電磁気観測による火山活動監視

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1） ACTIVEシステムによる火山活動監視
2）無人ヘリによる繰り返し空中磁気測量

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EM observations

(pre-)Maxwell equations

Ampere's law $$\nabla \times H = \sigma E + J$$

Faraday's law $$\nabla \times E = -\frac{\partial}{\partial t}\mu_0(H + M)$$
$$\equiv -\frac{\partial}{\partial t}(\mu H)$$

Observables: electric field E, magnetic field H

Target to monitor: (physical property):

- electrical conductivity σ
- magnetization M or magnetic permeability μ
- (non-Ohmic electric current density J)

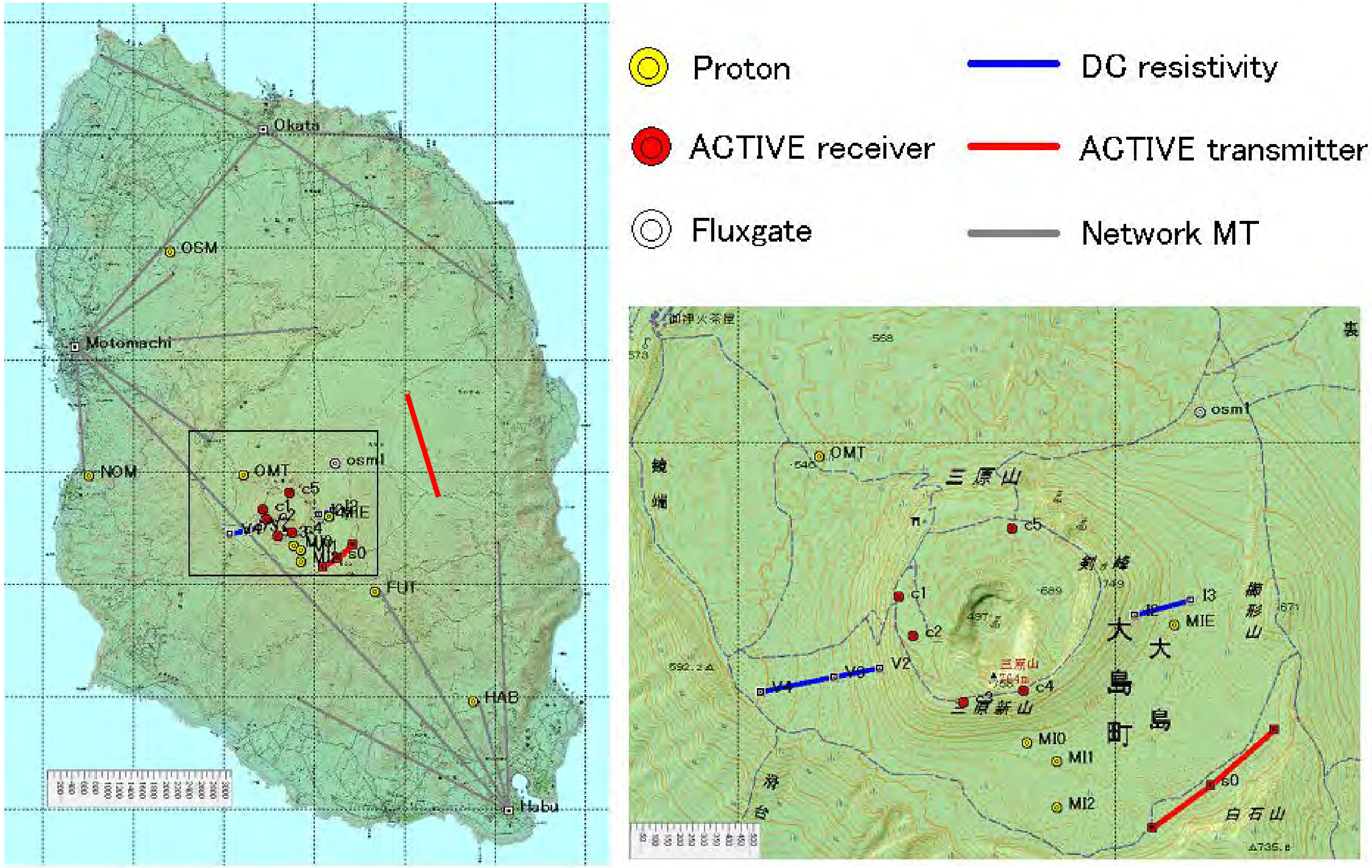
‘ACTIVE’ system : volcanic monitoring

outline

- EM observation in Izu-Oshima island
- Monitoring by controlled source EM (CSEM) method
- Simple conductivity model of Izu-Oshima
- Temporal change of CSEM signal response

EM observation in Izu-Oshima

Data are transferred by wireless LAN.



Geomagnetic total intensity measurement 1968～

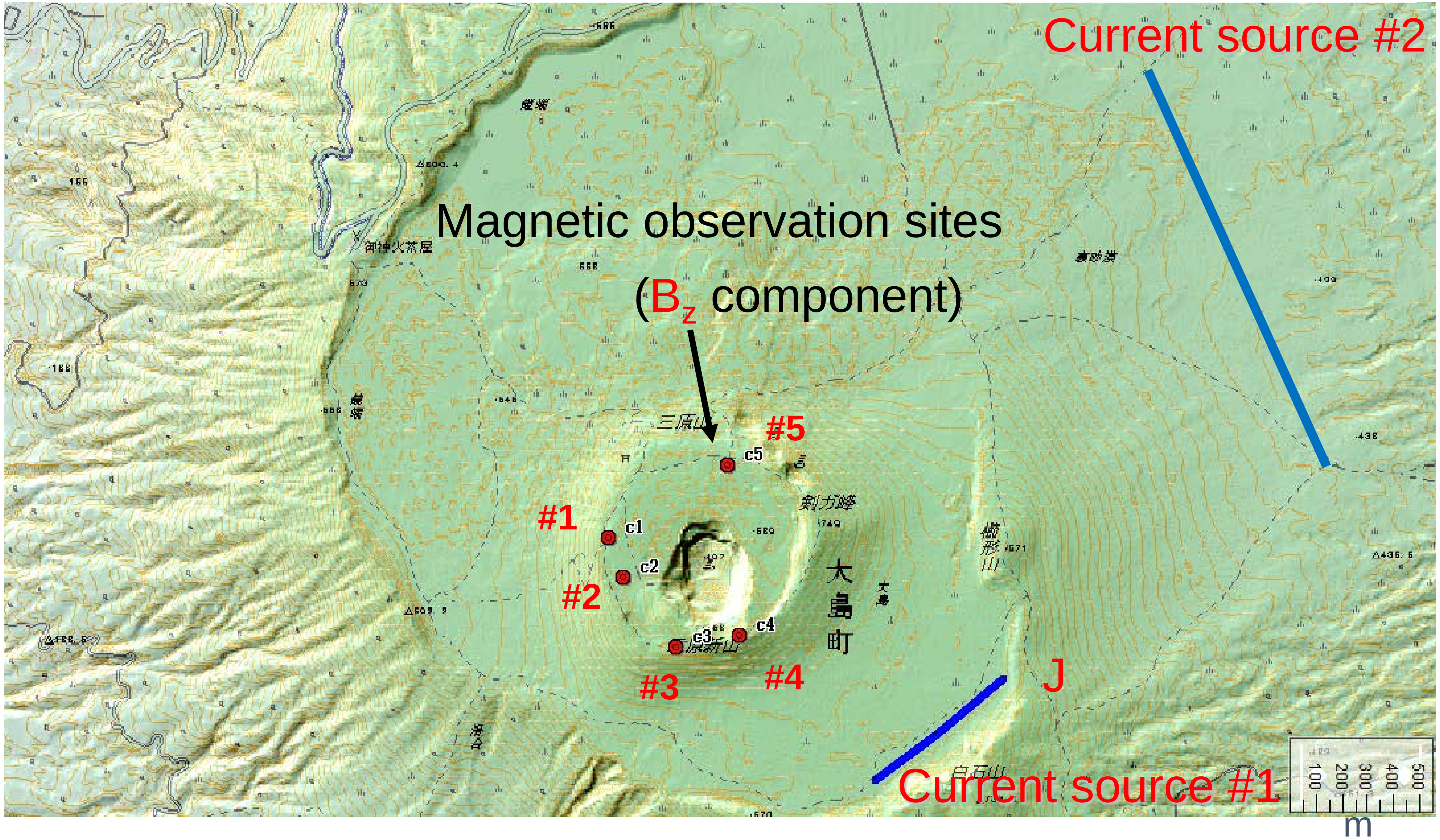
DC resistivity measurement 1975～

ACTIVE resistivity measurement (CSEM) 2003～

“ACTIVE” – CSEM system

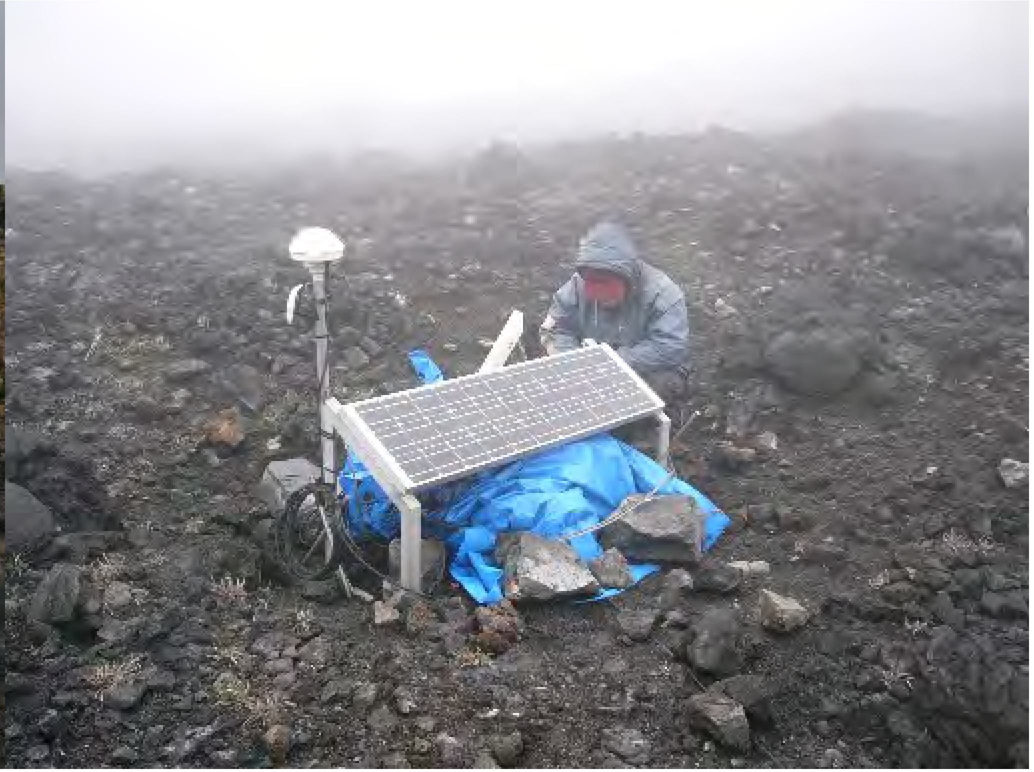
Array of Controlled Transient electromagnetics for Imaging Volcano Edifice.

(Takahashi, 2006; Utada et al., 2007)



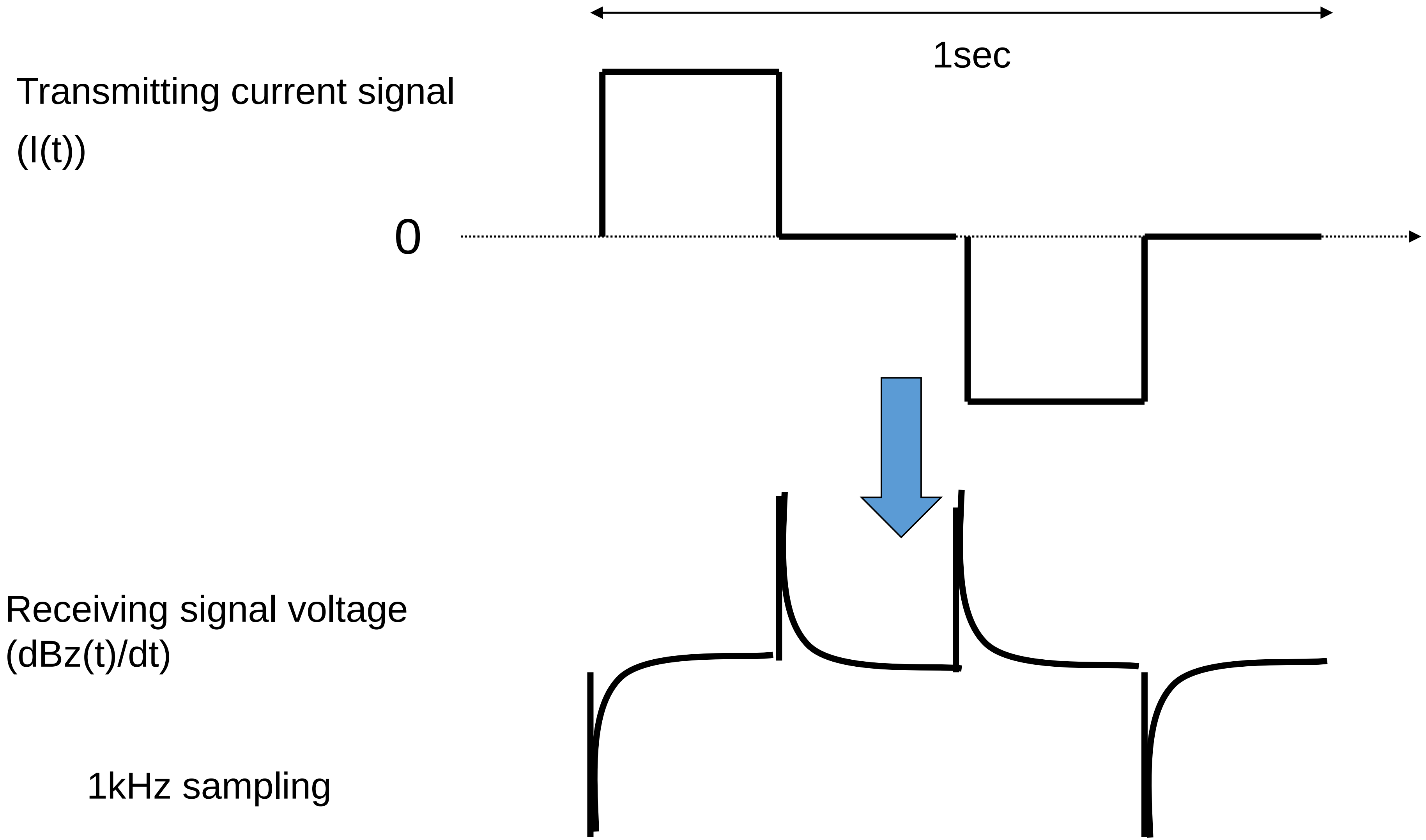
EM monitoring system of temporal change of conductivity structure by using the controlled electric current source

Transmitter of electric current source #1



Receiver system of magnetic signal

Schematic image of signal and received data



This measurement is done every mid-night.

→ Estimate : Response(f)=Bz(f)/I(f)

Daily Data Auto Processing

Oshima

ACTIVE transmitters
ACTIVE receivers

Timer mode (GPS clock synchronized)

Scheduled measurement

LAN on

WiFi, Telephone line

Rx protocol

ERI

Data server

Auto Processing

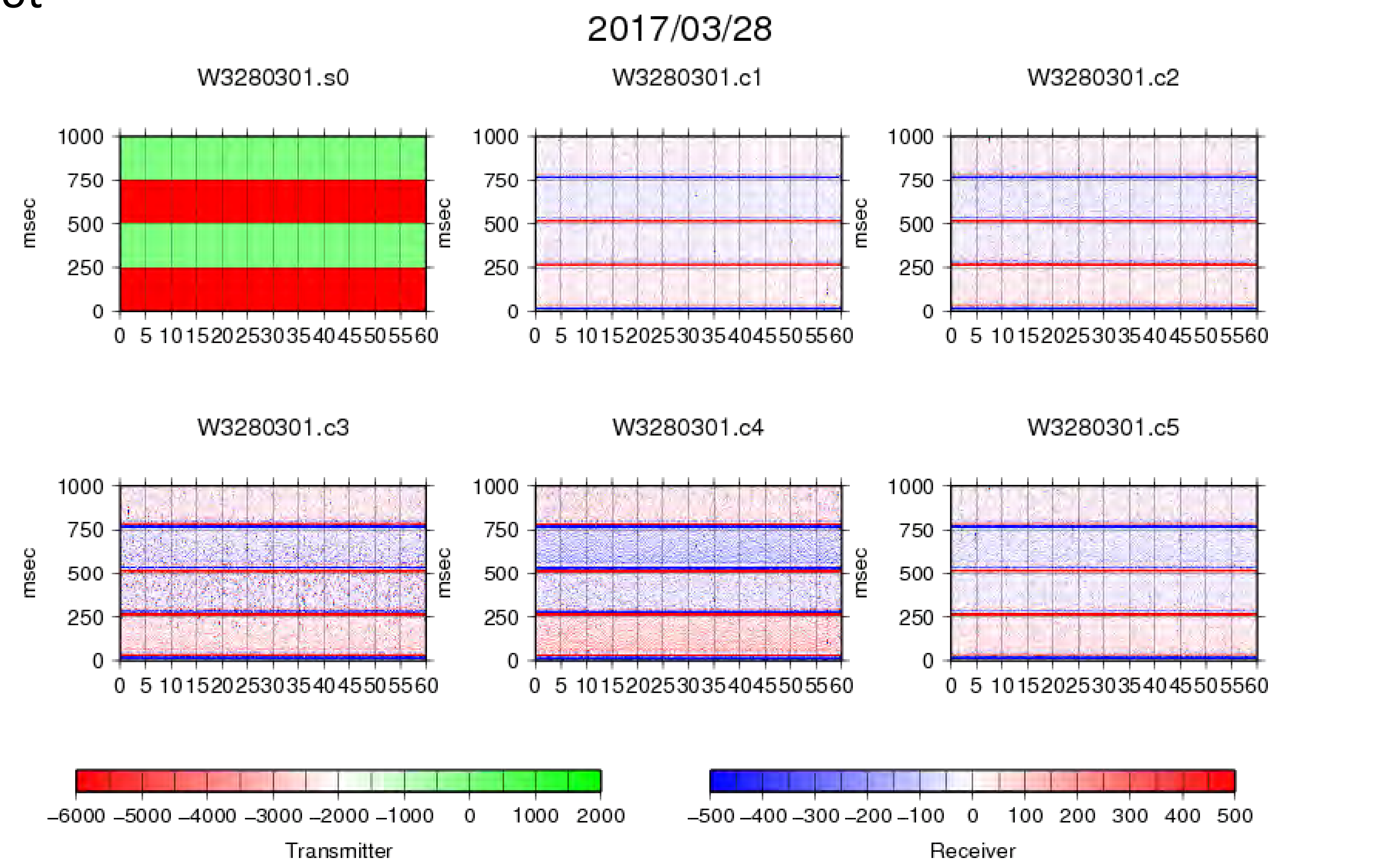
Time series analysis : Vtransmitter(t), Vreceiver(t) → Vtransmitter(f), Vreceiver(f)

Calibration: Vtransmitter(f), Vreceiver(f) → Itransmitter(f), Breceiver(f)

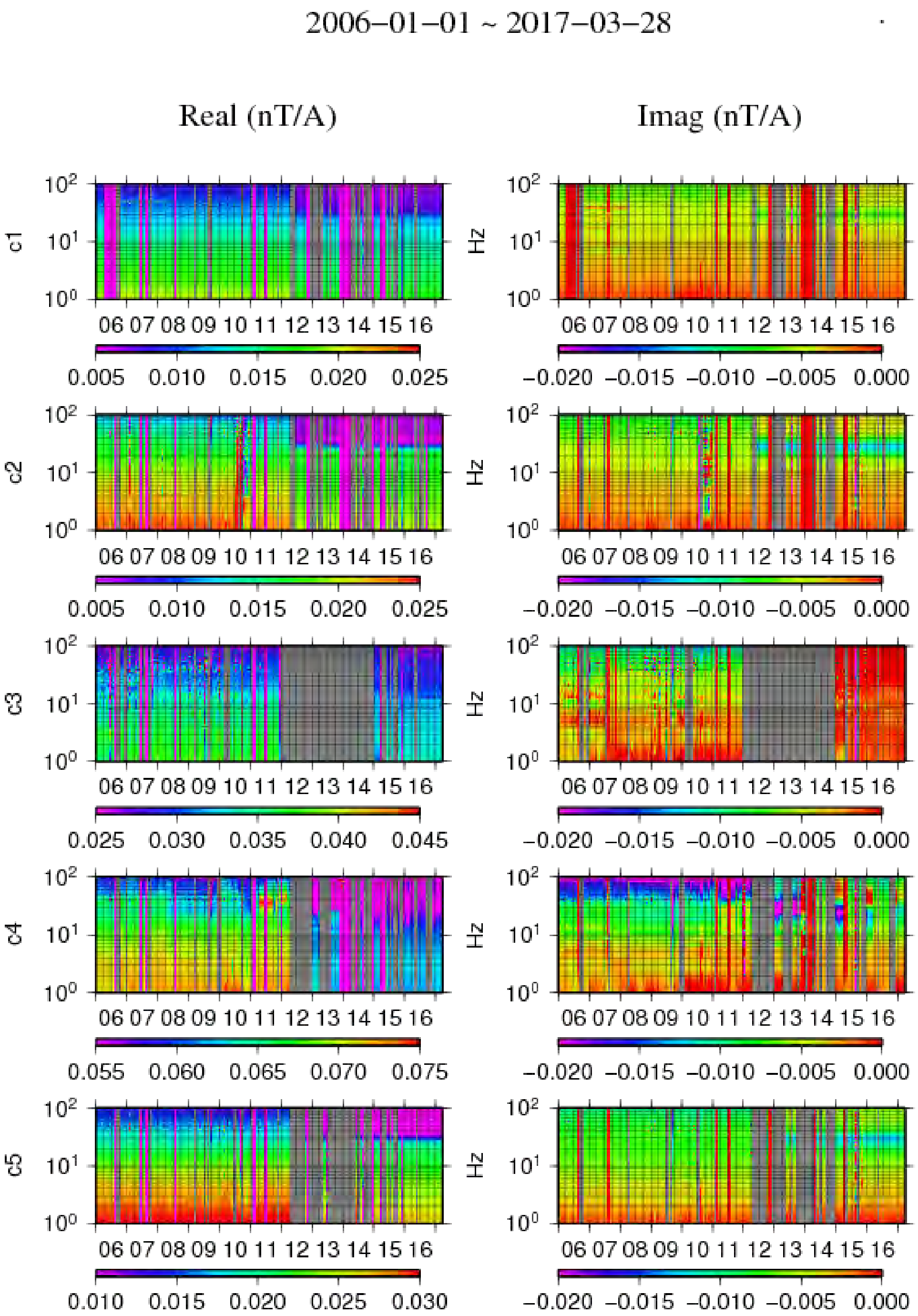
Daily Response estimation : Breceiver(f)/Itransmitter(f)

Plotting, WEB uploading, Alert mailing for some error cases

RAW data plot

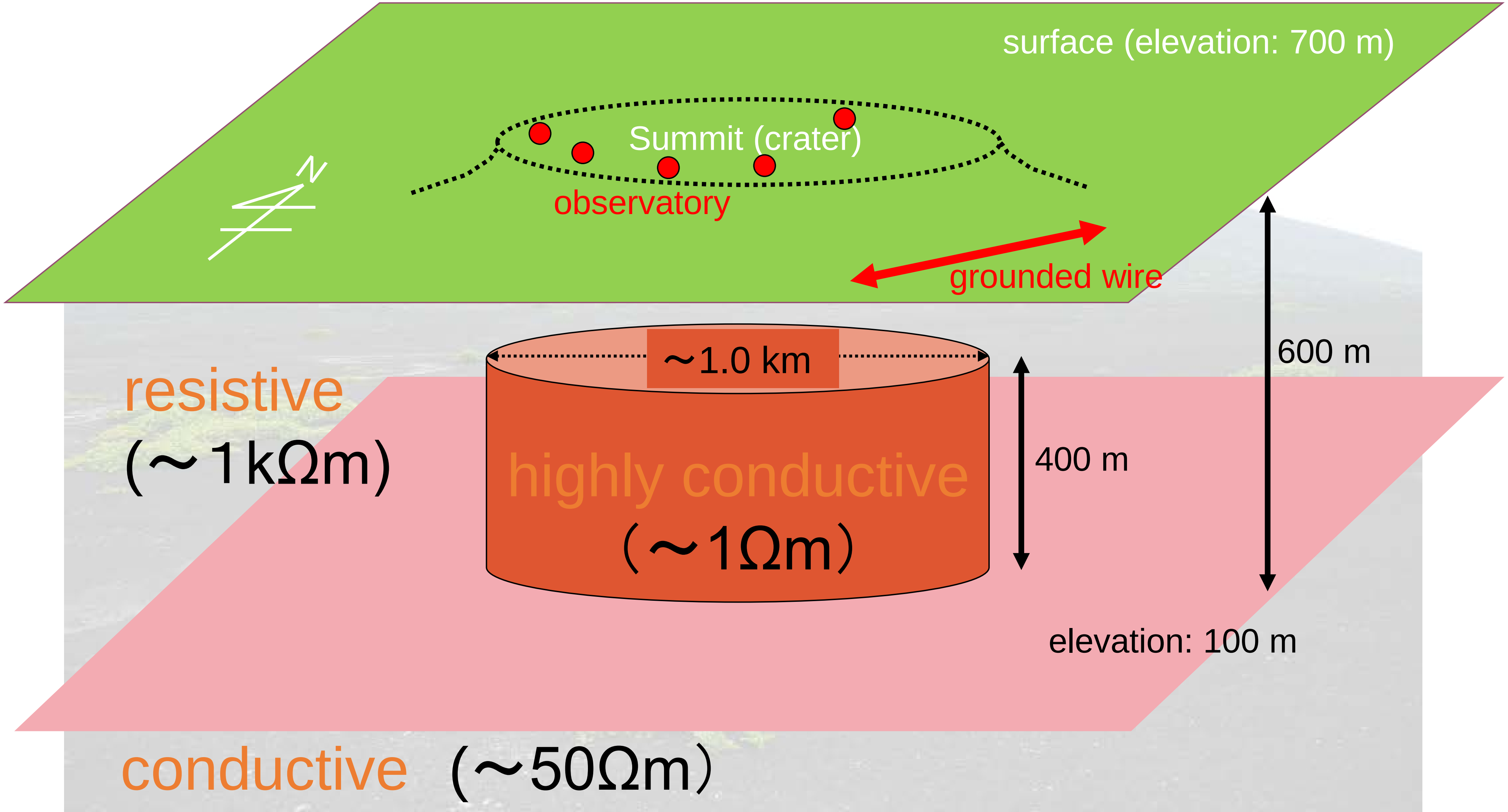


Response plot



Structure beneath Mt. Mihara (Utada 2003, Takahashi 2006)

→ Two layer with a highly conductive column



I try to determine 3 model parameters by grid search inversion.
(Other parameters are fixed.)

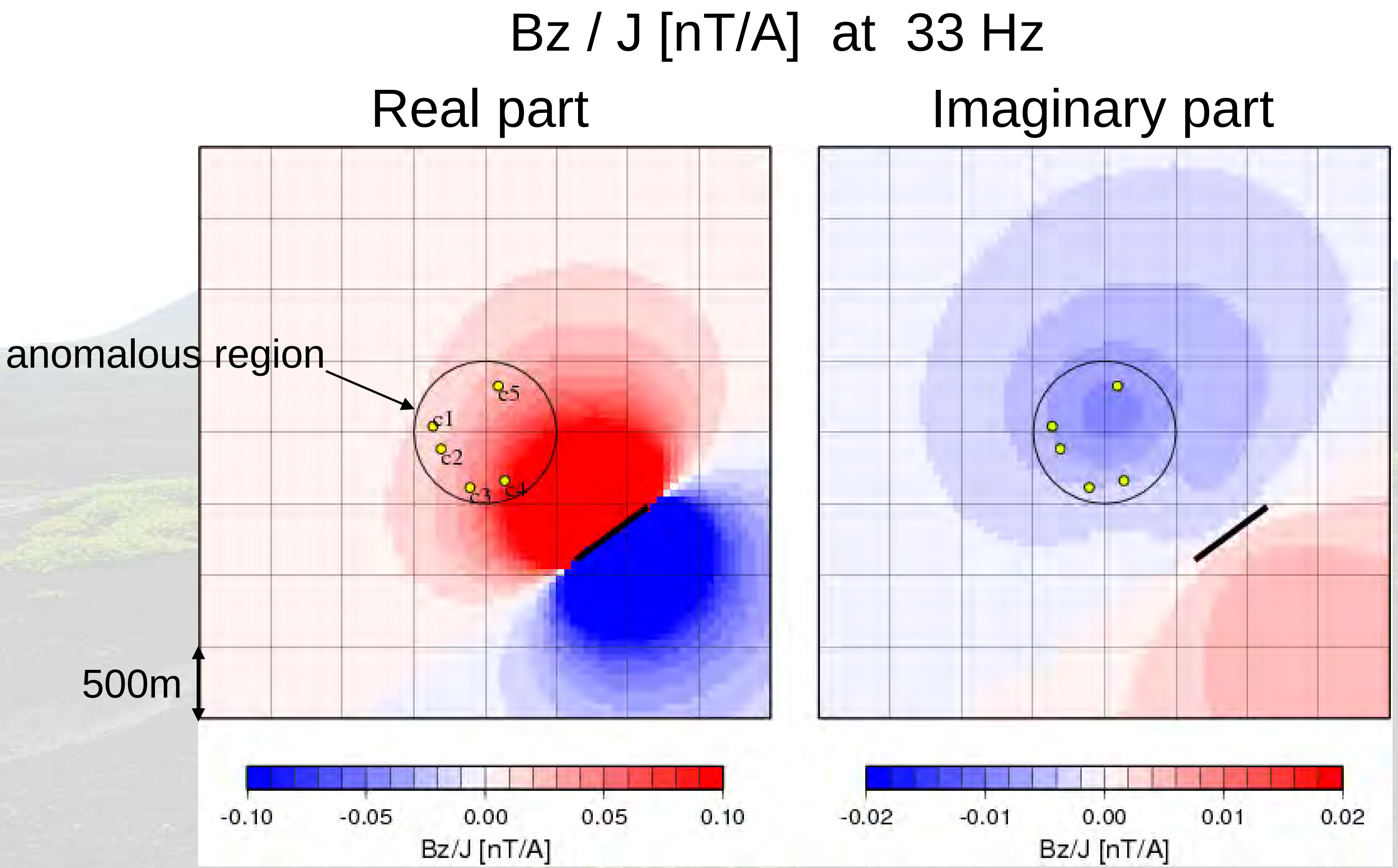
- Radius of column (0, 100, 200, 300, 400, 500 m)
- Resistivity of column (1, 2, 5, 10, 20, 50, 100 Ωm)
- Resistivity of top layer (0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10.0 kΩm)

↓ 9 Frequencies : 1, 3, 5, 7, 9, 17, 33, 65, and 99 Hz

Best solution

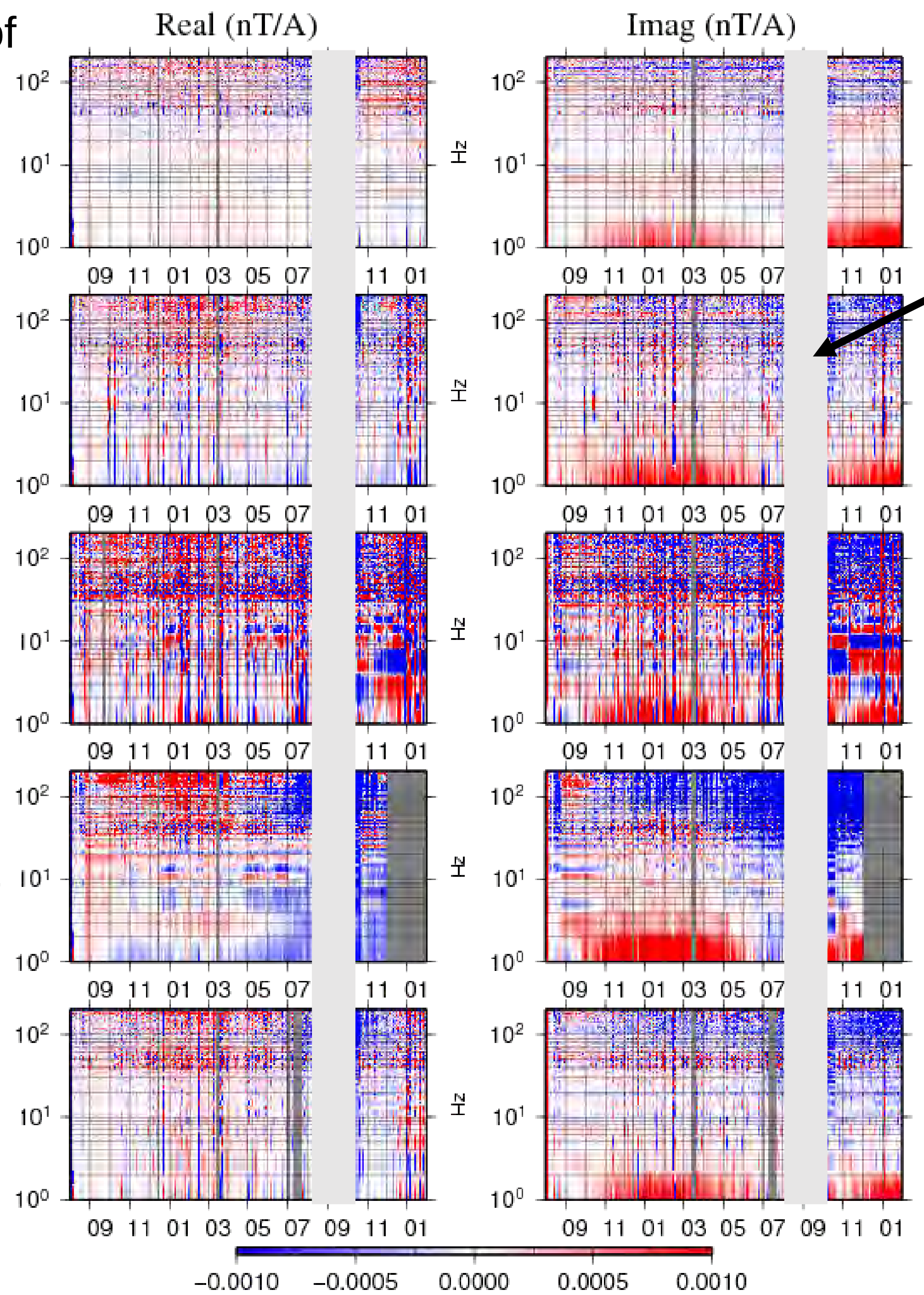
- Radius of column : 200 m
- Resistivity of column : 1 Ωm
- Resistivity of top layer : 0.2 kΩm

Numerical example : Forward modeling



Grid size : 50 m x 50 m x 25 m

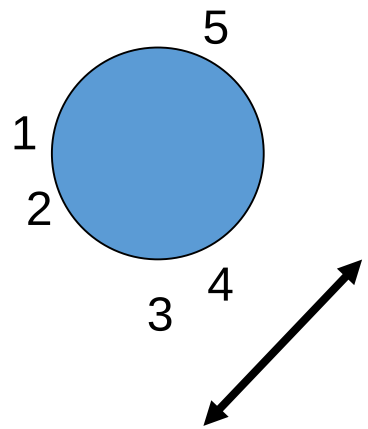
Running spectrum of ACTIVE response



Gray: lack of data

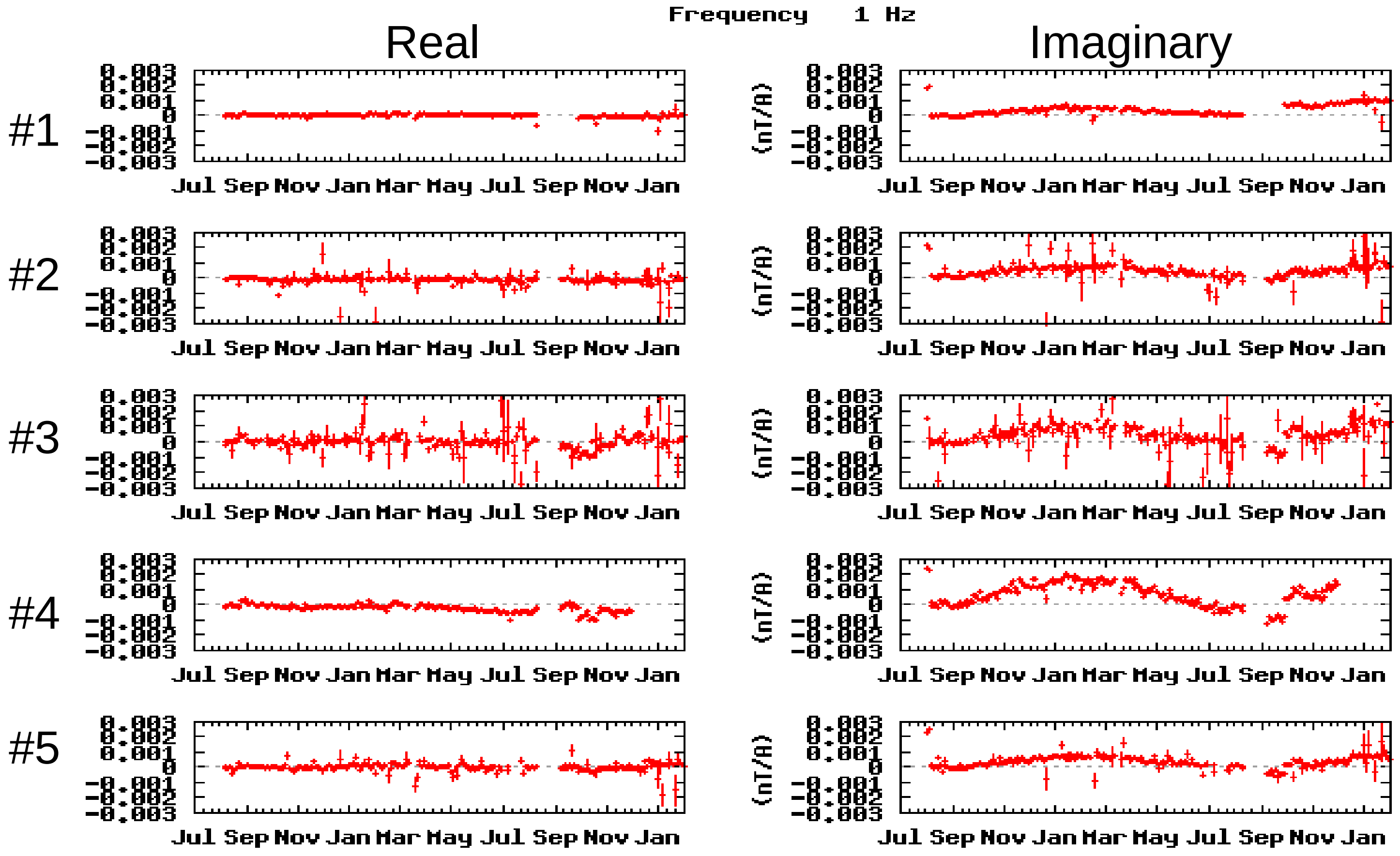
Horizontal axis: Time series (almost 1.5yr)

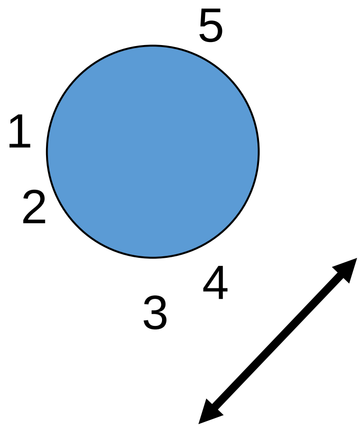
Vertical axis: Frequency (1-100Hz)



Running spectrum of ACTIVE response at the frequency of 1 Hz

→ Annual variation is visible

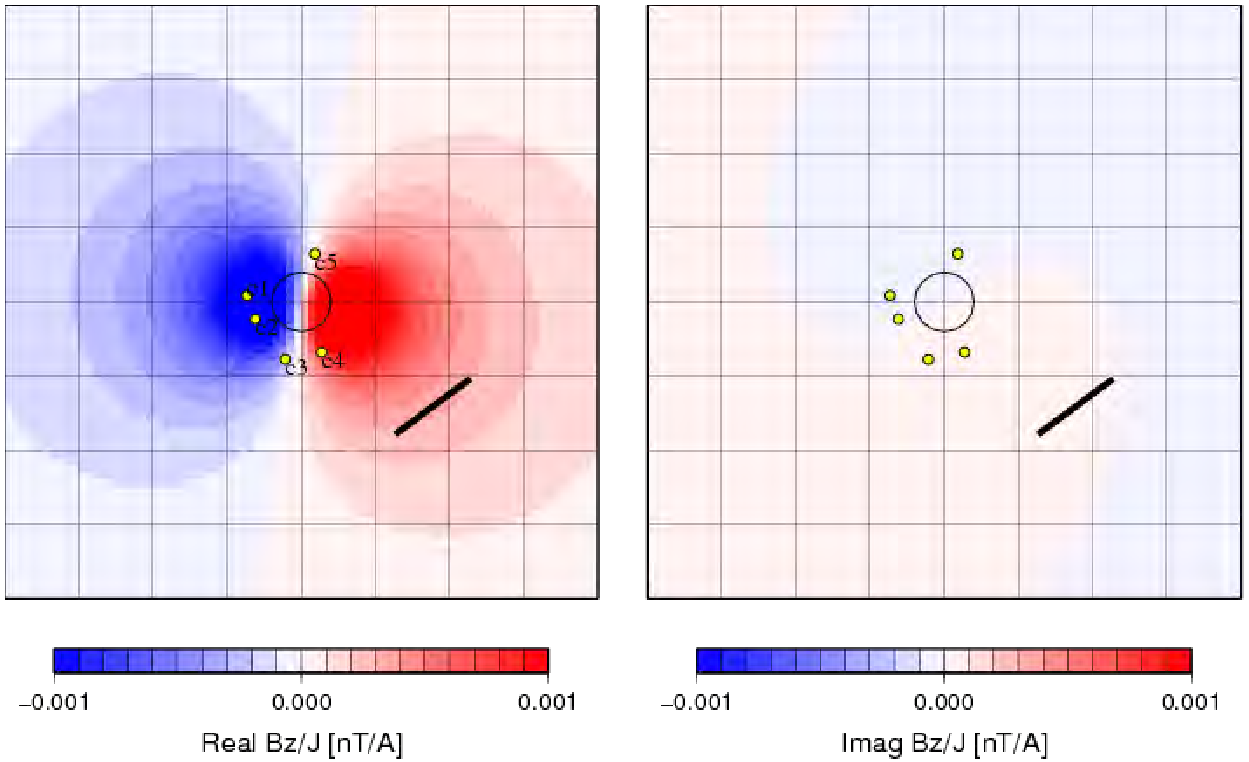




→ Real part has much less variation then imaginary part.
Changes of imaginary part has the same phase at all the sites

Numerical test 1

In the case that some conductor rises up beneath the “A” crater

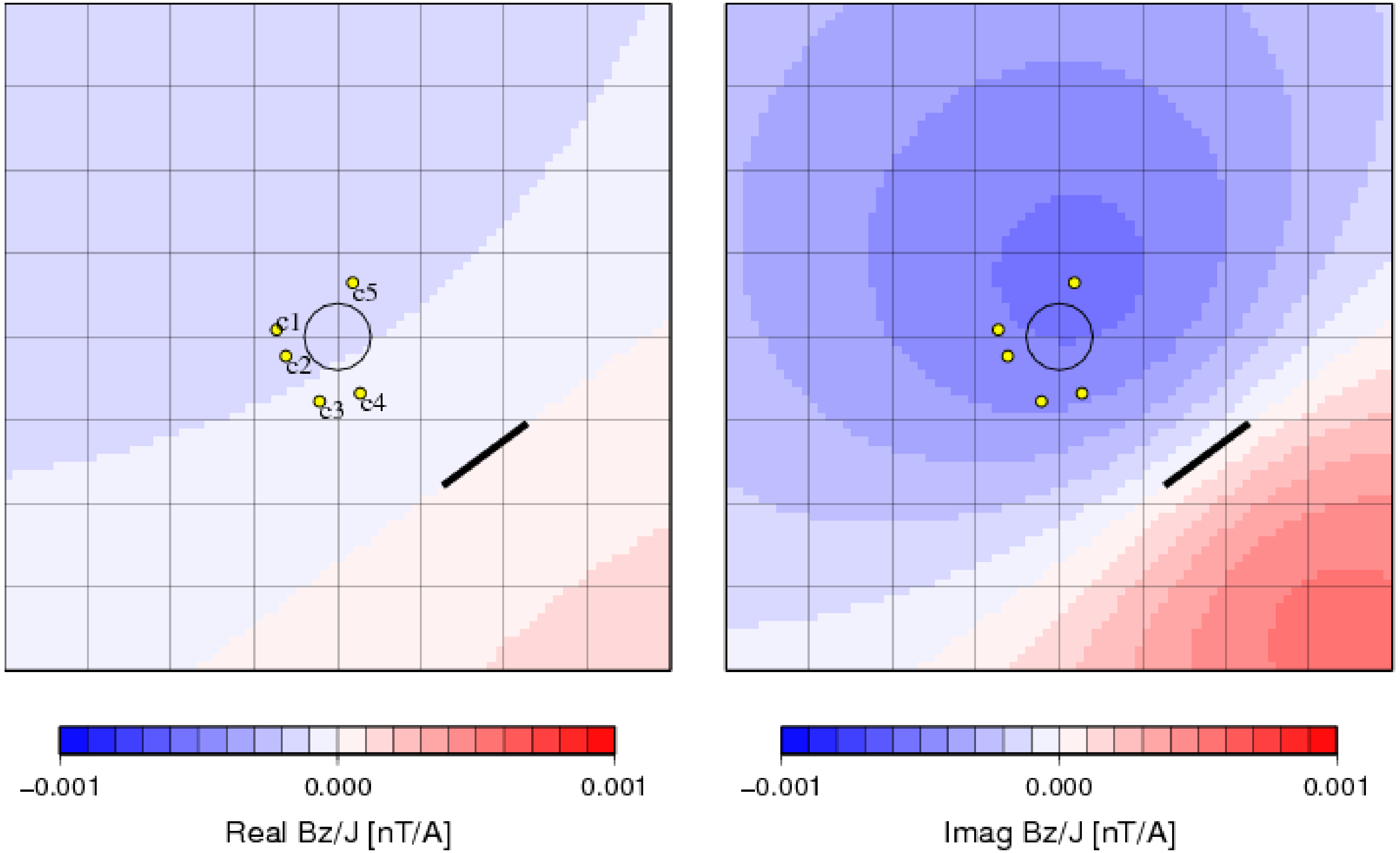


Real part is much bigger than imaginary part.
Phase are not the same at all the sites.

→ Observed annual change seems not to be caused by volcanic activity

Numerical test 2

In the case that the upper bound of lower layers rises up



Imaginary part is much bigger than real part

Phases are almost the same at all the sites

→ It may be caused by the change of depth of the surface of aquifer layer

Summary

- We're conducting continuous measurement by CSEM method

- A fast 3-D numerical forward calculation code was developed

- A simple model was estimated. A conductor beneath the "A" crater is supposed to be a thermal water or a alternated clay.

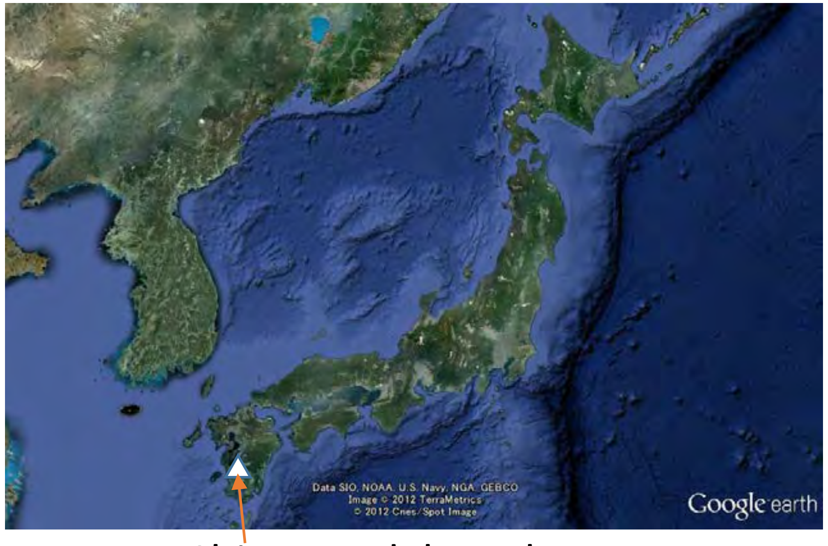
- A small annual variation could be detected. This may not be caused by volcanic activity, but be caused by uprising of upper bound of the aquifer layer.

Repeated aeromagnetic survey by using unmanned helicopter

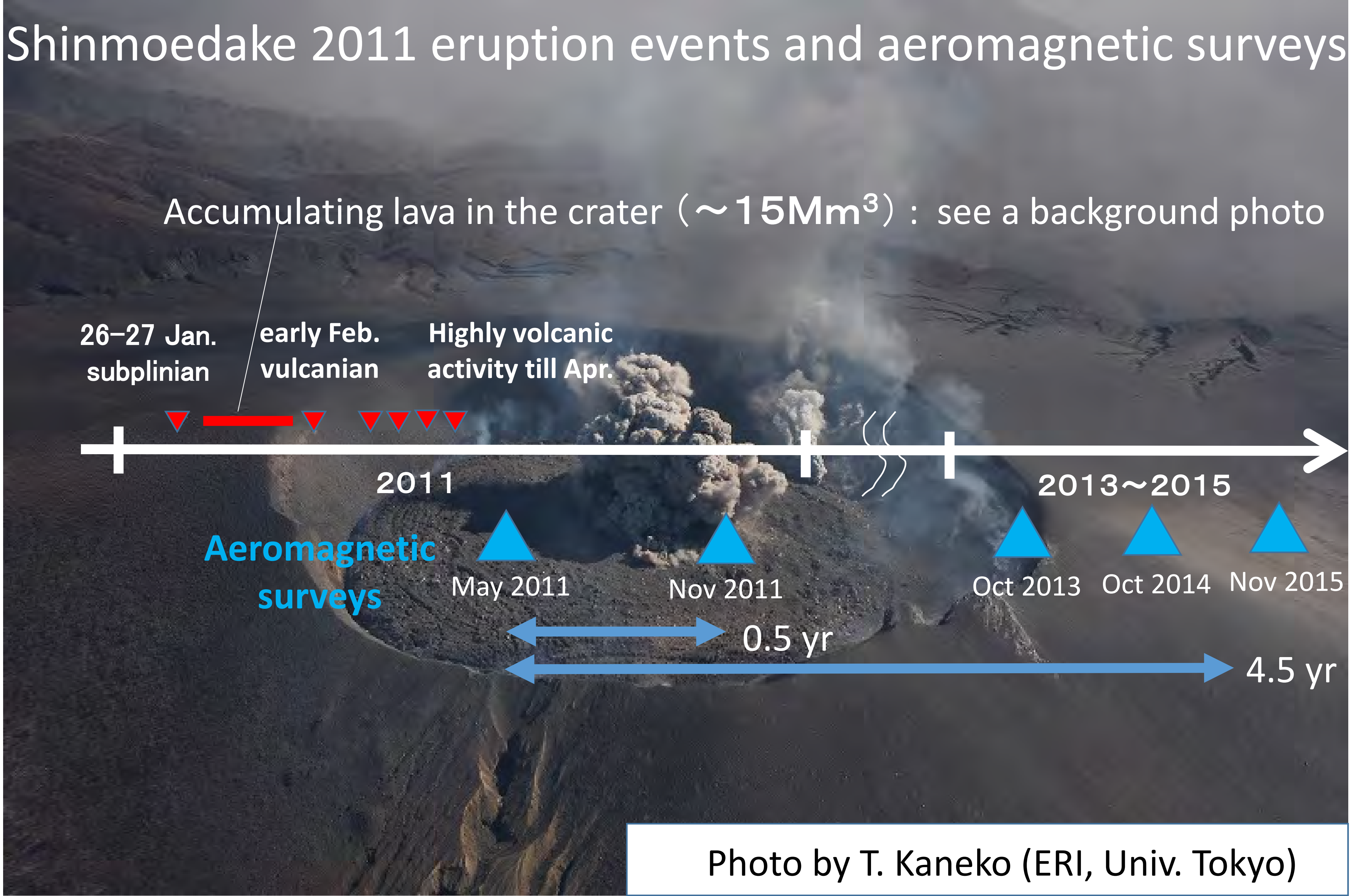
Outline

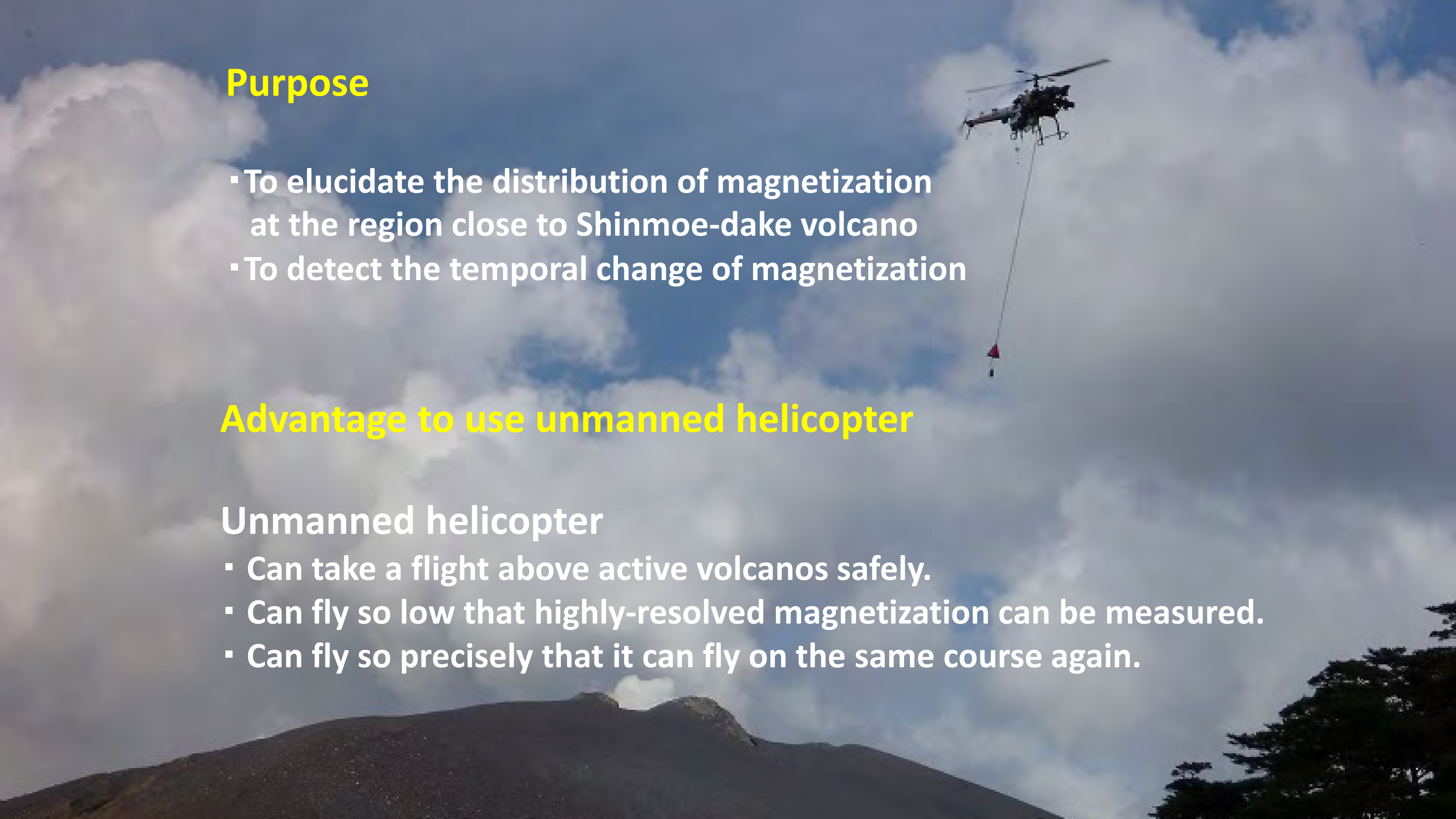
- Introduction of Shinmoe-dake volcano and its activity
- Aeromagnetic surveys by unmanned helicopter
- Detection of temporal change of geomagnetic field intensity
- Summary

Shinmoe-dake volcano Latest event : 2011 eruption



Shinmoe-dake volcano


Shinmoedake 2011 eruption events and aeromagnetic surveys
Accumulating lava in the crater（～15Mm³）: see a background photo
26–27 Jan.
subplinian
early Feb.
vulcanian
Highly volcanic
activity till Apr.
2011
2013～2015
Aeromagnetic
surveys
May 2011
Nov 2011
Oct 2013
Oct 2014
Nov 2015
0.5 yr
4.5 yr
Photo by T. Kaneko (ERI, Univ. Tokyo)



Purpose

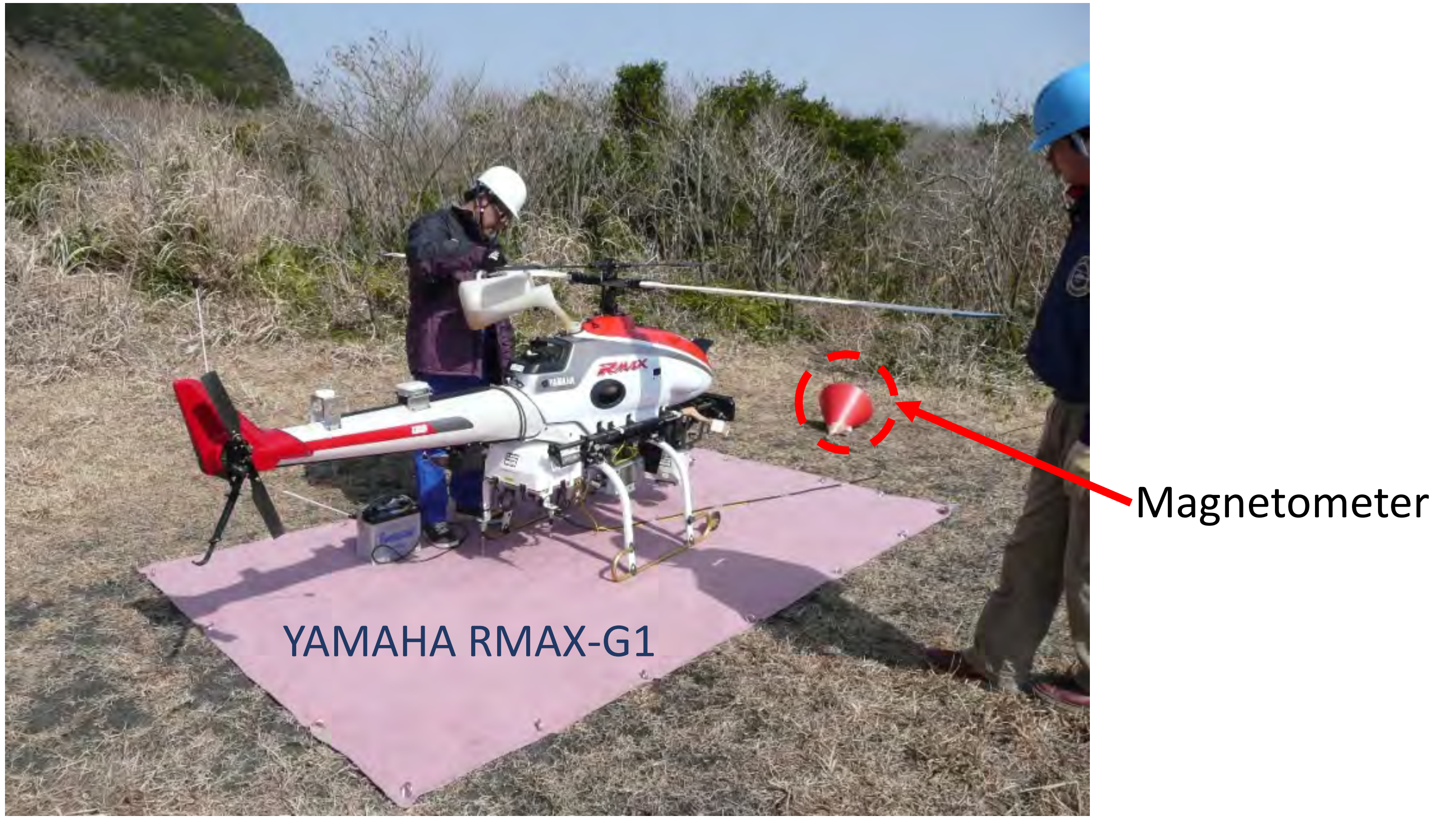
- To elucidate the distribution of magnetization at the region close to Shinmoe-dake volcano
- To detect the temporal change of magnetization

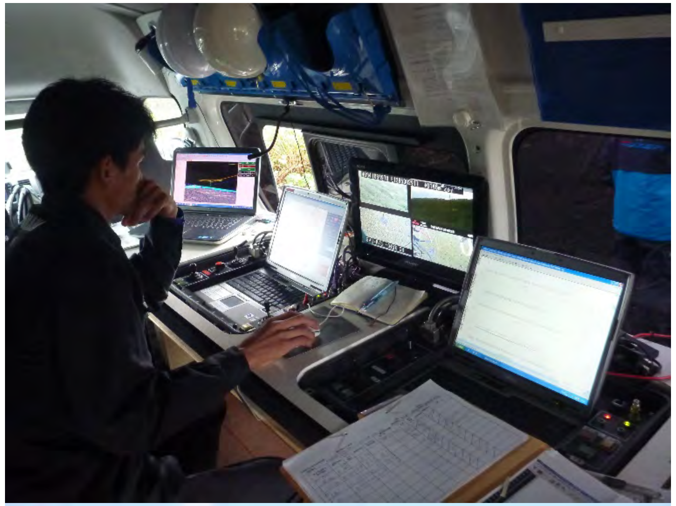
Advantage to use unmanned helicopter

Unmanned helicopter

- Can take a flight above active volcanos safely.
- Can fly so low that highly-resolved magnetization can be measured.
- Can fly so precisely that it can fly on the same course again.

Aeromagnetic surveys by unmanned helicopter





Base station

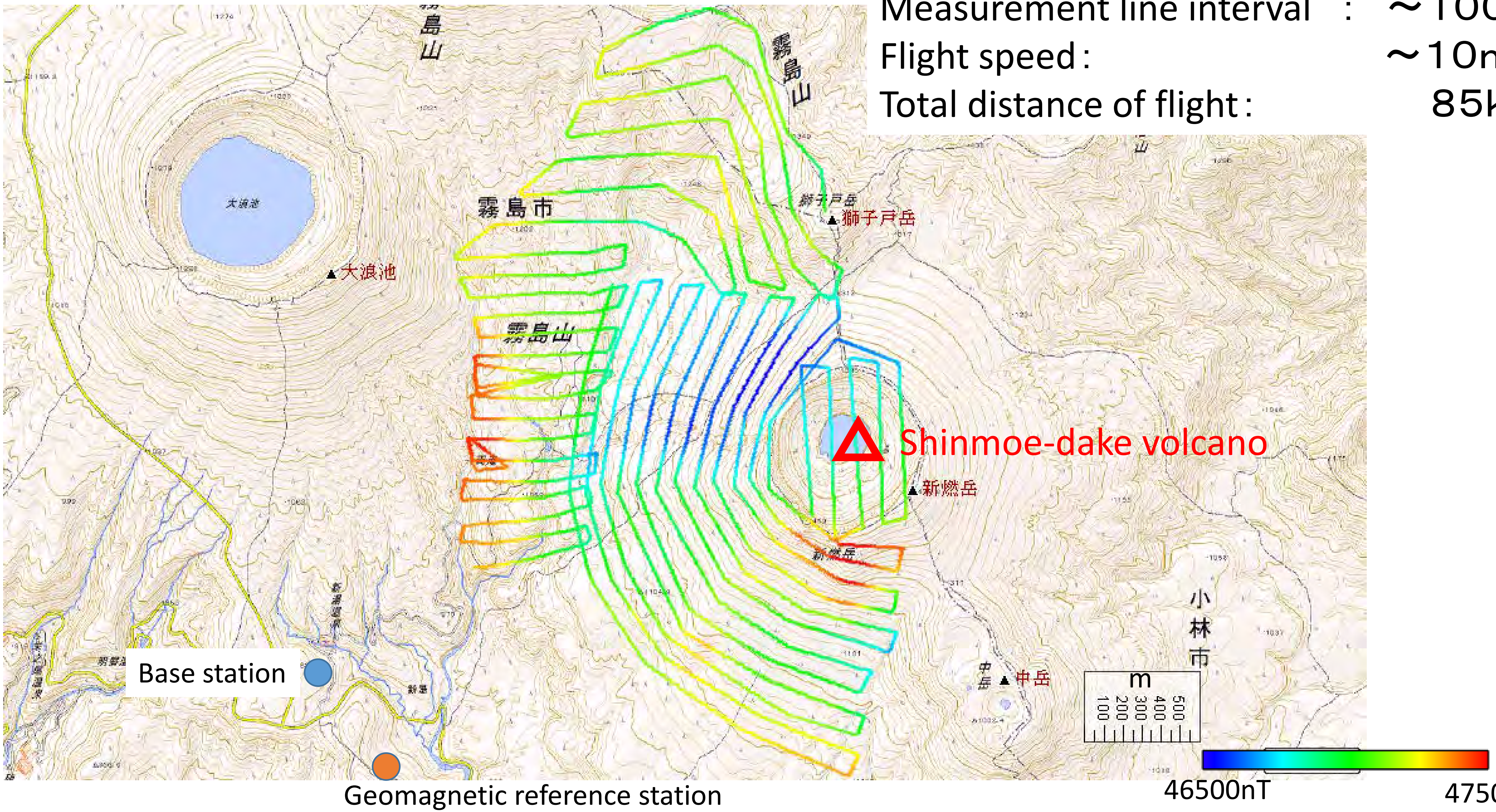
Unmanned helicopter - commonly used for spraying agricultural chemicals

Magnetometer – Cesium optical pumping total intensity magnetometer

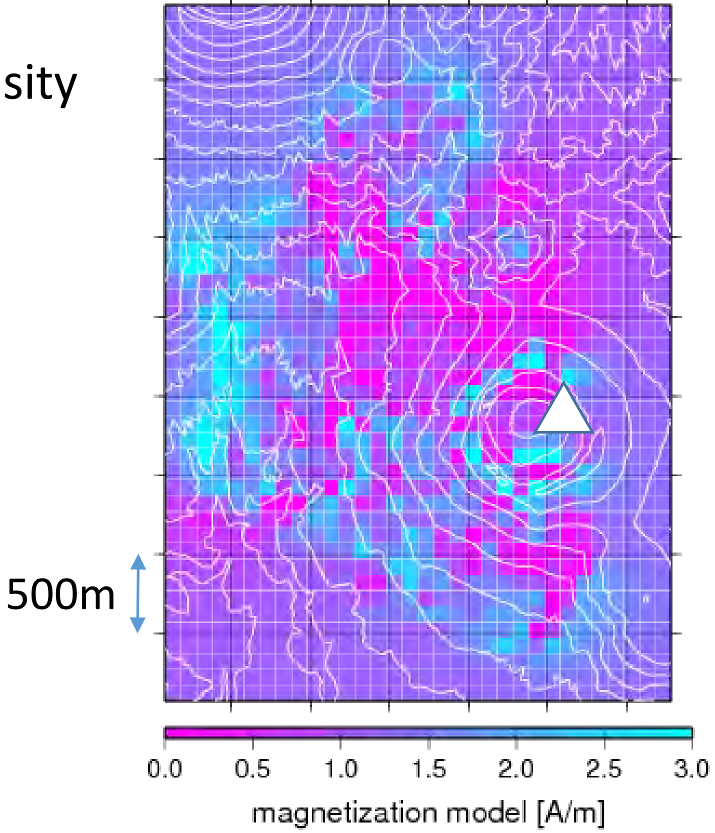
The helicopter is rent from YAMAHA and is operated by YAMAHA staffs

Survey map (4th survey 22nd Oct 2014)

Flight altitude above ground : ～100m
Measurement line interval : ～100m
Flight speed : ～10m/s
Total distance of flight : 85km



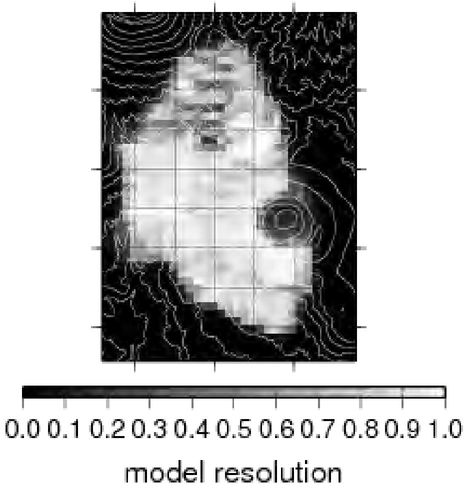
2-D estimated magnetization intensity

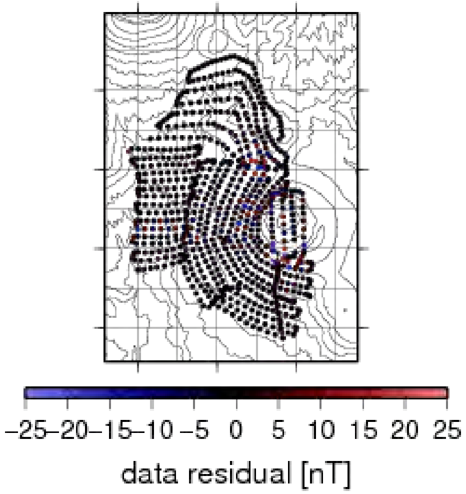


Mean value of magnetization

～ 1.2 A/m

※rock magnetization
1.1 ～ 8.9A/m
(Utada et al., 2000)

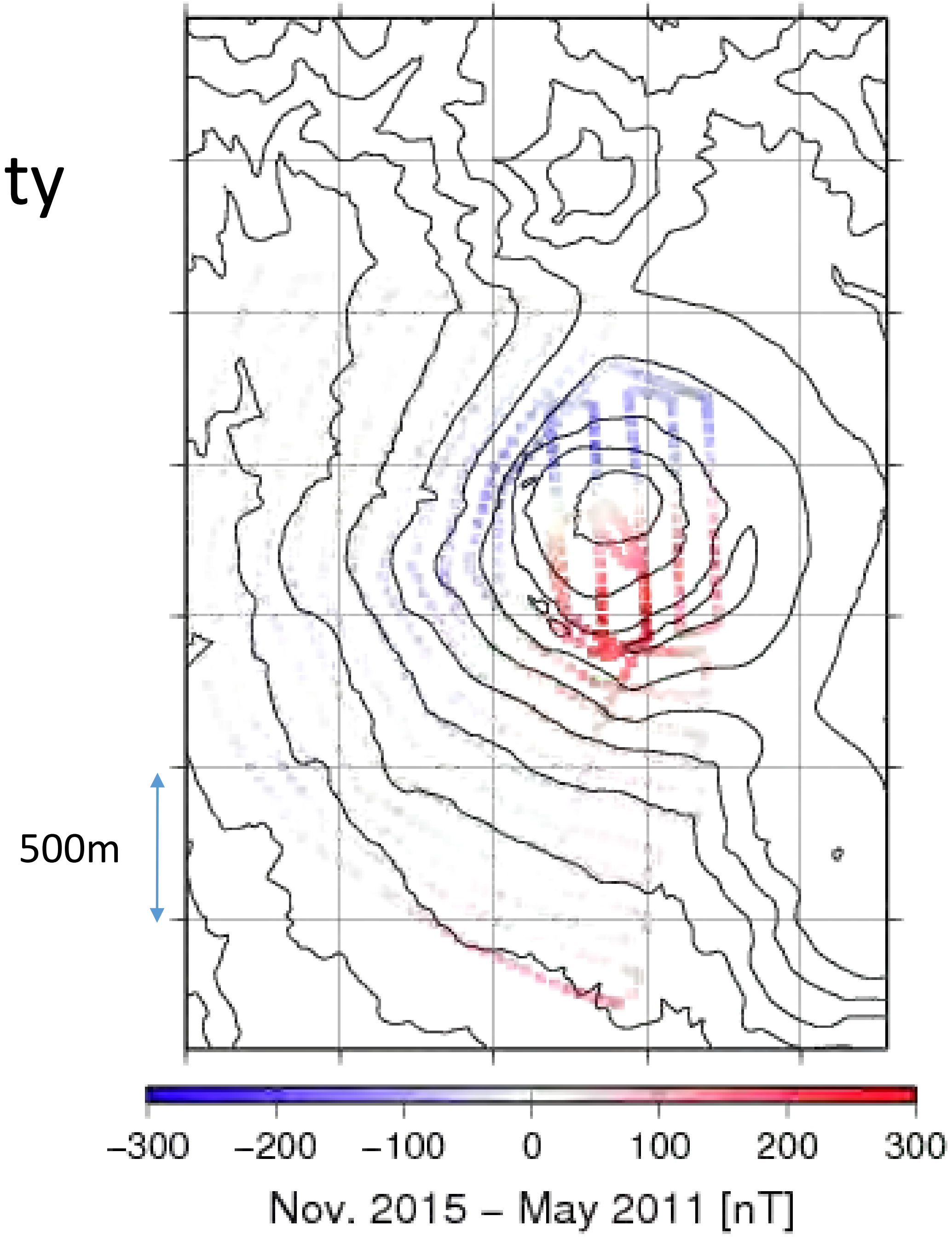




Temporal change of Geomagnetic total intensity

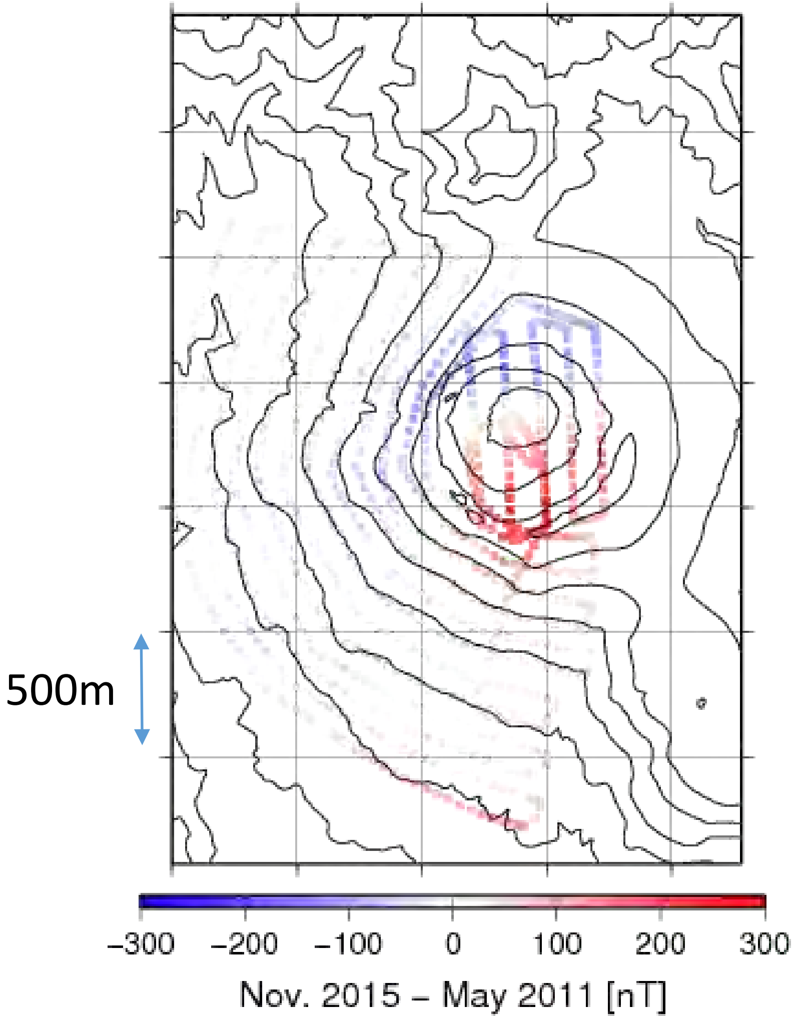
5th survey – 1st survey

Nov 2015 - May 2011
（4.5 years）

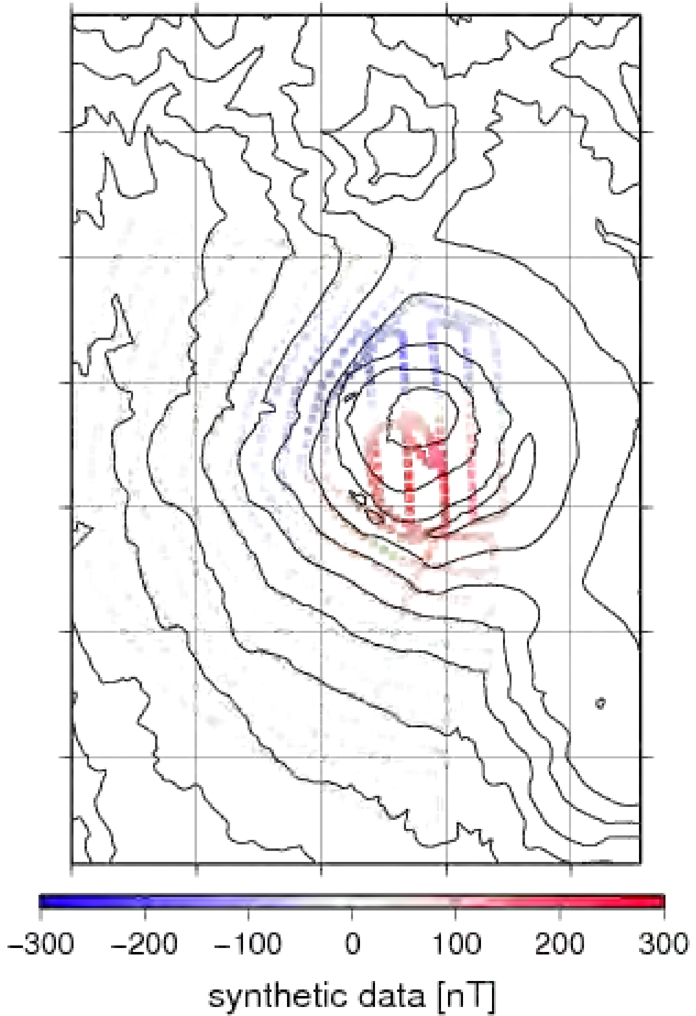


Estimate of dipole moment beneath crater

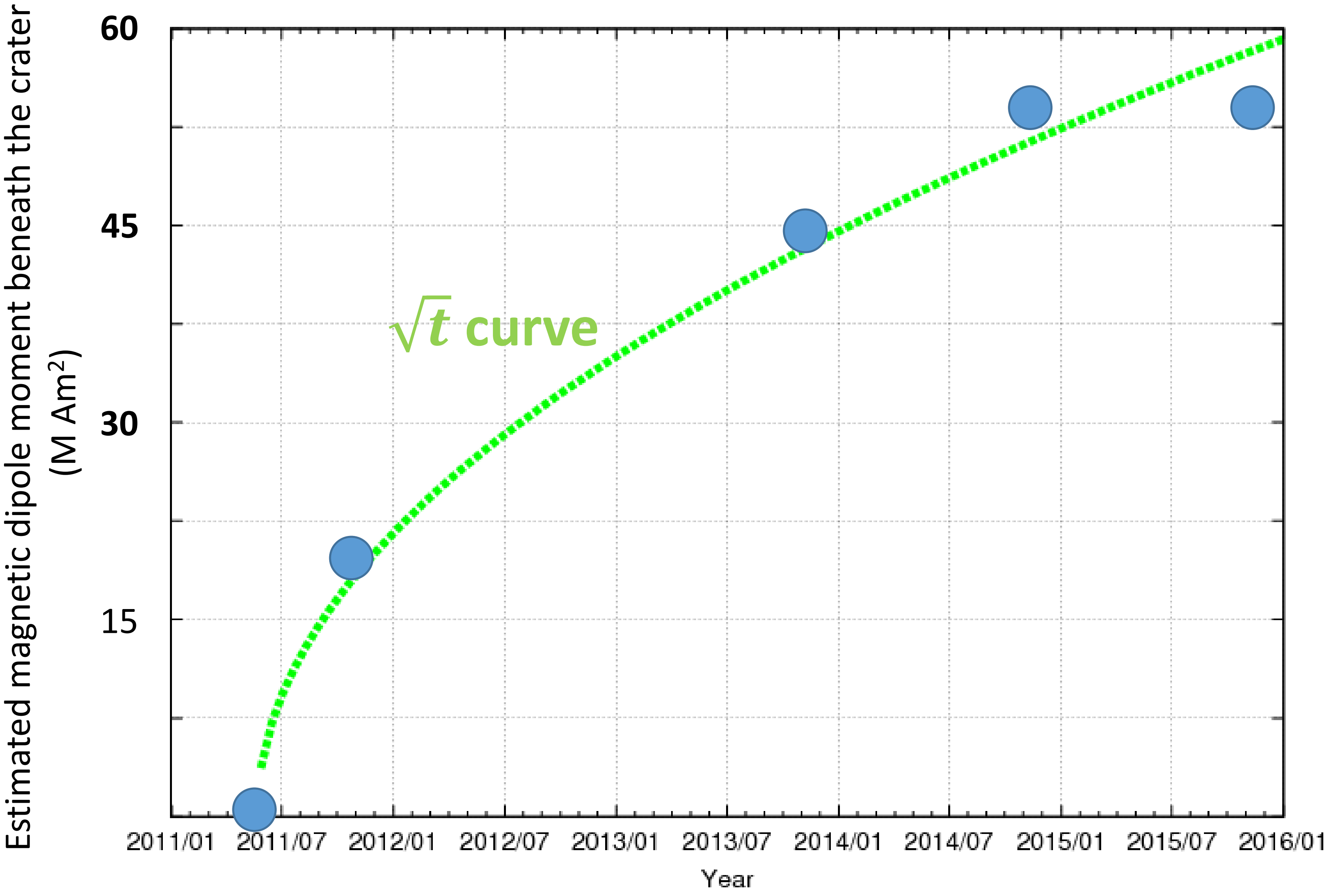
Temporal change of experimental data
Nov. 2015 – May 2011



Synthetic total intensity change
supposing 54 M Am^2 beneath the crater

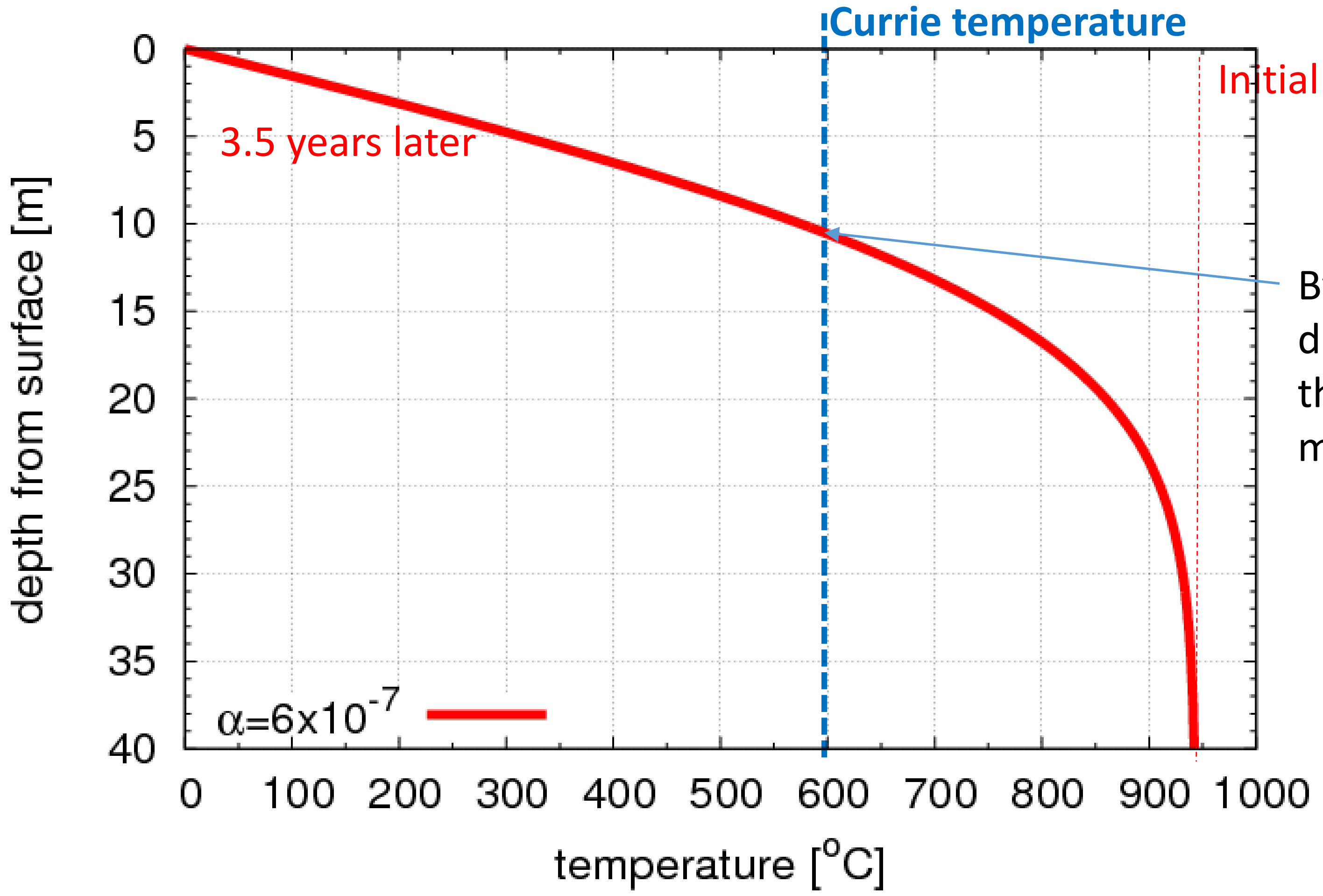


Temporal change of estimated dipole moment beneath the crater



It indicates the lava is cooling by thermal diffusion from the surface.

Depth-temperature distribution in 1-D thermal diffusion

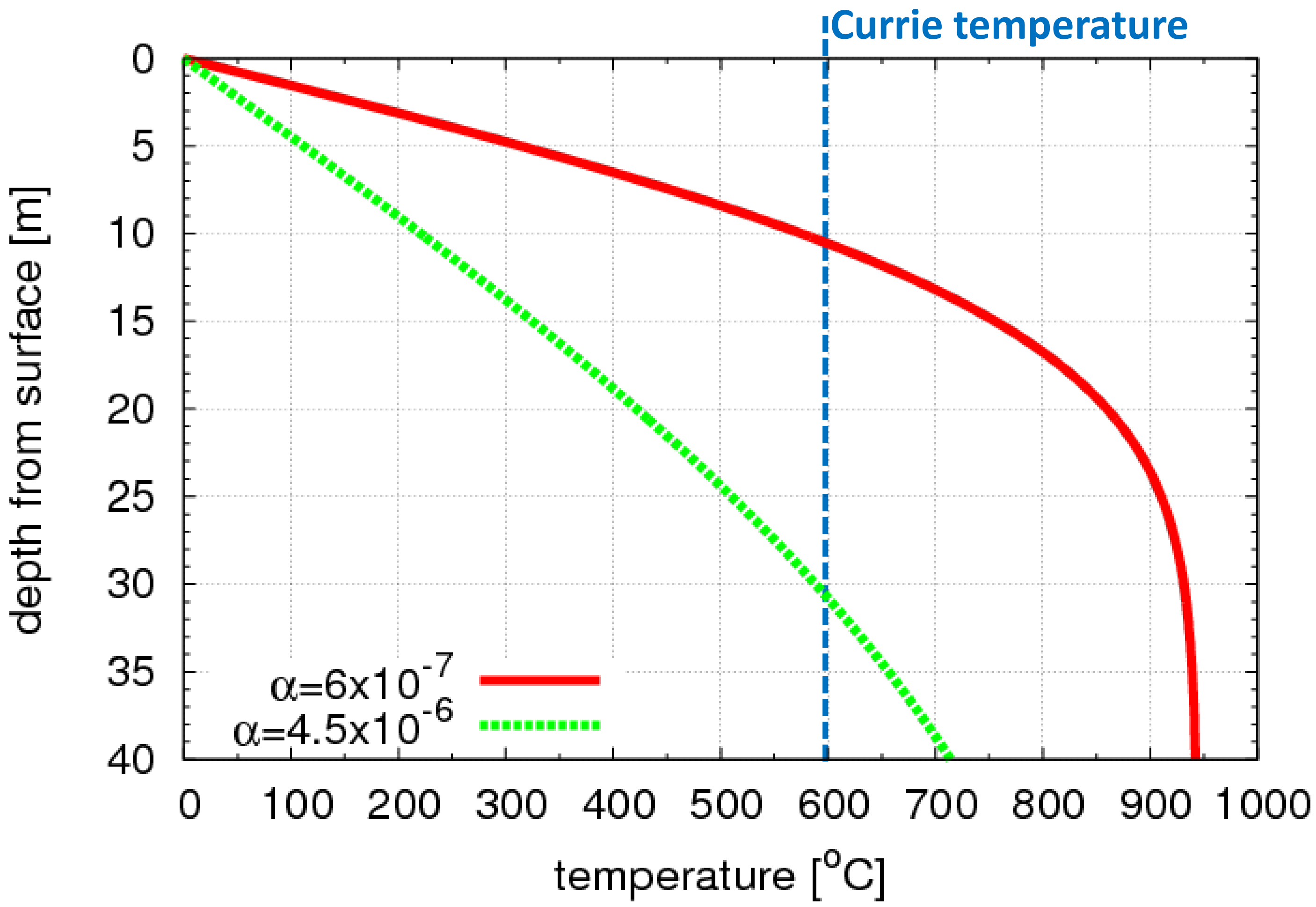


By using standard thermal diffusivity, only 10 m from the surface can obtain magnetization after 3.5 years.

→ To explain the dipole moment, the magnetization of lava is about 32 A/m TOO LARGE!

Supposing magnetization of lava by 10 A/m (Utada et al. 2000)

→ To explain dipole moment , 30 m from the surface must be magnetized.



→ "effective" thermal diffusivity 4.5×10^{-6} m^2/s

“Effective” thermal diffusivity :

Water penetrating in crater may be important role to raise the diffusivity

Heat Balance

Heat diffused by “effective” thermal diffusivity

2.15×10^{16} J @ 2014 Oct.

5.67×10^{15} J @ 2011 Nov.

Radius of lava cake : 250m
Density of lava : 2500 kg/m^3
Initial lava temperature : 950℃
Latent heat of lava : 2.1×10^5 J/kg
Specific heat capacity of lava : 10^3 J/kg/K

Heat to vapor water of lake and rainfalls in crater

1.61×10^{16} J @ 2014 Oct.

4.68×10^{15} J @ 2011 Nov.

Radius of crater (rainfall area) : 375m
Density of water : 1000 kg/m^3
Initial and vaporizing temperature : 0 and 100℃
Latent heat of water : 2.3×10^6 J/kg
Specific heat capacity of water : 4.2×10^3 J/kg/K
rain amount data is taken from Ebino observatory of JMA

Summary

5 repeated survey have been carried out by using unmanned helicopter

Notable temporal change by 400 nT maximum were clearly detected above the crater.

This change may be supposed to be due to cooling the lava
accumulating in the crater at 2011 eruption events.

Magnetic intensity is increasing by square root of elapsed time.

It indicates that cooling lava is done by thermal diffusion from the surface.

Diffusion rate is so fast and water vaporing may play an important role to raise it.