PHIVOLCS program**

**FINAL REPORT  
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**EMSEV Inter- Association (ElectroMagnetic Studies of Earthquakes and Volcanoes)**

<http://www.emsev-iugg.org/emsev/>

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### **Introduction**

Following an international workshop held in Manila in January 2003 for 'Initiating seismic and volcanic electromagnetic monitoring in Asian countries' the Inter-Association Working Group EMSEV has developed a scientific cooperation in the electromagnetic field and other geophysical methods with the Philippines Institute of Volcanology and Seismology (<http://www.phivolcs.dost.gov.ph/>). Priority was given to Taal volcano which may involve large eruptions with pyroclastic flows, base surges and violent phreatic explosions. The volcano has always shown signs of sporadic activity since the last period of activity (1965-1977) during which about 200 people were killed. In 1991, 1992, 2000-2004, 2006, and 2010 major seismic crises were recorded inducing occasionally felt earthquakes, opening of fissures, cyclic ground surface uplifts, increase in ground and water temperatures, bubbling in the acidic inner crater lake, and surface activity. Based on local authorities and PHIVOLCS researches, about 10,000 inhabitants should be concerned by a mild activity within a radius of only 7 km while more than 650,000 people should be affected in case of a violent eruption as that in 1749.

To respond and mitigate to this high level volcanic risk, EMSEV and PHIVOLCS have joined their best efforts for (1) understanding the interactions between the magma feeding system and the hydrothermal system buffered by both the hot acidic inner Crater Lake (MCL) and the cold outer Taal Lake (TL), the geological discontinuities along which heat and soil degassing prevail, (2) evaluating scenarios of activities, (3) monitoring the volcanic activity, and (4) constituting an electromagnetic scientific community at PHIVOLCS.

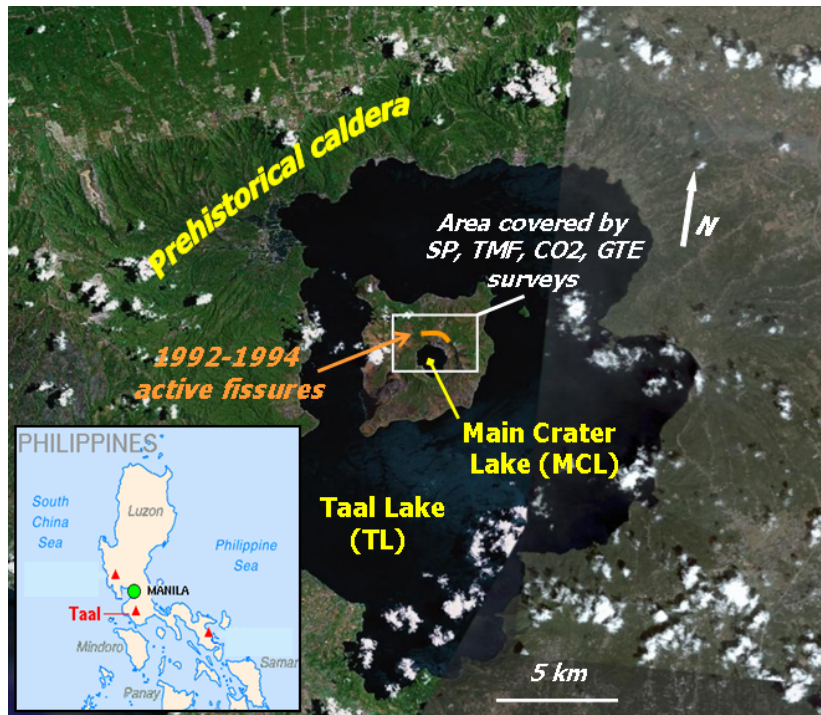


Figure 1: Topographic map of Taal volcano. White rectangle is the main area where EM and other geophysical field studies have been performed.

### Time line of the cooperation

#### ◆ 2003

International EMSEV-PHIVOLCS workshop in Manila held in January 2003 on 'Initiating seismic and volcanic electromagnetic monitoring in Asian countries'  
Formation of an international electromagnetic (EM) EMSEV team based on Japanese and French counterparts.

#### ◆ 2004

Memorandum of agreement signed by PHIVOLCS and EMSEV on 'The understanding of the geotectonics, seismicity and volcanism of the southern Luzon region'

#### ◆ 2005

PHIVOLCS designs an initial EM team. First joint field campaign on Taal.  
Magnetic (TMF), self-potential (SP), ground temperature (GT) and soil degassing surveys (CO<sub>2</sub>) are performed.  
A first continuous multi-parametric station located across the active fissures opened during the 1991-92 seismic activities is set. Data are recorded locally.

#### ◆ 2006

Two joint field campaigns are led. During the first January campaign, felt earthquakes incite people living on the volcanic Island to spontaneously evacuate for a few days.  
A network of magnetic benchmarks is achieved on which the total magnetic field is regularly measured.

#### ◆ 2007

Two tasks were simultaneously performed during the two multiparty field works. One is to extend the electromagnetic, soil degassing and temperature surveys on the ground through the two identified geothermal fields. The second task is to build a new continuous multi-parametric station located inside the crater above the second geothermal field.  
A real telemetry system was implemented between the two multi-parametric stations and the local Taal observatory. Data can be visualized and analyzed by PHIVOLCS.

Two continuous stations recording the total magnetic field were installed in the immediate vicinity of the two multi-parametric stations. Data which are recorded locally are collected every month by PHIVOLCS members.

One cross section of 13 audio-magnetotelluric soundings along a North-South direction highlights the rooting and the interconnection of the two geothermal fields.

During field work, particular attention is made to educate EM-PHIVOLCS team to the methods which are applied. EM-PHIVOLCS team is advised on best techniques to make measurements. Reports were written, and meetings were held at PHIVOLCS headquarter.

◆ **2008**

Two years IUGG grant is obtained. It greatly allows the cooperation to speed up research.

A memorandum of agreement was made on the use of geomagnetic data from Muntinlupa magnetic observatory in the Philippines. It was signed by the National Mapping and Resources Information Authority (Philippines), the Ocean Hemisphere Research Center, the Earthquake Research Institute (University of Tokyo) the Japan Agency for Marine-Earth Science and Technology, PHIVOLCS, and EMSEV. This memorandum allows EMSEV and PHIVOLCS to use Muntinlupa magnetic data as remote reference.

Magnetic and bathymetry surveys of the inner Crater Lake were performed during the two joint 2008 campaigns.

Water level and temperature of the Crater Lake are now recorded thanks to a combined sensor located in the middle of the Crater Lake.

Reports were, and meetings at PHIVOLCS were held.

◆ **2009**

Meetings at PHIVOLCS, and two common field work efforts were organized.

Detail and large scale magnetic, self-potential, soil degassing and ground temperature surveys are done.

Because of the relative quietness of the surface activity of the Crater Lake, water temperatures (WTE) at the bottom of the Lake were measured. Detail bathymetry was updated.

An outstanding effort was made by both parties to install a more reliable internet connection between the computer recording multi-parametric data at the local observatory and PHIVOLCS headquarter, and the French server. Automatic transfers were set, and data can now be visualized and processed routinely on the Virtual ElectroMagnetic Laboratory (VEML; <http://virtual-electromagnetic-laboratory.com/>).

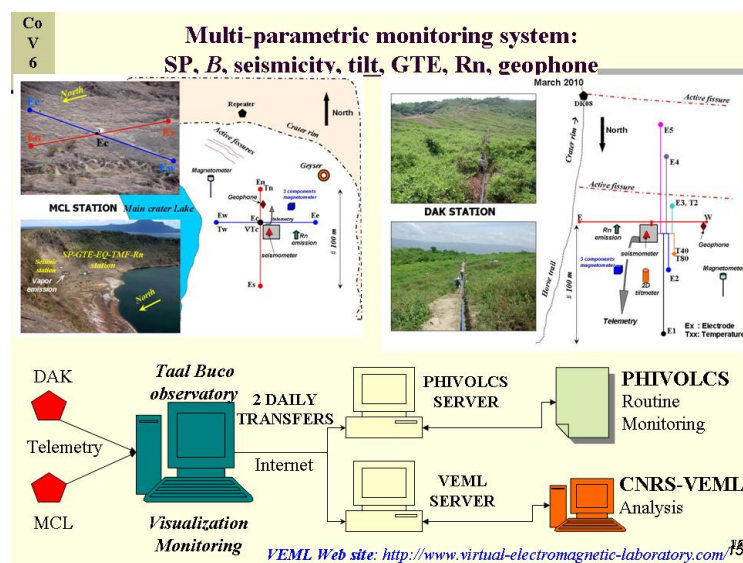


Figure 2: At MCL station, self-potential, ground temperature and gradient, seismic noise, components of the magnetic field, seismicity, , and Rn emission are recorded. At DAK station, in addition to the same parameters, two components of the tilt are also recorded (2010). 2 seconds

*sampled data are radio-transmitted in real time.*

◆ **2010**

Thanks to IUGG grant, PHIVOLCS and French Embassy supports, a second international workshop was held at PHIVOLCS. Title is 'Monitoring active volcanoes by electromagnetic and other geophysical methods; Application to Asian volcanoes'. About 60 participants attended the meeting (<http://www.emsev-iugg.org/emsev/>).

A new memorandum of agreement was signed between PHIVOLCS and EMSEV for the period 2010-2014.

Following the meeting, a large field campaign was organized:

- Resistivity, Very Low Frequency soundings are performed along the tracks followed by SP, ground temperature and soil degassing surveys (Greek participation).
- A borehole tiltmeter is installed at the northern multi-parametric station (DAK, USGS participation).
- Magnetic surveys were measured along the magnetic network of benchmarks, and new SP profiles allow building a complete map describing the extent of the hydrothermal field including the two geothermal fields.

In October and November 2010, a new step in the cooperation was achieved:

- Three magnetotelluric stations are installed under the framework of a JICA support (Japan).
- A new EMSEV multi-parametric station was built on the northwestern edge of the crater rim, at the limit of the northern geothermal field. Data recorded on site will be telemetered in real time in 2011.

From mid-April to the end of July, Taal volcano exhibited an abrupt and strong seismic crisis. PHIVOLCS raised the alert level from 1 to 2 temporarily and included a possible plan to partially evacuate the volcanic Island. Thanks to the real-time multi-parametric network, EMSEV was able to regularly process data and to inform PHIVOLCS about the observed signals and the interpretation. Two reports were sent to PHIVOLCS during this period. This several months of activity were useful for all the participants who rapidly communicate data, evaluation of the activity and so forth.

◆ **2011 prospective**

Two main field campaigns should be done during the year.

- Magnetotelluric soundings should be performed on the volcanic Island in order to study the deep structure,
- A fourth EMSEV multi-parametric station should be installed on the volcano. The objectives of this new station are multiple. First, parameters similar to those at the other stations (SP, temperature, gradient of temperature, seismic noise ...) will be recorded, and, second, a current system which will allow dipole-dipole resistivity soundings on the basis of the multi-parametric network will be implemented.
- Depending on the budgets that each foreign EM team will get, theoretical and applied studies and stages will be proposed to PHIVOLCS EM team members.

**Main results and achievements**

Combined SP, GT, WTE, soil degassing and TMF surveys indicate that the northern part of the volcano is undergoing strong thermal transfers and degassing. The activity takes place along E-W fissures that could be linked to the root of the northern border of the Crater (MC) at a depth of some hundreds of metres, and also connected to a thermal source near the MCL shore line. This thermal source location could be the initial spot of the next eruptive activity. In such a case, strong activity could induce a collapse of a part of the northern MC rim into the MCL, due to mechanical weakening by the active 1992-1994 fissures. To the south, this system appears to be bounded by a NW-SE fault suspected from the NW-SE alignment of negative SP and WT anomalies in the MC. Seismic activity and dike injection may be taking place along this alignment. Changes in SP, TMF

and GT are measured by means of repeat profiles, suggesting that potentially hazardous phreatic/and gas eruptions may be associated with future seismic unrest in these geothermal areas. The two geothermal fields are linked at several hundreds meters depth and the hydrothermal/volcanic fluids are prevailing in the northern part of the crater. Bathymetry and bottom water temperature of MCL clearly show that a bulge of 5 to 10 m high is present and is cut by active hot springs located along a N.NW-S.SE direction.

Resistivity soundings outline that hydrothermal fluids have mineralized and altered the northern rim of the crater which make it unconsolidated.

When one considers the background seismicity on the volcano, it is clear that seismic crises appear abruptly and are accompanied by rapid ground deformation as observed on many similar volcanoes. High levels of activity can be quickly reached. Therefore, real time monitoring and data analysis systems are a necessity for anticipating the level of hazard expected.

Earthquakes during the April-July 2010 crisis have again re-activated the 1991-94 fissures, which might unconsolidate the northern outer rim of the crater. Many data indicate that the region beneath the northern Crater Lake is still active. During this crisis, the near-surface activity in MCL is apparent, and one may consider that the general hydrothermal activity will again be similar to that observed in 2007 or before. Taking into consideration all the available data, it seems that a new crisis is serious although the details of the deep activity and its potential are not clear. Magmatic intrusion, together with hydrostatic overpressure, could be reactivating the region below the northern part of the volcano. Under this hypothesis, any depressurization, resulting from faulting triggered by teleseismic or local earthquakes, landsliding, etc, could destabilize the system and lead to a phreatic explosion on the volcano.

Four real time multi-parametric EMSEV stations will be operating in 2011. They allow continuous monitoring of the volcanic activity and greatly contribute to improved understanding of the ongoing activity. The program adds further value to the seismic networks, geophysical and geochemical surveys operated by PHIVOLCS. PHIVOLCS already integrate some of our results in the information planning to Local authorities and inhabitants.

Several PHIVOLCS members are now aware of EM methods and they would go further in the next years in the study of the EM field. Some of the methodologies developed during the cooperation may already be integrated in the monitoring of other volcanoes in the Philippines.

## **PHIVOLCS and International EMSEV consortium and evolution**

### **◆ PHIVOLCS team**

From the beginning of the cooperation PHIVOLCS (Director R. Solidum) made a huge effort to mobilize active researchers, engineers and technicians in the EMSEV-PHIVOLCS cooperation. The Institute has always largely contributed to providing adequate numbers of personnel in the field in order to complete joint field campaigns. PHIVOLCS has also financially supported the contribution of PHIVOLCS members on the field.

About 8 to 10 PHIVOLCS members may be regularly involved in the cooperation. Most of them are coming from the Volcanological section (directed by J. Sincioco). Two groups were constituted and each of them has focused his interest in the 'Magnetic field monitoring' (J.M. Gordon, Jr, P. Alanis, Freddy) or in the 'Electric field monitoring' (E. Villarcorte, L. Bong, P. Reniva). During each field visit, a representative (J.P. Sabit) of the volcanological section accompanies PHIVOLCS members on the field. The local support is given by Taal observatory (A. Loza Loic, L.A. C. Banes).

### **◆ EMSEV team and other contributions**

EMSEV team has largely increased during the past years.

- Initially the cooperation was supported by two teams mainly belonging to the Earthquake Prediction Research Centre (T. Nagao, M. Harada located at Tokai University, Shimizu) and Tokyo Metropolitan City (Y. Sasai) in Japan, and to the French National Research Centre in France (J. Zlotnicki, F. Fauquet, and P. Yvetot positioned at the Observatory of Physics of

Globe, Clermont-Fd). About 6 researchers and engineers, experts in the EM field, were involved.

From these countries other research teams joined the cooperation, bringing their own expertise: For instance the Aso observatory for total field magnetometers, and J.P. Toutain from the Laboratoire de Mécanismes de Transfert en Géologie for geochemical studies and soil degassing.

- Later on, F. Sortino from the Istituto Nazionale per la Vulcanologia of Palermo (INGV, Italy) contributed to heat fluxes and CO<sub>2</sub> degassing measurements, while A. Bernard from the Laboratoire de Géochimie et Minéralogie (Université Libre de Bruxelles, Belgium) focuses on Thermal Aster imagery of Taal Crater Lake.

- In 2010, G. Vargemezis from the Aristotle University of Thessaloniki entered the scientific consortium and manages the resistivity soundings on the volcano with J.R. Puertollano, R.C. Pigtain from PHIVOLCS. US Geological Survey greatly enlarges the monitoring of the volcano by setting a borehole tiltmeter at a first multi-parametric station (DAK). Now, M.J.S. Johnston is deeply involved in the monitoring of the volcano as the French and Japanese teams.

- Satellite observations progressively enlarge the multi-disciplinarity of the EMSEV consortium. EM observations by DEMETER are active til the end of the experiment. MOPITT observations are done by R.P. Singh working at Chapman University (USA). V. Tramutoli and N. Pergola from Department of Engineering and Physics of The Environment (DIFA, University of Basilicata) are presently setting a time domain analysis of robust satellite techniques (RST) for near real-time monitoring of active volcanoes and thermal precursor identification.

## Dissemination of results

### ◆ Articles

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