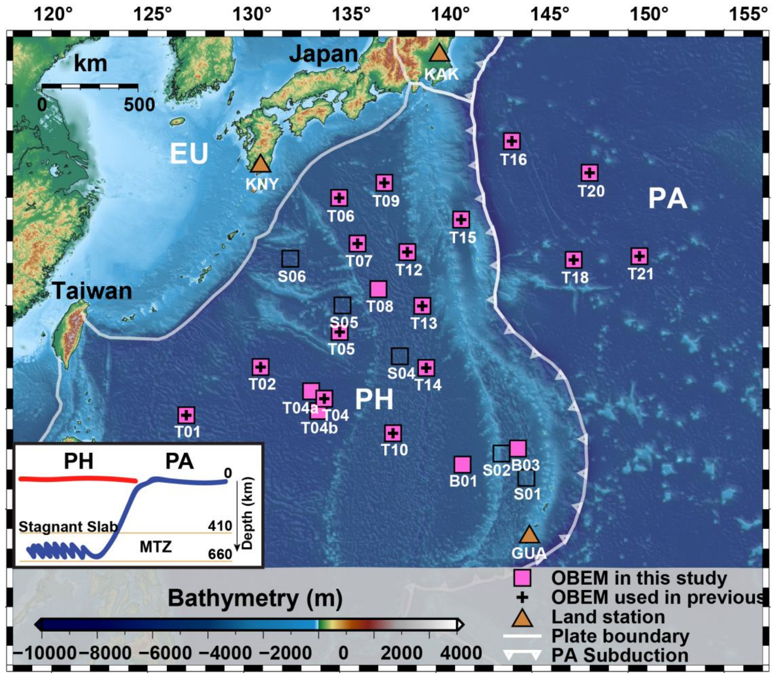
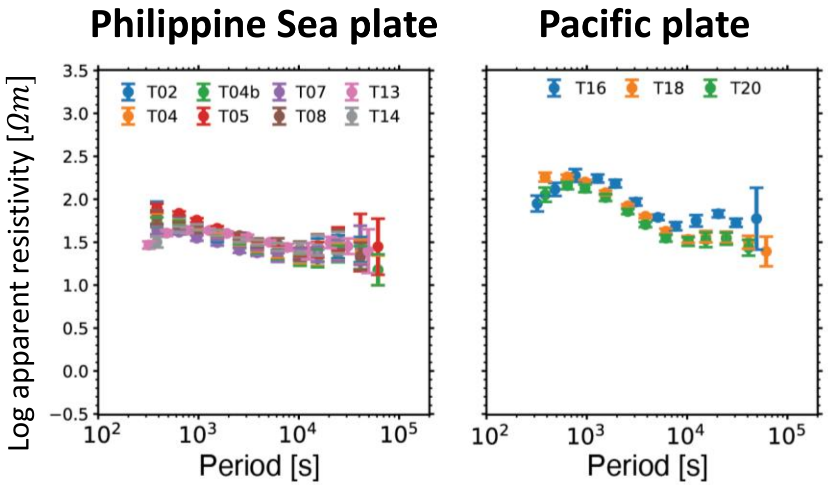
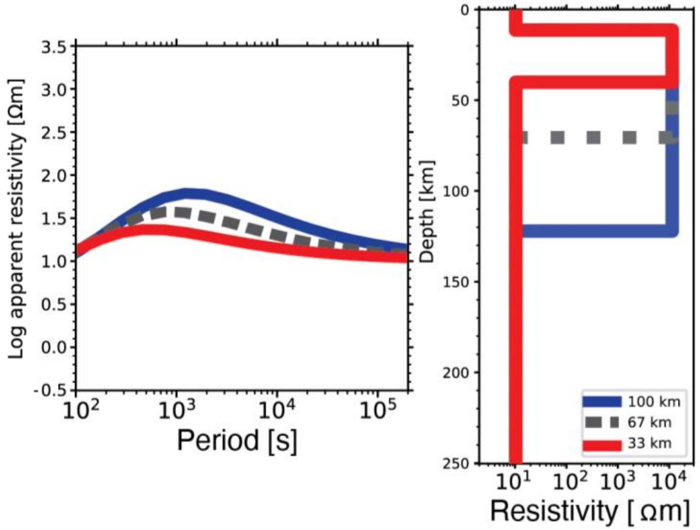



## Observed MT responses




## Forward Modeling




2021師大地科系暑期生

# 分析西太平洋海底電磁儀資料探討電磁場的特徵及其海床下電性構造
# The characteristics of seafloor electromagnetic observations and corresponding electrical conductivity imaging in the western Pacific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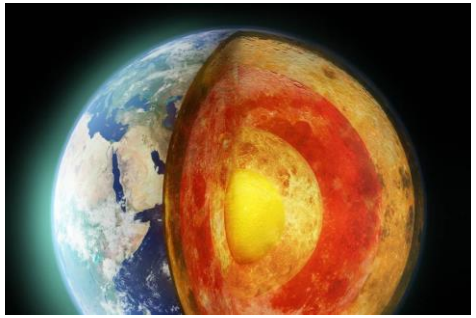
1 2 3

# Magnetotelluric Method (MT) 大地電磁法

## Passive (natural) sources

magnetosphere

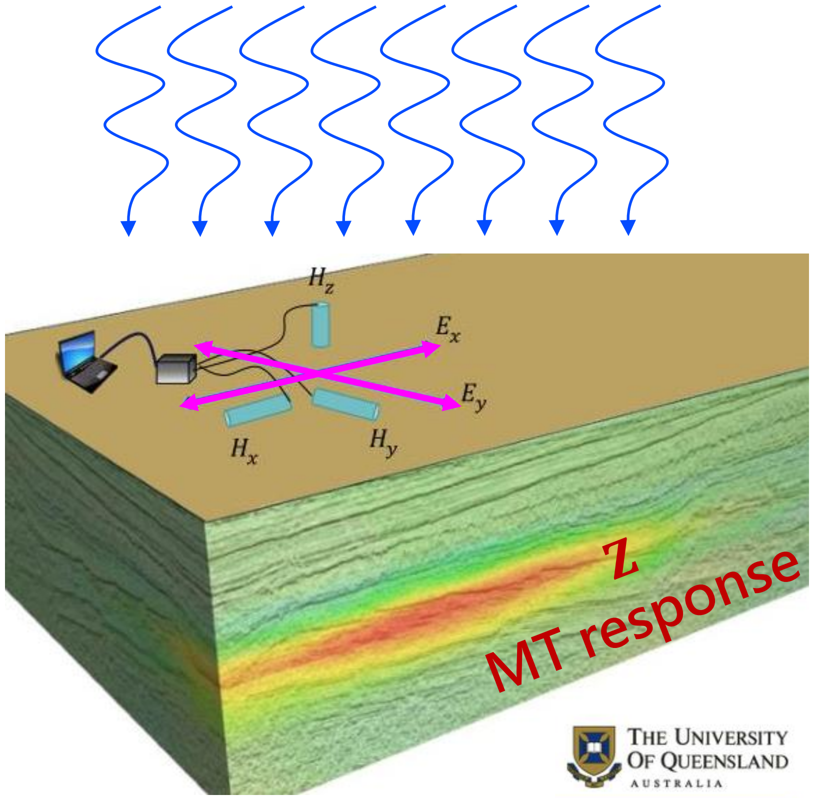
Solar wind



Chanapa Tantibanchachai, 2020

**B**

Magnetic Field




**E**

Induced Electric Field

The **MT response** (**Z**) describes the linear relationship between horizontal components of the **B** and **E** variations. It implies the underground **electrical features**.

$$\mathbf{Z} = \frac{\mathbf{E}}{\mathbf{B}}$$

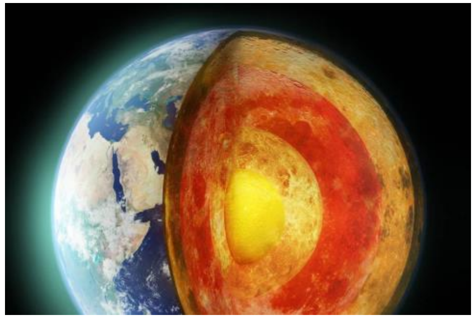
Resistivity is sensitive to water, carbon, partial melt, etc.

# Magnetotelluric Method (MT) 大地電磁法

## Passive (natural) sources

Solar wind

magnetosphere



Chanapa Tantibanchachai, 2020

**B**

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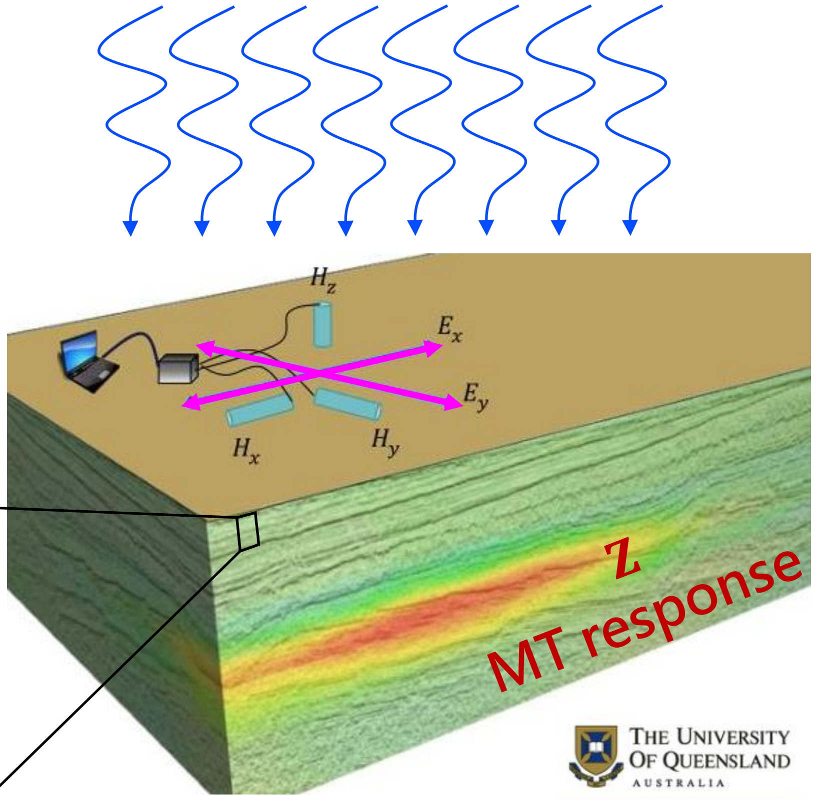



**E**

Induced Electric Field

The **MT response** (**Z**) describes the linear relationship between horizontal components of the **B** and **E** variations. It implies the underground **electrical features**.

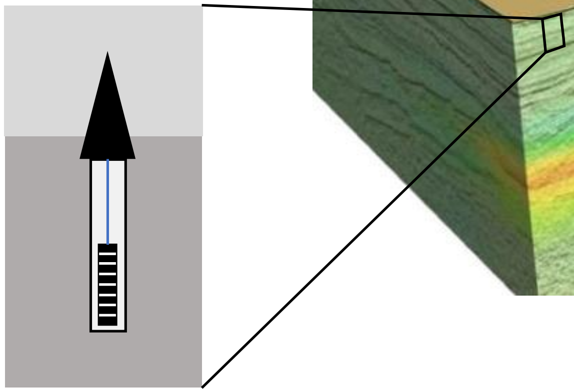
$$Z = \frac{E}{B}$$

Resistivity is sensitive to water, carbon, partial melt, etc.

- Deeper structure

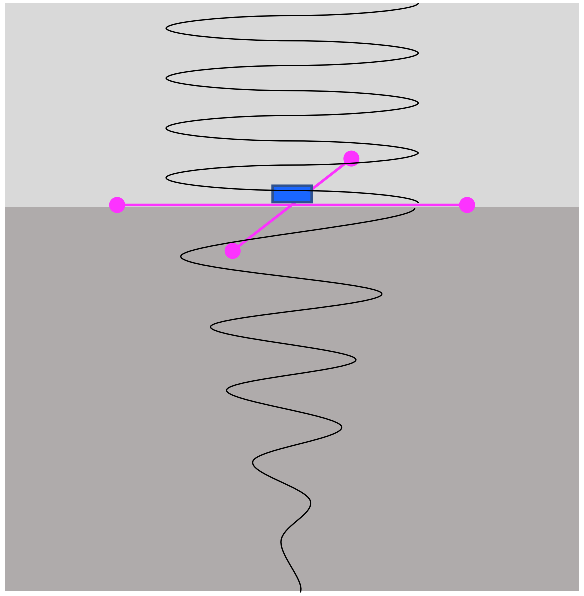
Well-logging

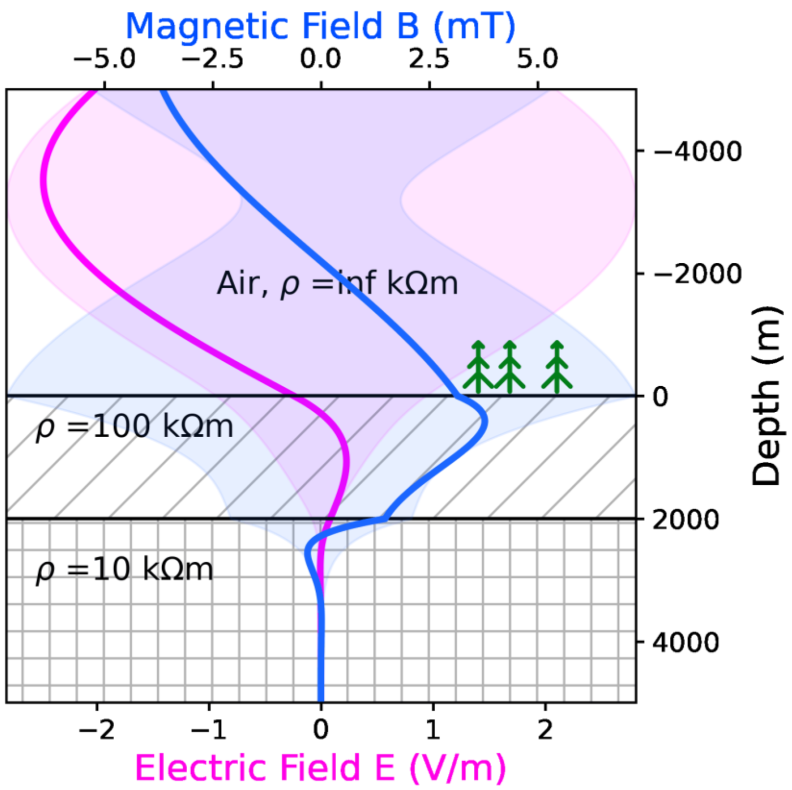
- Direct measurement
- Shallow structure



# Magnetotelluric Method (MT) 大地電磁法

## Electromagnetism—EM






- EM waves **attenuate with depth**

## Skin depth ($\boldsymbol{\delta}$)

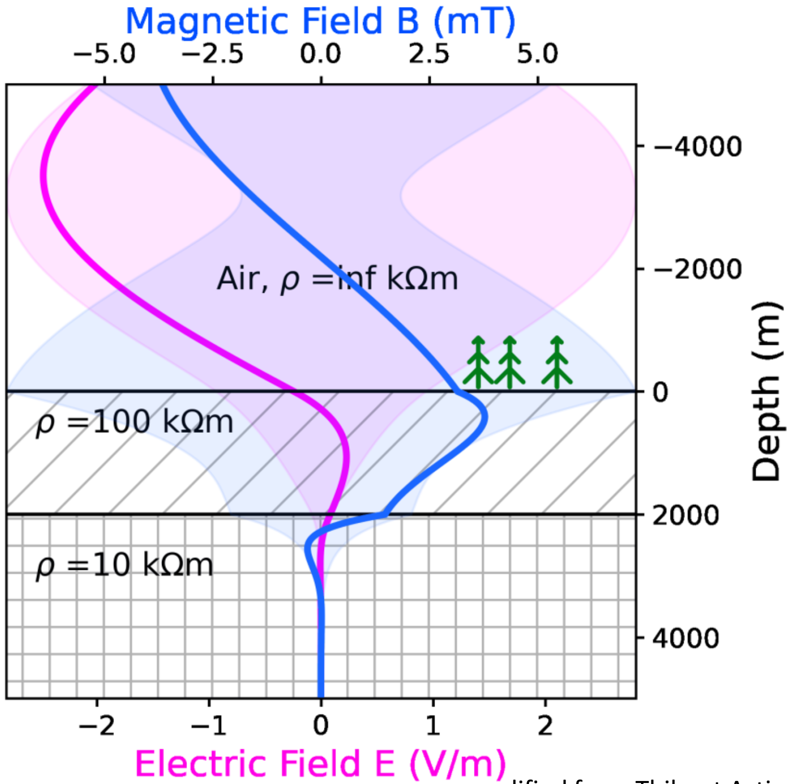
$$\boldsymbol{\delta} \cong \mathbf{500}\sqrt{\boldsymbol{\rho T}}$$

apparent resistivity ($\rho$), period ($T$)

The electromagnetic waves will attenuate with depth.
It usually be described as skin depth effect.
That is, the longer periods we use, the deeper structure could be seen.

# Magnetotelluric Method (MT) 大地電磁法

Z(T) is a complex number, so we usually present it as the combinations of apparent resistivity $\rho_{ij}(T)$ and impedance phase $\phi_{ij}(T)$.



modified from Thibaut Astic

$$\mathbf{Z}(T) = \frac{\mathbf{E}(T)}{\mathbf{B}(T)}$$

(complex number)

Z in terms of

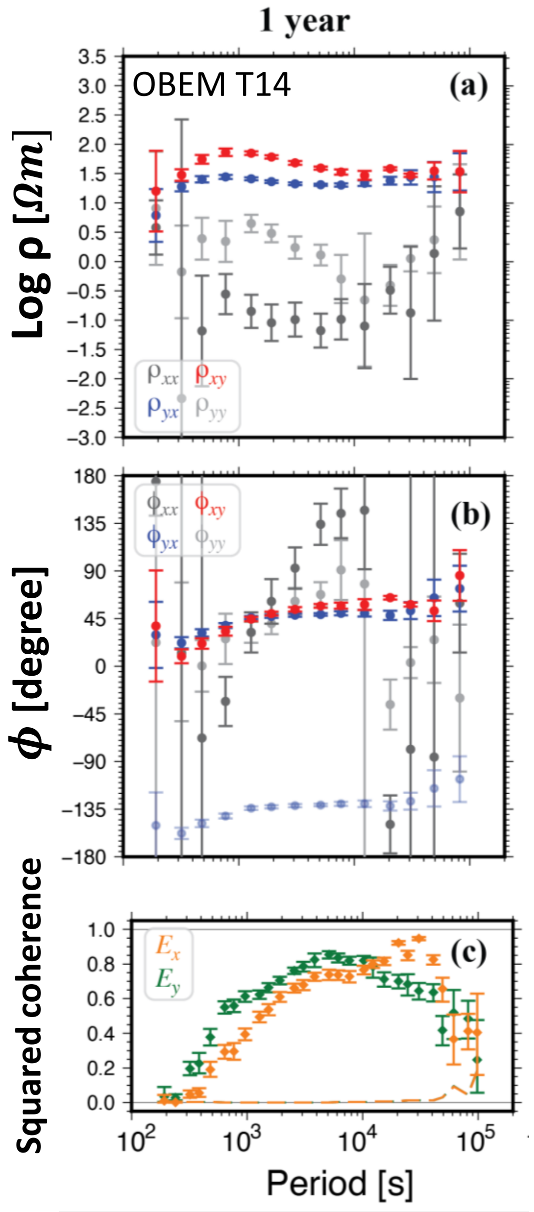
$$\rho_{ij}(T) = \frac{\mu T}{2\pi}\left|\mathbf{Z}_{ij}\right|^2$$

$$\phi_{ij}(T) = \tan^{-1}\left\{\frac{Im[\mathbf{Z}_{ij}]}{Re[\mathbf{Z}_{ij}]}\right\}$$

$\mu$: magnetic permeability;
$Re$[]: real number;
$Im$[]: imaginary number

The **MT response, Z(*T*),** can be presented as the combinations of →(a) **apparent resistivity,** $\rho_{ij}(T)$ &
視電阻率
(b) **impedance phase** , $\phi_{ij}(T)$
阻抗相位

# Magnetotelluric Method (MT) 大地電磁法




Z in terms of

$$\mathbf{Z}(T) = \frac{\mathbf{E}(T)}{\mathbf{B}(T)}$$

(complex number)

(a) **apparent resistivity,** $\rho_{ij}(T)$

視電阻率

(shows average resistivity of the half-space)

$$\begin{bmatrix} E_x(T) \\ E_y(T) \end{bmatrix} = \begin{bmatrix} Z_{xx}(T) & Z_{xy}(T) \\ Z_{yx}(T) & Z_{yy}(T) \end{bmatrix} \begin{bmatrix} B_x(T) \\ B_y(T) \end{bmatrix}$$

(b) **impedance phase** , $\phi_{ij}(T)$

阻抗相位

($\mathbf{E}$ is advanced $\boldsymbol{\phi}$ degrees to the $\mathbf{B}$)

coherence between

$\mathbf{E}_{\text{observed}}$ & $\mathbf{E}_{\text{predicted}}$

($\mathbf{E}_{\text{predicted}} = \mathbf{BZ}$)

Z(T) is a matrix, which has 4 elements.
We only focus on red and blue one, which shows on these figures.
In figure c, the higher coherence means well data quality.

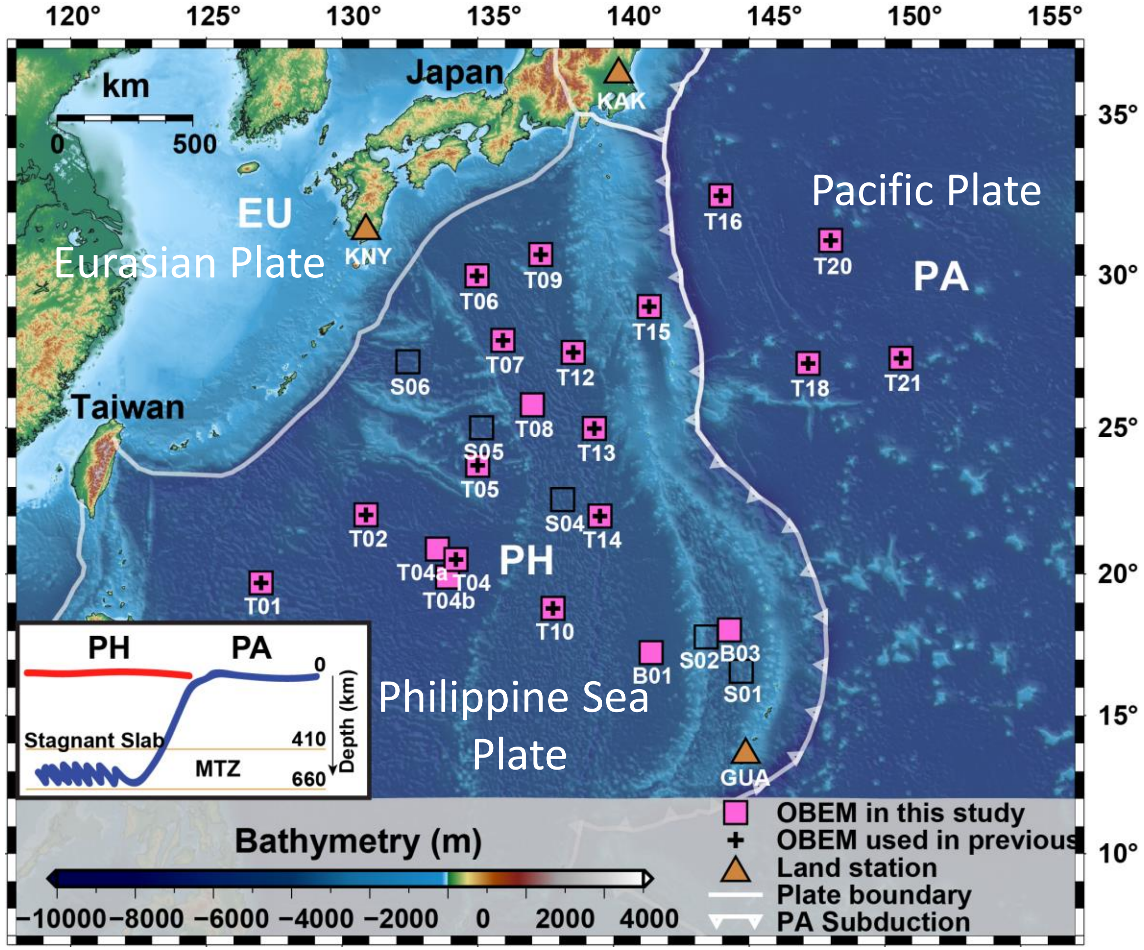
# Objectives and Data

## Scientific Goal

Electromagnetic exploration is used to image the electrical structures and can help us discuss back-arc basin mantle dynamics (e.g.: what are the geological consequences of slab falling and stagnating at mantle transition zone?)

Pacific plate is subducting beneath Philippine sea plate, but it stopped at mantle transition zone (MTZ). Therefore, we use MT data to explore electrical structures beneath this region.

**Distribution of used OBEM (21) and on-land sites (3)**

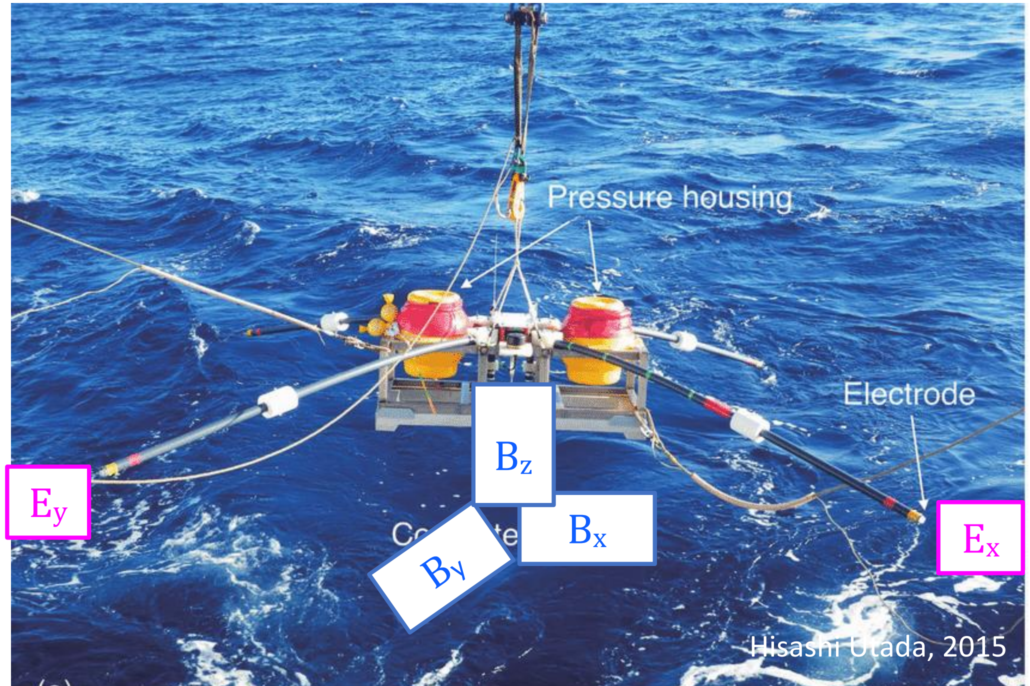


# Objectives and Data

## Scientific Goal

Electromagnetic exploration is used to image the electrical structures and can help us discuss back-arc basin mantle dynamics (e.g.: what are the geological consequences of slab falling and stagnating at mantle transition zone?)

**Ocean bottom electromagnetometer (OBEM)**



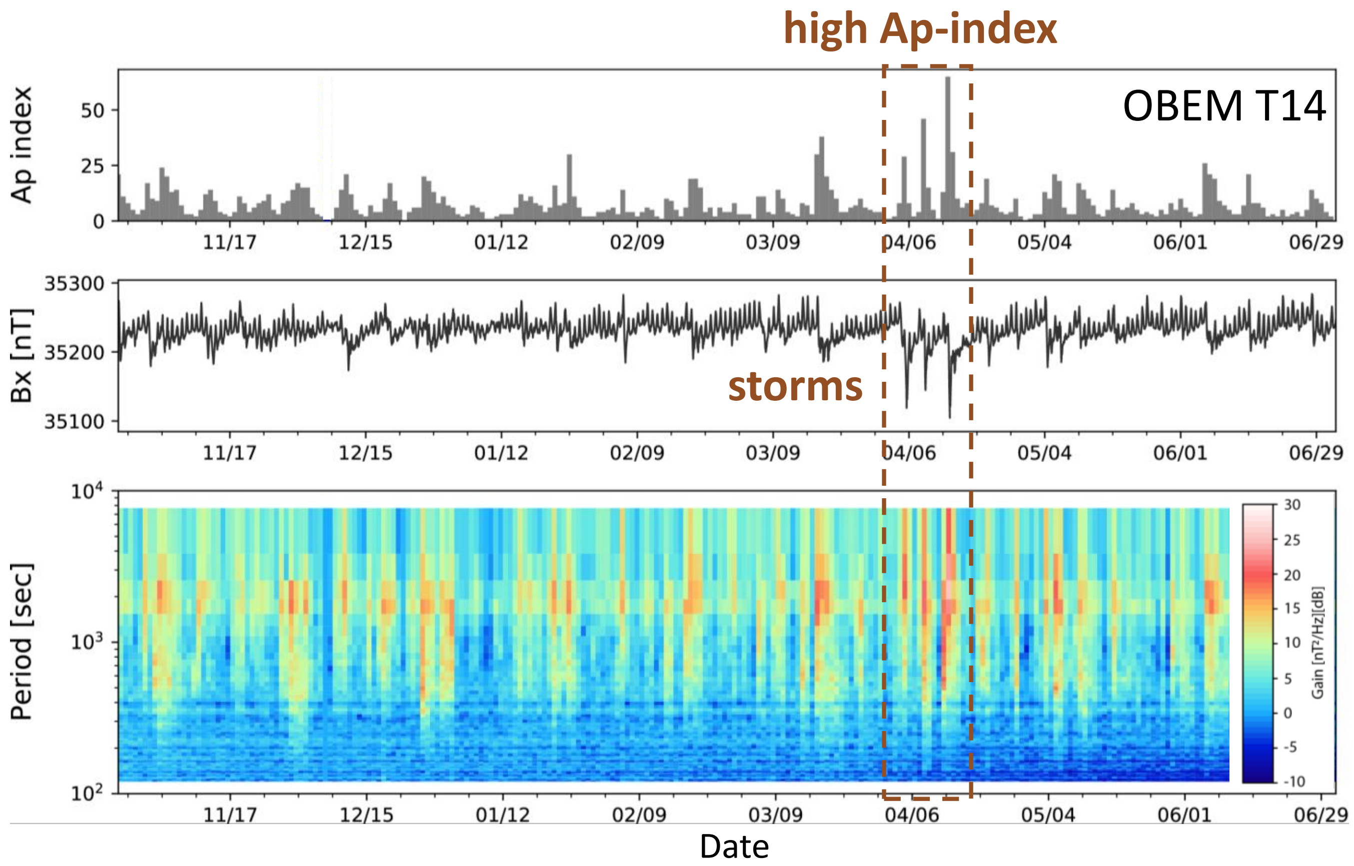

Data Acknowledgement

Ocean bottom electromagnetometer (OBEM) recorded 3 components magnetic data and 2 components electric data on the seafloor.

# Characteristics of Electromagnetic Field Data Recorded by OBEM

❶ The spectrogram of the observed magnetic fields shows clear variations due to **geomagnetic storms** (**high Ap-index**).

❶

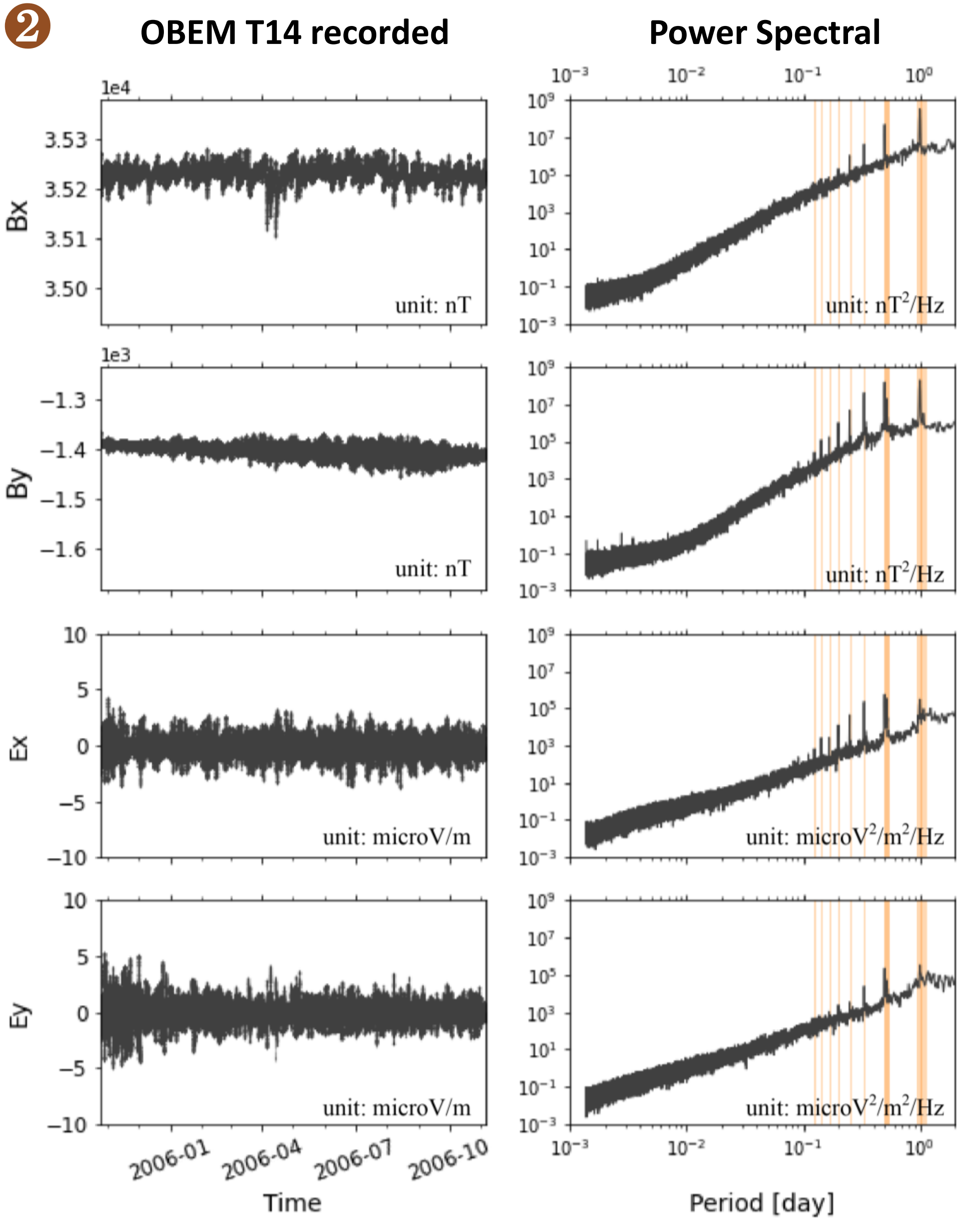



We can see Ap-index is high while there is a magnetic storm. Also, there are large variations in the magnetic time-series data. At the same time, strong (showing in red) energy appears in spectrogram.

# Characteristics of Electromagnetic Field Data Recorded by OBEM

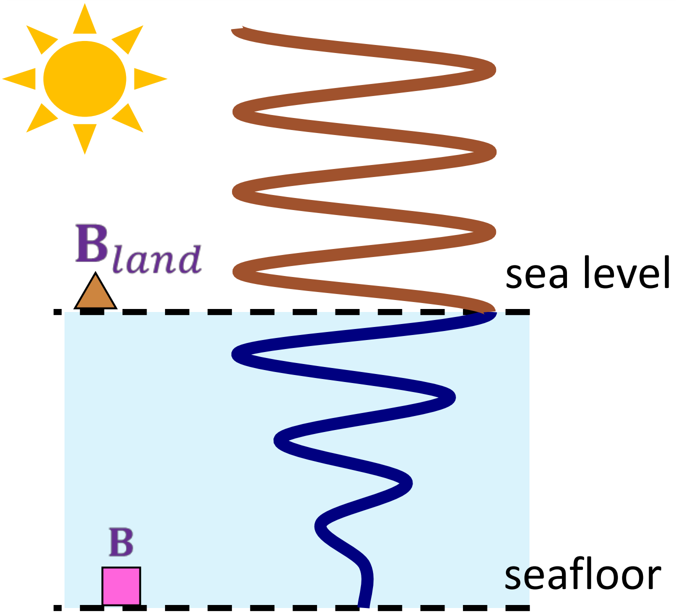
❶ The spectrogram of the observed magnetic fields shows clear variations due to **geomagnetic storms** (**high Ap-index**).

❷ The power spectral of the observed magnetic and electrical fields show clear variations caused by **solar quiet daily variation**, and its **higher harmonics**.

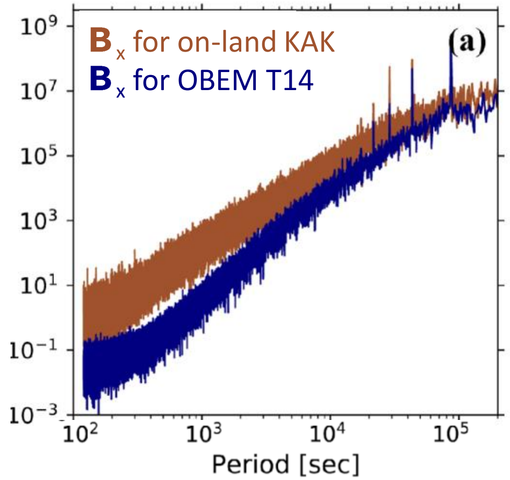



Left panel shows the magnetic and electrical time series data. Right panel shows the power spectrum. As you can see the peaks, where are marked in orange. These features are caused by solar quiet daily variation, and its higher harmonics.

# Differences between $B_{land}$ & $B_{OBEM}$




❶ Power Spectral Density




## Amplitude:

- Magnetic field recorded in **OBEM is weaker than on-land station** (< $10^4$ s) because of skin depth effect for **water column** (~5000 m depth).

## Skin depth $\delta$

$$\delta \cong 500\sqrt{\rho T}\ (unit: m)$$

$$\rho_{seawater} = 0.3\ \Omega m$$

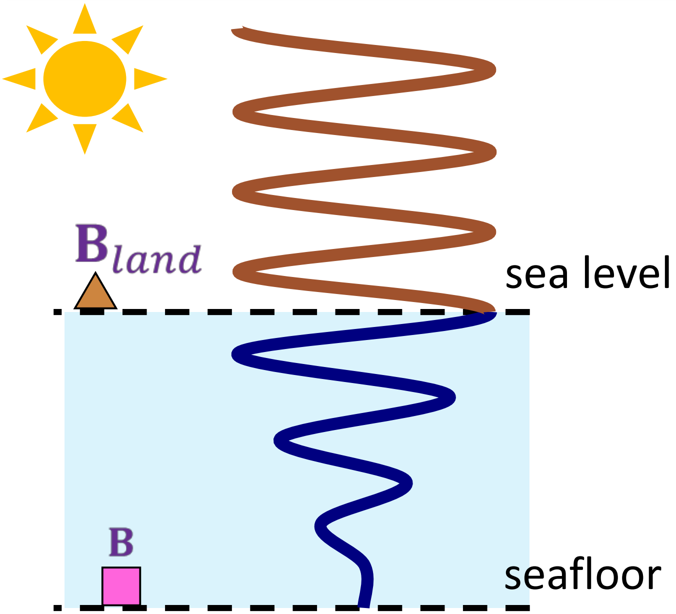
$T$ at 200 $s$ → $\delta \cong 4000\ m$

$T$ at $10^4$ $s$ → $\delta \cong 27000\ m$

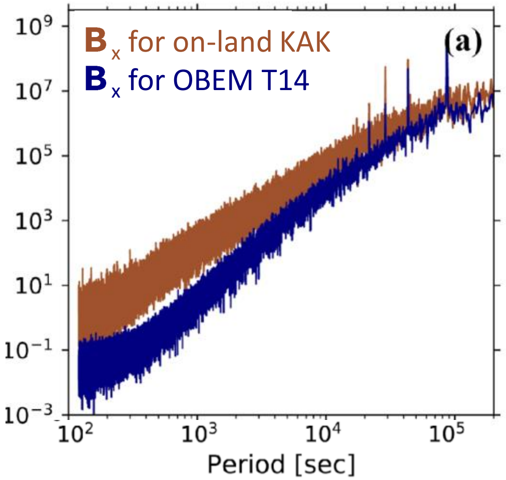
(27000 >> OBEM's depth)

We can also use skin depth to illustrate it. The 200 s signal will attenuate a lot at 4000 m depth. However, it need deeper depth for longer periods to have same attenuation.
So the shorter period, the weaker amplitude we can see on OBEM.

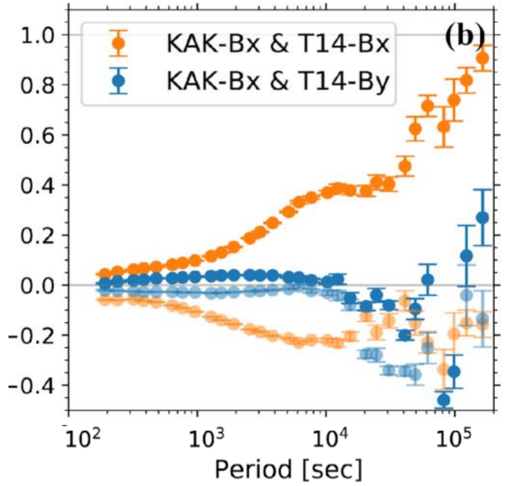
# Differences between $B_{land}$ & $B_{OBEM}$




❶ Power Spectral Density




❷ Transfer function




Transfer function can be used to quantify the amplitude differences. It showed the OBEM's amplitude is 0.1 times smaller than land station data at 100 s period. It's about 0.5 times smaller at 10,000 s.

## Amplitude:

- Magnetic field recorded in **OBEM is weaker than on-land** station (< $10^4$ s) because of skin depth effect for **water column** (~5000 m depth).

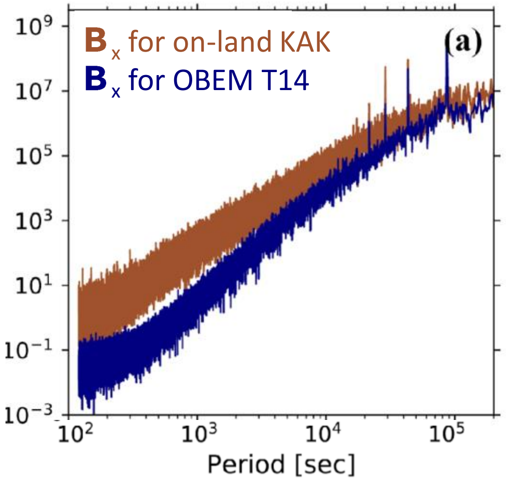
## Transfer function (TF):

Quantize the relationship of horizontal magnetic field between $\mathbf{B}$ and $\mathbf{B}_{land}$

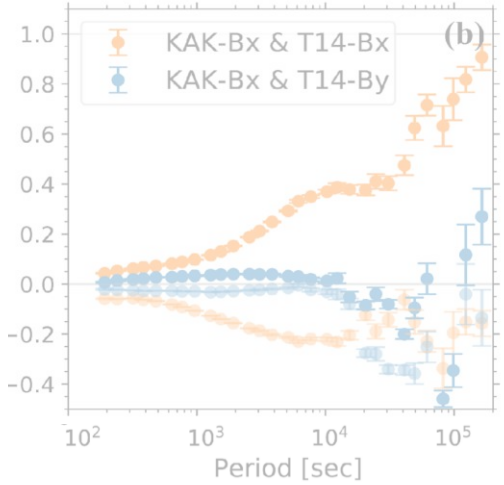
$$\mathbf{B} = \mathbf{B}_{land}\boxed{\mathbf{TF}} + \boldsymbol{\varepsilon}$$

# Differences between $B_{land}$ & $B_{OBEM}$

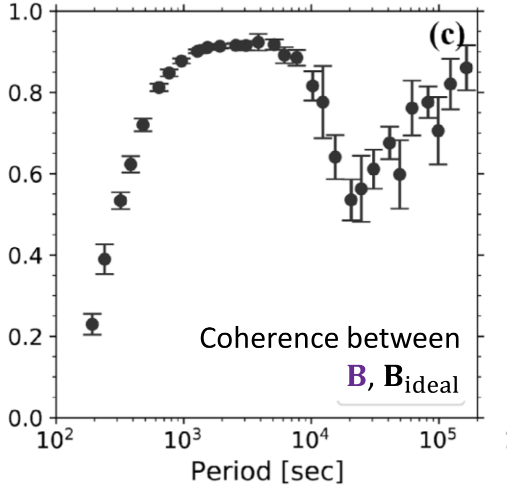
❶ Power Spectral Density




❷ Transfer function




❸ Squared Coherence




## Instrument noise:

The magnetic data reocrded at OBEM and land stations will record their own noises.

$$\mathbf{B} = \mathbf{B}_{ideal} + \boldsymbol{\varepsilon}$$ noise

$$\mathbf{B}_{land} = \mathbf{B}_{ideal} + \boldsymbol{\varepsilon}_{land}$$

KAK as a remote reference

- The noises (ε) often lead to estimate of **MT response** (Z) **being biased** if only one station data is analyzed.

Here, we use the KAK as a **remote reference** station to reduce the effect of site-dependent noises.

# Z Obtained by Remote Reference Methods

❶ Conventional remote method

$$\rightarrow \mathbf{Z} = (\mathbf{B}_{land}\mathbf{vB})^{-1}\mathbf{B}_{land}\mathbf{vE}$$

weighting

❷ 2-stage method

1st stage:

$$\mathbf{B}_{\text{ideal}} = \mathbf{B}_{land}(\mathbf{B}_{land}\mathbf{B}_{land})^{-1}\mathbf{B}_{land}\mathbf{B}$$

2nd stage:

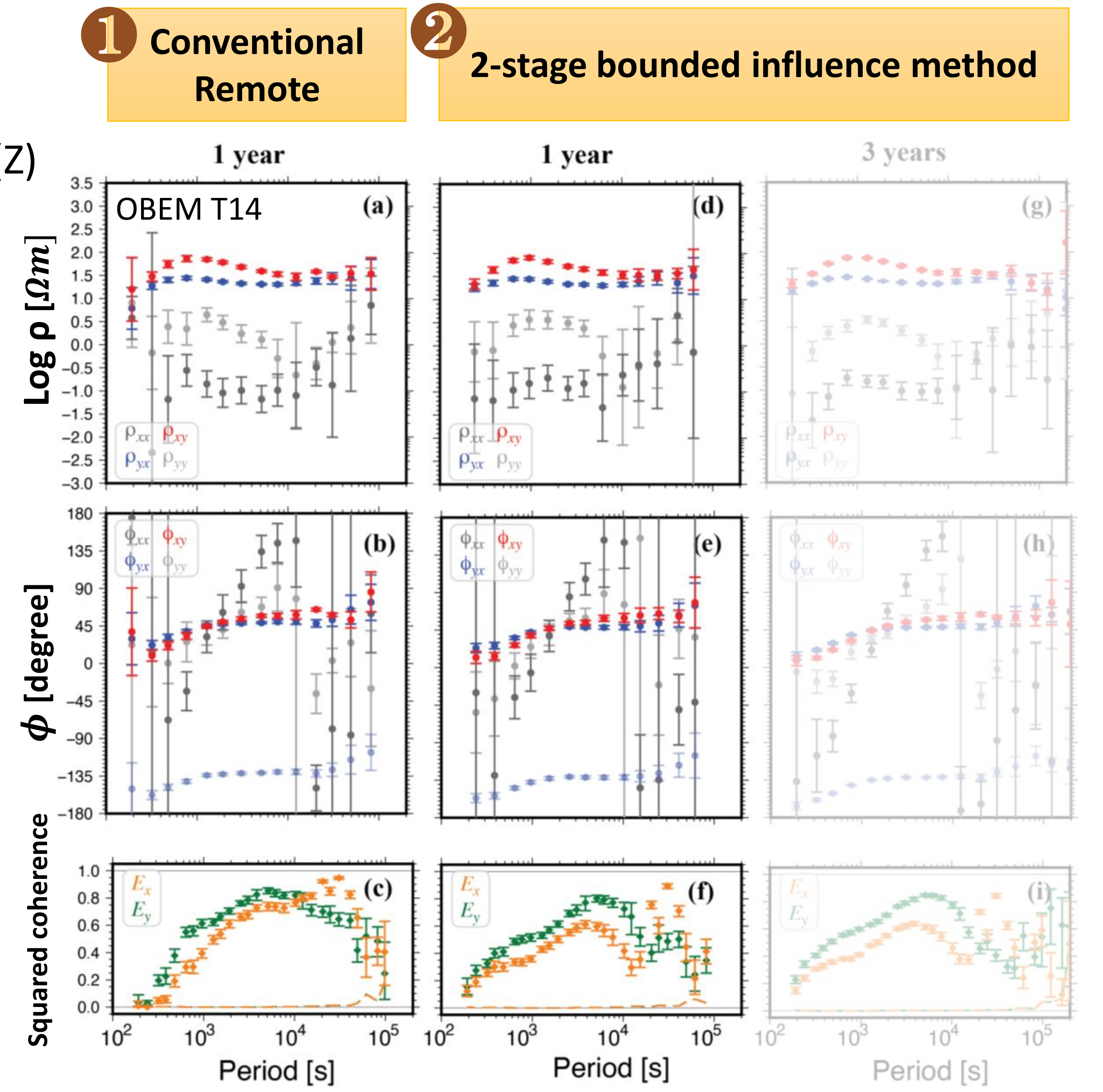
$$\rightarrow \mathbf{Z} = (\mathbf{B}_{\text{ideal}}\mathbf{vB})^{-1}\mathbf{B}_{\text{ideal}}\mathbf{vE}$$

MT responses (Z) in terms of

**apparent resistivity (ρ)**

&

**impedance phase ($\phi$)**

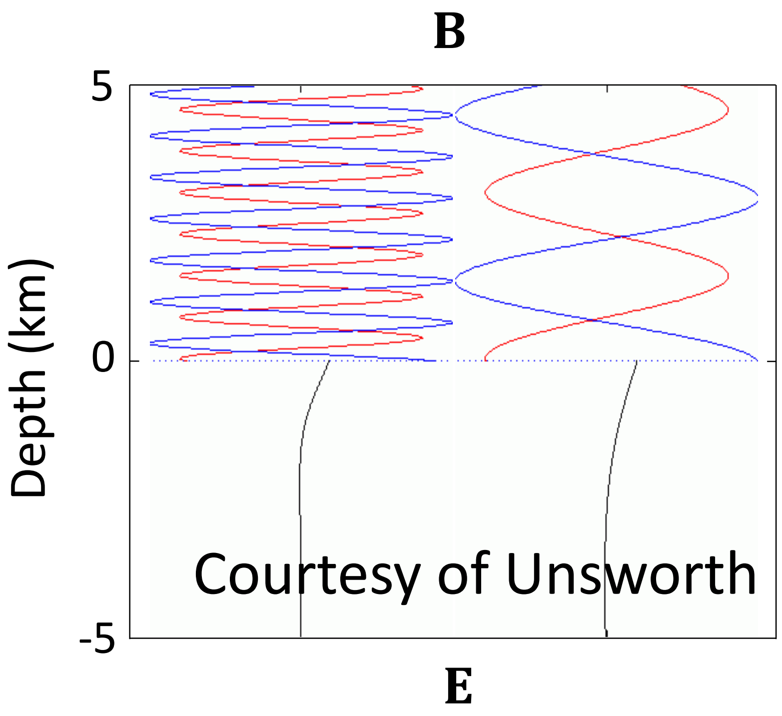



(Error bars indicate 95% confidence limits)

**Z(T)** are smooth, and smaller error bar with high coherences for both methods.

# Z Obtained for Longer Recovered Data by Remote Reference Methods

For those sites with longer recovery data, we are able to obtain **Z** **up to** period $\sim 2 \times 10^5$s.



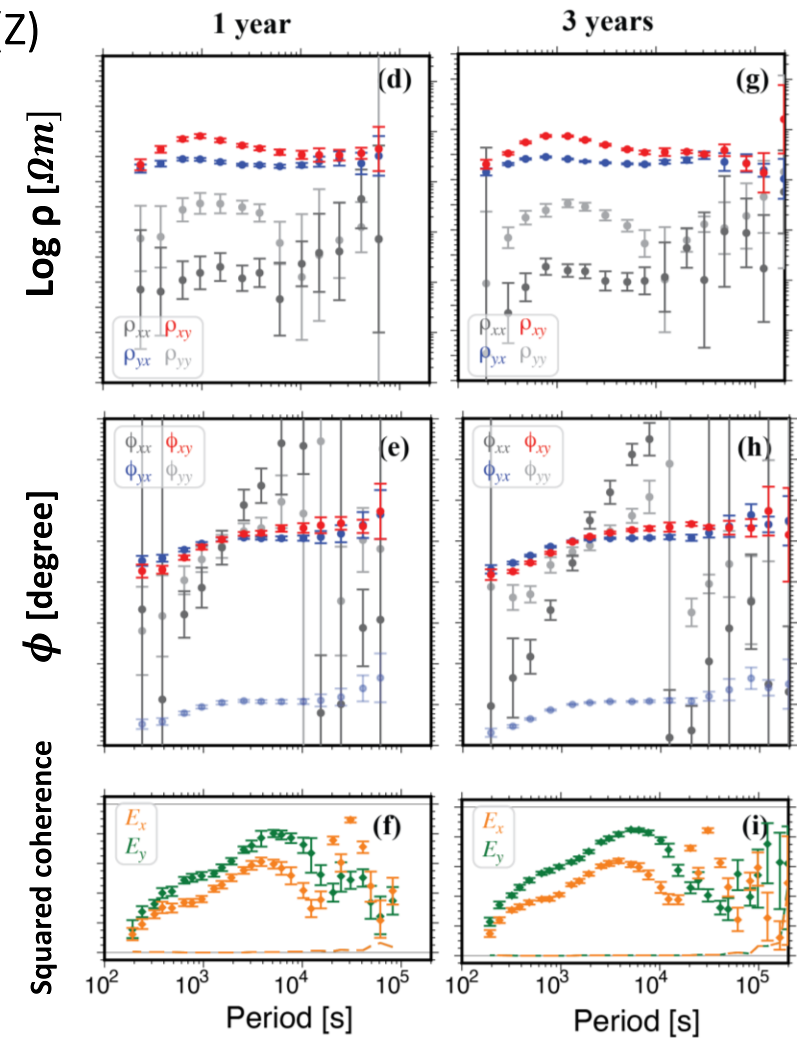

MT responses (Z) in terms of

**apparent resistivity (ρ)**

&

**impedance phase ($\phi$)**

**2-stage bounded influence method**




(Error bars indicate 95% confidence limits)

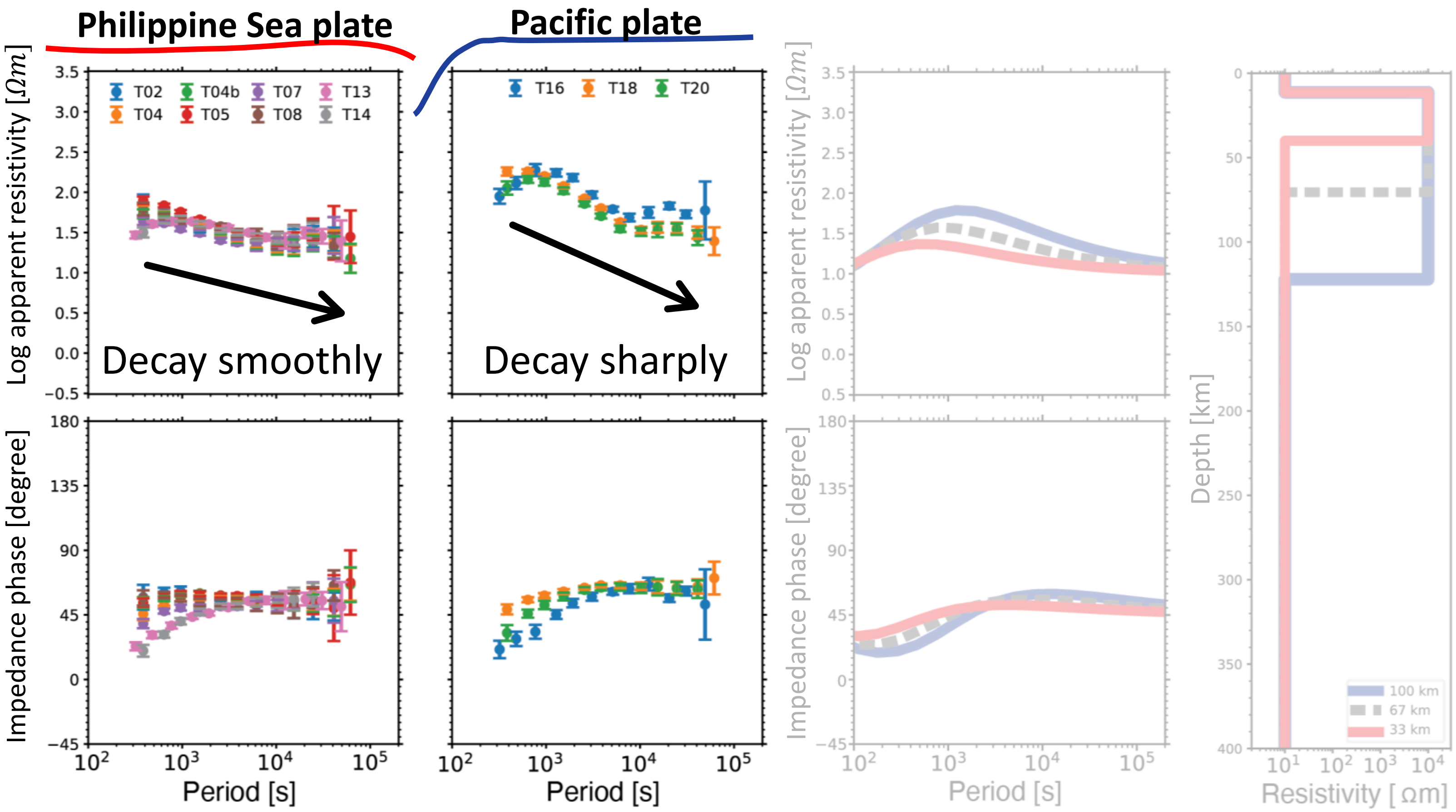
# Results: Obtained Z for OBEM Deployed on PH & PA Plates

We calculated the period-dependent MT responses for **all 21 sites** using 1-year long OBEM data.

- All sites show $\rho(T)$ have similar **primary features with a decreasing trend** with an increasing period.
- The tendency is **greater** for the sites on the **Pacific plate**.

**Observed MT responses**

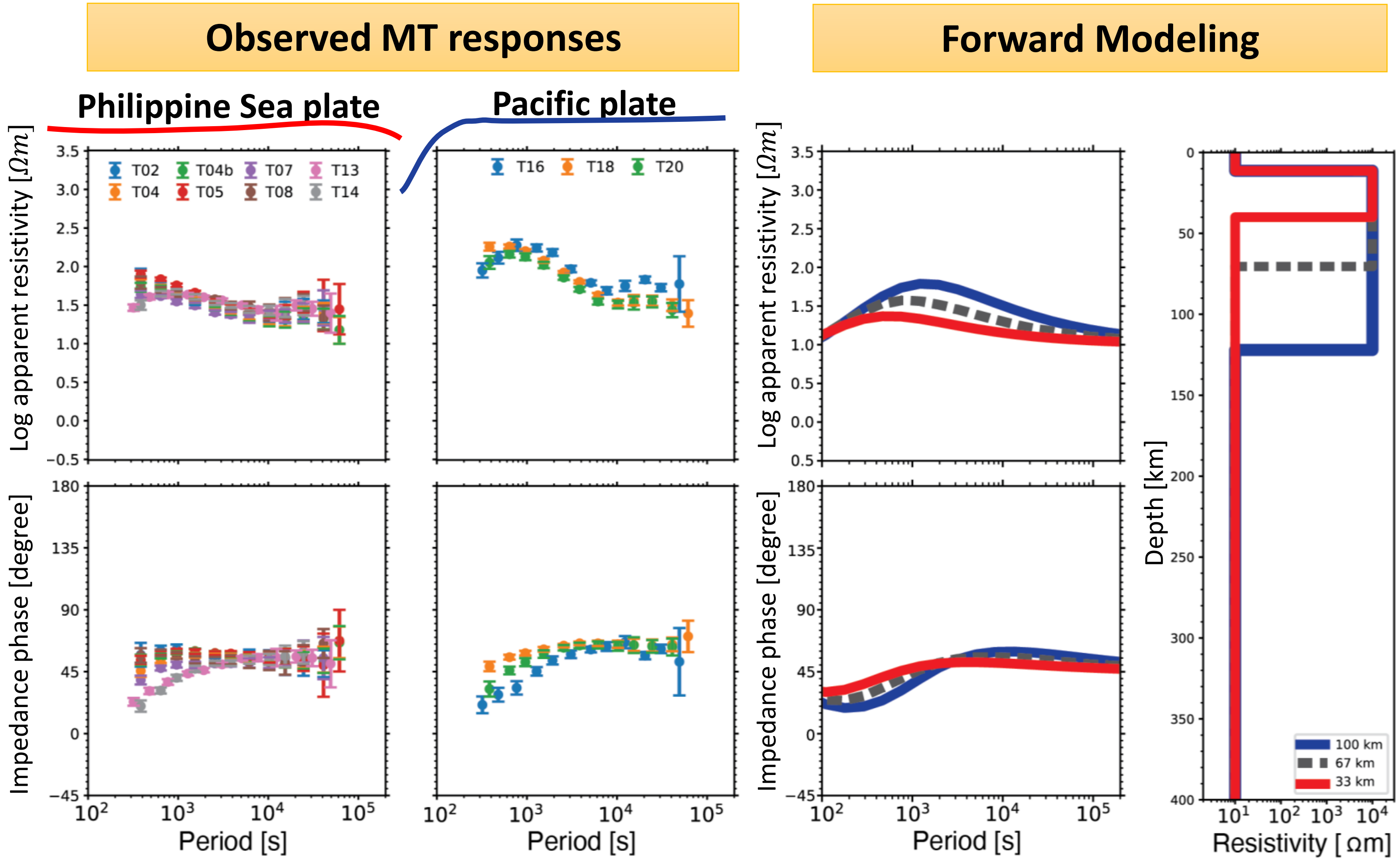
**Forward Modeling**



# Results: Obtained Z for OBEM Deployed on PH & PA Plates

Forward modeling is used to investigate the electrical structure beneath the study region

- We find this modeling needs a **high resistivity layer** in the **uppermost** mantle.
- The **high resistive layer** is thicker beneath the Pacific plate.



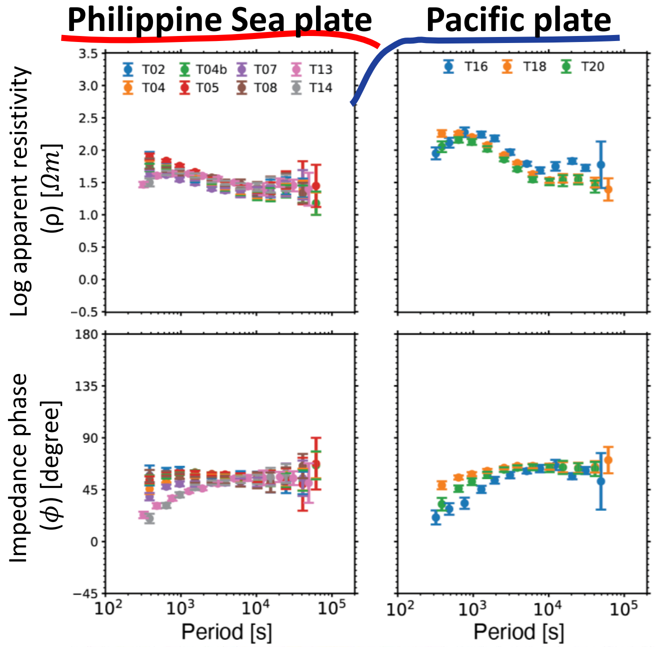
# Summary and Key Points

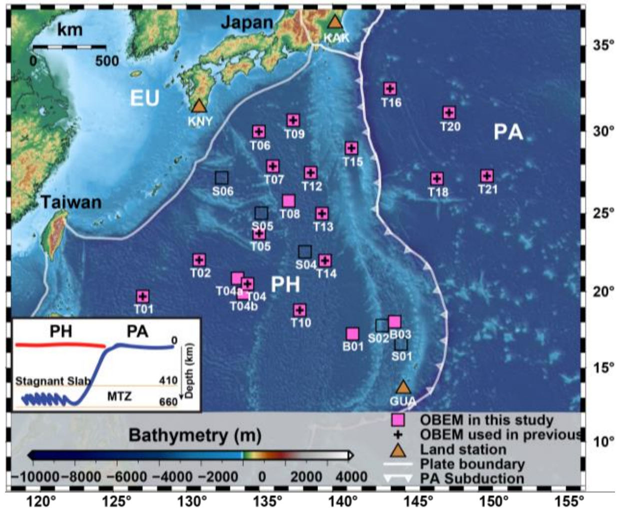
❶ $\rho(T)$ from **all** 21 sites show similar primary features with a **decreasing** trend with an increasing period. The tendency is **greater** for the sites on the **Pacific plate**.

❷ From the forward modeling, the observed features might indicate that the **Pacific plate** is **thicker**, older, and colder.

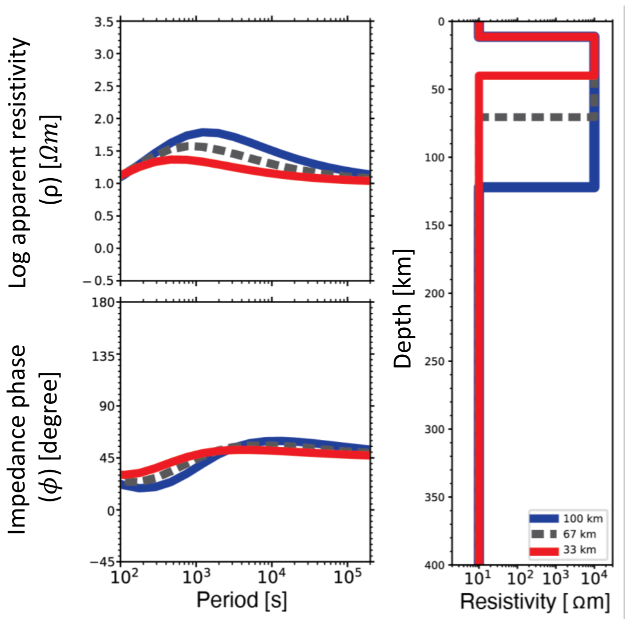
❸ In the future, we will use these $\mathbf{Z}(T)$ to do 1-D and then 3-D inversion to image the electrical structures and discuss back-arc basin mantle dynamics.

## ❶ Observed MT responses




## ❷ Forward Modeling




Acknowledgement