Contents

GNSS Navigation Lab (AAE4203-Guidance and Navigation)

1. Lab introduction:

Global Navigation Satellite Systems (GNSS) is a cornerstone of modern positioning, navigation, and timing (PNT) technologies. They provide accurate location and time information to users anywhere on Earth, under any weather conditions, and at any time. GNSS positioning has revolutionized many aspects of modern life, providing critical data for navigation, timing, and location-based services. As technology continues to advance, GNSS will become even more integral to our daily activities and various industries.

The GNSS navigation lab focuses on the data collection of the GNSS receiver and its data processing using Python programming. The student is expected to learn to use the GNSS receiver to collect the data and process the GNSS data, such as the GNSS single-point positioning. The expected learning outcome of this lab is as follows:

- *Objective 1*: Learn to use the usage of the GNSS data collection software, such as the u-center for the u-blox receiver data collection, and the GNSS Logger for GNSS data collection from the Android smartphone.
- *Objective 2*: GNSS data processing using the RTKLIB, including the position and velocity estimation.
- *Objective 3*: GNSS data processing using Python programming, including position and velocity estimation.
- *Objective 4*: Learn the analysis of the data, such as the positioning error evaluation using a static dataset. All these should be done using the Python code.
- *Objective 5*: Students are required to submit a 2-page report on the lab. The lab should include the following components: (1) GNSS positioning results and visualization (e.g. with RTKLIB), (2) evaluation of the static dataset collected in urban areas. (3) learning experiences in this lab.

Fig 1: (Left) Smartphone-based GNSS positioning in urban canyons. (Right) GNSS receiver-based positioning in urban canyons.

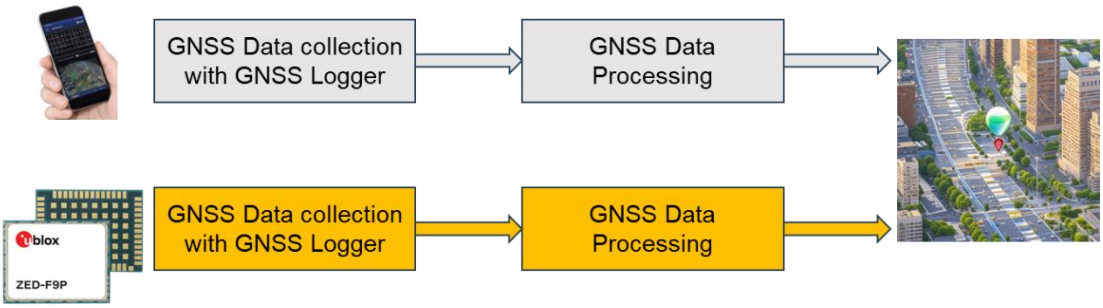

Fig 2: Overview of the lab. Two sets of GNSS receivers could be used for the data collection.

2. Q&&A

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- **Teaching Assistant**: Ruijie Xu, Xikun Liu, Yuan Li, Yihan Zhong.
- **Lecture Venue and Time**: BC303, Thu 15:30-18:20
- **Github issue**: https://github.com/weisongwen/AAE4203-2425S1/issues

3. GNSS positioning and analysis using u-blox receiver

3.1 U-blox receiver

u-blox provides commercial-grade GNSS receivers that support multi-constellation and multi-band signals for precise positioning.

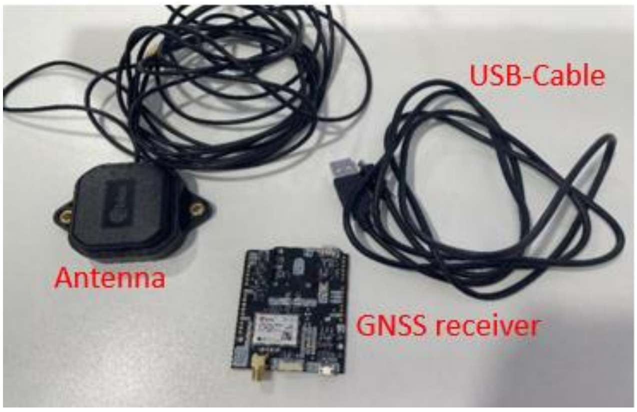


Fig 3: Illustration of the u-blox GNSS receiver kit.

- Multi-band GNSS Receiver: Supports concurrent reception of multiple GNSS constellations (GPS, GLONASS, Galileo, BeiDou).
- Concurrent Multi-Constellation Reception: Receives signals from various constellations simultaneously, improving accuracy and reliability.
- Small and Power-Efficient: The ZED-F9P module is compact and energy-efficient, making it suitable for integration into a variety of devices.

3.2 Data Collection with u-blox Receiver

3.2.1 Installation and Hardware Setup

Connect the antenna, receiver and computer as shown in Figure 4 (F9P) and Figure 5 (F10T).

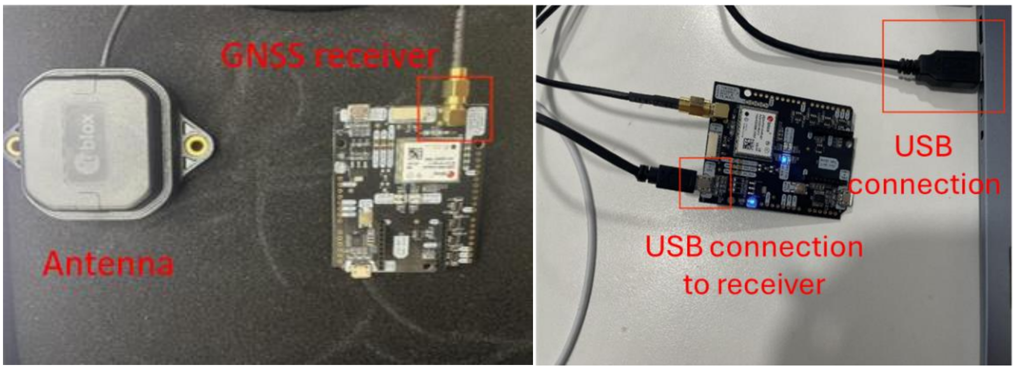


Fig 4: Illustration of the u-blox GNSS receiver F9P kit connection with the antenna.

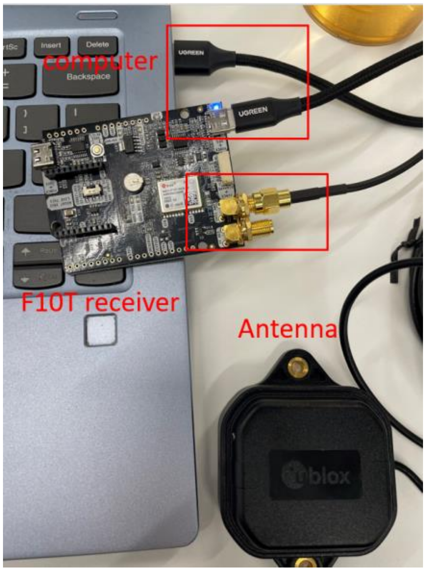


Fig 5: Illustration of the u-blox GNSS receiver F10T kit connection with the antenna.

3.2.2 Using u-center for GNSS Data Collection

u-blox provides u-center, a powerful evaluation software tool designed to configure, monitor, and analyze GNSS data. Follow these steps to collect data with u-center:

Step 1: Download and Install u-center:
https://www.u-blox.com/en/product/u-center.

Step 2: Open u-center, select connection and choose the correct COM port and set the baud rate(typically 9600 or 115200) to establish proper communication.

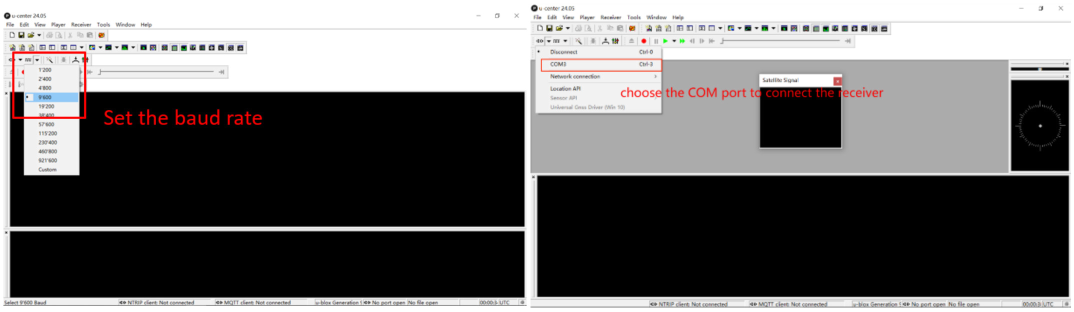


Fig 6: Illustration of the u-center software in the computer: connect receiver.

Step 3: Once the receiver is connected, the u-center will begin displaying real-time data from multiple GNSS constellations, including satellite count, signal strength, and positional coordinates. The Satellite View screen allows you to visualize the status of each satellite being received.

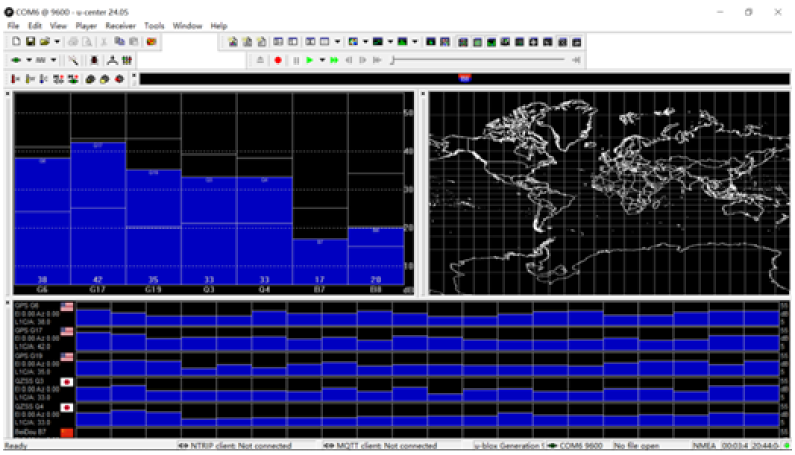


Fig 7: Illustration of the u-center software in the computer with satellite visualization.

Step 4: Click "record" in the menu bar to start recording, and then select a path to save the data file.

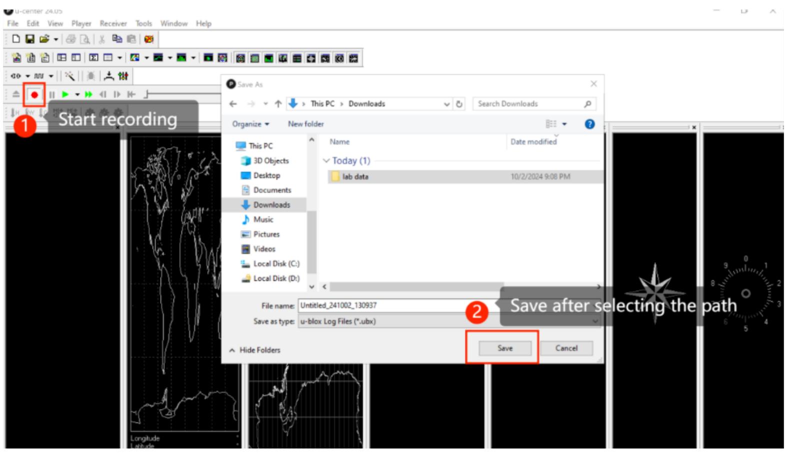


Fig 8: Illustration of the u-center software in the compute: start recording.

Step 5: The hardware and software are ready, let's start collecting data!

Step 6: After the collection is completed, click "Eject File" in the menu bar.

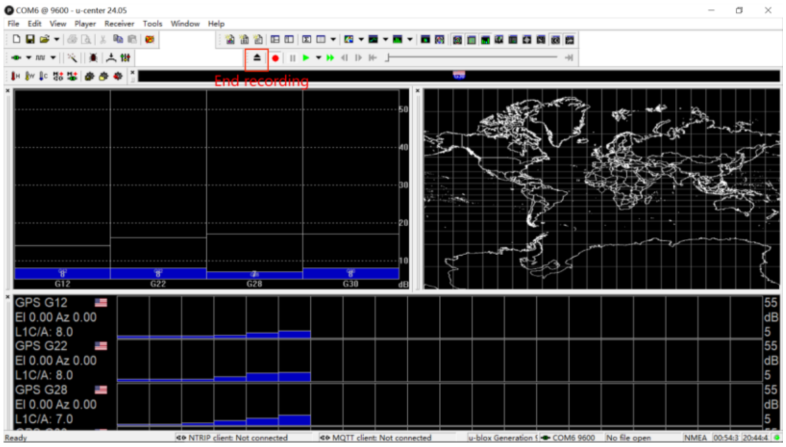


Fig 9: Illustration of the u-center software in the compute: stop recording.

3.3 Data analysis with RTKLIB

RTKLIB is an open-source software library for GNSS data processing, supporting Real-Time Kinematic (RTK) and post-processing modes.

Step 1: Download and install RTKLIB
rtklib_download
Step 2: Open "rtklauch.exe".

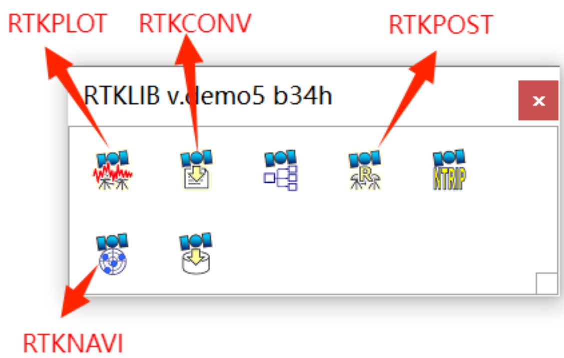


Fig 10: Illustration of the rtklauch in the compute.

3.3.1 Raw Data Format Conversion

Step 3: Open "RTKCONV" and then convert raw data (ubx file saved by u-center) to RINEX format.

- Do not check "Time Start(GPST)", "Time End(GPST)" and "Interval".
- "RTCM, RCV or RINEX OBS": the raw data file saved by U-center
- Format: choose UBX
- Make sure the ".obs" file and ".nav" file are checked. These are output files.

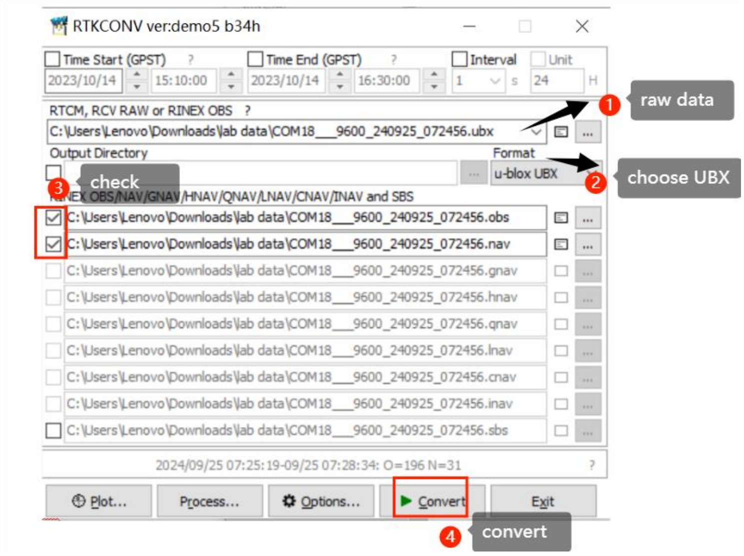


Fig 11: Illustration of the rtkconv software in the compute: convert .ubx to RINEX.

3.3.3 Ephmeris

Step 4: Go to the ephemeris website
https://www.geodetic.gov.hk/tc/rinex/downv.aspx

Step 5: Please select step 1 and step 2 according to the following example.

Step 1. Select the required stations

Hong Kong SatRef Station			
☐HKKS Kau Sai Chau	☐HKKT Kam Tin	☐HKLM Lamma Island	☐HKLT Lam Tei
☐HKMW Mui Wo	☐HKNP Ngong Ping	☐HKOH Obelisk Hill	☐HKPC Peng Chau
☑HKSC Stonecutters Island	☐HKSL Siu Lang Shui	☐HKSS Shap Sze Heung	☐HKST Sha Tin
☐HKTK Sha Tau Kok	☐HKWS Wong Shek	☐HKCL Chek Lap Kok	☐HKQT Quarry Bay
☐T430 Trig 430	☐HKFN Fanling	☐KYC1 Kau Yi Chau	TCHK* Tate's Cairn
Macao MoSRef Station			
☐COAL Coloane Alto	☐DSMG Taipa Grande	☐FOMO Monte Fortress	

*Note: 1. Satellite Reference Station summary has been replaced by Satellite Reference Station Coordinates List since 1 Apr, 2016.
2. Data of TCHK is not available

Step 2. Select Data Format

File Length	Interval	Data Format	
		RINEX 2.11	RINEX 3.02
1 Hour	1 Second	Not Select	Selected
	5 Seconds	Not Select	Not Select
24 Hours	5 Seconds	Not Select	Not Available
	30 Seconds	Not Select	Not Select

Fig 12: Illustration of step1 and step 2 of downloading ephemeris.

Step 6: Open the ".obs" output file in step 3 and note the start and end time.

- The time period in the figures is 25/09/2024 7 hour 25 minute – 25/09/2024 7 hour 28 minute.

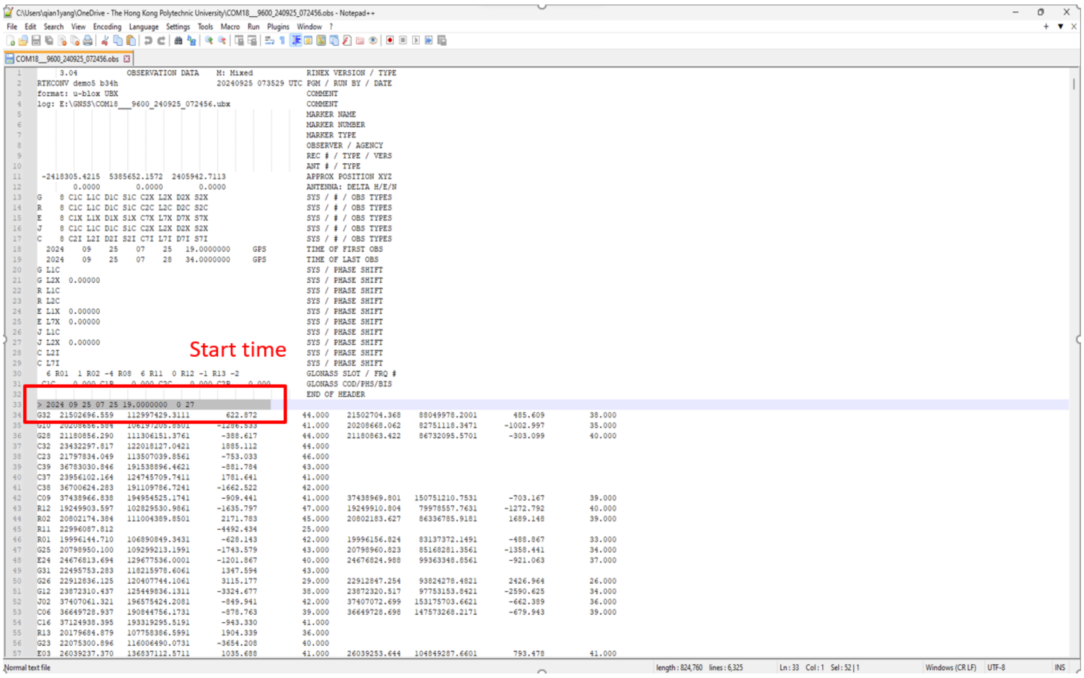


Fig 13: Illustration of the start time.

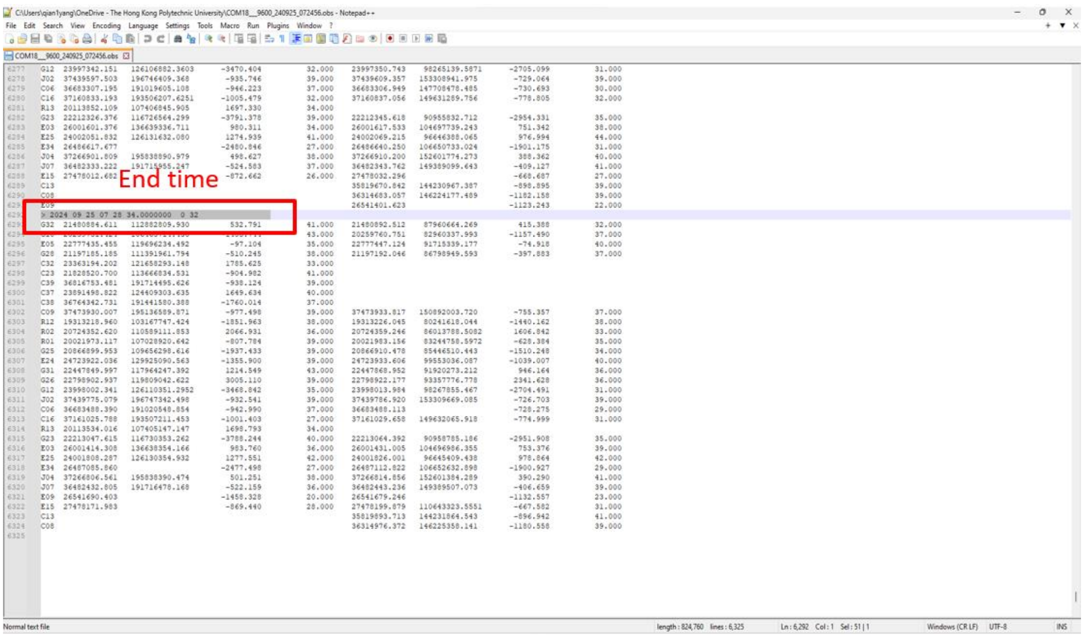
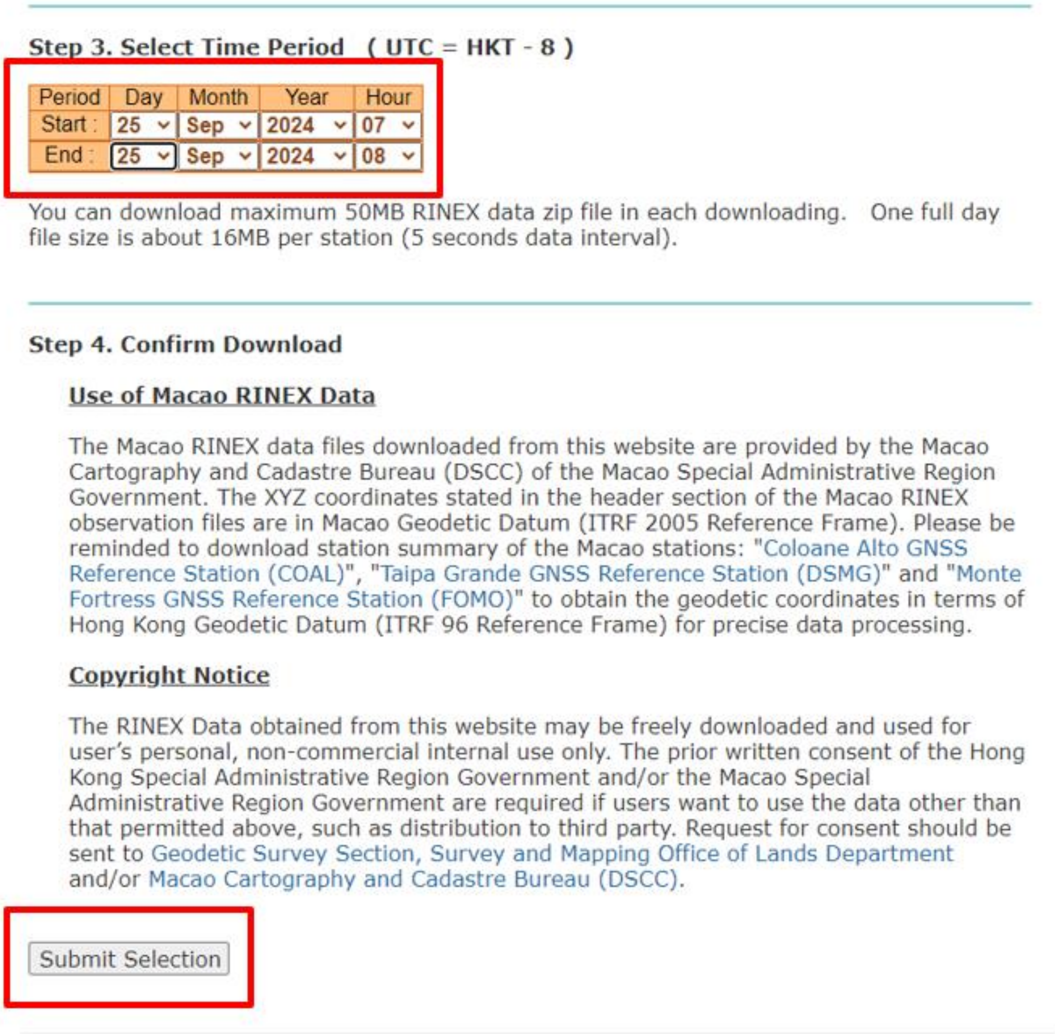


Fig 14: Illustration of the end time.

Step 7: Select the corresponding time period on the website and submit.

*Noted that time in the file is not HKT (UTC= HKT – 8)



Step 3. Select Time Period (UTC = HKT - 8)

Period	Day	Month	Year	Hour
Start :	25	Sep	2024	07
End :	25	Sep	2024	08

You can download maximum 50MB RINEX data zip file in each downloading. One full day file size is about 16MB per station (5 seconds data interval).

Step 4. Confirm Download

Use of Macao RINEX Data

The Macao RINEX data files downloaded from this website are provided by the Macao Cartography and Cadastre Bureau (DSCC) of the Macao Special Administrative Region Government. The XYZ coordinates stated in the header section of the Macao RINEX observation files are in Macao Geodetic Datum (ITRF 2005 Reference Frame). Please be reminded to download station summary of the Macao stations: "Coloane Alto GNSS Reference Station (COAL)", "Taipa Grande GNSS Reference Station (DSMG)" and "Monte Fortress GNSS Reference Station (FOMO)" to obtain the geodetic coordinates in terms of Hong Kong Geodetic Datum (ITRF 96 Reference Frame) for precise data processing.

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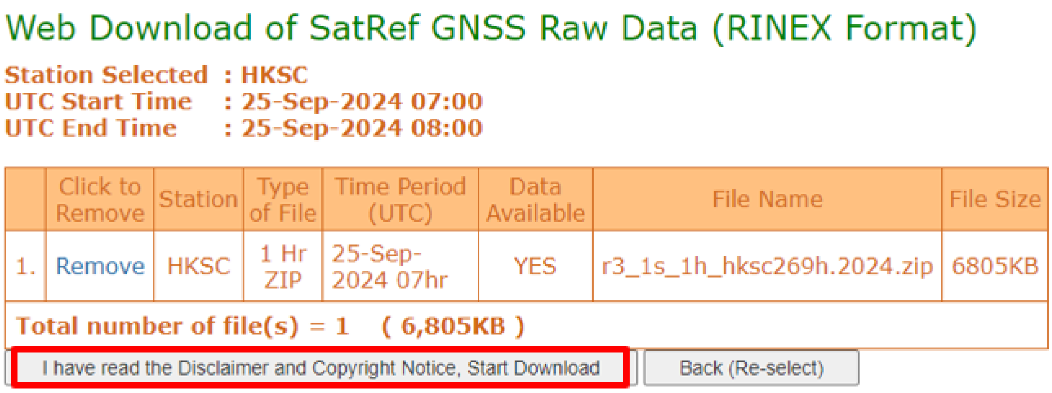
The RINEX Data obtained from this website may be freely downloaded and used for user's personal, non-commercial internal use only. The prior written consent of the Hong Kong Special Administrative Region Government and/or the Macao Special Administrative Region Government are required if users want to use the data other than that permitted above, such as distribution to third party. Request for consent should be sent to Geodetic Survey Section, Survey and Mapping Office of Lands Department and/or Macao Cartography and Cadastre Bureau (DSCC).

Submit Selection

Fig 15: Illustration of step3 and step 4 of downloading ephemeris.

Step 8: Download the ephemeris file.



Web Download of SatRef GNSS Raw Data (RINEX Format)

Station Selected : HKSC
UTC Start Time : 25-Sep-2024 07:00
UTC End Time : 25-Sep-2024 08:00

	Click to Remove	Station	Type of File	Time Period (UTC)	Data Available	File Name	File Size
1.	Remove	HKSC	1 Hr ZIP	25-Sep-2024 07hr	YES	r3_1s_1h_hksc269h.2024.zip	6805KB
Total number of file(s) = 1 (6,805KB)							

I have read the Disclaimer and Copyright Notice, Start Download   Back (Re-select)

Fig 16: Illustration of web download of SatRef GNSS Raw Data.

Step 9: Extract the ZIP file and then follow the steps in the figure below.

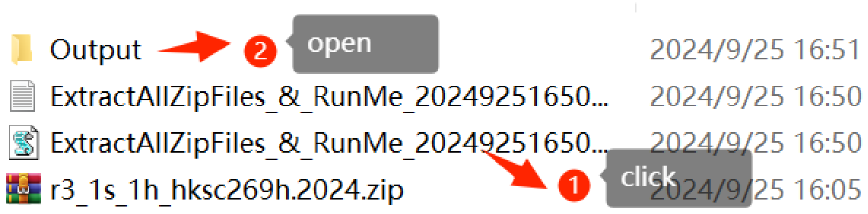


Fig 17: Illustration of how to get output folder.

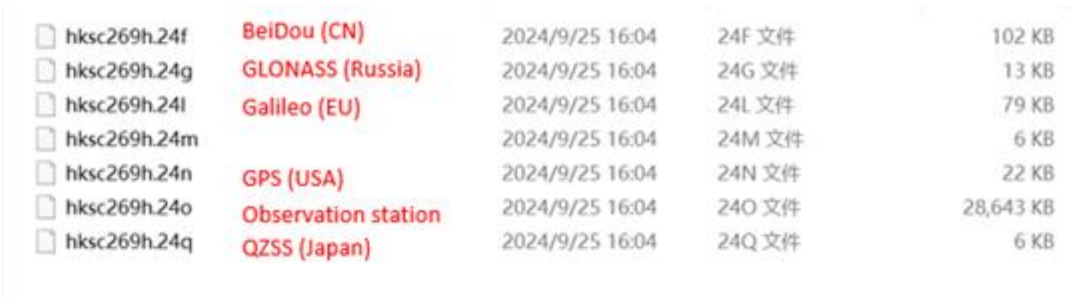


Fig 18: Illustration of ephemeris.

3.3.4 Configure Processing Options

Step 10: Open “RTKpost” through rtklauch and select the corresponding files.

- RINEX OBS Rover: the output .obs file in step 3 (rtkconv)
- RINEX OBS Base Station: “.24o” file in step 9.
- RINEXNAV/CLK: the output .nav file in step 3 (rtkconv)

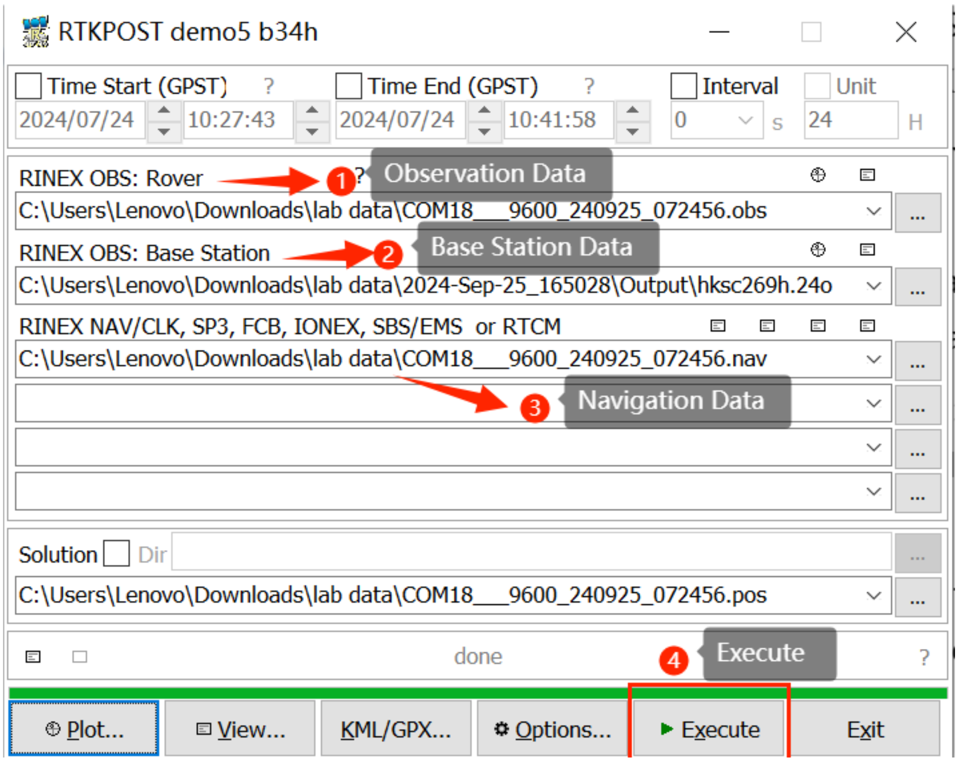


Fig 19: Illustration of the usage of rtkpost.

3.3.5 View and Analyze Results

Step 11: Click "plot".

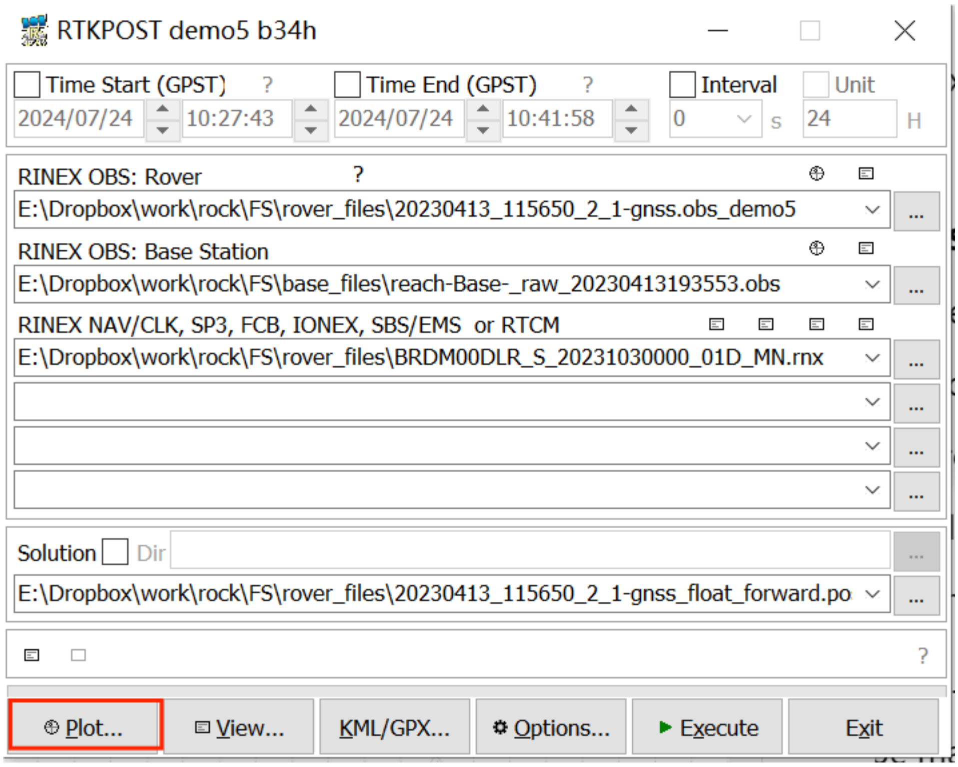


Fig 20: Illustration of plot button in rtkpost.

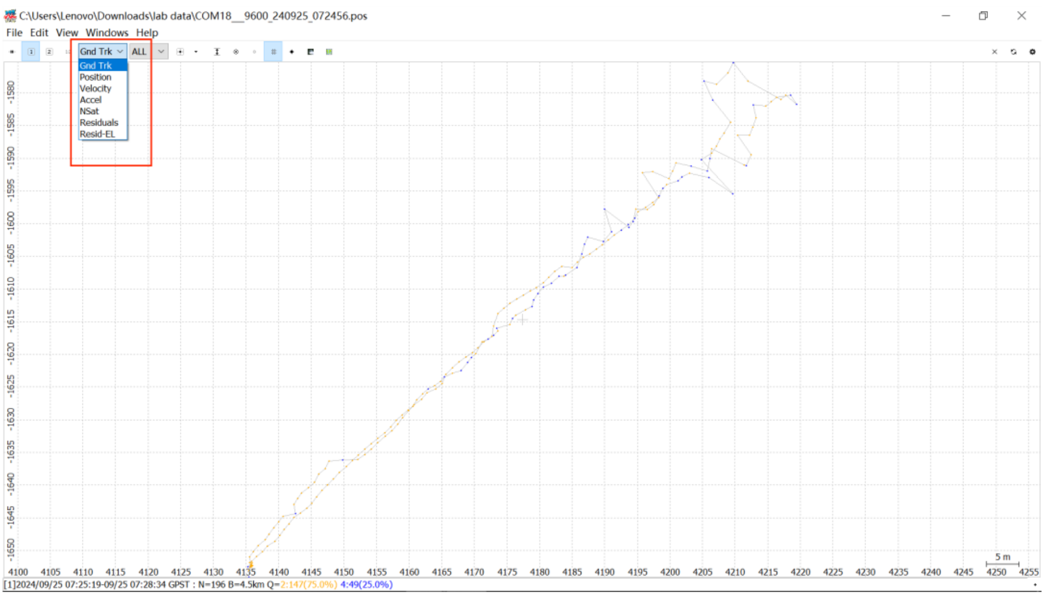


Fig 21: Illustration of the ground track.

3.3.6 Display results in Google Earth

Step 1: convert the output file from POS to KML

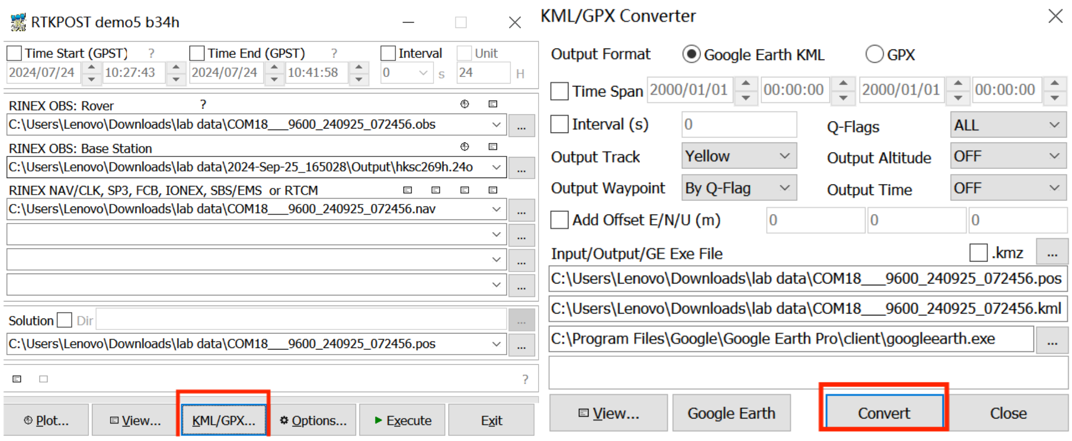


Fig 22: Illustration of rtkpost: convert .pos to KML.

Step 2: Open Google Earth website

[google earth]

Step 3: Upload the KML file.

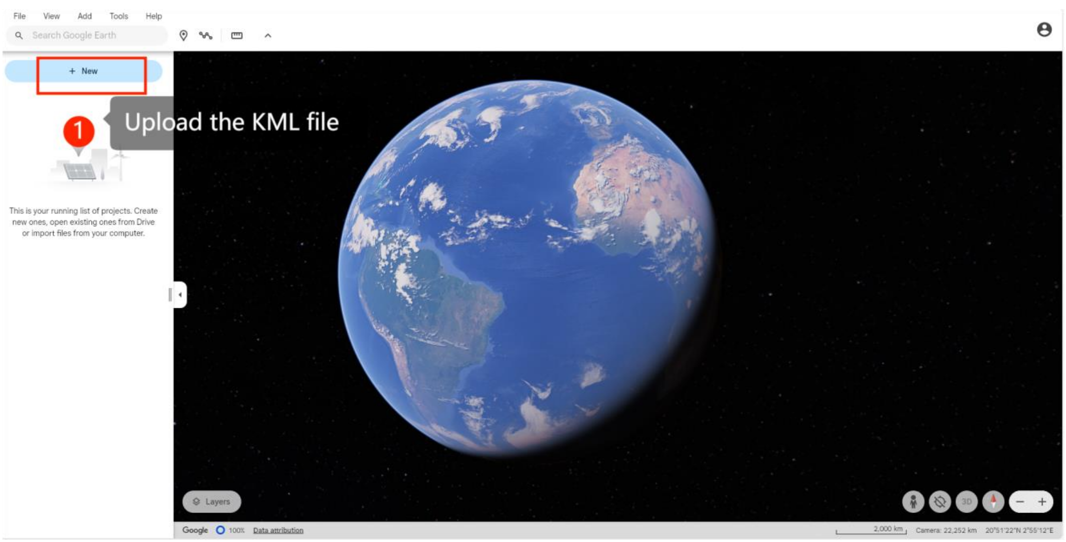


Fig 23: Illustration of google earth.

4. GNSS positioning and analysis using a smartphone receiver

4.1 Smartphone receiver

Using the smartphone Pixel 6 to collect data, GNSS hardware has been integrated into the smartphone. The software for data collection is the GnssLogger app.

Fig 24: Illustration of an Andoriod smartphone.

4.2 Data collection with smartphone receiver

See the video: https://www.bilibili.com/video/BV1qDsYe5EQA/

4.2.1 Collect data

Step 1: Open the GnssLogger app in the smartphone, and click the start log, the GNSS data will be collected. When the data collection is complete, click stop.

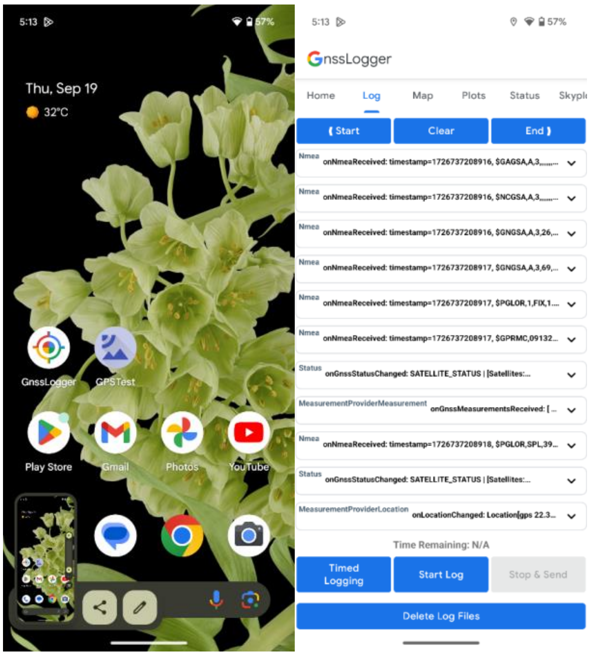


Fig 25: Illustration of GnssLogger app.

4.2.2 Get the data from the smartphone

Step 2: Use the USB to connect the smartphone to the computer.

Step 3: Enter the path \Pixel 6\Internal shared storage\Android\data\com.google.android.apps.location.gps.gnsslogger\files\gnss_log\

Fig 26: Illustration of path Pixel 6.

Step 4: Copy the corresponding data to the matlab folder according to the file time, which includes ".24o", ".nmea", ".txt" file

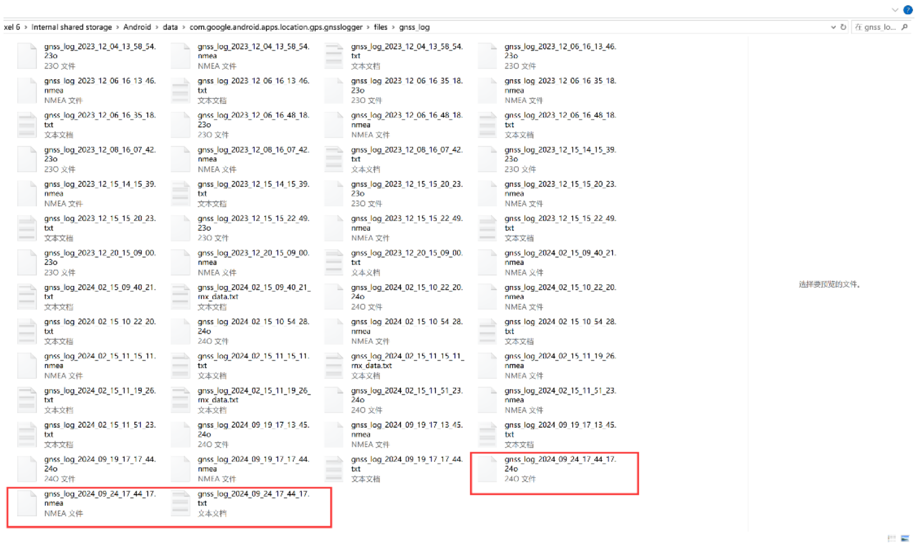


Fig 27: Illustration of ".24o", ".nmea", ".txt" file in computer.

4.3 Data analysis with Sing positioning

4.3.1 Download the navigation file in the Geodetic Survey of Hong Kong.

Step 5: Click the HKSC

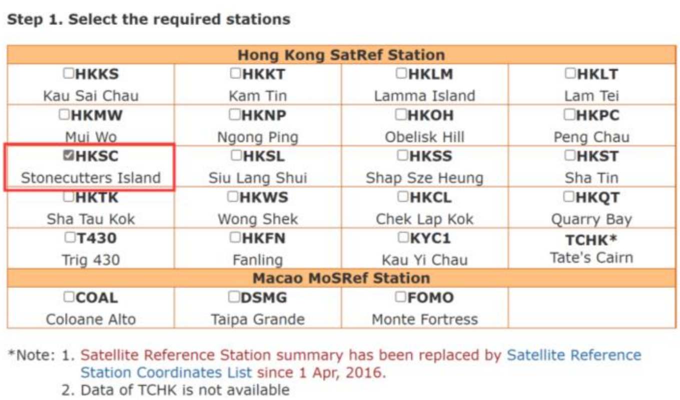


Fig 28: Illustration of web downloading navigation file: step 1.

Step 6: Select 1 hour and RINEX 3.02 format.

Step 2. Select Data Format

File Length	Interval	Data Format: RINEX 2.11	Data Format: RINEX 3.02
1 Hour	1 Second	Not Select	Selected
	5 Seconds	Not Select	Not Select
24 Hours	5 Seconds	Not Select	Not Available
	30 Seconds	Not Select	Not Select

Fig 28: Illustration of dweb ownloading navigation file: step 2.

Step 7: Choose the time form the .24o file (which is got by step 2, use the vscode sofeware) 2024 09 19 09 14 (time:2024/09/19 09:14)

```
E    8 C1C L1C D1C S1C C5Q L5Q D5Q S5Q                      SYS / # / OBS TYPES
  2024    09    19    09    14   04.0000000     GPS         TIME OF FIRST OBS
 2 R04  6 R15  0                                            GLONASS SLOT / FRQ #
G L1C                                                       SYS / PHASE SHIFT
G L5Q  0.00000                                              SYS / PHASE SHIFT
R L1C                                                       SYS / PHASE SHIFT
J L1C                                                       SYS / PHASE SHIFT
J L5Q  0.00000                                              SYS / PHASE SHIFT
C L2I                                                       SYS / PHASE SHIFT
C L7Q  0.00000                                              SYS / PHASE SHIFT
E L1C  0.00000                                              SYS / PHASE SHIFT
E L5Q  0.00000                                              SYS / PHASE SHIFT
 C1C    0.000 C1P    0.000 C2C    0.000 C2P    0.000        GLONASS COD/PHS/BIS
                                                            END OF HEADER
> 2024 09 19 09 14 04.0001040  0 29
G10  22439808.74406     63585.97306     -3363.06606      41.23806  22439645.65724     49423.40724     -2511.1
G16  22854872.60124    -41705.68624      3482.35024      23.97424
G26  20386060.42405    -27188.77205      1409.96005      34.28305  20385895.23805    -15623.79705      1053.7
G28  21620821.31706     13842.74706      -721.58306      35.90606  21620653.73305     13448.63005      -539.7
G31  21499947.99606     -8428.35106       439.78606      38.94906
```

Fig 28: Illustration of .24o file in computer.

Step 3. Select Time Period (UTC = HKT - 8)

Period	Day	Month	Year	Hour
Start	19	Sep	2024	09
End :	19	Sep	2024	10

You can download maximum 50MB RINEX data zip file in each downloading. One full day file size is about 16MB per station (5 seconds data interval).

Fig 29: Illustration of web downloading navigation file: step 3.

Step 8: Click the submit selection

Step 4. Confirm Download

Use of Macao RINEX Data

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Submit Selection

Fig 30: Illustration of web downloading navigation file: step 4.

Step 8: Click the download button.

Web Download of SatRef GNSS Raw Data (RINEX Format)

Station Selected : HKSC
UTC Start Time : 19-Sep-2024 09:00
UTC End Time : 19-Sep-2024 10:00

	Click to Remove	Station	Type of File	Time Period (UTC)	Data Available	File Name	File Size
1.	Remove	HKSC	1 Hr ZIP	19-Sep-2024 09hr	YES	r3_1s_1h_hksc263j.2024.zip	6611KB

Total number of file(s) = 1 (6,611KB)

I have read the Disclaimer and Copyright Notice, Start Download | Back (Re-select)

Fig 31: Illustration of web downloading navigation file: dowload.

Step 9: Extract the file and click the script.

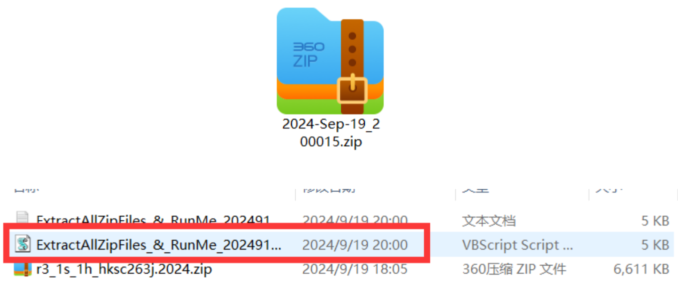

Fig 32: Illustration of the script.

hksc263j.24f	2024/9/19 18:05	24F 文件	105 KB
hksc263j.24g	2024/9/19 18:05	24G 文件	13 KB
hksc263j.24l	2024/9/19 18:05	24L 文件	64 KB
hksc263j.24m	2024/9/19 18:05	24M 文件	6 KB
hksc263j.24n	2024/9/19 18:05	24N 文件	22 KB
hksc263j.24o	2024/9/19 18:05	24O 文件	28,110 KB
hksc263j.24q	2024/9/19 18:05	24Q 文件	6 KB

Fig 33: Files in output folder.

Step 10: Move all files of the output folder to the smartphone gnss .obs file (for example, E:\TA\rtklib_matlab\data\2024_0919)

gnss_log_2024_09_19_17_13_45.24o	2024/9/19 17:17	24O 文件	759 KB
gnss_log_2024_09_19_17_13_45.nmea	2024/9/19 17:17	NMEA 文件	1,429 KB
hksc263j.24f	2024/9/19 18:05	24F 文件	105 KB
hksc263j.24g	2024/9/19 18:05	24G 文件	13 KB
hksc263j.24l	2024/9/19 18:05	24L 文件	64 KB
hksc263j.24m	2024/9/19 18:05	24M 文件	6 KB
hksc263j.24n	2024/9/19 18:05	24N 文件	22 KB
hksc263j.24o	2024/9/19 18:05	24O 文件	28,110 KB
hksc263j.24q	2024/9/19 18:05	24Q 文件	6 KB

Fig 34: The organized file example.

4.3.2 Obtain the ionospheric, tropospheric, pseudoranges, satellite clock bias and satellite positions.

Step 11: Open the Matlab, run the generate_the_data.m, and get the ionospheric_delay.csv, pseudoranges_meas.csv, satellite_clock_bias.csv, satellite_positions.csv, tropospheric_delay.csv files.

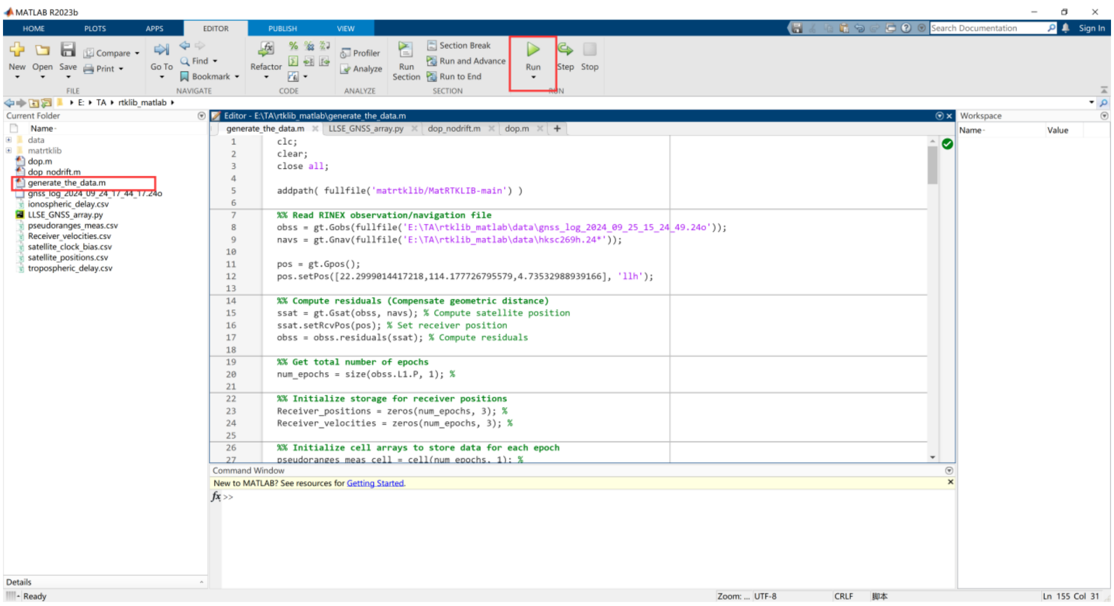

Fig 35: Illustration of MATLAB software in computer.

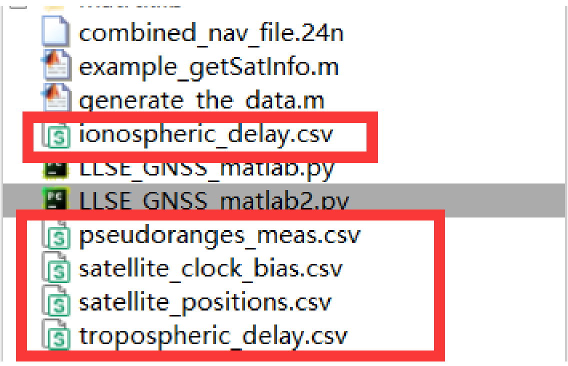

Fig 36: Illustration of the output files.

4.3.3 Use the python program of least square method to deal with the data, and get the position.

Step 12: Open the python program, “LLSE_GNSS_array.py” ,and change the file path, as shown below.

```
# Read the data from CSV files
satellite_positions = np.loadtxt('E:/TA/rtklib_matlab/satellite_positions.csv', delimiter=',')  # (max_num_sats, num_epochs*3)
pseudoranges_meas = np.loadtxt('E:/TA/rtklib_matlab/pseudoranges_meas.csv', delimiter=',')  # (max_num_sats, num_epochs)
satellite_clock_bias = np.loadtxt('E:/TA/rtklib_matlab/satellite_clock_bias.csv', delimiter=',')  # (max_num_sats, num_epochs)
ionospheric_delay = np.loadtxt('E:/TA/rtklib_matlab/ionospheric_delay.csv', delimiter=',')  # (max_num_sats, num_epochs)
tropospheric_delay = np.loadtxt('E:/TA/rtklib_matlab/tropospheric_delay.csv', delimiter=',')  # (max_num_sats, num_epochs)
```

Fig 37: Illustration of the python program.

Step 13: Run the Python program and get two graphs, the first graph is the longitude and latitude coordinates, and the second is the ENU coordinates.

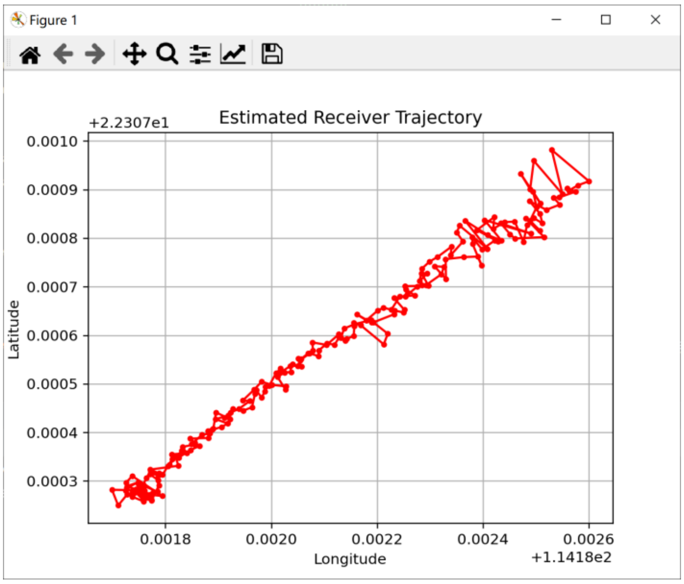

Fig 38: Estimated Receiver Trajectory in longitude and latitude coordinates.

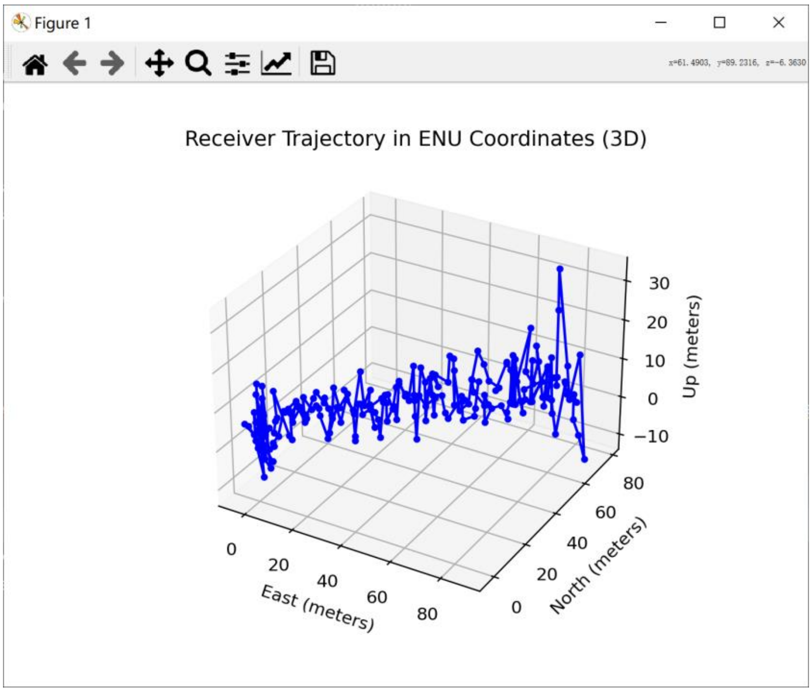

Fig 39: Estimated Receiver Trajectory in ENU coordinates.