Time scale algorithm

~ *basics to applications* ~

* Training *

Yuko Hanado（ Retired NICT, Japan）

Bureau International des Poids et Mesures

CCTF Technical Exchange: “Time scale algorithms "
June 25, 2025

Purpose of this training:

1. To learn how to use the Python program "*TAgen_basic.py*"
   ※ *TAgen_basic.py* is a simulation tool for "*TAb*" [Ref.2].
   ※ *TAb* is "*TA by basic averaging*", which is the most primitive form of *TA*.
2. To get familiar with "*TAgen_basic.py*" through self-exercise
3. To understand how *TAb* changes depending on calculation conditions

※ For the exercise, you will need to set up Python on your computer and download the necessary materials. (see *p.35*)

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Contents

1. Overview

■ What shall we do in this training?

- Calculate TAb using the actual clock data and evaluate its quality (stability, continuity).

$$TAb(t) \equiv \sum_{i=1}^{N} w_i \cdot h_i(t) \quad \text{Here} \quad \sum_{i=1}^{N} w_i = 1$$

We can't get the 'h_i' values...

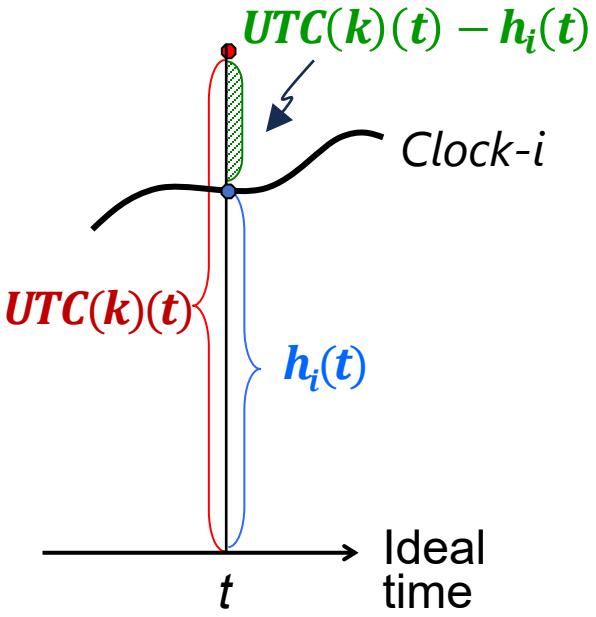
** See Eq.(1)&(2) of "TAb" in [Ref. 2]*

- Calculate "$UTC(k) - TAb$", and
- Compare its quality (stability, continuity) with "$UTC(k) - clocks$".

$$UTC(k) - TAb(t) \equiv \sum_{i=1}^{N} w_i \cdot \left(UTC(k) - h_i(t)\right)$$

Measurable !

$TAb(t)$: *average atomic time*
$h_i(t)$: *time(phase) difference of Clock-i from the ideal time*
w_i : *weight of Clock-i*

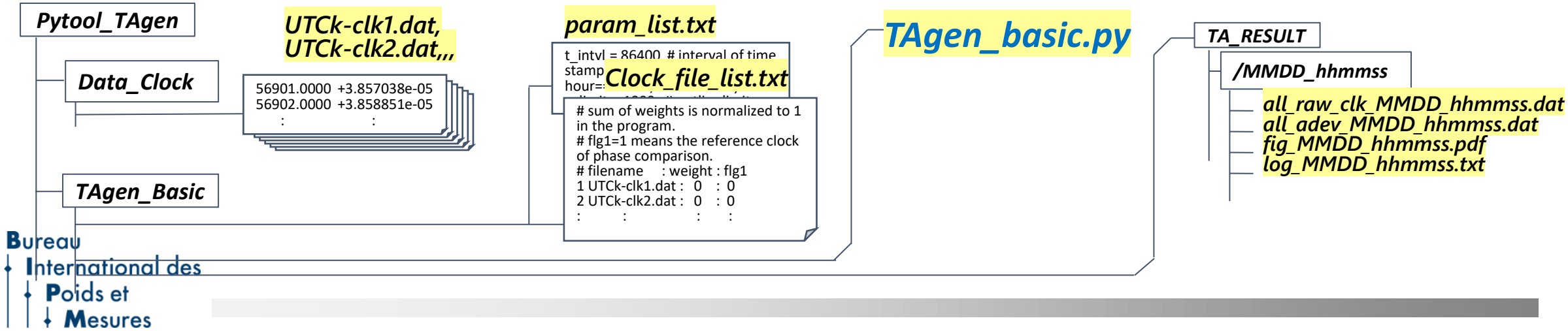


This is to be done with "*TAgen_basic.py*" !

1. Overview

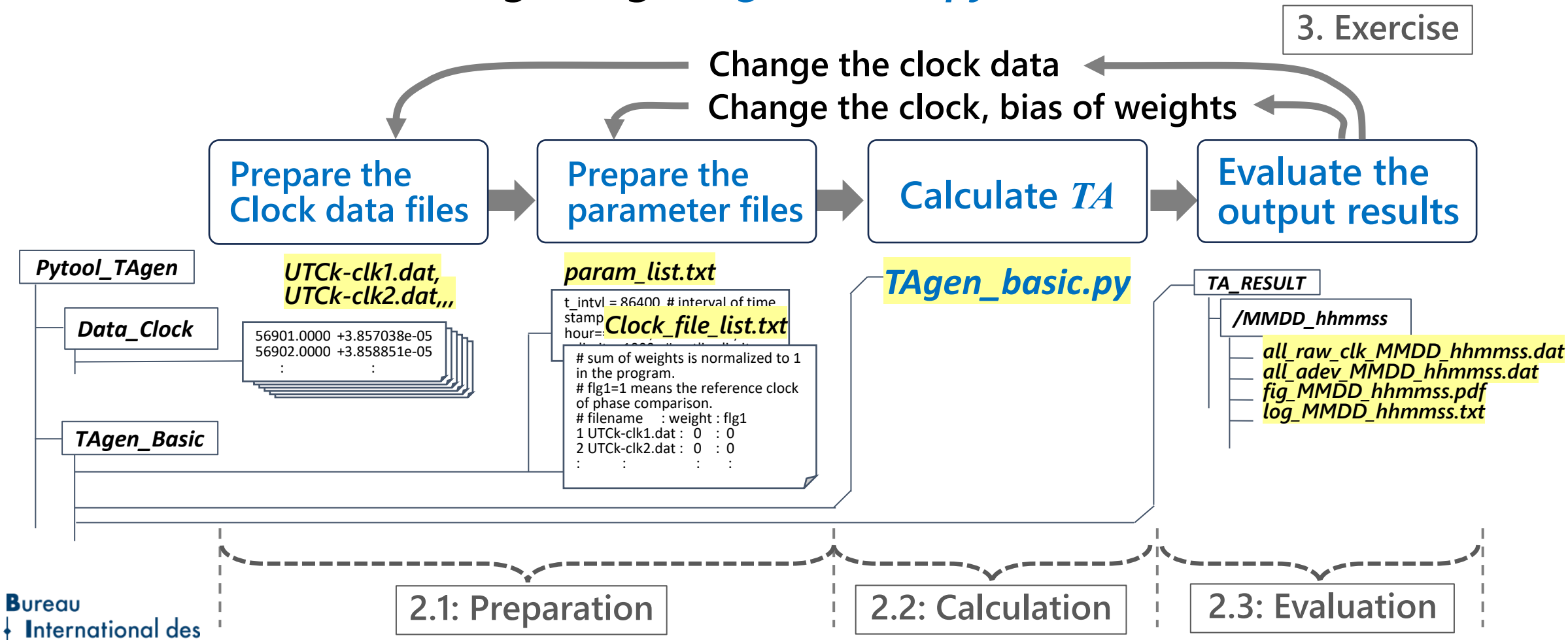
■ What is "*TAgen_basic.py*"?

- "***TAgen_basic.py***" is a simulation tool used for making ***TAb***, which is a basic weighted average of atomic clocks.
- It reads the clock data "***UTC(k)***-*clock*"s, calculates their average using the given starting weights, and displays the results of the "***UTC(k)***- ***TAb***" and its Allan deviation (*ADEV*).
- You can find further information about the ***TAb*** principle in the tutorial lecture [Ref. 2] and about the program in the user's manual [Ref. 3].



1. Overview

■ Process of the training using "*TAgen_basic.py*"

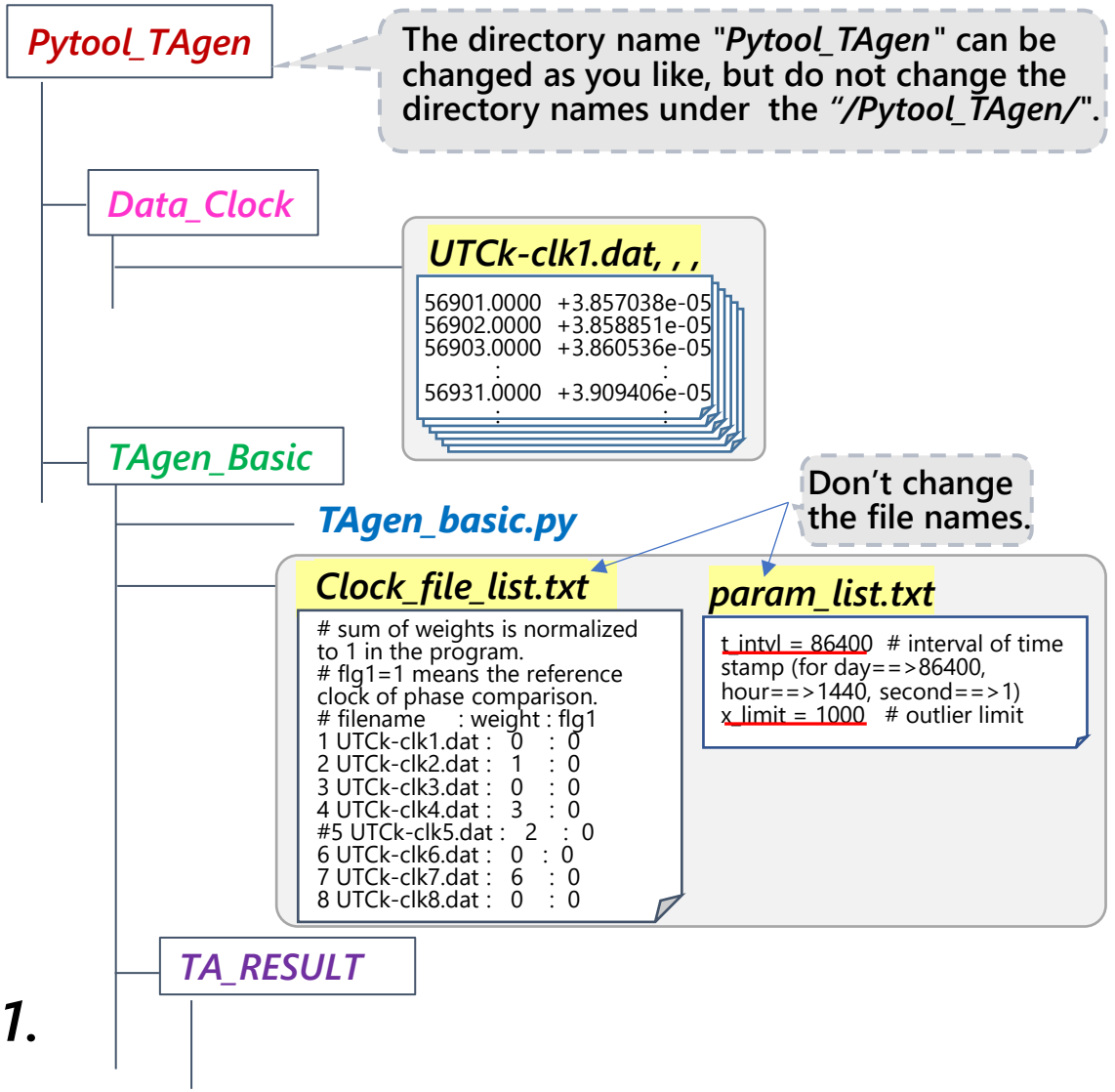


Contents

2.1 Preparation

1. Install Python on your computer.
2. Download all the materials [Ref.1].
   - All the directories and files should be copied correctly as in the right.
     - Clock measurement data : "/Pytool_TAgen/Data_Clock/***UTCk-(xxxx).dat***"
     - Clock-data name-list file : "/Pytool_TAgen/TAgen_Basic/***clock_file_list.txt***"
     - Parameter-list : "/Pytool_TAgen/TAgen_Basic/***param_list.txt***"
     - Python program : "***TAgen_basic.py***"

   ※ Do not change the names of the directories under "***/Pytool_TAgen/***", file names of "***clock_file_list.txt***" and "***param_list.txt***".
3. Check the execution of "***TAgen_basic.py***".



※ See the details in *Appendix-1*.

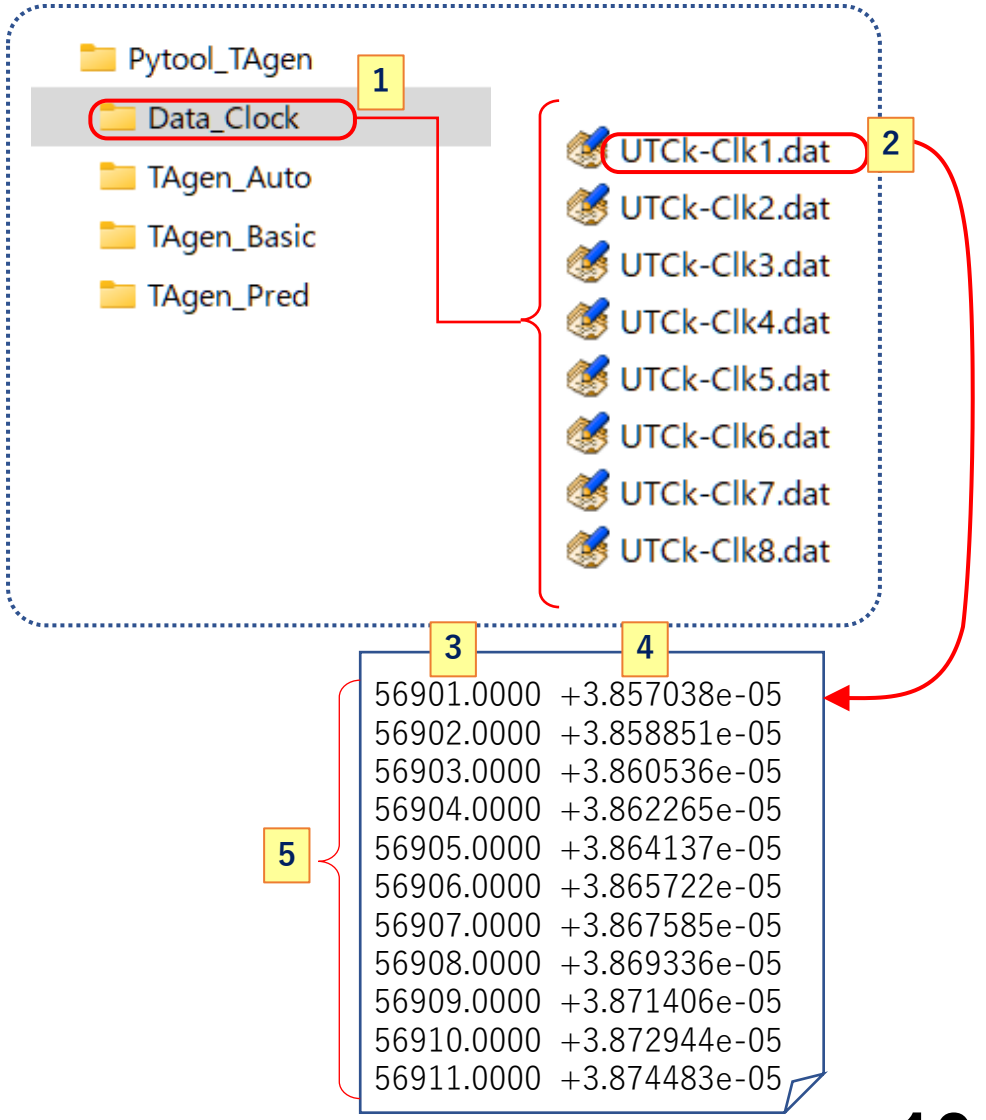
App-1 : Preparation for using "*TAgen_basic.py*"

[3] Prepare the clock measurement data in the folder "*/Pytool_TAgen/Data_Clock/*" 1

- One clock data is used for one data file.
- The file name should be "***UTCk-****.dat***" 2
  ("****" : clock name)
- The data should be the following format:
  - 1st column : observation time stamp 3
  - 2nd column : measurement time difference of "***UTC(k)*** – *clock*" (in seconds) 4
  - Delimiter : " "

※ The Interval of the 1st column should be specified as "***t_intvl***" in the "***param_list.txt***". 5

※ This sampling interval must be constant and continuous.



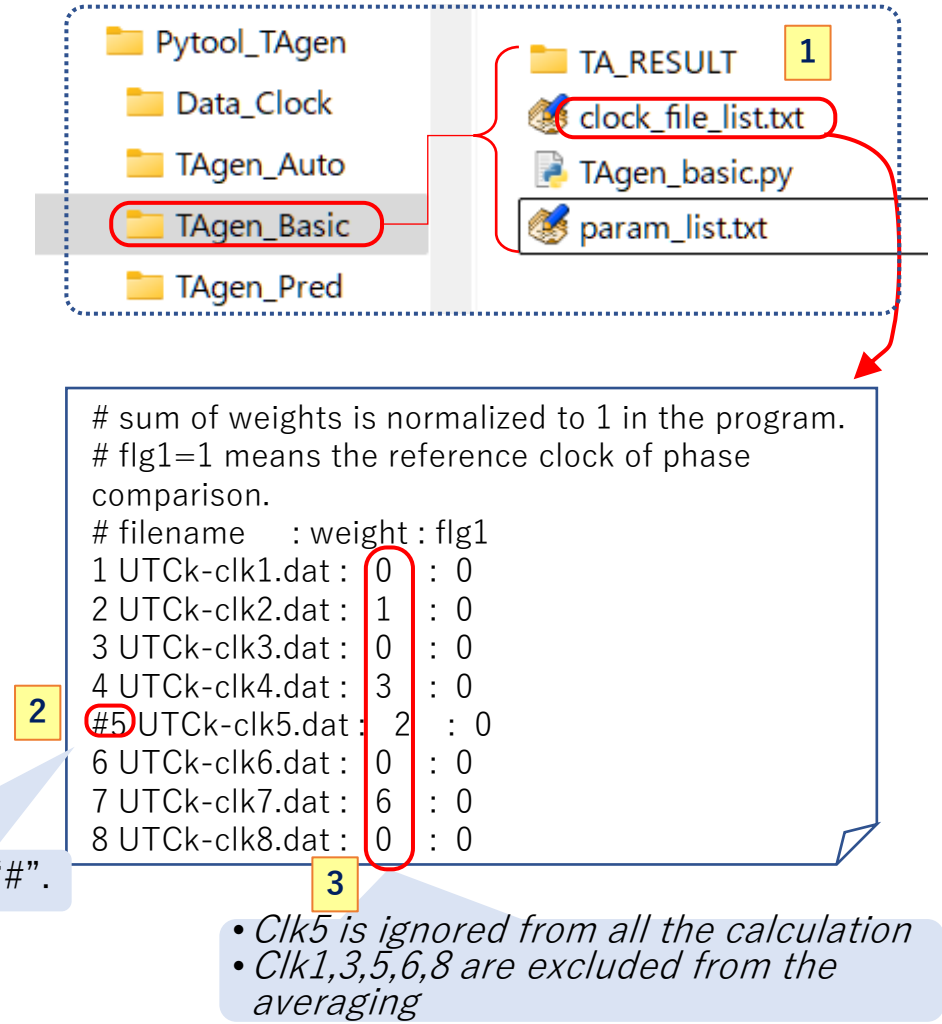
App-1 : Preparation for using "*TAgen_basic.py*"

[4] Prepare the clock-data name-list file:
"*/Pytool_TAgen/TAgen_Basic/clock_file_list.txt*" 1

- The "*clock_file_list.txt*" provides the conditions of each clock in the averaging process.
- The line starting with "**#**" is ignored. 2
  - 1st column : file No. (defines plot color)
  - 2nd column : data file name
  - 3rd column : weight in the averaging*1 3
  - 4th column : ***"flg1"*** (ignored) *2.

**1 : Each weight is normalized in the Python program.*

2 : The clock with **"flg1=1" plays a role in "**TAgen_pred.py**" and "**TAgen_auto.py**". **In TAgen_basic.py**", this flag is not used.*

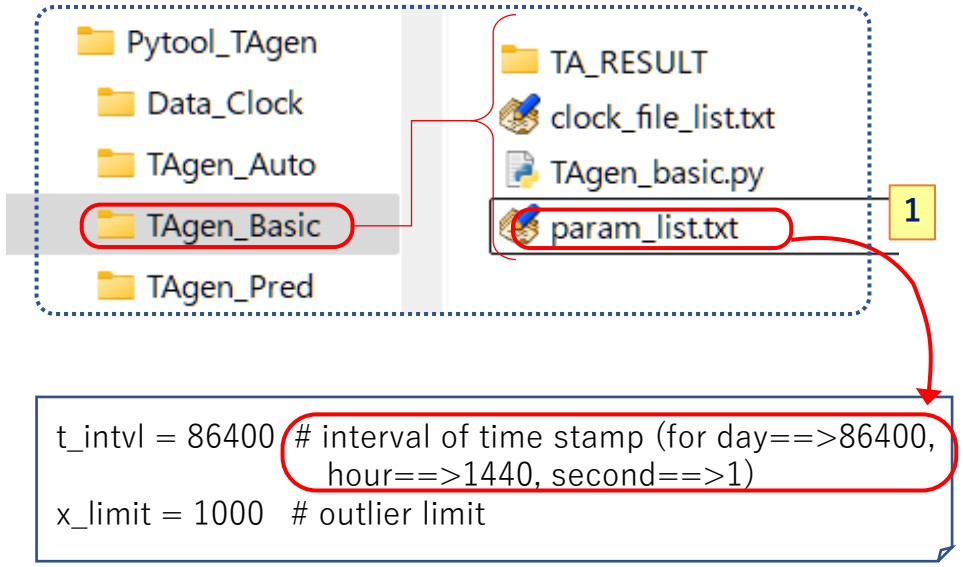


App-1 : Preparation for using "*TAgen_basic.py*"

[5] Prepare the parameter-list:

"/Pytool_TAgen/TAgen_Basic/param_list.txt" 1

- The parameter file "***param_list.txt***" provides the parameters in advance.
- These parameters are used with the same names in the program.
- The text after "**#**" provides the explanation of the parameter.
  - ***t_intvl*** : interval of time stamp
    (for day → *86400*, hour → *1440*, second → *1)*
  - ***x_limit*** : outlier limit



Contents

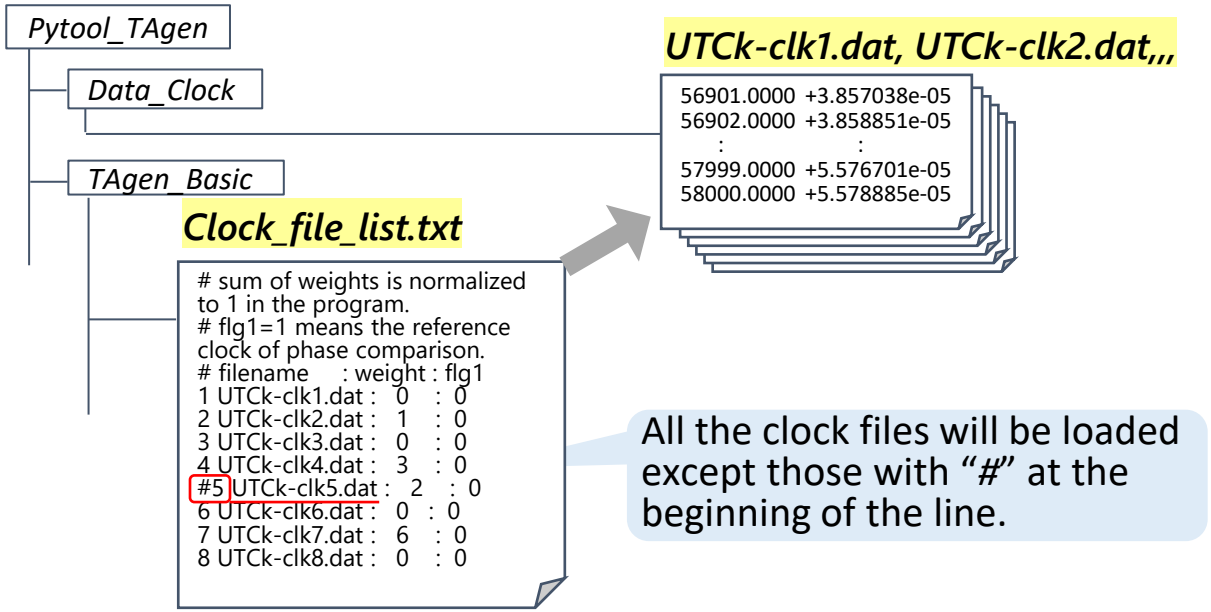
2.2 Calculation

■ Action-1 : Run "*TAgen_basic.py*"

➡ Initial processing is performed

1. Read the clock data listed in "*clock_file_list.txt*"

- Alert of outlier : outlier limit is set in the "***param_list.txt***". 1



Python 3.10.11 (tags/v3.10.11:7d4cc5a, Apr 5 2023, 00:38:17)
[MSC v.1929 64 bit (AMD64)]
Type "copyright", "credits" or "license" for more information.

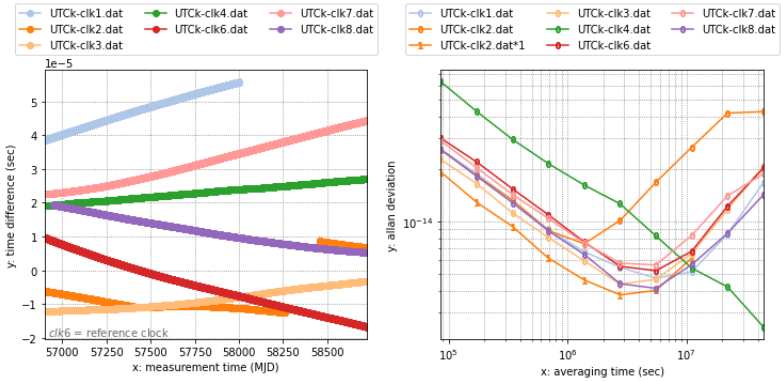
IPython 8.13.2 -- An enhanced Interactive Python.

runfile('C:/Mywork/Python/Pytool_TAgen/TAgen_Basic/TAgen_basic.py', wdir='C:/Mywork/Python/Pytool_TAgen/TAgen_Basic')

..... Reading initial data of 'UTC(k) - Clock'
..... Formatting the initial data for processing

********** Initial status of all clocks **********

!!!!! UTCk-clk2.dat includes outliers



????? Save figure? (y/n) =

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2.2 Calculation

■ Action-1 : Run "*TAgen_basic.py*"

➡ Initial processing is performed (Cont.)

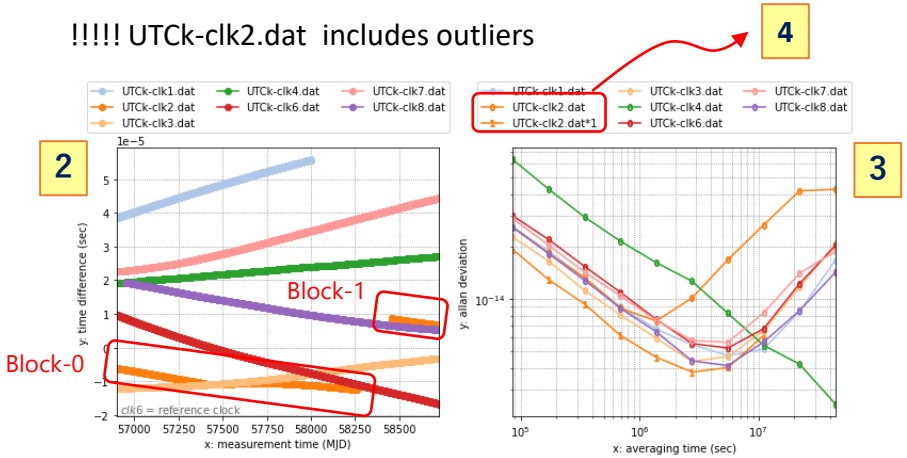
2. Plot all the raw data of "*UTC(k) – clock*"

- **Left fig. : Time difference of "*UTC(k) – clock*".** 2
  - *MJD*s are adopted for the maximum range of all data.
- **Right fig. : *ADEV* of "*UTC(k) – clock*".** 3
  - *ADEV* is calculated by "***AllanTools***" [Ref. 4].
  - If the data has discontinuous and divided into several blocks, the *ADEV* is plotted for each block and marked with "*1", "*2",,, .

  ("***UTCk_clk2.dat***" shows the ADEV of [block-0], and "***UTCk_clk2.dat*1***" shows the ADEV of [block-1].) 4

The purpose of this plotting is to confirm the condition of each clock data.

```
Python 3.10.11 (tags/v3.10.11:7d4cc5a, Apr  5 2023, 00:38:17)
[MSC v.1929 64 bit (AMD64)]
Type "copyright", "credits" or "license" for more information.

IPython 8.13.2 -- An enhanced Interactive Python.

runfile('C:/Mywork/Python/Pytool_TAgen/TAgen_Basic/TAgen_basi
c.py', wdir='C:/Mywork/Python/Pytool_TAgen/TAgen_Basic')

..... Reading initial data of 'UTC(k) - Clock'
..... Formatting the initial data for processing

************ Initial status of all clocks ************

!!!!! UTCk-clk2.dat  includes outliers
```




```
????? Save figure? (y/n) =
```

2.2 Calculation

■ Action-1 : Run "*TAgen_basic.py*"

➡ Initial processing is performed (Cont.)

3. Save the results, if required

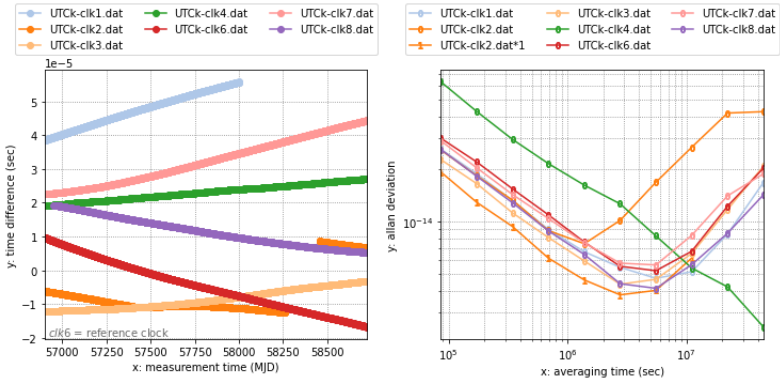
5

- If input "***y***" for "*Save figure (y/n) = "* ,
  four results are saved under the following directory
  "***./TA_RESULT/(time)/***" with a time stamp of data saving.

  - ***Log_(time).txt*** : **history of the process**
  - ***fig _(time).pdf*** : **both figures**
  - ***all_raw_clk_(time).dat***: "***UTC(k)-clock***" **(left fig)**
  - ***all_adev_(time).dat*** : ***ADEV* of "*UTC(k)-clock*" (right fig)**

※ *(time)* is "*MMDD_hhmmss*" of operation time-stamp

- *MMDD* : month and date
- *hhmmss* : hour, minute and second



????? Save figure? (y/n) = y 5

::::: save logfile = ./TA_RESULT/0523_161029/log_0523_161029.txt
::::: save figfile = ./TA_RESULT/0523_161029/fig_0523_161029.pdf
::::: save alldata = ./TA_RESULT/0523_161029/all_raw_clk_0523_161029.dat
::::: save ADEVdat = ./TA_RESULT/0523_161029/all_adev_0523_161029.dat

==========
Menu of the TA processing
---
0. Plot the "UTC(k)-Clock" data
1. Assign the MJD range
2. De-trend "UTC(k)-Clock" data
3. Make TA with simple averaging
10. Exit
==========

????? Input menu number ? >>

App-2 : Relation of input/output files

Clock_file_list.txt

```
# sum of weights is normalized
to 1 in the program.
# flg1=1 means the reference
clock of phase comparison.
# filename    : weight : flg1
1 UTCk-clk1.dat :  0   : 0
2 UTCk-clk2.dat :  1   : 0
3 UTCk-clk3.dat :  0   : 0
4 UTCk-clk4.dat :  3   : 0
#5 UTCk-clk5.dat :  2   : 0
6 UTCk-clk6.dat :  0   : 1
7 UTCk-clk7.dat :  6   : 0
8 UTCk-clk8.dat :  0   : 0
```

UTCk-clk1.dat

```
56901.0000  +3.857038e-05
56902.0000  +3.858851e-05
     :           :
57999.0000  +5.576701e-05
58000.0000  +5.578885e-05
```

all_raw_clk_0523_161029.dat

fname	UTCk-clk1.dat	UTCk-clk2.dat	UTCk-clk3.dat	UTCk-clk4.dat	UTCk-clk6.dat	UTCk-clk7.dat	UTCk-clk8.dat
Weight	0.0	1.0	0.0	3.0	0.0	6.0	0.0
flag	0	0	0	0	1	0	0
cid	1	2	3	4	6	7	8
56901	+3.857038e-05	-6.184638e-06	-1.215249e-05	+1.918367e-05	+9.635976e-06	+2.258480e-05	+nan
56902	+3.858851e-05	-6.197517e-06	-1.215115e-05	+1.919092e-05	+9.617261e-06	+2.258759e-05	+nan
:	:	:	:	:	:	:	:
58725	+nan	+6.693075e-06	-3.187783e-06	+2.707895e-05	-1.676407e-05	+4.440954e-05	+5.273111e-06
58726	+nan	+6.687379e-06	-3.180825e-06	+2.708426e-05	-1.677650e-05	+4.442301e-05	+5.270004e-06

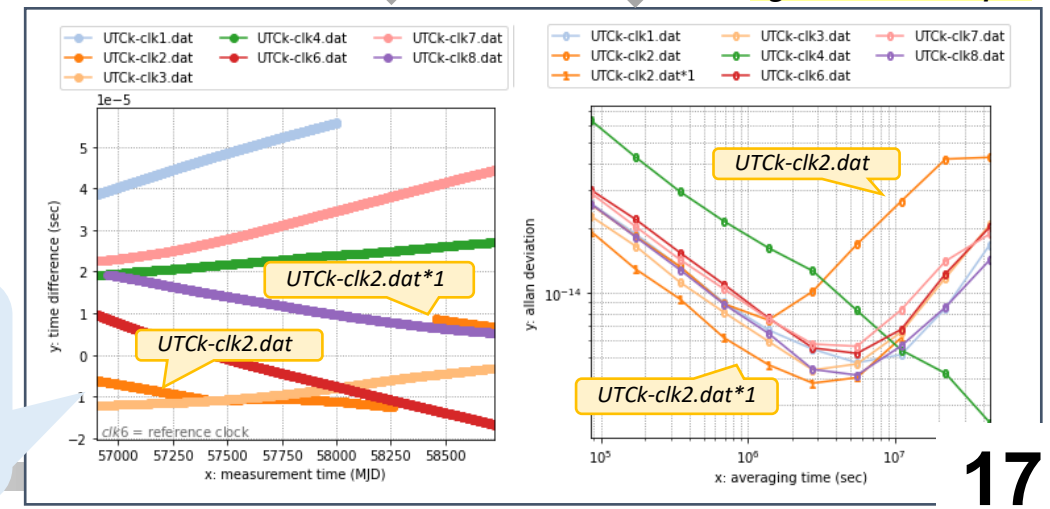
- The combined data of all '***UTC(k)-clock***' except *clk5*.
- The '***weight***','***flag***' **and** '***cid***' are the copies from '***Clock_flie_list.txt***'.
- *ADEV*s are calculated from this data.

all_adev_0523_161029.dat

Tau(s)	UTCk-clk1.dat	UTCk-clk2.dat	UTCk-clk2.dat*1	UTCk-clk3.dat	UTCk-clk4.dat	UTCk-clk6.dat	UTCk-clk7.dat	UTCk-clk8.dat
MJDspan	**56901-58000**	**56901-58260**	**58457-58726**	**56901-58726**	**56901-58726**	**56901-58726**	**56901-58726**	**56952-58726**
86400	+2.585226e-14	+2.559433e-14	+1.914455e-14	+2.255109e-14	+6.289309e-14	+2.989441e-14	+2.887262e-14	+2.576366e-14
172800	+1.871863e-14	+1.824332e-14	+1.284166e-14	+1.643061e-14	+4.258263e-14	+2.186610e-14	+2.024180e-14	+1.811728e-14
345600	+1.314144e-14	+1.320590e-14	+9.326690e-15	+1.116636e-14	+2.944345e-14	+1.532961e-14	+1.422621e-14	+1.275807e-14
:	:	:	:	:	:	:	:	:
22118400	+8.453397e-15	+4.172218e-14	+nan	+1.168016e-14	+4.207961e-15	+1.222042e-14	+1.399682e-14	+8.546454e-15
44236800	+1.668442e-14	+4.249225e-14	+nan	+2.068302e-14	+2.484683e-15	+2.016610e-14	+1.872125e-14	+1.418509e-14

- '***MJDspan***' is the period used in the *ADEV* calculation.
- If there are not sufficient samples, *ADEV* cannot be calculated and is expressed as '*nan*'.

fig_0523_161029.pdf



log_0523_161029.txt

```
# Data log at 2025.05.23_16h10m_29s
#
**0** Read and plot initial clock data and Allan deviation*****
::::: Input clocklist  : clock_file_list.txt
::::: Input clock file : ['UTCk-clk1.dat', 'UTCk-clk2.dat', 'UTCk-clk3.dat',
'UTCk-clk4.dat', 'UTCk-clk6.dat', 'UTCk-clk7.dat', 'UTCk-clk8.dat']
::::: data time interval (t_intval): 86400(sec)
::::: Outlier limit (x_limit))    : 1000.0
```

- Operated menu processes are serially added to the log file.

- "***UTCk-clk2***" includes anomalies on *MJD 58261 ~58456*, and they are treated as missing data.
- The data are divided into two blocks before/after the anomalies.
- *ADEV*s are calculated for each block.

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2.2 Calculation

■ Selection of the processing menu: 1

"0. Plot the "*UTC(k)-Clock*" data"

- Read all the data assigned in *"**clock_file_list.txt**"*, and plot the time differences vs ***UTC(k)*** and their *ADEV*s.
- **This operation Initializes all the processing to date.**

"1. Assign the MJD range"

- The specified range will be used for all subsequent processing unless "*menu-0*" is selected.

"2. De-trend "*UTC(k)-Clock*" data"

- De-trend the data over the entire data range.

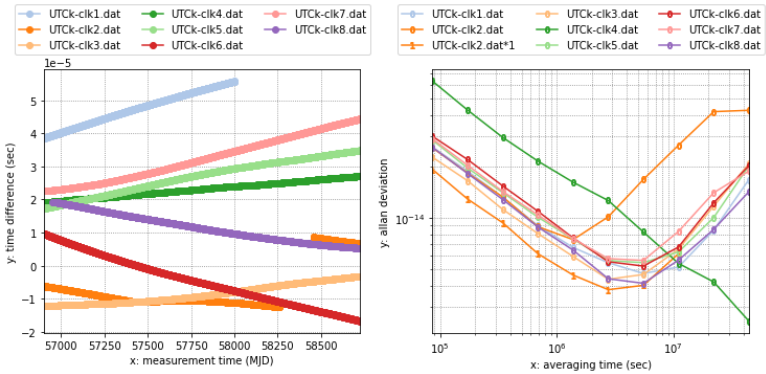
"3. Make *TA* with simple averaging*" *1

- Simple weighted average of "***UTC(k)-Clock***" data.

"10. Exit"

- Exit the program.

1: See "TAb**"in [Ref. 2]*



????? Save figure? (y/n) = y

::::: save logfile = ./TA_RESULT/0523_161029/log_0523_161029.txt
::::: save figfile = ./TA_RESULT/0523_161029/fig_0523_161029.pdf
::::: save alldata = ./TA_RESULT/0523_161029/all_raw_clk_0523_161029.dat
::::: save ADEVdat = ./TA_RESULT/0523_161029/all_adev_0523_161029.dat

```
=======================================
     Menu of the TA processing
---------------------------------------
 0.  Plot the "UTC(k)-Clock" data
 1.  Assign the MJD range
 2.  De-trend "UTC(k)-Clock" data
 3.  Make TA with simple averaging
10.  Exit
=======================================
```

1

????? Input menu number ? >>

2.2 Calculation

■ Action-2 : Select "*menu-3*" 1

1. Calculate $UTC(k) - TAb$ (See p.5)

$$TAb \equiv \sum_{i=1}^{N} w_i \cdot h_i \quad \text{here} \quad \sum_{i=1}^{N} w_i = 1$$

$$UTC(k) - TAb \equiv \sum_{i=1}^{N} w_i \quad UTC(k) - \sum_{i=1}^{N} w_i \cdot h_i$$

$$UTC(k) - TAb \equiv \sum_{i=1}^{N} w_i \cdot (UTC(k) - clock_i)$$

※1 "*UTC(k)-clock*" is the clock data under "*/Data_Clock*".

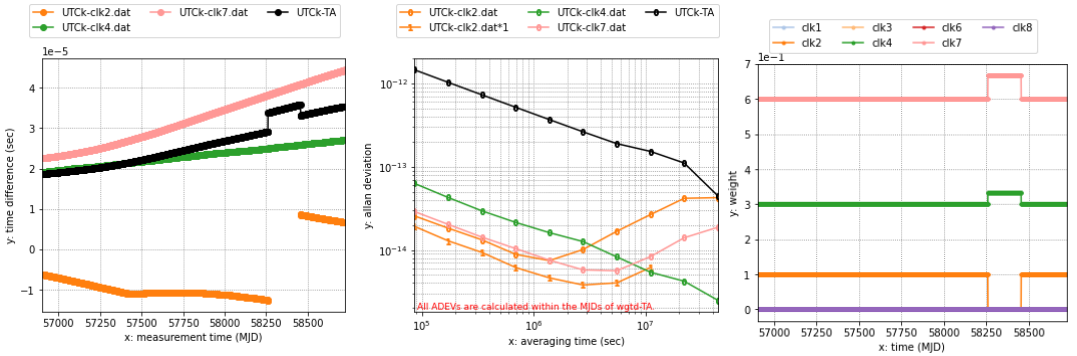
※2 "w_i" is a fixed weight given in "*clock_file_list.txt*".
(Normalized in the program.)

※3 Outlier (> "*x_limit*") is removed before averaging.
*("x_limit" is set in the "**param_list.txt**".)*

```
=======================================
    Menu of the TA processing
---------------------------------------
 0.  Plot the "UTC(k)-Clock" data
 1.  Assign the MJD range
 2.  De-trend "UTC(k)-Clock" data
 3.  Make TA with simple averaging
10.  Exit
=======================================

????? Input menu number ? >> 3   1

!!!!! UTCk-clk2.dat  includes outliers
!!!!! UTCk_clk2.txt  includes outliers
```




```
????? Save figure? (y/n) = y

::::: save logfile =  ./TA_RESULT/0531_151852/log_0531_151852.txt
::::: save figfile =  ./TA_RESULT/0531_151852/fig_0531_151852.pdf
::::: save alldata =  ./TA_RESULT/0531_151852/all_raw_clk_ave_0531_151852.dat
::::: save ADEVdat =  ./TA_RESULT/0531_151852/all_adev_0531_151852.dat
::::: save weights =  ./TA_RESULT/0531_151852/all_weight_0531_151852.dat
```

2.2 Calculation

■ Action-3 : Select "*menu-3*" (Cont.)

2. Plot "*UTC(k) – TA*" & "*UTC(k) – clock*" 2

- Left fig. : "***UTC(k)-TA***" & ***"UTC(k)-clock"***
- Middle : *ADEV* of each data of left figure
- Right : corresponding weights of used clocks

3. Save the results, if required 3

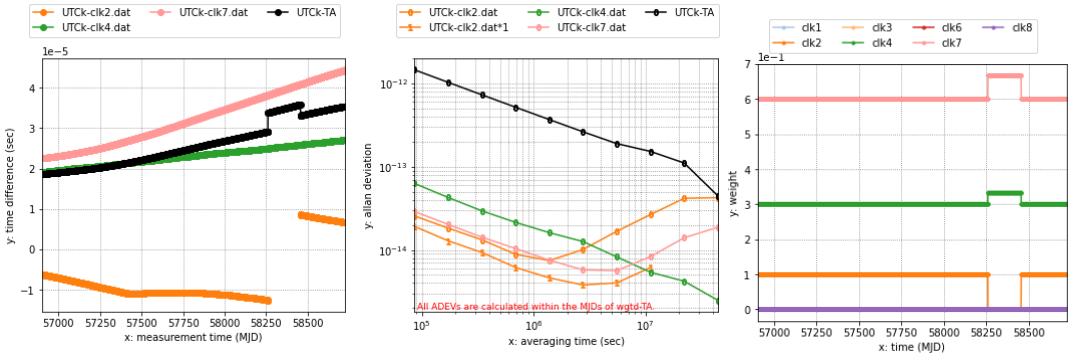
- The results are saved under ***"./TA_RESULT/(time)/"***.

- *Log_(time).txt* : history of the process
- *fig _(time).pdf* : all figures
- *all_("raw"/"det")_clk_ave_(time).dat* : (left fig)
- *all_adev_(time).dat* : *ADEV* data (right fig)

```
=======================================
    Menu of the TA processing
---------------------------------------
 0.  Plot the "UTC(k)-Clock" data
 1.  Assign the MJD range
 2.  De-trend "UTC(k)-Clock" data
 3.  Make TA with simple averaging
10.  Exit
=======================================
????? Input menu number ? >> 3   1

!!!!! UTCk-clk2.dat  includes outliers
!!!!! UTCk_clk2.txt  includes outliers
```

2




```
????? Save figure? (y/n) = y   3

::::: save logfile =  ./TA_RESULT/0531_151852/log_0531_151852.txt
::::: save figfile =  ./TA_RESULT/0531_151852/fig_0531_151852.pdf
::::: save alldata =  ./TA_RESULT/0531_151852/all_raw_clk_ave_0531_151852.dat
::::: save ADEVdat =  ./TA_RESULT/0531_151852/all_adev_0531_151852.dat
::::: save weights =  ./TA_RESULT/0531_151852/all_weight_0531_151852.dat
```

App-2 : Relation of input/output files

- ***"UTC(k)-TA"*** is the weighted average of ***"UTCk-clk.dat"*** of *clock2, clock4* and *clock7*.

Clock_file_list.txt

```
# sum of weights is normalized
to 1 in the program.
# flg1=1 means the reference
clock of phase comparison.
# filename    : weight : flg1
1 UTCk-clk1.dat :  0   : 0
2 UTCk-clk2.dat :  1   : 0
3 UTCk-clk3.dat :  0   : 0
4 UTCk-clk4.dat :  3   : 0
#5 UTCk-clk5.dat :  2   : 0
6 UTCk-clk6.dat :  0   : 1
7 UTCk-clk7.dat :  6   : 0
8 UTCk-clk8.dat :  0   : 0
```

Clocks used in the averaging

UTCk-clk1.dat

```
56901.0000  +3.857038e-05
56902.0000  +3.858851e-05
      :           :
57999.0000  +5.576701e-05
58000.0000  +5.578885e-05
```

all_raw_clk_ave_0531_151852.dat

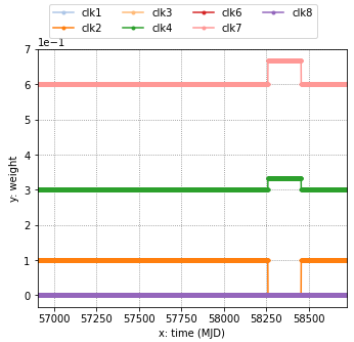
fname	UTCk-clk1.dat	UTCk-clk2.dat	UTCk-clk3.dat	UTCk-clk4.dat	UTCk-clk6.dat	UTCk-clk7.dat	UTCk-clk8.dat	UTCk-TA
Weight	0.0	1.0	0.0	3.0	0.0	6.0	0.0	0.0
flag	0	0	0	0	1	0	0	3
cid	1	2	3	4	6	7	8	0
56901	+3.857038e-05	-6.184638e-06	-1.215249e-05	+1.918367e-05	+9.635976e-06	+2.258480e-05	+nan	+1.868752e-05
56902	+3.858851e-05	-6.197517e-06	-1.215115e-05	+1.919092e-05	+9.617261e-06	+2.258759e-05	+nan	+1.869008e-05
:	:	:	:	:	:	:	:	:
58725	+nan	+6.693075e-06	-3.187783e-06	+2.707895e-05	-1.676407e-05	+4.440954e-05	+5.273111e-06	+3.543872e-05
58726	+nan	+6.687379e-06	-3.180825e-06	+2.708426e-05	-1.677650e-05	+4.442301e-05	+5.270004e-06	+3.544782e-05

- These weights are copied from "***clock_file_list.txt***". They are normalized in the averaging.

all_adev_0531_151852.dat

Tau(s)	UTCk-clk2.dat	UTCk-clk2.dat*1	UTCk-clk4.dat	UTCk-clk7.dat	UTCk-TA
MJDspan	56901-58260	58457-58726	56901-58726	56901-58726	56901-58726
86400	+2.559433e-14	+1.914455e-14	+6.289309e-14	+2.887262e-14	+1.459261e-12
172800	+1.824332e-14	+1.284166e-14	+4.258263e-14	+2.024180e-14	+1.031497e-12
345600	+1.320590e-14	+9.326690e-15	+2.944345e-14	+1.422621e-14	+7.309588e-13
:	:	:	:	:	:
11059200	+2.657653e-14	+6.159347e-15	+5.398695e-15	+8.314322e-15	+1.528285e-13
22118400	+4.172218e-14	+nan	+4.207961e-15	+1.399682e-14	+1.108404e-13
44236800	+4.249225e-14	+nan	+2.484683e-15	+1.872125e-14	+4.465014e-14

wgt_fig_0531_151832.dat

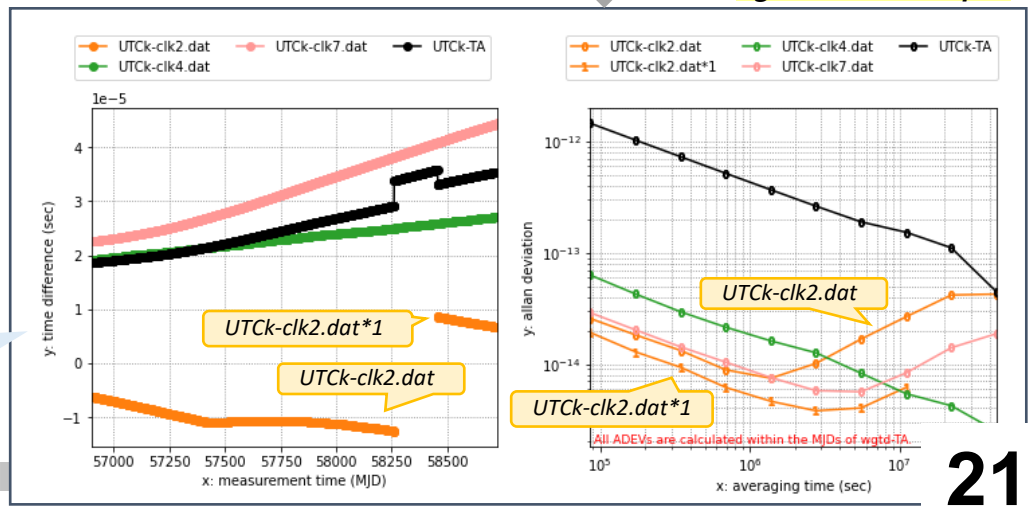


all_weight_0531_151852.dat

MJD	clk1	clk2	clk3	clk4	clk6	clk7	clk8
56901.0	0.00	0.10	0.00	0.30	0.00	0.60	0.00
56902.0	0.00	0.10	0.00	0.30	0.00	0.60	0.00
:	:	:	:	:	:	:	:
58260.0	0.00	0.10	0.00	0.30	0.00	0.60	0.00
58261.0	0.00	0.00	0.00	0.33	0.00	0.67	0.00
:	:	:	:	:	:	:	:
58726.0	0.00	0.00	0.00	0.33	0.00	0.67	0.00

- Due to an anomaly, *Clock2* lost the weight on *MJD58261,* and other weights were also affected by normalization.

fig_0531_151852.pdf



log_0531_151852.txt

```
# Data log at 2025.05.23_16h13m_33s
#
**0** Read and plot initial clock data and Allan deviation*****
::::: Input clocklist  : clock_file_list.txt
::::: Input clock file : ['UTCk-clk1.dat', 'UTCk-clk2.dat', 'UTCk-clk3.dat',
'UTCk-clk4.dat', 'UTCk-clk6.dat', 'UTCk-clk7.dat', 'UTCk-clk8.dat']
::::: data time interval (t_intval): 86400(sec)
::::: Outlier limit (x_limit))     : 1000.0

**3** Weighted average *****
::::: Input data file  : all_raw_clk.dat
::::: Saved joint data : all_raw_clk_ave.dat
::::: Weight of clocks : all_weight.dat
```

- ***TA*** shows a big jump due to *Clock2*, so that its *ADEV* does not reflect its intrinsic behavior.

- The operated menu processes are serially added in the log file.

Contents

2.3 Evaluation, and Change of conditions

■ Evaluation ~ What focus on?

※ **Run the program with the "*clock_file_list.txt*" on the right.**

Set all the weights for *Clock-5, Clock-6 and Clock-7* to '*1*'.

Case- 1

```
# sum of weights is normalized to 1 in the program.
# flg1=1 means the reference clock of phase comparison.
# filename     : weight : flg1
1 UTCk-clk1.dat :  0  : 0
2 UTCk-clk2.dat :  0  : 0
3 UTCk-clk3.dat :  0  : 0
4 UTCk-clk4.dat :  0  : 0
5 UTCk-clk5.dat :  1  : 0
6 UTCk-clk6.dat :  1  : 1
7 UTCk-clk7.dat :  1  : 0
8 UTCk-clk8.dat :  0  : 0
```

Correct the file with a text editor!

"clock_file_list.txt"

- **Continuity :**
  - In Fig.1, no unusual behaviors are in any clocks or ***TAb***. That is, clock selection is OK.
- **Stability :**
  - In Fig. 2, ***TAb*** shows better *ADEV* than each of the clocks.
  - Looking more closely, the short-term *ADEV* of ***TAb*** is approximately $1/\sqrt{3}$ of that of each clock.
  - This result is reasonable considering that the *ADEV* of each clock is almost the same.

Fig. 1

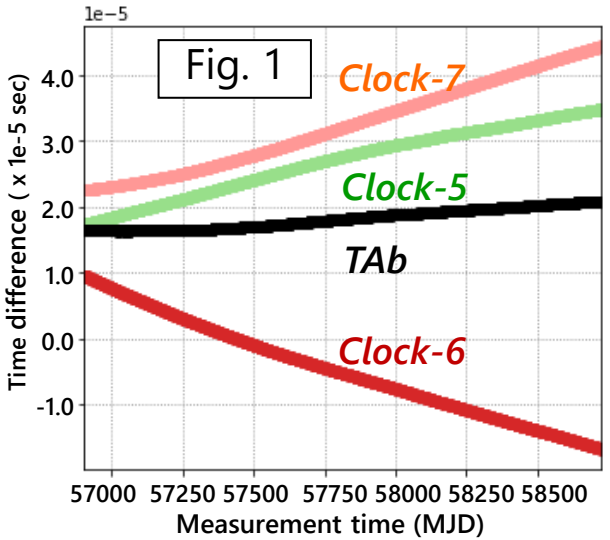
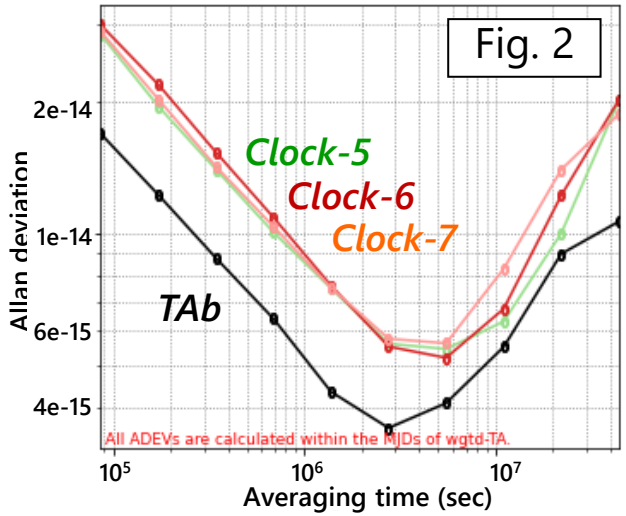


Fig. 2



/0531_161512

2.3 Evaluation, and Change of conditions

■ Try-1 : Change the clocks

※ **Run the program with the "*clock_file_list.txt*" on the right.**

Set all the weights for *Clock-2, Clock-4 and Clock-6* to '*1*'.

Case- 2

```
# sum of weights is normalized to 1 in the program.
# flg1=1 means the reference clock of phase comparison.
# filename     : weight : flg1
1 UTCk-clk1.dat :  0   : 0
2 UTCk-clk2.dat :  1   : 0
3 UTCk-clk3.dat :  0   : 0
4 UTCk-clk4.dat :  1   : 0
5 UTCk-clk5.dat :  0   : 0
6 UTCk-clk6.dat :  1   : 1
7 UTCk-clk7.dat :  0   : 0
8 UTCk-clk8.dat :  0   : 0
```

Correct the file with a text editor!

"clock_file_list.txt"

- **Continuity and Stability :**
  - Due to anomaly of *Clock-2* on *MJD58261~58456*, ***TAb*** shows a big jump and its *ADEV* was degraded. ..... Not good!

- **Let's try a different calculation range to avoid the anomaly event.**

Fig. 1

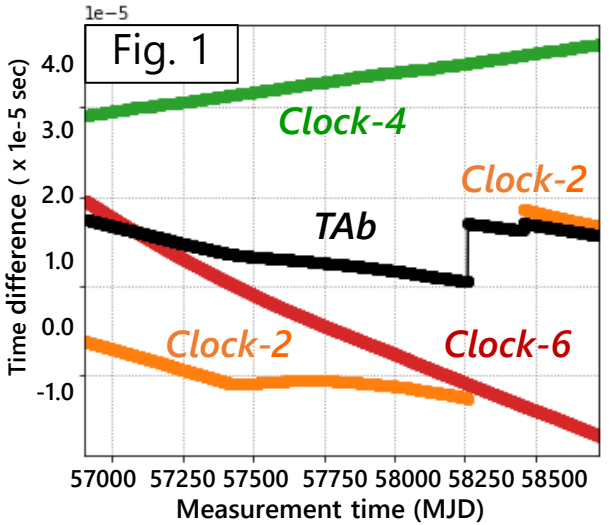
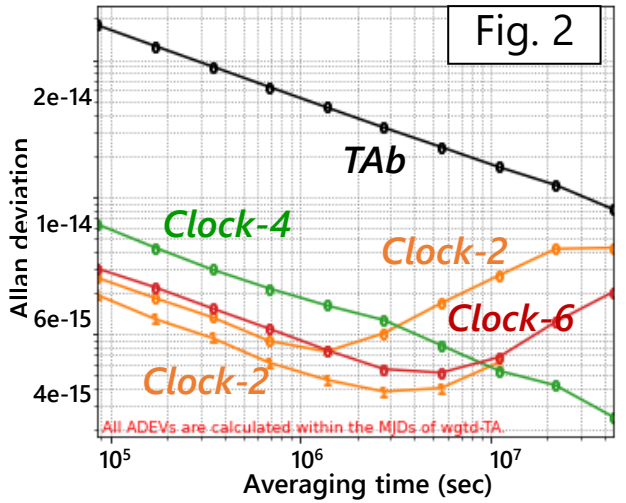


Fig. 2



/0531_161655

2.3 Evaluation, and Change of conditions

■ Try-2 : Change the calculation range

1. Select *"menu-1"* 1
   - The data range is assigned as "[*MJD1, MJD2*]".
2. Input *"MJD1"* and *"MJD2"* separated by a space 2
   - If the input values are outside the available range, re-entering is requested with an error message.
   - If the values are within the available range, the data processing range is updated.
   - *ADEV* is calculated using the new data range. 3
   - Save the results, if required. 4

※ This new data range will be used in any subsequent processes, unless initialization is done using *"menu-0"*.

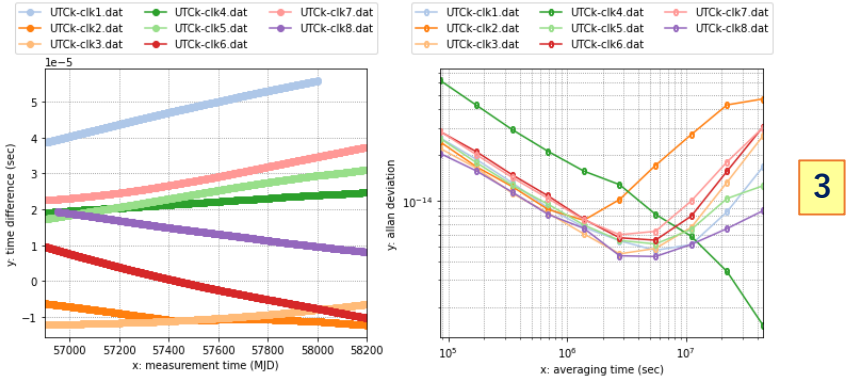
```
=======================================
    Menu of the TA processing
---------------------------------------
 0.  Plot the "UTC(k)-Clock" data
 1.  Assign the MJD range
 2.  De-trend "UTC(k)-Clock" data
 3.  Make TA with simple averaging
10.  Exit
=======================================

????? Input menu number ? >> 1   1

**1** Assign the MJD range for calculation in [56901,58726].

??1?? Input MJD1 and MJD2 with spacing = 56901 58200   2

**1** Selected range is : [ 56901  -  58200 ]
```



3

```
????? Save figure? (y/n) = n   4

=======================================
    Menu of the TA processing                (Cont.)
```

2.3 Evaluation, and Change of conditions

■ Try-2 : Change the calculation range (Cont.)

3. Select *"menu-3"* again 5

- *TAb* is calculated in the new assigned range.

- **By changing the calculation range, continuous *TAb* was calculated.**
- All the operation process and setting range are confirmed in the log-file.

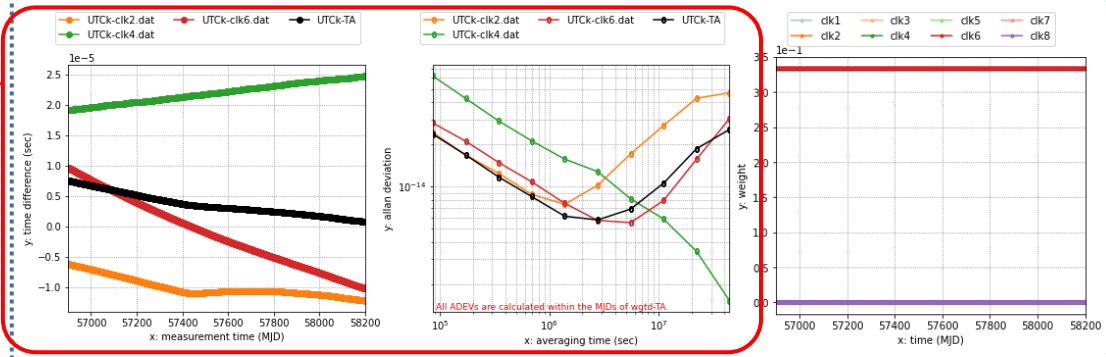
```
# Data log at 2025.05.27_19h46m_30s
#
**0** Read and plot initial clock data and Allan deviation*****
   :
**1** Assign the MJD range for calculation *****
::::: Selected MJD    :  [56901 - 58200]

**3** Weighted average *****
::::: Input data file  : all_raw_clk.dat
::::: Saved joint data : all_raw_clk_ave.dat
::::: Weight of clocks : all_weight.dat
```

```
????? Save figure? (y/n) = n

=======================================
    Menu of the TA processing                    (Cont.)
---------------------------------------
 0.  Plot the "UTC(k)-Clock" data
 1.  Assign the MJD range
 2.  De-trend "UTC(k)-Clock" data
 3.  Make TA with simple averaging
10.  Exit
=======================================

????? Input menu number ? 3   5
```




```
????? Save figure? (y/n) = y

::::: save logfile =  ./TA_RESULT/0531_162336/log_0531_162336.txt
::::: save figfile =  ./TA_RESULT/0531_162336/fig_0531_162336.pdf
::::: save alldata =  ./TA_RESULT/0531_162336/all_raw_clk_ave_0531_162336.dat
::::: save ADEVdat =  ./TA_RESULT/0531_162336/all_adev_0531_162336.dat
::::: save weights =  ./TA_RESULT/0531_162336/all_weight_0531_162336.dat
=======================================
    Menu of the TA processing
---------------------------------------
```

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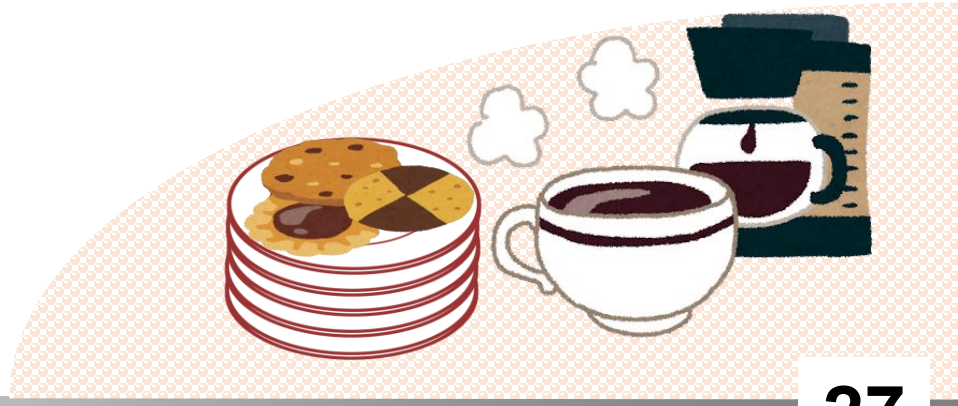
Contents



3. Exercise

A) Run "*TAgen_basic.py*", and get familiar with the operation

1. **Set the parameters of "*clock_file_list.txt*" as you like, in advance.**
   ※ Don't forget to save the file after making any correction.
2. **Run "*TAgen_basic.py*":**
   2.1. Select "*menu-3*".
   2.2. Save the results.
   ※ If you update the "*clock_file_list.txt*", you must exit and restart the program. (Otherwise, the previous "***clock_file_list.txt***" will remain in use.)
   ※ To initialize the operation, select "*menu-0*".
   ※ All processes of your operation can be confirmed in the "***log-MMDD_hhmmss.txt***."
3. **Confirm the output results in "*./TA_RESULT/*".**

For example:
[Case-1] on p.18,
[Case-2] on p.19.

3. Exercise

B) Change the ratio of the clock weights

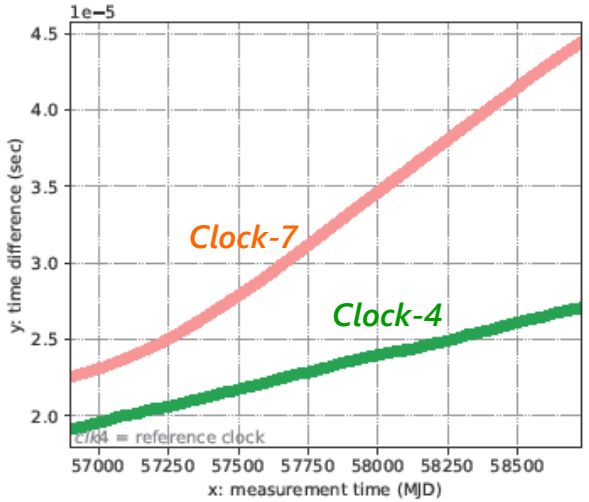
1. **Calculate *TAb* in the following three cases, and compare the results.**

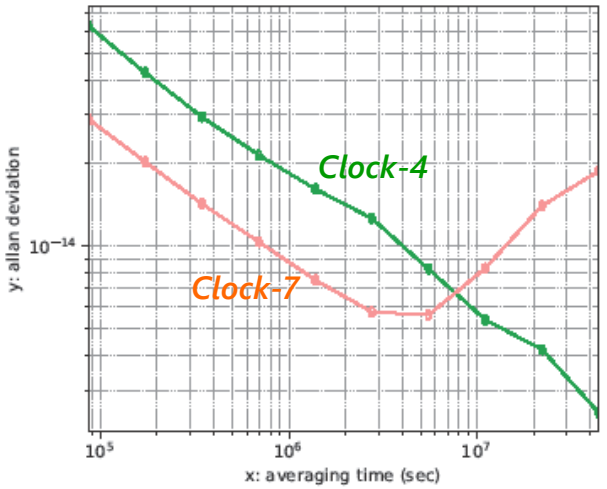
   [Case-3] *Clock-4 : weight=1, Clock-7 : weight=1, others : weight=0*

   [Case-4] *Clock-4 : weight=1, Clock-7 : weight=2, others : weight=0*

   [Case-5] *Clock-4 : weight=2, Clock-7 : weight=1, others : weight=0*

2. **Predict the differences between these *TAb*s in advance.**

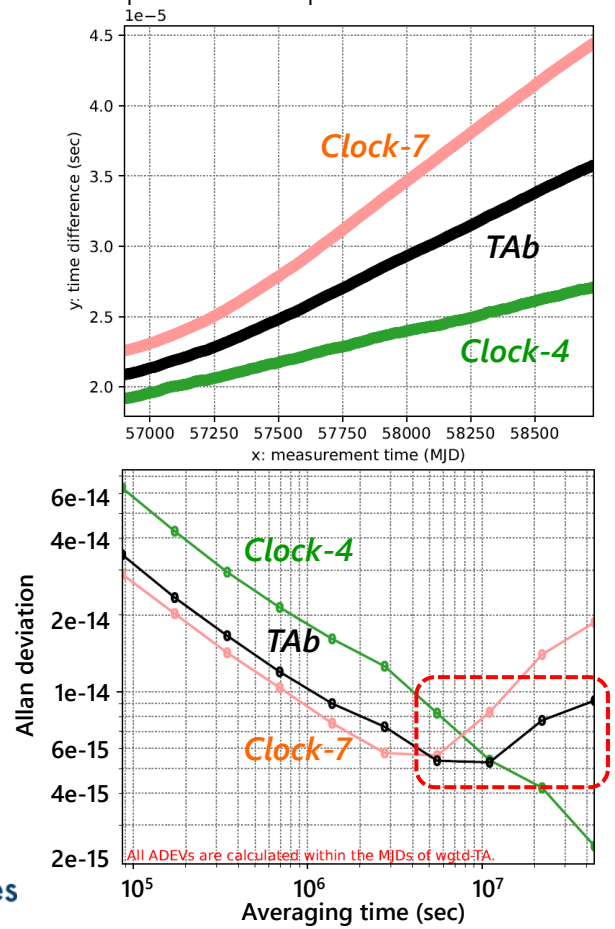




3. Exercise

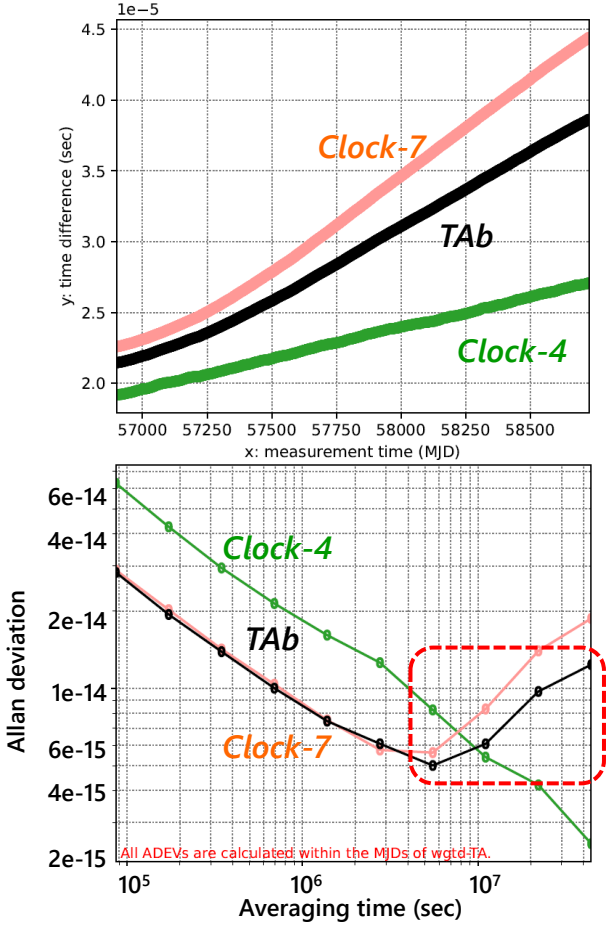
- ***TAb*** **become closer to the clocks with higher weight.**

Case-3 $w_4 : w_7 = 1 : 1$



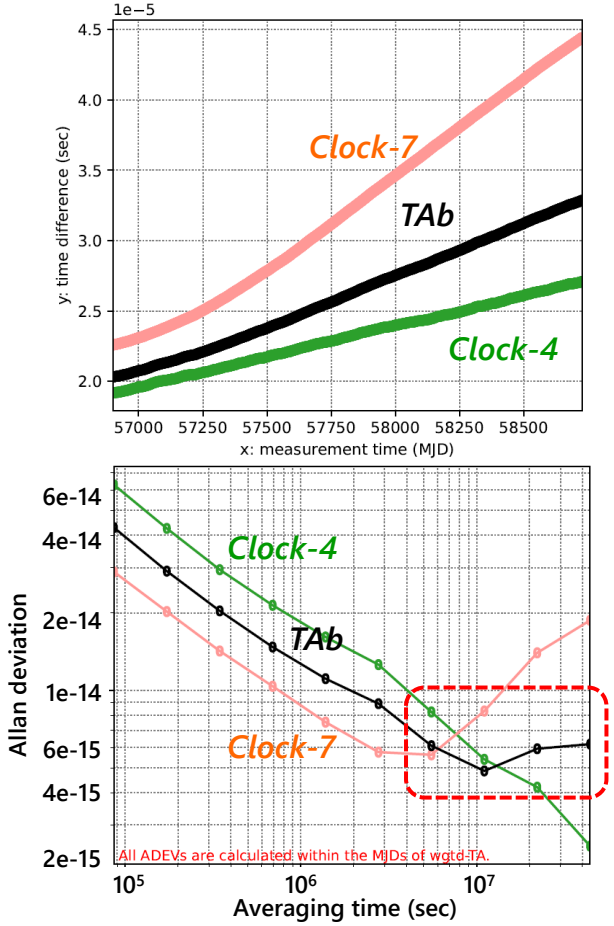
/0531_163950

Case-4 $w_4 : w_7 = 1 : 2$



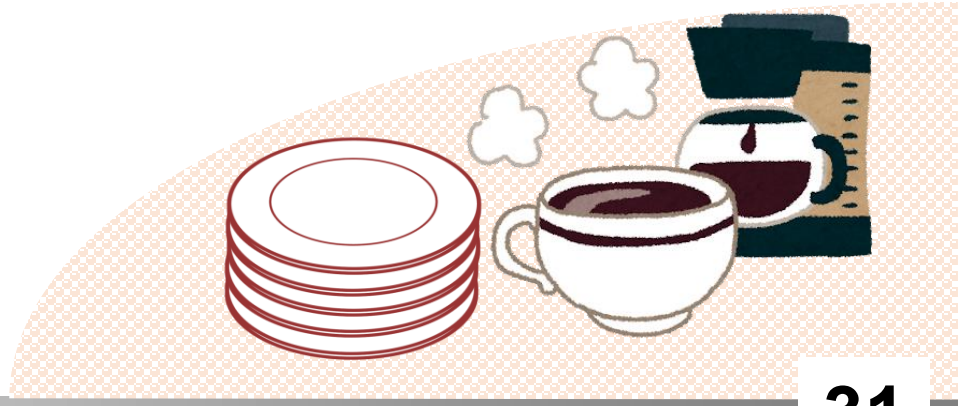
/0531_164046

Case-5 $w_4 : w_7 = 2 : 1$



/0531_164130

Contents



4. Summary and Comments

Summary

- This training aims to help participants understand the principles of *TAb* and how to make and evaluate it using the tutorial Python program *"TAgen_basic.py"*.
- Participants learnt how to use the program through the lecture and exercise of basic operation process.
- Further information about *TAb* and the program are provided in [Ref. 2] and [Ref. 3].

4. Summary and Comments

■ Comments

- This "*TAgen_basic.py*" was developed by a beginner in Python programming (i.e. me), so there may be bugs or areas that are not fully developed. If you find any issues, please contact me via BIPM.
- If you are interested in modifying the program, please refer to the user guide [Ref.3] which provides information on the program's construction and flow.
- For the simulation of "*TA with prediction*", an advanced form of *TA*, two more Python programs are required; "*TAgen_pred.py*" and "*TAgen_auto.py*".
- These programs and manuals are also included in the DL package, so please refer to them if you are interested. Another introductory explanation is being prepared for these.

Thank you very much for your kind attention!

※ Reference

[1] BIPM CBKT e-learning (https://e-learning.bipm.org/), BIPM course, "Time scale algorithms"
[2] CCTF TE tutorial lecture: *"Time scale algorithms ~basics an application~ *Lecture**"
[3] User's manual of Python program : "*User's Manual of "TAgen_basic.py"*
[4] Web site of *"AllanTools"*: *https://allantools.readthedocs.io/en/latest/*

Appendix-1

Preparation for using *"TAgen_basic.py"*

App-1 : Preparation for using "*TAgen_basic.py*"

[1] Install "*Python*" *in your computer*

- Set the path to the working directory.
- Following Python modules should be installed in advance;

  - *numpy*
  - *matplotlib*
  - *allantools*

For example, from the command prompt;

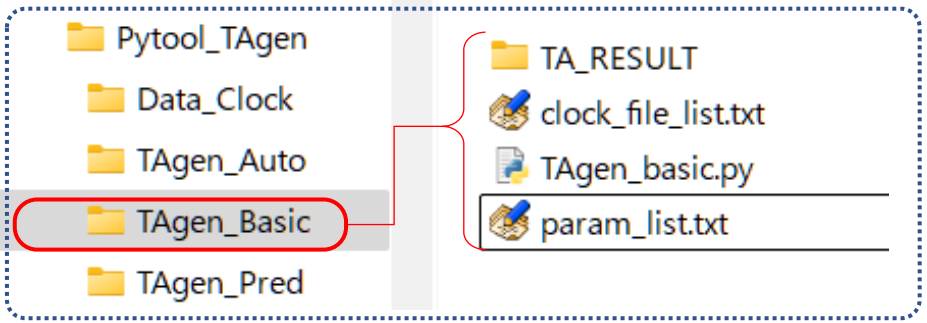
```
C:\Mywork>python -m pip install numpy
```

※ **"*Spyder*" is not necessary for running the tools, but is useful for debugging and modifying them.**

https://www.spyder-ide.org/

[2] Copy all the directories and files in "*/Pytool_TAgen/*"

- The directory name "***Pytool_TAgen***" can be changed as you like, but don't change the directory names under the "***/Pytool_TAgen/***".



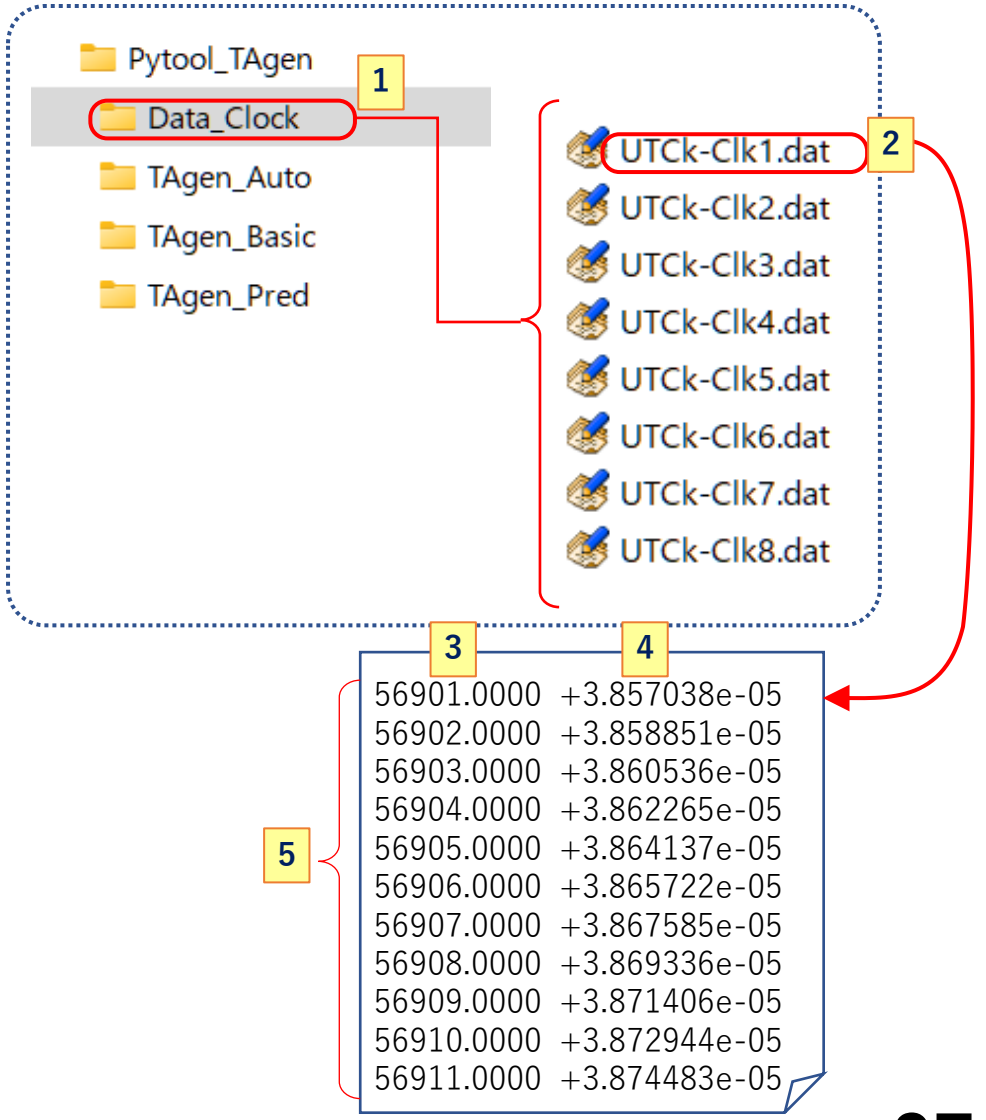
App-1 : Preparation for using "*TAgen_basic.py*"

[3] Prepare the clock measurement data in the folder "*/Pytool_TAgen/Data_Clock/*" 1

- One clock data is used for one data file.
- The file name should be "***UTCk-****.dat***" 2
  ("****" : clock name)
- The data should be the following format:
  - 1st column : observation time stamp 3
  - 2nd column : measurement time difference of "***UTC(k)*** – *clock*" (in seconds) 4
  - Delimiter : " "

※ The Interval of the 1st column should be specified as "***t_intvl***" in the "***param_list.txt***". 5

※ This sampling interval must be constant and continuous.



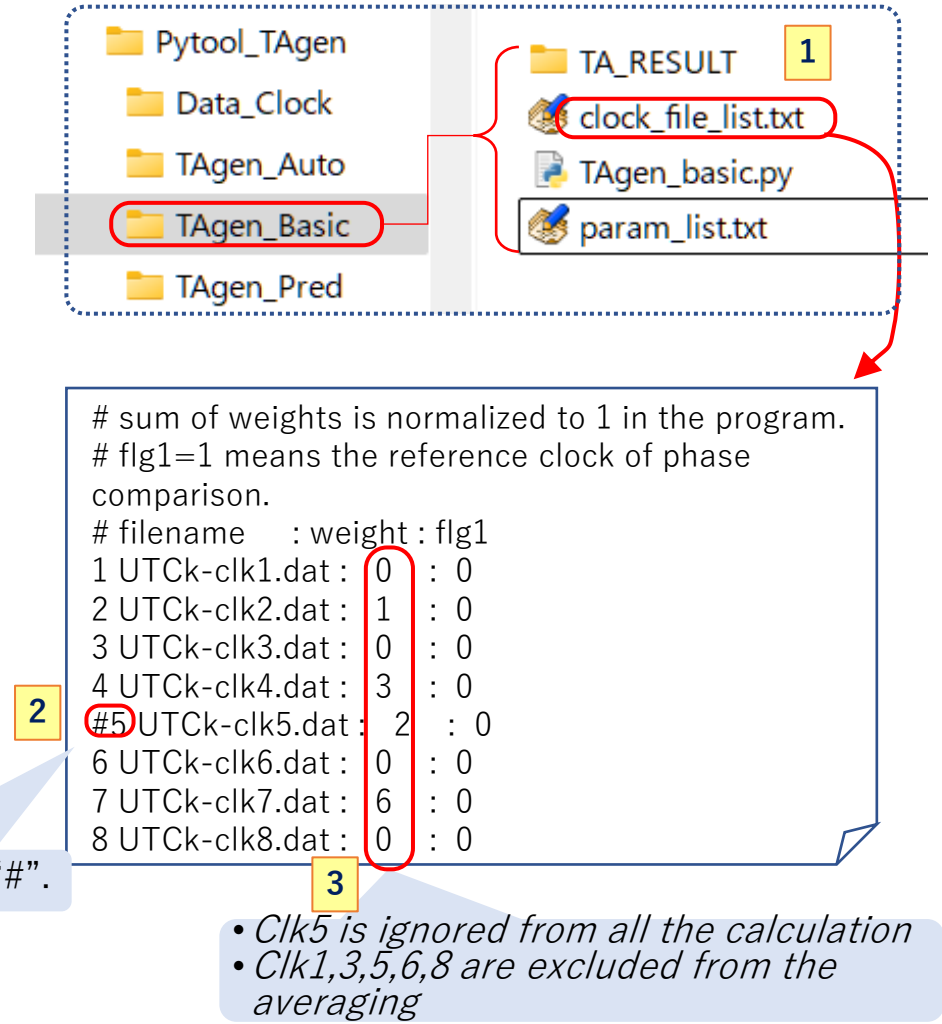
App-1 : Preparation for using "*TAgen_basic.py*"

[4] Prepare the clock-data name-list file:
"*/Pytool_TAgen/TAgen_Basic/clock_file_list.txt*" 1

- The "*clock_file_list.txt*" provide the conditions of each clock in the averaging process.
- The line starting with "**#**" is ignored. 2
  - 1st column : file No. (defines plot color)
  - 2nd column : data file name
  - 3rd column : weight in the averaging*1 3
  - 4th column : ***"flg1"*** (ignored) *2.

**1 : Each weight is normalized in the Python program.*

2 : The clock with **"flg1=1" plays a role in "**TAgen_pred.py**" and "**TAgen_auto.py**". **In TAgen_basic.py**", this flag is not used.*

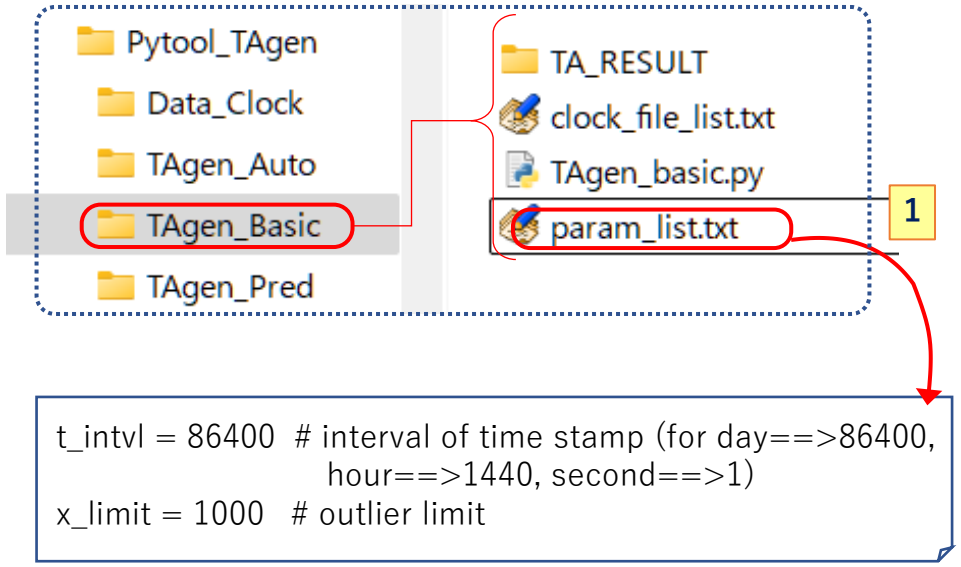


App-1 : Preparation for using "*TAgen_basic.py*"

[5] Prepare the parameter-list:

"/Pytool_TAgen/TAgen_Basic/param_list.txt" 1

- The parameter file "***param_list.txt***" provides the parameters in advance.
- These parameters are used with the same names in the program.
- The text after "**#**" provides the explanation of the parameter.
  - ***t_intvl*** : interval of time stamp
    (for day → *86400*, hour → *1440*, second → *1)*
  - ***x_limit*** : outlier limit



App-1 : Preparation for using "*TAgen_basic.py*"

[6] Check the execution of the program "*/TAgen_Basic/TAgen_basic.py*"

※ Case (1) : by "*Spyder*"

1. Select the following Python program from the menu of "*File --> open -> /Pytool_TAgen/TAgen_Basic/TAgen_basic.py*". 1
2. Click " ▶ " or "*Run*". 2

※ The result is shown in the "*Console*" window. 3

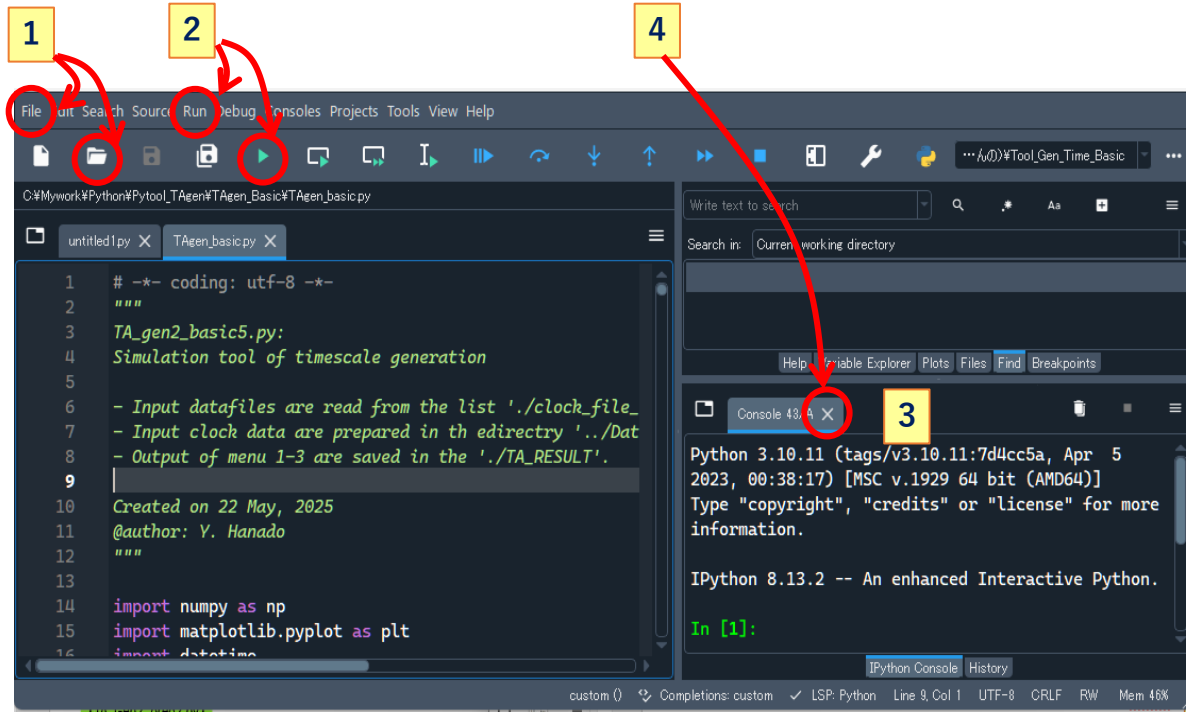
※ You can finish or refresh the process by "*X*" closing the current console. 4

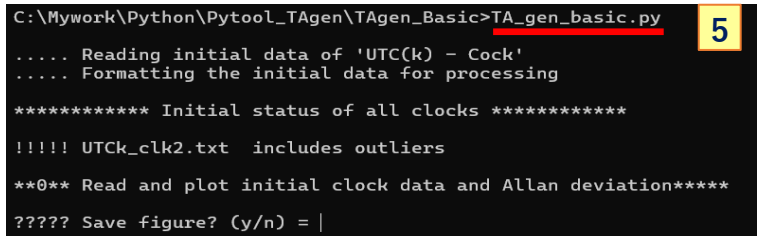
※ Case (2) : by command prompt

1. Go to the directory in advance including the "***Pytool_TAgen/TAgen_Basic/***" in advance.
2. Run "***TAgen_basic.py***" --> You can proceed with the program in the command prompt console. 5

※ The graph is shown in another window.

※ You can finish the process by "*Ctrl+Z*".





Appendix-2

"*TAgen_basic.py*" : Relation of input/output files

App-2 : Relation of input/output files

- Pytool_TAgen
  - Data_Clock
    - **UTCk-clk1.dat, , ,**

```
56901.0000   +3.857038e-05
56902.0000   +3.858851e-05
56903.0000   +3.860536e-05
      :             :
56931.0000   +3.909406e-05
      :             :
```

  - TAgen_Basic
    - **Clock_file_list.tx**

```
# sum of weights is normalized
to 1 in the program.
# flg1=1 means the reference
clock of phase comparison.
# filename     : weight : flg1
1 UTCk-clk1.dat :   0    : 0
2 UTCk-clk2.dat :   1    : 0
3 UTCk-clk3.dat :   0    : 0
4 UTCk-clk4.dat :   3    : 0
#5 UTCk-clk5.dat :   2    : 0
6 UTCk-clk6.dat :   0   : 0
7 UTCk-clk7.dat :   6    : 0
8 UTCk-clk8.dat :   0    : 0
```

    - **param_list.txt**

```
t_intvl = 86400  # interval of time
stamp (for day==>86400,
hour==>1440, second==>1)
x_limit = 1000   # outlier limit
```

  - TA_RESULT
    - /MMDD_hhmmss

- In the *Initial process, "menu-0", "menu-1"*
  - ***all_raw_clk_MMDD_hhmmss.dat***
  - ***all_adev_MMDD_hhmmss.dat***
  - ***fig_MMDD_hhmmss.pdf***
  - ***log_MMDD_hhmmss.txt***
- In the *"menu-2"*
  - ***all_det_clk_MMDD_hhmmss.dat***
  - ***all_adev_MMDD_hhmmss.dat***
  - ***fig_MMDD_hhmmss.pdf***
  - ***log_MMDD_hhmmss.txt***
- In the *"menu-3"*

[Case-1]
- ***all_raw_clk_ave_MMDD_hhmmss.dat***
- ***all_adev_MMDD_hhmmss.dat***
- ***fig_MMDD_hhmmss.pdf***
- ***log_MMDD_hhmmss.txt***
- ***all_weight_MMDD_hhmmss.dat***
- ***wgt_fig_MMDD_hhmmss.pdf***

[Case-2 (after "*menu-2*")]
- ***all_det_clk_ave_MMDD_hhmmss.dat***
- ***all_adev_MMDD_hhmmss.dat***
- ***fig_MMDD_hhmmss.pdf***
- ***log_MMDD_hhmmss.txt***
- ***all_weight_MMDD_hhmmss.dat***
- ***wgt_fig_MMDD_hhmmss.pdf***

App-2 : Relation of input/output files

- *"UTC(k)-TA"* is the weighted average of *"UTCk-clk.dat"* of *clk2, clk4* and *clk7*.

Clock_file_list.txt

```
# sum of weights is normalized
to 1 in the program.
# flg1=1 means the reference
clock of phase comparison.
# filename    : weight : flg1
1 UTCk-clk1.dat :  0   : 0
2 UTCk-clk2.dat :  1   : 0
3 UTCk-clk3.dat :  0   : 0
4 UTCk-clk4.dat :  3   : 0
#5 UTCk-clk5.dat :  2   : 0
6 UTCk-clk6.dat :  0   : 1
7 UTCk-clk7.dat :  6   : 0
8 UTCk-clk8.dat :  0   : 0
```

Clocks used in the averaging

UTCk-clk1.dat

56901.0000	+3.857038e-05
56902.0000	+3.858851e-05
:	:
57999.0000	+5.576701e-05
58000.0000	+5.578885e-05

all_raw_clk_ave_0531_151852.dat

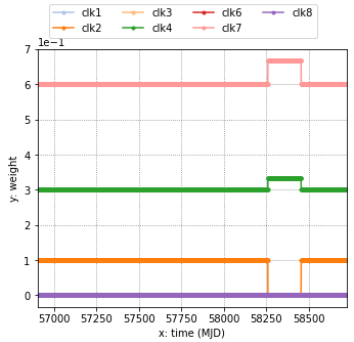
fname	UTCk-clk1.dat	UTCk-clk2.dat	UTCk-clk3.dat	UTCk-clk4.dat	UTCk-clk6.dat	UTCk-clk7.dat	UTCk-clk8.dat	UTCk-TA
Weight	0.0	1.0	0.0	3.0	0.0	6.0	0.0	0.0
flag	0	0	0	0	1	0	0	3
cid	1	2	3	4	6	7	8	0
56901	+3.857038e-05	-6.184638e-06	-1.215249e-05	+1.918367e-05	+9.635976e-06	+2.258480e-05	+nan	+1.868752e-05
56902	+3.858851e-05	-6.197517e-06	-1.215115e-05	+1.919092e-05	+9.617261e-06	+2.258759e-05	+nan	+1.869008e-05
:	:	:	:	:	:	:	:	:
58725	+nan	+6.693075e-06	-3.187783e-06	+2.707895e-05	-1.676407e-05	+4.440954e-05	+5.273111e-06	+3.543872e-05
58726	+nan	+6.687379e-06	-3.180825e-06	+2.708426e-05	-1.677650e-05	+4.442301e-05	+5.270004e-06	+3.544782e-05

- These weights are copied from '*clock_file_list.txt*'. They are normalized in the averaging.

all_adev_0531_151852.dat

Tau(s)	UTCk-clk2.dat	UTCk-clk2.dat*1	UTCk-clk4.dat	UTCk-clk7.dat	UTCk-TA
MJDspan	56901-58260	58457-58726	56901-58726	56901-58726	56901-58726
86400	+2.559433e-14	+1.914455e-14	+6.289309e-14	+2.887262e-14	+1.459261e-12
172800	+1.824332e-14	+1.284166e-14	+4.258263e-14	+2.024180e-14	+1.031497e-12
345600	+1.320590e-14	+9.326690e-15	+2.944345e-14	+1.422621e-14	+7.309588e-13
:	:	:	:	:	:
11059200	+2.657653e-14	+6.159347e-15	+5.398695e-15	+8.314322e-15	+1.528285e-13
22118400	+4.172218e-14	+nan	+4.207961e-15	+1.399682e-14	+1.108404e-13
44236800	+4.249225e-14	+nan	+2.484683e-15	+1.872125e-14	+4.465014e-14

wgt_fig_0531_151832.dat

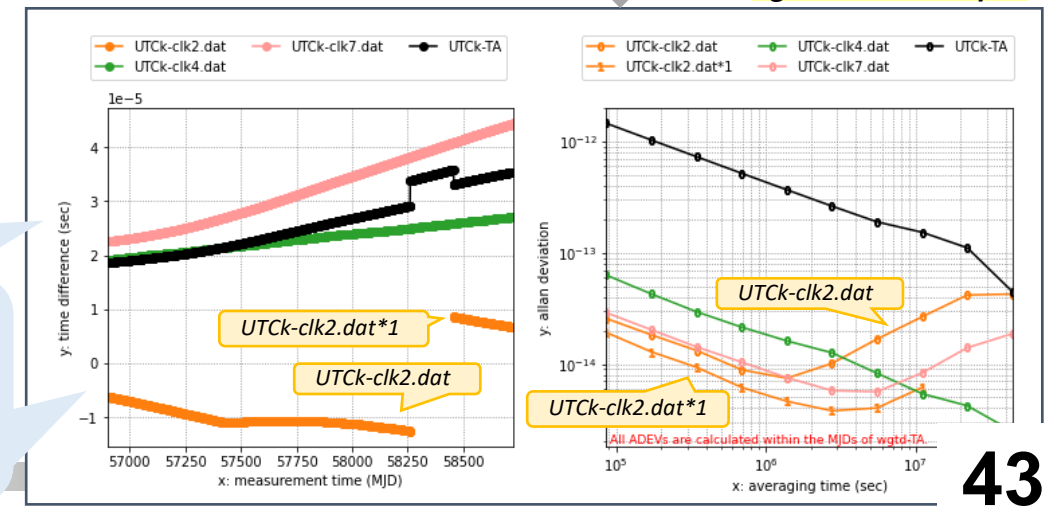


all_weight_0531_151852.dat

MJD	clk1	clk2	clk3	clk4	clk6	clk7	clk8
56901.0	0.00	0.10	0.00	0.30	0.00	0.60	0.00
56902.0	0.00	0.10	0.00	0.30	0.00	0.60	0.00
:	:	:	:	:	:	:	:
58260.0	0.00	0.10	0.00	0.30	0.00	0.60	0.00
58261.0	0.00	0.00	0.00	0.33	0.00	0.67	0.00
:	:	:	:	:	:	:	:
58726.0	0.00	0.00	0.00	0.33	0.00	0.67	0.00

- Due to anomaly, *Clock2* lost the weight on *MJD58261*, and other weights were also affected by normalization.

fig_0531_151852.pdf



log_0531_151852.txt

```
# Data log at 2025.05.23_16h13m_33s
#
**0** Read and plot initial clock data and Allan deviation*****
::::: Input clocklist  : clock_file_list.txt
::::: Input clock file : ['UTCk-clk1.dat', 'UTCk-clk2.dat', 'UTCk-clk3.dat',
'UTCk-clk4.dat', 'UTCk-clk6.dat', 'UTCk-clk7.dat', 'UTCk-clk8.dat']
::::: data time interval (t_intval): 86400(sec)
::::: Outlier limit (x_limit))     : 1000.0

**3** Weighted average *****
::::: Input data file  : all_raw_clk.dat
::::: Saved joint data : all_raw_clk_ave.dat
::::: Weight of clocks : all_weight.dat
```

- *TA* shows big jumps due to the *"UTCk-clk2"*, so that its *ADEV* does not show its intrinsic behavior.
- *"UTCk-clk2"* includes anomalies on *MJD 58261 ~58456*, and they are treated as missing data.
- The data is divided two blocks before/after the anomalies.
- *ADEV*s are calculated for each.

- The operated menu processes are serially added in the log file.