DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Computer Program to Predict Visibility of Global Positioning System (GPS) Satellites Using an IBM-PC or Compatible Micro-Computer

by

John T. Gann

U.S. Geological Survey

Open-File Report 87-274

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. (Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.) (Released in response to a Freedom of Information Act request.)

1987

CONTENTS

ILLUSTRATIONS

Introduction

The Global Positioning System (GPS) is a satellite based radio navigation system in provisional use while under development by the U.S. government. When complete the GPS will employ a constellation of 18 satellites operating in 12 hour orbits at an altitude of 20,000 km. There will be six orbital planes inclined 57 degrees from the equator. The GPS will provide three-dimensional positioning and velocity as well as precise time. Positional accuracy on the order of ten meters can be expected.

The GPS has three components: the space segment (satellites), the ground segment (tracking and monitoring stations) and the user equipment (various GPS receivers). The locations of the GPS satellites are known within a few meters. They are monitored and controlled by ground tracking stations. In operation, the GPS receiver measures ranges to three or more satellites and computes a position based on the intersection of these range measurements.

In 1987, there are seven operational GPS satellites in place. Several of these are operating well past their expected service life. The next launch of additional GPS satellites will not occur until October 1988. The existing network of seven satellites will provide precision navigation for at least several hours a day over most of the earth.

The GPS programs included in this open file are intended to be used as a mission planning aid. As with any ranging system, GPS has limitations relating to the geometry of the satellites with respect to each other and to the user. As the GPS constellation is incomplete, true global coverage is not yet a reality. These programs will predict the GPS coverage over a 24 hour period for any geographical postion and time. Using the prediction program a user can determine the number of hours of GPS coverage available at a given location and time. The quality of the GPS solution owing to satellite / user geometry is also available by examining the elevation and azimuth angles of each satellite. Mission planners can use these aids to efficiently utilize the GPS.

Hardware Requirements

The prediction program PREDICT can be executed on an IBM PC, XT, AT or compatible computer with at least 256K memory. The output is most conveniently stored on disk but can be directed to a line printer (LPT1:) or to the video screen.

The program LISTVIZ reads the visibility file produced from PREDICT and produces a formatted output file. The hardware requirements for LISTVIZ are the same as for PREDICT. The output from LISTVIZ is intended for the line printer but may be directed to disk for later printing.

The program POLAR requires a graphics monitor and extended graphics adaptor. POLAR will run with a CGA card but will not run with a monochrome/Hercules card.

The program GPSPLOT requires an HP97XX or HP74XX series plotter. The computer must be equipped with an RS232C standard communications interface. The plotter must be configured to operate at 9600 baud, even parity, 7 data bits and 1 stop bit.

The executable files require approximately 240K bytes of disk space. The included almanac files require less than 10K bytes of disk space each. A typical visibility file requires about 11K bytes of disk space.

Acknowledgements

The author thanks Len Kruzcinski for providing valuable assistance in solving the Kepler equations using successive approximations and in implementing the ICD - 200 equations. Len Kruzcinski is Chief Scientist at Trimble Navigation Limited.

PREDICT PROGRAM

The PREDICT program is the workhorse of this package. As its name suggests, PREDICT computes GPS satellite visibility, elevation and azimuth. Figures 1 and 2 illustrate a step by step sample of a typical execution of PREDICT. To run the PREDICT program simply type PREDICT and press return.

1. Almanac File. The user is prompted for an input satellite almanac file. The default almanac file is displayed within the <> symbols. In Figure 1 the default almanac file is 31MAR87.alm. This user selected 20DEC86.alm for his application. Unless you are familiar with the format of the almanac file you should use the default file provided. The default file may be selected by simply pressing return. The almanac file included is useful for one year from the date of the almanac. The date of the almanac is embedded in the almanac file name. The file 31MAR87.alm was recorded March 31, 1987 and will be useful until March 31, 1988. New almanac files may be obtained by contacting John Gann at the U.S.G.S, 3475 Deer Creek Road, Palo Alto, California 94304 (415) 354-3048 FTS 459-3048.

The almanac files were created using output from a Trimble 4000A GPS Navigator. This receiver has an option to allow satellite ephemeris and almanac data for each satellite to be output through a serial port on the receiver. Only the almanac parameters are used in visibility computations. There is no software included that will allow automatic almanac file creation from the receiver to the IBM PC or compatible. It is possible to edit the existing almanac files with new data from the receiver. Unless you are familiar with the Trimble 4000A output format, use the existing almanac files. For a full description of GPS almanac parameters and navigation equations please consult the Interface Control Document - 200 published by the U.S. Government (6592 ABG / DADF, P.O. Box 92960, WPC, Los Angeles, CA 90009).

Upon selection of an almanac file, PREDICT begins reading and loading the orbital parameters for each satellite contained in the almanac. As the almanac data for each satellite is read a loading message appears. See Figure 1.

2. Output device or file. The user is prompted for the destination of the output from PREDICT. The default selection is the video screen. It is selected by pressing return. More frequently the user will want to create a file of the output of PREDICT to be used by subsequent listing and graphics programs. The file name must conform to MS-DOS file naming conventions. Each PREDICT output file should be named with the ".viz" suffix. The ".viz" suffix can be used to group visibility files. Note that each ".viz" file will contain the satellite predictions for one complete day - the "date of interest".

3. Date of interest. Enter the date for which you require GPS coverage information. The date must be entered as mm/dd/yy and

must include leading zeroes. The GPS coverage changes only slightly from day to day. If your survey extends over several weeks or months, run PREDICT for each week of your mission, not for each day.

4. Latitude. The latitude may be entered in either degrees and minutes or in decimal degrees. The sign convention is that north latitudes are positive and south latitudes are negative. PREDICT will ignore N or S. For example, in Figure 1 this user entered 35 30 for 35 degrees 30 minutes north latitude. (The same result could have been obtained by entering 35.5). Positive (north) is assumed if no plus sign is entered.

5. Longitude. Like latitude, longitude may be entered in decimal degrees or in degrees and minutes. The sign convention is that longtiudes east of Greenwich are positive and west of Greenwich are negative. For example, in Figure 1 this user entered 139 30 for 139 degrees and 30 minutes east longitude. The same result could have been obtained by entering 139.5. To enter a longitude west of Greenwich the user would enter -122.2 <RTN> or -122 12 <RTN> for 122 degrees and 12 minutes of west longitude.

6. Geoidal height. If known, enter the height of the GPS receiver antennae in meters with respect to the WGS-84 ellipsoid. If not known, press return for the default value of zero. The errors contributed by incorrect geoidal heighths for these types of predictions are generally insignificant. (The same does not apply for the geoidal heighths used by the GPS receiver when navigating).

7. Elevation Mask. Most GPS receivers will not consistently track satellites that are very close to the horizon. The user may select an elevation angle below which satellites will not be considered. The default value is 10 degrees, i.e. satellites below 10 degrees elevation will not be output by PREDICT. You should adjust the elevation mask according to ability of your receiver to track low elevation satellites. The default value of 10 degrees is selected by pressing return.

Upon the last user entry, PREDICT begins the visibility computations. As each satellite is processed, a one line output message is displayed on the video screen. See Figure 2.

```
Enter almanac file name for sat prediction <31MAR87.alm>  ? 20DEC86.alm
```

```
loading almanac for PRN.... 03
loading almanac for PRN.... 06
loading almanac for PRN.... 08
loading almanac for PRN.... 09
loading almanac for PRN.... 11
loading almanac for PRN.... 12
loading almanac for PRN.... 13
```

```
Enter output device or file name <SCREEN:> ? Tokyo.viz
Enter date of interest (e.g. 01/01/87) 06/15/87
Enter latitude (e.g. 37 24.5) for prediction area 35 30
Enter longitude (e.g. -122 08.5) for prediction area 139 30
Enter geoid ht (mtr) for desired prediction area <0> ? 35
Enter elevation mask for sat visibility <10 deg> ? 2
```

Figure 1. PREDICT. Typical user responses to PREDICT program.

```
 35 30N              139 30E            Geoid Ht : 35        GPS Week:   388
Elv Mask : 2        MON 15 JUN 87       Almanac File: 20DEC86.alm


   UT          Sat ID          Range(m)          Elevation         Azimuth
 02:45         3             22517371.2            36.6              122.0




                        per cent complete  2
```

Figure 2. PREDICT. Sample video screen output from PREDICT during execution.

LISTVIZ PROGRAM

LISTVIZ is for users that do not have the graphics capability on their computer. LISTVIZ reads the ".viz" file produced from the prediction program PREDICT. The output is formatted for an 80-character line printer. It may also be directed to a disk file or to the default video screen. See Figure 3. To run the LISTVIZ program simply type LISTVIZ and press return.

1. Input Visibility File. The user is prompted to enter the name of the visibility file. The default file will be displayed within the inequality symbols. The user may select the default file by pressing return. A different file may be selected by entering the appropriate file name. If you have entered an improper file name LISTVIZ will respond with an error message and a directory of all the files with the ".viz" suffix on the default disk.

2. Output File Specification. The user may direct the file to disk, line printer (LPT1:) or the default video screen. Output will occur when LISTVIZ determines that 2 or more satellites are visible.

35 30N 139 30E Geoid Ht : 35 GPS Week: 388
Elv Mask : 2 MON 15 JUN 87 Almanac File: 20DEC86.alm
input file used : Tokyo.viz Listed on 04-21-1987 at 00:34:15 UT

UT	SAT ID	Elevation	Azimuth	Comments
00:15	9	10.5	47.7	
	11	2.6	30.1	
	12	50.8	18.8	
	13	8.5	87.6	
00:30	9	5.7	52.3	
	12	45.6	25.7	
	13	12.1	81.4	
00:45	12	40.7	32.2	
	13	15.1	74.8	
01:00	12	35.9	38.4	
	13	17.3	67.7	
01:15	3	6.9	144.6	
	12	31.4	44.6	
	13	18.5	60.5	
01:30	3	12.5	140.8	
	12	27.2	50.6	
	13	18.7	53.2	
01:45	3	18.5	136.9	
	12	23.1	56.7	
	13	17.8	46.2	
02:00	3	24.5	132.7	
	12	19.3	62.8	
	13	15.9	39.6	
02:15	3	30.7	127.8	
	12	15.6	68.8	
	13	13.0	33.8	
02:30	3	36.6	122.0	
	12	12.0	74.9	
	13	9.2	28.7	
02:45	3	42.2	114.9	
	12	8.4	81.0	
	13	4.9	24.5	
03:00	3	46.9	106.0	
	12	4.9	87.0	
09:30	6	6.0	335.6	
	8	26.8	275.7	unhealthy
09:45	6	11.4	332.5	

Figure 3. LISTVIZ. Sample output from LISTVIZ to printer.

POLAR PROGRAM

POLAR produces a polar plot with the users location at the center. See Figure 4. To run the POLAR program simply type POLAR and press return. GPS satellite elevation azimuth and ID are plotted using the users time and location. The concentric rings are separated by 15 degrees of elevation increasing towards the center. The horizon (zero degrees elevation) is farthest from center. The zenith (90 degrees elevation) occurs at the center. Each satellite ID will be plotted at the azimuth angle and elevation angle for each time interval the user selects.

POLAR begins at noon on the day of interest. The user may step forward in time by pressing either the right or up arrow keys. The up arrow will increment time by 2 hours. The right arrow increments time by 15 minutes. In the same way, the down arrow decrements time by two hours. The left arrow decrements time by 15 minutes. If the user attempts to increment past midnight, POLAR will wrap around to the beginning of the same day.

1. Input Visibility File. The user must enter a visibilty file produced by the PREDICT program or select the default file by pressing return. If the user enters an incorrect file name POLAR will provide a directory listing of all files with the ".viz" suffix on the default disk.

No file output is produced by POLAR.

Press the ESC key to exit POLAR.

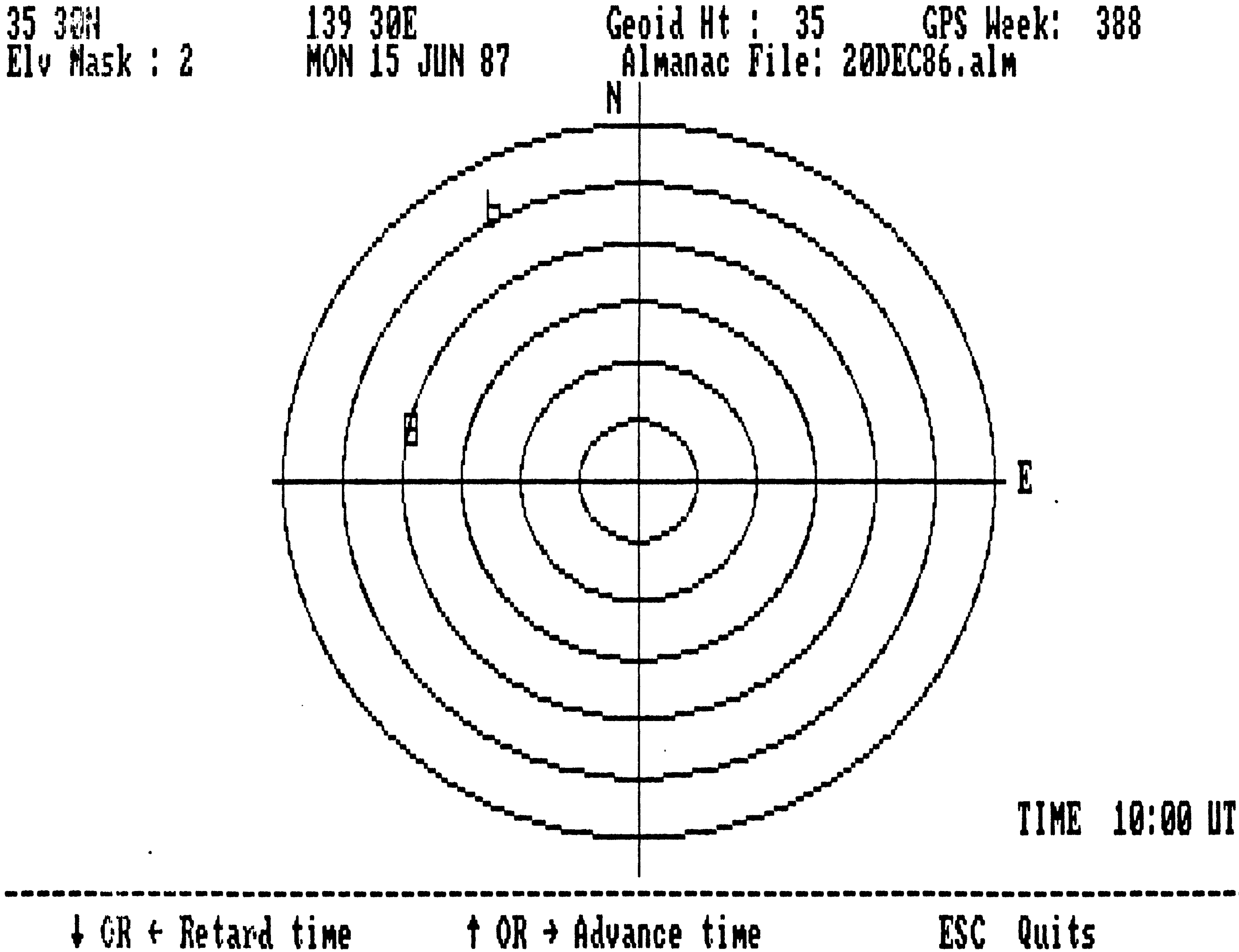

Figure 4. POLAR. Typical POLAR video screen display.

GPSPLOT PROGRAM

GPSPLOT is for users that have access to an HP plotter, as described in the Hardware Requirements section. The user is prompted for a visibility file. Next the user is presented a menu that allows three different plots, reselection of the visibility file or a quit option. See Figure 5. To run the GPSPLOT program simply type GPSPLOT and press return.

1. Elevation. The elevation plot displays GPS satellite elevation over the 24-hour period. Each elevation trace is labeled with the proper satellite ID. The y-axis represents elevation angle in degrees above the local horizon from 0 to 90. The x-axis represents time. See Figure 6.

2. Azimuth. The azimuth plot displays GPS satellite azimuths relative to north. Each azimuth trace is labeled with the appropriate satellite ID. The y-axis represents azimuth angle measured clockwise from north through 360 degrees. The x-axis represents time. See Figure 7.

3. Visibility. The visibility plot displays GPS satellites that are above the users elevation mask for the 24 hour period of interest. The y-axis represents the different satellite ID's. The x-axis represents time. See Figure 8.

4. Select another visibility file. The user may select another visibility file to be plotted by pressing 4.

5. Quit. The user may terminate execution of GPSPLOT by pressing 5.

```
------------------------------------------------------------------------------------------
                         source file: Tokyo.viz
------------------------------------------------------------------------------------------
    35 30N               139 30E            Geoid Ht :   35      GPS Week:   388
    Elv Mask : 2         MON 15 JUN 87 .     Almanac File: 20DEC86.alm
------------------------------------------------------------------------------------------

             1. Satellite Elevation Angle vs. Time(UT)

             2. Satellite Azimuth Angle vs. Time(UT)

             3. Number of Satellites Visible vs. Time(UT)

             4. Choose Another File to Plot

             5. Quit


                       Enter Number of Selection >>
```

Figure 5. GPSPLOT. Main Menu.

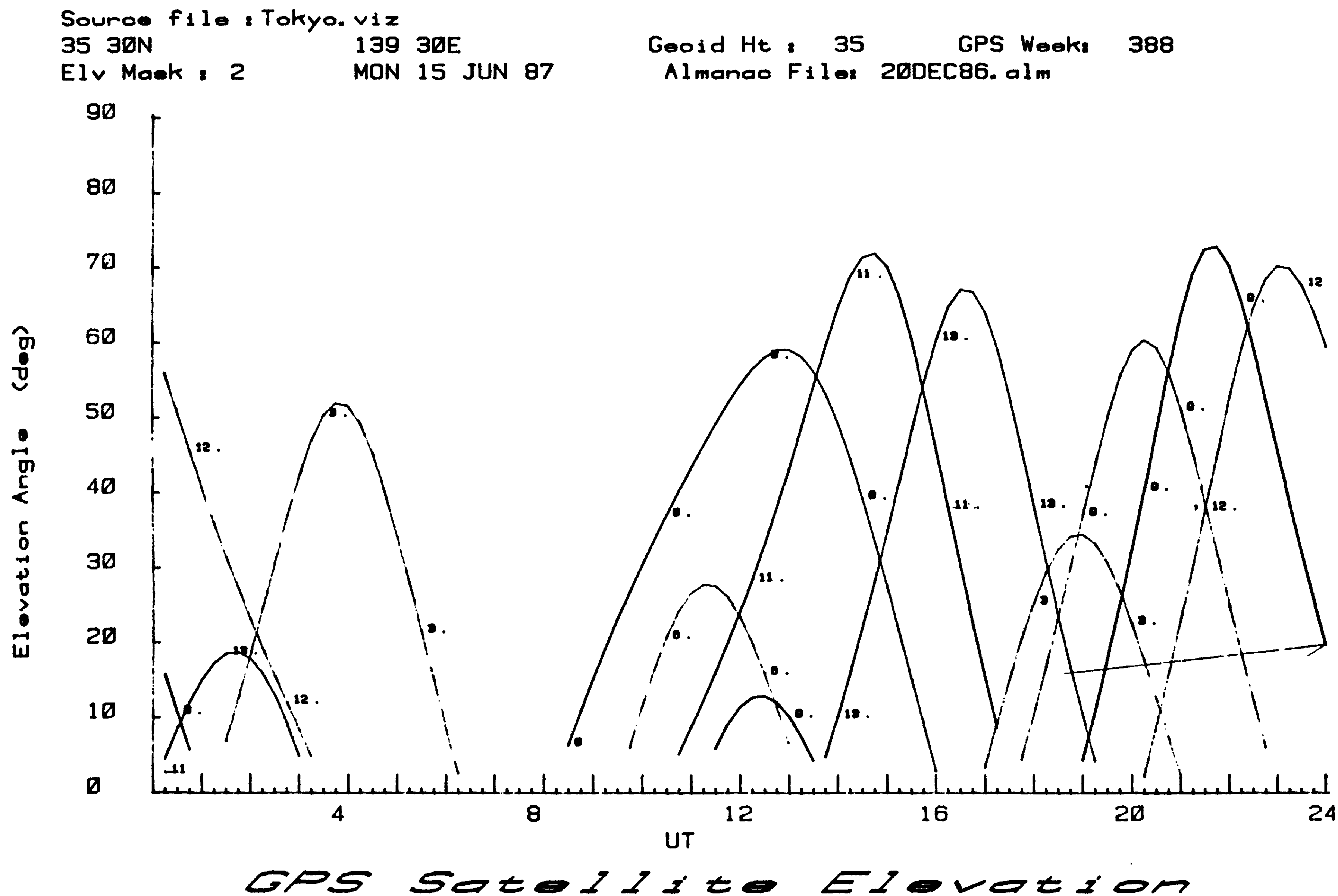

Figure 6. GPSPLOT. GPS satellite elevation angle vs. time.

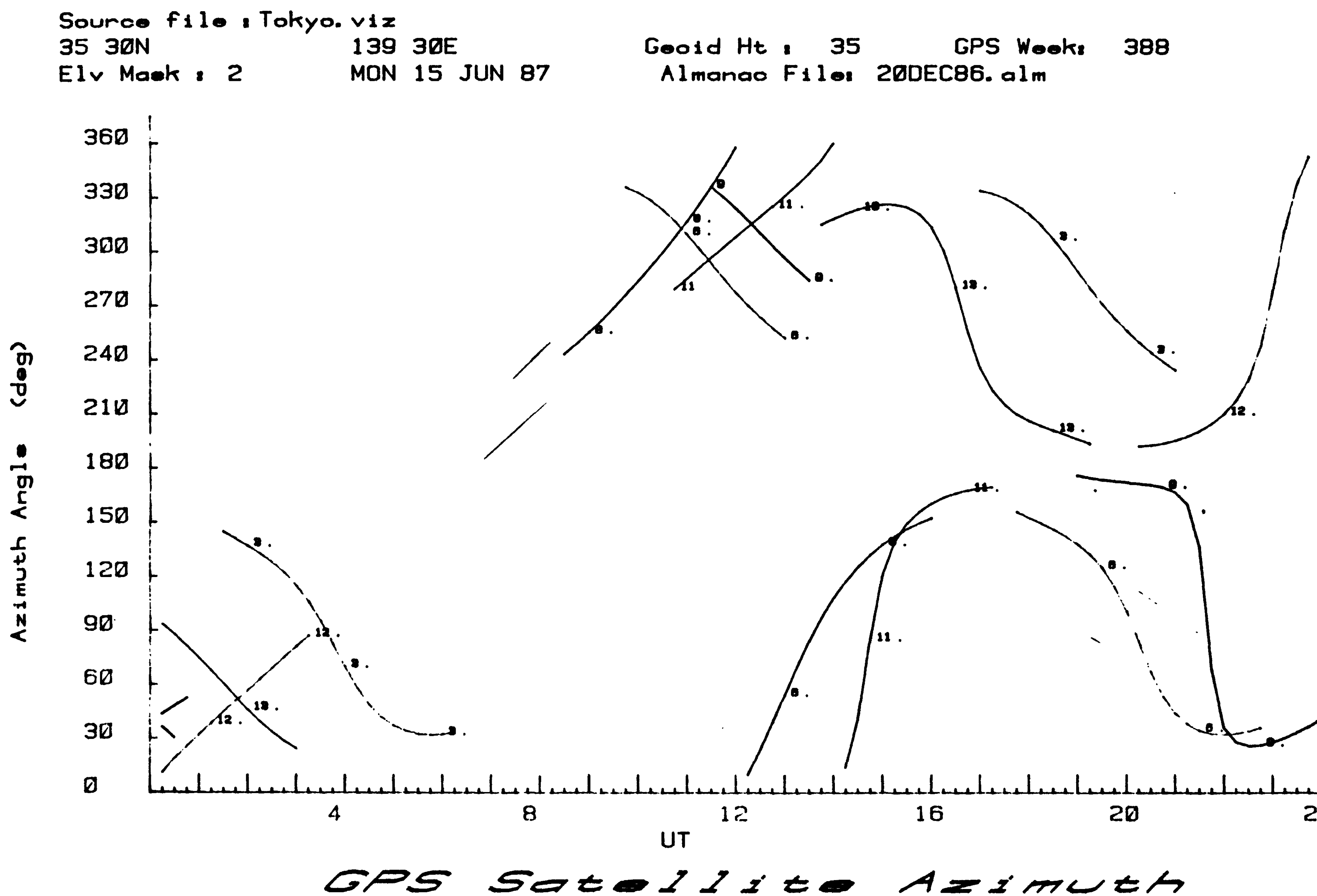

Figure 7. GPSPLOT. GPS satellite azimuth angle vs. time.

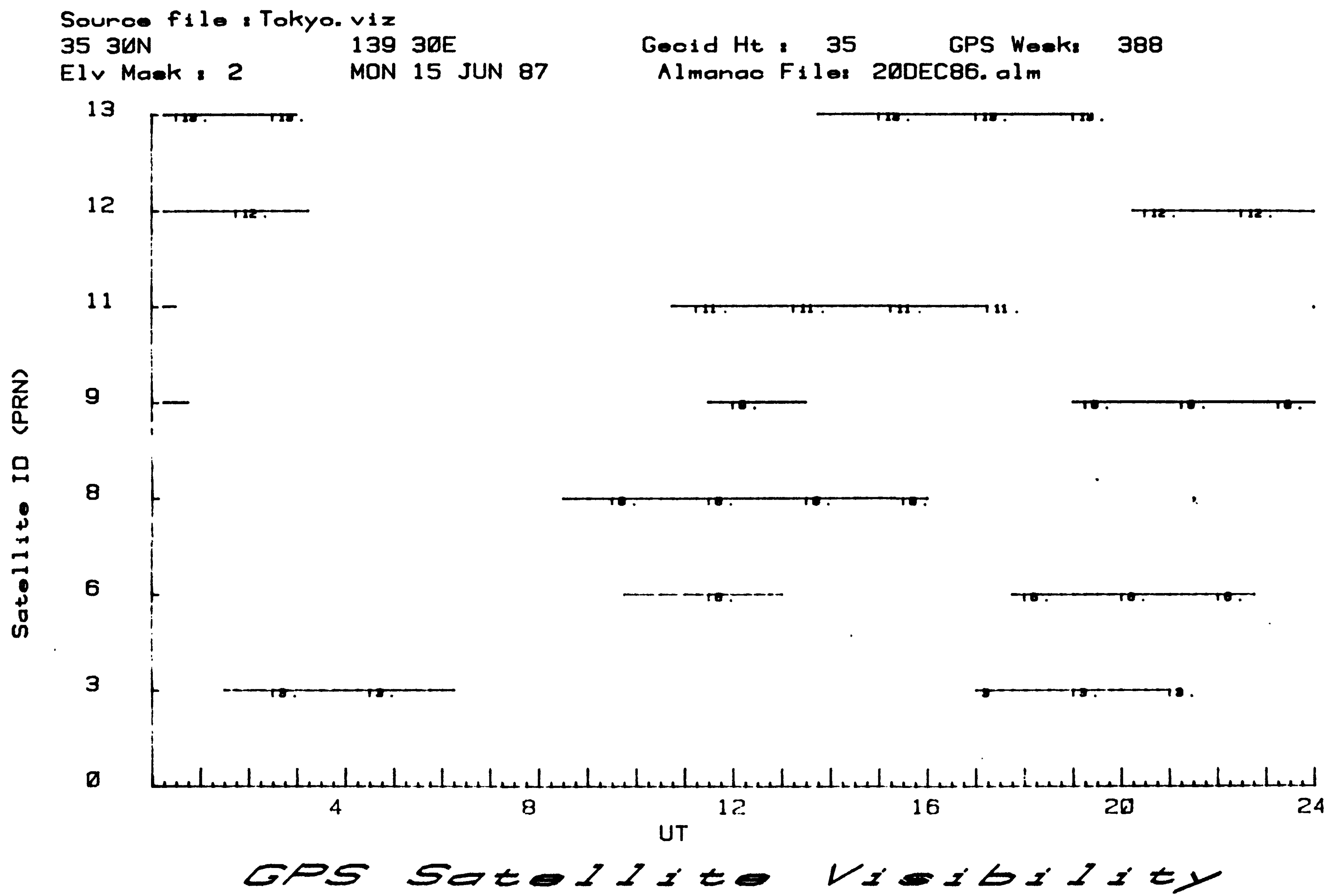

Figure 8. GPSPLOT. GPS satellite visibility vs. time.