Lab1 of ENGO 625

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Objectives

1. To look at some GPS data (observations and satellite positions)
2. To become familiar with analysis based on estimated accuracy and satellite geometry.
3. To improve programming skills with regards to Geomatics Engineering (C/C++, MATLAB, or Python only, please).

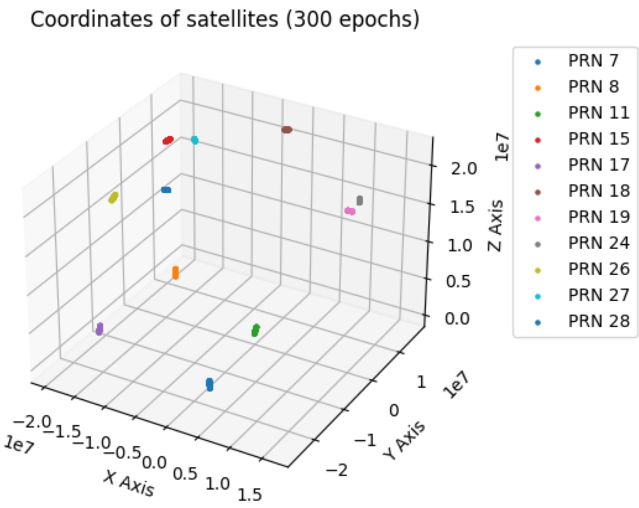
Data Description

Each student will be given three data files.

- A binary file containing 1 Hz GPS observations from a static NovAtel OEMV remote receiver.
- A binary file containing 1 Hz GPS observations from a static base station. You will be given the true coordinates of both receivers
- A binary file containing the satellite coordinates and velocity components in the Earth-Centred-Earth-Fixed (ECEF) frame, also at 1 Hz.

Tasks

1. Load the satellite coordinate file and the rover observation file
a. For the first 300 epochs, plot the coordinates of the satellites in 3D

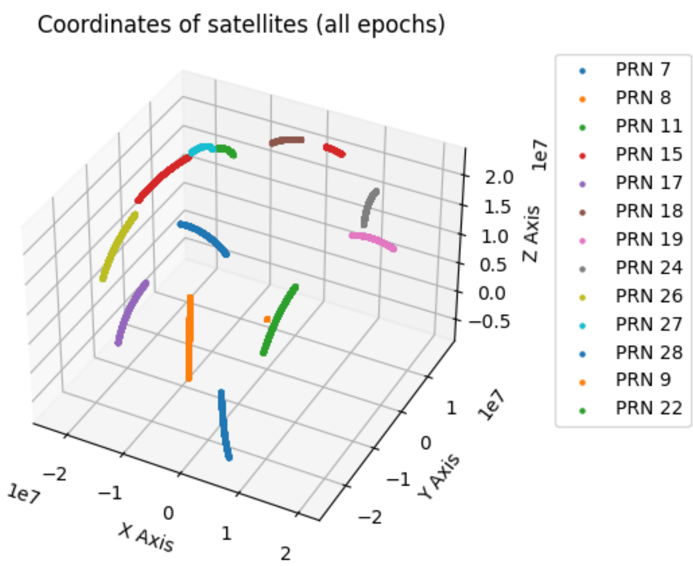


Plot 1. Coordinates of satellites (first 300 epochs)

For the first 300 epochs, 11 satellites' coordinates are recorded. Their paths are shown as above.

b. Discuss: How are the satellites distributed? Is 300 epochs enough time to see the satellite paths? If not, plot some more (possibly all) epochs and discuss.

The satellites appear to be distributed around a sphere and are relatively scattered. 300 epochs are not enough to see the satellite's paths. So I plotted all epochs.

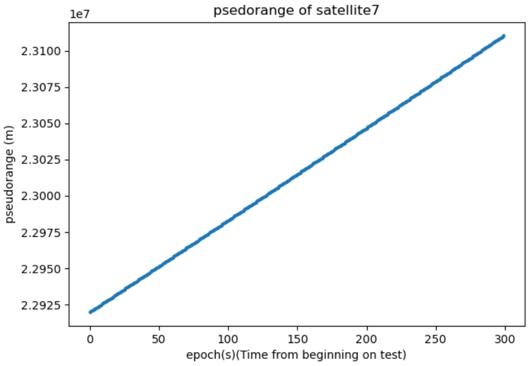


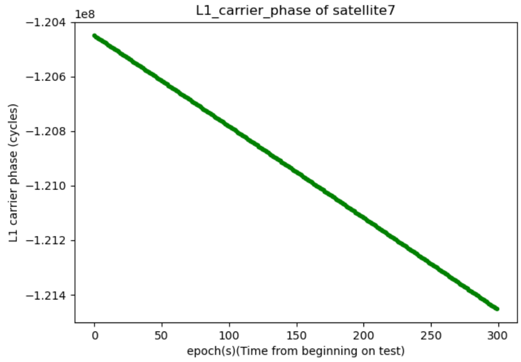
Plot 2. Coordinates of satellites (all epochs)

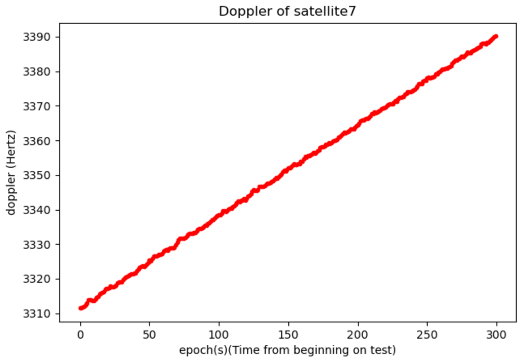
After I plotted all epochs, more satellite paths are appeared. Except for the previous satellites, there are two more satellites, with PRN 9 and 22 respectively. In additionsas, the coordinates of some previous satellites are not recorded after the first 300 epochs. The whole recording process is dynamic. Most epochs have satellites coming in and out.

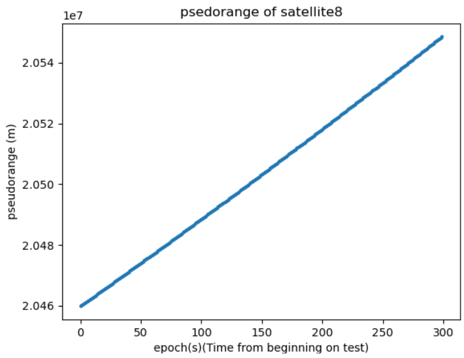
c. For the first 300 epochs, plot the pseudorange, Doppler, and L1 carrier phase observed for each of the satellites. You will need to read through the observation array you have loaded from the file row by row, because this receiver has stored the observations for each epoch in the first rows of each set of 12 rows.

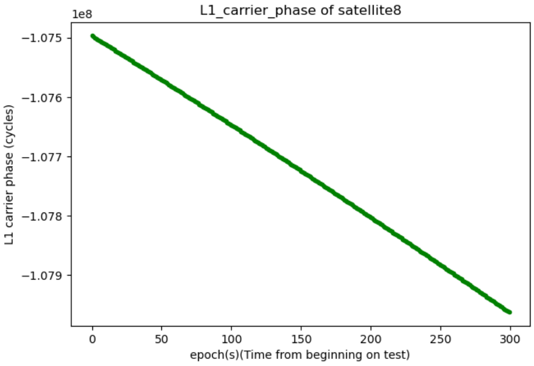
For the first 300 epochs, only 11 satellites' coordinates are recorded. Their pseudorange, Doppler and L1 carrier phase are as follow: (The line changes are not obvious at this scale, please scroll down the picture to observe)

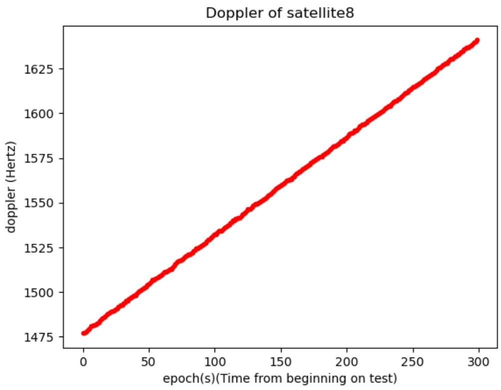

psedorange of satellite7
1e7
pseudorange (m)
epoch(s)(Time from beginning on test)

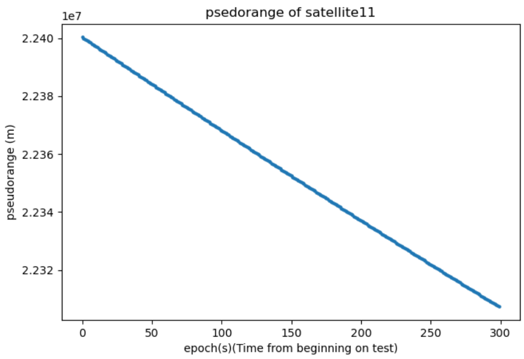

L1_carrier_phase of satellite7
1e8
L1 carrier phase (cycles)
epoch(s)(Time from beginning on test)

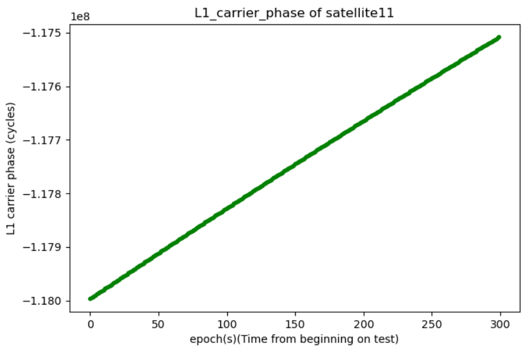

Doppler of satellite7
doppler (Hertz)
epoch(s)(Time from beginning on test)

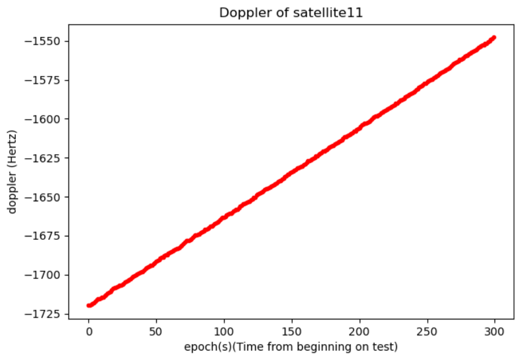

psedorange of satellite8
1e7
pseudorange (m)
epoch(s)(Time from beginning on test)

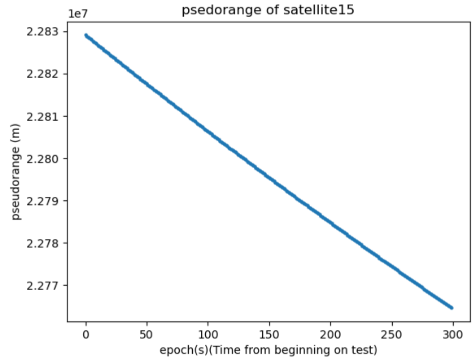

L1_carrier_phase of satellite8
1e8
L1 carrier phase (cycles)
epoch(s)(Time from beginning on test)

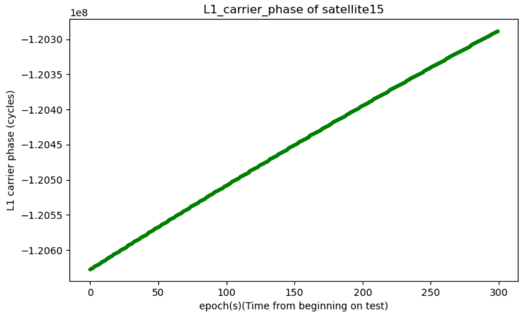

Doppler of satellite8
doppler (Hertz)
epoch(s)(Time from beginning on test)

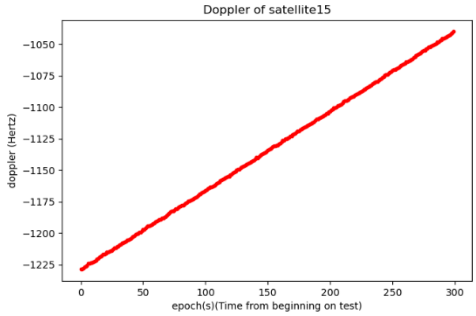

psedorange of satellite11
1e7
pseudorange (m)
epoch(s)(Time from beginning on test)

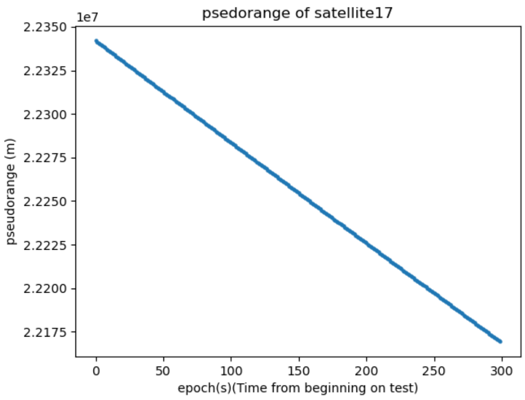

L1_carrier_phase of satellite11
1e8
L1 carrier phase (cycles)
epoch(s)(Time from beginning on test)

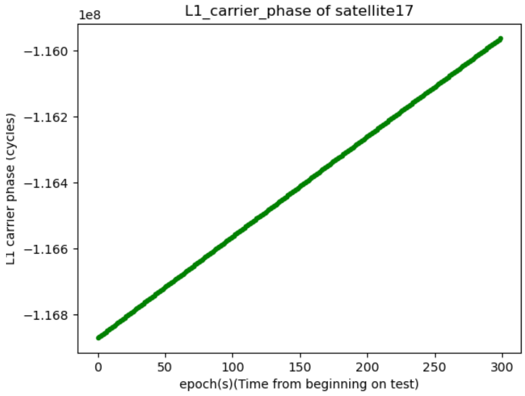

Doppler of satellite11
doppler (Hertz)
epoch(s)(Time from beginning on test)

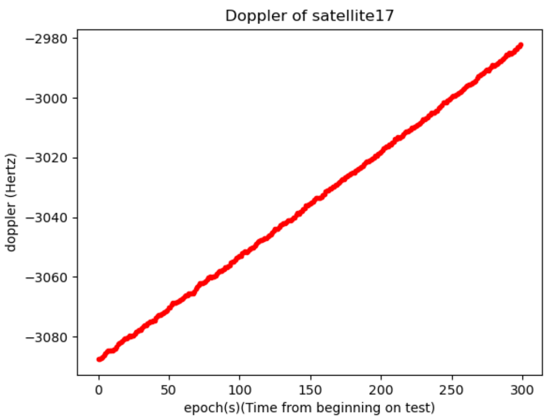

psedorange of satellite15
1e7
pseudorange (m)
epoch(s)(Time from beginning on test)

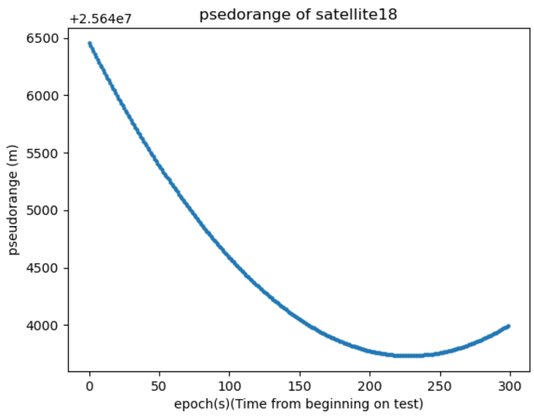

L1_carrier_phase of satellite15
1e8
L1 carrier phase (cycles)
epoch(s)(Time from beginning on test)

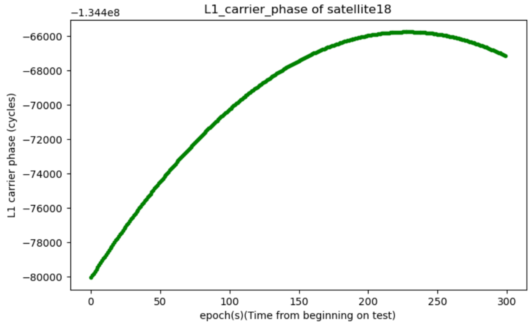

Doppler of satellite15
doppler (Hertz)
epoch(s)(Time from beginning on test)

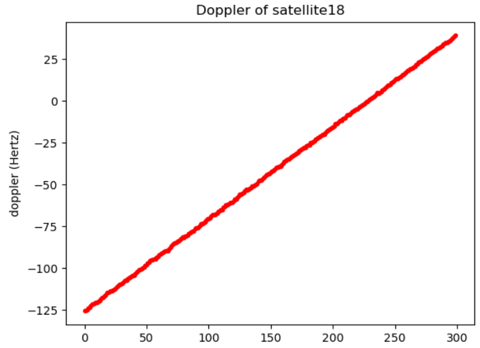

psedorange of satellite17
1e7
pseudorange (m)
epoch(s)(Time from beginning on test)

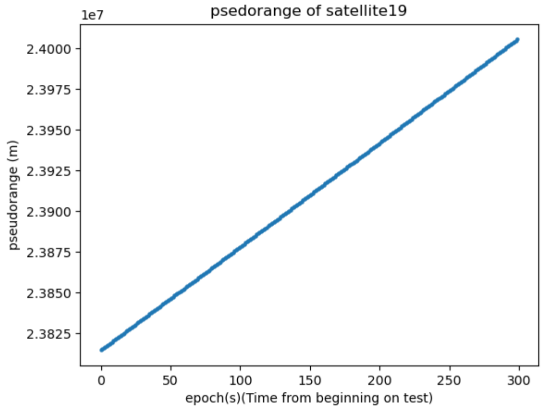

L1_carrier_phase of satellite17
1e8
L1 carrier phase (cycles)
epoch(s)(Time from beginning on test)

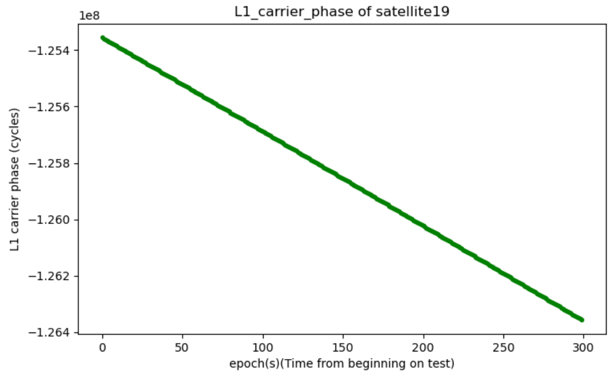

Doppler of satellite17
doppler (Hertz)
epoch(s)(Time from beginning on test)

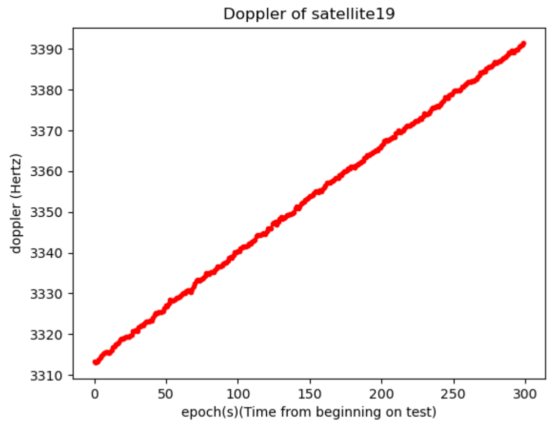

psedorange of satellite18
+2.564e7
pseudorange (m)
epoch(s)(Time from beginning on test)

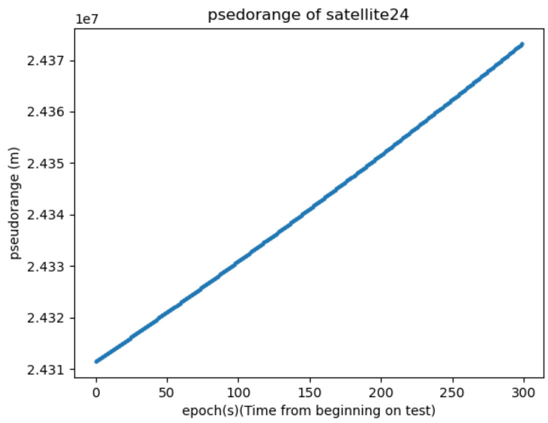

L1_carrier_phase of satellite18
−1.344e8
L1 carrier phase (cycles)
−66000
−68000
−70000
−72000
−74000
−76000
−78000
−80000
0 50 100 150 200 250 300
epoch(s)(Time from beginning on test)

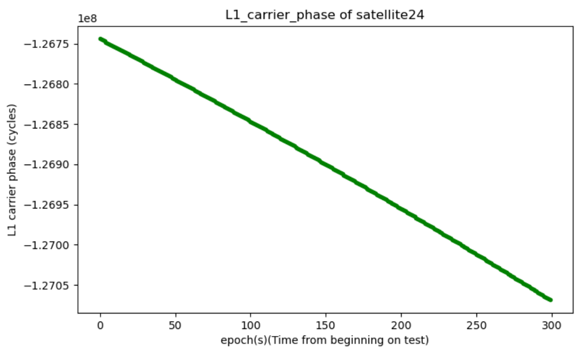

Doppler of satellite18
doppler (Hertz)
25
0
−25
−50
−75
−100
−125
0 50 100 150 200 250 300

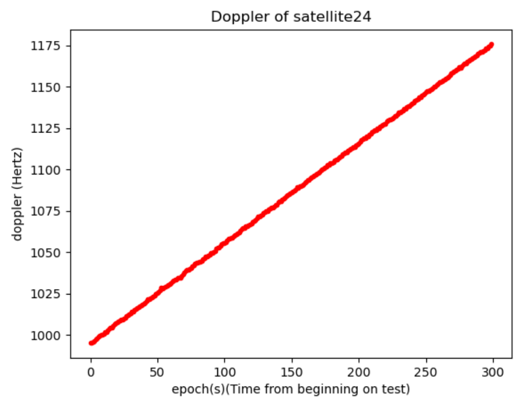

psedorange of satellite19
1e7
pseudorange (m)
2.4000
2.3975
2.3950
2.3925
2.3900
2.3875
2.3850
2.3825
0 50 100 150 200 250 300
epoch(s)(Time from beginning on test)

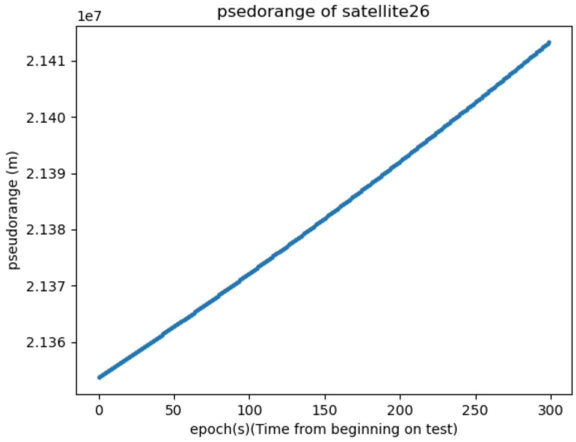

L1_carrier_phase of satellite19
1e8
L1 carrier phase (cycles)
−1.254
−1.256
−1.258
−1.260
−1.262
−1.264
0 50 100 150 200 250 300
epoch(s)(Time from beginning on test)

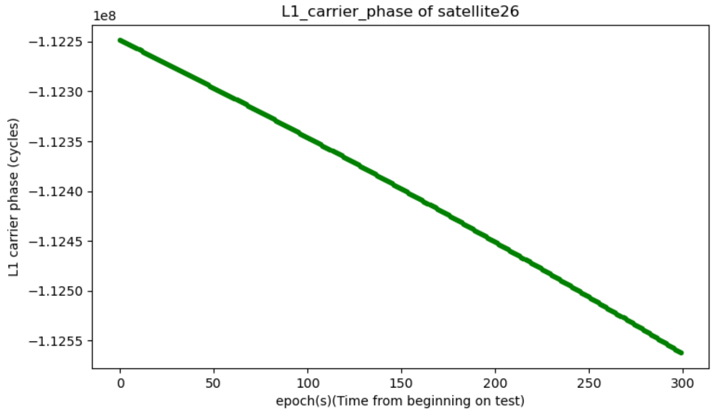

Doppler of satellite19
doppler (Hertz)
3390
3380
3370
3360
3350
3340
3330
3320
3310
0 50 100 150 200 250 300
epoch(s)(Time from beginning on test)

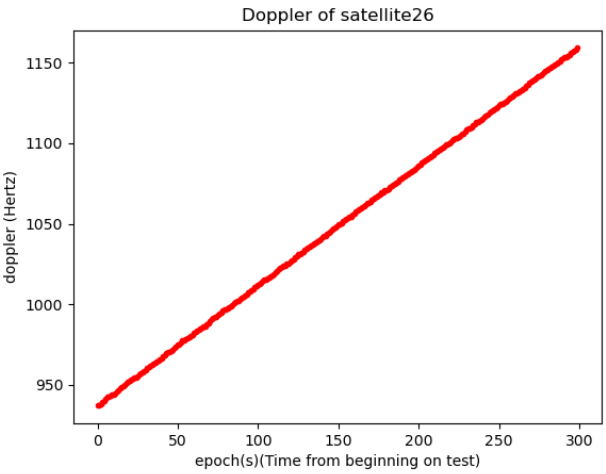

psedorange of satellite24
1e7
pseudorange (m)
2.437
2.436
2.435
2.434
2.433
2.432
2.431
0 50 100 150 200 250 300
epoch(s)(Time from beginning on test)

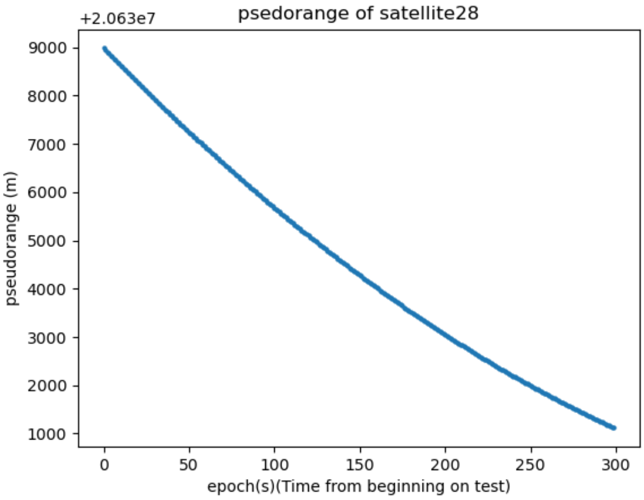

L1_carrier_phase of satellite24
1e8
L1 carrier phase (cycles)
−1.2675
−1.2680
−1.2685
−1.2690
−1.2695
−1.2700
−1.2705
0 50 100 150 200 250 300
epoch(s)(Time from beginning on test)

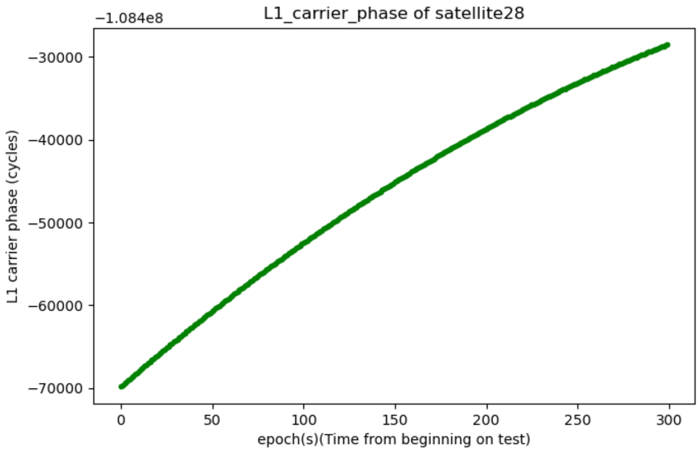

Doppler of satellite24
doppler (Hertz)
1175
1150
1125
1100
1075
1050
1025
1000
0 50 100 150 200 250 300
epoch(s)(Time from beginning on test)

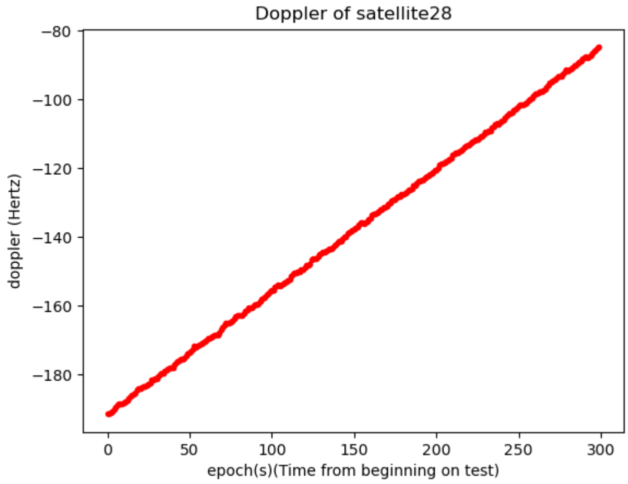

psedorange of satellite26
1e7
2.141
2.140
2.139
2.138
2.137
2.136
pseudorange (m)
0 50 100 150 200 250 300
epoch(s)(Time from beginning on test)


L1_carrier_phase of satellite26
1e8
−1.1225
−1.1230
−1.1235
−1.1240
−1.1245
−1.1250
−1.1255
L1 carrier phase (cycles)
0 50 100 150 200 250 300
epoch(s)(Time from beginning on test)


Doppler of satellite26
1150
1100
1050
1000
950
doppler (Hertz)
0 50 100 150 200 250 300
epoch(s)(Time from beginning on test)


psedorange of satellite28
+2.063e7
9000
8000
7000
6000
5000
4000
3000
2000
1000
pseudorange (m)
0 50 100 150 200 250 300
epoch(s)(Time from beginning on test)


L1_carrier_phase of satellite28
−1.084e8
−30000
−40000
−50000
−60000
−70000
L1 carrier phase (cycles)
0 50 100 150 200 250 300
epoch(s)(Time from beginning on test)


Doppler of satellite28
−80
−100
−120
−140
−160
−180
doppler (Hertz)
0 50 100 150 200 250 300
epoch(s)(Time from beginning on test)

d. Discuss: How much does the pseudorange vary from epoch to epoch. Does this match the change in the carrier phase? Does the carrier phase change match what you think it should based on the Doppler and the pseudorange?

It is clear that graphs show one-way changes. I print the difference of pseudorange and L1 carrier phase per epoch.

```
psedorange difference:-190675.95672400668
L1_carrier_phase difference:1002011.9482912123
Doppler:3351.992366604518
psedorange difference:-88705.83734063804
L1_carrier_phase difference:466155.9199026376
Doppler:1559.7189291045179
psedorange difference:93000.43987646326
L1_carrier_phase difference:-488715.72749607265
Doppler:-1634.0705256539113
psedorange difference:64565.62853365019
L1_carrier_phase difference:-339301.7911789715
Doppler:-1134.2884570876595
psedorange difference:172714.86221880838
L1_carrier_phase difference:-907625.0947985798
Doppler:-3035.2437653912675
psedorange difference:2457.289347715676
L1_carrier_phase difference:-12915.587636828423
Doppler:-42.44954290964233
psedorange difference:-190771.833451543
L1_carrier_phase difference:1002518.9371163249
Doppler:3353.788132928017
psedorange difference:-61761.756570622325
L1_carrier_phase difference:324563.14898626506
Doppler:1086.2395690310186
psedorange difference:-59655.63287719712
L1_carrier_phase difference:313501.6037147641
Doppler:1049.4810830198912
psedorange difference:176657.95000686124
L1_carrier_phase difference:-928364.0193524808
Doppler:-3104.4085102599456
psedorange difference:7861.844043157995
L1_carrier_phase difference:-41320.2378167063
Doppler:-137.63829664126752
```

From the result, we can see that the change in the pseudorange matches the change in the carrier phase. Their changing trends are inversely proportional. If the carrier phase shows an increasing trend, the doppler is negative, and if it shows a decreasing trend, the doppler is positive.

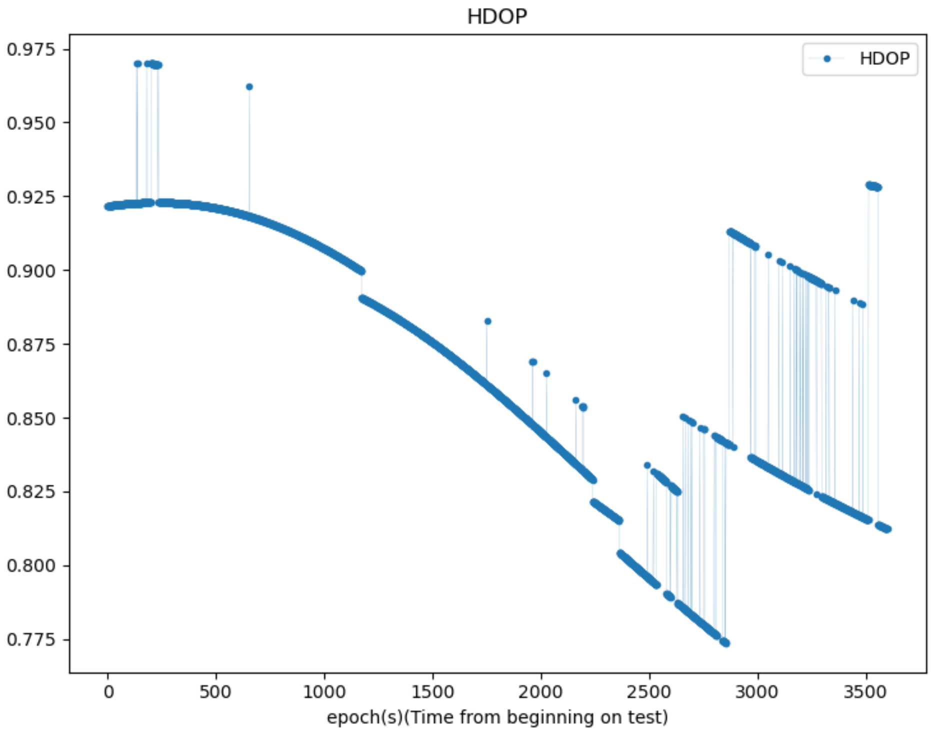
2. Build the design matrix for each epoch and then compute the HDOP and VDOP.
a. Plot each DOP as a time series. If you have built the design matrix ECEF, you will need to rotate the XYZ covariance matrix to a local geodetic frame to determine the H and VDOPs.

Firstly, build the design matrix based on the following formula and truth coordinates of the receiver.

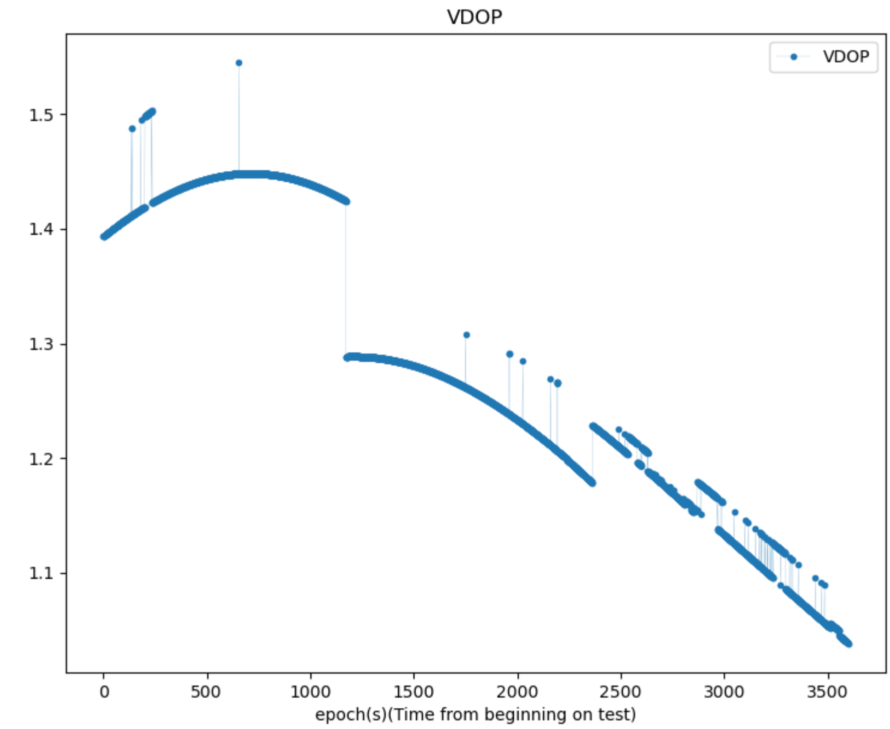
$$H=\begin{bmatrix} \frac{\partial P^i}{\partial x_r} & \frac{\partial P^i}{\partial y_r} & \frac{\partial P^i}{\partial z_r} & -1 \\ \frac{\partial P^j}{\partial x_r} & \frac{\partial P^j}{\partial y_r} & \frac{\partial P^j}{\partial z_r} & -1 \\ \frac{\partial P^k}{\partial x_r} & \frac{\partial P^k}{\partial y_r} & \frac{\partial P^k}{\partial z_r} & -1 \\ \frac{\partial P^l}{\partial x_r} & \frac{\partial P^l}{\partial y_r} & \frac{\partial P^l}{\partial z_r} & -1 \end{bmatrix} = \begin{bmatrix} -\frac{(x_s^i-x_r)}{\rho^i} & -\frac{(y_s^i-y_r)}{\rho^i} & -\frac{(z_s^i-z_r)}{\rho^i} & -1 \\ -\frac{(x_s^j-x_r)}{\rho^j} & -\frac{(y_s^j-y_r)}{\rho^j} & -\frac{(z_s^j-z_r)}{\rho^j} & -1 \\ -\frac{(x_s^k-x_r)}{\rho^k} & -\frac{(y_s^k-y_r)}{\rho^k} & -\frac{(z_s^k-z_r)}{\rho^k} & -1 \\ -\frac{(x_s^l-x_r)}{\rho^l} & -\frac{(y_s^l-y_r)}{\rho^l} & -\frac{(z_s^l-z_r)}{\rho^l} & -1 \end{bmatrix}$$

Then generate cofactor matrix and rotate it to a local geodetic frame. Finally, compute and plot the HDOP and VDOP as a time series.

$$HDOP=\sqrt{q_{xLxL}+q_{yLyL}}$$
$$VDOP=\sqrt{q_{hLhL}}$$



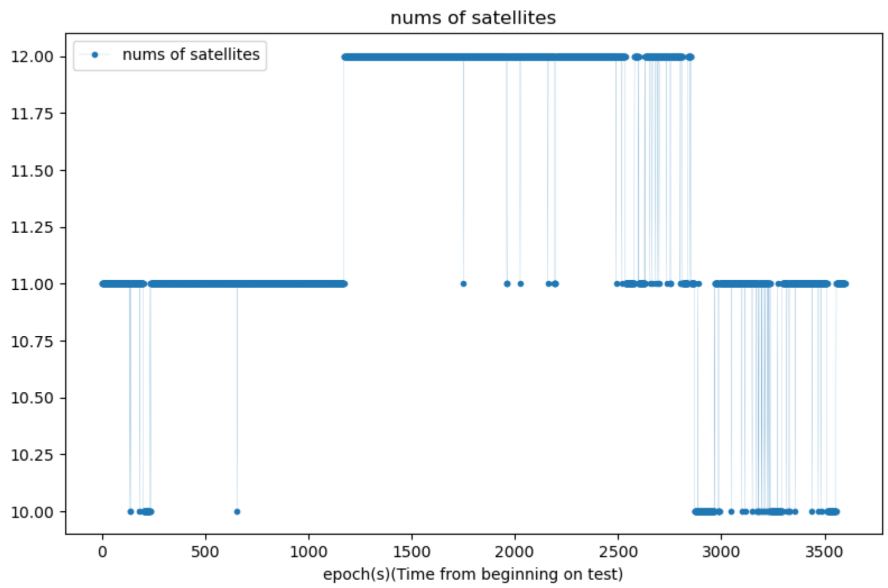
Plot 3. HDOP



Plot 4. VDOP

b. Plot a time series of the number of satellites.

My code records the number of satellites for each epoch when computing HDOP and VDOP. So just plot it.



Plot 5. Number of satellites

3. From the tasks above, draw an intuitive general conclusion on the quality of the position estimates you should expect from GPS based on the number of the satellites in view, their distribution in the sky as well as the quality of the pseudorange. In lab 2, you will use Least squares to compute the solutions.

Since positioning requires four unknowns, there should be data from at least four satellites at one epoch. The more satellites are observed, the more stable and accurate the positioning will be. In the provided data, we have at least 10 satellites. The quality of pseudorange is good because there is not much noise, and the graph looks clean. From the HDOP and VDOP, we can see that the value is small which means the distribution of the satellites is good. In conclusion, the quality of the position estimates we should expect from this data is not bad.