Satellite Geodesy

Exercise2-Klobuchar ionosphere correction
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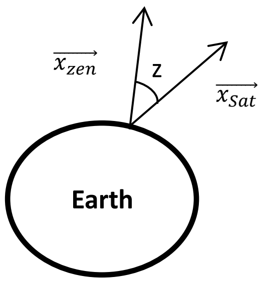
The file orbit.dat contains the position of all GPS satellites for September 1, 2014 between 8:00 UT1 and 10:00 UT1with respect to the WGS45 system. The Klobuchar coefficients for the same day are contained in the file CGIM2390.14N. An observer is located at the position $L = 9°.19$ and $B = 48°.79$ also with respect to WGS84.

1) Find all satellites, which are visible by the observer

Generally when the elevation angle is smaller than 0°, the satellite is considered nonvisible. For this reason, the key idea to find out visible satellites is that, to select the satellites with zenith angle $z < 90^{\circ}$.



First of all, the Cartesian coordinates of the observer should be computed.

$$\vec{x}_{OB} = \begin{bmatrix} (N+h)\cos B \cos L \\ (N+h)\cos B \sin L \\ (N(1-e^2)+h)\sin B \end{bmatrix}$$

$$\text{With } N = \frac{a}{\sqrt{1-e^2\sin^2\varphi}}, e^2 = \frac{a^2-b^2}{a^2}, f = \frac{a-b}{a}$$

In a certain period, a satellite has a coordinates $[x_S, y_S, z_S]^T$. Subtract the coordinates of the observer from the coordinates of a satellite, and then a vector pointed to the satellite is obtained.

$$\vec{x}_{Sat} = [x_S, y_S, z_S]^T - \vec{x}_{OB}$$

For the computation of zenith angle, the coordinates have to be transformed into a local level coordinate system.

$$\vec{x}_{SEU} = R_2(\frac{\pi}{2} - B)R_3(L)\vec{x}_{Sat}$$

In this way we get three components the $\vec{x}_{SEU}$:

$$\vec{x}_{SEU} = \begin{bmatrix} S \\ E \\ U \end{bmatrix}$$

In this coordinate system, the normalization of the U component is exactly the cosine function of the zenith angle. Therefore the zenith angel is derived by:

$$\text{zenith} = \arccos(\frac{U}{\sqrt{S^2 + E^2 + U^2}})$$

Finally, visible satellites and the corresponding number of visible epochs are given below:

PRN	**2**	**4**	**5**	**8**	**9**	**11**	**13**	**20**	**22**	**23**	**24**	**28**	**30**	**31**
NUM	9	2	8	6	3	9	9	3	1	7	9	9	9	2

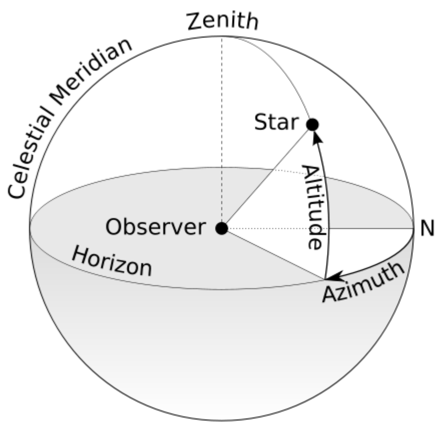
Hence, the visible satellites at all moments are 2, 11, 13, 24, 28, 30

2) Make a sky-plot of all visible satellites.

A sky plot is to determine the polar perspective of the satellite distribution. For this purpose, the PRN number, elevation angle (also called altitude), and azimuth are three key parameters for the plot. The geometric meaning of these three parameters is shown in the following figure.

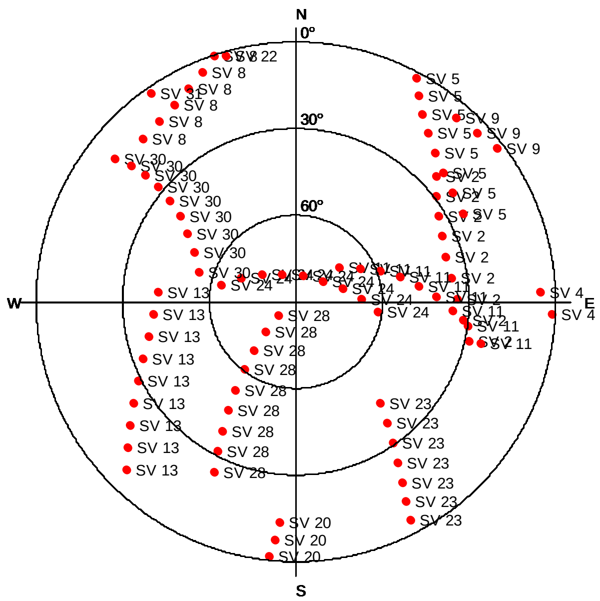
$$\text{azimuth} = \text{actan}(\frac{-S}{E})$$

$$\text{elevation} = \frac{\pi}{2} - \text{zenith}$$

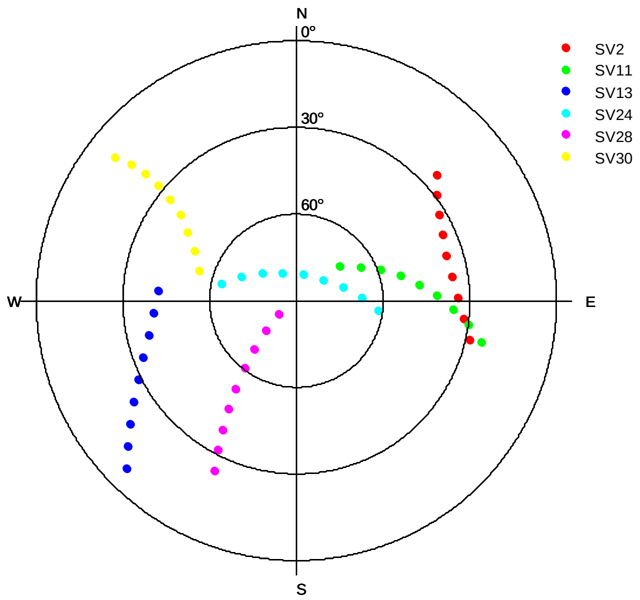


Source: http://en.wikipedia.org/wiki/Azimuth

The plot of all visible satellites is shown below:



The plot of satellites 2,4,11, 23, 28 (visible in every epoch) is shown below:



3) Compute the Klobuchar range-corrections on L1 for all visible satellites. Meanwhile, make a time-correction plot for all satellites.

The algorithm is described as:

Given

- Longitude and latitude ob observer $((\lambda = L, \phi = B))$
- Azimuth and elevation angle of the satellite (A, E)
- Klobuchar coefficients $\alpha_n, \beta_{n,} n = 0, \ldots, 3$

a. Calculate the Earth-centered angle (elevation in semicircles).

$$\psi = \frac{0.0137}{E + 0.11} - 0.022$$

b. Compute the latitude of the Ionospheric Pierce Point (IPP).

$$\phi_I = \phi + \psi \cos A$$

$$\text{if } \begin{cases} \phi_I > 0.416, \mathit{then}\ \phi_I = 0.416 \\ \phi_I < -0.416, \mathit{then}\ \phi_I = -0.416 \end{cases}$$

c. Compute the longitude of the IPP.

$$\lambda_I = \lambda + \frac{\psi \sin A}{\cos \phi}$$

d. Find the geomagnetic latitude of the IPP.

$$\phi_m = \phi_I + 0.064 \cos(\lambda_I - 1.617)$$

e. Find the local time at the IPP. (with constrain $0 \le t < 86400$)

$$t = 43200 \lambda_I + t_{GPS}$$

f. Compute the amplitude of ionospheric delay [s]

$$A_I = \max\left\{0, \sum_{n=0}^{3} \alpha_n \phi_m^n\right\}$$

g. Compute the period of ionospheric delay [s]

$$P_I = \max\left\{72000, \sum_{n=0}^{3} \beta_n \phi_m^n\right\}$$

h. Compute the phase of ionospheric delay.

$$X_I = \frac{2\pi(t - 50400)}{P_I}$$

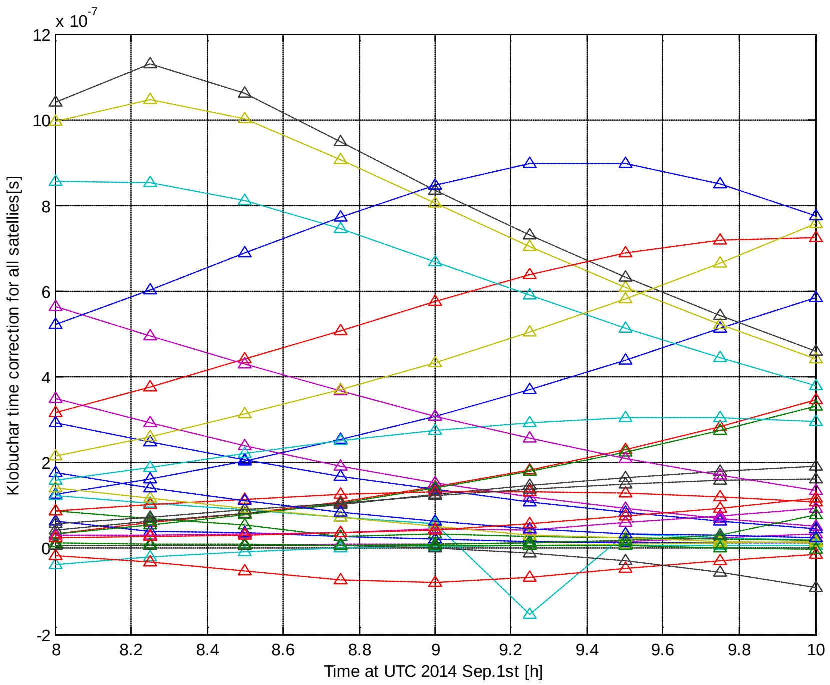
i. Compute the slant factor (elevation E in semicircles).

$$F = 1.0 + 16(0.53 - E)^3$$

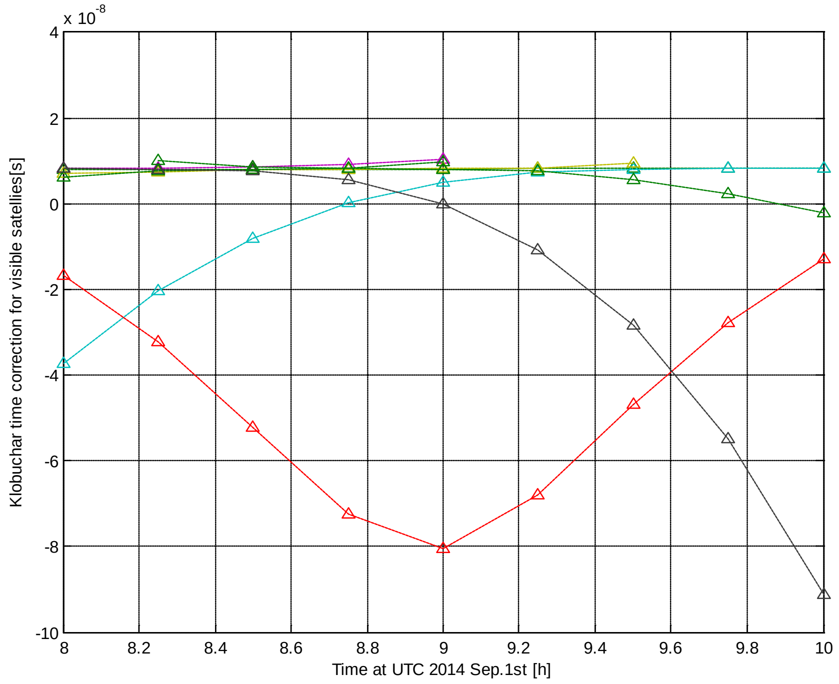
j. Compute the ionospheric time delay.

$$d\tau_{L1} = \begin{cases} \left[5 \cdot 10^{-9} + \sum_{n=0}^{3} \alpha_n \phi_m^n \cdot \left(1 - \frac{X_I^2}{2} - \frac{X_I^4}{24}\right)\right] F, & |X_I| \leq 1.57 \\ 5 \cdot 10^{-9} F & \text{, else} \end{cases}$$

The time correction for all satellites is shown by the following figure:



The time correction for visible satellites is shown by the following figure:



4) Discuss the relation between the correction and the elevation angle.

The time correction with respect to elevation angle is a decreasing function. Moreover, the absolute value of the changing rate is larger and larger in terms of the increasing elevation angle.