EMSEV REPORT ON

December field campaign on Taal volcano (Philippines)

November 30 to December 11, 2015

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1. Objective

The objectives of Yoichi Sasai and Jacques Zlotnicki of EMSEV bureau were (1) to inform PHIVOLCS leaders, researchers and collaborators on the state of recent results obtained on Taal volcano, (2) to write a new MEMORANDUM of agreement for the next 5 years of cooperation, and (3) to update the multi-parameter network as well as to resurvey magnetic and electric benchmarks.

Edouard Régis, Engineer at the Observatoire de Physique du Globe de Clermont-Fd (France), accompanied the team for repairing and upgrading the monitoring networks.

2. Meeting at PHIVOLCS

Upon our arrival, a meeting was held at PHIVOLCS headquarter between PHIVOLCS and EMSEV. Rene Solidum, Director of PHIVOLCS, could not participated, because called by a governmental issue.

Ms Marition Bornas, head of the volcano Department, Paul Alanis, PhD working in electromagnetic field (EM) on Taal volcano , and an administration representative were present.

2.1. EMSEV presentation

Jacques Zlotnicki focused his talk on:

- The state of knowledge on Taal volcano from EMSEV point of view
- The promotion of the joint EMSEV-PHIVOLCS cooperation
- The state of equipments and network
- The way to improve the cooperation
- The future experiments and a prospective

From these topics some key points were highlighted:

- The outcomes of the study of 2010-2011 seismovolcanic were described.

In particular, the chronology of the sources of activity rapidly moving with time and space from about 5 km depth to 2.5 km was described. It was underlined the possibility to observe a collapse of the northern part of the crater in case of strong volcanic reactivation. Finally it was also put into light that only a multi-parameter study has allowed to understand the genesis of the activity during this crisis.

- It was noticed that the opportunity to have invited short stays in France was lost by lack of communication. A new budget will be asked for 2016, and it would be important to prepare this possibility if budget is found.
- It was proposed to hold a new International Workshop in 2017, the conditions of which have to be studied.

Yoichi Sasai focused his presentation on the new experiments that Japanese colleagues would like to undertake mainly on Taal volcano and partly on Mayon volcano. The proposal has been submitted to JSPS by Professor Toshiyasu Nagao, from Tokai University and Secretary of EMSEV inter-association. The content concerns:
- GPS and ground deformation,
- Sampling of gas on Taal volcano,
- Gravimetry,
- Some other topics might be developed later.

2.2. PHIVOLCS presentation

Ms Ma. Bornas was primarily concerned by updating the last MEMORANDUN signed in 2010 for a 5-years period. She asked to consider the new updating draft, before to give it to Director Rene Solidum for agreement and signature.
Ms Ma. Bornas expressed the fact that now the appropriate counterpart in EMSEV-PHIVOLCS cooperation is Paul Alanis, although exchanges of emails and others should be carbon copy to her.
It was also said that EMSEV is allowed to contact other researchers/engineers/technicians working at PHIVOLCS for getting general information, as on geology, tectonic, and on other subjects.

<u>Remark</u>
During our stay the draft of the MOU was sent to Toshiyasu Nagao and Malcolm Johnston for their approval. It was accepted.
At the end of our EMSEV visit, we were told that the agreement by PHIVOLCS was essentially approved.

3. Joint work on Taal volcano

We were very well welcome at Buco Observatory by PHIVOLCS members. During our stay, everyone did his best for contributing to repair and update the networks.
We Thanks Paul Karson B. Alanis (Science Research Specialist II), Paolo D. Reniva (Science Research Specialist I, Resident Volcanologist of Taal and in charge of Buco Observatory), Lawrence Aaron C. Banes (Science Research Assistant, technician), Gerald A. Malipot (Science Research Specialist I, engineer), Ric Seda (Technician), and Florence V. Ramirez (Senior Science Research Specialist) who did a temporary placement.
From the side, Jacques Zlotnicki was accompanied by Edouard Régis (Engineer at Clermont-Fd, France).

Several workers contributed to carry new equipments, dig new trenches, and clean the stations.

During the 10 days field work, we focused the labor on the re-installation of the real-time network and data transmission to servers. It was not possible to go far beyond.

3.1. Real-time telemetry network

3.1.1. Real-time Data Acquisition Centre

Buco Observatory was partly damaged during the last 2014 cyclone, and the French data acquisition system was removed from the Data Centre Room at that time.

E. Régis with P. Reniva and L. Banes re-installed the PC computer and the antenna receiver on the roof of the Observatory. A fourth receiving channel was added for putting into operation four real-time stations (DAK, MCL, PAN, and CUT)(Figure 1).

E. Régis upgraded software and checked that the PC was sending daily data by Internet to PHIVOLCS server in Manila and to the French server.

P. Reniva and L. Banes were watchful to the operation mode.

Figure 1. Location of stations on Taal volcano.

3.1.2. Multiparameter stations

E. Régis and J. Zlotnicki, mainly accompanied by P. Reniva and G. Malipot have checked the stations one after the other. Work was achieved in a week.

<u>PAN station</u>

The two batteries (120 Ah and 70 Ah) on which the tiltmeter and the data logger were connected were out of order (2 Volts). Station was cleaned and a new battery

was installed (120 Ah). Grass and trees were cut around the station. Station was cleaned.
Data logger was shut down and data could not be recovered at the laboratory.
It was possible to "re-zero" the tiltmeter (x=-311 mV, y=+169 mV).
A new data logger recording data at 2 seconds was installed and initialized on December 6 (lieu 03).

<u>DAK station</u>

One battery (50Ah) was connected to the equipments. The battery was dried and down (8 Volts), and both data loggers recording data at 2 seconds (real-time telemetry system) and 20 Hz were shut down. No data could be recovered from these systems.
Station was cleaned and a new battery was installed (120 Ah).
A short-circuit affected the tiltmeter, and was not repairable on the field.
Two new data loggers (2 seconds and 20 Hz) were installed and initialized on December 6 (Lieu 01 and 02 for 2 sec and 20 Hz, respectively).

<u>MCL station</u>

The shelter is deteriorated and concrete progressively is disaggregating. It requires to be renovated in the very next future. Grass was cut around the station.
Upon our arrival, batteries in the shelter indicated 6 and 9 Volts. The two data loggers (2 seconds and 20 Hz) were shut down. It was not possible to recover the data. Station was cleaned and grass around was cut.
Two second-hand batteries were installed (45 Ah). A new data logger recording data at 2 seconds was installed, which has allowed the real-time telemetry system to be again in operation. Station was re-initialized on December 4.
Unfortunately, we had no spare equipment for replacing the deficient data logger working at 20 Hz.

<u>Transmitter</u>

This transmitter is located on the northern rim of the crater. It transfers data emitted by MCL station to Buco observatory.
The voltage of the 90 Ah battery was 11.5 Volts in spite of the recharge done by a 100 W solar panel. The equipment was checked and re-initialized.

<u>CUT-CUS station</u>

Grass and trees were cut around the station.

- *Station CUS*

The voltage of the batteries were about 13 Volts. The data logger was in operation, but the current system did not deliver periodic current injections. The station was stopped and replaced by a new system.
On December 6, the station was definitively run (Lieu 05). It is a self-recording station.

- *Station CUT*

The 120 Ah battery was almost dried and 6 liters of distilled water was necessary for filling it. Data logger was shut down. No data could be recovered at this stage. A new data logger was installed.

Successive trials were operated for "re-zeroing" the tiltmeter, but it could done completely. It has appeared that the tiltmeter should be vertically-re-aligned.

At this station, the objectives were:
- To integrate this fourth station in the real-time monitoring network,
- To implement measurements of the ground temperature,
- To record two components of the electric field.

Therefore, two orthogonal lines were dug in the East and South directions. Lengths were 50 m and sensors were buried at 60 cm depth at the end of each line.
Nearby the station, two other sensors were buried at 40 and 80 cm depth.

The new configuration is given Figure 2.

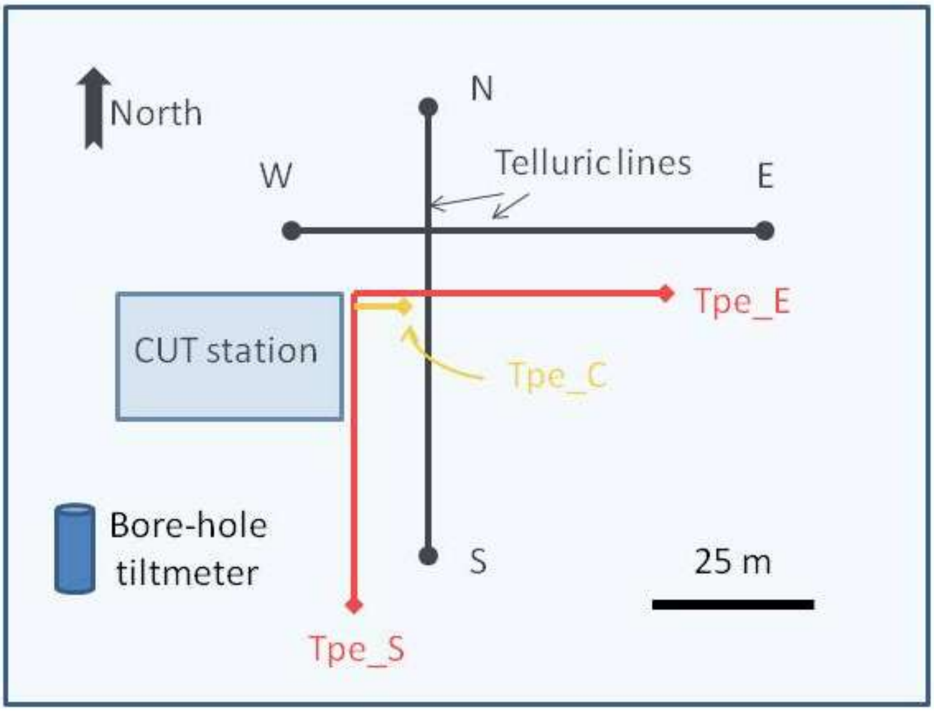

Figure 2. Scheme of CUT station after December 10, 2015 (J. Zlotnicki, E. Regis).

Station was initialized on December 6 (Lieu 04).

<u>WATER LEVEL and TEMPERATURE in Main Crater Lake</u>
Barometer at Buco observatory was not found.
Water level and temperature sensors at Boulder rock have disappeared.
Therefore, no data is available along the past year.

3.1.3. Scheme of the real-time Data Acquisition Centre

During the stay, we have tested the receiving data centre, as well as the structure of daily files related to the fourth stations DAK, MCL, PAN, and CUT. A synthetic document was let near the computer were data are displayed in real-time.

- Data from each station is received by four receivers every two seconds, and transfer to the computer.

- The computer displays the real-time values on the screen for a better analysis of the quality of data and the maintenance.

- Every day, data are written in a daily files in the same format as on the screen. At the beginning of each day, data are transferred by Internet to appropriate servers.

DAK station

Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6	Ch 7	Ch 8
Tilt x	Tilt y	n-s	e-w	Tpe1	Tpe2	Tpe3	Geophone

MCL station

Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6	Ch 7	Ch 8
n-s	d	e-w	h	tpeN	TpeW	Tpe80cm	Tpe40cm

PAN station

Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6	Ch 7	Ch 8
n-s	e-w	Tilt x	Tilt y	tpeN	TpeE	Tpe40cm	Tpe80cm

CUT station

Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6	Ch 7	Ch 8
Tilt x	Tilt y	n-s	e-w	tpeE	TpeS	Tpe40cm	Tpe80cm

- Daily files are in c: ...\acquisition\archives
- Mean daily files are in c: ... \acquisition\sendtophivolcs

Diagram of the multi-parameter monitoring system is given below (Figure 3).

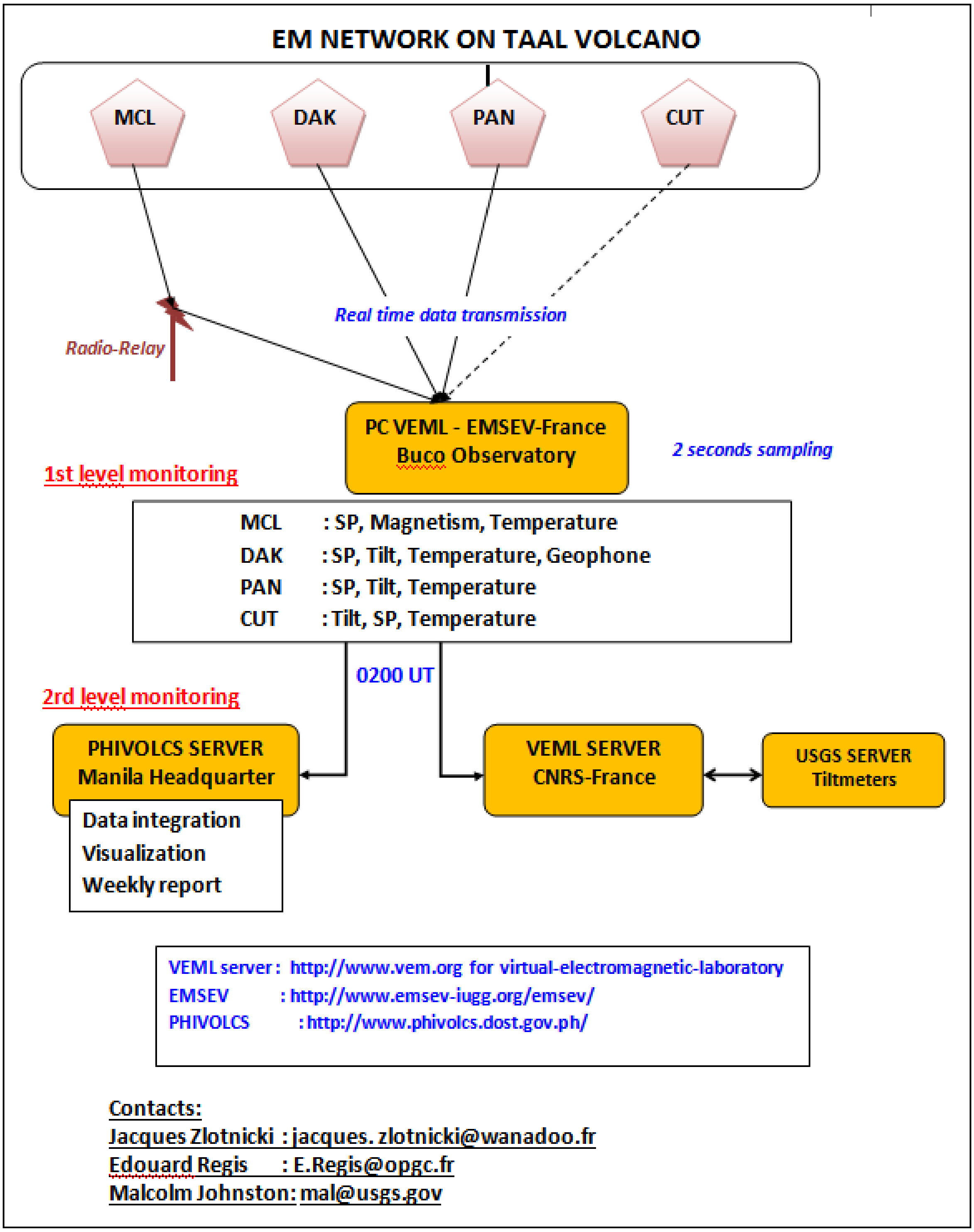

Figure 3. Scheme of the telemetry system.

3.1.4. Self-potential survey

Two surveys have been done by PHIVOLCS, one 2014 and one in 2015. These surveys are processed by PHIVOLCS.

A new survey along the northern trace starting above Pira-Piraso and ending at the crater rim. This survey was performed by J. Zlotnicki, P. Reniva and Bino.

Preliminary observation shows that the pattern of the SP curve keeps its major feature (Figure 4). A decay of the SP values as the path is getting higher in altitude, until the main northern border of the active - well known northern geothermal field - is reached. The amplitude of the anomaly related to the geothermal field reaches in December 2015 about 250 mV. Thermal anomalies are still present when main active fissures cross the SP survey.

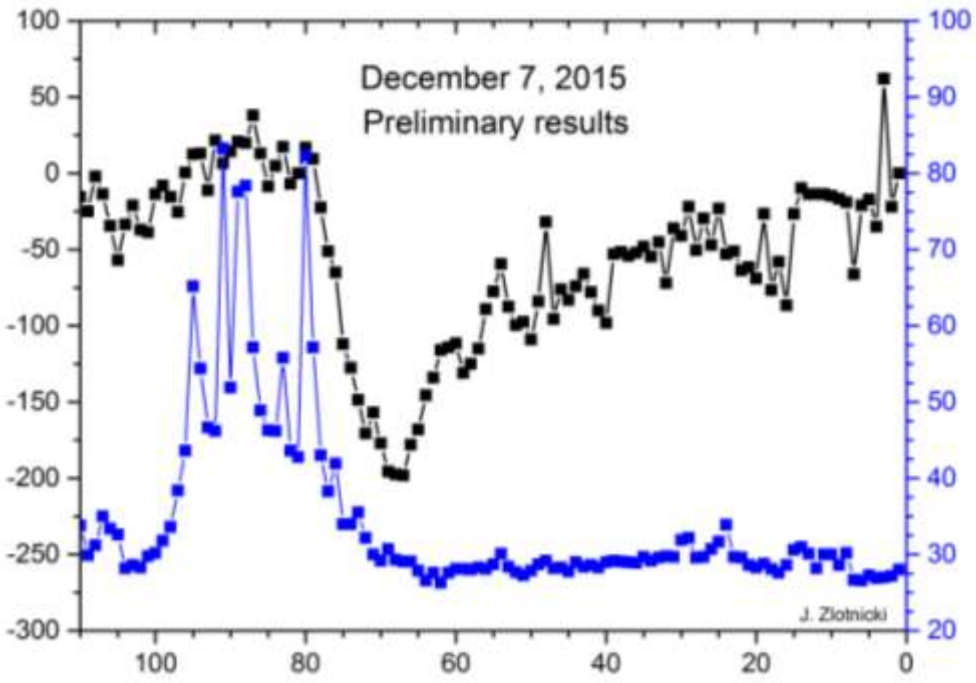

Figure 4. SP survey done in December 2015 (Preliminary result, J. Zlotnicki).

3.1.5. Recovery of OH magnetometer at VTBM station

The magnetic team (Y. Sasai, P. Alanis, F. Ramirez) spent full two days to recover the OH (Overhauser) magnetometer at VTBM station. It has been in defect since April 2015. Since the beginning of our repeat magnetic surveys in January 2005, our reference station has been Muntinlupa (MUT) Magnetic Observatory, of which data are available by courtesy of MAMRIA. However, unfortunately, the OH magnetometer at MUT suffered from some artificial disturbances since April, 2013. The VTBM station was established in December, 2011. It is located rather far from the central part of Volcano Island, and VTBM can be used as the reference station. The only defect in the magnetometer was the damaged cable, which was replaced with a new one by digging up the old cable and burying the new one again.

Figure 5 shows the overall changes in TMF at these stations during the period from December 2007 till April 2011. Repeat survey results have a gap before and after April, 2013, because we can no longer use TMF data at MUT as reference values. On the other hand, we use a portable OH magnetometer and the same OH type magnetometer at VTBM with the same sampling rate of 1 second, which largely improves the accuracy of repeat TMF surveys.

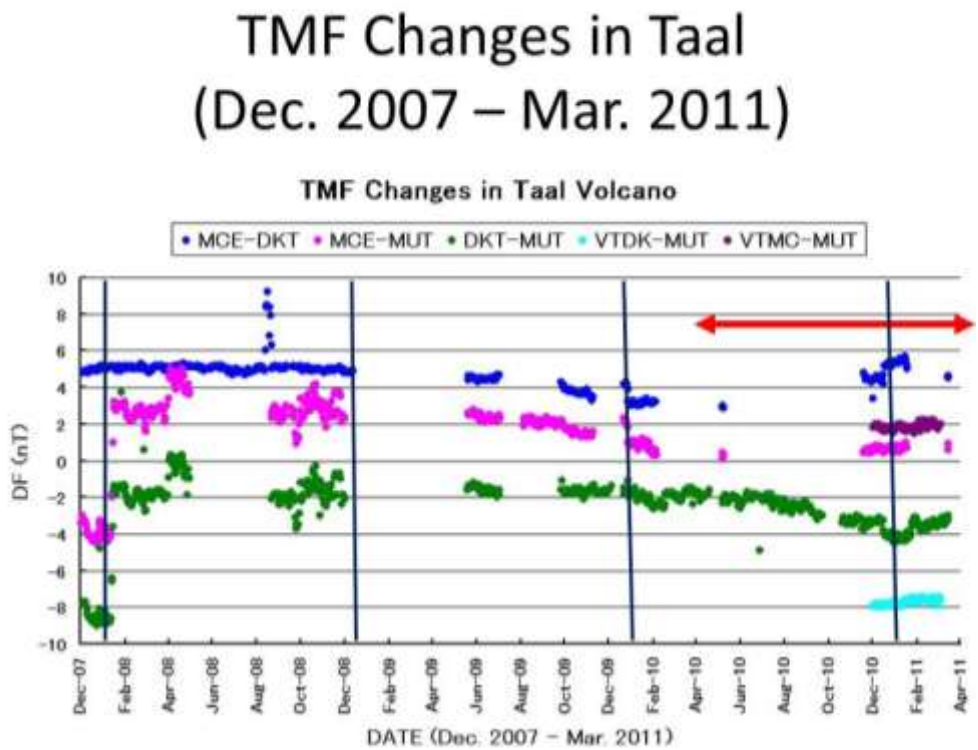

Figure 5. TMF changes in Taal volcano during the period from December 2007 till April 2011. Thick red bar indicates the duration of the 2010-11 seismovolcanic crisis.

3.1.6. Magnetic survey

In December 2015, magnetic survey was conducted using the portable OH magnetometer. The previous survey was conducted in March and May in 2014, when the non-magnetic tripod was first used for stable holding of the sensor pole. Although the interval between the two surveys is rather long, we had no chance to conduct the repeat survey in November 2014 because of the Mayon volcano crisis and ASC meeting held in Manila during the same time. The results of the survey are given in Table 1, in which the changes in TMF during the period from March/May 2014 till December 2015 are summarized. The TMF difference at TA20 is most probably due to the effect of a EDM mirror installed nearby. The cause for the anomalous TMF difference at TA18 is not clear. This point may be a place where the local field gradient is anomalously large.

In order to see the spatial pattern of the TMF changes, the amount of TMF change is given on a map showing the position of each survey point in Figure 6. We find that TMF changes are generally negative on the northern slope of Volcano Island (Daang Kastilla area), while they are positive on the southeastern slope along the Calauit trail. In this Figure 6, numerals at some survey points are masked owing to overlapping with each other. One will find that the value at TA11, for example, on the northern slope is more or less similar to the surrounding points.

NSTA	MON	IDY	TIME(UT)	F_ST	F_VTBM	DF	DF(Prev.)	dF
TA01	12	7	1:57:22	40654.41	41023.53	-369.12	-369.16	0.04
TA02	12	7	2:26:01	40971.49	41027.76	-56.27	-55.66	-0.61
TA03	12	7	4:00:49	41200.54	41029.87	170.67	170.47	0.2
TA04	12	7	4:59:59	40607.47	41023.67	-416.2	-422.45	6.25
TA05	12	7	5:44:11	40596.55	41008.46	-411.91	-408.21	-3.7
TA06	12	5	4:06:39	40174.28	41025.87	-851.59	-844.95	-6.64
TA07	12	5	3:35:42	41080.33	41032.61	47.72	49.57	-1.85
TA08	12	5	3:02:17	40709.63	41032.53	-322.9	-321.84	-1.06
TA09	12	9	1:06:39	40150.26	41030.34	-880.08	-881.17	1.09
TA10	12	9	2:30:28	40669.77	41032.71	-362.94	-363.9	0.96
TA11	12	5	5:37:58	40892.19	41019.5	-127.31	-122.65	-4.66
TA14	12	6	2:37:25	41486.75	41037.28	449.47	447.91	1.56
TA15	12	6	3:22:11	41137.8	41039.34	98.46	97.57	0.89
TA16	12	6	1:46:26	41066.79	41024.78	42.01	44.64	-2.63
TA17	12	5	4:57:04	40455.43	41025.94	-570.51	-564.57	-5.94
TA18	12	8	1:11:53	40216.42	41011.16	-794.74	-812.39	17.65?
TA19	12	8	1:47:33	40594.86	41013.47	-418.61	-425.77	7.16
TA20	12	8	2:16:27	41070.93	41017.9	53.03	-8.13	61.16?
TA21	12	8	2:49:28	40598.06	41018.68	-420.62	-427.72	7.1
TA22	12	6	0:27:30	41176.12	41013.49	162.63	164.94	-2.31
TA23	12	9	1:40:26	40378.31	41029.27	-650.96	-649.37	-1.59
TA24	12	9	3:01:11	40639.04	41031.68	-392.64	-388.73	-3.91
TA25	12	5	2:34:10	40160.02	41032.72	-872.7	-872.39	-0.31
TA27	12	6	4:03:06	40764.63	41020.54	-255.91	-252.27	-3.64

Table 1: Results of repeat TMF surveys for December 2015. Previous survey was conducted in March and May 2014. Unit is in nT (by Alanis and Sasai).

Let's go back to Figure 5. Taal volcano experienced the 2010-2011 seismovolcanic crisis as shown by a thick red bar. We have had continuous TMF data at DAK and MCE since Dec. 2007, while new stations VTDK and VTMC were established in December 2011. Note that TMF showed remarkable decrease during the later phase (phase 3b and 3c) of the activity. This activity was caused by a pressure source that emerged at a depth of 5 km, and be replaced by a shallow one at 2.5 km depth some weeks later. Repeated expansion and shrinkage of the shallow hydrothermal reservoir then occurred till March 2011 (Zlotnicki et al., submitted to BUVO). The phase 3b and 3c activity was caused by inflation of HTR, which was approximated by the Mogi source centered at a depth of 2.5 km with a spherical radius of 1.5 km.

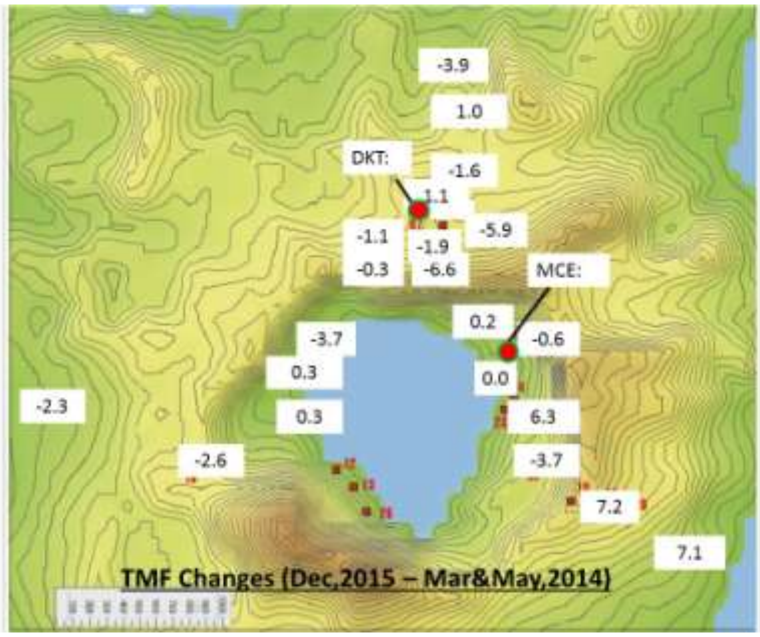

Figure 6. TMF changes between December 2015 and March-May 2014. Unit is in nT.

According to piezomagnetic computation based on Mogi model, the inflation of a shallow hydrothermal reservoir (HTR) produces negative changes in TMF on the north and positive ones on the south side of the HTR as shown in Figure 7. The amount of magnetic changes is proportional to the internal hydrostatic pressure.

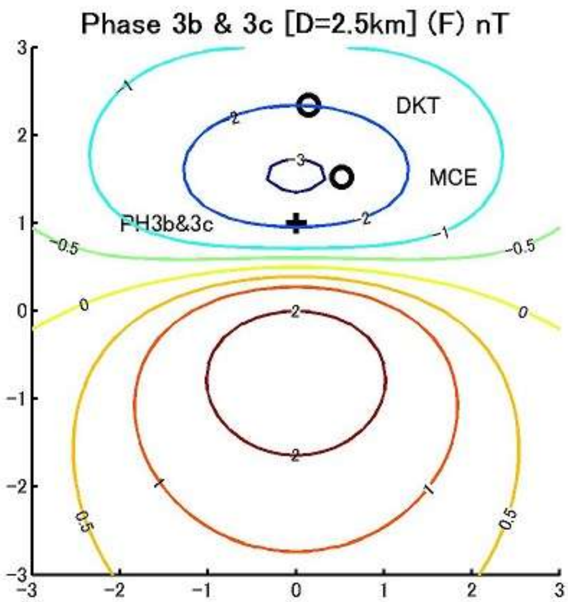

Figure 7. TMF changes associated with the inflation of the HTR during the period of phase 3b and 3c (August-December, 2011).

Remarkable changes in TMF were also observed during the 2005 activity. However, the sign of magnetic changes was opposite to the present observations, i.e. TMF increased by ~10 nT in 2005 and the geothermal activity largely enhanced in 2005-2006 (Figure 8).

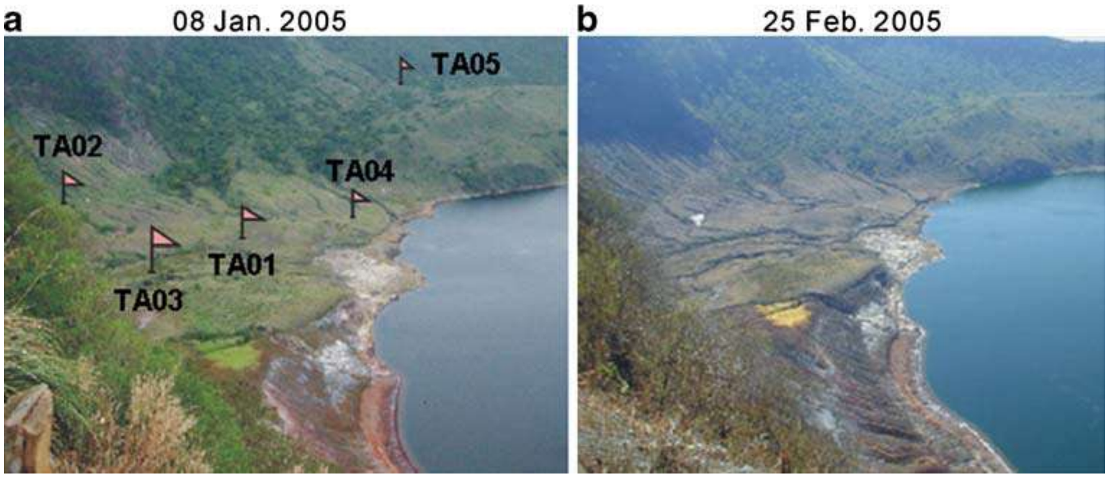

Figure 8. Comparison of the vegetation before (left) and after (right) the remarkable changes in TMF.

4. EMSEV discussion on the volcano activity

During our visit on Taal volcano we were led to highlight several observations:

- Magnetic data appear to show noticeable changes.
- SP data indicate that the pattern of anomaly related to the northern geothermal field is well-developed. The thermal anomalies concern a large part of the geothermal field and probably much more. A detail research will be done on this topic by J. Zlotnicki and co-authors.
- PHIVOLCS informed us that the water of Main Crater Lake has decreased between the end of 2013 and the end of 2015 of about 70 cm. This lack of water, which can be estimated to 1,000,000 m^3, could partly be attributed to the deficit of annual rainfalls.
- PHIVOLCS informed us that some small tilting inside the crater could have occurred during the last year(s). The amplitude would be at most of a few millimeters, with a corresponding inflation to the East of the crater.
- PHIVOLCS informed us that leveling surveys performed outside the crater indicate that a smooth inflation of the volcano persists with a centre located to the East of the crater. It would be noticeable that during at least the last months inflation more or less stopped.
- PHIVOLCS informed us that no major volcanic earthquake has occurred since about last February, while a few small magnitude earthquakes are recorded daily.

Unfortunately, we could not recover the last year data at the multi-parameter stations for analyzing the activity described above.

However, the smooth extension of the geothermal activity both inside and outside the crater should be noticed. It could partly be generated by the lack of rainfalls during the last years which has prevented an efficient cooling of the volcano surface. An hypothesis of this behavior could stand in the large porosity of the materials which form the inner part of the crater and are mechanically weakened by geochemical processes and highly saturated by warm ground fluids. This mechanism

could occur without large seismicity. The possible inhomogeneous deformation located in the crater would suggest that a scenario involving a small renew of activity in the crater should be envisioned.
If active fissures located in the northern geothermal field are involved in a renew of activity (as it was in 2010), it would be possible to monitor the changes based on the real-time stations located to the North of the crater.

During our visit on Taal volcano we were led to highlight other observations:
- Magnetic data appear to show some inflation event happened and is still going on.
1) When did this event start? It was most likely in early February 2015, when seismic activity suddenly enhanced and continued for about a week. Analysis of continuous TMF data could identify the onset time of the inflation of HTR.
2) For the moment, it seems that the outlet of hydrothermal fluids is clogged to cause the inflation. However, the 'outlet' from HTR is not a narrow exit but the entire bottom surface of the MCL (after Alain Bernard). Large bubbling areas from the MCL bottom were observed when we went to the Boulder rock and around by boat. More accurate estimate of CO_2 emission should be obtained by aerial survey of CO_2 on MCL.
3) In Figure 5, we find that TMF at MCE decreased prior to the onset of the 2010-2011 crisis. It may suggest that a similar phenomenon went on in the HTR, one year before the crisis.
4) Then, what comes next? Figure 6 reminds us what happened in the 2005-2006 activity of Taal volcano. On January 9, 2005, a rather strong earthquake was felt near around Calauit village. A number of inhabitants evacuated from the Island. We had begun the repeat the magnetic survey a few days ago, and resurveyed at the already established bench marks. We found decrease of TMF by a few nT (Figure 8). The alert level was raised from 1 to 2 at the end of January and the Main Crater was assigned off-limit. PHIVOLCS magnetic team conducted the repeat magnetic survey in February, and found the increase in TMF by about 10 nT at almost every points on Volcano Island. In those days we ascribed the cause of the magnetic change to thermal demagnetization at a very shallow depth (~5-10 m). Actually, the vegetation was withered on the land near the eastern shore of the MCL. Then the geyser activity appeared on the eastern shore of MCL and the almost half of the lake surface was covered with white bubbles.
5) However, we now suspect that the observed phenomena may have been those associated with the stress release of HTR, i.e. the discharge of CO_2 gas resulting in the shrinkage of HTR and increase in TMF. Grass does wither not only by heat but by CO_2 gas as well (see Figure 8).
6) In our EM observation system in Taal, the lack of continuous measurement stations on the southern side out of the Main Crater is a rather serious defect for the moment. Dr. Alanis plans to conduct TMF observations with the portable OH magnetometer simultaneously when PHIVOLCS team carries out the precise leveling (dry-tilt) along the Calauit route, which is scheduled once every three months.
7) Daily mean simple differences among TMF stations and VTBM should be analyzed as soon as possible.