

**FEDERAL STATE  
AUTONOMOUS EDUCATIONAL INSTITUTION  
OF HIGHER EDUCATION  
«SAMARA STATE AEROSPACE UNIVERSITY  
named after academician S.P. KOROLEV  
(NATIONAL RESEARCH UNIVERSITY)»**

**Stereographic Sky Plot of Satellite Orbits  
and  
Plots Showing Satellites Above  
a Given Local Horizon**

**Samara 2014**

Author: Kai Borre

Stereographic sky plot of satellite orbits and plots showing satellites above a given local horizon/ Samara State Aerospace University. Samara 2014

Recommended for the students studying programs 11.04.01 «GNSS receivers. Hardware and software» and 03.04.01 «Algorithms and software»

This edition contains insight GNSS orbits and the required Matlab coding.

Printed according the decision of editorial committee of Samara State Aerospace University.

© Samara State Aerospace University 2014

## Introduction

The present course project combines useful and basic insight to GNSS orbits and the necessary Matlab coding. At the same time we try to visualize GNSS orbits and familiarize students with orbit descriptions as given by an almanac. This topic is fundamental for any new GNSS in its initial phase when only a few satellites of the system are launched. *Knowing the time windows in which the satellites are visible at a given location is essential for an observer.*

Much of the necessary theoretical background you may find in Chapter 9 of Borre&Strang (2012). However, this manual details central issues of the code and which may be difficult to find in a textbook.

In Table 1 we collect the six Keplerian elements which uniquely describe a satellite orbit.

The orbital information is provided in slightly different form for the individual GNSS. We restrict ourselves to details of GPS and GLONASS.

### 1 The GPS orbital information

The GPS orbital information comes in two versions, as almanacs and as ephemerides. The former contains among others the Keplerian elements while the latter one is meant for actual precise computations. Hence the Keplerian elements and their variation with time are included. This takes about 21 parameters. They are listed below in the sequence which I used in all my software developed since 1997, especially in the Easysuite. An alternative sequence is used in the Receiver INdependent EXchange (RINEX) format. However, we maintain our own defined sequence which originally was introduced in our and other non-commercial software:

```
GM = 3.986005e14; % earth's universal gravitational
% parameter m^3/s^2
Omegae_dot = 7.2921151467e - 5; % earth rotation rate, rad/s

% Units are either seconds, meters, or radians
% Assigning the local variables to eph
svprn = eph(1);
af2 = eph(2);
```

Table 1 Keplerian orbit elements: Satellite position

$a$	semi major axis	size and shape of orbit
$e$	eccentricity	
$\omega$	argument of perigee	the orbital plane in the apparent system
$\Omega$	right ascension of ascending node	
$i$	inclination	
$\mu$	mean anomaly	position in the plane

Table 2 Example of GLONASS almanac

NS	Date	TOW[s]	T[s]	e[]	i[degree]	$\Omega$ [degree]	$\omega$ [degree]	dt <sub>2</sub> [s]	K[]	$\Delta T$ [s]
01	28.08.14	31051.781	40543.78	0.00046	64.21347	157.9295	-38.92456	$1.6021729^{-4}$	1	$-6.1035156^{-5}$
02	28.08.14	36072.812	40544.016	0.00161	64.68503	136.99419	-112.19238	$-8.773804^{-5}$	-4	$-6.1035156^{-5}$
03	28.08.14	631.09375	40544.023	0.00161	64.51577	-74.719734	-106.62781	$-1.9073486^{-5}$	5	$-3.0517578^{-4}$
04	28.08.14	5769.5938	40544.05	0.00075	64.53568	-96.28933	-101.40381	$-8.392334^{-4}$	6	$-3.6621094^{-4}$
05	28.08.14	10778.031	40543.984	0.00014	64.20026	-117.414154	25.570679	$3.8146973^{-6}$	1	$-1.2207031^{-4}$
...										

$M0 = \text{eph}(3);$   
 $\text{roota} = \text{eph}(4);$   
 $\text{deltan} = \text{eph}(5);$   
 $\text{ecc} = \text{eph}(6);$   
 $\text{omega} = \text{eph}(7);$   
 $\text{cuc} = \text{eph}(8);$   
 $\text{cus} = \text{eph}(9);$   
 $\text{crc} = \text{eph}(10);$   
 $\text{crs} = \text{eph}(11);$   
 $i0 = \text{eph}(12);$   
 $\text{idot} = \text{eph}(13);$   
 $\text{cic} = \text{eph}(14);$   
 $\text{cis} = \text{eph}(15);$   
 $\text{Omega0} = \text{eph}(16);$   
 $\text{Omegadot} = \text{eph}(17);$   
 $\text{toe} = \text{eph}(18);$   
 $\text{af0} = \text{eph}(19);$   
 $\text{af1} = \text{eph}(20);$   
 $\text{toc} = \text{eph}(21);$

The matrix eph has 21 rows keeping the Kepler elements and other information. After an almanac file is run through rinexe the matrix eph has multiple columns with several values for a given PRN.

You may formally create an ephemeris from an almanac by setting all parameters not defined in the almanac to zero in the ephemeris.

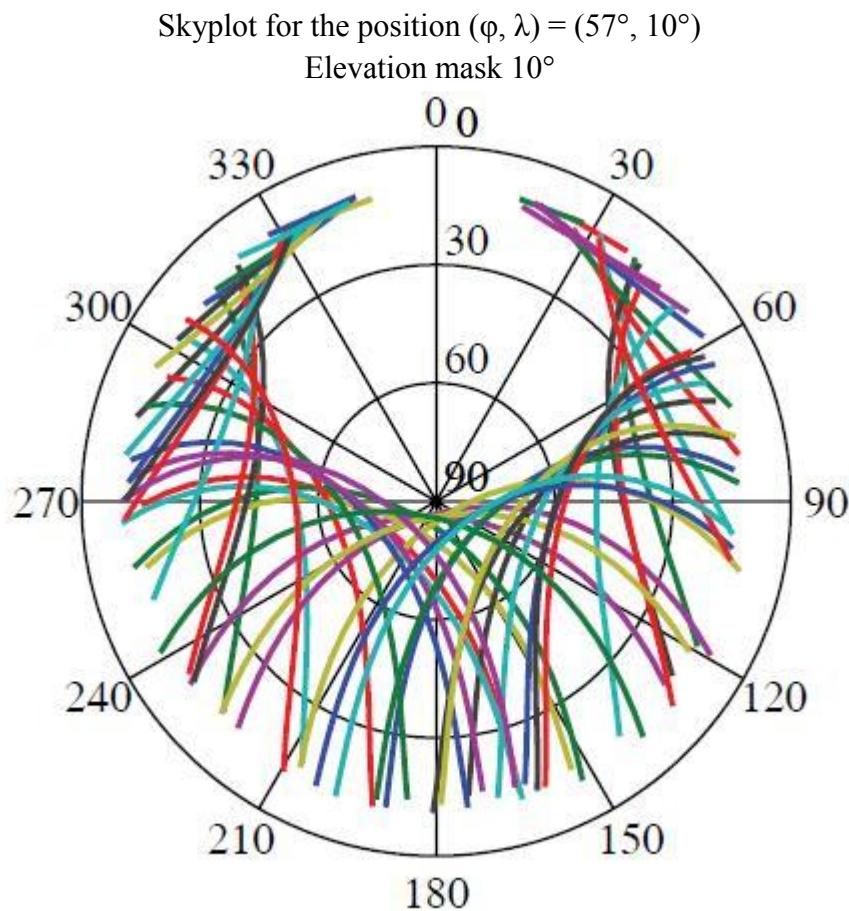
We emphasize that the parameter sequence is different from the one used in the RINEX format for Navigation message files.

We stress that this course project only outputs graphical results, and no numerical results, so we stick to use only almanacs for all satellites.

GPS almanacs can be downloaded from <http://navcen.uscg.gov/?pageName=gpsAlmanacs>

## 2 The GLONASS orbit information

The GLONASS orbit information comes in almanacs as shown in Table 2. In the table the first column is the satellite number, the fourth column is the time T for one revolution, seventh column is right ascension  $\Omega$  for the ascending node, eighth column is argument of perigee  $\omega$ , ninth column is  $dt_2$  correction to board time scale, tenth



All PRNs except 1

Figure 1 - Sky plot including all GPS satellites for a period of 24 hours at a given position. The elevation mask is  $10^\circ$

column is an integer  $K$  for computing the frequency change  $df = \frac{9}{16}K0.5625\text{MHz}$ , and the eleventh column indicates rate of the draconic period variation  $\Delta T$ .

The draconic period is the time that elapses between two passages of the satellite through its ascending node, the point of its orbit where it crosses the ecliptic from the southern to the northern hemisphere. The orbital plane of the satellite precesses causing the draconic period to differ from the sidereal period. Explicitly the draconic period in GLONASS is 11 hours 15 minutes 44 seconds.

The GLONASS almanac does not immediately expose the Keplerian elements, but they can be derived from the given parameters. The mean anomaly  $\mu$  is defined as

$$\mu = n(t - t_0)$$

where  $t_0$  equals the given *TOW* and  $t$  is the actual time for computing a satellite position.

The mean motion  $n$  is computed as  $n = 2\pi/T$ .

Finally the semi-major axis  $a$  is computed from Kepler's third law:

$$2\pi/T = \sqrt{\frac{GM}{a^3}}$$

The value of the product  $GM = 3.986\,005 \cdot 10^{14} \text{ m}^3/\text{s}^2$ .

Almanacs for GLONASS can be downloaded from

<https://glonass - iac.ru/en/GLONASS/ephemeris.php>

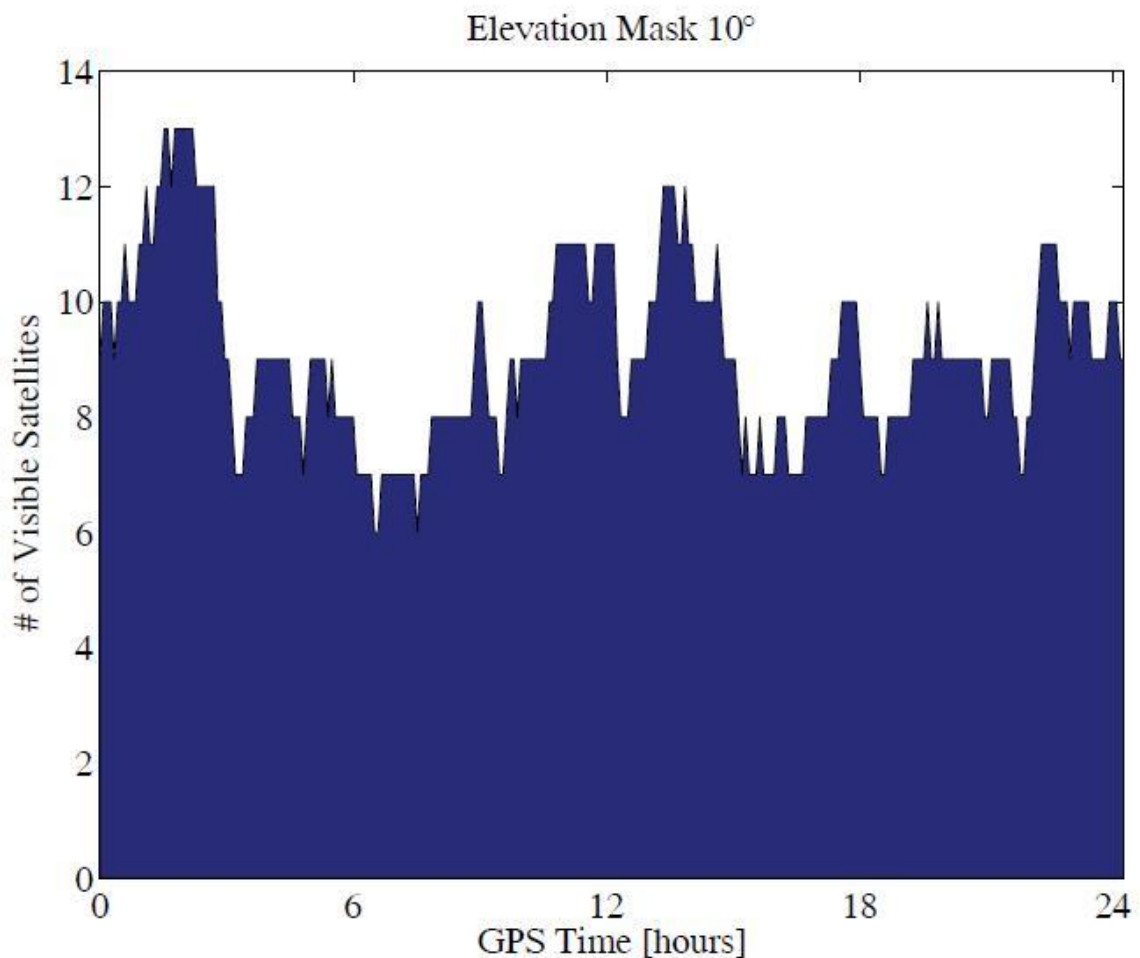


Figure 2 - Number of visible satellites

The downloaded almanacs must be reformatted into MATLAB's binary format for ephemerides using the *M*-file *rinexe*.

We start by the following recipe and later on add useful details:

1. Input an almanac: GPS or GLONASS
2. Input the value of the elevation mask

3. Input ( $\varphi$ ,) for the local horizon
4. Read and reformat the ephemerides to eph-format
5. Transform ( $\varphi$ ,) to ( $X, Y, Z$ )
6. Compute ( $az, el$ ) for each satellite for every 10 or 15 minutes over a period of 24 hours
7. Create Figure(1); % stereographic plot
8. Create Figure(2); % visibility plot with a resolution of 5 minutes
9. Create Figure(3); % another visibility plot
10. Create Figure(4); % number of visible satellites in x hours

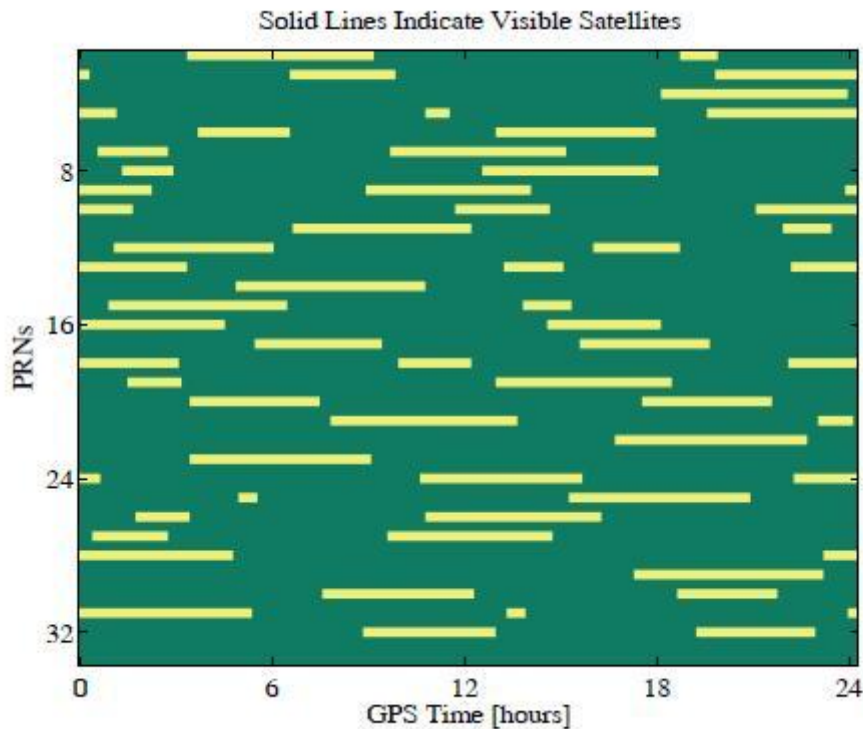


Figure 3 - Time period when the visible satellites are  $10^0$  or higher above the horizon

The user must enter ( $\varphi, \lambda$ ) for the position where the plot is to be used, and a value for the elevation mask to be set. Then the azimuth and elevation angles for all visible positions of the included satellites are computed and plotted as polar coordinates. Next follows bookkeeping on how many satellites are visible during the day and which ones in which periods.

The easy-Suite starts with a polar plot of satellite orbits as viewed from a given location, a graph showing the number of visible satellites and the period of time when they are visible during 24 consecutive hours.

If you need help have a look at easy11.m. That is an implementation of the course project for GPS. Try to do your own implementation using a recent GLONASS almanac.

## References

1. Borre, Kai & Strang, Gilbert. Algorithms for Global Positioning. Wellesley-Cambridge Press, Wellesley MA, 2012

Educational edition

Stereographic sky plot of satellite orbits and plots showing satellites above a given local horizon/ Samara State Aerospace University

Learner's guide

Authors: Kai Borre

Samara State Aerospace University (SSAU)