Rise and Set of an Earth Satellite

This document describes several MATLAB scripts that can be used to determine rise and set conditions of Earth satellites relative to a ground site on an oblate Earth. The user can specify a minimum elevation or "mask" angle for several simulations. Scripts are included that propagate a satellite's orbit using Kozai's method, the SGP4 algorithm and numerical integration. Several of these scripts use a combination of one-dimensional minimization and root-finding to calculate visibility conditions.

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

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

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.

riseset1.m – Kozai orbit propagation

This application determines rise and set conditions of an Earth satellite using Kozai's method of orbit propagation.

The following is a typical user interaction with this script.

```
              program riseset1

   < rise and set of an Earth satellite >

         < Kozai orbit propagation >


   please input the calendar date
```

(1 <= month <= 12, 1 <= day <= 31, year = all digits!)
? **1,1,1998**

please input the universal time
(0 <= hours <= 24, 0 <= minutes <= 60, 0 <= seconds <= 60)
? **0,0,0**

initial orbital elements

please input the semimajor axis (kilometers)
(semimajor axis > 0)
? **8000**

please input the orbital eccentricity (non-dimensional)
(0 <= eccentricity < 1)
? **0**

please input the orbital inclination (degrees)
(0 <= inclination <= 180)
? **28.5**

please input the right ascension of the ascending node (degrees)
(0 <= raan <= 360)
? **100**

please input the true anomaly (degrees)
(0 <= true anomaly <= 360)
? **45**

ground site coordinates

please input the geographic latitude of the ground site
(-90 <= degrees <= +90, 0 <= minutes <= 60, 0 <= seconds <= 60)
(north latitude is positive, south latitude is negative)
? **40,0,0**

please input the geographic longitude of the ground site
(0 <= degrees <= 360, 0 <= minutes <= 60, 0 <= seconds <= 60)
(east longitude is positive, west longitude is negative)
? **-105,0,0**

please input the altitude of the ground site (meters)
(positive above sea level, negative below sea level)
? **0**

would you like to enforce an elevation angle constraint (y = yes, n = no)
? **y**

please input the minimum elevation angle constraint (degrees)
? **5**

please input the simulation duration in days
? **5**

The script will ask if you would like to create a screen display of the visibility conditions during the simulation. This prompt appears as follows:

```
would you like screen output (y = yes, n = no)
?
```

The following is a typical screen display of the first rise, maximum elevation and set conditions for this example.

```
rise conditions

calendar date           01-Jan-1998
universal time          07:44:06.765

Julian date             2450814.8223

topocentric azimuth angle     178.3280  degrees
topocentric elevation angle     5.0000  degrees

topocentric slant range      4298.6787  kilometers


 maximum elevation conditions

calendar date           01-Jan-1998
universal time          07:50:01.382

Julian date             2450814.8264

topocentric azimuth angle     145.9483  degrees
topocentric elevation angle    10.2005  degrees

topocentric slant range      3829.0803  kilometers


 set conditions

calendar date           01-Jan-1998
universal time          07:55:55.215

Julian date             2450814.8305

topocentric azimuth angle     113.7348  degrees
topocentric elevation angle     5.0000  degrees

topocentric slant range      4309.7357  kilometers

event duration                 11.8075  minutes
```

After the simulation is complete the software will ask if you would like to create a data file of the visibility conditions. This prompt appears as follows:

```
would you like to create an ascii data file (y = yes, n = no)
?
```

If you respond with `y` for yes, the software will ask you to input the name of the data file with

```
please input the rise-set data file name
(be sure to include a file name extension)
?
```

Since the user must manually cycle each screen display, you may not want to create screen displays when requesting a data file for long rise-set simulations.

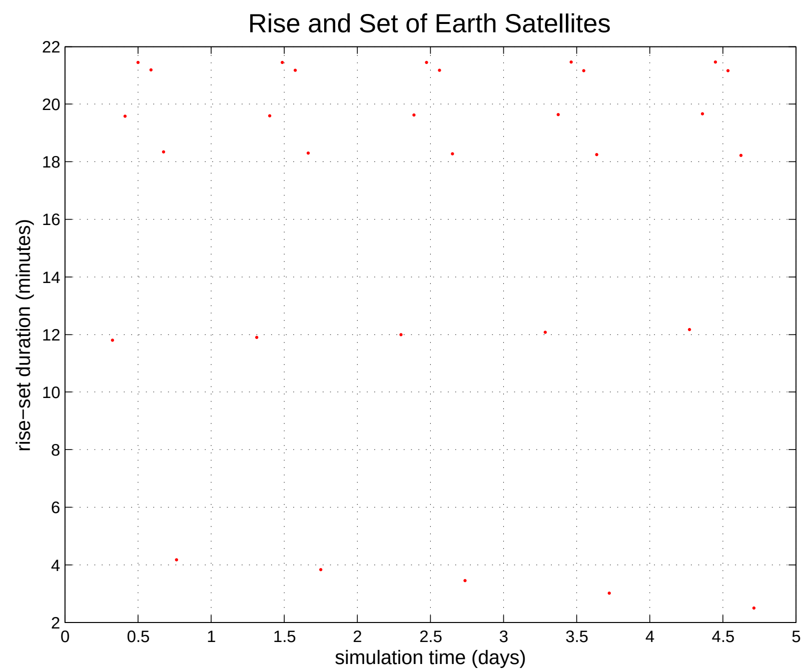
The following is part of the data file for this example. The first column is the simulation time at which visibility begins, the second column is the simulation time at maximum elevation, and the third column is the simulation time at which visibility ends. The fourth column is the event duration in minutes.

```
 rise time     max time     set time    duration
  (days)        (days)       (days)     (minutes)

   0.3223       0.3264       0.3305      11.8075
   0.4071       0.4139       0.4207      19.5760
   0.4943       0.5017       0.5092      21.4471
   0.5823       0.5896       0.5970      21.1856
```

The script will also ask if you would like to create a graphics display of the event duration versus simulation time with this final prompt. The form of this prompt is

```
would you like to display graphics (y = yes, n = no)
?
```

If you respond with `y` for yes, the software will create a graphics display similar to the following:



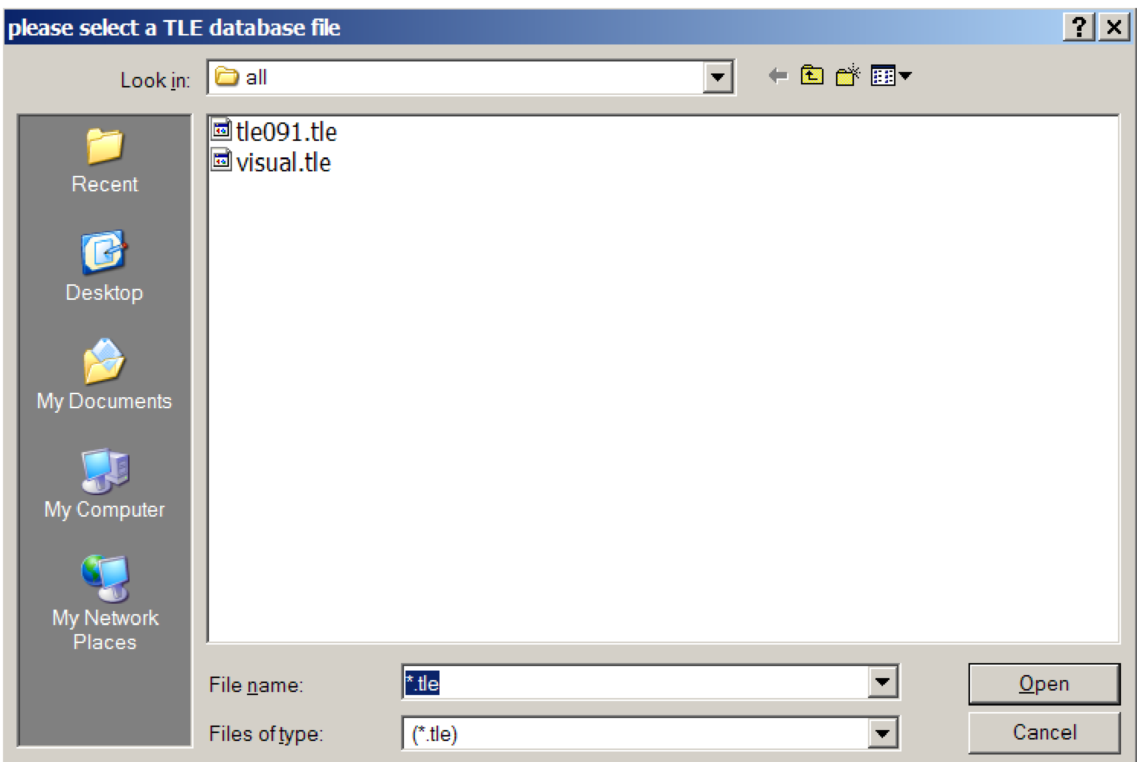
riseset2.m – SGP4 orbit propagation

This MATLAB script determines rise and set conditions using the SGP4 orbit propagation algorithm. The software will prompt you for the name of a TLE database file and ask you for the name of a satellite in the database file.

The following is a typical user interaction with this script.

```
              program riseset2

   < rise and set of an Earth satellite >

         < SGP4 orbit propagation >
```

The script will prompt you for the name of the TLE database file with a screen display similar to the following;




```
please input the name of the satellite
? mir
```

If the user-defined satellite is found, the program will print the epoch of the TLE.

```
the epoch of this TLE is

01-Apr-1999
03:43:43
```

The program continues with this next series of prompts:

```
please input the calendar date
(1 <= month <= 12, 1 <= day <= 31, year = all digits!)
? 5,1,1999

please input the universal time
(0 <= hours <= 24, 0 <= minutes <= 60, 0 <= seconds <= 60)
? 0,0,0


ground site coordinates

please input the geographic latitude of the ground site
(-90 <= degrees <= +90, 0 <= minutes <= 60, 0 <= seconds <= 60)
(north latitude is positive, south latitude is negative)
? 40,0,0

please input the geographic longitude of the ground site
(0 <= degrees <= 360, 0 <= minutes <= 60, 0 <= seconds <= 60)
(east longitude is positive, west longitude is negative)
? -105,0,0

please input the altitude of the ground site (meters)
(positive above sea level, negative below sea level)
? 0


would you like to enforce an elevation angle constraint (y = yes, n = no)
? y

please input the minimum elevation angle constraint (degrees)
? 5

please input the simulation duration in days
? 5

would you like screen output (y = yes, n = no)
? y
```

The following is the screen output for the first rise-set for this example.

```
 rise conditions

calendar date           01-May-1999
universal time          08:41:37

Julian date             2451299.8622

topocentric azimuth angle     172.8116  degrees
topocentric elevation angle     5.0000  degrees

topocentric slant range      1611.4889  kilometers


 maximum elevation conditions
```

```
calendar date           01-May-1999
universal time          08:44:05

Julian date             2451299.8639

topocentric azimuth angle     129.7691  degrees
topocentric elevation angle    11.0044  degrees

topocentric slant range      1208.6420  kilometers


 set conditions

calendar date           01-May-1999
universal time          08:46:34

Julian date             2451299.8657

topocentric azimuth angle      86.8212  degrees
topocentric elevation angle     5.0000  degrees

topocentric slant range      1618.8843  kilometers

event duration                  4.9538  minutes
```

This script also includes the data file and graphics display options described in the previous `riseset1` script.

riseset3.m – numerically integrated orbital motion

This script uses numerical integration to propagate the orbits of two satellites while searching for rise-set. The algorithm includes the effect of Earth oblateness J_2 but can easily be modified to include higher-order gravity effects and other orbital perturbations.

The following is a typical user interaction with this program.

```
           program riseset3

< rise and set of an Earth satellite >

   < numerical integration method >


please input the calendar date
(1 <= month <= 12, 1 <= day <= 31, year = all digits!)
? 1,1,1998

please input the universal time
(0 <= hours <= 24, 0 <= minutes <= 60, 0 <= seconds <= 60)
? 0,0,0


initial orbital elements
```

```
please input the semimajor axis (kilometers)
(semimajor axis > 0)
? 8000

please input the orbital eccentricity (non-dimensional)
(0 <= eccentricity < 1)
? 0

please input the orbital inclination (degrees)
(0 <= inclination <= 180)
? 28.5

please input the right ascension of the ascending node (degrees)
(0 <= raan <= 360)
? 100

please input the true anomaly (degrees)
(0 <= true anomaly <= 360)
? 45


ground site coordinates

please input the geographic latitude of the ground site
(-90 <= degrees <= +90, 0 <= minutes <= 60, 0 <= seconds <= 60)
(north latitude is positive, south latitude is negative)
? 40,30,15

please input the geographic longitude of the ground site
(0 <= degrees <= 360, 0 <= minutes <= 60, 0 <= seconds <= 60)
(east longitude is positive, west longitude is negative)
? -105,10,40

please input the altitude of the ground site (meters)
(positive above sea level, negative below sea level)
? 0


would you like to enforce an elevation angle constraint (y = yes, n = no)
? y

please input the minimum elevation angle constraint (degrees)
? 5

please input the simulation duration in days
? 5

would you like screen output (y = yes, n = no)
? y
```

The following is the screen output for the first rise-set for this example.

```
 rise conditions

calendar date          01-Jan-1998
```

```
universal time          07:44:29

Julian date             2450814.8226

topocentric azimuth angle     176.2342  degrees
topocentric elevation angle     5.0000  degrees

topocentric slant range      4297.4457  kilometers


 maximum elevation conditions

calendar date           01-Jan-1998
universal time          07:50:05

Julian date             2450814.8264

topocentric azimuth angle     145.7535  degrees
topocentric elevation angle     9.5677  degrees

topocentric slant range      3882.6681  kilometers


 set conditions

calendar date           01-Jan-1998
universal time          07:55:40

Julian date             2450814.8303

topocentric azimuth angle     115.4240  degrees
topocentric elevation angle     5.0000  degrees

topocentric slant range      4309.2442  kilometers

event duration                11.1813  minutes
```

This script also includes the data file and graphics display options described in the previous `riseset1` script.

griseset.m – graphics display of visibility conditions

This script graphically displays rise and set conditions using Kozai's method for orbit propagation. This software simply propagates a satellite's orbit for a user specified time duration and step size while collecting rise-set information whenever the elevation angle of the Earth satellite is positive.

After the orbit propagation is complete the user can elect to graphically display one or more of the following items:

- topocentric azimuth
- topocentric elevation

- topocentric slant range
- topocentric azimuth rate
- topocentric elevation rate
- topocentric range rate

The following is a typical user interaction with this script.

```
               program griseset

< graphics display of rise-set conditions >

       < Kozai orbit propagation >

please input the calendar date
(1 <= month <= 12, 1 <= day <= 31, year = all digits!)
? 1,1,1998

please input the universal time
(0 <= hours <= 24, 0 <= minutes <= 60, 0 <= seconds <= 60)
? 0,0,0

initial orbital elements

please input the semimajor axis (kilometers)
(semimajor axis > 0)
? 8000

please input the orbital eccentricity (non-dimensional)
(0 <= eccentricity < 1)
? 0

please input the orbital inclination (degrees)
(0 <= inclination <= 180)
? 28.5

please input the right ascension of the ascending node (degrees)
(0 <= raan <= 360)
? 100

please input the true anomaly (degrees)
(0 <= true anomaly <= 360)
? 45

ground site coordinates

please input the geographic latitude of the ground site
(-90 <= degrees <= +90, 0 <= minutes <= 60, 0 <= seconds <= 60)
(north latitude is positive, south latitude is negative)
? 40,0,0

please input the geographic longitude of the ground site
(0 <= degrees <= 360, 0 <= minutes <= 60, 0 <= seconds <= 60)
```

```
(east longitude is positive, west longitude is negative)
? -105,0,0

please input the altitude of the ground site (meters)
(positive above sea level, negative below sea level)
? 0

please input the simulation duration in days
? 1

please input the step size in seconds
? 10
```

After the propagation is complete the script will ask you what data item to plot. This request and menu appear as follows:

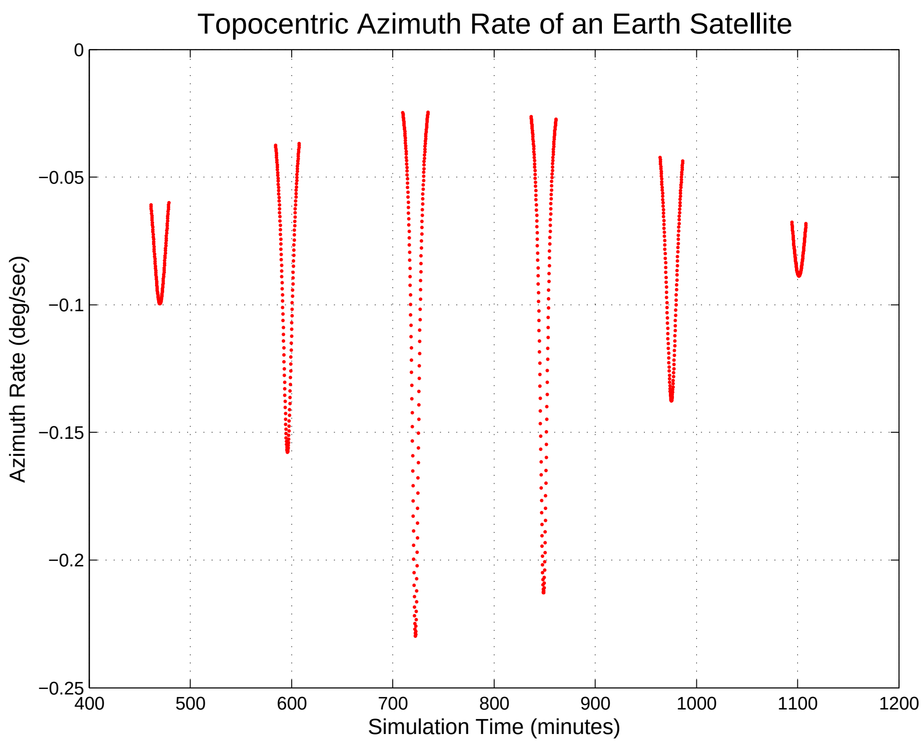
```
please select the item to plot

 <1> topocentric azimuth

 <2> topocentric elevation

 <3> topocentric slant range

 <4> topocentric azimuth rate

 <5> topocentric elevation rate

 <6> topocentric range rate

?
```

After a plot is created the user can elect to create another plot by responding with `y` for yes to the following prompt.

```
would you like to create another plot (y = yes, n = no)
?
```

If you respond with `n` for no the script will terminate.

In this application the topocentric elevation angle is corrected for atmospheric refraction. The following is a typical graphic display created with this software. The data points are plotted at the step size input by the user.


Topocentric Azimuth Rate of an Earth Satellite
0
−0.05
−0.1
−0.15
−0.2
−0.25
Azimuth Rate (deg/sec)
400
500
600
700
800
900
1000
1100
1200
Simulation Time (minutes)