

# Input files

| File name              | Content  |
|------------------------|--|
| param.dat              | Parameters controlling TRACMT.<br><br>Lines prefixed with # are recognized as comment lines. |
| <i>Arbitrary names</i> | Time-series data   |

# Output files

| File name                          | Content   |
|------------------------------------|---|
| TRACMT.log                         | Execution logs  |
| TRACMT.cvg                         | Detained information of computation processes   |
| response_functions.csv             | Resultant transfer function estimates and their error estimates   |
| apparent_resistivity_and_phase.csv | Estimates of the apparent resistivity and phase and their error estimates (keyword “OUTPUT_RHOA_PHS” is required) |

# How to run TRACMT

You need to execute the following command in the directory where input files exist.

TRACMT

# File format of param.dat (1/6)

| Keyword       | Content   | Data type            | Option | Default                      | Example   |
|---------------|---|----------------------|--------|------------------------------|---|
| NUM_OUT       | Number of output channels <sup>*1)</sup>  | Positive Integer     |        |                              | NUM_OUT<br>2  |
| SAMPLING_FREQ | Sampling frequency (Hz)   | Positive real number |        |                              | SAMPLING_FREQ<br>32   |
| NUM_THREADS   | Number of OpenMP threads  | Positive integer     |        |                              | NUM_THREADS<br>4  |
| AZIMUTH       | Measurement direction (clockwise angle (deg.) from the north) of all channels including remote reference data                         | Real numbers         |        |                              | AZIMUTH<br>0.0 90.0<br>0.0 90.0<br>0.0 90.0                   |
| ROTATION      | Rotation angle (deg.) (positive clockwise) of the coordinate system where transfer functions are estimated from the NS/EW coordinates | Real number          |        | 0                            | ROTATION<br>30  |
| CAL_FILES     | File names used for instrumental calibration <sup>*1)</sup>   | Characters           |        | Calibration is not performed | CAL_FILES<br>hz.cal<br>hx.cal<br>hy.cal<br>hrx.cal<br>hry,cal |

\*1) For example, when you estimate the impedance tensor from two electric field components and the magnetic field, the number of output channels is two. The file format of calibration files is shown in a subsequent slide.

# File format of param.dat (2/6)

| Keyword     | Content   | Data type  | Option  | Default | Example   |
|-------------|---|--|---|---------|---|
| PROCEDURE   | Transfer function estimation method   | Integer  | 0: Ordinary robust remote reference method<br>1: RRMS estimator | 0       | PROCEDURE<br>0                                    |
| RRMS        | Parameters of RRMS estimator  | Detail of this option is described in a subsequent slide |   |         | RRMS<br>1<br>100<br>3<br>0.05<br>10<br>16<br>0.01 |
| MESTIMATORS | M-estimators used in the ordinary robust remote reference method <sup>*1)</sup> | Two integers for the first and second M-estimators       |   |         | MESTIMATORS<br>1 2                                |

\*1) In the ordinary robust remote reference method, iterative re-weighted least square (IRWLS) is performed twice. In the first IRWLS, the scale of the residual magnitude is also updated as well as transfer functions, while the scale parameter is fixed in the second IRWLS.

If you write “-1 -1” in this option, the ordinary least square is performed.

\*2) The severe weight function used in Chave & Thomson (1989, 2004)

# File format of param.dat (3/6)

| Keyword          | Content  | Data type        | Option   | Default                            | Example  |
|------------------|--|------------------|--|------------------------------------|--|
| ERROR_ESTIMATION | Error estimation method                                  | Integer          | 0: Parametric approach<br>1: Fixed-weights bootstrap<br>2: Ordinary (strict) bootstrap<br>4: Fixed-weights Jackknife<br>5: Subset deletion Jackknife<br>(Eisel & Egbert, 2001) | 1                                  | ERROR_ESTIMATION<br>1  |
| BOOTSTRAP        | Number of bootstrap samples                              | Positive integer |  | 1000                               | BOOTSTRAP<br>1000  |
| PREWHITENING     | Detail of this option is described in a subsequent slide | Three integers   |  | Any pre-whitening is NOT performed | PREWHITENING<br>1<br>10<br>5   |
| ROBUST_FILTER    | Detail of this option is described in a subsequent slide | Integers         |  | Robust filter is not applied       | ROBUST_FILTER<br>0<br>10 12 50<br>10 12 50<br>10 12 50<br>10 12 50<br>10 12 50<br>10 12 50 |

## File format of param.dat (4/6)

| Keyword            | Content  | Data type  | Option | Default                                      | Example                              |
|--------------------|--|--|--------|--|--------------------------------------|
| DECIMATION         | Decimation interval, length of antialiasing (FIR) filter, and width between the passband and stopband*1) frequency in the logarithmic scale. | Two positive integers and one positive real number |        | Decimation (down-sampling) is not performed. | DECIMATION<br>32<br>100<br>0.5       |
| HIGH_PASS          | Cutoff frequency of high-pass filter (Hz)  | Positive real number                               |        | HPF is not applied                           | HIGH_PASS<br>0.1                     |
| LOW_PASS           | Cutoff frequency of low-pass filter (Hz)   | Positive real number                               |        | LPF is not applied                           | LOW_PASS<br>0.1                      |
| NOTCH              | Cutoff frequencies (Hz) following the number of them   | Integer and positive real numbers                  |        | Notch filters are not applied                | NOTCH<br>6<br>50 100 150 200 250 300 |
| COHERENCE_CRITERIA | Number of segments used for calculating transfer functions followed by the threshold of squared coherence*1)                                 | Positive integer and non-negative real number      |        | Coherence thresholding is not performed.     | COHERENCE_CRITERIA<br>10<br>0.3      |

\*1) The stopband frequency is the Nyquist frequency after decimation.

\*2) If the squared coherence is lower than the threshold, all segments used for calculating the corresponding transfer functions are excluded in the transfer function estimation.

# File format of param.dat (5/6)

| Keyword            | Content  | Data type                      | Option  | Default                           | Example   |
|--------------------|--|--------------------------------|---|-----------------------------------|---|
| ATS_BINARY         | Read .ats files of Metronix instruments            |                                |   | Text files (ascii files) are read | ATS_BINARY  |
| MFS_CAL            | Coil carburation files of Metronix instruments*2). | Characters and/or real numbers |   | Calibration is not performed      | MFS_CAL<br>30.0<br>30.0<br>MFS06375.TXT<br>MFS06376.TXT<br>MFS06e549.TXT<br>MFS06e576.TXT |
| ELOGMT_BINARY      | Read .dat files of ELOG-MT                         |                                |   | Text files (ascii files) are read | ELOGMT_BINARY   |
| ELOGMT_READ_OPTION | Components that are read from .dat files           | Integer                        | 0: $E_x, E_y, H_z, H_x, H_y, H_{rx}, H_{ry}$<br>1: $E_x, E_y, H_x, H_y, H_{rx}, H_{ry}$<br>2: $H_z, H_x, H_y, H_{rx}, H_{ry}$ | 0                                 | ELOGMT_READ_OPTION<br>0   |

\*1) The file format of the calibration files are shown in a subsequent slide. Carburation files for the remote reference data are also required.

\*2) If you write a real number instead of a character, this number is recognized as a dipole length (m) of an electric field channel.



# File format of param.dat (6/6)

| Keyword            | Content  | Data type  | Option | Default                          | Example  |
|--------------------|--|--|--------|----------------------------------|--|
| NUM_SECTION        | Number of time-series data files for each channel  | Positive Integer   |        |                                  | NUM_SECTION<br>1                                       |
| SEGMENT            | Segments lengths (section lengths) of the overlapped section averaging method and indexes of the Fourier transforms <sup>*2)</sup> | Positive integers (detail of this option is described in a subsequent slide) |        |                                  | SEGMENT<br>3<br>1024 3 2 3 4<br>512 2 3 4<br>256 2 3 4 |
| DATA_FILES         | File names of time-series data and numbers of data to be read  | Detail of this option is described in a subsequent slide                     |        |                                  | Detail of this option is described in the next slide   |
| MERGE_SECTIONS     | Merge time-series of different files into a continuous time-series. (detail of this option is described in a subsequent slide)     | Integers.  |        | Merge operation is not performed | MERGE_SECTIONS<br>2<br>0 2<br>3 5                      |
| OUTPUT_TIME_SERIES | Output input time-series data to csv files   |  |        |                                  |  |
| OUTPUT_RHOA_PHS    | Output apparent resistivity and phase to a csv file in addition to the impedance tensor <sup>*1)</sup>                             |  |        |                                  |  |
| END                | End of controlling parameters  |  |        |                                  | END  |

<sup>\*1)</sup> Apparent resistivity (Ohm-m) is calculated assuming that the units of the electric and magnetic field is mV/km and nT, respectively.

# Keyword RRMS

## RRMS

Are initial candidate sets of the ISTFs randomly selected for each frequency?

0: No. TFs at the previous (lower) frequency are used as an initial candidate set.

1: Yes.

Number of the initial candidate sets of the ISTFs (positive integer)

Maximum number of iteration of the first parameter updates (positive integer)

Convegence criteria of the first parameter updates (positive real number)

Maximum number of the candidate sets of the second parameter updates (positive integer)

Maximum number of iteration of the second parameter updates (positive integer)

Convegence criteria of the second parameter updates (positive real number)

Default setting:

RRMS

1

100

3

0.05

10

16

0.01

Convegence criteria means the threshold of the change rates of weighted norm of each residual and the robust scale of the Mahalanobis distance.

# Keyword PREWHITENING

## PREWHITENING

Prewhitening method

0: Non-robust prewhitening

1: Robust prewhitening

Maximum degrees of the AR model used for prewhitening<sup>1)</sup>

Number of initial candidates (it is used only in the robust prewhitening)

If you do not write this keyword, any pre-whitening is not performed

1) I recommend you use a higher value than five.

# Keyword ROBUST\_FILTER

## ROBUST\_FILTER

Are filtered time-series directly used for the transfer function estimation

0: No

1: Yes

Parameters for the 1<sup>st</sup> channel

The 1<sup>st</sup> threshold

The 2<sup>nd</sup> threshold

Maximum number of  
consecutive replacements

Parameters for the 2<sup>nd</sup> channel

The 1<sup>st</sup> threshold

The 2<sup>nd</sup> threshold

Maximum number of  
consecutive replacements

⋮

Recommended setting

ROBUST\_FILTER

0

10 12 50

10 12 50

10 12 50

10 12 50

10 12 50

10 12 50

Number of  
data channels

If you do not write this keyword, robust filter is not applied in the prewhitening

# Keyword SEGMENT

## SEGMENT

Number of segment lengths

The 1<sup>st</sup> segment length

Number of indexes

The 1<sup>st</sup> index

...

The last index

The 2<sup>nd</sup> segment length

Number of indexes

The 1<sup>st</sup> index

...

The last index

⋮

Number of indexes

Number of  
segment lengths

[NOTE]

- Segment length should be a power of two.
- I recommend you use three or higher as indexes if the prewhitening is performed and otherwise use seven or higher.

Frequency (Hz) for which the transfer function is estimated is determined from the segment length ( $L$ ), index ( $i$ ), and sampling interval ( $\Delta t$ ), as follows.

$$f = \frac{i}{L\Delta t}$$

For example, the following setting leads to the transfer functions at 0.2344 and 0.3125 (Hz) if the sampling interval is 0.1 (sec).

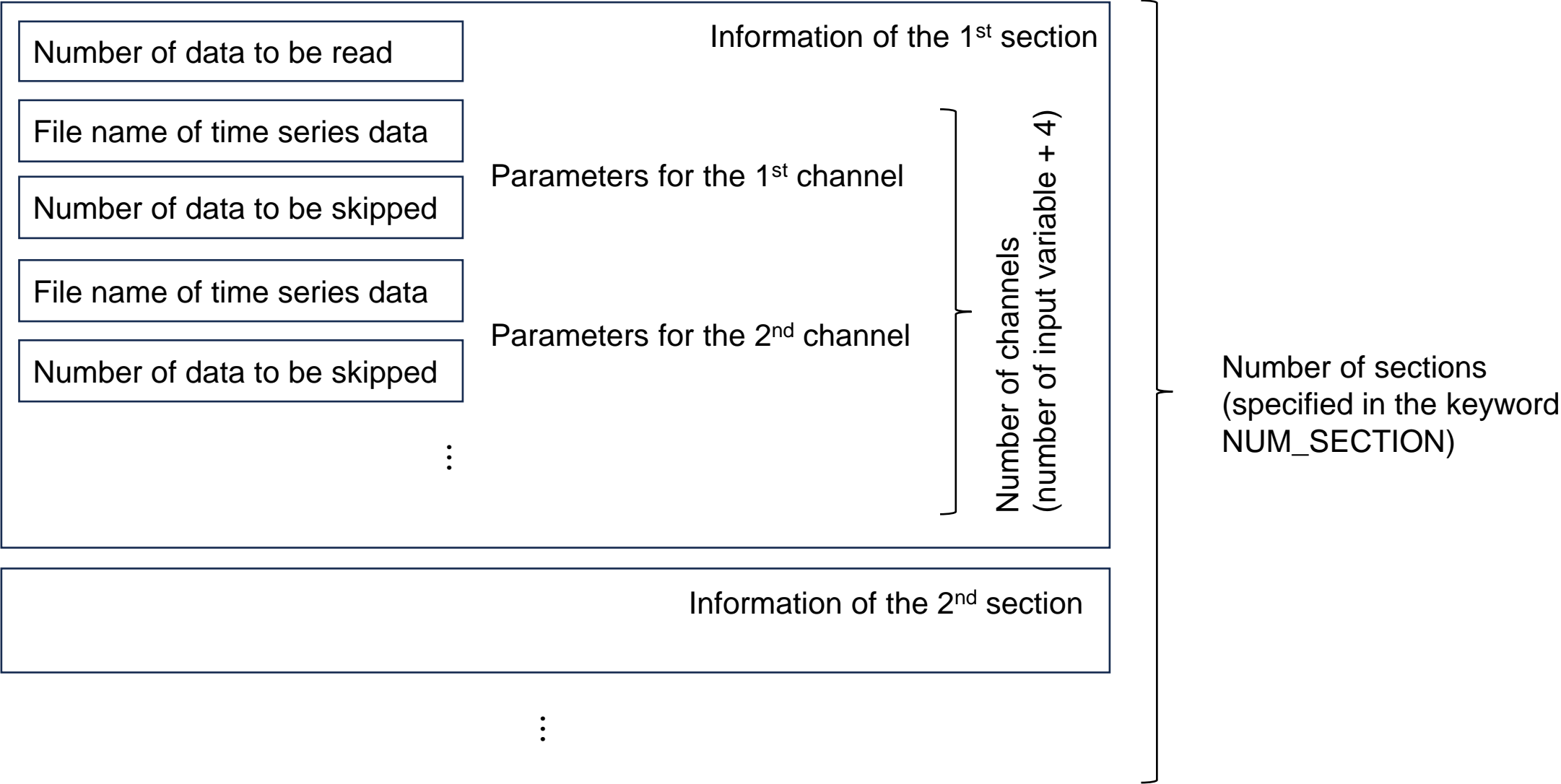
| Segment length | Number of indexes | The 1 <sup>st</sup> index | The 2 <sup>nd</sup> index |
|----------------|-------------------|---------------------------|---------------------------|
| 128            | 2                 | 3                         | 4                         |

$$f_1 = \frac{3}{128 \times 0.1} = 0.2344 \text{ (Hz)}$$

$$f_2 = \frac{4}{128 \times 0.1} = 0.3125 \text{ (Hz)}$$

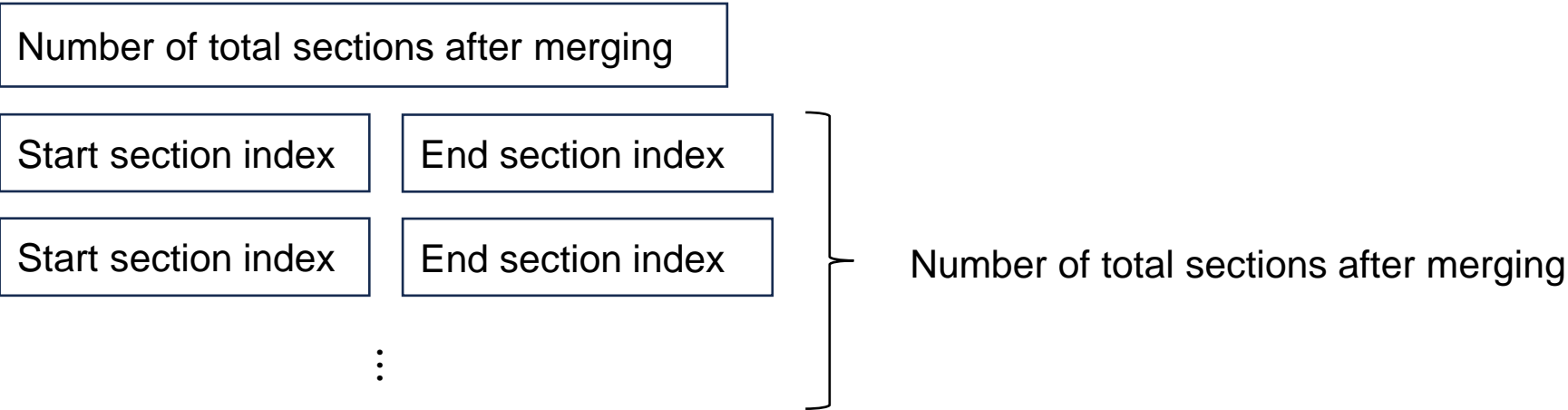
# Keyword DATA\_FILES

## DATA\_FILES



# Keyword MERGE\_SECTIONS

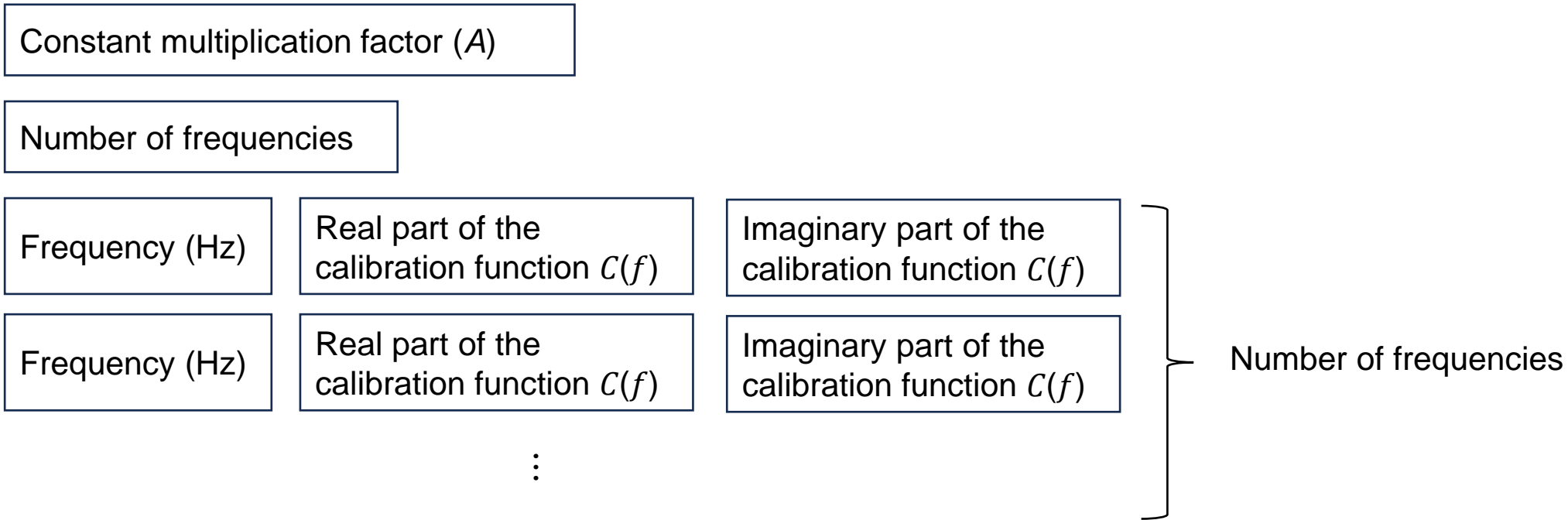
MERGE\_SECTIONS



For example, following setting merges the data from the section #0 to the section #3 into a section without gap.

```
MERGE_SECTIONS
1
0 3
```

# File format of calibration files



Instrumental characteristics are corrected in the frequency domain by multiplying  $A$  and  $C(f)$ .

The calibration function is interpolated for the frequency at which  $C(f)$  is not specified.

$$A \times C(f_1)E_x(f_1) \rightarrow E_x(f_1)$$

$$A \times C(f_2)E_x(f_2) \rightarrow E_x(f_2)$$

...



# File format of output file

The resultant transfer functions are outputted to csv files with headers such as “resp\_real\_0\_2”, “resp\_imag\_0\_2”, “coherence\_0\_2+3”, and “dresp\_0\_2”.

The number of header indicates index of channels.

For example,

|           | Channel indexes |    |    |     |     |     |     |                                   |
|-----------|-----------------|----|----|-----|-----|-----|-----|-----------------------------------|
|           | 0               | 1  | 2  | 3   | 4   | 5   | 6   |                                   |
|           | Ex              | Ey | Hz | Hx  | Hy  | Hrx | Hry | (Number of output variables is 3) |
| Variables | Ex              | Ey | Hx | Hy  | Hrx | Hry |     | (Number of output variables is 2) |
|           | Hz              | Hx | Hy | Hrx | Hry |     |     | (Number of output variables is 1) |

resp\_real\_i\_j: Real parts of the transfer function relating channel #i to channel #j

resp\_imag\_i\_j : Imaginary parts of the transfer function relating channel #i to channel #j

coherence\_i\_j+k: Squared coherence for channel#i

dresp\_i\_j: Standard error for the transfer function relating channel #i to channel #j

For example, if the output variables are Ex and Ey, resp\_real\_0\_3 and resp\_imag\_0\_3 are real and imaginary components of Zxy of the impedance tensor.

# How to read ats files of Metronix instruments

**ATS\_BINARY**

**MFS\_CAL**

30.0

30.0

MFS06375.TXT

MFS06376.TXT

MFS06e549.TXT

MFS06e576.TXT

If you write a real number instead of a character, this number is recognized as a dipole length (m) of an electric field channel, and the data at the channel is divided by the real number in the calibration stage.

# How to read .ats files of Metronix instruments

**ATS\_BINARY**

**MFS\_CAL**

30.0

30.0

MFS06375.TXT

MFS06376.TXT

MFS06e549.TXT

MFS06e576.TXT

**DATA\_FILES**

691200

063\_V01\_C00\_R008\_TEx\_BL\_32H.ats

0

063\_V01\_C01\_R008\_TEy\_BL\_32H.ats

0

063\_V01\_C02\_R008\_THx\_BL\_32H.ats

0

063\_V01\_C03\_R008\_THy\_BL\_32H.ats

0

382\_V01\_C02\_R069\_THx\_BL\_32H.ats

0

382\_V01\_C03\_R069\_THy\_BL\_32H.ats

0

If you write a real number instead of a character, this number is recognized as a dipole length (km) of an electric field channel, and the data at the channel is divided by the real number in the calibration stage.

You can write .ats file directly if you use the keyword “ATS\_BINARY”.

# How to read .dat files of ELOG-MT

ELOGMT\_BINARY

ELOGMT\_READ\_OPTION

1

→

0:  $E_x, E_y, H_z, H_x, H_y, H_{rx}, H_{ry}$

1:  $E_x, E_y, H_x, H_y, H_{rx}, H_{ry}$

2:  $H_z, H_x, H_y, H_{rx}, H_{ry}$

## DATA\_FILES

115200

D:Site1/20221023/20221023-010000\_32Hz.dat

0

D:Site1/20221023/20221023-010000\_32Hz.dat

0

D:Site1/20221023/20221023-010000\_32Hz.dat

0

D:Site1/20221023/20221023-010000\_32Hz.dat

0

D:Site2/20221023/20221023-010000\_32Hz.dat

0

D:Site2/20221023/20221023-010000\_32Hz.dat

0

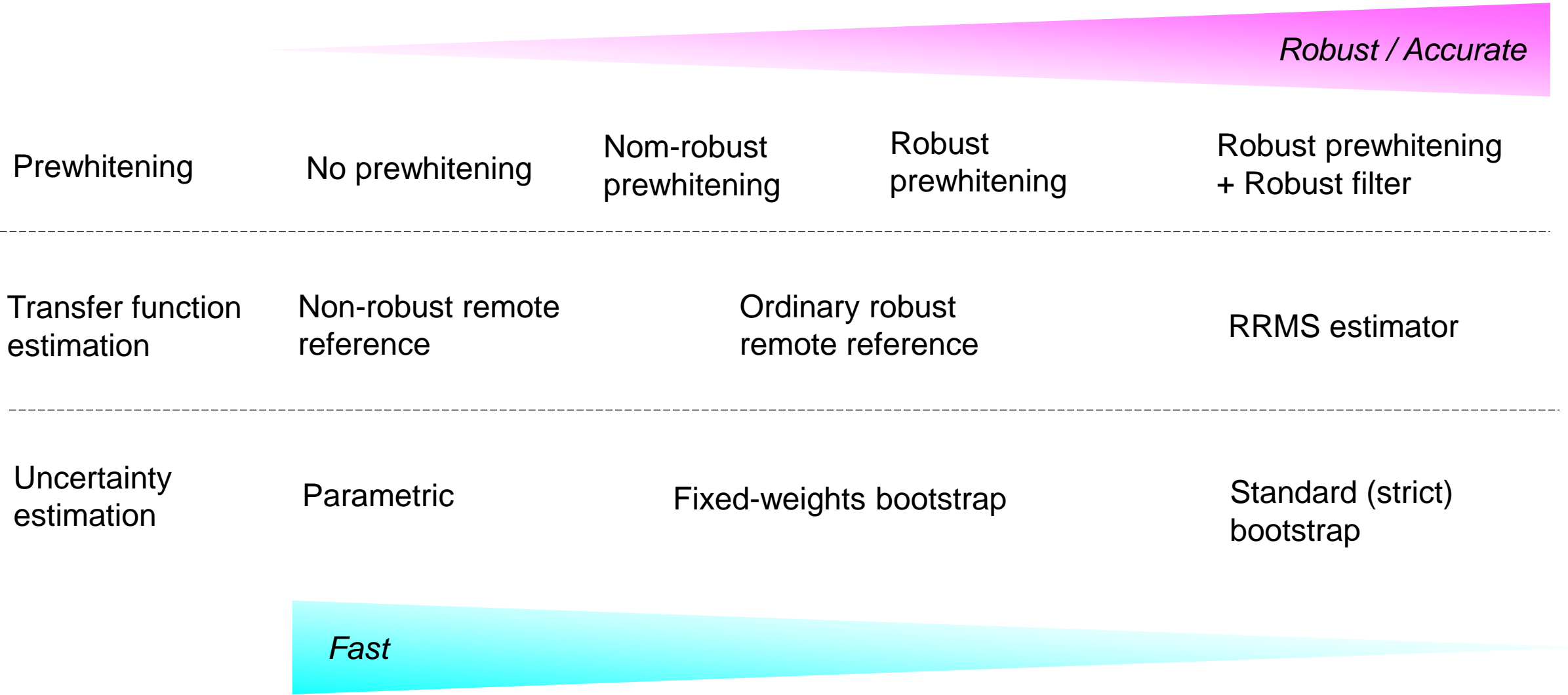
You can write .dat file directly if you use the keyword “ELOGMT\_BINARY”.

If your compiler supports C++17, you can use the following function by activating preprocessor “\_USE\_FILESYSTEM” in compiling.

If you write “\*.dat” under the directory name, all data files (of corresponding sampling frequency) under the directory are automatically read.

# Tradeoff between robustness and calculation speed

There are tradeoffs between robustness/accuracy and calculation speed



# Example of parameter setting (1) (Fast but not robust case)

|                         |   |                             |
|-------------------------|---|-----------------------------|
| <b>PROCEDURE</b>        |   |                             |
| 0                       | } | Non-robust remote reference |
| <b>MESTIMATORS</b>      |   |                             |
| -1                      |   |                             |
| -1                      |   |                             |
| <b>PREWHITENING</b>     | } | Non-robust prewhitening     |
| 0                       |   |                             |
| 10                      |   |                             |
| 5                       |   |                             |
| <b>ERROR_ESTIMATION</b> |   | Parametric error estimation |
| 0                       |   |                             |

# Example of parameter setting (2) (Intermediate case)

**PROCEDURE**

1 RRMS estimator

**RRMS**

0 TFs at the previous (lower) frequency are used as an initial candidate set, taking advantage of the smooth nature of MT TFs.  
100

3

0.05

10

16

0.01

**PREWHITENING**

1 Robust prewhitening

10

5

**ERROR\_ESTIMATION**

1 Fixed-weights bootstrap

# Example of parameter setting (3) (robust but not efficient case)

**PROCEDURE**

1 RRMS estimator

**PREWHITENING**

1  
10 Robust prewhitening  
5

**ROBUST\_FILTER**

0  
10 12 50 Robust filter  
10 12 50  
10 12 50  
10 12 50  
10 12 50  
10 12 50

**ERROR\_ESTIMATION**

2 Strict bootstrap