Integrated Electromagnetic and Geochemical methods applied to volcanic hydrothermal systems: Application to Taal volcano (Philippines)

EMSEV-2008, Sinaia, Romania

(EMSEV activities: http://www.emsev-iugg.org/emsev/)

J. Zlotnicki[1], Y. Sasai[2], J.P. Toutain[3], E.U. Villacorte[4], A. Bernard[5], J.M Cordon Jr.[4], F. Sortino[6], J. P. Sabit[4], M. Harada[7], PHIVOLCS EM team[4], J. Sincioco[4], H. Hase[8], T. Nagao[8]

(1) National Scientific Research Centre, OPGC-UMR6524-UBP, France; (jacques.zlotnicki@opgc.univ-bpclermont.fr)

(2) The Disaster Prevention Specialist, Tokyo Metropolitan Government

(3) LMTG, Observatoire Midi-Pyrénées, Toulouse, France

(4) Philippines Institute of Volcanology and Seismology, Philippines

(5) Université Libre de Bruxelles, Belgium

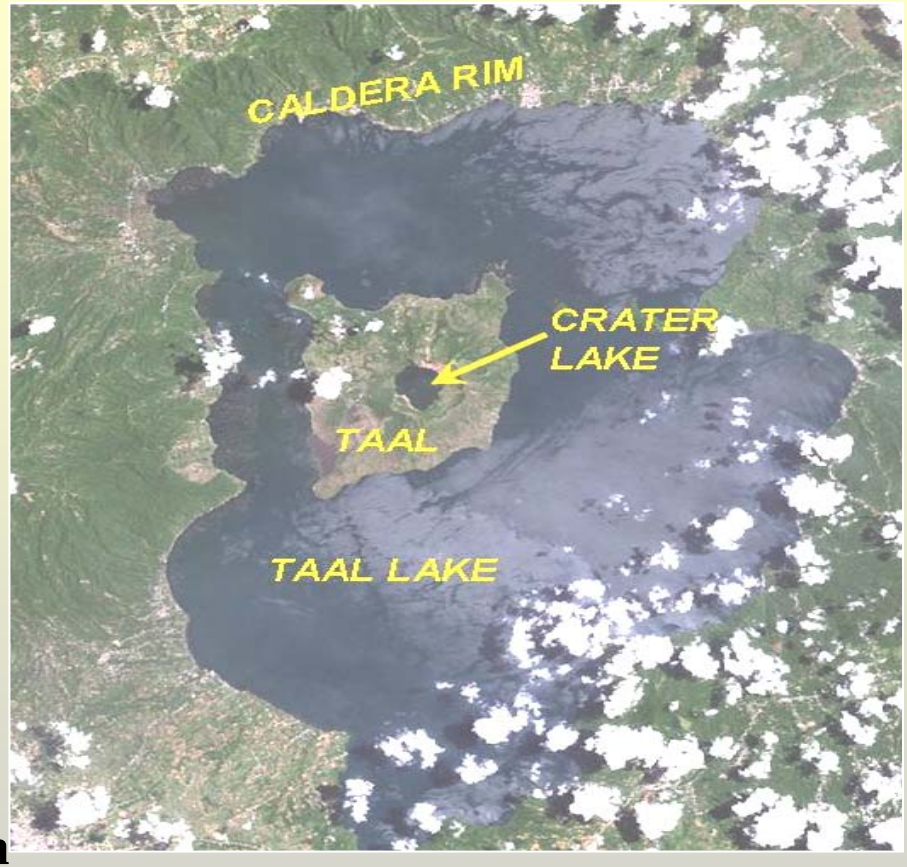
(6) Istituto Nazionale di Vulcanologia, Palerme, Italy

(7) Earthquake Prediction Research Center, Tokai University, Japan

(8) Graduate School of Science, Hokkaido University, Japan

Supports: EMSEV, IUGG & Associations, PHIVOLCS, French Embassy, CNES, JSPS, EPRC-Tokai Univ., Tokyo Geographical Society

Taal main features

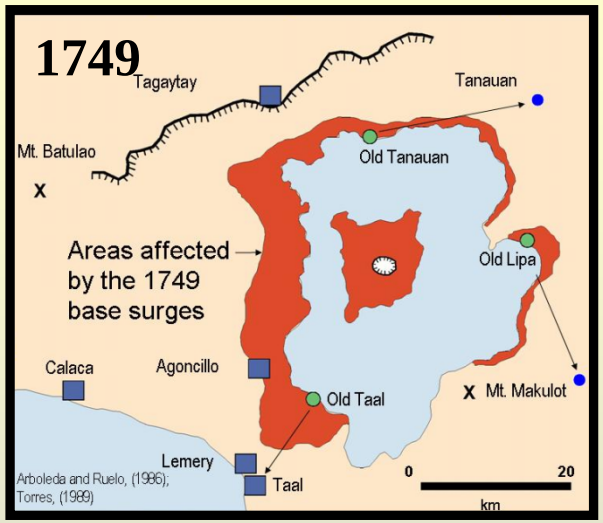


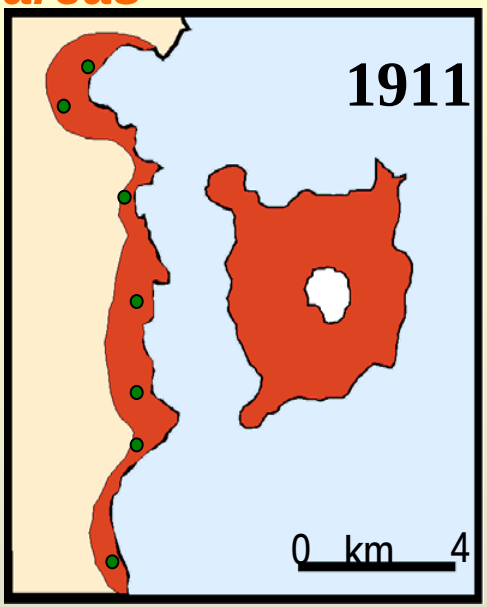
- **Stratovolcano located at 60 km of Manila**
- **Set in a pre-historical caldera (16 km x 27 km) formed between 140 & 5.4 ky. BP**
- **Volcano Island is 5 km in diameter (311 m high)**
- **1.2 km diameter crater filled by a 70 m deep lake (MCL) : V~ 45×10^6 m^3**

~8 000 inhabitants are living on the Island
About 1M inhabitants are in Taal vicinity

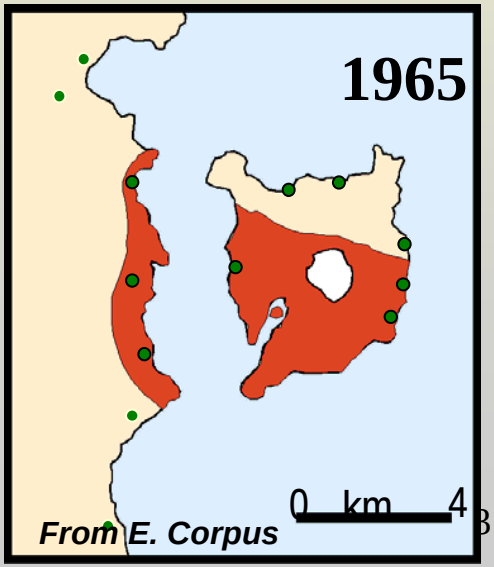
Past activity and casualties

Devasted areas



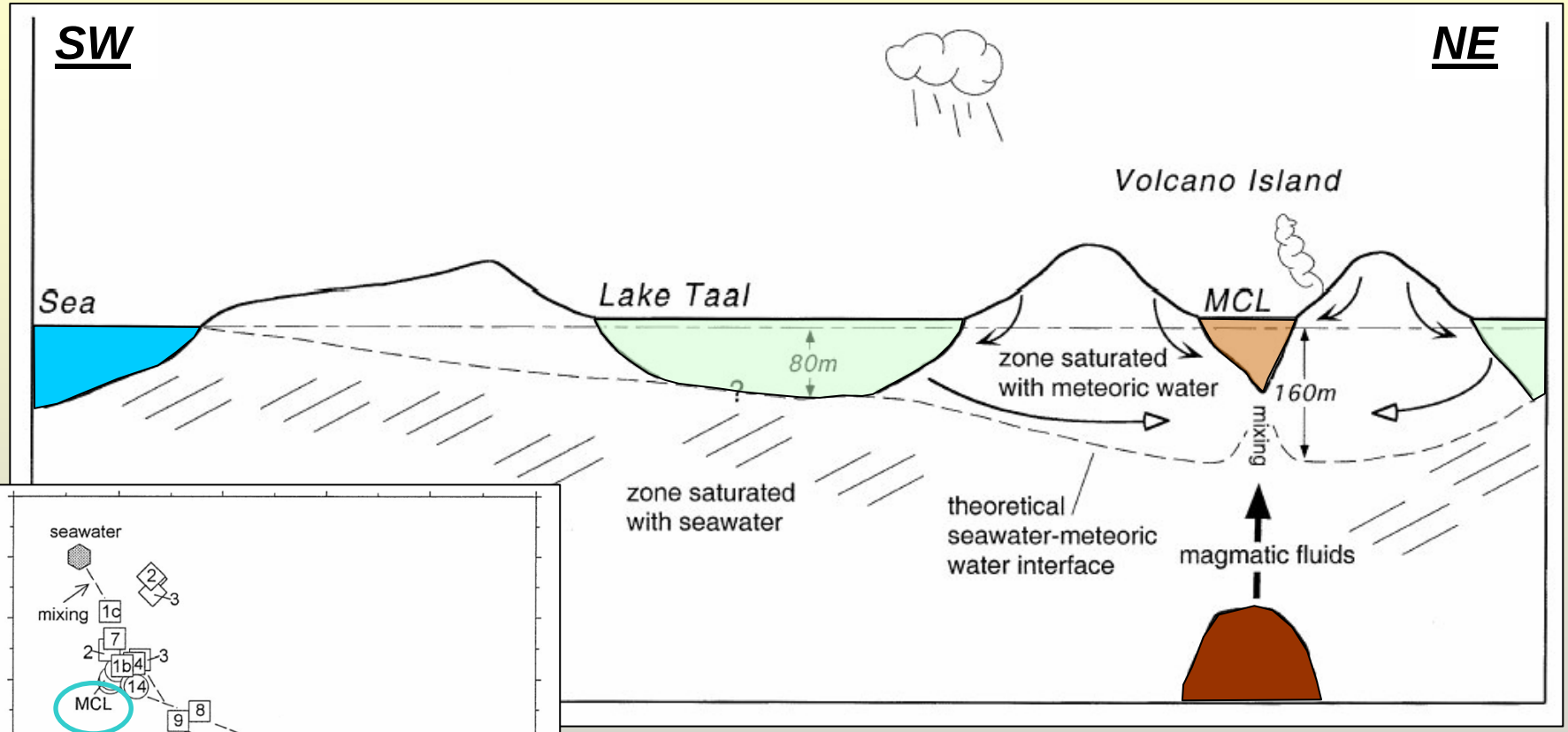


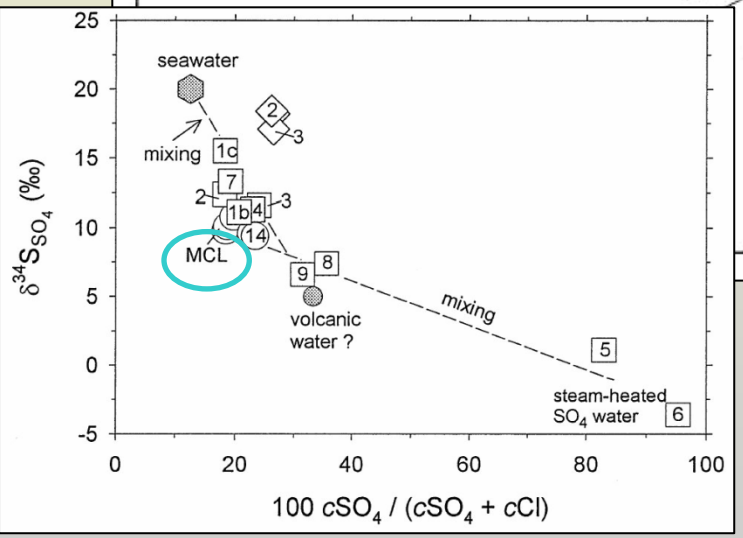
Settlements



- **Complex of cinders and tuff cones**
- **Destructive eruptions: 1749, 1754, 1911, 1965**
- **Phreatic (1878, 1911(ashes in Manila), 1970);**
- **Phreatomagmatic (1749, 1965, 1966); strombolian (1968, 1969); plinian (1754)**
  - **Deaths 1911: 1334; 1965: 200**

Geological setting and hydrothermal activity





China sea, Taal lake and MCL are almost at the same level

Geochemical studies indicate that seawater infiltrates the MCL

MCL: mean water temperature: 33°C (100°C locally)

MCL: 45×10^6 m^3 in volume

MCL: pH~2-3

(After Delmelle et al., 1998)

Objectives:

How the hydrothermal system controls the volcanic activity?

Work plan:

- Mapping the hydrothermal system and find out the connection(s) with magmatic source(s),
- Evaluation of possible scenarios of a future activity
  (i.e. sudden phreatic explosions, collapse of crater rims),
- Assessment of fluids transfer through the lakes and the volcano. Computation of the heat discharge,
- Development of continuous real time multi-parametric monitoring stations and processing,

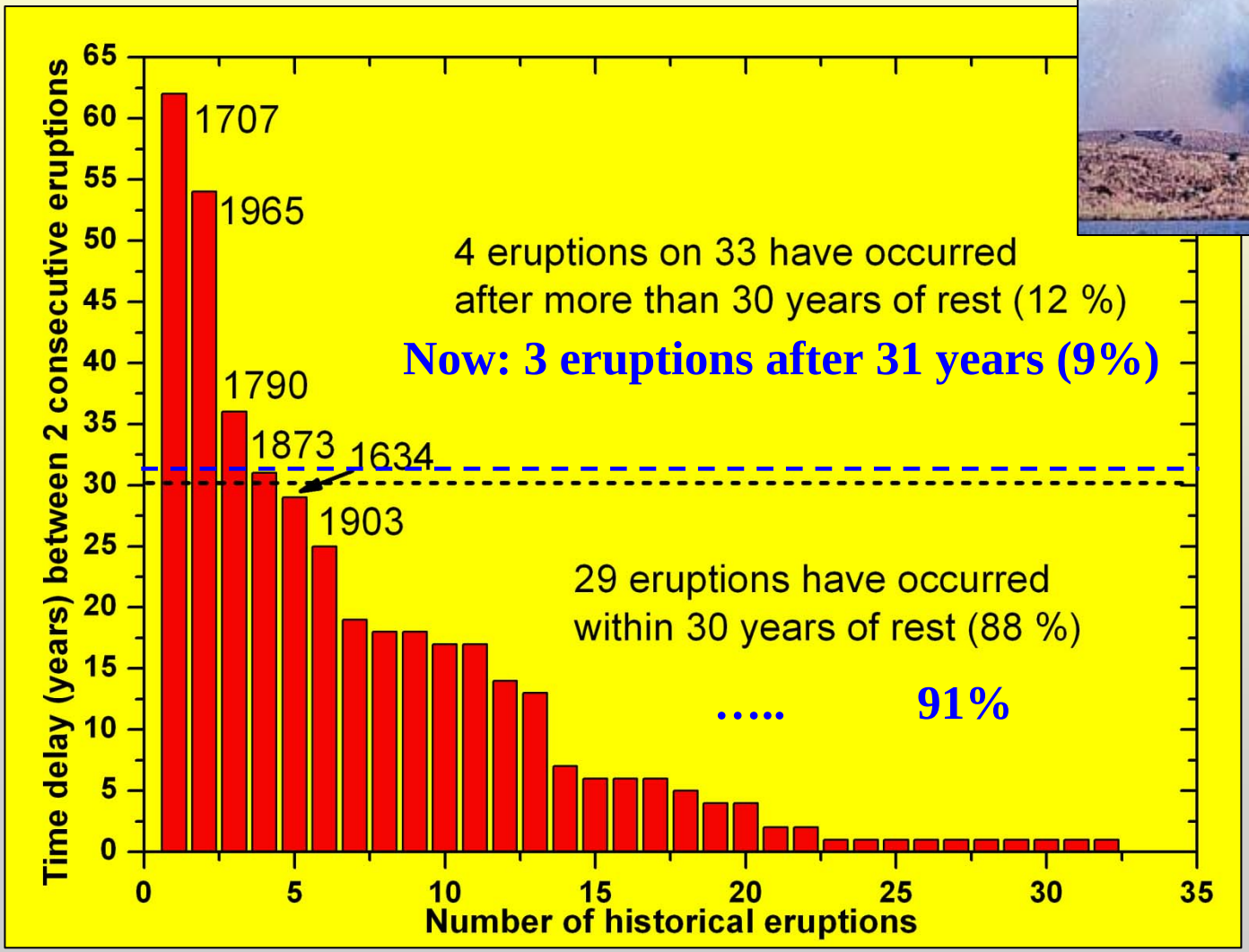
Methodology:

Integration of Geophysical (EM) and Geochemical studies, from ground to satellite observations

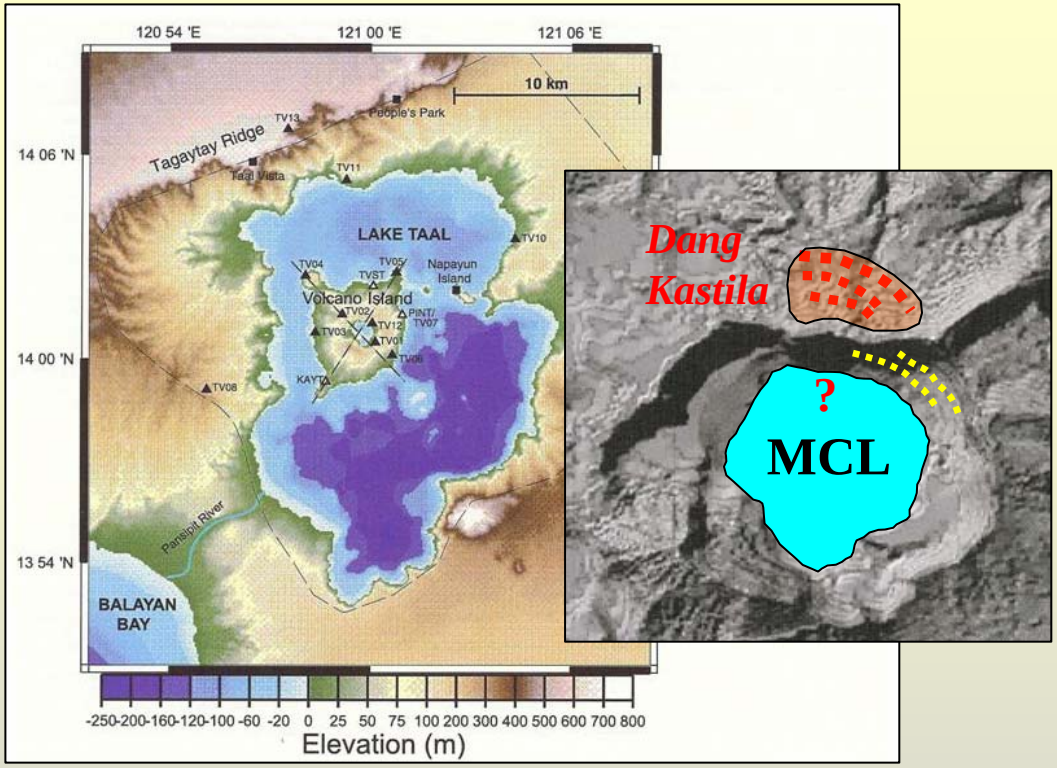
- Self-potential (SP), magnetic (TMF) and magnetotelluric surveys (MT)
- Ground soil degassing (CO2), Ground (GTE) and water lake (WTE) tpes & fluxes, WT level changes in the crater lake
- Data of ASTER, MOPITT and Demeter satellites
- ….

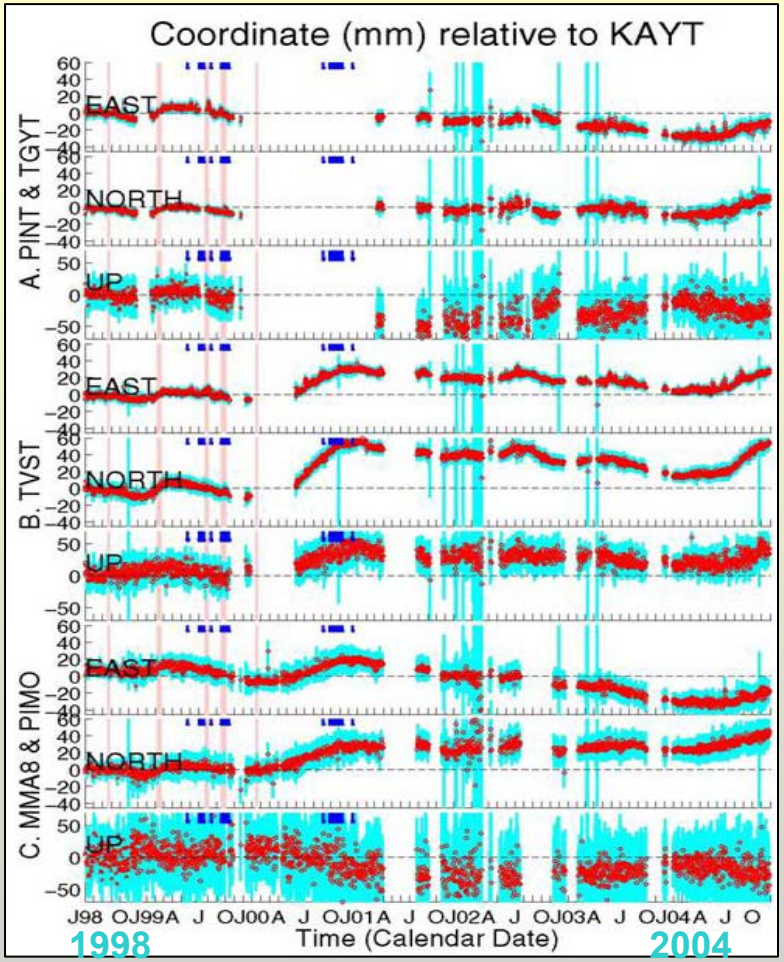
Statistics: Towards a new eruption?

Mt. Tabaro 1977 eruption



Continuous GPS monitoring





1992-94: Seismic crises,

Opening of fissures on the North flank

Since 1998 :

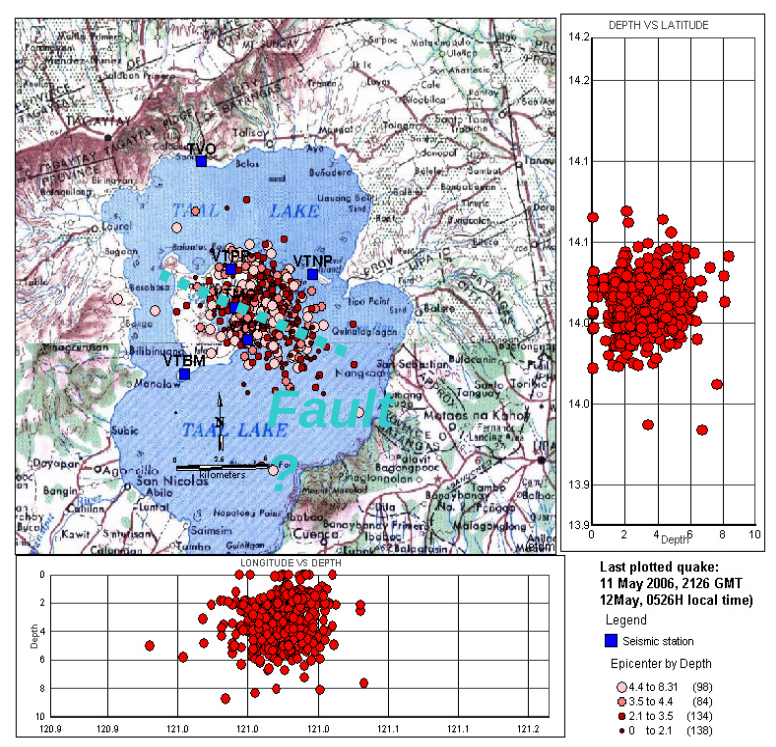
Several cycles of inflation and deflation have occurred (2000, 2004)

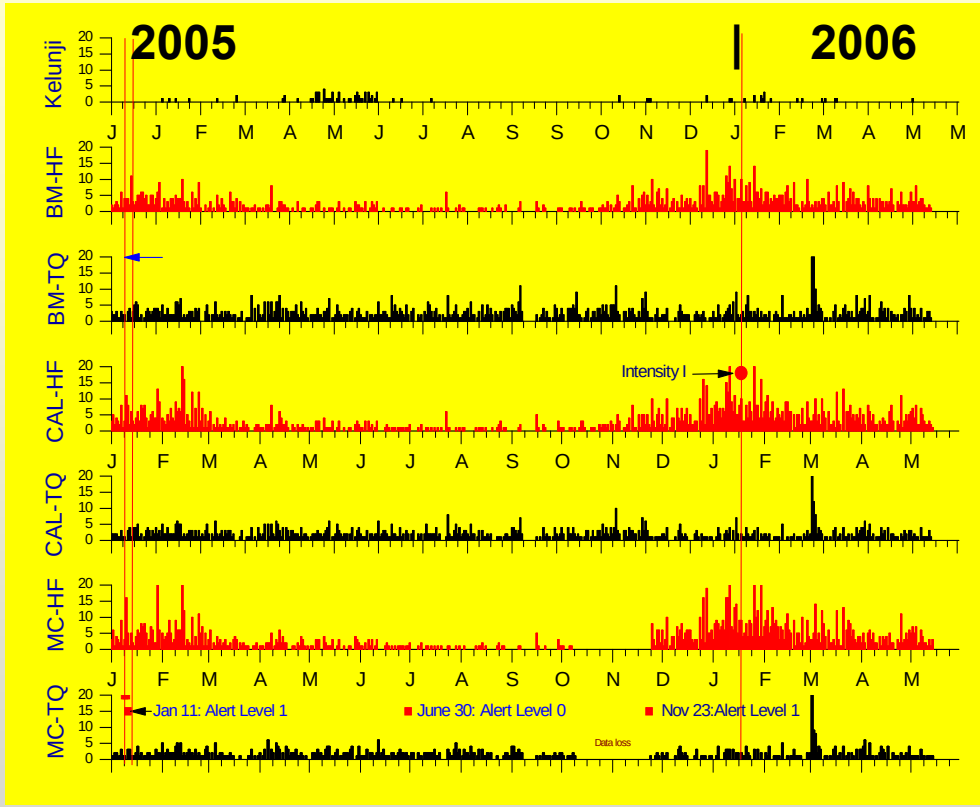
→ 120 mm uplift of the volcano centre occurred in Feb.-Nov. 2000

→ Mogi models estimate sources between 4.2 and 5.2 km depth

After Bartel et al., 2002, 2003

Seismicity



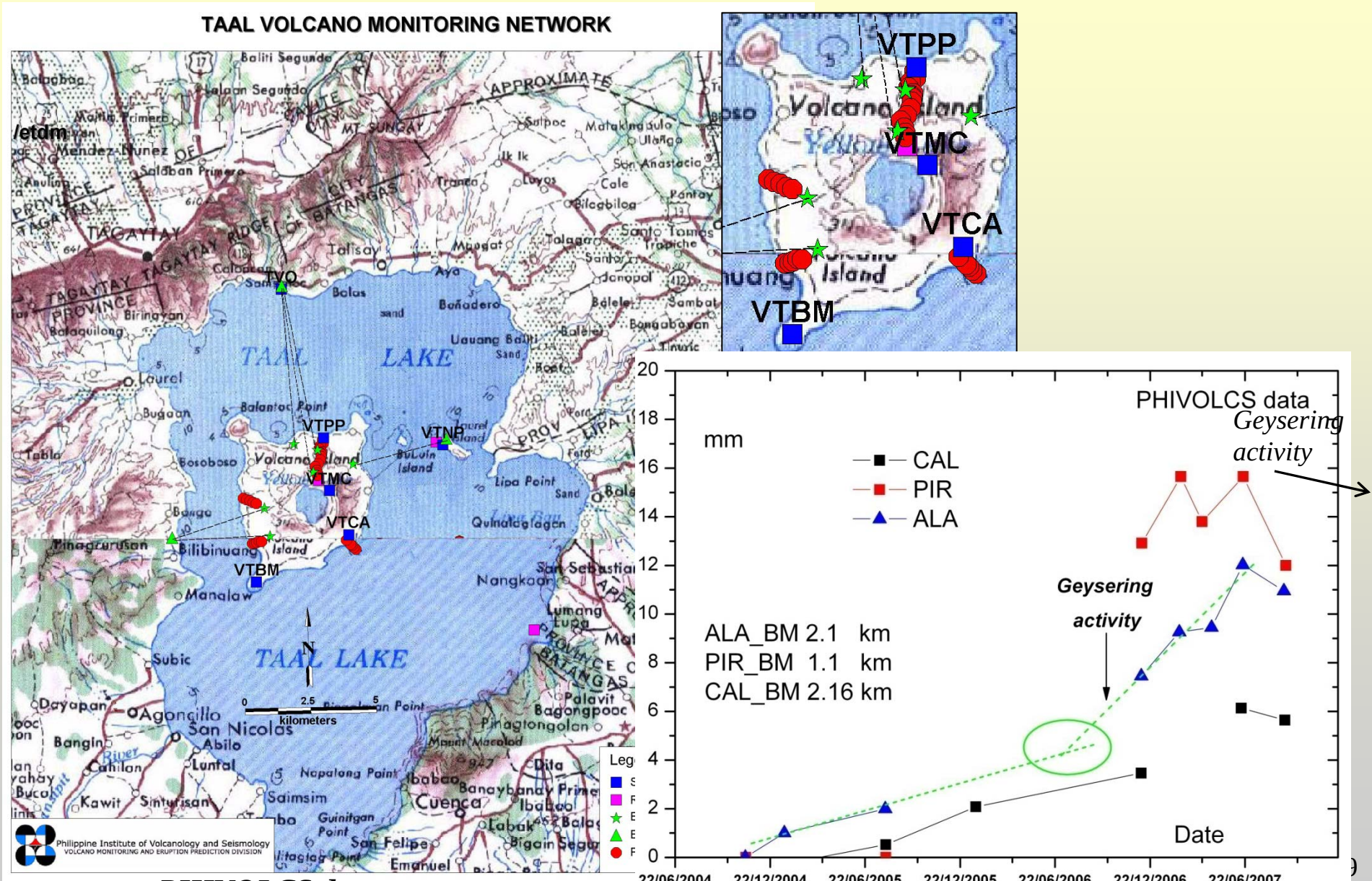


→ ***Seismicity seems to take place along a "NW-SE fault" along which dikes could intrude***

→ EQ are 'regularly' felt. In Jan., 2005, hundreds of people evacuated for a few days

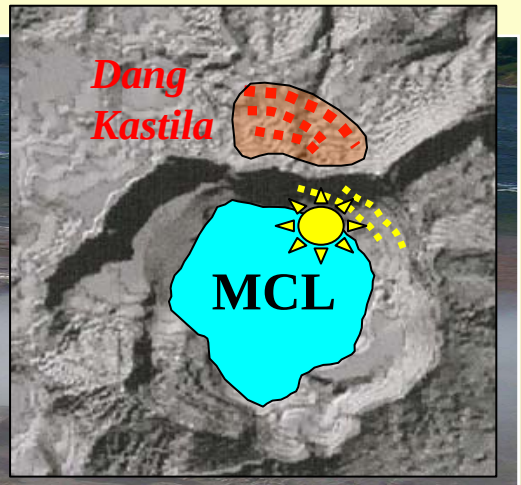
→ Alert 1 on a scale of 5 is often set: Oct. 2004, Nov. 2005, Oct. 2006→mid-2007

Levelling surveys: 06/2004 – 09/2007



PHIVOLCS document

Geysering phenomena in MCL: 15 days in Nov. 2006

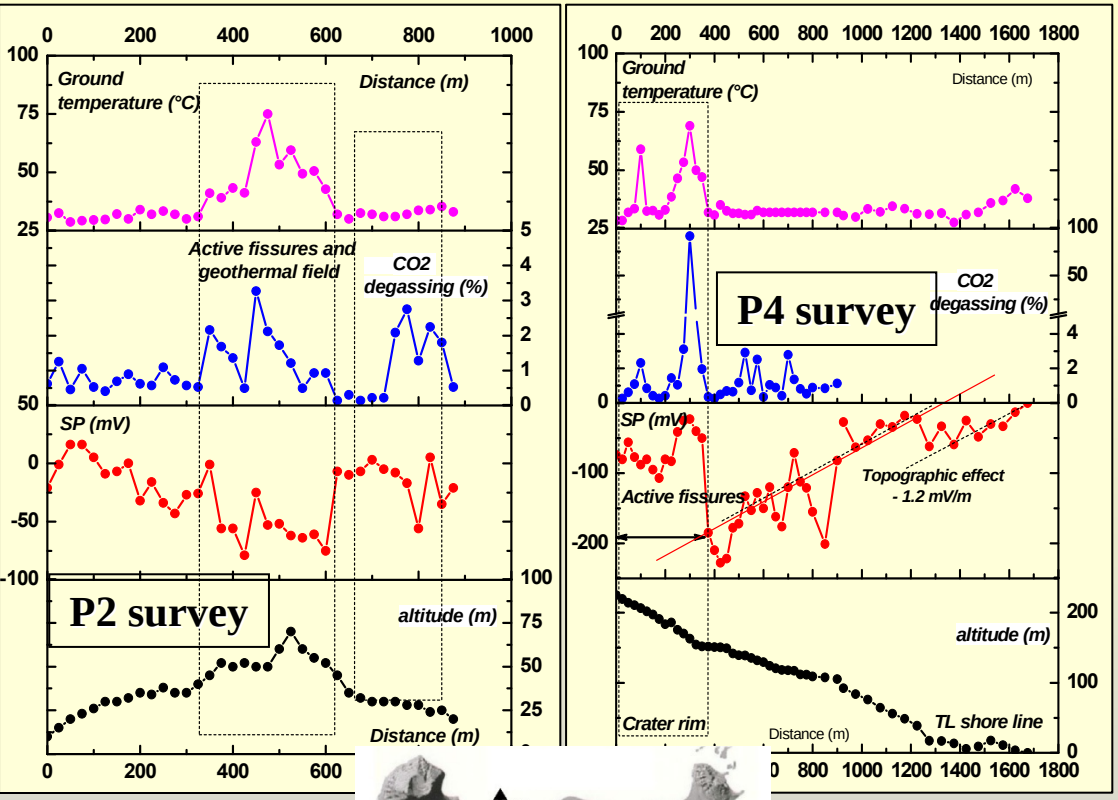


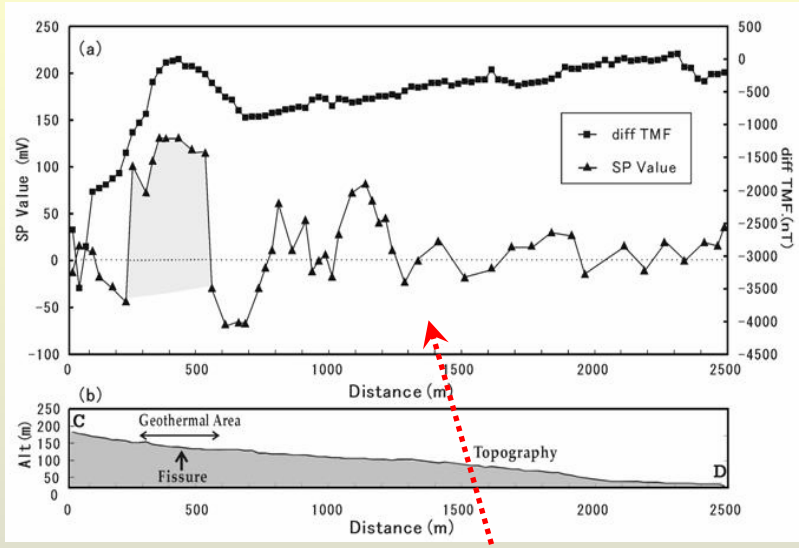
11/17/2006

11/28/2006

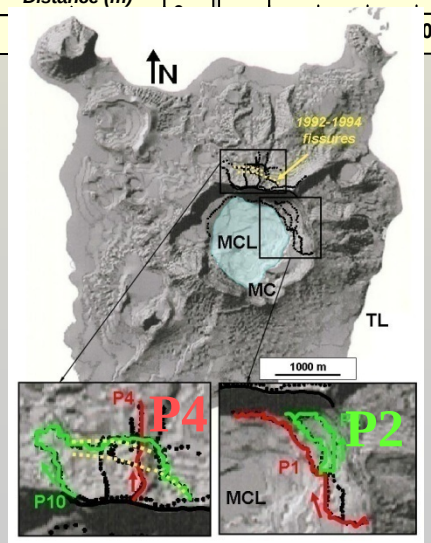
PHIVOLCS document

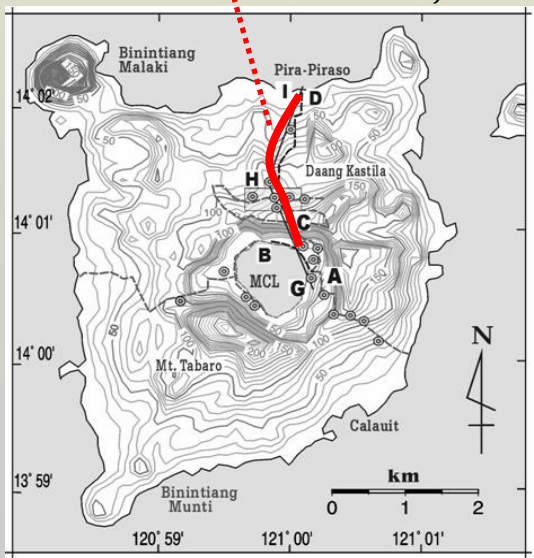
SP, CO_2, GT and TMF profiles: 2005





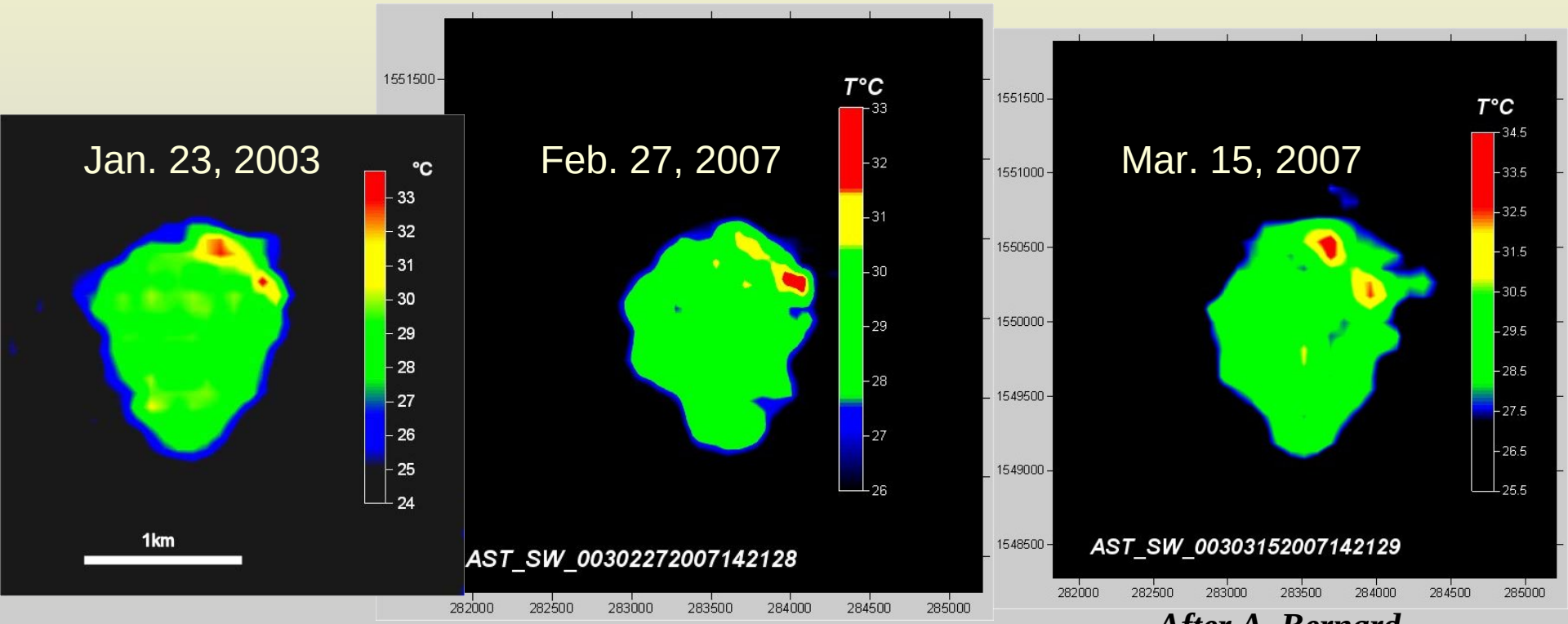
Harada et al., 2005





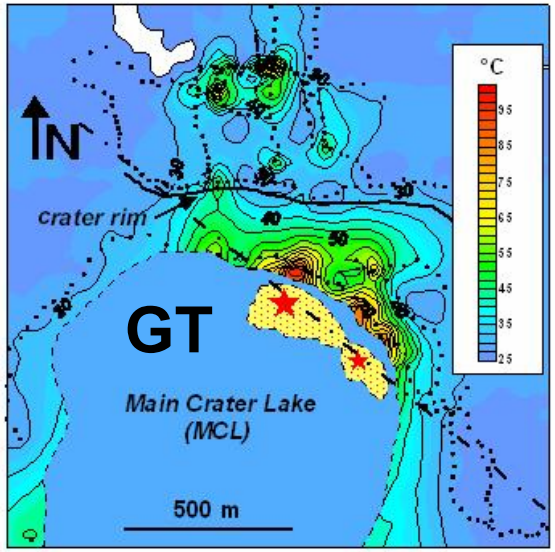
Satellite thermal mapping : 2007

- **ASTER satellite (Advanced Spaceborne Thermal Emission and Reflection Radiometer)**
  - **Spectral bands : visible (VNIR), near infra-red (SWIR) and thermal infra-red (TIR)**
  - **Spatial resolution: 15 m (visible); 90 m (TIR)**
  - **Taal lake is taken as temperature reference, comparison with MODIS data (sea) gives a precision of about 0.3°C**



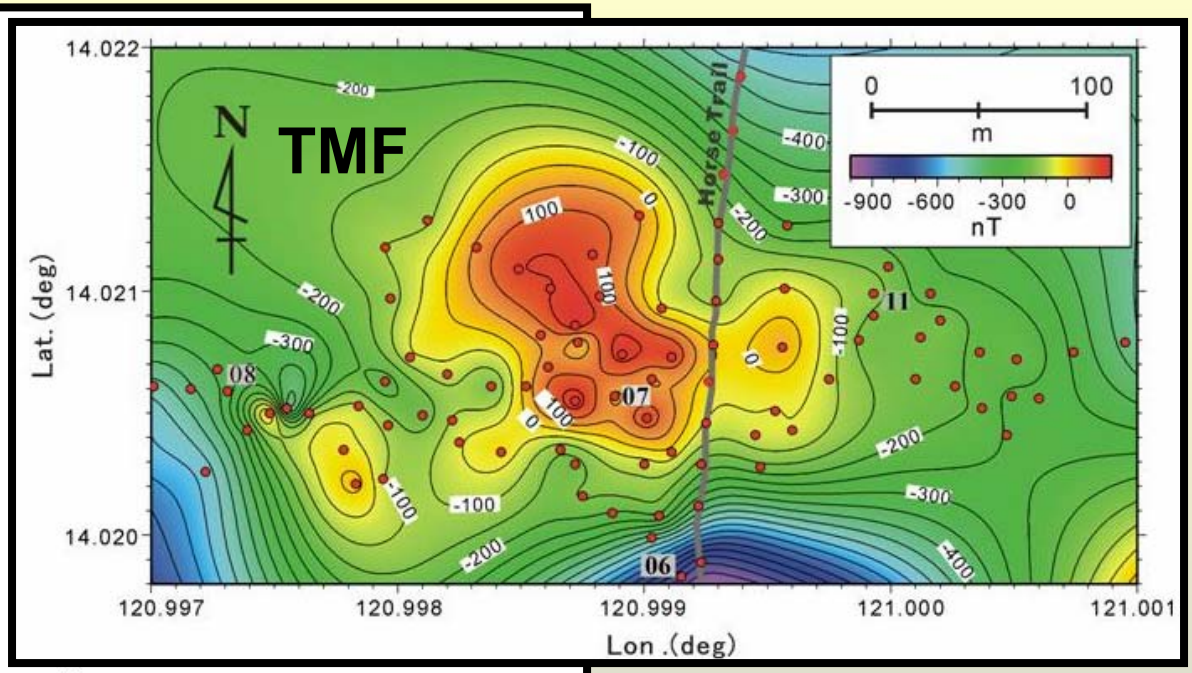
After A. Bernard

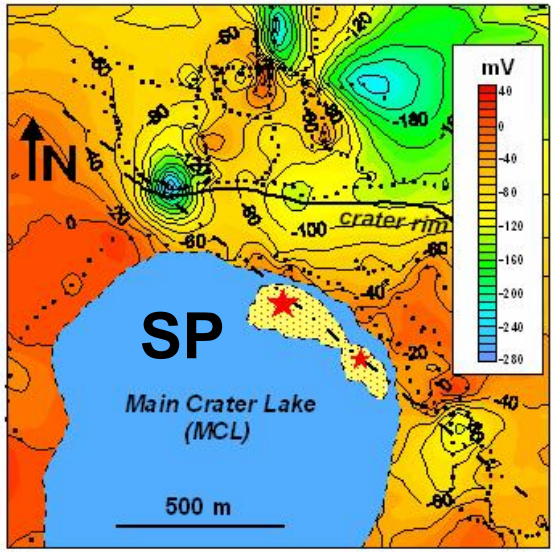
SP, CO_2 and GT mappings: 2005-2006

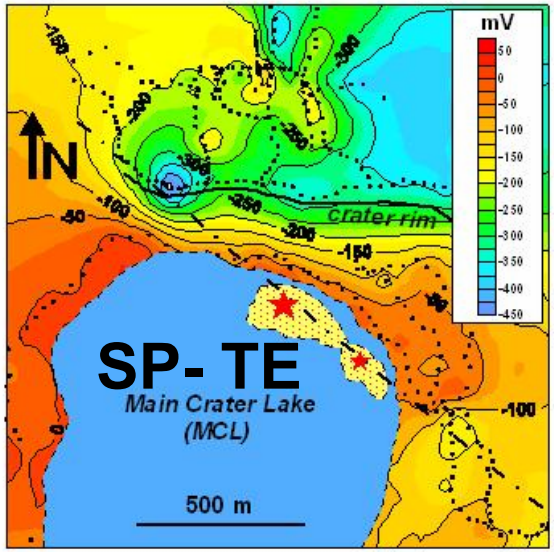


A

C

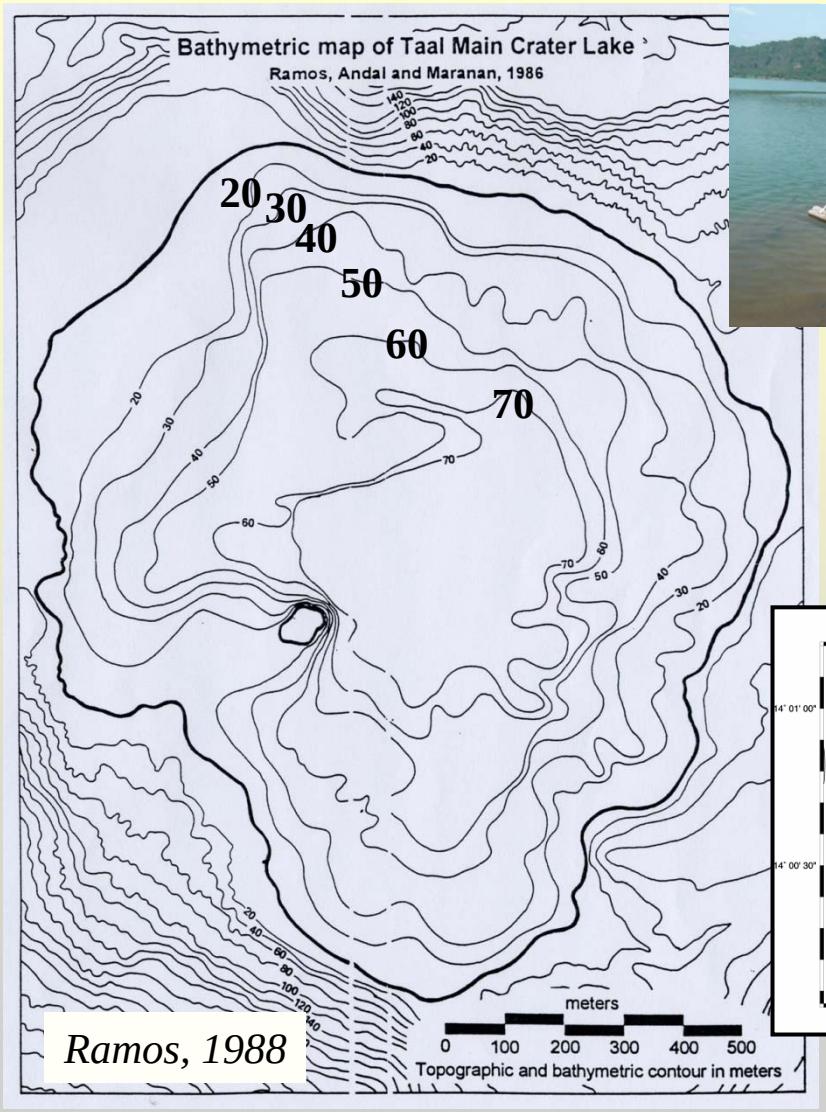




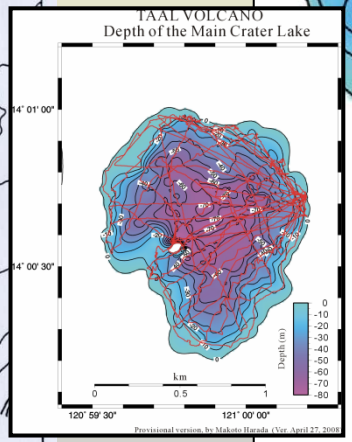


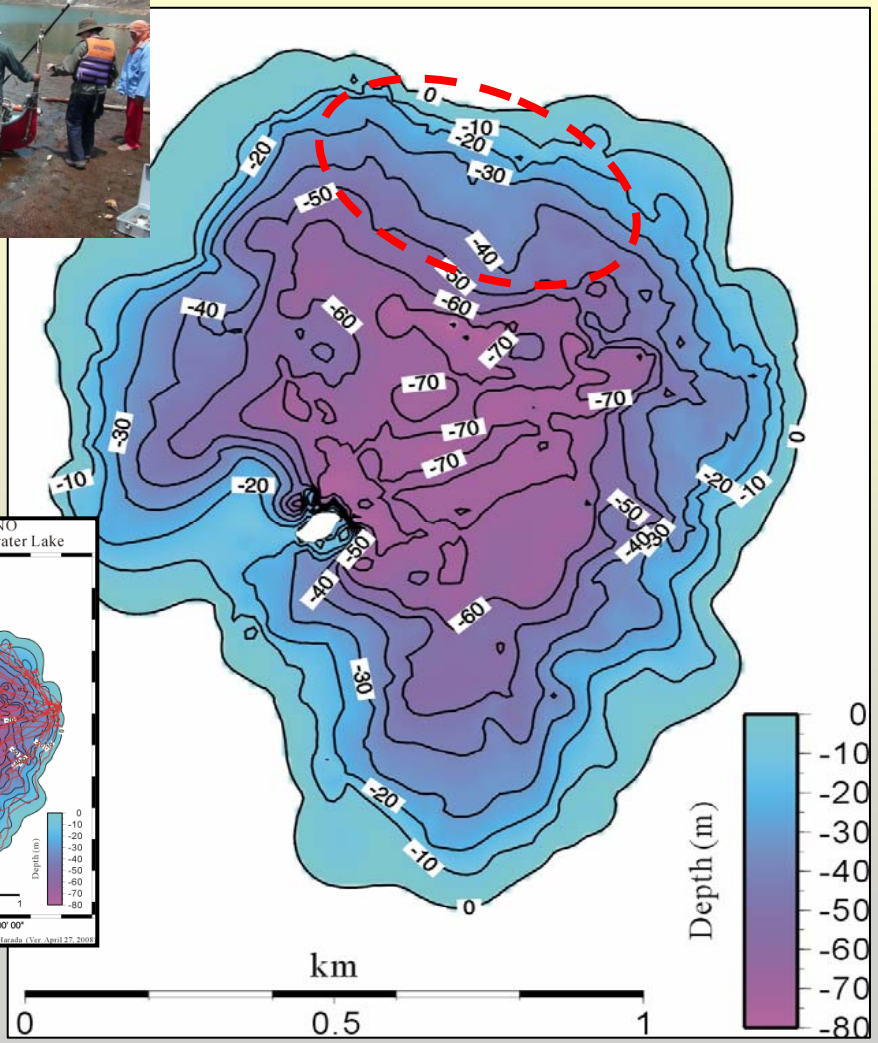
Zlotnicki et al., 2008

Bathymetry of MCL: 1966 and 2008



Ramos, 1988

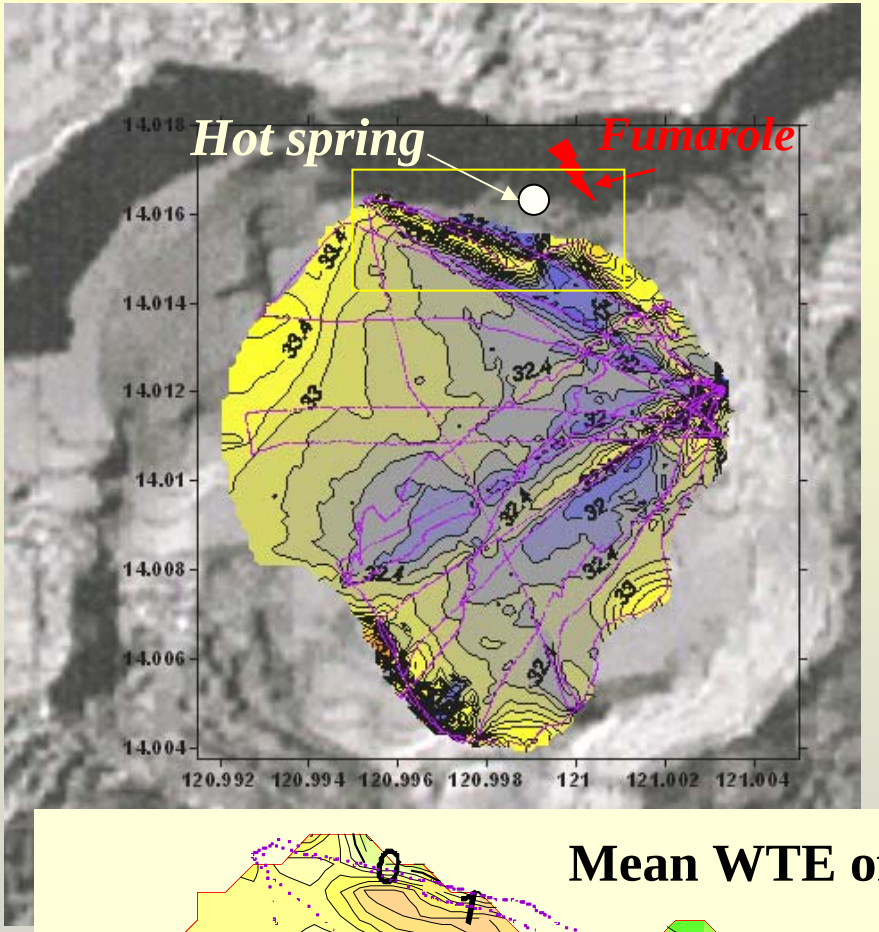


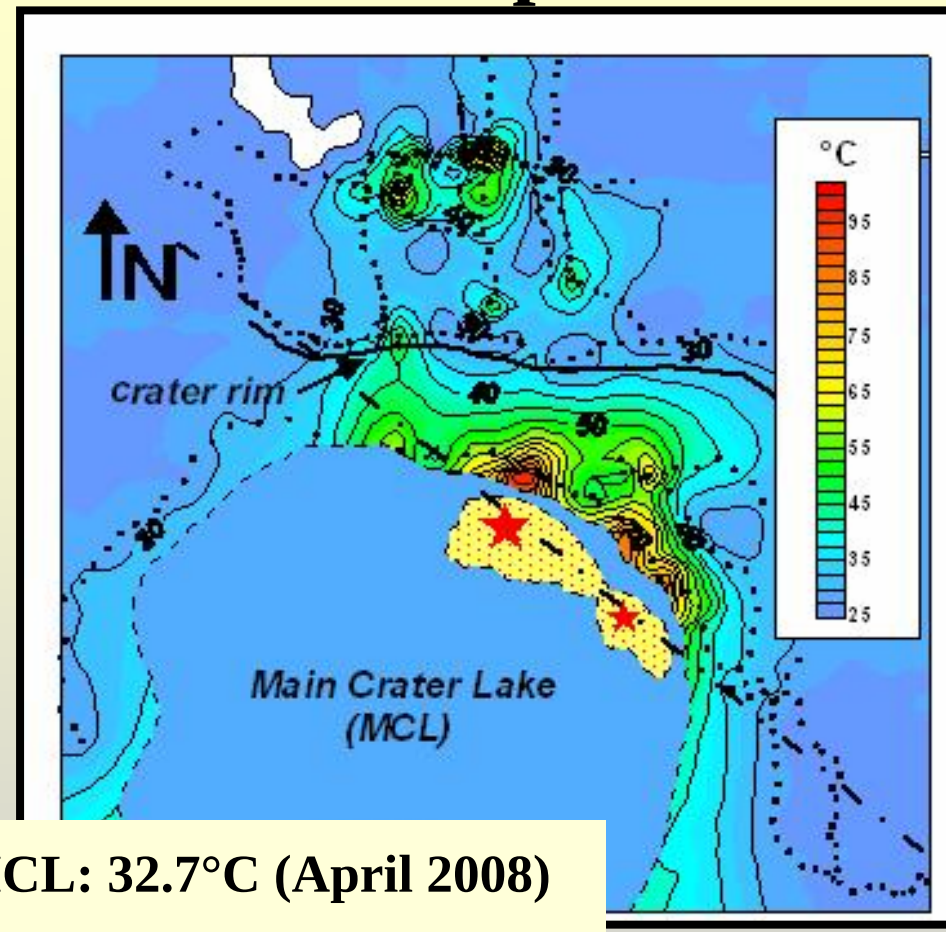


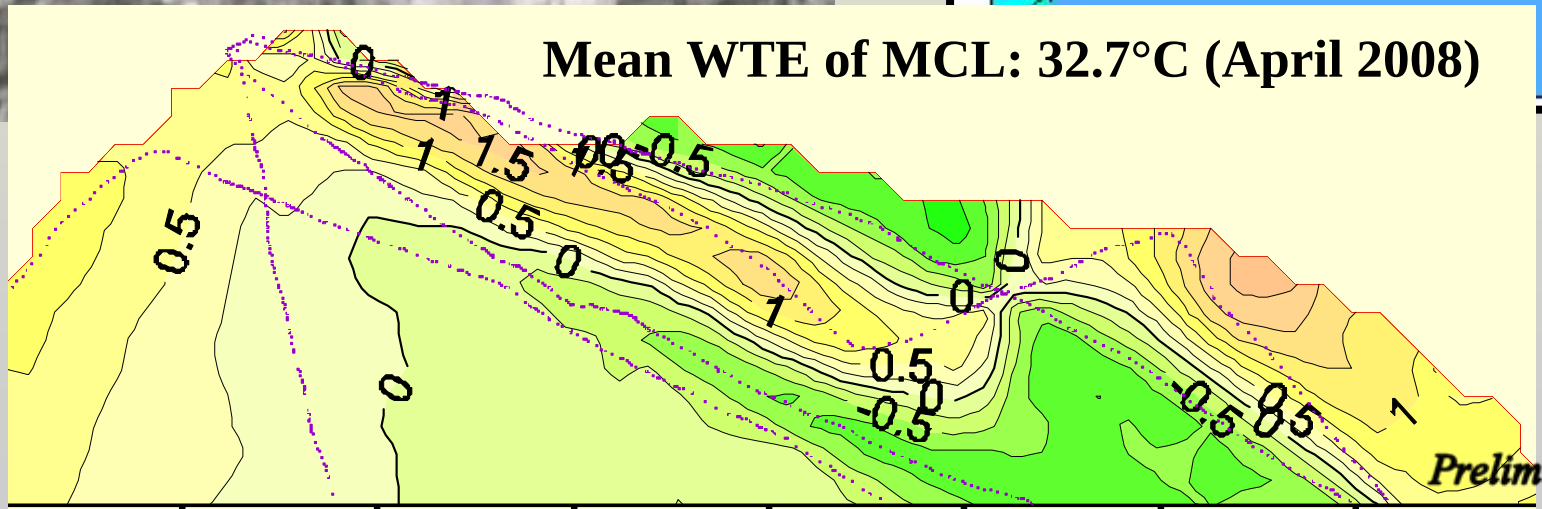
- **A variation of several meters (5 to 10) seems to take place on the northern part of MCL**

After Harada, provisional document

MCL water temperature: 1m depth



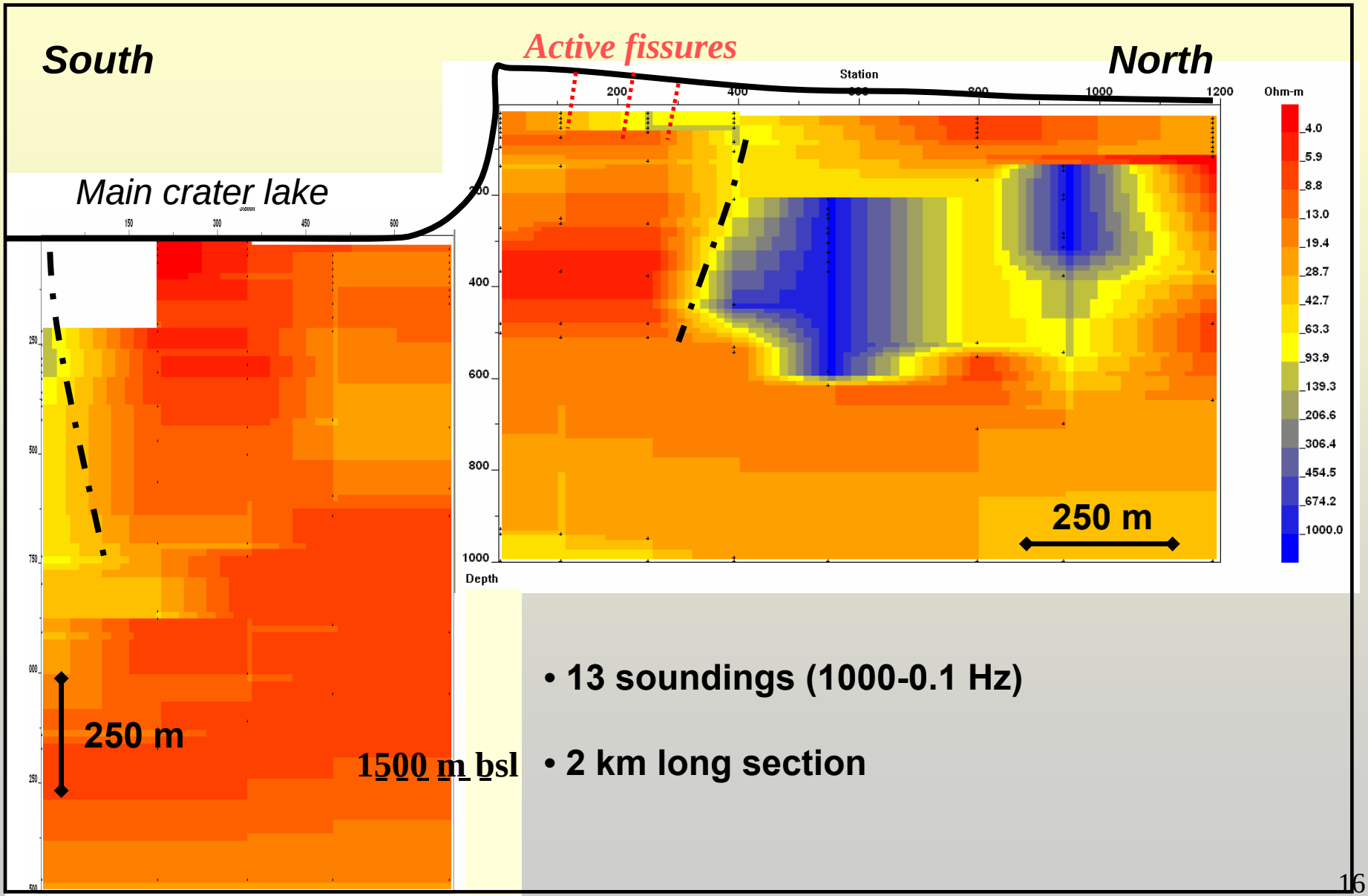




GTE & Aster anomalies

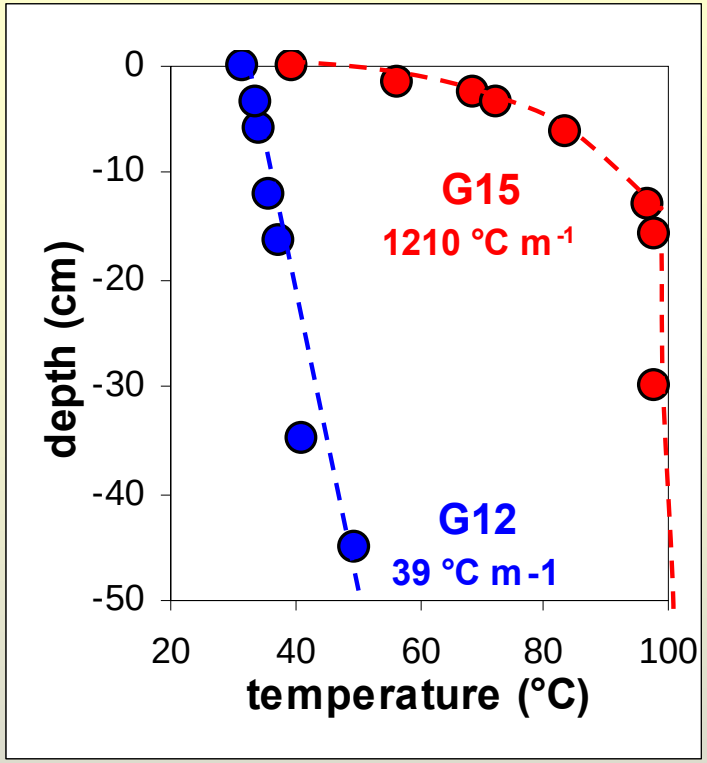
Preliminary results

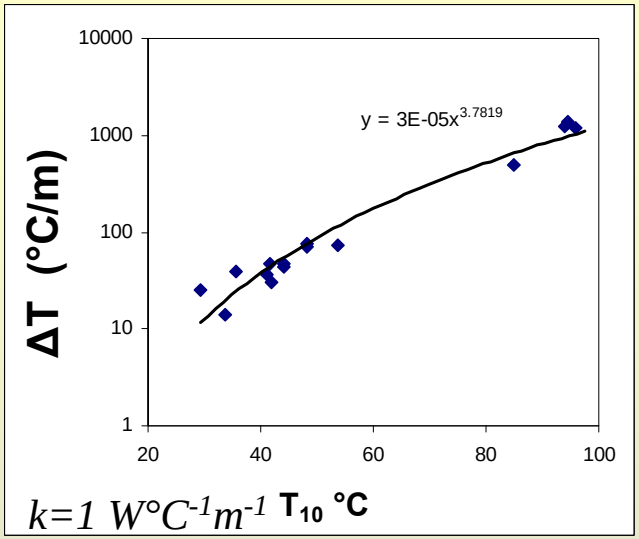
Magnetotelluric soundings along a S-N cross section



- 13 soundings (1000-0.1 Hz)
- 2 km long section

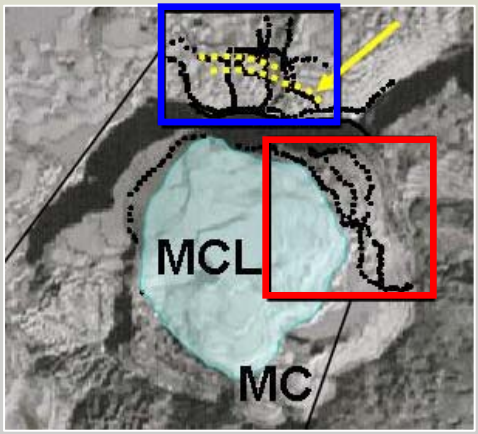
Temperature gradients and CO_2 fluxes: Feb. 2007



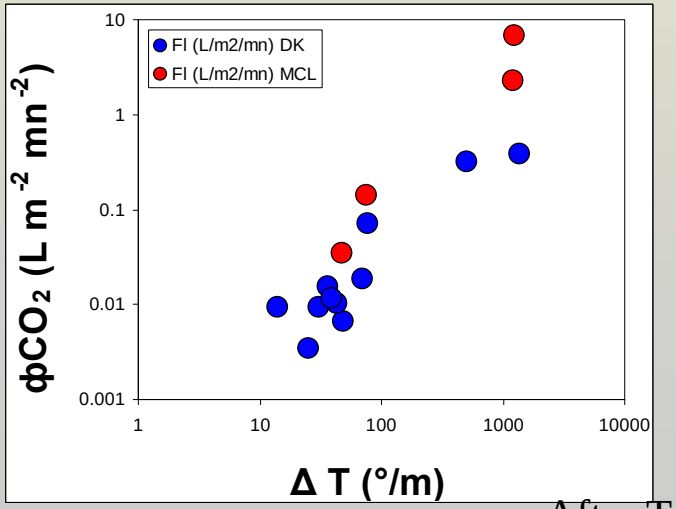


Heat Flow : DAK: 2 MW
MCL: 7.3 MW
in MCL: ~7.5 MW

Heat discharge →15 MW



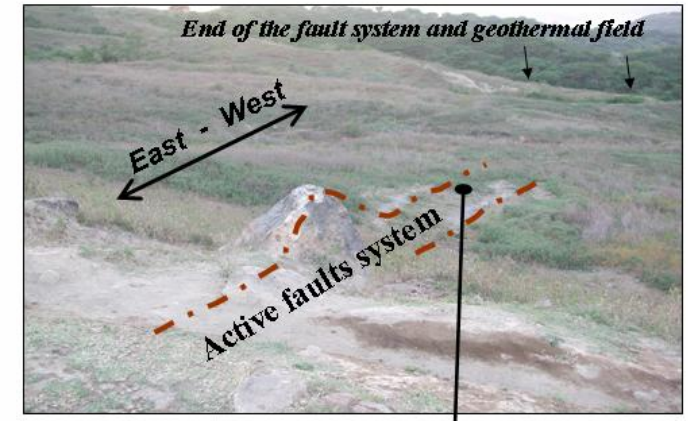
Higher ∇T
Higher CO_2 fluxes take place in MC

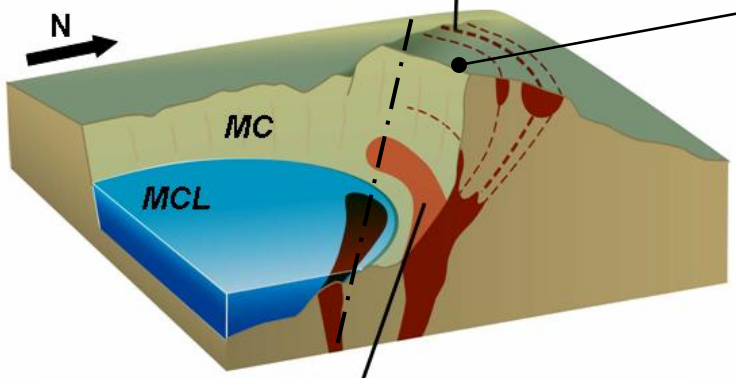


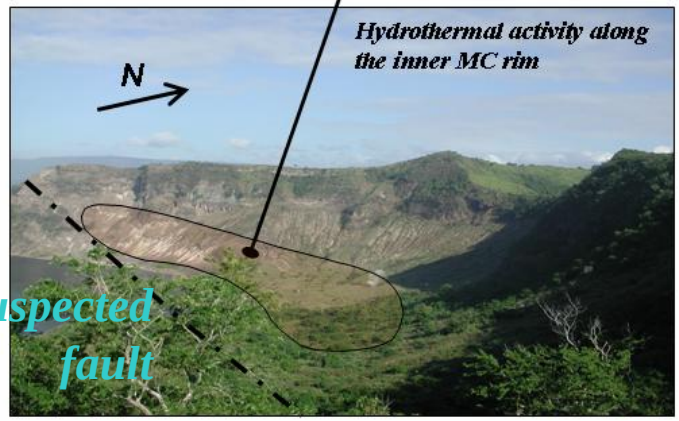
After Toutain

After Toutain

Possible centre of the next activity & scenario



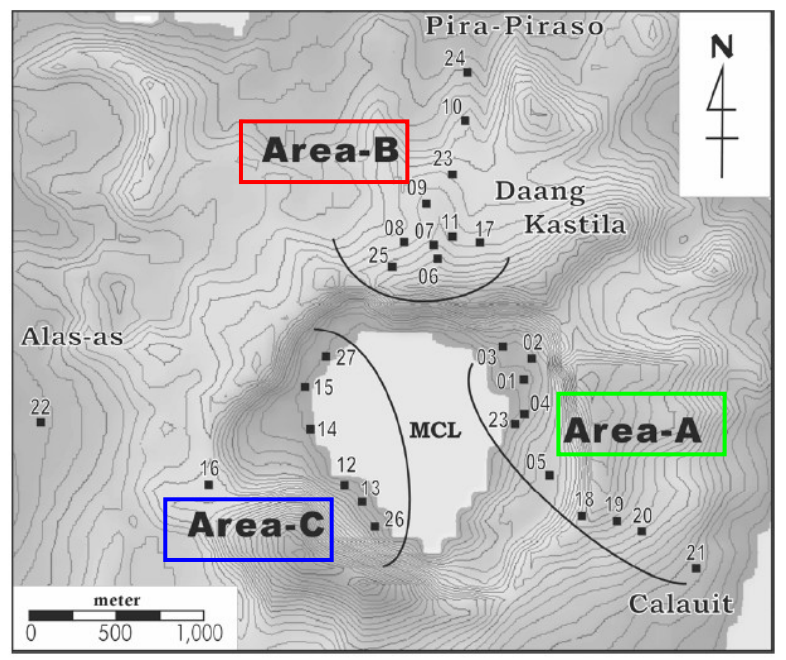


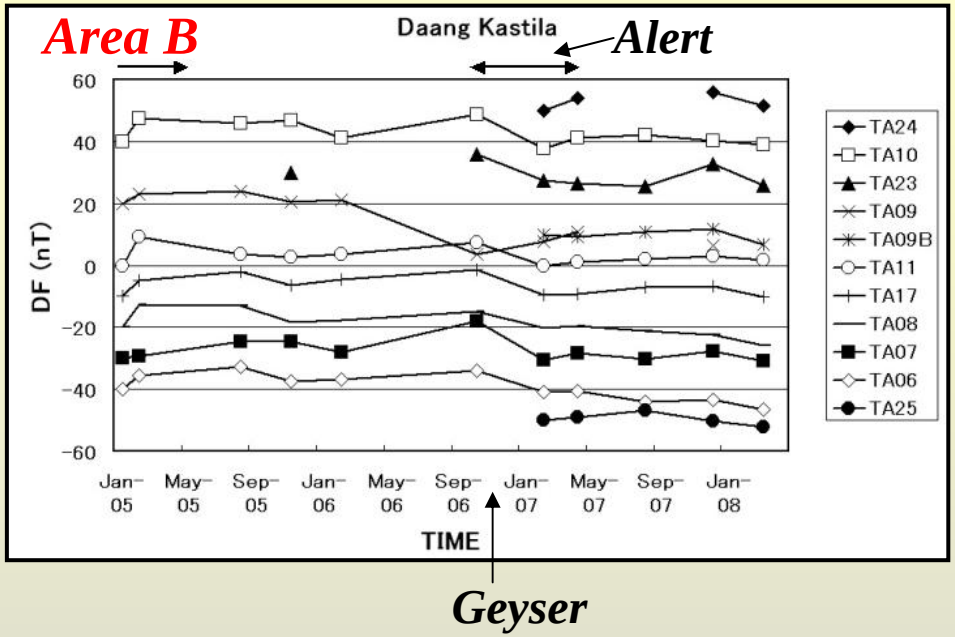


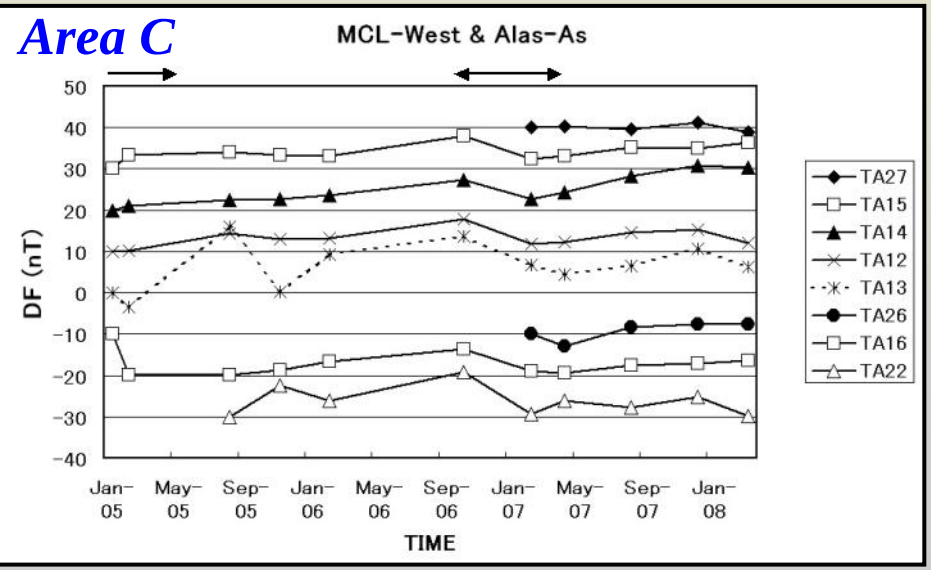
Every day about 100 to 200 persons climb the volcano

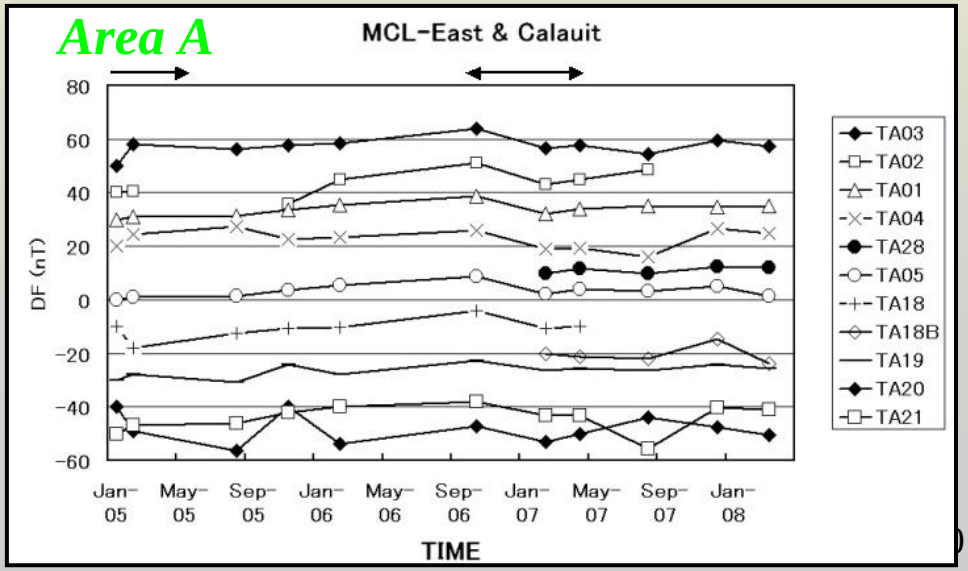
HYDROTHERMAL ACTIVITY DURING THE PAST YEARS

Repeated magnetic surveys: 2005-2007



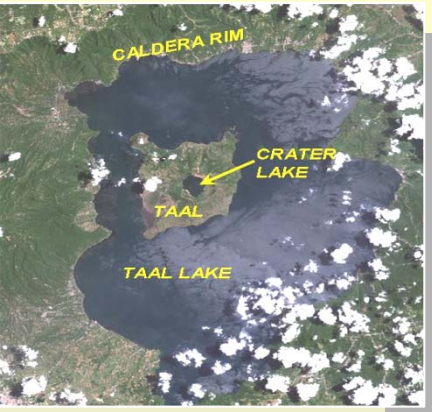


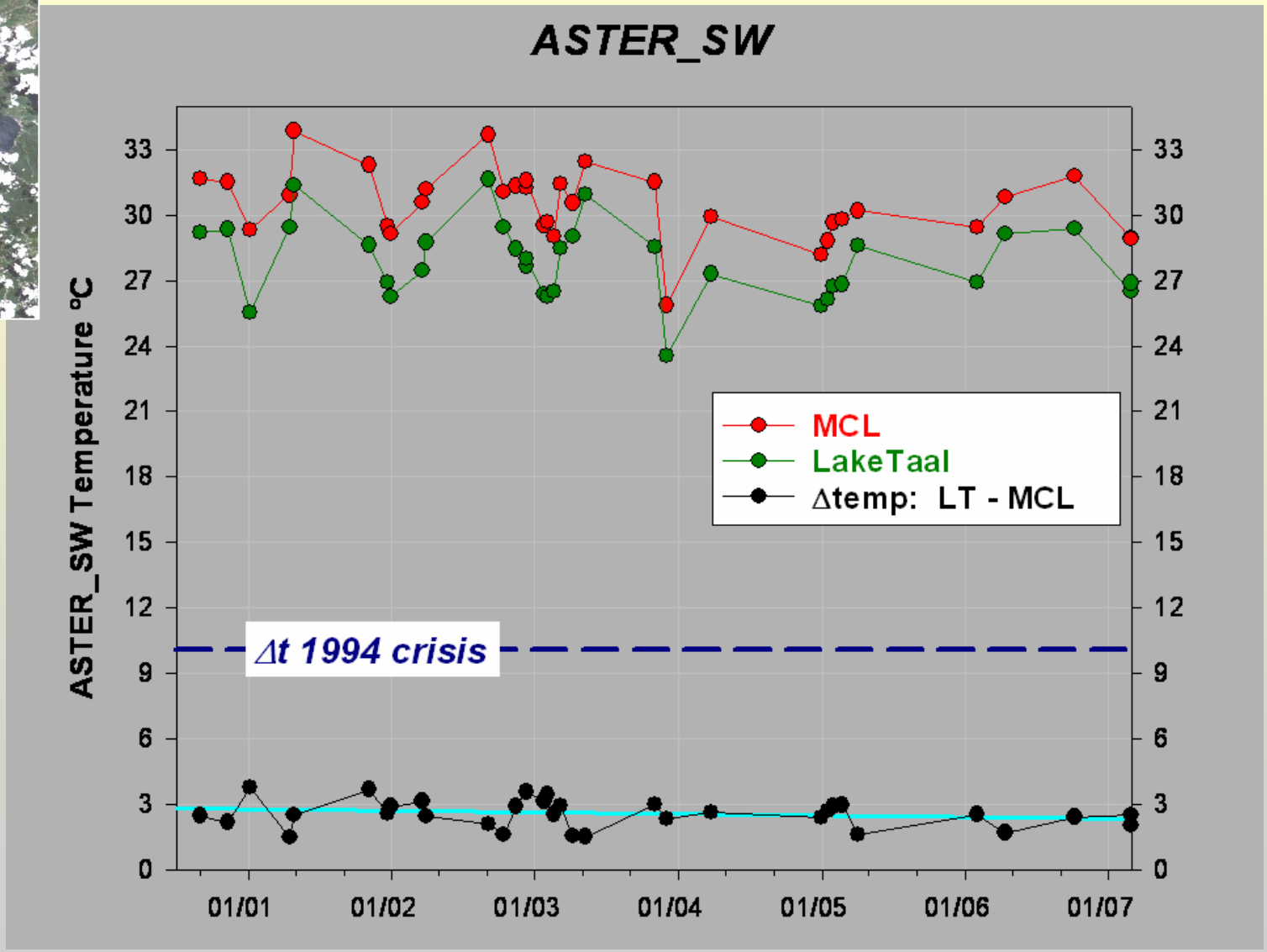




Repeated SP, CO2, GTE Surveys: 2005-2007

Aster thermal imaging and time evolution:2001-2007

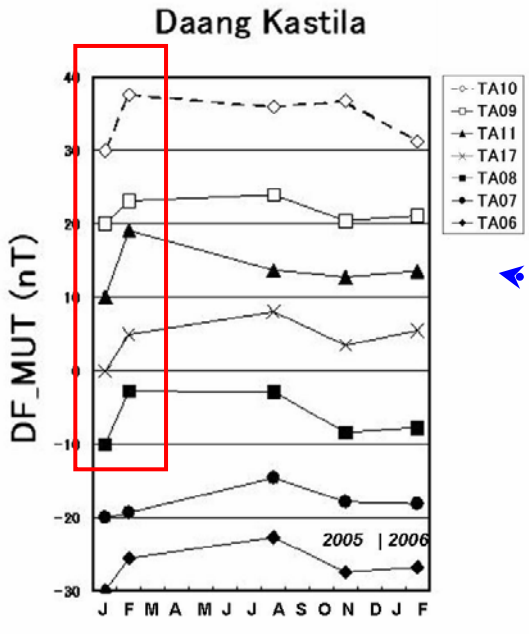


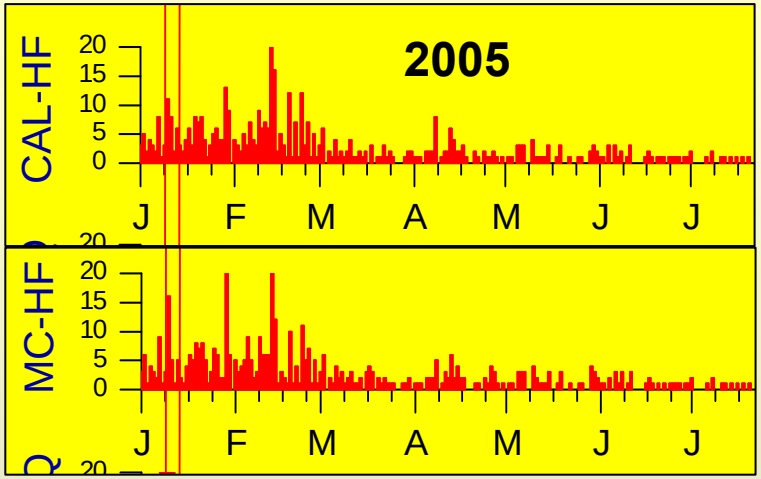


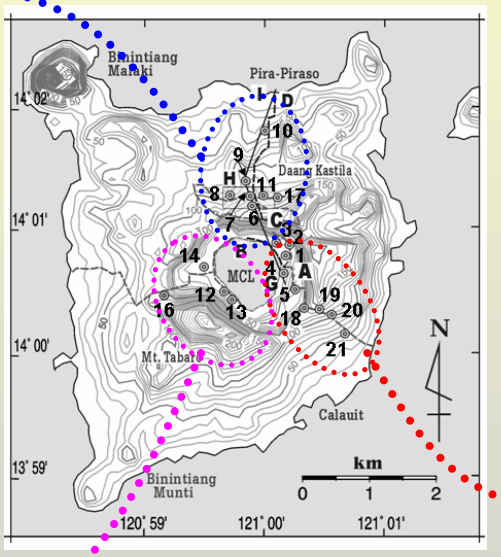
After A. Bernard

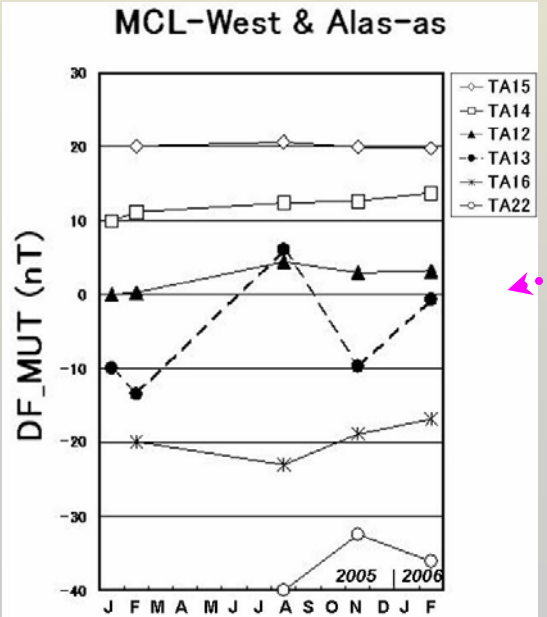
TRANSIENT SIGNALS
RELATED TO SEISMIC CRISES

Magnetic signals related to Jan. 2005 seismic crisis

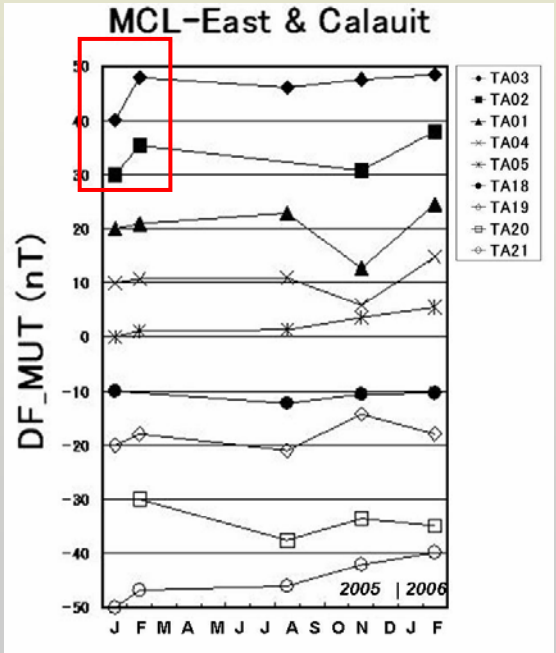




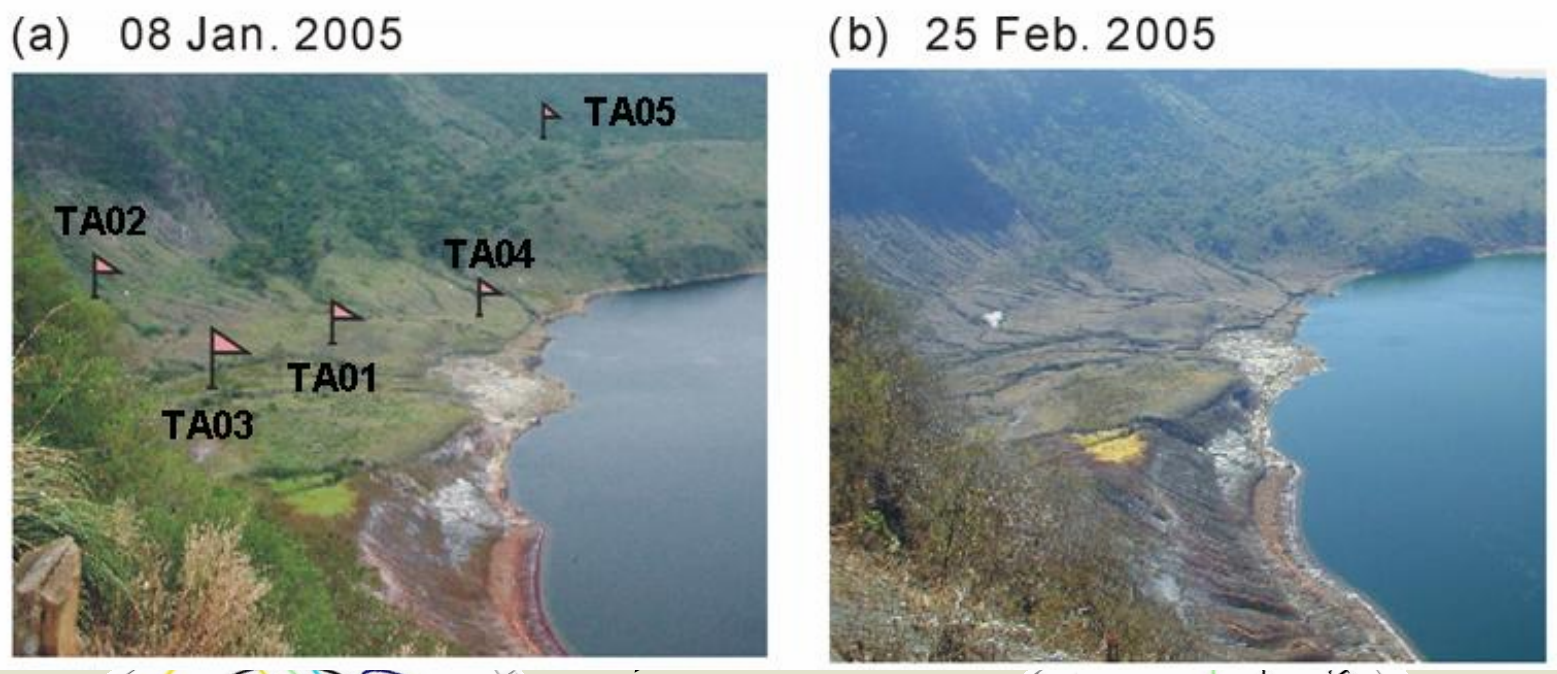




Spontaneous evacuation of the Islanders in the night Alert 1 was set



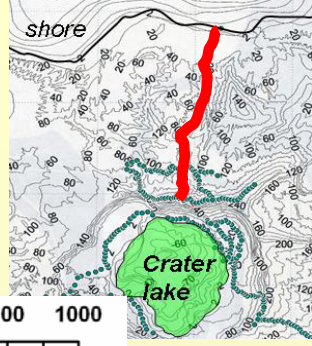
TMF Modeling

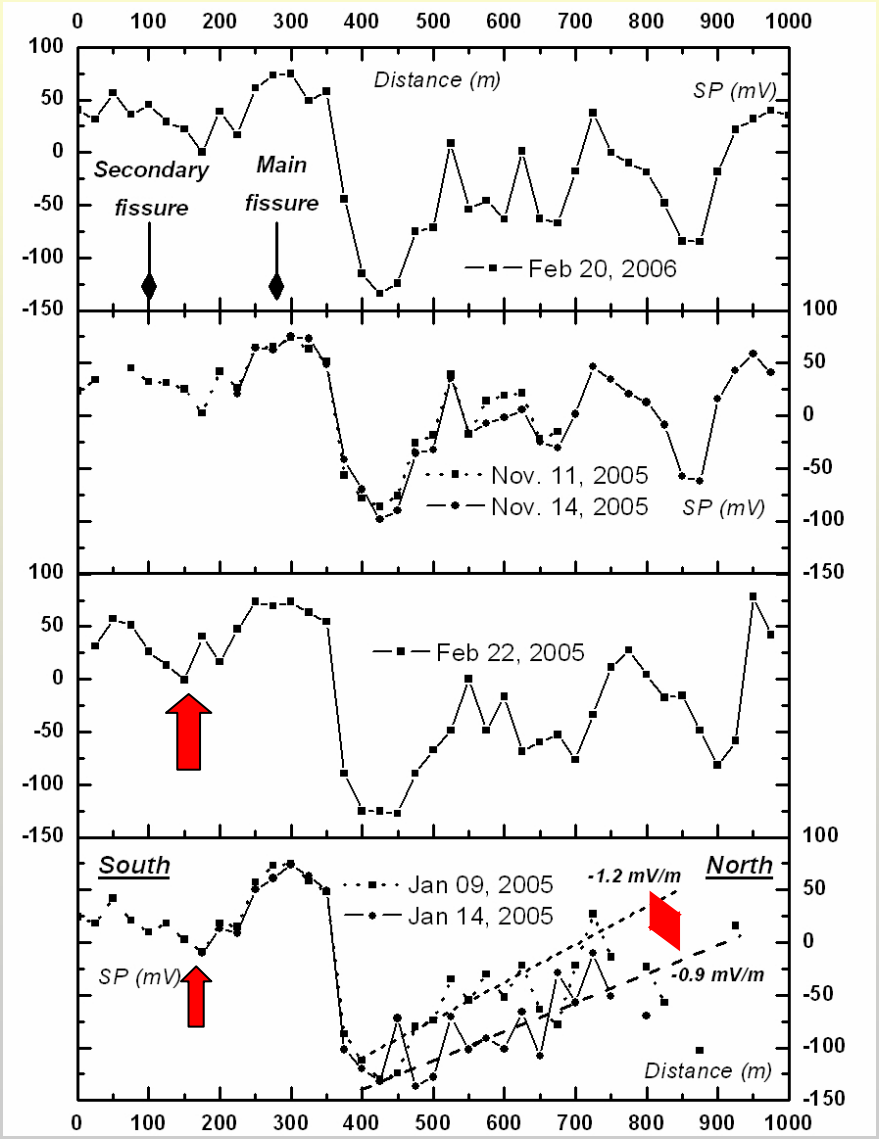


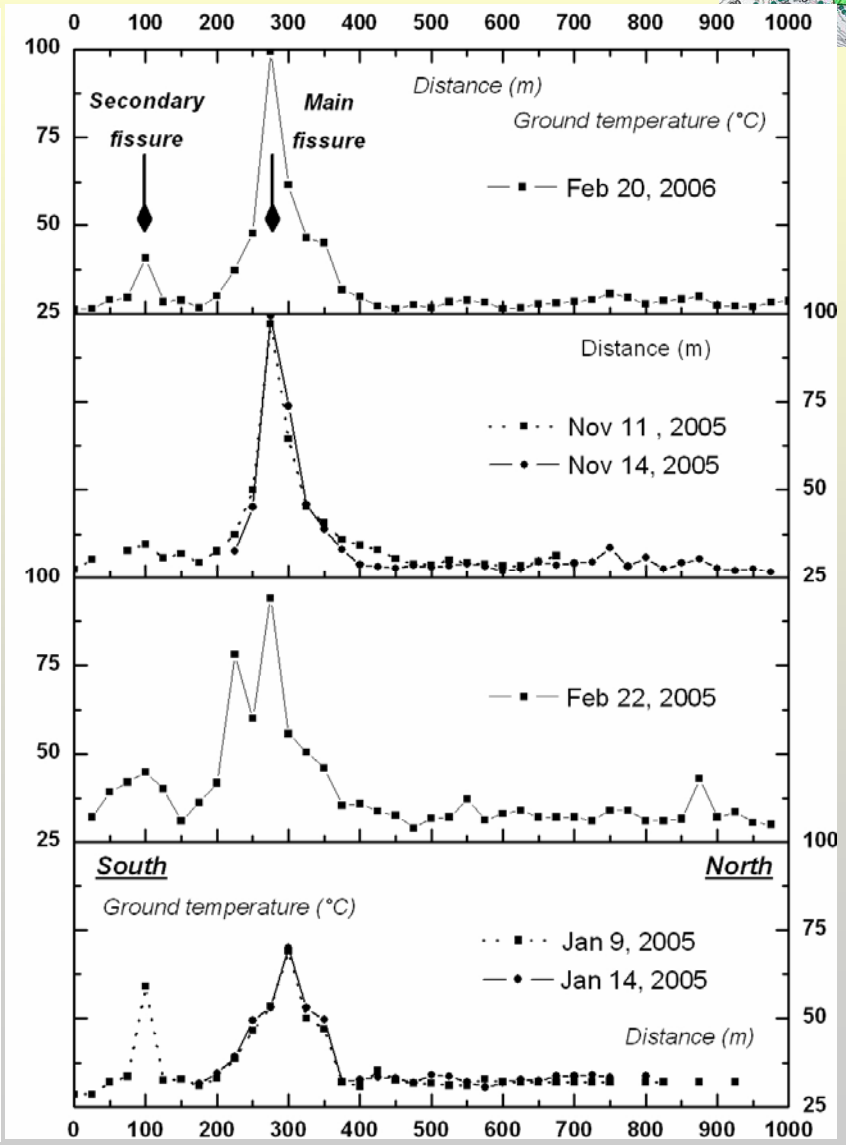
Demagnetized triaxial ellipsoid at shallow depth (50 & 10 m) obtained by a increase of few degrees

Harada et al., 2005

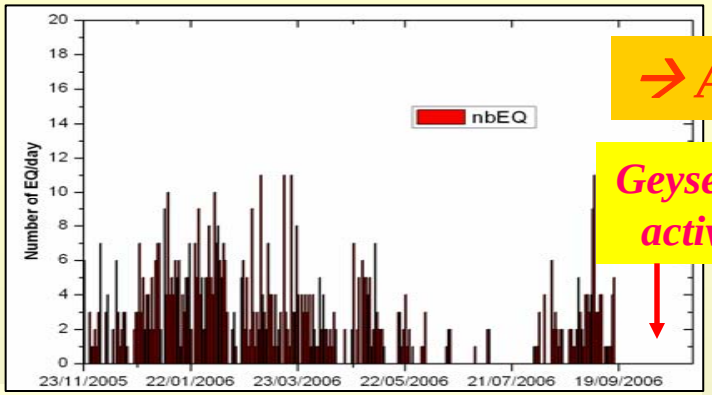
Transient SP and GT anomalies evidenced by repeated surveys





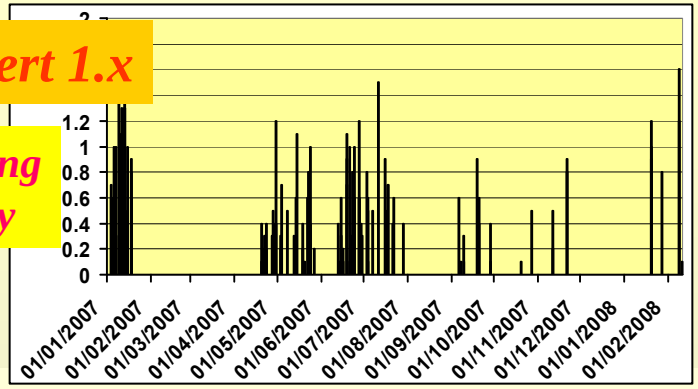


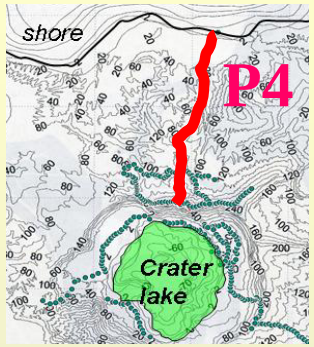
Transient SP, CO_2 and GT anomalies: 2007



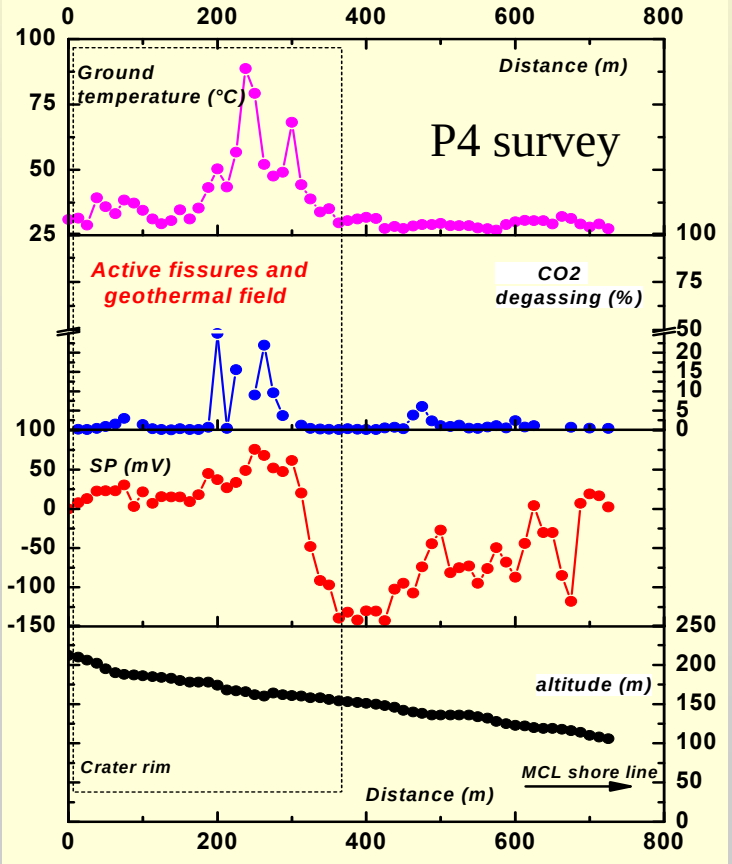
→ *Alert 1.x*

Geysering activity

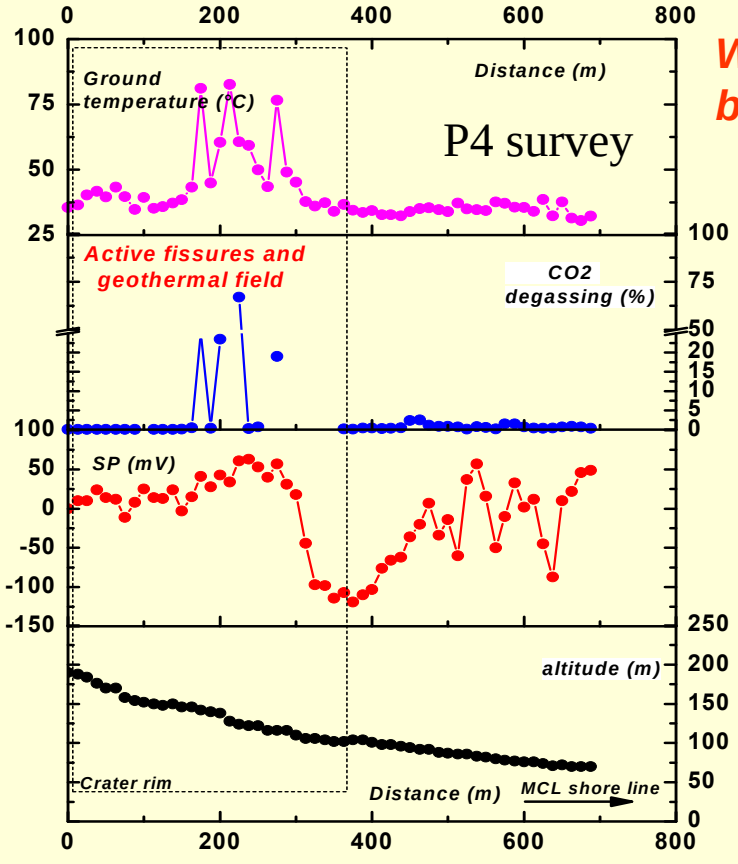




February 2007

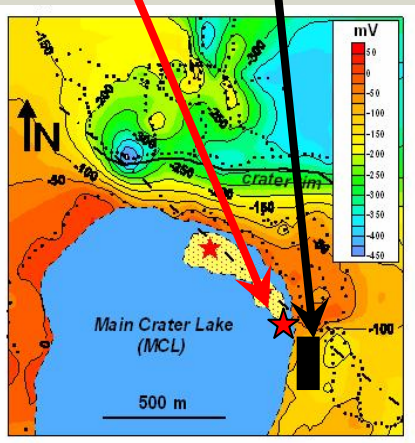


April 2007



Weak bubbling area

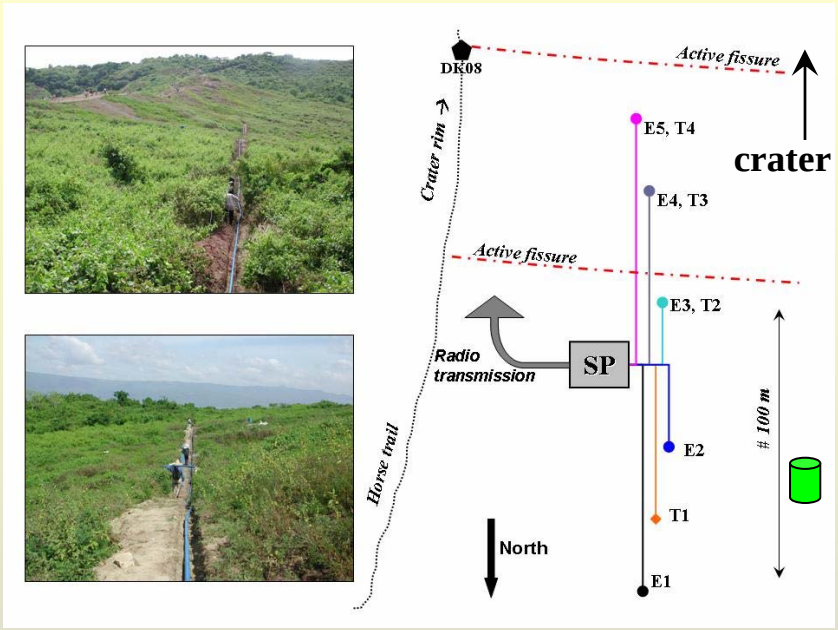
SP-GTE anomalies



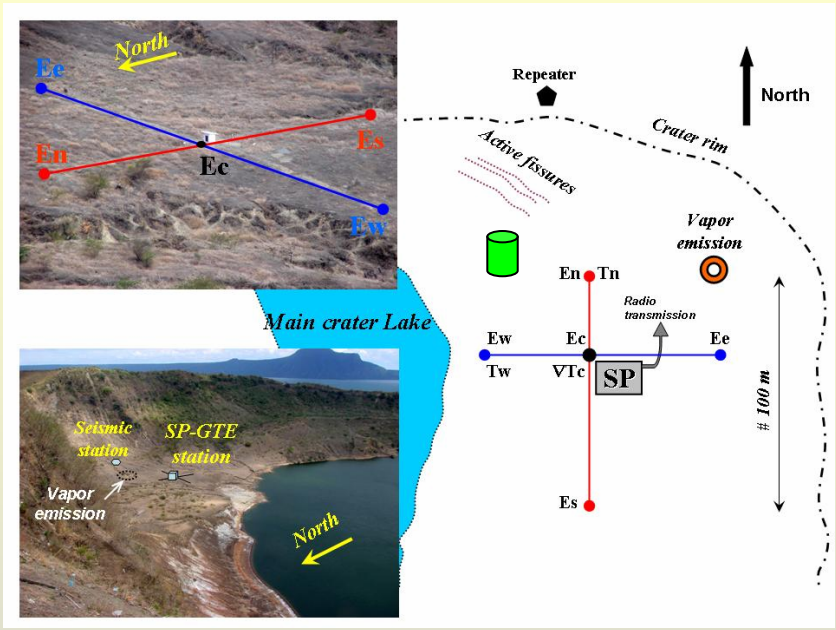
SETTING CONTINUOUS MULTI-PARAMETRIC STATIONS

2006 - 2008

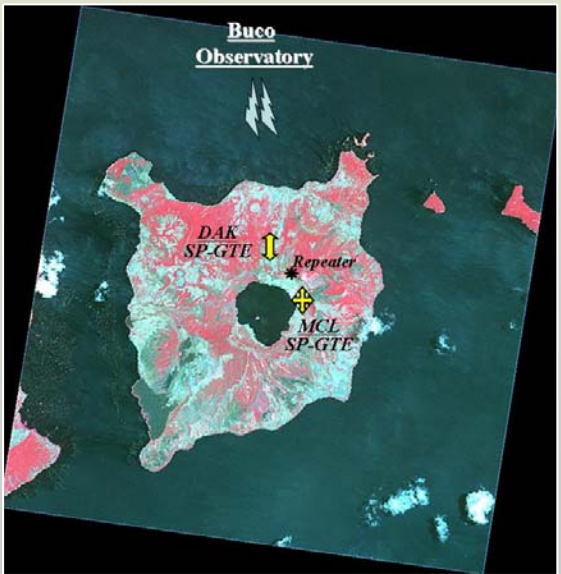
Continuous SP, GTE, Rn and TMF stations



2006

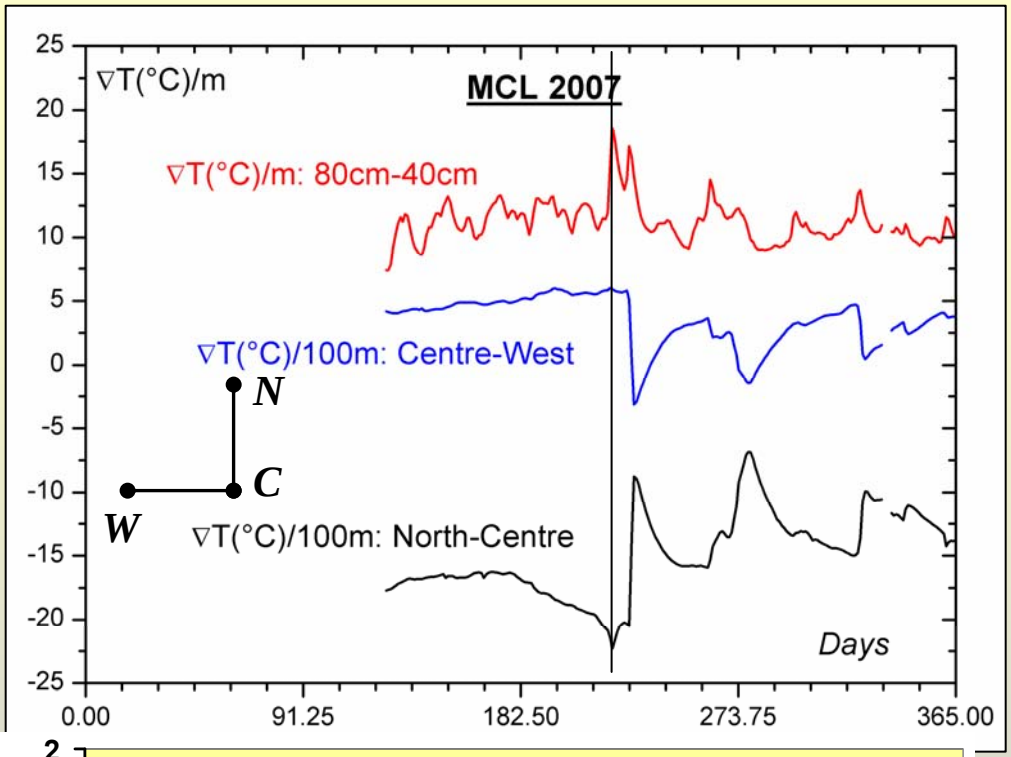


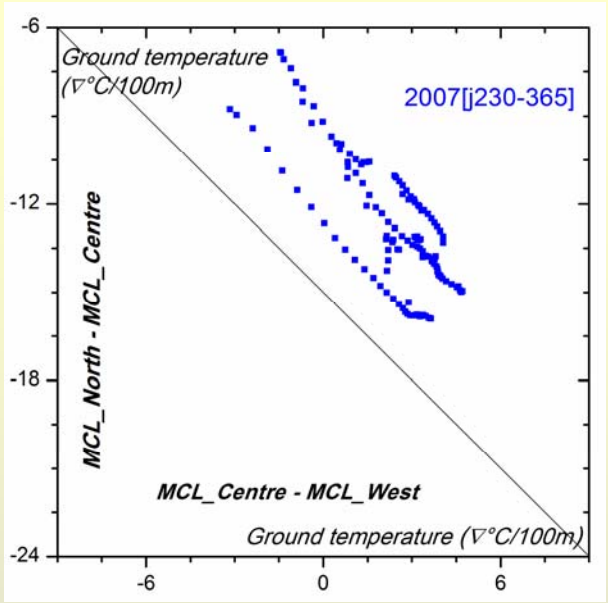
2007

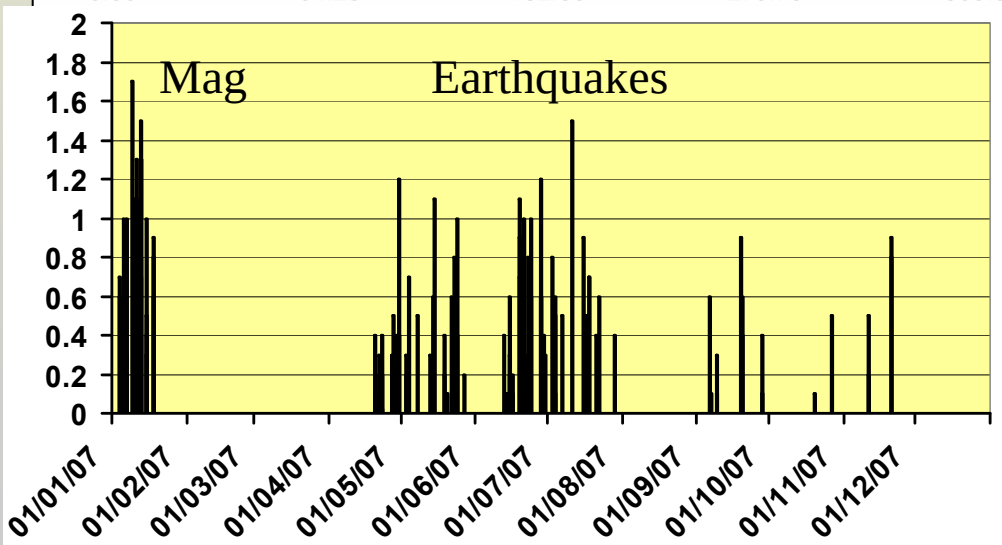


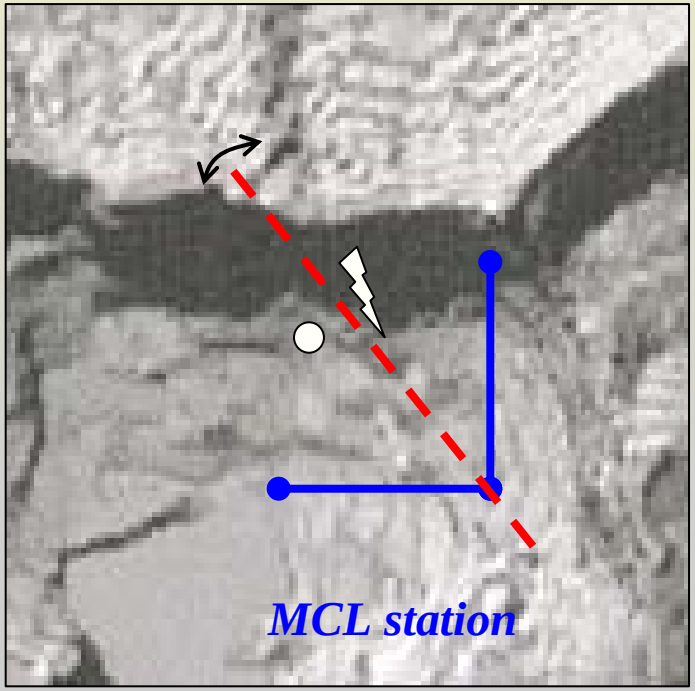
The 2 stations are telemetered to the local observatory

Ground temperature gradient in MCL

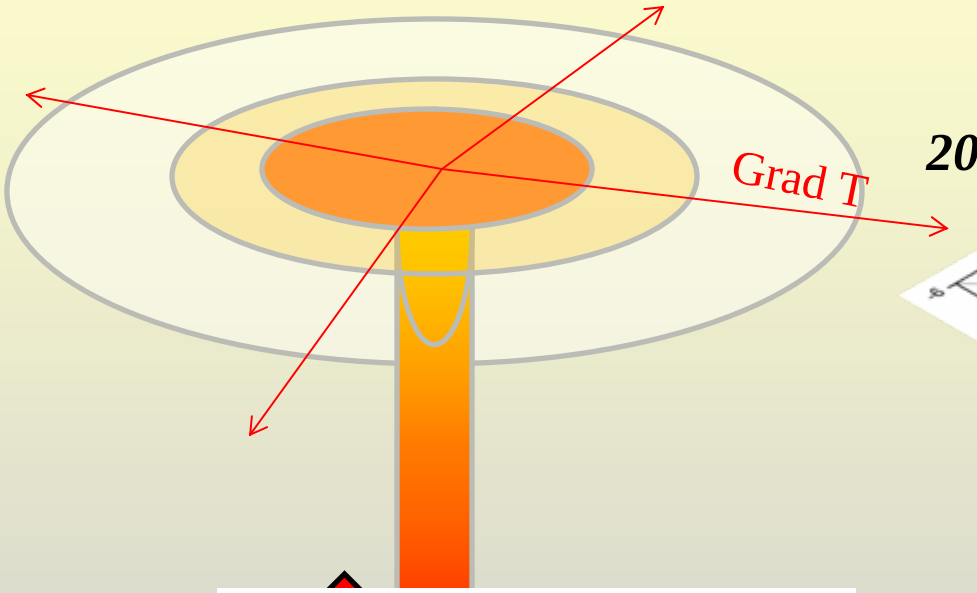




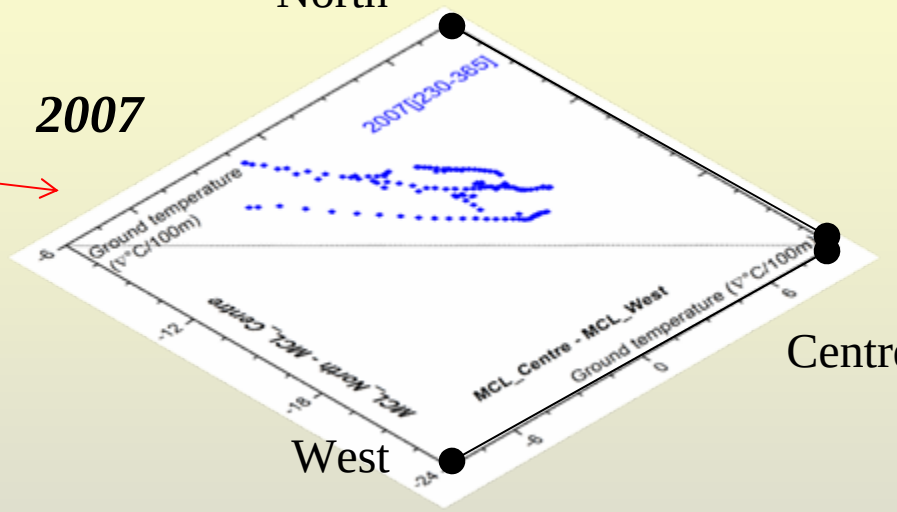




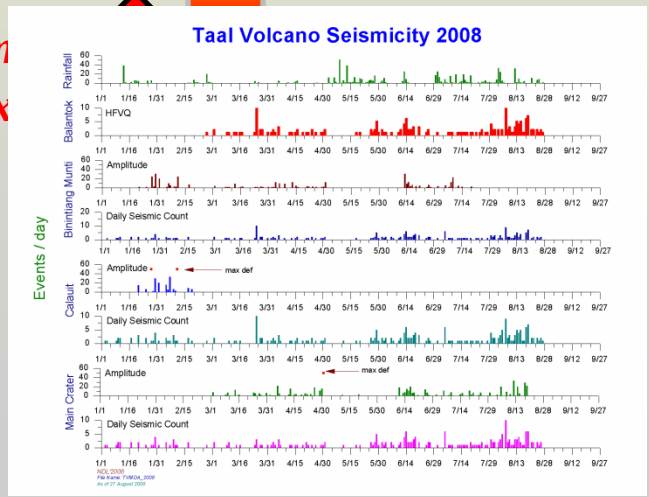
Surface temperature activity



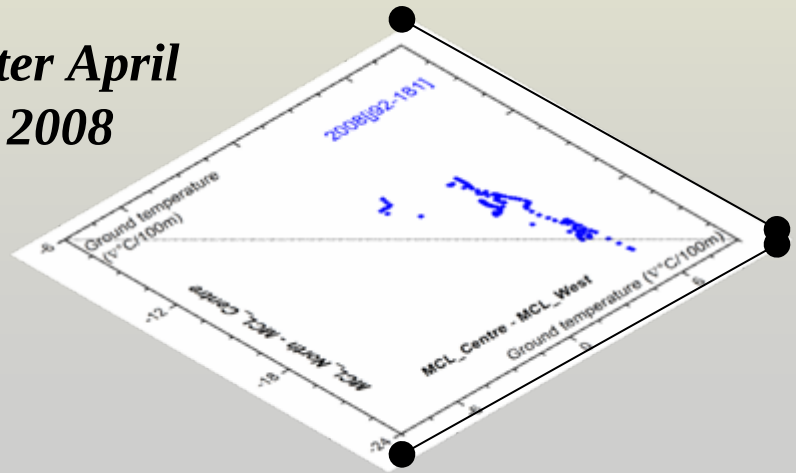
2007



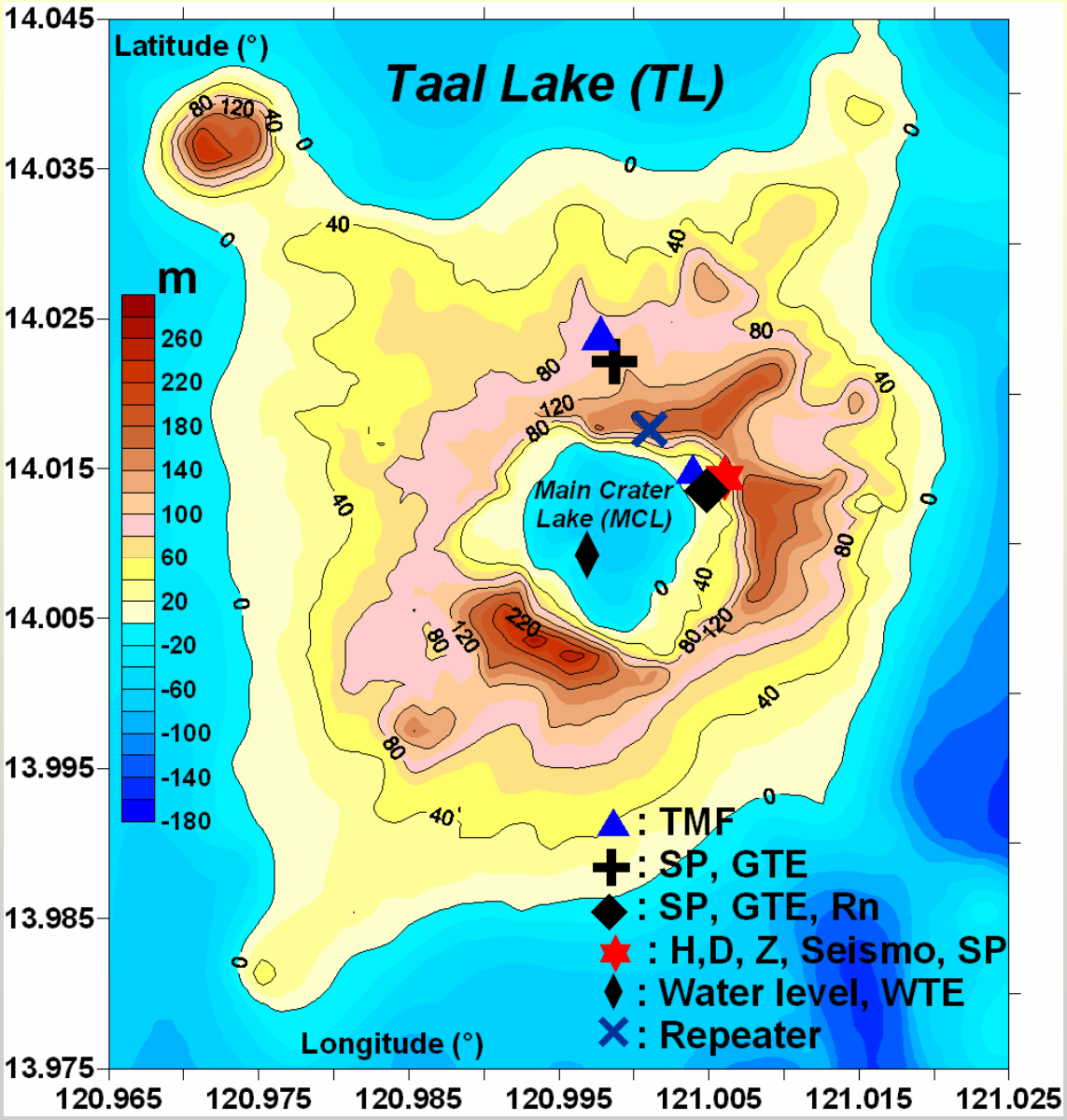
Therm
flux



After April 2008



Multi-parametric stations: April 2008



Other measurements:

PHIVOLCS
- Pluviometry
- Seismicity
- Ground leveling, DEM
- Geochemistry
- Visual observations

- Continuous GPS

- SAR interferometry
- IR observations
- Demeter observations
- MOPITT observations

+ and ◆ are telemetered stations with data acquisition at the local observatory

State of Taal activity

- **The extension of the hydrothermal system has been defined**
- **Hydrothermal activity take place in the first ~2 km depth**
- **The highest activity is located in the northern part of MC**
- **The 1992-94 fissures remain active and are connected in depth with the hydrothermal system.**
- **Bending fissures are the most prominent features (hydrothermal & gas transfers)**
- **Dikes may intrude along a SE-NW regional fault into MC?**
- **The outer part between MC and the 1992-94 could collapse in MCL**

- **The hydrothermal activity seems more or less constant between 2005 and 2008**
- **BUT sporadic and intense seismic crises produce bursts of transient surface activity**
  - **Increase of thermal activity,**
  - **Geysering phenomena,**
  - **Intense bubbling activity**
- **Low inflation of the summit is still observed**

Phreatic explosions could occur in a short time period

Phreatic activity can rapidly turn into violent phreatomagmatic activity