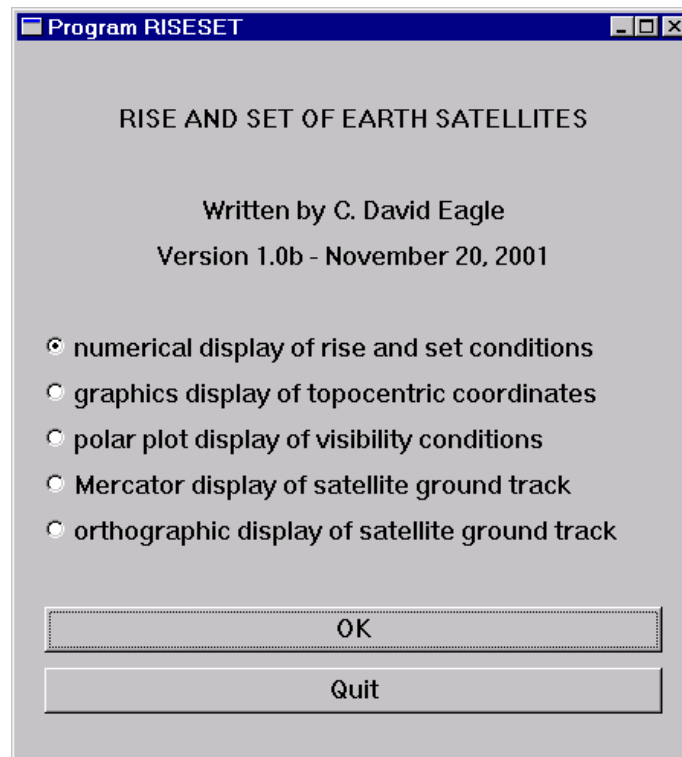


Rise and Set of Earth Satellites

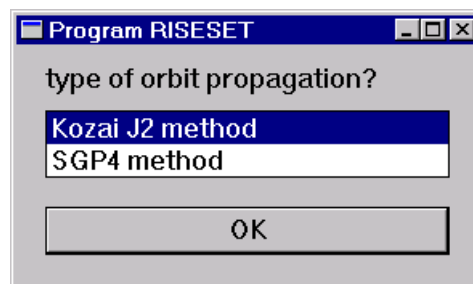
This interactive Windows XP/Vista/7 computer program (`riserset.exe`) can be used to determine rise and set conditions of Earth satellites with respect to a ground site on an oblate Earth. During the visibility calculations, a satellite's orbit can be propagated using either a J_2 Kozai method or the NORAD SGP4 algorithm. The software can also be used to create azimuth-elevation polar plots and Mercator and orthographic ground track graphics during visibility.

Before starting the program, make sure the downloaded geographic map files are saved in a directory located at `c:\dislin\map`. The executable program and support DLL can be located anywhere the user chooses. However, the executable program and support DLL must be saved in the same directory.

All program options are selected using the following main menu:



Each program option will prompt the user for the type of orbit propagation to use with the following screen:



If the Kozai orbit propagation method is selected, the software will display the following *initial conditions* data entry screen:

initial date and time		initial orbital elements	
date (mm, dd, yyyy)	3,21,1999	semimajor axis (km)	8000
UT (hr, min, sec)	18,0,0	eccentricity	0
observer coordinates		inclination (degrees)	28.5
latitude (d, m, s)	40,0,0.0	argument of perigee	0
longitude (d, m, s)	-105,0,0.0	RAAN (degrees)	100
altitude (meters)	100	true anomaly (degrees)	45
elevation angle (deg)	5.0	<input type="checkbox"/> include refraction	
sim duration (days)	1	OK	
		Quit	

The user can edit any data item on this screen to define a simulation. Checking the include refraction box will cause the program to calculate visibility with a simple atmospheric refraction correction algorithm due to Meeus. The elevation angle field can be used to enforce a minimum elevation angle constraint or mask during the simulation.

If the user elects to propagate the orbit with SGP4, the software will prompt for a two-line element (TLE) database file with a *file selection screen* similar to the following:

Look in: dislin

- esplit
- fsplit
- map
- runtime
- win
- wmf
- Tle682.txt
- Tle861.txt

File name:

Files of type: Mask (tle*.txt)

Open as read-only

Open Cancel

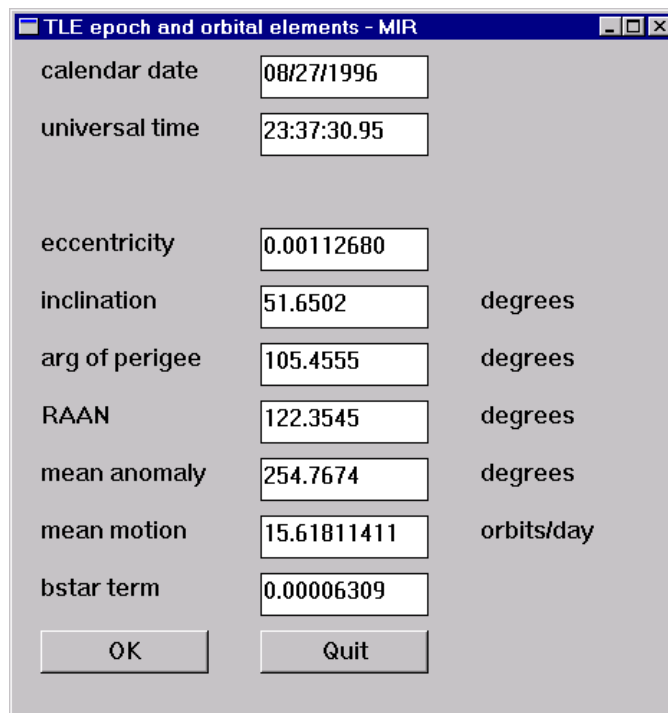
The default file name mask for TLE database files is `t1e*.txt`. However, any SGP4 compatible file can be selected. The following illustrates the format of a typical TLE database file.

```
1996049B
1 24286U 96049B   96239.55606907 .00002170 00000-0 20530-3 0   137
2 24286  82.9884 175.9325 2213190 152.7820 220.9138 10.81388938   552
FAST
1 24285U 96049A   96239.83213868 .00001416 00000-0 13803-3 0    66
2 24285  83.0028 175.8069 2208087 152.2391 221.6551 10.81689475   595
1996048B
1 24283U 96048B   96239.90394890 .00028650 00000-0 10859-2 0   152
2 24283  27.2621 112.8179 5643668 190.9132 148.5598  4.66444912   407
```

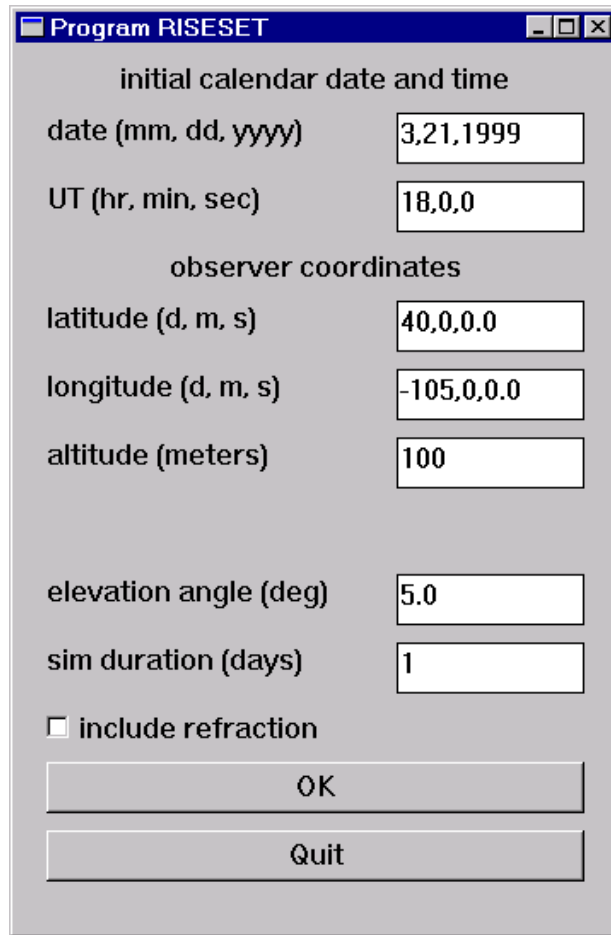
After a TLE database file is selected, the software will ask you to input the name of the satellite with the following prompt:



The satellite name is not case sensitive but must be spelled correctly. The software will search the database file, find the satellite and print a TLE epoch screen similar to the following:



The initial conditions data entry screen for the SGP4 program option is similar to the following:

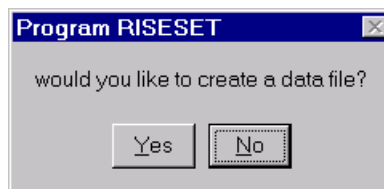


The screenshot shows a window titled "Program RISESET" with the following fields and options:

- initial calendar date and time
 - date (mm, dd, yyyy): 3,21,1999
 - UT (hr, min, sec): 18,0,0
- observer coordinates
 - latitude (d, m, s): 40,0,0.0
 - longitude (d, m, s): -105,0,0.0
 - altitude (meters): 100
- elevation angle (deg): 5.0
- sim duration (days): 1
- include refraction
- Buttons: OK, Quit

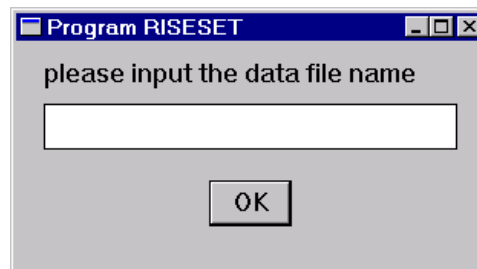
numerical display of rise and set conditions

This program option can be used to create a screen display and/or an ASCII data file of visibility conditions. The prompt for the data file option is



The dialog box titled "Program RISESET" contains the text "would you like to create a data file?" and two buttons: "Yes" and "No".

If you select Yes the software will ask for the name of the data file with this next request.

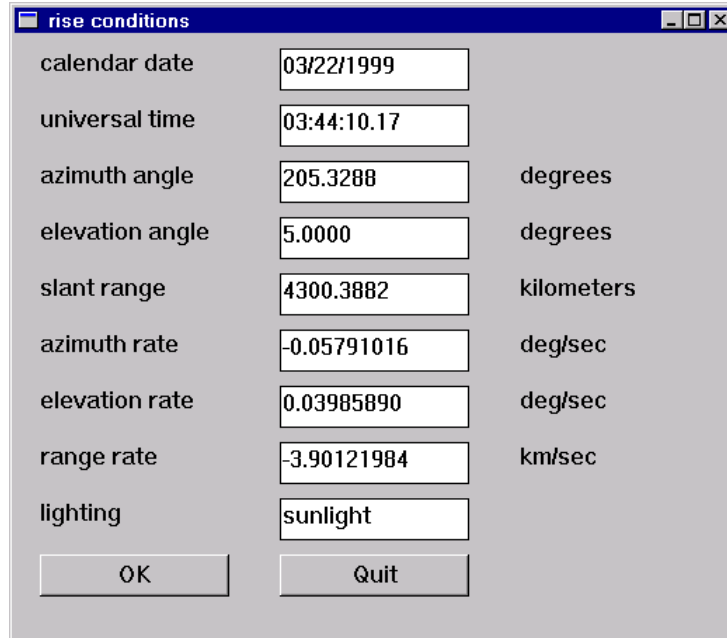


The dialog box titled "Program RISESET" contains the text "please input the data file name" and a text input field. Below the input field is an "OK" button.

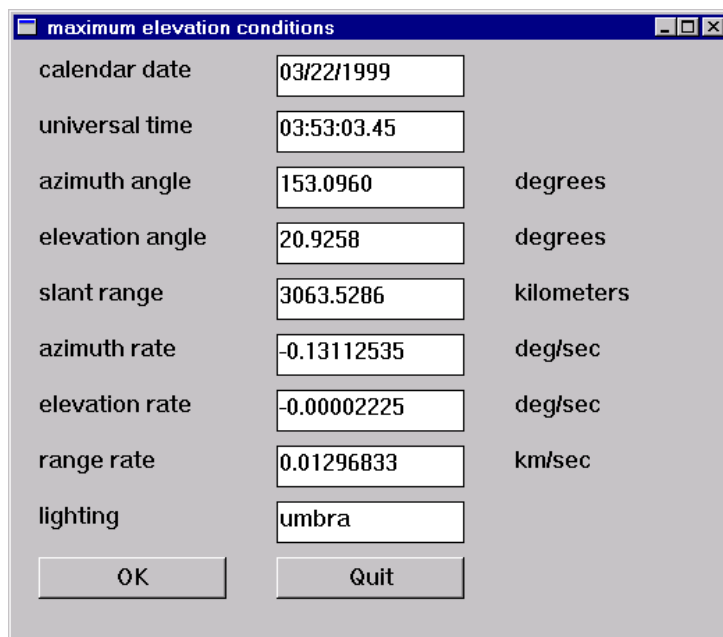
The software will also ask if you would like to create screen displays of visibility conditions during the simulation with



The following is a screen display of typical rise conditions:



This next screen shows conditions at maximum elevation angle.



This third screen shows typical set conditions.

If you select the Main menu box and click on the OK button, the program will terminate the current visibility calculations and return to the main menu. The following is part of a typical output data file created with this program option.

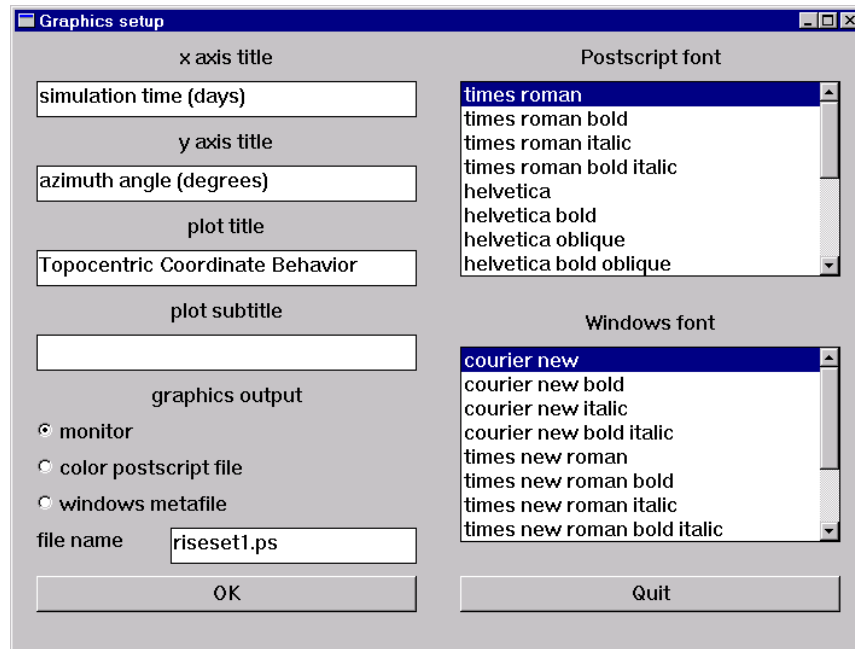
```
#Calendar      Universal      Time      Azimuth      Elevation      Range      Range-rate      Az rate      ...
# Date        Time          (days)   (degrees)    (degrees)     (km)       (km/sec)       (deg/sec)   ...
03/22/1999,  03:44:10.17,  0.4056733E+00,  0.2053288E+03,  0.5000000E+01,  0.4300388E+04,  -.3901220E+01,  -.5791015E-01,  ...
03/22/1999,  03:53:03.45,  0.4118455E+00,  0.1530960E+03,  0.2092578E+02,  0.3063529E+04,  0.1296833E-01,  -.1311253E+00,  ...
```

graphics display of topocentric coordinates

This program option can be used to create an x-y graphics display of a satellite's topocentric coordinates and rates during visibility conditions. The setup screen for this option is

This screen lets the user define the topocentric coordinate to plot, the initial and final plot times, and the plot step size. The user can also elect to create a simple ASCII text file of all coordinates.

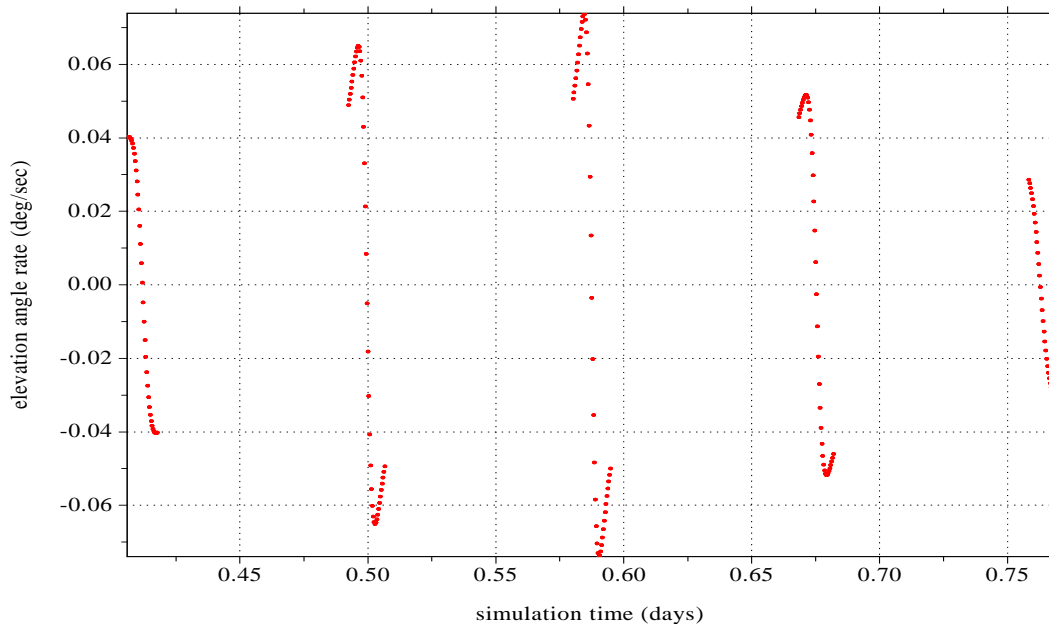
After leaving this screen, the software will display the following *graphics setup* screen.



This screen allows the user to define such things as the graphics output destination, the font to use and the titles for the graph. Please note that the Windows font selection defines the font for both screen (monitor) and Windows metafile graphics.

The following is a typical graphics display.

Topocentric Coordinate Behavior

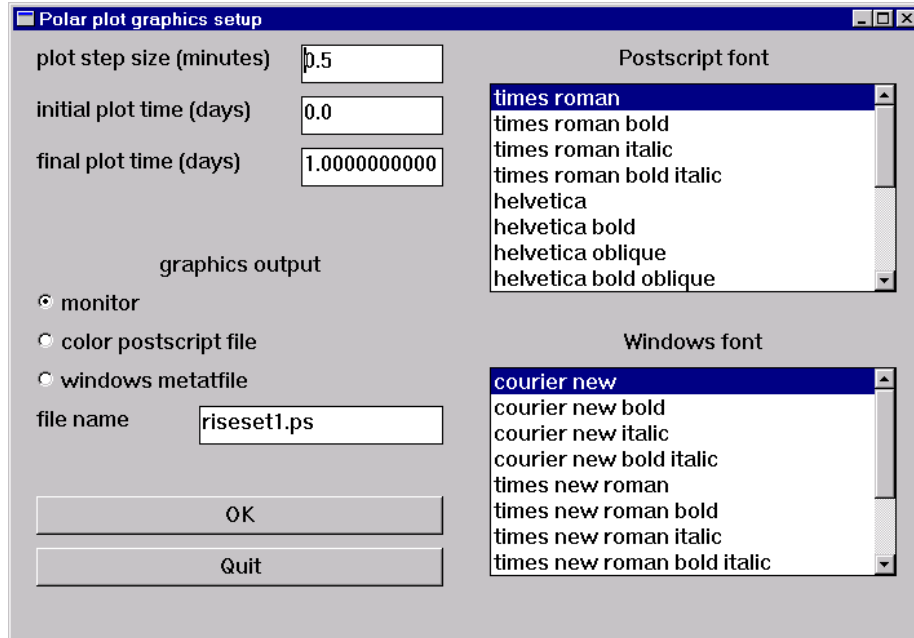


The following is part of a data file created with this software option.

```
#Calendar    Universal    Time    Azimuth    Elevation    Range    Range-rate    Az rate    ...
# Date      Time      (days)  (degrees)  (degrees)    (km)     (km/sec)     (deg/sec)  ...
03/22/1999, 03:44:30.00, 0.4059028E+00, 0.2041565E+03, 0.5793565E+01, 0.4223551E+04, -.3834112E+01, -.6022567E-01, ...
03/22/1999, 03:45:00.00, 0.4062500E+00, 0.2022925E+03, 0.6999691E+01, 0.4109954E+04, -.3723272E+01, -.6395380E-01, ...
03/22/1999, 03:45:30.00, 0.4065972E+00, 0.2003123E+03, 0.8209401E+01, 0.3999864E+04, -.3600462E+01, -.6796006E-01, ...
```

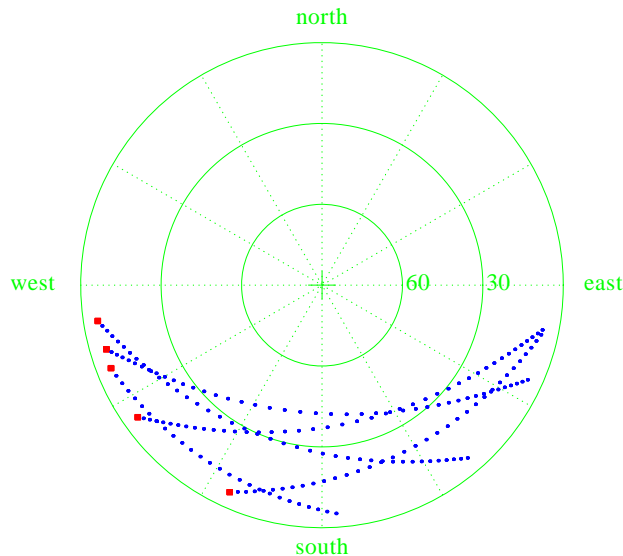
polar plot display of visibility conditions

This program option can be used to create a polar plot display of a satellite's topocentric azimuth and elevation during visibility conditions. The graphics setup screen for this option is



The following is a typical polar plot. Rise conditions are marked with small squares.

Azimuth and Elevation Polar Plot



Mercator display of satellite ground track

This program option can be used to create a Mercator graphics display of a satellite's ground track during visibility conditions. The setup screen for this option is as following:

Mercator graphics setup

viewpoint latitude (dms)

viewpoint longitude (dms)

delta longitude (deg)

map resolution

low resolution

high resolution

plot step size (minutes)

initial plot time (days)

final plot time (days)

graphics output

monitor

color postscript file

windows metafile

file name

Postscript font

- times roman
- times roman bold
- times roman italic
- times roman bold italic
- helvetica
- helvetica bold
- helvetica oblique
- helvetica bold oblique

Windows font

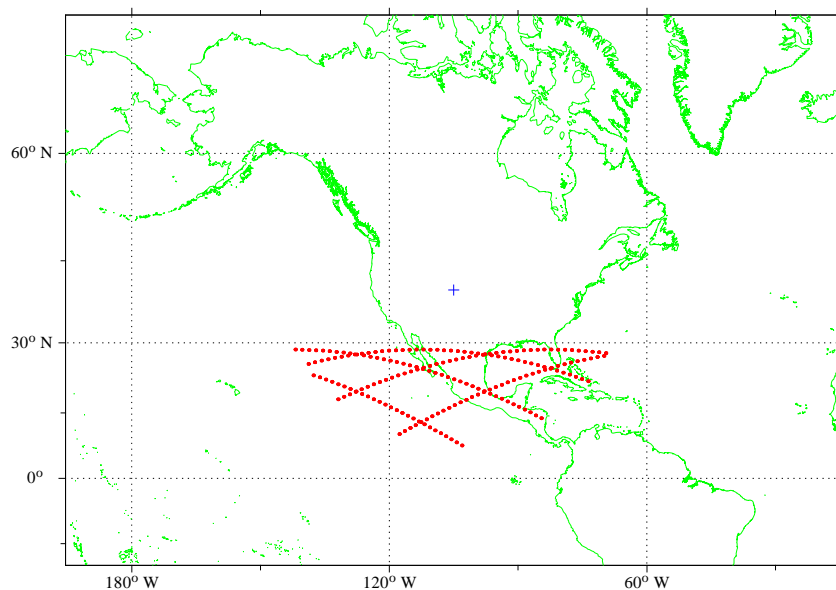
- courier new
- courier new bold
- courier new italic
- courier new bold italic
- times new roman
- times new roman bold
- times new roman italic
- times new roman bold italic

OK

Quit

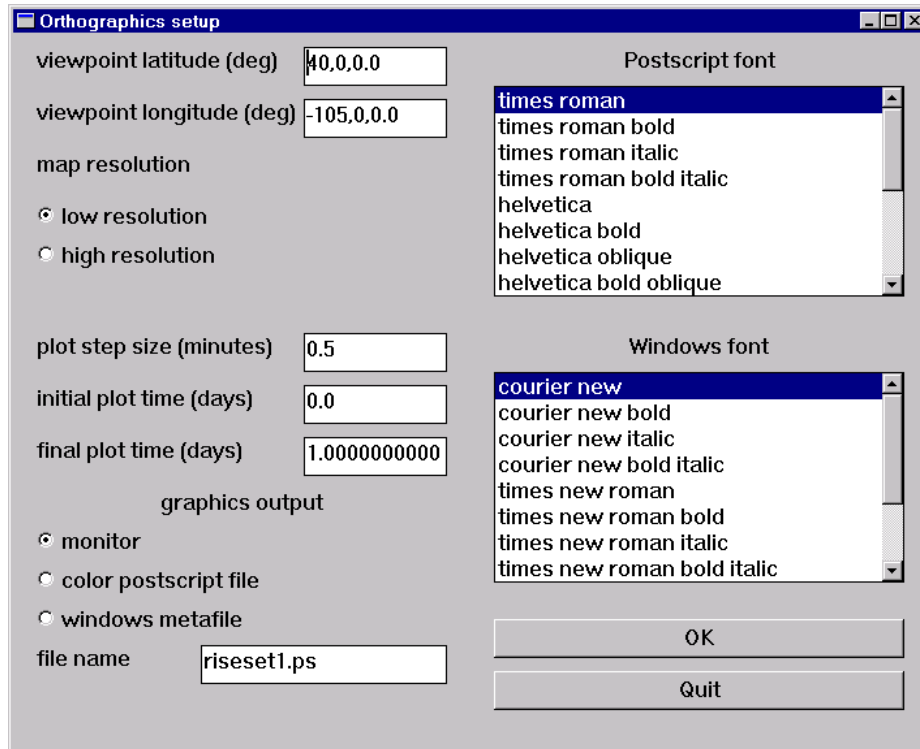
The following is a typical Mercator graphics display. The + is the ground site location.

Mercator Display of Satellite Ground Track



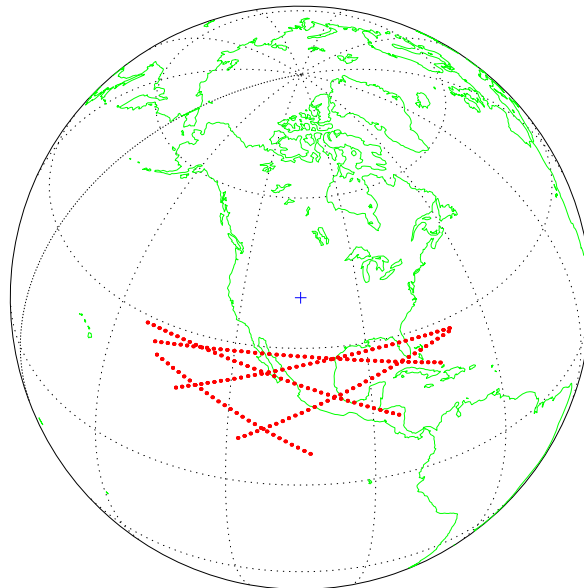
orthographic display of satellite ground track

This program option can be used to create an orthographic display of a satellite's ground track during visibility conditions. The graphics setup screen for this option is



The following is a typical orthographic display. The viewpoint is marked with a +.

Orthographic Display of Satellite Ground Track



Technical Discussion

The topocentric elevation angle of an Earth satellite can be calculated from

$$E = \sin^{-1} \left(r_{z_{topo}} \right)$$

where the components of the satellite's topocentric position vector \mathbf{r}_{ecf} are determined from the following transformation matrix and the ECI position vector \mathbf{r}_{eci} of the satellite:

$$\mathbf{r}_{topo} = \begin{bmatrix} \sin \phi \cos \lambda & \sin \phi \sin \lambda & -\cos \phi \\ -\sin \theta & \cos \theta & 0 \\ \cos \phi \cos \lambda & \cos \phi \sin \lambda & \sin \phi \end{bmatrix} \mathbf{r}_{eci}$$

In this matrix-vector equation, ϕ is the geodetic latitude of the ground site, λ is the geographic longitude of the ground site and θ is the local sidereal time.

The objective function used to calculate visibility conditions is given by the expression

$$f_{obj}(t) = -E + E_{\min}$$

where E_{\min} is an *optional* minimum elevation angle constraint or “mask”. Notice that this is actually a maximization problem since we are using the negative value of this function.

The Kozai J2 method orbit propagation option uses a J_2 form of *Kozai's method* (“The Motion of a Close Earth Satellite”, *The Astronomical Journal*, **64**, No. 1274, pp. 367-377) to propagate the orbit of an Earth satellite during the search for visibility. Therefore, all orbital elements input to the program are assumed to be Kozai “mean” elements. These orbital elements include the J_2 secular effects on mean anomaly, argument of perigee and right ascension of ascending node.

According to Kozai's method, the time evolution of the mean orbital elements is given by the following three equations:

$$M(t) = M_0 + \tilde{n}(t - t_0)$$

$$\Omega(t) = \Omega_0 + \dot{\Omega}(t - t_0)$$

$$\omega(t) = \omega_0 + \dot{\omega}(t - t_0)$$

where M_0 is the mean anomaly, Ω_0 is the right ascension of the ascending node (RAAN) and ω_0 is the argument of perigee, all at the initial time t_0 . In the first expression \tilde{n} is called the *perturbed mean motion* and is equal to the time rate of change of mean anomaly.

The perturbed mean motion can be calculated from:

$$\tilde{n} = \frac{dM}{dt} = n \left\{ 1 + \frac{3}{2} J_2 \left(\frac{r_{eq}}{p} \right)^2 \sqrt{1-e^2} \left(1 - \frac{3}{2} \sin^2 i \right) \right\}$$

The time rate of change of the right ascension of the ascending node is determined from

$$\dot{\Omega} = \frac{d\Omega}{dt} = -\frac{3}{2} J_2 \tilde{n} \left(\frac{r_{eq}}{p} \right)^2 \cos i$$

The secular perturbation of the argument of perigee is given by:

$$\dot{\omega} = \frac{d\omega}{dt} = \frac{3}{2} J_2 \tilde{n} \left(\frac{r_{eq}}{p} \right)^2 \left(2 - \frac{5}{2} \sin^2 i \right)$$

where

n = unperturbed or Keplerian mean motion

J_2 = Earth oblateness gravity term

r_{eq} = equatorial radius of the Earth

e = orbital eccentricity

i = orbital inclination

$p = a(1 - e^2)$ = semiparameter

a = semimajor axis

NORAD Two-Line Element Sets (TLE)

The NORAD orbit propagators are popular, accurate and easy to use. They are based on the work of Dirk Brouwer, Lane and Cranford, and others. The Two Line Element (TLE) sets required by these propagators are widely distributed on the Internet and maintained by NORAD. Each algorithm is documented in the classic SpaceTrack Report No. 3, "Models for Propagation of NORAD Element Sets" by Felix R. Hoots and Ronald L. Roehrich. This document also contains Fortran source code and test cases for each propagator.

The following is a typical TLE for the NOAA 14 spacecraft:

```
NOAA 14
1 23455U 94089A 97320.90946019 .00000140 00000-0 10191-3 0 2621
2 23455 99.0090 272.6745 0008546 223.1686 136.8816 14.11711747148495
```

The *mean* orbital elements contained in this data are ECI coordinates with respect to the true equator of date and the mean equinox of date. They do not include the effect of nutation.

The following is a brief description of the data contained in each line of a Two Line Element Set. Each item must appear in its row and column field in exactly the format specified. Most TLE databases actually contain *three* lines of data for each space object.

Line 1

The first line is a twenty-four character satellite name. Software which reads a database of TLEs will look for this name in order to find the correct data.

Line 2

Column	Description
01	line number of element data
03-07	satellite number
08	classification (u=unclassified)
10-11	international designator (last two digits of launch year)
12-14	international designator (launch number of the year)
15-17	international designator (piece of the launch)
19-20	epoch year (last two digits of year)
21-32	epoch (day of the year and fractional portion of the day)
34-43	first time derivative of the mean motion
45-52	second time derivative of mean motion (decimal point assumed)
54-61	bstar drag term (decimal point assumed)
63	ephemeris type
65-68	element number
69	checksum (modulo 10) (letters, blanks, periods, plus signs = 0; minus signs = 1)

Line 3

Column	Description
01	line number of element data
03-07	satellite number
09-16	orbital inclination (degrees)
18-25	right ascension of the ascending node (degrees)
27-33	orbital eccentricity (decimal point assumed)
35-42	argument of perigee (degrees)
44-51	mean anomaly (degrees)
53-63	mean motion (orbits per day)
64-68	revolution number at epoch (orbits)
69	checksum (modulo 10)

All other columns are blank or fixed.

A good Internet source for the latest Two Line Element Sets is Dr. Thomas Kelso's web site which is located at

<http://celestrak.com>

You can also find a Postscript and PDF version of SpaceTrack Report No. 3 at this location.

Warning: Do not use TLEs with other orbit propagators. They are only compatible with the SGP4, SDP4 and other algorithms developed by NORAD.