SatCal Version 11.8 Manual

Gerhard HOLTKAMP

27-MAR-2013

Contents

1 Installation and Running **5**
1.1 System Requirements 5
1.2 Installation 5
1.3 Starting and Exiting SatCal 6
1.4 Online Help 6
1.5 Accelerator keys / hot keys 6
1.6 Fonts 7
1.7 IMPORTANT TIPS 7

2 Select an Orbit Element File **8**

3 Selecting Satellites, Dates/Times, Observing Site and IERS Parameters **8**
3.1 Selecting Satellites 8
3.2 Removing a Selected Satellite 10
3.3 Selecting Next Satellites to Pass 10
3.4 Input of Date and Time 11
3.5 Input of Observing Site 12
3.6 Setting IERS Parameters 12

4 Calculating Contact (Visibility) Times / Iridium Flares **13**
4.1 Display a list of AOS (Visibility) Times 13
4.2 Display Pass Details 14
4.3 Calculate the passes of ALL satellites of a TLE file 15
4.4 List of Iridium Flares 16
4.5 Writing Orbit Tracks on File 18

5 Groundtrack / Sky Map Display **19**
5.1 Activating the Map Display 19
5.2 What the Map Display shows 21
5.3 Real Time Display 22
5.4 Delta Time Display 23
5.5 Next Pass and Last Pass Display 23

5.6 Step Mode 24
5.7 Local Visibility Information 24
5.8 Show Satellite Names 26
5.9 Show State Vector 26

6 Switch between Satellites / Relative Satellite Mode 26
6.1 Switching the Prime Satellite 26
6.2 Relative Satellite Mode 26

7 Time Step, Visibility Conditions and Occultations 27
7.1 Changing the Time Step 27
7.2 Specifying Visibility Conditions 28
7.3 Moonlight Visibility 28
7.4 Sun/Moon Transit or R.A./Decl. Occulations 29
7.5 Flare Calculations 31
7.6 Solar Eclipse Checks 34

8 Display Magnitude 34

9 Edit Orbit Elements / Launch Orbit / Delta-V 35
9.1 Edit / Changing Orbit Elements 35
9.2 Delta-V Maneuver 37
9.3 Launch Orbit 38
9.4 Rendezvous Launch Orbits 40
9.5 Generating Geostationary Orbits 41
9.6 Adding a New Satellite 41
9.7 Adjusting Orbit Elements of Older TLE Files 41
9.8 Using the SDP4 Code 42
9.9 Use of WGS84 Constants 43

10 Orbit Determination 43
10.1 Orbit Determination 43
10.2 Finding Matching Satellites 44

11 Sky Picture Astrometry 46
11.1 Loading and Initializing Pictures 46
11.2 Satellite Trail Astrometry 47

12 Saving Data on File 48
12.1 Standard Save 48
12.2 Changing the Name of the Save File 48
12.3 Saving the Pass Details Information 49
12.4 Saving the Map on file 49
12.5 Saving Orbit Elements 49
12.6 Changing the Name of the TLE Save File 49
12.7 Online Update of TLE Files 50

13 Numeric Orbit Propagation **51**
13.1 Activating Numeric Propagation 51
13.2 Editing the State Vector 52
13.3 Configure System Parameters 53
13.4 Numeric Propagation Internals 54

14 References / Internet Sites **54**

A APPENDIX **56**
A.1 LIST OF HOT KEYS 56
A.2 PRECISION 57
A.3 FORMATS USED FOR STORING ORBIT ELEMENTS 57
A.4 INSTALLATION 59
A.5 TROUBLE SHOOTING 60

•

The primary purpose of SatCal is to provide calculations regarding the visual observation of satellites in Earth orbit either between the satellites and a ground station or between different satellites. A groundtrack map or a sky map can be displayed together with relevant positional and visibility information. The orbit elements can be read from standard Two-Line-Element files or entered, generated or changed manually. Simple delta-v maneuvers can be performed and approximate launch orbits calculated. SatCal will also perform a simple orbit determination if two observations of a circular orbit were made from a single position. Also possible is the generation of maps which show the geographic positions of places where transits of satellites in front of specified positions in the sky or flares can be observed. Alternatively lists of such events within a certain radius from the observer as well as Iridium flares can be calculated. Pictures of satellites tracks can be loaded and analyzed.

SatCal uses three different models for orbit calculation: A simple low precision one and the more precise Spacetrack SGP4 model which should be employed for Spacetrack-supplied Two-Line-Elements; in addition to these two analytical models a numeric orbit propagation is possible.

New in Version 11.8:

Update IERS Parameters and adding a Delete All Button to the Remove Satellite dialog.

New in Version 11.7:

Reading and writing floating point numbers is now independent of the localization (a dot and not a comma is always taken as a decimal point).

New in Version 11.5 / 11.6:

Including the Low Orbit and New Orbit filters in the Select Satellite Dialog. Saving orbit coordinates directly on file. Providing a Marble-Widget for producing more detailed maps from ground tracks and flare tracks saved by SatCal.

New in Version 11.3 / 11.4:

Qt Library compatibility adjustments.

New in Version 11.2:

The sky chart can now show not only the sky from an observer's site but also as viewed from a satellite.

New in Version 11.1:

Updated delta UTC-TAI. Solar power during an eclipse can be displayed.

New in Version 11.0:

Ported from Qt3 to Qt4. Added the astrometry of sky pictures with satellite trails.

New in Version 10.5:

Possibility to state Keplerian elements also in J2000 rather than just Mean-of-Date. Some re-arrangement of sources and documentation.

New in Version 10.4:

The course of a satellite across the sky is also shown in the Local Visibility Display. Fixing a bug with the loading of satellites at startup.

New in Version 10.3:

Introducing checks for cylindrical flares.

New in Version 10.2:

Allow for a Real-Time clock offset for simulations. Some internal code changes to make the program more compatible with different compilers.

New in Version 10.1:

Refinement of the Yaw Steering Mode calculation. Swap of colors for second and third satellite.

New in Version 10.0:

Physical world map. Fixing a minor problem with satellite names and designations.

New in Version 9.0 - 9.9:

Numeric orbit propagation is now possible and allows continuous thrust and atmospheric reentry calculations. General increase in precision of the orbit calculations. The Pass Details will show the coordinates of the central line of transits and flares if these were selected. This information and also the ground track coordinates can be directly saved on a file which can be used by other programs to generate map overlays etc. Some changes to the launch orbit calculation. Some internal changes to the calculation of dates and time. Update of the SGP4 model to eliminate many deficiencies particularly of the SDP4 part (which is now used again as default for high orbits) . The duration of the simulation can now be saved. Changes to the calculation of magnitudes. The magnitude of general flares can be displayed. Adding a small feature to the Local Visibility Display. Doppler frequency can be displayed instead of range rate. The output of groundtrack coordinates in the Pass Details is now consistent with the coordinates of the central line of transits and flares. Iridium Solar Panel flares have been included. Update of launch orbit calculations and the list of launch site coordinates. Conversion of Keplerian elements into SGP4 mean elements after leaving the State Vector dialog or the delta-v or launch orbit calculation if the SGP4 model was selected.

1 Installation and Running

1.1 System Requirements

SatCal needs only very limited system resources and should run on almost any PC on the market today. Releases are available for Windows (it seems to run under most Windows Systems) and Linux.

The Linux release was compiled under Open SUSE 12.1 but can run without re-compilation on a number of other distributions. It needs the Qt4 library which is automatically the case for the KDE desktop but most distributions supply this library also with GNOME. See the Appendix A.4 for how to compile SatCal if necessary.

1.2 Installation

At present there is no automatic setup program for SatCal but the manual installation is quickly done:

For Windows unzip the file SatCal_11.8_Win.zip, for Linux extract the file SatCal_11.8_lx.tar.gz . The directory SatCal will contain the needed files almost ready to run. The file README will explain the few steps necessary to complete the setup.

The content of the file README is also listed in Appendix A.4.

1.3 Starting and Exiting SatCal

Simply click the satcal.exe icon or the satcal executable in the folder you created or on the desktop (if you placed a link there). Upon starting, SatCal normally expects a file with the name Satcal.cfg to be present in the executive (bin) directory. This file contains the configuration of the last run of SatCal (like the geographic coordinates used and the name for the TLE file). If this file is not present default values will be used for the startup. (This will be the case on the very first run.) Set your location etc. then select `File`, `Exit` to have the configuration file generated and the settings saved.

The timezone can be set automatically to the system timezone. If it has been set manually, the SatCal timezone is checked against the timezone used by the system. A message will be displayed at startup if the timezones do not agree. This may be intentional (e.g. a user might set the computer time to Universal Time but wants to use local time for SatCal calculations).

To Exit SatCal, select `File`, then `Exit` or click the windows close icon in the upper right corner. Note that there is a difference between these two exit options. Using the `File-Exit` menu option will cause SatCal to write the currently settings to the file `satcal.cfg`. These values will then be used for the initialization of the next SatCal run. If you exit SatCal by clicking the windows close icon nothing will be written to the file `satcal.cfg` and the current configuration will not be preserved.

1.4 Online Help

Online help is available via the Help menu where `Help` will provide you with an abbreviated version of this manual but also via tool tips. Where ever there is a tool tip (a brief comment appearing when you move the mouse over a position) there is also a more detailed "What's This" info. This is available for all menu items but also for a number of dialog items (typically those items which are not immediately obvious). Depending on your system the "What's This" info is activated by clicking on the `?` on the menu bar and then moving the cursor over the item in question and clicking again or by clicking the item with the right mouse button. There are also hints on the Status Bar at bottom.

1.5 Accelerator keys / hot keys

As with other programs, menu items can be activated by mouse click or by key selections. There are also special accelerator keys like `<crtl> + D` for the Date dialog. For lazy people like me who don't want to press two keys at once

SatCal allows to enter just the letter without the `<crtl>` key. The lazy method works great but has one small problem: Some mouse operations will cause he focus to shift and SatCal might not respond to your key input. The recovery is simple: Just press the `<crtl>` key (as you should have done anyway!) once.

1.6 Fonts

Although the different releases of SatCal have been generated from identical source code it will look slightly different under different systems due to different fonts and window styles used. SatCal lets you adjust the font size to compensate for that (or to suit your different taste). `View, Font Size` lets you select a font size between `8` or `12` for the main text display and also for the Pass Details. The overall window size of SatCal during startup will also be adjusted accordingly. My personal font preferences are`10` for normal cases and `8` on small Netbook screens.

The font for the map display can be selected via `View, Map View / Sky Map`. I prefer the small size for all systems and `bold` except for Netbooks. But you may have different opinions. Anyway these settings are preserved when exiting SatCal.

1.7 IMPORTANT TIPS

SatCal provides defaults for making the most common uses as easy as possible. To exploit the more elaborate SatCal possibilites three places are of particular importance: The Visibility Dialog (`View, Visibility` - see section 7.2) governs to a great extent what SatCal does how. The Edit Orbit Elements Dialog (`Maneuver, Edit Orbit Elements` - see section 9.1) influences how orbit elements are treated and even lets you generate certain elements automatically. The way things are displayed is managed by the Map View Dialog (`View, Map View / Sky Map` - see section 5). In these and some other dialogs most items are provided with online help. Just move the cursor over the respective fields and click with the right mouse button and click again on `What's This?`.

Four sample TLE files are supplied with SatCal: `visual.txt` contains a list of bright satellites (many of them in low orbits for which updates would be needed for reliable predictions). `iridium.txt` contains a list of Iridium TLE's which is needed for Iridium flare calculations (with special care you might be able to use them for over a year - see section 9.7). `hist.tle` contains a rather personal selection of elements which I found important at one time or another - like the Mir orbit shortly before its de-orbit, the final orbits of Columbia, the first manned Chinese flight, the very first satellite (Sputnik 1 and its booster) and the Rosetta Flyby #1 at the Earth. Feel free to delete this file (or to use it if you wish). In addition there is a list of classified military satellites `classfd.tle` which was compiled by amateur observers.

A tutorial for SatCal is on file `SatCal_Tut.pdf`. If you are not familiar with SatCal you should go through this tutorial for a quick introduction and to get a feel on how to work with it.

2 Select an Orbit Element File

Select `File`, then `Open` or click the `File Open` icon or press the `F` key. An open file dialog box appears which lets you choose an existing TLE (Two-Line-Element) file. (These are files that contain the orbit elements in the so-called Two-Line-Element format.) Standard file extensions are `.TLE` and `.TXT` but any other file extension is acceptable. SatCal provides a default TLE name if no TLE file has been selected. Note that the file must already exist and is expected to be in the usual TLE format supplied by a number of sources via the Internet[1]. To update TLE files via the Internet select `File`, then `Online TLE Update` (see also section 12.7).

You can select orbit elements for different satellites from different TLE files if you like but only one TLE file can be open at any one time.

Note that SatCal starts with a default name or the name of the TLE file last used if you start the program. If the file no longer exists and you try to select satellites from it you will get an error message. (Note: A file with the right name could be in the wrong directory if you place SatCal somewhere else or just installed it!) The directory of the currently selected TLE file will also be the default directory for any output files created by SatCal.

3 Selecting Satellites, Dates/Times, Observing Site and IERS Parameters

3.1 Selecting Satellites

This assumes that a valid TLE file has been selected (see above under 2). Note that SatCal also allows the generation of certain orbits so that a number of actions can be done even without TLE files (see under sections 9.1 and 9.3).

To select a satellite, select `Input`, then `Select Satellite` or click the `Select Satellite` icon or press the `S` key. This will display the Select Satellite Dialog box. The name of the currently selected Orbit Element File will be shown together with presently selected satellites. If you want to select satellites from a different file you first have to open that file (see above under 2.)

Enter the name of the satellite into the respective name box, then click the `Find` button. SatCal then looks for matching names on the presently selected Orbit Element File. Once an entry with a matching name has been found it will be displayed together with the respective orbital elements. To select this entry press the `Select` button. If more matching entries are on the TLE file, a `More` button appears and pressing it will show the next match. Sometimes more than one entry relating to a particular satellite might appear. For example, `ISS` might designate the International Space Station and `ISS deb` might be some debris

[1]SatCal accepts a special format with four lines rather than two for numeric orbit propagation. This (SatCal-specific) format can be mixed with the ordinary Two-Line-Elements on the same file.

which originated from the ISS and is now tracked independently. Entering an * will result in all file entries to be displayed.

Once a satellite has been selected up to nine more can be chosen. After the maximum of ten satellites have been selected, any new entry will overwrite the 10th satellite. To exit the dialog box press the `Close` button or `<esc>`. The first satellite selected in the list becomes the Prime Satellite for which the visibility calculations are done. To switch the prime to another satellite in the list use the `Switch Prime Satellite` option (see section 6.1.)

Re-entering the Select Satellite dialog after one or more satellites have already been selected will show the `New Set` button. Press this button before starting your selection if you want to clear all previous entries and start a fresh list. Otherwise the new selections will be added to the already existing list (which would be the case if you wanted to add satellites from different TLE files to the satellite list).

Alternatively the search can done via the International Launch Designation. To do so mark the `Select Int.Launch#` box and enter the designation instead of the name.Note that the designation must be entered in full, e.g. `1998-067A` (for the ISS). Entering a * instead of the designator will lead to all satellites being looked at. This option also works if there are only the traditional two lines per satellite (as opposed to three lines where the first line contains the name). Unlike the option with looking for a name where multiple fits will be indicated only the first occurence of a fitting Internation Launch Designator will be shown. If there are more entries for the same satellite on the file you will have to use the wildcard option *.

On occasion you might want the search done by NORAD# instead of the satellite name. (Nowadays, the "Two-Line-Elements" normally contain a third line giving the name of the satellite but in some compact versions like yearly lists of orbital elements, only the traditional two lines are present in which the satellite is identified by its NORAD[2] number.) In this case mark the `NORAD#` checkbox and enter the respective number in the NORAD# box and proceed as before. If you want to look for all satellites on the file via this option, enter a * for the satellite name and check the `NORAD#` checkbox . The NORAD number will then be igonred. (It is very rare nowadays to come across those files and you hardly ever will have to worry about setting the `NORAD#` checkbox. But I included it anyway just in case it is ever needed.)

If there was no line with the satellite name SatCal will substitute the International Launch Designation for the satellite name in the listings and the plots for this satellite.

You can restrict the search for satellites to those with low orbits (less than 250 km mean altitude) and newly launched satellites (satellites with less than 100 revolutions at epoch or in case of medium or high orbits those with less than 10 revolutions). To do so you must check the `Low Orbits Only` or the `Recent Launches` checkboxes. Note that in case of the low orbit option only

[2]The name NORAD was originally used for the USSPACECOM (US Space Command). The TLEs are generated by Spacetrack which (I think) is a sub-division of USSPACECOM.

satellites with orbit elements of less than one week of the currently set time will be considered. If you just started the program this will be the time of the day otherwise this time is whatever you set it in the time dialog!

IMPORTANT NOTE: Satellites must be selected by pressing the `Select` button. If you fail to do this the respective satellite(s) will be missing in the calculations and plots! In the beginning it may happen a few times that you found a satellite and saw its orbit elements displayed but then forgot to press the `Select` button to actually have it included in the SatCal active satellite list. But you quickly will get used to this. (A reason for not having the satellite automatically selected after a match is found is that there may be multiple matches and it's up to you to decide which one is the right one.)

3.2 Removing a Selected Satellite

Select `Input`, then `Remove Satellite` or press the `Z` key. The Delete Satellite From Selection dialog box will appear which lists the currently selected satellites. Mark the respective satellites and press `OK` to have those satellite removed from the list.

If the removed satellite had been the Prime Satellite, the next lower satellite in the list will become the new prime. A satellite which is removed from the middle or the bottom of the list will cause the other satellites to move down one notch in the list to fill the gap. Note that the satellites which move positions in the list will change their colors correspondingly to match their new ordinal number. If the `Remove Satellite` command was issued while the Map Display was shown an automatic refresh of the display will be executed to avoid any confusion with colors (but if issued while the text display was shown no such automatic refresh takes place). If the removed satellite was a partner in a relative satellite mode the next satellite in the list (if available) will take over the new role of relative satellite.

To delete all satellites from the list press the `Delete All` button or you can use the Select Satellite option (see above under 3.1) and press the `New Set` button.

3.3 Selecting Next Satellites to Pass

Select `Input`, then `Next Satellites` or click the `Select Next Satellites to Pass` icon or press the `P` key. SatCal then checks whether any satellites of the currently selected TLE file will pass (according to the set visibility conditions - see section 7.2) within the next 2 hours. (The Real Time clock is used for this feature. The setting of the Date/Time has no effect on this except if you set an R/T Offset - see section 3.4.) Up to 10 such satellites will be selected (if available). If any satellite satisfying the visibility conditions was found the previous satellite selections will be overridden. If no suitable satellite was found a warning message will be displayed. In this case the previous selection will be retained. If suitable satellites were found the Map Display will appear with the Real Time clock running. An automatic refresh of the display will be executed to avoid any confusion with the old satellite list. Satellites for which the pass is already in progress will be ignored.

This feature is particularly useful if you want to observe the next few satellites passing your site. Typically the appropriate TLE file for this is `VISUAL.TXT` which contains a number of bright satellites which often can be seen with the naked eye. Note that if you want to display the next few satellites passing in plain daylight during the day (let's say some of the next Iridium satellites) you must adjust the visibility conditions correspondingly (in this case set the `maximum sun angle` to `+90`). If you are interested in any satellite pass at all regardless of the sun angle and illlumination (e.g. in case you are interested in radio contacts) set the `maximum sun angle` to `+90` and do NOT mark the `Visible Passes Only` checkbox in the Select Visibility dialog box (see section 7.2).

NOTE: Most geostationary satellites will be ignored by this search as their visibility condition hardly changes during the interval.

3.4 Input of Date and Time

Select `Input`, then `Date/Time` or click the respective icon or press the `D` key. The date and time entered here form the start time for the contact calculations as well as for the Delta-Time plot.

The timezone (difference in hours from UTC) can be changed at any time during the run and set to whatever timezone you want the data displayed in. It does not have to be the same as the timezone set at your system. If you want the timezone to adjust automatically to the system timezone mark the `Use System Timezone` checkbox.

Note that although the SatCal timezone may be changed at any time during the run the timzone of the system clock must not be changed while SatCal is running lest it be ignored by SatCal and lead to an erroneous real/time clock. Timezones toward the East are positive (e.g. Singapore `+8`, Venezuela `-4`). To enter half hour timezones add 0.5 (e.g. for India `+5.5`). If you enter values `>14` or `<-14`, the timezone will be set to `0` as those timezones don't exist. In case you set the timezone manually remember to adjust the timezone if your local time switches from daylight savings (summer) time to standard time or vice versa. During startup SatCal will check whether its timezone agrees with the set system timezone and display a message if they differ.

The duration parameter (which has to be given in days and fractions of a day) specifies how long the contact (visibility) times or Delta-Time will be calculated for. If you want to have just a few orbits of a low flying satellite, `0.2` days might be adaquate. If on the other hand you want to get the visibility times for a complete week you obviously need `7` days. Note that this duration parameter also determines how long a search for the `Next Pass`, or `Sun Transit` etc options will continue if no suitable pass is found. The duration parameter will be saved if you leave SatCal via `File`, `Exit`. (The saved parameter will be limited to be between 1 day and 14 days.)

The parameter R/T Offset lets you offset the time specified by the system clock by the given amount of hours (and fractions of hours). This can be useful for simulations if you want to see the satellite as it will pass at some future (or past) date. This setting also affects the Next Satellites to Pass calculation.

NOTE: On occasion the timezone may be set wrongly on your system by one hour during summer (daylight savings) time (if the respective system table is incorrect for your country). If this occurs you will have to set the timezone manually. If you leave SatCal via File, Exit this timezone will be saved. If you want to use SatCal in real/time mode this real/time will be wrong however by one hour. In this case set the parameter R/T Offset to -1 to remedy the situation. (This parameter will not be saved and has to be reset on a subsequent startup).

3.5 Input of Observing Site

Select Input, then Location or click the Location icon or press the C key. To enter geographic latitude and longitude in decimal degrees mark the Decimal Degrees radio button. For angles in Degrees, minutes and seconds mark the DD.MMSS radio button; (in this case an angle of e.g. 48 deg, 28 min, 45 sec has to be entered as 48.2845) North is positive, South negative, East is positive and West is negative. The height is in meters.

The name of the location is abitrary text but limited to 25 characters.

NOTE: The setting of the Decimal Degrees / DD.MMSS radio button will also affect the display of geographic coordinates on the map.

3.6 Setting IERS Parameters

Select Input, then IERS Parameters. Here you can set the parameters UTC-TAI (Coordinated Universal Time - International Atomic Time), UT1-UTC (Universal Time UT1) and the Polar Motion coordinates (the x and y coordinates of the Celestial Ephemeris Pole in arcsec) as given by the International Earth Rotation Service in Bulletin A, B and C on:
http://hpiers.obspm.fr/eop-pc/
You normally keep the Use Defaults option marked unless you want to perform a precise numerical propagation. Typically the error by using the Default rather than specifying the actual values as given by the IERS will amount to something like 300 meters or so in position. The Polar Motion coordinates amount to at most 10 meters so you can leave them 0 most of the time. If you use the SPG4 analytical model (which is recommended for TLE's) you will not get a more precise calculation anyway.

If you unmark the Use Defaults checkbox SatCal will use a more precise nutation model and will correct for light time when calculating orbits (for numeric as well as for analytic models). So even if you don't change any of the default options you might realize (very small) differences in the result.

Note that the setting of the IERS parameters affects all selected satellites. SatCal does not provide for individual settings of these parameters for different satellites.

4 Calculating Contact (Visibility) Times / Iridium Flares

4.1 Display a list of AOS (Visibility) Times

Select `Calculate`, then `AOS (Visibility) Times` or click the `Calculate Contact Times` icon or press the `A` key. A list with the start, maximum and end times of a pass of the currently selected Prime Satellite with regard to the specified observation site is displayed. In brackets behind each time is the azimuth and elevation of the satellite as viewed from the observation site at the respective time. In order to be listed as a pass the satellite has to satisfy the visibility conditions (maximum sun elevation at the observer, minimum satellite elevation and whether the satellite is in sunlight - see also section 7.2.) The parameters used are listed at the beginning. The maximum of passes that can be displayed at one time is 120. Note that if the beginning or the end of a pass is with a higher elevation than the minimum elevation specified this will be an indication that the satellite entered or exited shadow or that the sun elevation limit at the observer's site was met at that moment.

If the Relative Satellite Mode is activated (and more than one satellite selected) only the times for the beginning and end of their mutual contact is shown as well as the geographic latitude and longitude of the Prime Satellite (in brackets behind the times). See section 6.2 for details about the Relative Satellite Mode. Finding these contact times usually takes more time than calculating the visibility times for single satellites.

If `Occultation/Transit` or `Flares` with `known surface` options were selected (see sections 7.4 and 7.5) a dialog box appears asking for specification of a distance (default 50km). Exiting this dialog with `OK` will cause a calculation of such events for the selected Prime Satellite if they fall within the specified distance of the observation site. Exiting with `Cancel` will skip this calculation. If events are found their time, azimuth and elevation as well as minimum distance will be listed. In the special case of Sun and Moon transits the width of the zone (or rather the maximum perpendicular distance from the center line in km - this is an approximate number) as well as the duration of the transit (in seconds) and the direction (e.g. 90° means from left to right, 225° means from upper right to lower left) will also be indicated (for satellites in low and medium orbits only). (The direction angle is calculated in the Horizontal System as viewed through a non-tracking telescope.) Also in this special case if the maximum distance was set to `0` only events visible directly from the observation site will be listed. Note that the general visibility conditions remain valid. In the special case of Sun transits the maximum sun elevation will temporarily be set to 90° so you can leave this parameter the way it is.

If the `Iridium Flares` option was selected in the Visibility Dialog (see section 4.4) the list of Iridium flares will be displayed (but not copied on file).

Note: If the Real Time Plot was active while the AOS Times calculations are called the Real Time Plot will be halted.

4.2 Display Pass Details

Clicking the RIGHT mouse button (or the left one if the left button was enabled via `View, Enable Left Button`) on a line in the AOS listings (see above under 4.1) will cause a more detailed listing of the respective pass (a list of azimuth and elevation in decimal degrees as well as apparent Right Ascension in hours and minutes and Declination in degrees and minutes of the satellite as viewed from the observer during the selected pass. The default time step is 15 sec but can be changed (see section 7.1.) Normally the times start with the beginning of visibility (which is calculated up to the second) and then proceed with the respective time step. However, if the time step is exactly one minute the listing will show only the integer minutes which are within the calculated visibility range.

If the selected time step is less than 1 sec the time will be displayed with fractions of a second. It this case the start of the pass will likewise begin within a fraction of a second. If the `RA/Dec with 4 digits` checkbox was marked in the Map Settings dialog (see section 5.1) the Right Ascension and Declination will be shown in HH.MMSS (hours, minutes and seconds) and DD.MMSS (degrees, minutes and seconds) respectively. Note that these coordinates are referred to the selected epoch (see the `Year of Epoch` parameter in the Visibility dialog, section 7.2).

Also given at the end of the listing is the apparent pole of the satellite track in azimuth, elevation (in degrees) as well as Right Ascension (in HH.MM) and Declination (in DD.MM). Aligning a telescope along this direction (instead of aligning it with the North or South Pole) will minimize the adjustment in the second (the declination) axis when tracking the satellite. Note that as the Earth turns while the satellite passes the position of the pole of the track will also change slightly so you need a slight adjustment in the declination axis while the major movement will be along the Right Ascension axis. The pole is calculated for about the time of maximum elevation of the pass (when the apparent satellite movement would be fastest).

If the Relative Satellite Mode is activated (and more than one satellite selected) the geographic latitude and longitude of the Prime Satellite (in decimal degrees) is given instead of the Right Ascension and Declination. See section 6.2 for details about the Relative Satellite Mode.

If you click on the `Save` button the information of the Pass Details will be written on the currently selected Save File (default `satsave.txt`). A standard format is used for the numbers in this case which should make it easier to process this file with other programs.

If the Sun or Moon Transit or Occultation or the Flare Mode (known flares only) have been selected (see section 7.4 and 7.5) the coordinates of the central line from where the event can be seen are given instead of azimuth, elevation etc. (This is only for the time interval for which the set visibility conditions at the specified observing site are valid. If there is no central line at the respective time a comment No Intersection is given.) As you can copy the contents of the Pass Details window (by clicking the `Save` button) you can then use this information to list it in an e-mail or use it in another program to e.g. produce a map overlay for a detailed topographic map (depending on what maps and map software you have for your region)[3]. Note that the longitude and latitude will be displayed as decimal numbers in this case independent of the DD.MMSS setting.

If you want the groundtrack coordinates saved press the `G-Track` button. Like the just mentioned `Save` option the information will be written to the currently selected Save File. And once again only that portion of the groundtrack will be written for which the set visibility conditions are valid. Depending on what you want to do with this information you may have to select a different time step to get more or fewer data points.

NOTE: If you switched to the map display after the AOS calculation and then switch back to the AOS listings (via pressing `X` or selecting `View, Show Last Text`) there will no reaction to mouse clicks. You have to issue the AOS command again before you can select the Pass Details.

4.3 Calculate the passes of ALL satellites of a TLE file

SatCal allows to check the passes of all the satellites of a complete TLE file with one single command.

Select `Calculate`, then `All Satellite Passes`. There is no icon for this option.

The rest now runs automatically as SatCal will calculate the contact times for all the satellites of the currently selected TLE file and write the result to the currently selected standard save file (see section 12.1). The contact times will not be displayed on the screen with this option. You have to open the standard save file (the default name of this file is usually `satsave.txt`) with a text editor. (If the columns are not properly aligned you should select another font (like Courier New) with the text editor.) Upon completion a confirmation will be given that the information was written to the save file. If SatCal was unable to open the TLE file a respective error message will be given.

If `Occultation/Transit` or `Flares` with `known surface` options were selected (see sections 7.4 and 7.5) a dialog box appears asking for specification of a distance (default 50km). Exiting this dialog with `OK` will cause a calculation of such events for all satellites of the selected TLE file if they fall within the specified distance of the observation site. (In the special case of Sun or Moon transits if the maximum distance was set to `0` only events visible directly from the observation site will be listed. Also in this special case satellites found will be added to the list of satellites as long as space is available to allow the immediate detailed look at this pass.) Exiting with `Cancel` will skip this calculation.

[3]A sample C++ program to produce such an overlay is provided with this release. You can modify it correspondingly for to suit whatever programs you may have.

If events are found their time, azimuth and elevation as well as minimum distance will be listed.

Do not use the `Iridium Flares` option when performing the `All Satellite Passes`. See below under 4.4 for how to do those calculations.

If you repeat this command during the same run (you might have selected another TLE file to also check satellites from that file) the new information will be sorted into the existing one and the header will be added. If you want the information kept seperate you have to select another save file. Note that if you issued the `Save` command (see section 12) to get contact times of a selected satellite before the `All Satellite Passes` command the information will likewise be mixed into the new one which might cause confusion. You should use seperate save files for these two options.

Note that depending on the number of satellites on the TLE file this option can take some time to run. You typically want to check the visibility of the whole set of satellites for a duration of at most a day (or just half a day to cover the upcoming night).

4.4 List of Iridium Flares

You must have a TLE file with the set of Iridium satellites on it (they are typically called `IRIDIUM.TLE` or `IRIDIUM.TXT` - these files can be two or three weeks old and still give quite accurate predictions). You can activate the Iridium Flare option in two different ways. If your TLE file has the name `IRIDIUM.TXT` and if you want the output on the screen as well as on a file called `IRIDIUMF.DOC` you can use the express option: Select `Calculate`, then `Iridium Flares` or click the Iridium Flare icon. SatCal will automatically select the file `IRIDIUM.TXT` for TLE's and `IRIDIUMF.DOC` for output, perform the calculations and then revert to the originally selected TLE and output files. In this case the output file `IRIDUMF.DOC` will be rewritten each time you call this option. Alternatively you can select the `Iridium Flare` checkbox in the Visibility dialog (see section 7.2; note that you do not have to set this checkbox for the express option), then use the `Calculate AOS (Visibility) times` or the `File Save` option to perform the respective calculations. In this case you have to select the Iridium TLE file manually (which now can have any name). The currently selected output file will be used for the `File Save` option and it will be appended on successive calls.

In either case a dialog box will appear asking for the apparent minimum magnitude of the flare (the default is mag `1.0`). Exiting this dialog with `OK` will cause a calculation of such events for all satellites of the selected (Iridium-) TLE file if their apparent magnitude is brighter than the minimum one specified. Exiting with `Cancel` will skip this calculation. If the `Operational Orbits Only` checkbox is marked (recommended) only those satellites which have correct height will be considered. Iridium satellites in lower orbits typically have failed or are still to be brought into service. Most of them will not maintain their operational attitude making flare predictions unreliable. Of course satellites in operational orbits might suffer a defect and fail their attitude in which case a predicted flare will not materialize. Also the operational attitude of Iridium satellites is allowed some small deviations which would cause the actual magnitude of a flare to differ from the calculated one (by up to a few magnitudes in extreme cases - but most of the time the predictions come out quite well). If the `Include Solar Panel Flares` checkbox is marked SatCal will also check for those flares. They are rarer than the MMA (Main Mission Antenna) flares but can be almost as bright. Checking this will take extra time. Note that the observed magnitudes of solar panel flares show greater fluctuations from the predictions than the MMA flares due to larger tolerances in the solar panel pointing. Also they seem to be quite unevenly distributed over the year. There may be some months with plenty of them and other months with no such flares at all.

If flare events are found their time, azimuth and elevation, main antenna which caused the flare (`Front`, `Left`, `Right` or in case of solar panel flares `Solar`), the direction of movement of the satellite (`->N` for North, `->S` for South) as well as the predicted magnitude and the name of the satellite will be displayed on the screen and (if the express option or the `Save` or the `All Satellite Passes` option is used) also written on the respective Save File. If the respective satellite is below the operational altitude (in case `Operational Orbits Only` was not marked) a question mark `?` will be placed as a warning after the predicted magnitude to indicate that there might not be a flare in this case. Matching satellites found will be added to the satellite list if less than 10 satellites have been selected so far and their passes can be studied in more detail via the map etc.

Note that the selected visibility conditions (see section 7.2) remain valid. That means that only passes which satisfy the specified minimum elevation and maximum sun condition will be considered. As Iridium Flares can get very bright you might want to set the minimum satellite elevation to 10° or so. If the `Moon Visibility` option was selected Iridium Flares caused by the Moon (while the satellite was not illuminated at the same time by the Sun; the `Visible Passes Only` option must be specified too) will be calculated. (Typically Moon-Iridium-Flares need the winter time as during the summer the Iridium satellites will be in sunlight most of the time. Only a few days around Full Moon are suitable as only then will the magnitude of the flares ever reach something in the range of mag +6 to +8. SatCal does take into account the respective Moonshine magnitude.)

If for some reason you want to check the flare ground track of a particular satellite you could manually set the Flare option (see section 7.5) with Yaw and Pitch angles of (-120, -40) for left-, (+120, -40) for right- and (0, -40) for front mirror (antenna). (In this case you do not get the apparent flare magnitude but the flare angle is given which is the deviation from the ideal direction for a maximum flare - the smaller the better. If you have set the Flare option and use the File Save option the distance from the set observation site to the place to see a maximum flare will be given instead of the flare angle.) To get the ground track of an Iridium solar panel flare you should first mark the Iridium Flares checkbox and calculate the flare for a particular moment. Then mark the

Flare option. The just calculated orientation of the solar panel (which changes all the time) will still be stored in the Yaw and Pitch fields. You can use these for the next few seconds to get a ground track, then go back to Iridium Flares to calculate the new orientation, go back to Flares etc. It's not very convenient - I realize that!

Calculating Iridium flares via the `Save` option various times will cause the information to be appended (and sorted into) the already existing information on the selected Save File. This may be intended if, for instance, you want to prepare a list of satellite events for a particular night and first issue the `All Satellite Passes` command to find the visibility times for bright satellites of the `VISUAL.TXT` list, then switch to `IRIDIUM.TXT` and have the Iridium Flares added (sorted) to this list. If you want to start a completely fresh list you must select a new Save File (or reselect and thus overwrite the old one) via the `Save File As` option (see section 12.2). Note that the express option via `Calculate`, `Iridium Flares` always overwrites the old output file.

NOTE: A standard correction for atmospheric extinction is being applied to the apparent magnitude for elevations below 33° assuming clear skies. This should help you not to expect an unrealistically bright flare if the satellite is low in the sky. If you don't want this correction to be done unmark the `Extinction` checkbox in the System Parameter dialog (see section 13.3).

Note that the Iridium Flares calculation puts a heavy workload on your CPU although with the ever increasing speed of today's computers you shouldn't have to wait too long.

NOTE: To get the light profile of an individual flare during a pass, select the respective satellite, mark the `Iridium Flares` checkbox in the Visibility dialog and set the `Characterstic Length` in the `Magnitude` dialog to `0.2`. (See also section 8.)

NOTE: If your `IRIDIUM.TXT` file is older than one month or so you may still get reasonable predictions of iridium flares by using the `Adjust` option in the `Edit Orbit Elements` menu (see section 9.7).

4.5 Writing Orbit Tracks on File

If you Select `Calculate`, then `Write Orbit Track` the geographic coordinates of the groundtrack or of the track of the occultation, transit or flare (which ever is just selected by the *Visibility* option) will be written on the save file (usually *satsave.txt*). The time will run from the time currently set via the *Date/Time* dialog for the set duration and using the time step set with *Time Step*. This file can then be used by other programs to plot the coordinates on a map etc. Note that each time this option is called the save file will be overwritten while with other options which write to the save file information will normally be appended.

5 Groundtrack / Sky Map Display

5.1 Activating the Map Display

To activate the Map Display select `View`, then `Refresh` or the `Refresh Map` icon or activate any of the Plot menu options (Real Time, Delta Time, Current Step, Next Pass, Last Pass or Step Mode). To switch between the Map Display and the Text Display press `X`.

To change the way the map looks select `View`, then `MapView / SkyMap` or click the `Change map settings / Skymap` icon or press `Y`. Available are groundtrack maps and sky maps. You can now select the coordinate grid pattern (`10 deg` or `30 deg` spacing or `no coordinates` - the grid will only be displayed on the groundtrack map [4]) and the background color (`white`, `grey` or `black`). A black background can be useful at night if you want to track a satellite while at the same time observing its groundtrack on the screen. Some satellite colors are better visible on a grey or black background. The following possibilites are available for the groundtrack map: A standard world map (either as a simple outline or as a physical map), and stereographic projections of either the Northern or the Southern hemisphere (just as simple outlines). Just mark the respective bullet. The central meridian of the groundtrack map can also be specified. To show the Pacific region in the center you could for instance specify a central meridian of 180°. The Northern hemisphere stereographic projection will look more familiar if you specify a central meridian of 180°.

If the `RA/Dec with 4 digits` checkbox is marked, the apparent Right Ascension and Declination of the satellite will be displayed with 4 digits after the decimal point instead of the usual two. In this case the geographic latitude and longitude will be displayed with 3 digits after the decimal point if decimal degrees are displayed or with 4 digits if they are displayed in degrees/min/sec.

The Map Settings dialog also lets you select the font size for the map legend.

If the `Show Day/Night - No Trail` checkbox is marked, the night hemisphere of the Earth will be shaded (if a black background was selected, the shading is inverse e.g. the night side will be lighter than black). Also if this checkbox is marked the satellites will leave no trails and the map will automatically be refreshed every 14 minutes to adjust to the moving darkness.

To switch to the Sky Map option mark the `Sky Map` checkbox. This shows the sky as viewed from the selected observer's site. Marked are stars up to magnitude 4.5 as well as the Sun, Moon and the planets Mercury, Venus, Mars, Jupiter and Saturn. (The background color black typically looks best on the Sky Map.) There are different projections available: `Zenith` is a stereographic projection of the entire visible hemisphere centered around the zenith. The color-coding of the planets which appear on the map is shown on the left side of the screen. The directions of the sky are also indicated. `North`, `East`, `South`, `West` and `Azimuth/Auto` are Mollweide-projections showing half the hemisphere with the center of the horizon facing in the indicated direction. If

[4] The 10° grid is only available on the standard world map. In stereographic Northern or Southern hemisphere projections only a 30° grid will be displayed.

`Azimuth/Auto` was selected you can specify the central azimuth in the respective `Ctr.Azimuth` box. In this case the Next Pass / Last Pass options (see section 5.5) will result in an automatic selection of the azimuth which best shows the pass found. This is useful if you want to get a quick idea how a specific satellite will pass across the sky over the next few passes. Note that the upper left and upper right corner of the window will be empty due to the selected Mollweide projection (but not enough space was left here for the explanation of the color-coding of the planets - refer to the one in the stereoscopic projection). (Close to these borders the trails will look somewhat strange due to the Mollweide projection but over the major part of the map the sky looks fairly undistorted.) The sky map will automatically be refreshed every 1 to 6 minutes (depending on the case) to adjust for the moving sky. By placing the cursor on a spot of the map and clicking the right mouse button the azimuth and elevation as well as the corresponding Right Ascension and Declination of the respective site will be displayed together with the apparent angular distance between that spot and the selected prime satellite.

Instead of showing the sky as viewed from an observer's site you can display the sky as viewed from the selected prime satellite. To do so mark the `Satellite View` checkbox which appears right above the Sky Map checkbox. You can choose the same projections as in the standard sky map. The local horizontal is marked with a circle in the stereographic zenith projection and the sky directions (North, East etc.) in the Mollweide projections are likewise at that position. But due to the height of the satellite the actual Earth horizon will be below the local horizontal and thus you see stars at those positions as well. Note that in this mode the text below the display no longer gives correct values for Right Ascension, Declination, Azimuth, Elevation, Range and Rate. The time and the satellite's position are correctly displayed, however, and while SatSun gives the elevation of the Sun above the Earth horizon as viewed from the satellite and ObsSun now gives the Sun's elevation as measured from local horizontal.

If you want to display Doppler frequency shift rather than Range Rate on the map then set the entry for `Doppler Frequency` to the nominal frequency in Hz. (If this entry is set to 0 Range Rate will be displayed instead which is the default.) Note that the Doppler shift is calculated as a one way shift (a signal sent from the satellite to the ground or from the ground to the satellite but not from the ground up and back again).

NOTE: The Relative Satellite Mode (see section 6.2) cannot be used while a sky map is displayed.

NOTE: The `Sun/Moon Plot` to show transits can only be activated and deactivated via the Visibility dialog (see section 7.4) but not in the Map View dialog. The grid and color parameters are saved when exiting SatCal and will be used at the startup of the next run.

To (manually) refresh the Map Display select `View`, then `Refresh` or click the `Refresh Map` icon. Pressing the `<Delete>` key will likewise refresh the Map Display. The Map Display can be scrolled horizontally and vertically via the horizontal and vertical scroll bars. Vertical scrolling can also be done via the

Arrow Up and Arrow Down keys. Pressing the <Home> key will return the display to the default upper left alignment. Normally, however, you don't have to scroll as the Map Display will fit completely into most screens.(The map size is fixed. You cannot enlarge it!)

While the Map Display is active you can revert to the last text screen display by selecting View, then Show Last Text or simply press X.

NOTE: Sometimes you want to plot groundtrack or transit tracks etc. on maps with a much larger scale than the small fixed ones provided by SatCal. To do so you can have the coordinates saved via the Display Pass Details option (see section 4.2) and then use the C++ programs provided in the overlay subdirectory for placing them on another map. See the remarks in the README file in the overlay subdirectory.

5.2 What the Map Display shows

The position of the satellite(s) is marked on the groundtrack map at the indicated time together with the circle of visibility (the area where the satellite is above the horizon). Each satellite is marked by a different color. The satellite first selected is displayed in black (or in white in case of a black background), the second satellite in red, the third one in blue, the fourth in green, the fifth in yellow and the sixt (and consecutive ones) in purple. You can select View, then Show Names or simply press the N key to have the names of the satellites displayed in their respective colors at their respective positions. The trail of the satellite will be marked on the map except if the Show Day/Night - No Trail option was selected.

The position of the observer is show as a blue-green circle. The sub-solar point (the place on Earth where the Sun is in the zenith) is indicated as a yellow star with a red dot in the center.

If the Sky Map had been selected, the satellites will be shown only when visible in the selected field of view. If the Visible Passes Only checkbox is marked (in the Visibility dialog - see section 7.2 - satellites will be shown only when illuminated. Note that the trails of the satellites across the sky will be marked unless the Show Day/Night - No Trail option was selected.

In case of satellite transits in front of the Sun or the Moon an alternative map can be selected showing the passage of the satellite in front of the disk of the Sun or the Moon (see section 7.4).

Columns of data are displayed below the map. The first column shows the time and timezone. Also an R/T will appear if a real time plot is active. The other columns refer to the Prime Satellite. (This is the one indicated by name on the right. The color of that name corresponds with the color used to represent that satellite on the map. To switch to a different satellite use the Switch Satellite option; see below in section 6.1. The second column shows the latitude, longitude and height (in km) of the (prime) satellite. If the height is negative the numbers will be written in black to indicate that the calculation makes no sense at this stage. (This can happen if you try to project a rapidly decaying satellite orbit too far into the future.) Height is defined here as the vertical height above the sub-satellite point on the Earth ellipsoid. (Other definitions are possible and will lead to slightly different values!) If decimal degrees were selected (the default) for the geographic coordinates (this switch can be set under the input of geographic coordinates; see section 3.5) the coordinates will be marked with 2 or 3 digits after the decimal point. In this case the ° sign will follow the number. If DD.MMSS was selected the coordinates are given in degrees and minutes (or also seconds). In this case the ° sign will replace the decimal point. (Example: -45.76° or -45.761° or -45°36 or -45°3539 would be displayed for the same position depending on the respective settings.)

The third data column gives apparent Right Ascension (in hours.min) and Declination (in Degrees.min) as viewed from the observer as well as the angle of the sun above the horizon as viewed from the satellite (in decimal degrees). If this sun angle is negative - which would mean that the satellite is in darkness - this column will be in black. Note however that a satellite might still be visible at a small negative sun angle due to the Earth's refraction. The brightness of the satellite fades more or less rapidly at this stage. Instead of displaying the Right Ascension and Declination in HH.MM and DD.MM format you can display them in a HH.MMSS and DD.MMSS format. To do so select `View`, then `Map View` and mark the `RA/Dec with 4 digits` checkbox. Note however that only when using the SGP4 model or the numeric orbit propagation will the precision of the extra digits be warranted.

The fourth column gives azimuth and elevation (in decimal degrees) and range (the distance, in km) of the satellite with regard to the observer. This will be in black if the satellite is below the horizon. Range Rate (relative speed, in km/s) of the satellite with regard to the observer is in the last column together with the elevation of the sun at the observer's site. Instead of Range Rate you can display the Doppler frequency shift (in Hz) if the respective entry for the nominal frequency (in Hz) in the `MapView/SkyMap` dialog was set > 0.

A standard correction for refraction is applied to the elevation. This can be turned of via the System Settings dialog (`Settings`, `Configure System`, then unmark the `Refraction` checkbox).

NOTE: Some of these data are different while in Relative Satellite Mode (see section 6.2) or for occulation or transit track displays (see 7.4) as well as for Flare calculations (see 7.5) or for solar eclipse checks (see 7.6).

While the cursor moves over the Map Display it changes to crosshairs. By positioning it and using the right mouse button you can get information about satellite visibilities at the respective locality (see below under 5.7).

5.3 Real Time Display

Select `Plot`, then `Real Time` or click the `Real Time` icon or press the `R` key. Appart from this manual start the Real Time Display will be activated automatically after a successful call to the Select Next Satellites to Pass options (see section 3.3). The timezone you specify within SatCal (see section 3.4) can be changed at any time to have the Real Time displayed correspondingly. However, if you change your system timezone (via the Date/Time option of your system) this change will not be recognized by SatCal while the program is still running and this most likely would result in an erroneous time to be used as Real Time. Most likely you would not do this anyway while any other programs are running. If you do change you system timezone you should exit SatCal first and re-start SatCal only after the system timezone change has been completed.

To stop the Real Time display, click the `Real Time` icon again or start any other display mode. While in Real Time mode, `R/T` is displayed at lower left.

Note that you can offset the Real Time from the system clock via the Date/Time dialog if you perform a simulation (see section 3.4) .

5.4 Delta Time Display

Select `Plot`, then `Delta Time` or click the `Delta Time` icon or press the `G` key. Starting with the date and time specified in the input date/time dialog (see section 3.4) and for the specified duration a groundtrack will be plotted (without the visibility circles). Be aware that if you have a low flying satellite choosing a duration of more than about 0.5 days usually results in a fairly cluttered display (although for certain missions this would allow you to recognize repeating patterns of passes). To stop the Delta Time display click `Delta Time` again or you may activate any other option like `Real Time` or `Step Forward` (there might be a small delay for SatCal to react to this).

5.5 Next Pass and Last Pass Display

Select `Plot`, then `Next Pass` or click the `Next Pass` icon. Alternatively you may press the `<Page Down>` key or the `<Tab>` key while the Map Display is active. The display will now jump to the time of the next pass (consistent with the visibility conditions and which lies within a timespan specified by the Duration parameter). In normal mode, the time will be at the maximum of the pass; in Relative Satellite Mode it will be at the beginning of the mutual contact between the two satellites.

The start time of the search is the time specified by the Date/Time input dialog box (see section 3.4) if no other calculations had been done before or if a Real Time Plot was active. Selecting `Next Pass` again will result in a search from the end of the currently found pass or otherwise from the currently displayed time onward. In either case the maximum duration of the search will be given by the duration parameter (in the Date/Time input dialog). If no suitable pass was found within the timespan an error message will be given. Choose the duration parameter long enough so that a pass can be found within its time frame but short enough so that SatCal doesn't embark for too long a time on a futile search if no passes are available. You'll quickly learn of what to expect.

To find the previous pass select `Plot`, then `Last Pass` or press the `<Page Up>` key. There is no icon available for this option. This option is like the Next Pass option except that the search runs backwards. Once again the duration parameter in the Date/Time input dialog determines the maximum (backward) search time. In normal mode, the time shown once again will be at the maximum of the pass while in Relative Satellite Mode it will be at the end of the mutual contact between the two satellites (as opposed to the beginning in case of the forward search).

NOTE: To get a good idea how the satellite will pass across the sky mark the `Sky Map` checkbox in the `Map View / Sky Map` dialog (press `Y`) and then select `Azimuth/Auto`. The sky map will then be selected for each new pass found to provide the best view of that pass.

5.6 Step Mode

In order to move one time step forward or backward you could select `Plot`, then `Step Forward` or `Step Backward` (and if the text display rather than the map was active the Map Display will automatically appear in this case). But the best way is to simply press the `Right Arrow` and `Left Arrow` keys (while the Map Display is shown). This has the added advantage that while you keep them pressed the time continuously moves on. This is a good way to follow a pass step by step.

The time step is 15 seconds by default but can be changed (see section 7.1). (For the sky map you typically want it 5 sec or less.)

Note: If it ever happens that there is no reaction when pressing the arrow keys try pressing `<Crtl>` once together with the arrow key.

5.7 Local Visibility Information

The visibility of the Prime satellite at the specified groundstation is shown on the map (see section 5.2). To find out about the visibility at other sites, you can position the cursor crosshairs over the respective location on the map and click the right mouse button. A box appears showing the coordinates of the clicked location and the sun angle at that site as well as the azimuth and elevation and the sun angle at the position of the satellite for each of the selected satellites. To be able to see a satellite the location should be within the circle of visibility. On some systems using the right mouse button will cause an additional popup menu to appear (for select and copy). If you find this annoying, use `View, Enable Left Button` to be able to use the left mouse button instead in which case the popup menu doesn't show. This setting will be saved upon exiting SatCal.

Alternatively, you can press the Spacebar while the Map Display is active and the location dialog appears. Enter the required geographic coordinates just as it was explained in section 3.5 and after that the Local Visibility Information will appear for that location. This allows for more precise coordinates as the Map Display has a resolution of just 0.5 degrees. The coordinates of the originally selected observing site will be restored after the information has been displayed.

If only one satellite was selected the Local Visibility Information will also include the Along-the-Surface-Distance (in km) of the satellite (if the satellite is closer to the Moon than to the Earth and if numeric propagation is used the distance to the surface of the Moon will be shown instead in this case). This is the great-circle distance of the groundtrack position of the satellite from the respective selected geographic location. Also shown will be the osculating state vector (in Mean-of-Date) and the Beta angle (this is the angle between the orbit plane and the Sun) as well as the azimuth and elevation of the Sun as viewed from the satellite. This azimuth normally refers to the +V direction of the satellite movement (e.g. an azimuth of 90° means that the Sun would shine on the right side of the satellite). If the Yaw Steering Mode option has been activated (see section 7.5) the respective yaw steering mode attitude is taken into account. Also shown in this case is the direction of the observer as viewed from the local satellite frame. This is given as Yaw, Pitch (in the same way as directions of flare surfaces would be indicated) and also as Azimuth (taken as the angle from true North - declination would be the same as the Pitch angle). Note that the observer's location in this case is the position you clicked with the mouse on the world map (if you want the location which was set via Input, Location activate the Local Visibility Display by pressing the `Spacebar` and then `Return`). If the Local Attitude was de-selected (it is the flare calculations are done for an inertial attitude) only the Sun's azimuth is displayed and would be taken from true North at the satellite's position. This will be indicated in the display.[5]

NOTE: The time for which the Local Visibiltiy Information is calculated is the same as the one currently used (and displayed) on the map. If you haven't activated the map yet (the blue area below the map doesn't show any numbers as yet) an undefined time will have been used for the calculation and the result is meaningless. Make sure to activate either the Real Time Display, the Delta Time Display, the Next Pass Display or the Step Mode at least once before displaying the Local Visibility Information. If the Real Time Display was active while you clicked the right mouse button or pressed the Spacebar the real time run will halt as long as the Local Visibility Information is displayed. As soon as you press the `OK` button to end the display of the visibility information the Real Time Display will resume.

NOTE: The selection of a site via the mouse click is only possible while the world map is displayed but is inactive in case of the Sun/Moon transit plot.

If the Sky Map was selected the Azimuth, Elevation, Right Ascension and Declination of the marked spot will be shown as well as the angular distance from this spot to the prime satellite. Also show is the course of the satellite across the sky with regard of Right Ascension and Declination. This can be useful if you have a picture of a satellite trail across the sky which also shows star trails but you are not sure which stars they are. As the star trails would follow lines of equal declination knowing the course of the satellite at a particular

[5]The different displays of Sun azimuth can actually be used to calculate the bearing of the trajectory: Subtract the +V azimuth from the North azimuth reference to get the inertial bearing of the trajectory. Use the Yaw Steering Mode azimuth instead of the +V azimuth to get the bearing with regard to the moving Earth surface (this would be the direction of the groundtrack on a map).

point would narrow down the sky coordinates where to look for.

In case of the sky map a selection via the Spacebar is not possible.

5.8 Show Satellite Names

To have the names of the selected satellites displayed on the map at their respective positions and in their respective colors select `View`, then `Show Names` or press the `N` key. This will toggle the `Show Name` switch.

5.9 Show State Vector

If only one satellite was selected SatCal can display the osculating state vector of that satellite in mean-of-date (equatorial) coordinates. The state vector (in km and km/sec) will then be shown each time you activate the Local Visibility Information (see section 5.7) in addition to the usually displayed information.

6 Switch between Satellites / Relative Satellite Mode

6.1 Switching the Prime Satellite

If more than one satellite has been selected you can switch the Prime Satellite (the one for which the data are displayed on the map and also the one for which the contact (visibility) times will be calculated). To do so select `View`, then `Switch Sat's` or click the `Switch Satellite` icon or press the `W` key. The Switch Satellite Display dialog box will appear which lists the currently selected satellites. Mark the respective satellite become the Prime Satellite.

As a shortcut you can press the number of the satellite directly on the keyboard in order to switch to that satellite without using this dialog. (Use `1` for #1, `2` for #2, ... `0` for #10)

6.2 Relative Satellite Mode

While in the Switch Satellite Display dialog box (see above under 6.1) you can mark the `Relative Satellite Mode` checkbox. If more than one satellite has been selected, the data below the map will now refer to the relative positions of two satellites. Apart from the selected Prime Satellite the second satellite will be the one following the prime in the Switch Satellite list. (If the prime was the last one in the list, the first one in the list will be taken as the second satellite. The selection occurs in a cycle.).

To indicate that the Relative Satellite Mode is active the name of the second satellite will be displayed below the one for prime in the Map Display (at the position where normally the Sun elevation at the observer is displayed). In Relative Satellite Mode the second data column below the map gives the position of the Prime Satellite as before but the third column now shows the position of the second satellite. Azimuth and elevation (uncorrected for refraction) now refer to the Prime Satellite as viewed by the second satellite (don't be surprised to get very negative angles at times as one satellite might fly above another!) and range and range rate are between the two satellites. The azimuth and elevation column will be in white if the the visibility condition is met, otherwise it will be in black. The visibility condition is met if the two satellites are in line-of-sight (and are both sunlit in case the `Visible Pass Only` option is set - see next paragraph).

The `Next Pass` option will now cause a jump to the next start of mutual contact between the two satellites and the contact times calculated with the respective option will likewise be the (start and end) times of line-of-sight between the two satellites. The maximum sun angle and minimum satellite elevation angle in the Contact (Visibility) Settings will be ignored in Relative Satellite Mode whereas the `Visible Passes Only` option (if selected) has now the meaning that both satellites must be in sunlight for a line-of-sight pass to be accepted. Note that if you are only interested in the possibility of mutual line-of-sight radio contact between the two satellites you should de-select the `Visible Passes Only` option.

The Relative Satellite Mode is useful for finding contact times between satellites but can also be used to figure out if, when and where two satellites might be seen at the same time from an observer.

Note that finding passes usually takes longer while in Relative Satellite Mode as compared to a similar time span for normal visibility times of single satellites. You may have to be a little more patient!

NOTE: If you select the Sky Map display or the Picture display, the Relative Satellite Mode will be reset to standard mode.

7 Time Step, Visibility Conditions and Occultations

7.1 Changing the Time Step

Select `View`, then `Time Step` or click the `Change Time Step` icon or press the `T` key. A small dialog box appears in which you can change the minutes and seconds of the time step. The time step is needed for the Pass Details and for the Step Mode and Delta Time Mode of the map. You can specify minutes and seconds at the same time. The values will be added correspondingly. The seconds can be 60 or larger. It is possible (though not recommended for reasons of clarity) to specify e.g. 2 min and 125 seconds (which would result in a time step of 4 minutes and 5 seconds).

It is possible to specify fractions of seconds. If you enter `0.1` into the Seconds field SatCal will move in increments of 1/10th of a second. If the time step is less than 1 second the time in the lower left of the world map will be indicated to the tenth of a second as will the time in the Pass Details.

7.2 Specifying Visibility Conditions

Select View, then Visibility or click the Visibility icon or press the V key. This will display the Contact (Visibility) dialog box. **THIS VISIBILITY DIALOG BOX IS CENTRAL TO GOVERNING THE BEHAVIOUR OF SATCAL IN MANY OF ITS CALCULATIONS. READ THIS SECTION CAREFULLY TO LEARN ABOUT THE VARIOUS POSSIBILITIES OF SATCAL.**

The Visibility parameters are needed for the calculation of visibility (contact) times in the main window and the Jump to Next Satellite Pass in the Map Window. Here you can specify the maximum sun elevation at the observer and the minimum satellite elevation (both in decimal degrees). A pass will only be considered if the sun elevation at the observer is less than the maximum sun elevation parameter at that time and the satellite is more than the minimum elevation above the horizon (not corrected for refraction). If you want to allow daylight passes set the maximum sun angle to +90. For visual observations you mostly will set it to -6 or -12 to mark twilight conditions. (Typically for ISS or Iridium Flare calculations use a maximum sun angle of -4 and a minimum elevation of 10. For many other satellites angles of -10 and 20 respectively might be appropriate.)

If the Visible Passes Only checkbox is marked only those passes will be considered where the satellite is illuminated by the sun (meaning that the elevation center of the sun above the horizon as viewed by the satellite -uncorrected for refraction- is greater than 0 so in reality, the satellite is in daylight for just a little longer) , otherwise dark passes will also be considered (e.g. if you are interested in radio contacts rather than visual sightings or maybe a transit of a dark ISS in front of an illuminated Moon).

There is also the option to check for visibility under Moonlight. This is what the Moon Visibility checkbox is for. See below under 7.3 for details.

The year of epoch for the (third column) display of Right Ascension and declination and also for R.A. and Dec. entries for orbit determination and for occultations can be specified in the respective field Year of Epoch. Enter 0 for True of Date epoch.

If the Occultation/Transit checkbox is marked the tracks displayed will be the respective occultation or transit locations (see below under 7.4).

If the Flares checkbox is marked flare (mirror) calculations can be performed (see below under 7.5).

If the Iridium Flares checkbox is marked Iridium flare calculations can be performed (see section 4.4).

NOTE: While in Relative Satellite Mode, the two angles (maximum sun and minimum satellite elevation) are ignored and the Visible Passes Only parameter now means that both satellites have to be in sunlight.

7.3 Moonlight Visibility

SatCal allows the calculation of visibility passes under Moonlight illumination. This only makes sense for the very largest satellites (e.g. the space station).

Both the `Visible Passes Only` checkbox and the `Moon Visibility` checkbox must be marked in the Visibility dialog box (see above under 7.2). The satellite will then be considered visible if it is in moonlight but not in sunlight (and the maximum sun and minimum elevation conditions are also met). This option is ignored in Relative Satellite Mode. (Note that the satellite will of course be even more visible while in sunlight but this is disregarded for this option).

When this condition is met the Map Display will show the Right Ascension / Declination column (as well as the magnitude if chosen) in yellow. Also the tables for visibility times, detailed visibilities etc. will refer to those times of moonlight visibility (but not sunlight visibility).

NOTE: Right after sunset (or just before sunrise) the satellite will be in (solar) twilight. This will often be brighter that the illumination by moonlight. This effect will be ignored here. If the sun's elevation as viewed from the satellite is < 0 SatCal will switch to moonlight calculations in this case (if the Moon is visible from the satellite at that time) even though for another 1 or 2 degrees below the (geometric) horizon the sunlight will dominate due to refraction and twilight.

7.4 Sun/Moon Transit or R.A./Decl. Occulations

If the `Occulation/Transit` checkbox is marked SatCal is in a special Occulation Mode. Depending on whether the `Sun Transit`, the `Moon Transit` or `R.A/Dec.` button was selected the tracks on the map will no longer show the satellite position but the position from where the satellite is seen to transit the Sun, the Moon or occult the specified R.A./Dec. position in the sky respectively. The third map display data column will now show the geographic latitude and longitude of that position together with the remark `Sun Transit`, `Moon Transit` or `Occultation` instead of the usual R.A. and Dec. If at a particular time there is no such position the message `No Intersection` appears. If there is an intersection the distance in km of that geographic position to the observer's site will be given as `dst:` in the rightmost column instead of the `Rate` or `Mag` information normally displayed there.

If you do select `R.A./Dec` two fields will appear for you to enter the Right Ascension (in HH.MMSS) and the Declination (in DD.MMSS). This allows you to check for occultations (or transits) of star clusters etc. (To enter a Right Ascension of 12h15m34s enter `12.1534`, to enter a declination of -12°45′30″ enter `-12.4530`) Note that these data refer to the epoch specified under `Year of Epoch`.

After having set this Occultation/Transit option you can get a list of such events which can be seen within a specified distance from your observation site in addition to the interactive use of the map by issuing the `AOS` (Visibility) Times or the `All Satellite Passes` command (see sections 4.1 and 4.3). Note that the Relative Satellite Mode will be off while the Occultation/Transit Mode is on.

For Sun or Moon transits an additional checkbox appears with the name of `Sun/Moon Plot`. Marking this checkbox will show the disk of the Sun or the Moon instead of the usual world map or sky map. By selecting the time of such a transit you can then see how a satellite moves in front of the Sun or the Moon as viewed from the site of the observer. As this event takes just a second or so you should set the time step to `0.1` sec or so and move along with the right or left arrow key as usual. The location of the observer must be close enough to the central line of the event (as shown in the list of such events as calculated via the `AOS (Visibility)` times. In case of the disk of the Moon the phase of the Moon will be indicated. The display shows the view in the Horizontal system that is as viewed through a scope which shows the world right way up like in a pair of binoculars. Depending on your telescope you might see the picture upside down or left and right changed. If your scope is polar aligned you might have attached your (video etc.) equipment such that it is aligned in the Equatorial system. The Sun/Moon Plot in SatCal shows a line in the center of the disk labeled with an `N` pointing toward the direction of the celestial North Pole (e.g. the equatorial North). (Only if a coordinate grid has been selected for the world map - `View`, `MapView / SkyMap`, `Grid`.) This will give you the reference for the Equatorial system. Typically, you would first calculate a list of such events for a period of maybe 2 weeks or so, then select a particular event and check its central line on the world map, decide on a suitable observation site, enter these new coordinates and then check with the `Sun/Moon Plot` how the transit would look like at that site.

NOTE: The calculation is referred to a surface which is at the same height above the standard sea level as the height indication of the observer's site (see section 3.5). A correction for atmospheric refraction is applied.

NOTE: The coloring of the third data column is maintained. This means that the data will be in white if the satellite is in sunlight, in black if it is in the dark or in yellow if it is in moonshine (if the `Moonlight Visibility` option was also selected).

NOTE: When observing a satellite transit in front of the Sun or the Moon you should be aware of how large (or small) a spot to expect. If the linear dimensions of the satellite are `d` meters and the range at the time of transit is `r` km then the apparent size of the satellite in arcseconds is given as $206 \times \frac{d}{r}$.

NOTE: If you wanted to observe the occultation of something as small as the disk of Jupiter by the ISS etc. you would have to be within a few hundert meters of the right location and also the calculated position of the satellite would have to be that accurate. The simple low precision orbit model of SatCal is not adequately precise for that purpose but even the more accurate SGP4 Model might not suffice in that instance. Only if you have a very precise state vector for that epoch and use numeric propagation would you have any chance at all! The Sun, Moon and extended star clusters etc. are much larger targets and you stand a better chance to see such a transit within the accuracy of SatCal. In any case you will need very up-do-date orbital elements as even a minor difference in the elements will make you miss the event. These conditions will be much more relaxed if you are only interested in finding out (let's say for the sake of photography) when and where the ISS will pass the belt of

Orion or something like that.

NOTE: To copy a list of coordinates of the central line of the event (e.g. in order to use this information in detailed maps) first make a list of the events via the AOS option (see section 4.1) and then click with the right mouse button on the respective line to get the Pass Details (see section 4.2). You can then copy this information from the Pass Details window onto the clipboard. Alternatively you can press the `Save` button in the Pass Details window to have the information written to the standard save file.

7.5 Flare Calculations

If the Flares checkbox is marked SatCal is in a special Flare Calculation Mode which serves to calculate specular (mirror) reflections which might result in flares as viewed by the observer. Two further checkboxes will appear in this case which govern the way in which these calculations are done: You either know which surface of the satellite acts like a mirror and want to find out when and where flares from this surface can be observed or you have seen a flare at your observing site and want to find out which surface may have caused this flare.

The direction of the mirror surface is given as the normal-to-the-surface either as Local Attitude Yaw/Pitch or as Inertial Right Ascension / Declination. Many satellites (particularly Earth-observing satellites but also communication satellites like the Iridums) maintain a local attitude with regard to the (center of the) Earth and their direction of flight. Other satellites (for instance astronomy satellites like the HST) maintain (at least for some time) an inertial attitude with regard to a particular position in the sky. The ISS normally maintains a local attitude, the Shuttle flies local as well as inertial attitudes depending on the timeline within the mission. Mark the `Local Attitude` checkbox if you want the surface to be specified as a local yaw/pitch attitude; otherwise it will be given as an inertial Right Ascension (in HH.MMSS) and Declination (in DD.MMSS). The local yaw/pitch attitude is defined in the following way: Imagine the satellite like an airplane with its nose in direction of flight and its bottom pointing to the center of the Earth. First `Yaw` (move to the left or right; positive if right), then `Pitch` (move the nose up or down; positive if up) to point toward the new direction. The angles must be given in degrees. Thus to point toward the center of the Earth (or the sub-satellite position) use a Yaw of 0° and a Pitch of -90°. A Yaw of -90° and a Pitch of 0° points out of the orbit plane toward the positive angular momentum vector. The antennas of the Iridium satellites point toward the rear left with a Yaw of 240° and a Pitch of -40°; toward the rear right (Yaw 120°, Pitch -40°) and toward the front (Yaw 0°, Pitch -40°).

If the `Known Surface` checkbox is marked the Yaw/Pitch or R.A./Dec. angles must be entered into the respective fields on the right. In this case the geographic position of the flare (resulting from that surface) will be shown similar to the Sun Transit (see section 7.4) except with the remark `Flare Position`. In this case the last column contains an entry `FlrAng` which gives the angle between the ideally reflected light ray and the direction of the observer in degrees (as viewed from the satellite). The smaller this angle the larger the flare.

Otherwise if the `Known Surface` checkbox is *not* marked the angles of the surface which would produce a flare at the observer are displayed in the third column (as `Y` yaw and `P` pitch or as `R.A.` and `Dec.`) together with the remark `Flare Angle` (The map in this case continues to show the position(s) of the satellite(s) as usual.). If the `Moon Visibility` checkbox is marked flares are with regard to the Moon instead of the Sun (independent of a yellow or white color). (I don't know whether this makes any sense but it was easy to implement - maybe somebody will find a use for this!)

There are various different ways in use to define local attitudes. They differ from each other because orbits are not perfect circles and the Earth is not a perferct sphere and is also rotating. Another point is the way in which local attiudes are achieved in practice. A number of satellites use a constant rotation equal to the mean orbital motion ("Orbit Rate"). They deviate from a "Local Vertical" in Pitch but in most cases their orbits are so close to circles that the difference is on the order of 0.1° or 0.2° - often well within their attitude deadbands (And keep in mind with regard to specular reflections that the Sun has an apparent diameter of 0.5°.). Using the velocity vector as SatCal does actually defines a local attitude which is about halfway between Orbit Rate and Local Vertical. Some sophisticated Earth observation satellites with stringent pointing requirements (like Envisat or Metop) might use giros to continuously adjust their attitude during a revolution for "Local Relative Yaw Steering" in which the local vertical is defined by the normal to the Earth's reference ellipsoid but more importantly the 0-Yaw direction is now defined by the direction of the relative motion with respect to the surface of the moving Earth. This causes deviations in yaw from the other local attitude systems depending on the geographic latitude (largest at the equator - about 4°). This effect will be accounted for if the `Yaw Steering Mode` checkbox is marked. In most cases however you want to have this checkbox NOT marked and rather use the standard local attitude.

Special option for Solar Panel Flares: Solar panels normally point toward the Sun. Occasionally, this direction is close to the ideal flare angle. With SatCal you can check this angle directly in the following way: Unmark both the `Know Surface` and the `Local Attitude` checkbox. A new checkbox appears with the name `Solar Panel Flares`. Mark this box. Now the angle between the direction of the Sun and the ideal flare surface direction will be displayed in the third column together with `Solar Panel`. If this angle is very small (1° or so) you might expect a flare. The smaller the angle the smaller the flare. Note however that the apparent magnitude displayed (if so selected) will not be influenced by this setting (contrary to what happens with the Iridium-Flares) as SatCal does not have information about the solar panels of arbitrary satellites.

SatCal also allows to check for possible flares from cylindrical surfaces. Assume you have a reflecting cylinder (like the structure of the Hubble Space Telescope) which points into a specific direction. If the direction of a mirror surface which would produce a flare is 90° off the pointing direction of the cylinder you could expect a definite brightening (if not an outright flare) because a stripe along the whole length of the cylinder would be just right to produce a flare. To check this with SatCal unmark the `Known Surface` checkbox. You will now see a checkbox labeled `Cylindrical Flares` which you have to mark. Enter the direction of the (longitudinal) axis of the cylinder as Yaw and Pitch for local attitudes or as R.A. and Dec. for inertial attitudes in the respective fields. If you now step through a satellite pass you will see the flare angles needed for a perfect specular flare (with regard to the set observer's location) displayed below the map as usual but in addition the angle between the specified pointing direction of the cylinder and that flare ange is displayed in the final column (at the lower right) as `CylAng`. If this number is close to 90° you might expect a flare. (It might even work for conic surfaces if you check for the cone angle instead.) Note that in order for this option to work neither the Magnitude nor the Doppler display must be active (see 8 and 5.1) as in that case those data will be displayed instead of the cylindrical angle.

Normally the flare angle will be displayed for flares from known surfaces. To find out what the expected magnitude of the flare will be proceed as follows: The `Known Surface` checkbox must marked and the Yaw/Pitch or R.A./Dec. angles must be entered into the respective fields. Now mark the `Display Flare Magnitude` checkbox. A field `Maximum Flare Magnitude` will appear. Enter the expected maximum magnitude of this kind of flare. This is the magnitude you would observe if you are at the center line of the flare and the relative flare geometry is optimal (for Iridium MMA flares this magnitude would be -8.7 but for other satellites it will depend on the individual satellite and the surface in question - typically you might have done some observations before to calibrate this type of flare). One other item needs to be done: You must have enabled the display of magnitude via `View, Magnitude` (see section 8, the `Charact. Length` must be > 0). The magnitude will be displayed instead of the flare angle. (The calculation assumes a flare characteristic similar to the Iridium MMA antenna. This may or may not produce an acceptable result. Only actual observations can tell whether this works for the satellite in question.)

NOTE: If you do see a satellite flare you might not necessarily be at the position of the maximum flare in which case the calculated surface would point in a slightly different direction than the actual surface. Typically the speed and magnitude of the change in brightness is an indication of how close you are to the maximum flare position. A very fast and large change would indicate a position close to the maximum.

NOTE: A correction for atmospheric refraction is applied to the calculation of the geographic position of the flare in the `Known Surface` case. It is however ignored in the flare angle calculation if the mirror surface is not known. This effect can normally be ignored except for very low elevations.

NOTE: To calculate Iridium-Flares you can use the respective option (see section 4.4) which automatically takes care of the needed settings. You do not have to mark the Flare option in this case.

NOTE: To copy a list of coordinates of the central line of known flares (e.g. in order to use this information in detailed maps) first make a list of the events via the AOS option (see section 4.1) and then click with the right mouse button on the respective line to get the Pass Details (see section 4.2). You can then copy this information from the Pass Details window onto the clipboard. Alternatively you can press the `Save` button in the Pass Details window to write the information to the standard save file.

7.6 Solar Eclipse Checks

If the `Solar Eclipse Check` box is marked the relative Sun/Moon distance at the selected (prime) satellite's position is calculated and displayed as `S/M Ang.` in the third column. If the angle is small enough to cause a solar eclipse the respective magnitude of the eclipse is displayed together with an indication whether the eclipse is partial, total or annular at the respective time.

If the apparent visual magnitude of the satellite is also displayed (see below under 8) the change in brightness due to the eclipse will be taken into account. In this case the relative sunlight as a percentage of the normal (non-eclipsed) sun is displayed as `Ecl.Pow.` instead of the eclipse magnitude below the Sun/Moon distance. This would typically correspond to the power still available from the solar arrays during the eclipse.

NOTE: The solar eclipse checks are not performed when in Relative Satellite Mode (see section 6.2).

8 Display Magnitude

A (very) approximate value for the apparent magnitude of the satellite can be displayed instead of the range rate. To activate this feature, select `View`, then `Magnitude` or press the `M` key. Enter a positive number different from 0 as the `Characteristic Length`. This is a length typical of the radius of a circle with roughly the same area as brightly reflecting parts of the satellite. Adjust this to fit the satellite in question. A typical value for the ISS would be 20 - 30 m during its final stage. Many satellites fall into the `1` meter category but mini or micro satellites are smaller than that. The actual value you entered will also be influenced by the general reflectivity of the satellite. A large satellite which is relatively dark because of a gold foil covering might be as bright as a smaller but whitely painted satellite. You have to experiment a little yourself to find reasonable values. SatCal assumes a spherical satellite of uniform coating which can be very far off from the real shape of the satellite! Of course, often the magnitude will depend on the actual attitude of the satellite at the moment of passage and this may only be known to mission controllers (or nobody) at the time. So most of the time the apparent magnitude displayed by SatCal is just an indication of how it might be. You have to gauge it with your own sightings.

This magnitude calculation is based on non-specular reflection so there are always lot's of surprises in store on individual passes (as every satellite observer knows). Note that atmospheric extinction is normally accounted for. To disable this unmark the `Extintion` checkbox in the Configure System Parameter dialog (see section 13.3). To have the magnitude of Iridium Flares considered, mark the `Iridium Flares` checkbox in the Visibility dialog box (`View`, then `Visibility`) in addition to setting the `Charactersitic Length` (to something like `0.2` or `0.3`) as just explained. SatCal will then assume that the selected satellite is an Iridium in its proper attitude and check whether any of its three main antennas will cause a specular reflection (flare) which exceeds the normal magnitude and display the corresponding value. This allows to follow the light profile of such a flare. (Iridium satellites can become visible to the naked eye even half a minute before the maximum flare magnitude.)

NOTE: When the `Moon Visibility` option is active (see section 7.3) the magnitude in moonlight will be shown in yellow if the respective conditions are met. The calculation SatCal does for the apparent brightness of the Moon will be too optimistic within 4 days or so around New Moon, otherwise it is reasonably accurate for our approximate magnitude calculation. If you are too close to New Moon the lunar brightness is so small that you will hardly be able to see anything even through a larger telescope. When the `Moon Visibility` condition is not met the magnitude will be displayed with regard to the sun as usual and is in white (if the satellite is in sunlight) or in black (if the satellite is neither in sunlight nor in moonlight). In other words sunlight will always take precedence over moonlight.

9 Edit Orbit Elements / Launch Orbit / Delta-V

9.1 Edit / Changing Orbit Elements

The orbit elements of the currently selected Prime Satellite can be changed or a new satellite can be defined manually. To do so select `Maneuver`, then `Edit Orbit Elements` or click the `Edit Orbit Elements` icon or press the `E` key.

The Edit Orbit Elements dialog box will appear and displays the fields for the satellite name, the NORAD #, year of epoch and the day of year and fraction of day of the epoch (as ddd.fffffff), as well as the Right Ascension of the Ascending Node, the Argument of Perigee, the Mean Anomaly at epoch, the eccentricity and inclination (all angles are in degrees). If you want to change the epoch you may either enter the respective values directly or you can press the `Edit Time` button to change the date via the normal Date/Time dialog.

Two items can be stated in alternative ways. Either the `Mean Motion` (in revolutions / day) or the `semi-major axis` (in km) can be entered. SatCal will take the value from the field which was last changed and calculate the corresponding value for the remaining field. Likewise the first derivative of the mean motion can be given either in the `ndot` field (change in mean motion per day / 2) which is the parameter used in the Two-Line-Element format or in the `adot` field as the change of the semi-major axis in km/day. The field last changed will be taken and the corresponding field value calculated.

If you know the height of Perigee and Apogee instead of the Mean Motion / Semi-major axis and eccentricity mark the `Perigee/Apogee` checkbox and enter the values for Perigee and Apogee (as km above the equatorial Earth radius of 6378.137km) into the respective fields.

You can also specify the second derivative `n2dot` of the Mean Motion (in revolution/day^3). In most cases you will leave this field `0`.

SatCal allows you to choose between three different orbit propagation models: A simple low precision one and the higher precision Spacetrack SGP4 Model for analytic calculation as well as a numeric propagation model. When selecting data from TLE files SatCal normally will set the model automatically to SGP4 as this is the accurate method to use with those elements. With this model the parameters `ndot`, `adot` and `n2dot` will be ignored and cannot be edited. Instead a parameter named `BSTAR` is employed (which is supplied by the TLE files) to figure out the effects of drag. This is the situation if the checkbox `SGP4 Model` is marked. If this checkbox is not marked, the simple model will be employed and in this case you can edit `ndot`, `adot` and `n2dot` but not `BSTAR` which is ignored in this case. Typically when using Two-Line-Elements you want to use the SGP4 Model but if you manually enter orbit elements which you got from somewhere else (or if you use the SatCal orbit determination or Launch orbit calculations) you should use the simple orbit model because the SGP4 Model assumes that the orbit elements are mean elements calculated according to a particular procedure employed by Spacetrack. For orbits with periods greater than 225 minutes Spacetrack recommends a modified code - the SDP4 code. You can however de-activate the SDP4 code, see section 9.8 if the TLEs have been generated by the standard SGP model (which might be the case for TLEs from independent observers). To use the numeric propagation model mark the `Numeric Prop` checkbox, see section 13.

To update related fields (e.g. you changed perigee and apogee and want to know the resulting values for semi-major axis and eccentricity and Mean Motion) click the `Refresh` button. This is for your information only as an automatic update of all related elements will be performed when leaving the dialog via `OK`.

Hyperbolic orbits: For an eccentricity > 1 (hyperbolic orbits) the Mean Anomaly will be ignored. The Epoch will be taken as the time of perigee passage. The perigee distance `q` will be entered in the field for Mean Motion or alternatively a (negative) semimajor axis can be given. The `SGP4 Model` checkbox will automatically be de-selected as hyperbolic orbits are not defined in this model. SatCal calculates hyperbolic orbits as a purely non-perturbed Keplerian orbit in the analytic model case. You normally would prefer the numeric propagation for hyperbolic trajectories as this does include perturbations by the Sun and Moon.

State Vector entry: The orbit data can also be entered as an osculating state vector. Press the `State Vec.` button. The epoch is the one given above. Note that when entering a state vector the corresponding Kepler elements will be mean SGP4 elements if the `SGP4 Model` Checkbox is selected and osculating elements if this checkbox is not selected. This is important in case you want to proceed with an analytical calculation. But having a state vector you normally would want to perform a numeric propagation. You can select the coordinates of the state vector to be in `Mean Equator of Date`, `True of Date`, `J2000` or in `Earth Fixed` coordinates. Just click the right button. If you use the numeric propagation model additional information will appear in the State Vector dialog, see section 13.

See below under 9.5 and 9.7 about generating geostationary orbits and adjusting elements of older files.

NOTE: SatCal uses two different formulae for calculating the semi-major axis from the Mean Motion depending on whether the SGP4 Model was selected or not. However, only one formula is used for calculating the Mean Motion from the semi-major axis. Changing from one to the other and then back could give you slightly different results. It is recommended that while using the SGP4 Model you should edit only the Mean Motion but not the semi-major axis.

NOTE: There will be limit checks on Mean Motion and semi-major axis. If the value for Mean Motion is 0, SatCal tries to use the semi-major axis value instead even if it had not been changed prior.

NOTE: The orbit elements displayed in the Edit Orbit Elements dialog are “True Equator Mean Equinox” for the SGP4 model and "Mean-of-Date" otherwise. If you want to enter Keplerian elements given for J2000 proceed as follows: Unmark the checkbox `SGP4 Model`. Enter the elements and then exit the Edit Orbit Elements dialog. Calculate (display) the position of the satellite for the epoch given (this serves to create a state vector internally). Re-enter the Edit Orbit Elements dialog, mark the `Numeric Prop` checkbox and enter the State Vector dialog. Unmark the `Reset Current State Vector` checkbox and then select `J2000` coordinates, then mark the `Reset Current State Vector` checkbox again. The Keplerian elements have now been converted to Mean-of-Date. You can either keep the `Numeric Prop` checkbox marked and continue with numeric propagation or unmark the checkbox to continue with a Keplerian calculation when leaving the State Vector dialog.

9.2 Delta-V Maneuver

Select `Maneuver`, then `Delta-V`. There is no icon for this option. A satellite must have been selected for this option to operate (if it hasn’t an error message appears and the dialog box will be terminated). The delta-v maneuver will be performed on the Prime Satellite.

First the Date/Time dialog box appears. Enter the date, time and timezone of the maneuver. (The maneuver is assumed to be an instantaneous impuls.) The entry for duration will be ignored.

Next comes the Delta-V dialog box where you have to enter the velocity increment (in m/s) and the direction in which the delta-v vector will be added. This direction is specified as yaw and pitch angles (in degrees) taken from the orbit plane and direction of flight as reference. You can think of the satellite to fly like an airplane with its nose in direction of flight and its bottom pointing to the center of the Earth. First Yaw (move to the left or right; positive if right), then Pitch (move the nose up or down; positive if up) to point toward the new direction. The angles must be given in degrees. Thus to point toward the center of the Earth (or the sub-satellite position) use a Yaw of 0° and a Pitch of -90°. A Yaw of -90° and a Pitch of 0° points out of the orbit plane toward the positive angular momentum vector. (If this direction is used at the Ascending Node of the orbit it would increase the inclination of the orbit plane.) Specify both yaw and pitch as `0` if you just want to increase or decrease the speed along the velocity vector; this is probably what you want to do most often.

Press `Execute` to perform the maneuver.

If the delta-v maneuver resulted in a hyperbolic escape trajectory a respective message will be displayed.

Hint: Performing a maneuver with a `0` delta-v will result in the orbit elements to be recalculated to the epoch at which this maneuver was executed (with the date and time that was specified for it). This can sometimes be useful. For instance if you got the news that a nearly circular orbit was increased by 1.5 km you would not need to recreate the maneuver exactly (the details of which you might not learn of if you are not in the respective control center) but merely perform a `0` delta-v at the approximate time and after that manually edit the semi-major axis (to increase it by `1.5`) with the `Edit Orbit Elements` option. This would give you a sufficiently accurate orbit to work with until updated orbit elements are made available. This method would also work for some quick mission planning.

For numerically propagated orbits you have the additional choice to specify continuous thrust in mm/s^2. The direction is as specified above (yaw, pitch). Just mark the `Continous Thrust` checkbox. This continuous thrust will be active until this checkbox is de-activated. You can also mark the `Sunshine Required` checkbox if the continuous thrust only operates while the spacecraft is in sunshine (e.g. for solar electric propulsion). Typical values for solar electric propulsion would be from 0.1 to a few mm/s^2. Mark the `Update Epoch State` checkbox if the Epoch State Vector is to be updated after each integration step. This can be useful if you want to follow the change in osculating Keplerian elements by looking in the Edit Orbit Elements dialog from time to time (you otherwise would see the elements at their original epoch). On the other hand you might want to be able to go back to the original state vector at epoch and repeat the calculation with some new settings. In this case you would leave the `Update Epoch State` checkbox unmarked.

Note: If the program was in R/T map display mode the Real Time clock will be stopped before the delta-v maneuver is being done and a refresh of the World Map (which then appears blank of satellites).

9.3 Launch Orbit

SatCal allows the calculation of an approximate launch orbit if the launch site, date and inclination and height are known.

Select Maneuver, then Launch or press the L key. There is no icon for this feature. A satellite does not have to be selected beforehand as this command will allow you to generate suitable orbit elements. If satellites were already selected the Launch Orbit option will overwrite the current Prime Satellite orbit elements but leave the other satellites unchanged. (If you want to keep the current prime satellite you can add a new satellite in the Edit Orbit Elements dialog, see section 9.6.)

First the Date/Time dialog box appears. Enter the date, time and timezone of the launch. The entry for duration will be ignored.

Next comes the Edit Orbit Elements dialog box (see section 9.1). Here you should enter the satellite name, eccentricity, inclination, Mean Motion (or semi-major axis) and ndot (or adot). (Instead of the eccentricity, mean motion and semi-major axis you can alternatively enter the height of perigee and apogee.) Epoch, Right Ascension, Argument of Perigee and Mean Anomaly will be ignored and actually calculated to suit the launch data. Note that the (magnitude of the) inclination should be at least as large as the geographic latitude as the simplified calculation used by SatCal does not consider any "tricky" ascent maneuvers sometimes employed in actual launches.

Finally comes the Launch dialog box. You may select a pre-defined launch site via the combo box or (if User is selected) you can specify the coordinates of the launch site manually (latitude and longitude in decimal degrees). t cutoff is the time needed (in minutes) from liftoff to orbit insertion. A continuous burn is assumed. (It might be necessary to specify a shorter time as the actual one to get better results on occasion. This is particularly true for long burn times where the major thrust was at the beginning and the longer remaining part is at a much lower thrust.) Typical times for a Shuttle or the ShenZhou are 8.9 min or for a Soyus launch 8.7 min. Try something like 26 min for launches of Delta rockets into sun-synchronous orbits or 34 min for GTO's by Ariane (even though the actual burn time would be much longer due to upper stages). Launches with refurbished ICBM rockets like the Cosmos seem to go best with a smaller cutoff time of 6.6 min or so. You also have to specify whether the launch azimuth is in a northerly or southerly direction by checking the right button in the Launch Azimuth Group Box. Launches from Baikonur and from the Kennedy Space Center will almost always be toward the North (or exactly toward the East in which case either North or South could be selected). Satellite launches from Vandenberg are toward the South as are most launches from Chinese sites. A general rule (also applicable to the other launch sites) is that you try to launch away from populated land areas.

Press OK to calculate an approximate launch orbit. A message will appear giving you the launch azimuth for that orbit.

Note: The launch calculation done by SatCal gives only an approximate orbit. To be any more accurate SatCal would need to know a lot more details about the launch sequence etc. which may be hard to come by anyway. The kind of calculation performed can, however, be useful for some preliminary mission planning and most importantly to check about visibility conditions for the first few orbits after launch when accurate orbit elements might not yet be available over the Internet. After a day or so these preliminary orbit elements are typically wrong by several minutes and there would also be some cross range deviations depending on how accurate the mean motion (or semi-major axis) in particular had been specified. But by that time accurate data are usually available on the Internet (or you might even be able to update the data with your own sightings). The SatCal launch calculation assumes that the launch takes place directly into the specified inclination (orbit plane). On occasion launches would start out with a different plane and then change the plane later in the flight. If you know the flight plan you could calculate that with a corresponding launch orbit and delta-v maneuver. (Otherwise the SatCal launch calculation would be off considerably in this case).

Note: The following Cutoff values might be reasonable to use for specific launches: Shuttle (KSC, North) 8.9 min; Soyus (Baikonur, North) 8.7 min; Shen-Zhou (Jiuaquan, South) 8.9 min; Delta II (Vandenberg, South) 26 min; Ariane 5 (Kourou, North for sun-synchronous orbits, South for GTO) 34 min; Cosmos 3M (Plesetsk, North) 6.6 min; Tanegashima (South for sun-synchronous orbits) 14 min. But it is best if you have data from a previous similar launch which you can use to check out.

Note: The calculated launch orbit is valid only after orbit insertion (engine cutoff). This is why the orbit appears to be extended backwards over the launch site if you look at the groundtrack at the time of liftoff. SatCal assumes a flight angle of 0° at insertion (which results in the position of perigee at that point). Some launches will have a flight angle greater than 0 in which case the actual position of perigee is moved backwards. As SatCal doesn't know the flight angle at insertion the calculated launch orbit would deviate more or less from the actual one. If you have small eccentricities you might get better results by simply assuming a circular orbit of mean altitude. You will find that some orbits come out quite well while others really cannot be properly done by the simple SatCal procedure.

Note: SatCal assumes that the launch takes place directly into the intended orbit plane. This is not always the case. For example a launch from Tanegashima, Japan, into a sun-synchronous polar orbit will first move out to the South-East for a few degrees of longitude before turning South. This costs more fuel but is necessary due to range safety reasons. (You could model this with SatCal by changing the longitude of the launch site some 5 degrees to the East and also using a launch time some three minutes later than the actual one.)

Note: If the program was in R/T map display mode the Real Time clock will be stopped before the launch orbit determination is being done and a refresh of the World Map (which then appears blank of satellites).

9.4 Rendezvous Launch Orbits

SatCal provides a way to calculate the time of launch of a satellite which is to rendezvous with a target satellite like the Shuttle or Soyus fly to the ISS. The target satellite must have been selected (and be the Prime Satellite). Now select `Maneuver`, then `Rendezvous`. First the `Time until close approach (in days)` must be specified. Keep the default of `1.30` for Shuttle or Soyus launches to the ISS even if the actual rendezvous takes place after about two days. The final half day or so is needed for close approach maneuvers when the orbits don't differ too much anymore. (But if you want to launch into a pre-existing orbit plane with the proper altitude already just set this time to 0.) SatCal now performs the Launch Orbit calculation as just explained above under 9.3. You only have to specify the date of the launch. SatCal tries to come up with an appopriate launch time. The orbit elements of the target satellite have been copied to the launch set. You would want to change the name, of course but otherwise leave the orbit elements as they are except that the height of the new satellite should now be set lower than the target satellite to be able to catch up with it. How much lower depends on the relative positions at the time of launch. (Typical values for launches to the ISS might be 200 - 250 km) It may be necessary to try two or three different heights. In this very simplified calculation SatCal assumes that the chasing satellite stays in this lower orbit until the specified time of close approach and then instantly is placed into the higher orbit of the target. In reality a number of orbit maneuvers are performed throughout the two days in order to come ever closer. So use your own judgement on how to best approximate reality with this method. At the end of the calculation SatCal displays the respective launch time.

9.5 Generating Geostationary Orbits

To generate a geostationary orbit, press the `GEO` button in the Edit Orbit Elements dialog and enter the geographic longitude of the satellite. SatCal will then calculate corresponding orbit elements. The SGP4 option will be deactivated in this case. Likewise a numeric propagation model would have been de-selected (you can go back to numeric propagation by first leaving the Edit Orbit Elements dialog, then re-entering it and marking the `Numeric Prop` checkbox).Note that actual geostationary satellites perform small movements about their nominal position (which SatCal assumes in this case) but typically will stay within a deadband of 0.1° or better of that position.

9.6 Adding a New Satellite

To define a new satellite press the `New` button in the Edit Orbit Elements dialog. If the number of currently selected satellites is less than 10 the new satellite will be added to the current list; otherwise it will overwrite the last entry. You will get a set of blank elements which you can then fill in correspondinly.

9.7 Adjusting Orbit Elements of Older TLE Files

If TLE files are older than a month or so they often become too inaccurate for further use. SatCal provides a way in which certain orbit elements can be used a lot longer. This works in particular for satellite constellations in which the relative positions of satellites remain fixed (like the Iridium system). Press the

`Adjust` button and mark `Activate Adjustment`. If the TLE file is less than 3 months old this may be all that is needed. What actually happens in this case is that any satellites now being selected will automatically switch from the SGP4 model to the simple orbit model (stangely enough, even though the SGP4 model is more elaborate and supposed to give better results this is only the case over a few days after the epoch. For calculations which are much further away from the epoch the simple model often performs better). Also the adot, ndot and n2dot parameters are set 0 (so the orbit is assumed not to decay which will be the case if the orbit is maintained).

For still older files you may have to set the `Set Mean Motion` field to a typical value for the particular constellation (like `14.342173` for Iridium satellites). Any satellites now being selected will have this value substituted for their Mean Motion. The rationale behind this is that the satellites of a given constellation should maintain their relative positions which is ensured by this measure. In case of the Iridium constellation this seems to allow for Iridium Flare prediction from TLE files which are up to a year old. (But make sure you use the `Operational Orbits Only` option when calculating Iridium Flares this way because otherwise those satellites in wrong orbits would get their mean motion adjusted in the same way and this most certainly leeds to erroneous predictions.)

As an additional measure you can adjust the epoch. If (for instance by observing particular satellites from a constellation) you find out that they are on average earlier or later than predicted you can adjust that via the `Adjust Epoch` field. As a last resort you can also adjust the Right Ascension but you normally leave this field `0`. Typically after a year or so there will be changes to a constellation (satellites drop out, new satellites are added). Eventually you simply do need a fresh TLE file.

Note that this system will NOT work for quickly decaying satellites for which there is no orbit maintenance.

Note also that satellites already selected are not affected by this option as are four line orbit elements for numeric propagation.

9.8 Using the SDP4 Code

To calculate orbits via the TLEs Spacetrack has outlined a procedure and issued some recommended code. For orbits of period less than 225 minutes (low orbits) an analytic model called SGP4 should be used but for longer period orbits a semi-analytic model called SDP4 is recommended. Due to some deficiencies in the original SDP4 code some SatCal versions earlier than version 9.8 had switched off the SDP4 part per default. But SatCal Version 9.8 contains a significantly improved code and is using SDP4 for high orbits as recommended.

However, if you do not want to use the SDP4 code for high orbits (which could be the case if the TLEs have been created by someone other than Spacetrack which use just the standard SGP model) you can de-activate it by clicking the `Adjust` button in the Edit Orbit Elements dialog and then unmark the `Use SDP4 model` checkbox. As long as this checkbox is marked the SDP4 model will be used for long period orbits of all currently selected satellites for which the SGP4 model has been marked.

9.9 Use of WGS84 Constants

The SGP4 model as presently defined uses WGS72 constants. This is the default in SatCal. If at some time TLEs were generated by using the more modern WGS84 constants you can have SatCal use those constants in the SGP4 model by clicking the `Adjust` button in the Edit Orbit Elements dialog and then mark the `Use WGS84 constants for SGP4 model` checkbox. Note that the changes are usually much less than the precision of the TLEs. The numerical integration procedures by SatCal always use the WGS84 constants.

10 Orbit Determination

10.1 Orbit Determination

A satellite does not have to be selected beforehand as this command will allow you to generate suitable orbit elements.

SatCal performs a simplified orbit determination for the special case of a circular orbit. The minimum height of the orbit must be 100 km. It is assumed that a single observer took two different relative positions of the satellite during a pass. The coordinates of the observer are those already entered as the observing site (If those data do not agree with the observer's position you first have to change them with the Input of Observing Site option, see section 3.5).

To start the Orbit Determination procedure select `Maneuver`, then `Orbit Determination`. There is no icon for this option.

First to appear is the dialog box to enter the date, time and timezone of the first position. (The Duration parameter will be ignored). Press `OK`.

Next appears the Orbit Determination dialog box. Here you enter the azimuth and elevation (in decimal degrees) of the first and the second observation and the time difference (in seconds) between the two observations. If instead of azimuth and elevation the positions are given in apparent Right Ascension (in HH.MMSS format) and Declination (in DD.MMSS format) enter those numbers and check the respective checkboxes on the right. (To enter a Right Ascension of 12h15m33s enter `12.1533`, to enter a declination of -31°45′12" enter `-31.4512`). (It is possible to have one of the observations in azimuth/elevation and the other one in Right Ascension / Declination.) The longer the arc and the more accurate the data (in particular the time difference) the better the resulting orbit elements will be. Dummy values will result if the time difference is 0.

Now press `OK`. Finally the Edit Orbit Element dialog box appears. This is the same one as explained in section 9.1 and serves to show the result of the orbit determination. The name `New` will be displayed as the satellite name if the orbit determination was successful, otherwise the text `No Convergence` will appear instead. While still in the Edit Orbit Element dialog box you can of course edit any of the fields as usual. In particular you probably might want to change the satellite name and might also specify ndot or adot parameters. Note that the eccentricity and the mean anomaly of the orbit are set to 0 to define the circular orbit.

If you want to interchange the two observation positions (if you have a picture of a satellite trail you may not know whether the satellite was moving right to left or the other way around) you can click the `Reverse` button.

If you have a picture of satellite trails loaded (see section 11) you can select the last two positions marked on the picture by clicking the `Picture` button.

SatCal will try to find matching satellites in addition to calculating an orbit if the the `Match Satellite` checkbox is marked. This will be according to the options set in the `Find Matching Satellites` option (see section 10.2 below).

Note: The results of the orbit determination will only be meaningful if the satellite was in a near circular orbit. If, for instance, the two observations were done close to perigee of a highly eccentric orbit a completely irrelevant orbit would result. So be apprehensive of the data! The inclination and the semi-major axis (or height) of the satellite will often indicate what kind of satellite it was (and who launched it).

Note: If the program was in R/T map display mode the Real Time clock will be stopped before the orbit determination is being done and a refresh of the World Map (which then appears blank of satellites).

10.2 Finding Matching Satellites

This feature has different applications. The most obvious one is that if an observer sees a satellite at a particular position and time in the sky, SatCal can try to find matching satellites from the current TLE file. The coordinates of the observer are those already entered (see section 3.5).

To initiate the search select `Calculate`, then `Find Matching Sats` or click the `Find Matching Satellites` icon. First to appear is the Date and Time Dialog box where you enter the date, time and timezone of the event. (The Duration parameter will be ignored). Then press `OK`.

Next appears the Search Matching Satellites dialog box. The target direction in the sky can be entered either as azimuth and elevation (in decimal degrees) or in apparent Right Ascension (in HH.MMSS) and Declination (in DD.MMSS) if the the respective checkbox on the right has been marked. The parameter `Max.Distance` gives the maximum angular distance (in degrees) the calculated satellite position can have from the given target. As an example, assumed you saw a satellite pass within about a degree of the Orion Nebula (R.A. 5h35m, Decl. -5°30'). Mark the `Position as R.A./Dec` checkbox (this is actually the default) and enter `5.35` as Right Ascension and `-5.30` as Declination. You could set `Max.Distance` to `2` degrees to allow for some uncertainity in the satellite's orbit (and maybe your own observation).

You can include the direction of movement of the satellite as an additional constraint. To do so mark the `Direction Search` checkbox and enter the position angle of the movement (in degrees) in the direction box. This position angle is the direction of movement as viewed by the observer facing the satellite. Thus a movement to the right would be 90° , toward the left -90° and 45° would indicate movement to the upper right etc. The satellite has to move into a direction within 45° deg of the specified one to be accepted (this seems to be very coarse but it helps to weed out a satellite moving in the opposite direction or at a right angle to the desired one). If the target search area includes the zenith this direction will be ignored to avoid any confusion about left and right, up and down which otherwise might occur in this situation.

Finally, the time interval of the search in minutes has to be given. SatCal will search within plus/minus that interval around the specified time. If you got the time of your observation exactly then 1 minute might be a good value (and would get you quickly through the search). But if the orbit elements on the TLE file are very old or if you are looking into rapidly decaying orbits larger intervals from a few minutes up to half an hour or so might be appropriate (in that case you should also allow for a larger `Max.Distance` radius - but it will take longer for SatCal to do the search in this case).

If you use the ALL_TLE file from SatTrack which presently contains some 14000+ objects you might get matches from a number of small (debris) objects in addition to what you have actually seen. To weed out these dim objects you can mark the the `Brighter Objects Only` checkbox. This will cause objects with an International Launch Designation ending with letter F or higher as well as objects in high orbits to be ignored as these will typically be observable only with larger telescopes (but there are exceptions!).

Press `OK` to start the search. Any matching satellites found will be listed together with their NORAD number, International Launch Designation, name, inclination, perigee and apogee. Also given will be the total number of satellites searched and the number of possible matches. Note that a maximum number of 50 matches can be displayed due to buffer limitations. (A respective message will appear if that number has been reached.)

Originally selected satellites will remain selected but if there is enough space (up to a maximum of ten) matching satellites found will be added to the list and can be used afterwards. (To have an empty list to start with you could first perform a `Select Satellite` command, then `New Set` before you call the Matching Satellites option.)

Other uses of the Find Matching Satellites option are for instance the possibility to check beforehand whether a satellite might pass the field of view of a picture to be taken of a deep sky object. In this case the Right Ascension and Declination will be those of the deep sky object and the Max.Distance will be the field of view. The time interval would correspond to the length of the exposure. Of course, you would have to check the TLE master list which is excessive to be sure that no artificial objects are passing your picture. But the `VISUAL.TXT` file (available under celestrak.com, see 12. below for the internet sites) which list the 100 or so brightest objects (actually more like 150 objects) might be enough to warn you of some of the most disturbing objects. Another use could be the sighting of a satellite burning up in the atmosphere. In this case you could check the orbit elements of the a TLE file which list decaying objects. Due to the uncertainity of decaying orbits you should allow for a generous margin in the search area and the time interval.

Note: If you marked the `Position as R.A./Dec` checkbox and the time interval of the search is larger than 2 minutes the search area will be updated for every minute to keep moving with the sky target. If you specified azimuth and elevation instead the search area will remain fixed within the horizontal system.

Note: The Visibility settings Maximum Sun Elevation, Minimum Satellite Elevation and Visible Passes Only (see section 7.2) will remain active. Satellites will have to comply with these settings before being considered for matching.

Note: The Finding Matching Satellite option will search even a large TLE file in a fairly short time if the time interval stays within a few minutes. But the time needed will quickly grow larger if you increase that interval. So make a few test on your own computer to find out how far you want to push the limits!

Note: In the unlikely case that you use a TLE file with just the two lines per entry (instead of the three lines including the satellite's name) you must mark the `Select Int.Launch#` or the `Select NORAD#` checkbox in the Select Satellite dialog box. (See also section 3.1)

Note: The `VISUAL.TXT` file lists just some 150 objects or so. A number of times I have been able to identify satellites via this file but more often I didn't. You would have to work with the ALL_TLE master list (some 2 MByte at the moment) and also have the data of some of the military satellites for which elements are not officially available to have an (almost) 100% success rate. So try to be a good sport!

11 Sky Picture Astrometry

SatCal provides a simple astrometry function to investigate photographs with satellite trails.

11.1 Loading and Initializing Pictures

Select `File`, then `Picture` to enter the Open Picture dialog. A number of different image formats are being supported (not just the PNG, JPG and BMP mentioned specifically). Select the respective picture file. The image will be displayed. To return to the Map Display select `View`, then unmark the `Show Picture` checkbox. Marking this checkbox will get you back to the image display. To switch between the Picture Display and the Text Display press `X`.

You can have the image displayed at 50% or 25% of its original size or return to the normal size by selecting `View`, then `Set Picture Size 50%` or `Set Picture Size 25%` or `Normal Size`.

Once an image has been loaded SatCal has to know which part of the sky it shows. For this you have to select three stars as reference stars by clicking with the mouse on them. You will be asked to enter the respective coordinates as Right Ascension (in HH.MMSS) and Declination (in DD.MMSS). Press `OK` to store the coordinates. If you press `Abort` the initialization will be aborted and all the reference coordinates deleted. The reference stars should cover the area of interest of your picture. The geometric distortions present in any imaging system (and especially in wide angle photographs) will otherwise skew your results significantly.

Note that the reference gets lost if the image is resized. But you can quickly re-initialize the picture by clicking at the same reference stars in the same sequence as before because SatCal has remembered those coordinates and displays them for you to accept (or to change if you made a mistake!).

Note: On some Windows systems problems were encountered to directly load JPG files. If that happens you should convert the JPG image into a PNG format with an image processing program and load the PNG file instead. (I haven't been able to figure out why this problems occurs as everything runs correctly on my own Windows system and under Linux.)

11.2 Satellite Trail Astrometry

Once the loaded sky picture has been initialized as explained above clicking on any part of the image will display the respective coordinates. The last two coordinates will be remembered. Thus after clicking on the endpoints of a satellite trail in the picture you can then go to the Orbit Determination routine by selecting `Maneuver`, then `Orbit Determination`. (You must have set the geographic coordinates of the location where the picture was taken.) As explained in section 10.1 you can select these last two positions marked on the picture by clicking the `Picture` button and then proceed to get a circular orbit fitting the trail as well as checking for matching satellites. You may have to repeat this procedure by checking the reverse direction if you don't know how the satellite was moving. The determined satellite as well as found matches will be selected (up to 10 satellites). By using the right and left arrow keys you can see how those objects move across your picture just as they would move across the normal map display. The time will be displayed as well as the sky coordinates and name of the selected prime satellite. If the `Show Names` checkbox has been marked in the View menu the names of the satellites will be displayed next to their postions. You typically want to set the time step to 1 sec to avoid the satellites jumping too fast across the picture. You can now see how well the movement of the different objects match the trail on the image. Note however that you need fairly recent orbit elements to avoid large deviations.

If you know up front which satellite it is you don't need the orbit determination routine but can load the satellite elements directly as usual and then display its movement over the picture right away. This could be particularly useful if you observe flares. If you have marked the Local Attitude Flare option in the Visibility Dialog but unmarked the Known Surface checkbox (see section 7.5) the respective Pitch and Yaw angles of a surface which would cause a flare at that position will be displayed. You can cross-check this directly with the brightness of the satellite trail and the respective position on the image.

On non-tracked images the displayed movement of the satellite might be slightly tilted against the shown trail due to the movement of the sky during the exposure.

Note: If you were looking for matching satellites the settings used by the Matching Satellites Dialog will determine what is being looked at. The default setting of the maximum distance of 2 degrees is a good value for many pictures. But if you have a long focal length with a narrow field of view a value of 1 degree might be better. For very wide angle pictures with larger image distortions it is preferable to set a larger angle (maybe of 4 degrees) to allow for some margin of error. If you have set the Brighter Objects Only option only those objects will be considered.

12 Saving Data on File

12.1 Standard Save

Select `File`, then `Save` or press the `Save File` Icon to write the table of visibility times to the currently selected save file. The default for this file is `SATSAVE.TXT` and it will be placed in the same directory as the selected TLE file. A confirmation will be given for each file save.

Consecutive saves will be appended to the same file. Note that the contact time calculations will be re-done for the file save and this may cause a short delay before SatCal is ready to continue, particularly if a long duration was specified.

If `Occultation/Transit` or `Flares with known surface` options were selected (see sections 7.4 and 7.5) a dialog box appears asking for specification of a distance (default 50km). Exiting this dialog with `OK` will cause a calculation of such events for the selected Prime Satellite if they fall within the specified distance of the observation site. Exiting with `Cancel` will skip this calculation.

If the `Iridium Flares` option was selected a list of Iridium flares will be written on the file (see section 4.4 for details).

To view or print the information on the Save File, open this file with a text editor. To get the tables right you may have to select a particular font, like `COURIER NEW`.

12.2 Changing the Name of the Save File

To change the name of the save file select `File`, then `Save As`. If you enter a filename which already exists you will get a message and be asked whether you want to overwrite the existing file. A standard `Save` will be performed automatically after this call.

12.3 Saving the Pass Details Information

Pressing the `Save` button in the Pass Details window will write the information to the standard Save File in a standard format. Alternatively you can copy this information to the clipboard and then paste it into a text file using the following procedure: Move the mouse to the Pass Details Window and click the right mouse button. Select `All`, then `Copy`. You can now paste the contents of the clipboard into a text file. In this case the format is as it appears in the Pass Details window. (Alternatively you may press the Windows Document key if you have one.) Note that this method can also be used for the central line of Transits and Flares as this will also be shown in the Pass Details Window if the respective option has been set.

12.4 Saving the Map on file

The Save File option does not save the information from the map. To do so use any screenshot program or procedure available on your system.

12.5 Saving Orbit Elements

Select `File`, then `Save Orbit Elements`. The orbit elements of the selected satellites (up to 10) will be written in TLE format on the TLE Save File. The default for this file is `SATCAL.TLE` and it will be placed in the same directory as the current TLE file. A confirmation will be given for each file save. A warning will be given and nothing written if no satellites have been selected.

Consecutive TLE saves will be appended to the same file unless the file name is changed (see below under 12.6).

If Numeric Propagation was selected for a particular satellite the state vector and associated information needed for the numeric integration will be saved in a special format of four rather than two lines. (This is a SatCal-specific format and not the sometimes used Four-Line Elements. See Appendix A.3.) SatCal will read this information correspondingly just like it does with the usual TLE format when satellites are selected.

12.6 Changing the Name of the TLE Save File

To change the name of the TLE Save File select `File`, then `Save TLE File As`. If you enter a filename which already exists the old file will be overwriten. If successful, the orbit elements of the currently selected satellites will be written on this new save file. Note that the name of the TLE Save File will not be saved on exiting SatCal. When starting SatCal you always will find the default name `SATCAL.TLE`.

NOTE: The TLE files saved by SatCal are primarily ment for re-use by SatCal. Those orbit elements which were read from another TLE-file and not edited but just copied would be alright to be used with other programs but if you edited any elements in a way which is not compatible with the NORAD mean elements you might get poor results with other programs. When saving TLE's SatCal will place a `9` into the position of the model for those element sets which were marked to be used with the simple orbit model and will use a `0` for the SGP4 Model. Hyperbolic orbits will always be marked with a `9` as the classical two-line elements are only defined for elliptic orbits. Numeric orbits are saved in a SatCal-specific format. See Appendix A.3.

12.7 Online Update of TLE Files

To update the currently selected TLE file via the Internet you must be logged in. Select `File`, then `Online TLE Update` or press `<ctrl> + I`. A dialog appears where you must specify the URL (web address) of the update file to be downloaded. SatCal will automatically suggest the currently selected TLE file which it appends to the currently active URL base address (the default is `www.celectrak.com/NORAD/elements/` which is where you will find the `visual.txt` and `iridium.txt` files among others. (Whatever base address you last specified will be saved upon exit so that you can use your favorite choice the next time around.) If you specify the URL of a file which does not yet exist in the current directory it will be downloaded as a new file otherwise the existing file will be overwritten. If you press `Cancel` at this URL dialog the download is aborted and the existing file kept as is. Note that the download is done asynchronously. You can continue to work with SatCal while the update is in progress except use the very file which is updated. A message is displayed when the update is finished.

Only one file can be updated at any one time. After the message about the completed download appears you can select a new TLE file and then repeat the procedure to update this file also. Alternatively you can directly specify the new filename in the URL dialog.

Note that satellites already loaded by SatCal will not automatically be reloaded with the new updated orbit elements. You would have to select them anew to get the updated elements. So it is best to perform the update before you select the respective satellites. You do not have to update TLE files each time you use SatCal. Typically the file `visual.txt` needs an update once a week or so and the `iridium.txt` file can often be used for almost a month. Of course you might prefer to perform the download of the TLE file using your favorite web browser instead of using the SatCal option. You should do this every now and then anyway as there might be important messages about the availability or changes of the respective website.

NOTE: The SatCal TLE Online Update might not work if you are connected to the Internet via a proxy server (it probably depends on the settings of this server). In this case you will have to use a web browser to copy the needed files. You also might run into problems if you try to retrieve files from a site for which you need a specific access password.

13 Numeric Orbit Propagation

13.1 Activating Numeric Propagation

Apart from the simple Keplerian or the SGP4 analytic model SatCal offers a numeric orbit propagation. All SatCal functions operate in the same way independent of the orbit calculation selected. You can switch from one model to the other at any time. Note however that when switching from a numeric propagation to the analytical models you will continue with mean SGP4 elements if the SGP4 model was selected, otherwise with osculating elements. One reason to use the numeric propagation is that you can calculate a few things you cannot do analytically like continuous thrust solar electric propulsion or de-orbiting. Or you might want to check the influence that the Moon has on a particular orbit. Another reason is that the numerical calculation done by SatCal can be about a factor of 10 more accurate than the SGP4 model. But to be more accurate you need to specify a correspondingly accurate state vector. Just taking the TLE's of a satellite and switching to numeric propagation does not give you a more accurate calculation because the TLE's are mean elements supposed to be used with the SGP4 model.

To select numeric orbit propagation go to the Edit Orbit Elements dialog. Select `Maneuver`, then `Edit Orbit Elements` (or click the respective icon or press `E`) then mark the `Numeric Prop` checkbox.

If you had done an analytic calculation up to that point SatCal will now continue the calculation numerically (and vice versa if you unmark the `Numeric Prop` checkbox). In many cases however you don't want to numerically continue an analytic calculation but rather start with a given state vector right away. In this case you press the `State Vec` button within the Edit Orbit Elements dialog and enter the state vector and additional information (see below under 9.2).

The step for the numeric integration is the same as the one specified via View, Time Step. SatCal uses a variable step width integration so the actual step can be partitioned into smaller steps to stay within the specified tolerance but this is transparent to the user. If you jump in time SatCal will try a larger step size up to a maximum of 20 minutes.

If the altitude drops to 0 (the satellite reaching the ground) the movement of the satellite will be together with the Earth rotation, so its geographic coordinates don't change anymore. At this stage you can not reverse the integration to an earlier time.

Depending on the accuracy you need you may want to specify the IERS parameters manually (select `Input`, `IERS Parameters`, then unmark the `Use Defaults` checkbox as explained in section 3.6. Note that these parameters act on all the currently selected satellites (numeric or not).

Although the numeric propagation puts a heavier load on your computer you normally will not realize a difference given the speed in today's computers. Only when you jump over a larger time interval will there be an appreciable delay until you see the result. You will find out quickly about that once you start trying.

13.2 Editing the State Vector

Editing the state vector but also the parameters needed by the force models is done in the State Vector dialog (select `State Vec` while in the Edit Orbit Elements dialog). The `Numeric Prop` checkbox must be marked if you want to edit the force model parameters.

The epoch can be entered into the `Year` and `Day of Year` fields or via `Edit Time`. If you need fraction of seconds you must enter it in the Day of Year / Fraction of Day field as the Edit Time dialog allows only full .seconds.

The state vector can be entered in `True-of-Date`, `Mean-of-Date`, `J2000` or `Earth Fixed` coordinates. Mark the corresponding button. Note that when you mark the respective epoch button the state vector that has been entered will be converted correspondingly. To prevent this temporarily unmark the `Reset Current State Vector` checkbox before marking the new epoch button.

For satellites with an altitude of < 2500km atmospheric drag will be calculated. For the density SatCal needs the `F10.7` (90 day) average and the daily solar flux (in units of 1E4 Jy. If you don't know the daily flux but only the average you could set the daily flux to the same value as the average). Also needed is the Geomagnetic `Kp` index. One of a number of websites from where to get these data is:

```
www.sec.noaa.gov/ftpdir/latest/RSGA.txt
```

The F10.7 3-month average and daily flux numbers are directly on this page. But instead of the Kp index the page list the geomagnetic Ap index. The following shows the relation between the two:

Ap:	0	4	7	15	27	48	80	132	207	400
Kp:	0	1	2	3	4	5	6	7	8	9

Also needed for the drag calculation is the `Drag Coefficient` Cd and the `Area/Mass` ratio.

To calculate solar radiation pressure the `Radiation Pressure Coefficient` Cr is needed (and also the Area/Mass ratio).

Normally upon exiting the State Vector dialog the epoch state vector will be updated correspondingly. If you do not want this unmark the `Reset Current State Vector` checkbox. This can make sense if you want to change only one of the parameters (like the Kp index) in the course of a propagation but leave the original epoch as is. You can always return to the origial state vector by going back to the epoch time. (To do so the difference to the last displayed time and the epoch must be > 20 minutes. Note that even while the state vector is reset the F10.7, Kp, Cd, Cr and A/m parameters are kept as they are.)

Note: There are different atmospheric density models in use. If you find a Cd value and Area/Mass given for some state vector of a Low Earth Orbit satellite it may have been to fit a particular density model. Sometimes changing these values slightly might give you a more accurate result with the SatCal force model.

13.3 Configure System Parameters

This mostly applies to numeric orbit propagation (with two exceptions).

Select `Settings`, then `Configure System`.

You normally leave all the values in the Configure System Parameter dialog as they are.

The `Relative Tolerance for Numeric Integration` will influence the accuracy of the integration. A smaller tolerance will lead to a more accurate calculation but will force smaller integration steps and a higher processing time. But there is a limit to how small a tolerance would make sense before the increased number of steps will lead to larger errors again.

The `Maximum Number of Iterations` limits individual integration steps to that number of iterations to find a step size in line with the specified tolerance. This prevents a nearly endless loop if for some reason the system is poorly conditioned. Set this number to 0 if you don't want the number of iterations to be limited so that the integration will always respect the tolerance. The default maximum number of 20 usually provides more than enough margin for any sensible problem.

The `Lift/Drag Ratio` is used for calculating the lift by multiplying this value with the Drag coefficient. This is done only for numeric orbit calculations if the altitude is less than 90 km - typically for reentry.

The three Space Weather parameters (the F10.7 average and daily flux as well as the geomagnetic Kp index) and and the three spacecraft parameters (Cd, Cr and A/m) mentioned above (13.2) can be preset here. When you define a new state vector these will be the default values used until you edit them for an individual satellite via the State Vector dialog. These values will be saved when exiting SatCal. Setting these values here can be useful if you the spacecraft you are dealing with have similar characteristics or if the solar activity at the time of interest is high or low.

You can switch off the solar and lunar perturbations by unmarking the respective checkboxes. This only makes sense if you want to check the influence of these perturbations on a specific orbit. You normally always keep these checkboxes marked!

The elevation of a satellite as seen from the specified observation site will be corrected for a standard atmospheric refraction. If you don't want that unmark the `Refraction` checkbox. This can be useful if you prefer to do your own corrections (because of very different atmospheric conditions or so). This item affects all satellites numeric or not.

When calculating magnitudes a standard correction for atmospheric extinction is being performed for elevations < 33°. If you don't want this correction to be done unmark the `Extinction` checkbox. This item affects all satellites numeric or not.

13.4 Numeric Propagation Internals

SatCal uses a variable step width RKF4(5) integration. The force model used by SatCal uses gravity field harmonics up to order 20 (depending on the altitude of the satellite), a modified Jacchia 71 atmospheric density model, solar radiation pressure and the Sun and Moon. Below an altitude of 90 km the density of the atmosphere is extended in a simple exponential way and lift will also be considered (the default lift coefficient 0.15 times the drag coefficient unless changed in the Configure System Parameters dialog). This allows a (very simple) reentry calculation.

Two copies of the state vector are kept: The state vector at epoch and the (running) current state vector. But only one set of additional parameters (solar flux, drag coefficient etc.) is kept. The state vector at epoch is the one shown during the state vector edit and it is also the one being saved on a file if you save the orbit elements. Should you load a set of (numeric) orbit elements from a save file and directly proceed to a time which is very different from the epoch you will experience a delay (which can last a while) until the propagation reaches the desired time. If you jump in time by more than 20 minutes SatCal will check whether the running state vector or the epoch state vector are closer in time and whichever is closest will be used in the calculation. (As a consequence do not use a time step of more than 20 minutes when using continuous thrust without also updating the state vector automatically - see section 9.2.)

If you leave the State Vector dialog a corrsponding set of Keplerian elements is kept so that you can switch to an analytic model (and vice versa when loading TLE's a corresponding state vector will be kept). The adot, ndot or BSTAR parameters however will not be changed by SatCal in this case.

14 References / Internet Sites

The calculation of Sun with a reasonably high precision suitable for use in PCs, coordinate conversions and many other userful algorithms are covered in

O.Montebruck and T.Pfleger, "Astronomy with a PC", Springer Verlag, Berlin, Heidelberg, New York, 1989 (newer version available now). This book also contains a good formula for the delta TDT - UT calculation (implicit in some of the calculation done by SatCal).

For an excellent introduction into the (numeric) calculation of satellite orbits the following book is highly recommended:

O.Montebruck and E.Gill, “Satellite Orbits”, Springer Verlag, Berlin, Heidelberg, New York, 2001. This book deals with all aspects in a very clear and accurate way.

Another useful book is the Explanatory Supplement to the Astronomical Almanac, University Science Books, Mill Valley, California, 1992

A good introduction to orbital mechanics is Roger Bate, Donald Mueller, Jerry White, "Fundamentals of Astrodynamics", Dover Publications, New York, 1971.

An excellent introduction into numerical calculus is J.M.A. Danby, “Computer Modeling from Sports to Spaceflight ... From Order to Chaos”, Willman Bell, Richmond, Virginia, 1997.

The following Internet site offers fresh orbital elements and also some explanations:
`http://www.celestrak.com`
(TLE Page ordered in different categories)
This site contains current (and also historic) TLE elements sorted into different satellite categories. The most useful one is probably the `100 or so Brightest` which can be downloaded as the file `VISUAL.TXT`. There are other useful categories as you can discover. At the time of this writing this site is fully operational but it might close down sometime in the future due to new US Government regulations. You will find advice there on how to proceed. It is suggested to obtain a SpaceTrack account (`http://www.space-track.org`).

Another site for TLE’s ordererd into different categories is
`http://www.tle.info`
Here you will also find a master list of all the (non-classified) satellites relayed from Space Track.
`http://www.tle.info/data/ALL_TLE.zip`
These TLEs are relayed from SpaceTrack.

TLE’s of classified satellites not in the above list which were compiled by amateur observers can be found on
`http://www.prismnet.com/~mmccants/tles/classfd.zip`

A site for TLE’s for the ISS and Shuttle flights can be found on
`http://spaceflight.nasa.gov/realdata/elements`
Here you will find suitable state vectors and Keplerian elements predicted even for about a week in advance.

Another site to check which itself is a source for further links is
`http://www.satobs.org/satintro.html`

The following two sites provide information about the Earth rotation parameters and the Solar flux and geomagnetic index values:
`http://hpiers.obspm.fr/eop-pc/`

`www.sec.noaa.gov/ftpdir/latest/RSGA.txt`

Note however that the internet is a very dynamic medium and changes can happen all the time.

A APPENDIX

A.1 LIST OF HOT KEYS

A number of SatCal functions can be handled by pressing Hot Keys. Here is a list of the respective keys.

`A` List AOS Times (Passes)
`C` (Observer) Location
`D` Date
`E` Edit Orbit Elements
`F` Open TLE File
`G` Groundtrack (Delta Mode)
`H` Display Help Info
`L` Launch Calculation
`M` Set Magnitude Parameter
`N` Display Satellite Names
`P` Next Satellite Passes
`Q` Find Matching Satellites
`R` Start/Stop Real Time Mode
`S` Select Satellites
`T` Time Step
`U` Current Step
`V` Visibility Conditions
`W` Switch Satellies
`X` Switch between Map Display and Last Text
`Y` Map View / Sky Map
`Z` Delete Satellite
-> Forward Step
<- Backward Step
`PAGE UP` Last Pass
`PAGE DOWN` Next Pass
`DELETE` Refresh Screen
`SPACEBAR` Display Map or Local Visibility
`HOME` Move scrolled display to upper left.

You are supposed to press these keys together with the `<crtl>` key. If you press these keys without `<crtl>` it still works - most of the time. The exception: If you had accidentally still highlighted a menu while pressing the key SatCal might not respond to your key input. The recovery is simple: Just press the `<crtl>` key (as you should have done anyway!) once.

A.2 PRECISION

The low precision model of SatCal will have a typical accuracy of some 10 to 20 km or so for satellite positions[6] (given correct Two Line Elements). This seems to be more than adaquate for predictions of visual observations and also for early stages of mission planning. Be aware that if you use more precise calculations your orbit elements should not be older than a day or so (particularly at times of high solar activity) lest your prediction will be hardly better than the one offered by the low precision model! I often use orbit elements which are one or two weeks old and found that by adjusting the `ndot` or `adot` parameter (in the Edit Orbit Element option of SatCal) to fit a visual observation I am able to predict the passes for the next few days within a few seconds by which time higher precision programs without this observational update might already be wrong by a minute or more!

Very low and very high satellites will show greater relative errors than satellites in medium altitudes as SatCal ignores higher order perturbations relevant in those cases.

The precision of the SGP4 Model is probably on the order of better than 1km or so. More details about this model and its accuracy can be found under `http://www.celestrak.com`. Of course, the older the orbit elements you work with the less accurate the result regardless of the model used. Actually Sun transit calculations with new orbit elements using this model seem to be within a few hundert meters of the actually observed site.

The integration method and the force model used for the numeric propagation should allow an accuracy in the 10 m range for a few orbits if the input data are that accurate. Over a period of one day you could expect something like 100 m or so in accuracy depending on the orbit. A higher precision over a longer period of time would require a more advanced force model and a higher order integration method. Some test have shown the SatCal numeric propagation to stay within a km over a period of a week for typical orbits. It depends on the problem at hand. Do your own tests to check what you can expect for your problems.

The launch orbit calculation is very sketchy. There simply are too many variables in a real launch to be include here. But it should be enough to give you an idea if the satellite is visible during its first few orbits and when and where to look. Launches into GTO give poor results as there tends to be a flight angle > 0 at cutoff which leads to a differnt position of perigee than the one SatCal assumes at cutoff.

A.3 FORMATS USED FOR STORING ORBIT ELEMENTS

The following is a description about the TLE format used for storing the orbit elements of the analytic models:

[6] Very high and very eccentric orbits and orbits displaying resonances as well times far enough from the epoch can of course deviate much more.

First Line (Line 0) : Satellite name (from Pos 1 on)
The program assumes that this line is
< 30 characters long.

Second Line : Pos.1 : ’1’
Pos.10-17 : International Launch Designator
Pos.19-20 : Last 2 digits of epoch year
Pos.21-32 : Epoch days ddd.ffffffff
Pos.34-43 : Ndot2 term
Pos.45-52 : Ndot6 term +XXXXX-X
Pos.54-61 : BSTAR term +XXXXX-X
Pos.63 : Ephemeris Type

Third Line : Pos.1 : ’2’
Pos. 9-16 : Inclination
Pos.18-25 : Right Asc.Ascending Node
Pos.27-33 : Eccentricity (fractional part)
or 26 - 33 for hyperbolic orbits
Pos.35-42 : Argument of Perigee
Pos.44-51 : Mean Anomaly
Pos.53-63 : Mean Motion (perigee for hyperbolic)
Pos.64-68 : Revolution Number at Epoch

Note that the alternative use of Pos.26 - 33 and of Pos.53 - 63 in case of hyperbolic orbits is not standard and can only be used by SatCal. Likewise, SatCal uses a special format format to store the state vector and associated data of a satellite for which numeric orbit propagation has been selected. Although this format uses four lines (instead of the two lines of the TLE format) this is not the same as the Four-Line-Element format used by some organizations.

First Line (Line 0) : Satellite name (from Pos 1 on)
The program assumes that this line is
< 30 characters long.

Second Line : Pos.1 : ’1’
Pos.10-17 : International Launch Designator
Pos.19-20 : Last 2 digits of epoch year
Pos.21-32 : Epoch days ddd.ffffffff
Pos.37: ’0’
Pos.39 - 57: “+++++STATEVCT1+++++")
Pos.68: ’1’

Third Line (Line 2):
Pos. 1 - 63: x, y, z position of state vector in meters
Pos.68: ’2’

Fourth Line (Line 3):
Pos. 1 - 63: x, y, z velocity of state vector in meters/sec.
Pos.68: '3'

Fifth Line (Line 4):
Pos.1 - 66: F10.7 daily flux, F10.7 average flux, Kp index, Cd, Cr, Area/Mass
Pos.68: '4'

A.4 INSTALLATION

SatCal Version 11.8

The Windows version of SatCal 11.8 is contained in file `SatCal_11.8_Win.zip.` The Linux version is contained in file `SatCal_11.8_lx.tar.gz`.

After unpacking you will find the following files and directories:

The directory SatCal contains four sample TLE files and a subdirectory `bin` which holds the executable together with auxilliary files needed for the correct running of the program. Always keep the files in the `bin` subdirectory together.

The subdirectory `documents` contains the documentation with a handbook and a tutorial.

The source code used to generate the executable is in `source`. There is also a subdirectory `overlay` which contains a sample C++ program how to create overlays for maps from SatCal files.

INSTALLATION:

Put the unpacked directory `SatCal` anywhere you like. To start the program simply click `satcal.exe` (for Windows) or `satcal` (for Linux) in the `bin` subdirectory. If you use SatCal more often you might want to place a link to the desktop or some other place (make sure its just a link not a copy as SatCal needs all the files in the `bin` directory). To supply the link with the right icon use `satcal.ico` or `satcal32.png` which you find in the `bin` subdirectory.

The SatCal's Graphical User Interface has been implemented with the Qt4 library. Under Window the needed DLL files have been put in the `bin` subdirectory. Under Linux nothing extra is needed if you run the KDE desktop as this is built with the Qt4 library. If for non-KDE desktops this is missing you will have to install the respective package from you distribution.

Should you want to recompile SatCal from the source you need the Qt4 development library. You will find instructions on the README file in the `source` subdirectory.

Note to Linux users: The supplied SatCal executive should run under newer distributions (`satcal` is for 32 bit and `satcal64` for 64 bit systems).

INITIALIZATION:

When starting SatCal for the first time, default values will be used for a number of items. Enter your observation site coordinates via menu `Input`, `Location`. Select a TLE-file via `File`, `Open TLE File` (this will typically be the file `visual.txt` in the SatCal directory but can be anywhere, particularly if you have other programs which also access TLE files - keep in mind that default output files generated by SatCal will also be in the same directory as the current TLE file). When using SatCal under Windows you might want to enable the left mouse button (for pass details). Select `View`, `Enable Left Button`. Now exit SatCal via `File`, `Exit` to save these settings.

NOTE: File names (with complete path) are restricted to a maximum of 104 characters.

A.5 TROUBLE SHOOTING

Although most of the following situations have already been dealt with above, the following is a list of (perceived or real) problems you could encounter with SatCal.

- A message `No Satellite Selected` appears even after having been in the Select Satellite Dialog

Various options of SatCal require a satellite to have been selected first. If you failed to do that messages like `No Satellite Selected` will appear. A common mistake is that you sometime search for a satellite in the Select Satellite Dialog and after finding the satellite press `Close` (or `<Return>`) before having pressed `Select` to actually include the satellite in the active list.

- The saved file names and other parameters don't appear when starting SatCal

When SatCal is exited via `File`, `Exit` the currently selected file names and other parameters (like coordinates of observers site) are save on the file `satcal.cfg` which resides in the working directory where the SatCal executable is located. If you change your directory structure or re-locate SatCal the absolute path of the file names may no longer be valid. If you encounter any problems with the saved parameters delete the file `satcal.cfg` and re-start SatCal. You will have to overwrite the default parameters displayed with what you like them to be and exit SatCal again via `File`, `Exit`. From now on the start-up information should be properly saved.

- The time on the Real Time Display seems to be wrong

This can happen in the very unlikely event that you changed the timezone of your system clock via the Date/Time option in your system control while SatCal was running. In this case SatCal doesn't "get the news" about the change and still uses the old system timezone to convert into Universal Time (and then into its own specified timezone). Exit SatCal and restart the program in this case. Should the problem persist you could adjust the Real Time via the `R/T Offset` parameter in the Date/Time dialog.

- The Visibility Circle does not appear

The visibility circle around a satellite does not appear on the map during a delta-time plot. It will also be absent (for obvious reasons) if the height of the satellite is < 0 (which could happen if you project the satellite position of a decaying orbit too far into the future).

The visibility circle will also be missing if the SatCal is in Occultation/Transit Mode or in Flare Calculation Mode or if the Sky Map is displayed.

- There is no satellite visible on the map

You might be in `Occultation/Transit` Mode or in `Flare Mode` and at present there is `No Intersection`, meaning no point on the map which satisfies the specified conditions.

- There is no map although a map should be seen

You may have scrolled down the display for a lengthy table and then issued a map command like Real Time. SatCal does not scroll up automatically in this case. The map is there but out of sight! You can press the `<home>` button or manually scroll up.

- The Pass Details cannot be activated via the mouse

You click the AOS listing via the right (or if activated the left) mouse button to get the Pass Details but nothing happens. You probably had switched to the map display after the AOS listing and then switched back to the AOS listing. In this case the mouse click will no longer activate the Pass Details. You have to re-issue the AOS command before you can get the Pass Details in this case.

- Message `Maximum Number of Matches`

This can happen if more than 50 satellite matches were found in the "Search for Matching Satellite" option. This is due to buffer limitations. You could set the search criteria more stringent (smaller search area and shorter time interval) to avoid this problem. You normally shouldn't run into this problem if you use the usual TLE files and reasonable search intervals.

- Message `INITIALIZATION ERROR` or `Problems with the output file` or `TLE Save Error`

This really shouldn't happen. If it does it might indicate that there was not enough memory available. Try closing other programs which are running at the same time or restart everything.

- Message `Problems with the input file`

You may have been in a wrong directory or TLE files could be missing. For example if you try to do an automatic Iridium flare calculation and there is no file `iridium.txt` this message would appear.

- Message `No suitable pass found within the time interval`

The satellite does not pass the observer at all (due to its inclination) or the passes do not comform to the conditions set with regard to minimum elevation and sunlight (see section 7.2). You may have to specify a larger duration in the Date/Time input. Be aware, however that there can be lengthy periods (up to several months) before conditions for visibility are favorable again.

- The satellite jumps chaotically across the map

You probably made a mistake editing the orbital elements (maybe you entered 0 in the mean motion or the semi-major axis field). Enter the Edit Orbit Elements option and in particular check the values for the mean motion (and the semi-major axis). Or you may have projected the satellite too far into the future by which the orbit has decayed.

- There is no physical world map, just a simple outline

Check whether the `Physical World Map` button is checked in the Map Settings dialog. Also make sure there is a file `satpearth.jpg` in the SatCal/bin directory.

- No satellite appears on the Sun/Moon Plot

The event typically takes just a second or so and your location must be within a few kilometers of the center line. Make sure the time coincides exactly with the event and the geographic location of the observer site is close enough. Also take a time step of `0.1` sec or so.

- A satellite does not appear on the Sky Map

The satellite either was not within the field of view or (in case the visibility was set to `Visible Passes Only`) it was not illuminated.

- No satellite trail appears on the Sky Map or Groundtrack Map

If the `Show Day/Night - No Trail` option was marked in the Change Map Settings / Sky Map dialog trails will not be shown.

- A numeric propagation orbit was selected but nothing seems to happen

If the epoch of the orbit is very different from the current time for which you want to calculate the position it will take some time for SatCal to integrate from the epoch to the that current time. (For analytic orbits it doesn't matter how different the epoch is from the current time - it's an instantaneous calculation.)

- The ground position of the numerically propagated satellite does not change

That will happen if the height of the satellite drops below 0. After the satellite hits the ground the integration of the orbit stops and it also cannot be reversed anymore to an earlier time.

- The groundtrack extends backwards over the launch site after the Launch calculation

This is normal. The launch orbit calculated is valid only after orbit insertion (the time of engine cutoff).

- The Relative Satellite Mode was automatically reset.

This will happen on purpose when switching to or running the Sky Map.

- The displayed magnitude suddenly jumps.

Normally a correction for atmospheric extinction is applied to the calculation of the apparent magnitude of the satellite. But this applies only if the elevation of the satellite (as viewed from the observer) is > 0 and < 33°. If the satellite drops below the horizon no such correction is being done any more and the displayed magnitude suddenly seems to jump (but in this case the magnitude is irrelevant anyway). Note that the elevation displayed might be corrected for refraction but the jump occurs when the geometric (uncorrected) elevation drops below 0.

- Program crashes

SatCal is usually very resistent to program or system crashes even under extreme conditions as special care was taken to prevent any exception cases. The only known case leading to a rare crash would be if you run completely ancient orbit elements under the SGP4 model years after the satellite is decayed (in which case the displayed data would be meaningless anyway - the simple orbit model actually tolerates even this abuse).

If SatCal crashes upon startup delete the file `satcal.cfg` in the directory where the SatCal executable is located and re-initialize SatCal. (SatCal should be robust enough to handle even badly corrupted configuration files so I don't think this case will ever happen - I included it to be on the save side).