StarCal Software User Manual

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StarCal

StarCal is used to calibrate the telescope for pointing errors. It includes features for collecting, processing and analyzing data in order to generate a new mount model for the telescope. This mount model can then be downloaded and installed into the **Telescope Server** application.

The program is typically located in C:\EOST\Clients\StarCal\StarCal.exe.

1 Quick Start Guide

Run StarCal then press a key or click anywhere in the splash screen to proceed. Select the *Telescope | Connect Telescope* menu item and click *OK* in the *Connect Telescope* dialog. **StarCal** will display the current sky visible to the telescope.

Click on a star and it will be highlighted in red. Now select the *Operations | Observe Selected Star* menu item and click *Yes* in the Question dialog to take control of the telescope. The telescope will move to the selected star and track it. The current status of the telescope is shown in the status bar along the bottom of the window.

Click the *Close* button in the *Observe Star* dialog to stop tracking the star.

If at any stage an error is encountered (for example, a telescope tracking error) then check the **Telescope Interface** for more information, correct any possible issues then try the failed action again.

2 Application Structure

2.1 Windows

StarCal consists of a main window which can display four different pages of information plus a series of menu commands which provide access to many of its functions. Most of the operations performed using **StarCal** are carried out from within various dialog boxes launched from the menu.

Figure 1 shows the four information pages which can be accessed using the tabs at the bottom of the main window. See §2.4 for more information.
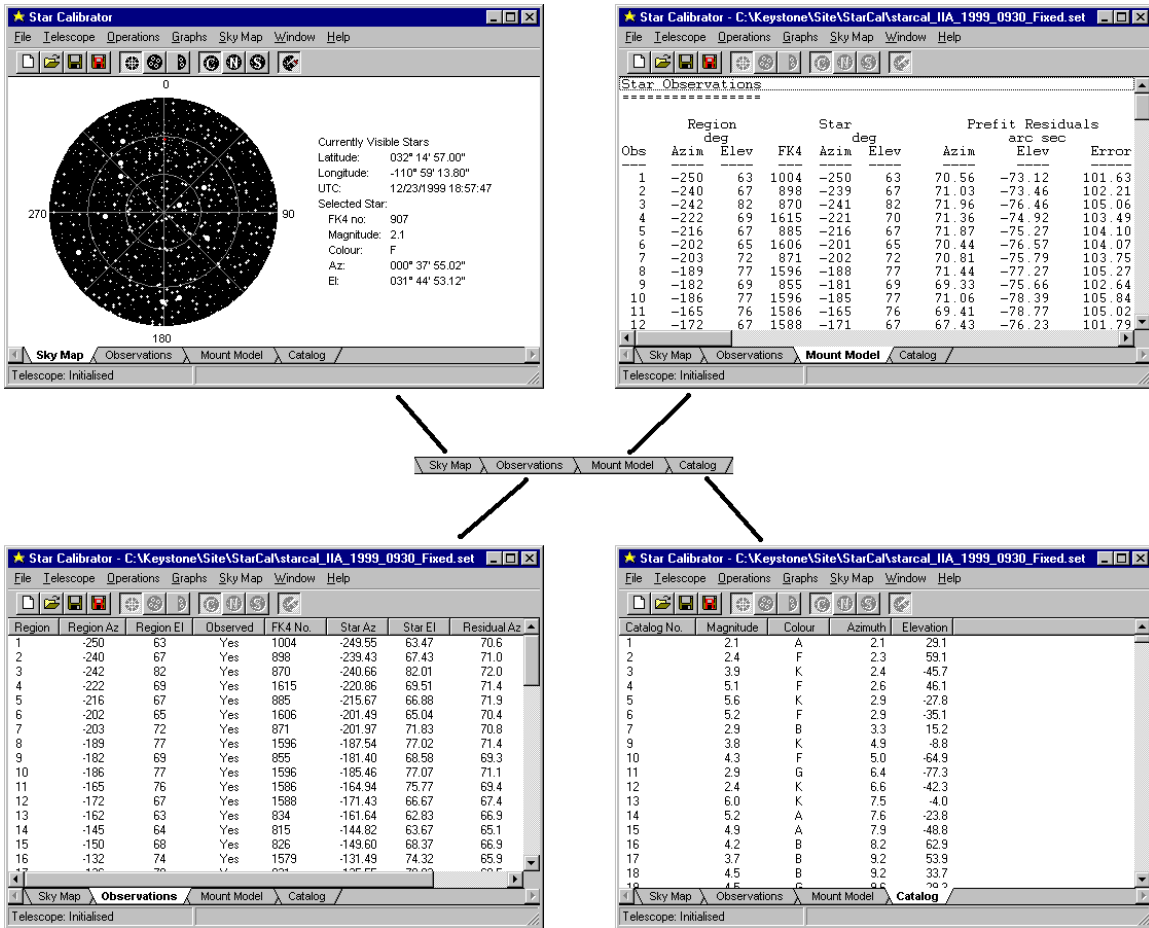
Star Calibrator

File Telescope Operations Graphs Sky Map Window Help

```
0
```
```
270                        90
```
```
180
```

Currently Visible Stars
Latitude: 032° 14' 57.00"
Longitude: -110° 59' 13.80"
UTC: 12/23/1999 18:57:47
Selected Star:
FK4 no: 907
Magnitude: 2.1
Colour: F
Az: 000° 37' 55.02"
El: 031° 44' 53.12"

Sky Map Observations Mount Model Catalog

Telescope: Initialised

Star Calibrator - C:\Keystone\Site\StarCal\starcal_IIA_1999_0930_Fixed.set

File Telescope Operations Graphs Sky Map Window Help

Star Observations
==================

		Region deg		Star deg		Prefit Residuals arc sec		
Obs	Azim	Elev	FK4	Azim	Elev	Azim	Elev	Error
1	-250	63	1004	-250	63	70.56	-73.12	101.63
2	-240	67	898	-239	67	71.03	-73.46	102.21
3	-242	82	870	-241	82	71.96	-76.46	105.06
4	-222	69	1615	-221	70	71.36	-74.92	103.49
5	-216	67	885	-216	67	71.87	-75.27	104.10
6	-202	65	1606	-201	65	70.44	-76.57	104.07
7	-203	72	871	-202	72	70.81	-75.79	103.75
8	-189	77	1596	-188	77	71.44	-77.27	105.27
9	-182	69	855	-181	69	69.33	-75.66	102.64
10	-186	77	1596	-185	77	71.06	-78.39	105.84
11	-165	76	1586	-165	76	69.41	-78.77	105.02
12	-172	67	1588	-171	67	67.43	-76.23	101.79

Sky Map Observations **Mount Model** Catalog

Telescope: Initialised

Sky Map Observations Mount Model Catalog

Star Calibrator - C:\Keystone\Site\StarCal\starcal_IIA_1999_0930_Fixed.set

File Telescope Operations Graphs Sky Map Window Help

Region	Region Az	Region El	Observed	FK4 No.	Star Az	Star El	Residual Az
1	-250	63	Yes	1004	-249.55	63.47	70.6
2	-240	67	Yes	898	-239.43	67.43	71.0
3	-242	82	Yes	870	-240.66	82.01	72.0
4	-222	69	Yes	1615	-220.86	69.51	71.4
5	-216	67	Yes	885	-215.67	66.88	71.9
6	-202	65	Yes	1606	-201.49	65.04	70.4
7	-203	72	Yes	871	-201.97	71.83	70.8
8	-189	77	Yes	1596	-187.54	77.02	71.4
9	-182	69	Yes	855	-181.40	68.58	69.3
10	-186	77	Yes	1596	-185.46	77.07	71.1
11	-165	76	Yes	1586	-164.94	75.77	69.4
12	-172	67	Yes	1588	-171.43	66.67	67.4
13	-162	63	Yes	834	-161.64	62.83	66.9
14	-145	64	Yes	815	-144.82	63.67	65.1
15	-150	68	Yes	826	-149.60	68.37	66.9
16	-132	74	Yes	1579	-131.49	74.32	65.9

Sky Map **Observations** Mount Model Catalog

Telescope: Initialised

Star Calibrator - C:\Keystone\Site\StarCal\starcal_IIA_1999_0930_Fixed.set

File Telescope Operations Graphs Sky Map Window Help

Catalog No.	Magnitude	Colour	Azimuth	Elevation
1	2.1	A	2.1	29.1
2	2.4	F	2.3	59.1
3	3.9	K	2.4	-45.7
4	5.1	F	2.6	46.1
5	5.6	K	2.9	-27.8
6	5.2	F	2.9	-35.1
7	2.9	B	3.3	15.2
9	3.8	K	4.9	-8.8
10	4.3	F	5.0	-64.9
11	2.9	G	6.4	-77.3
12	2.4	K	6.6	-42.3
13	6.0	K	7.5	-4.0
14	5.2	A	7.6	-23.8
15	4.9	A	7.9	-48.8
16	4.2	B	8.2	62.9
17	3.7	B	9.2	53.9
18	4.5	B	9.2	33.7

Sky Map Observations Mount Model **Catalog**

Telescope: Initialised

Figure 1 StarCal main window pages

2.2   Menus

2.2.1 *File* Menu

File | New...

> Choose this menu item to begin a new observation sequence. The *New StarCal Dataset* dialog will be displayed allowing the user to specify various parameters affecting the observation sequence.

File | Open...

> Open an observation set and mount model saved previously using the *File | Save* command. This action discards any observations or mount model currently held in memory.

File | Save

> Saves the current observation set and mount model if any to a file. If this is a newly created observation set the user is prompted for the filename before saving.

File | Save As...

Like *File | Save* but always prompts for a filename before saving. This menu item can be used to save the data to a file with a different name.

File | Save Report

Create a text file of the contents displayed by the *Mount Model* page in the main window.

File | Save TPOINT Data

Create a **TPOINT**-compatible text file of the mount model data. This file can be imported into the **TPOINT** program (a popular third-party package) for analysis of the pointing data.

File | Print...

This function is not implemented in the current release of the software.

File | Print Setup...

This function is not implemented in the current release of the software.

File | Load Catalog...

Select a new star catalog to load. The default catalog is the FK5 (Fundamental Katalog, 5th edition).

File | Exit

Quit **StarCal** after asking for confirmation from the user. The Windows close button (*X*) in the top right corner of the window can also be used to exit the application.

2.2.2   Telescope Menu

Telescope | Connect Telescope...

Establish a connection to a telescope at a specified site. This menu command brings up the *Connect Telescope* dialog box which allows the user to choose to which telescope (site) to connect. The default login and password are both "a".

Telescope | Disconnect Telescope...

Close an existing connection to a telescope. This command is usually only necessary prior to connecting to a different telescope. Note that other client applications can connect to the telescope while **StarCal** is connected.

Telescope | Take Telescope Control

Request control of the telescope so that **StarCal** can track stars. Only one client application can be in control of the telescope so while **StarCal** is in control other applications such as **Telescope Interface** will be unable to move the telescope.

If another application is already in control of the telescope the request will be rejected and a dialog box will appear indicating which application has control.

Telescope | Release Telescope Control

Release control of the telescope so that other applications can take control and move the telescope. Only one client application can be in control of the

telescope so while **StarCal** is in control other applications such as **Telescope Interface** will be unable to move the telescope

Telescope | Home telescope....

This menu item displays a dialog which allows all telescope axes to be homed. See Figure 2.

Figure 2 Telescope home

Telescope | View Mount Model...

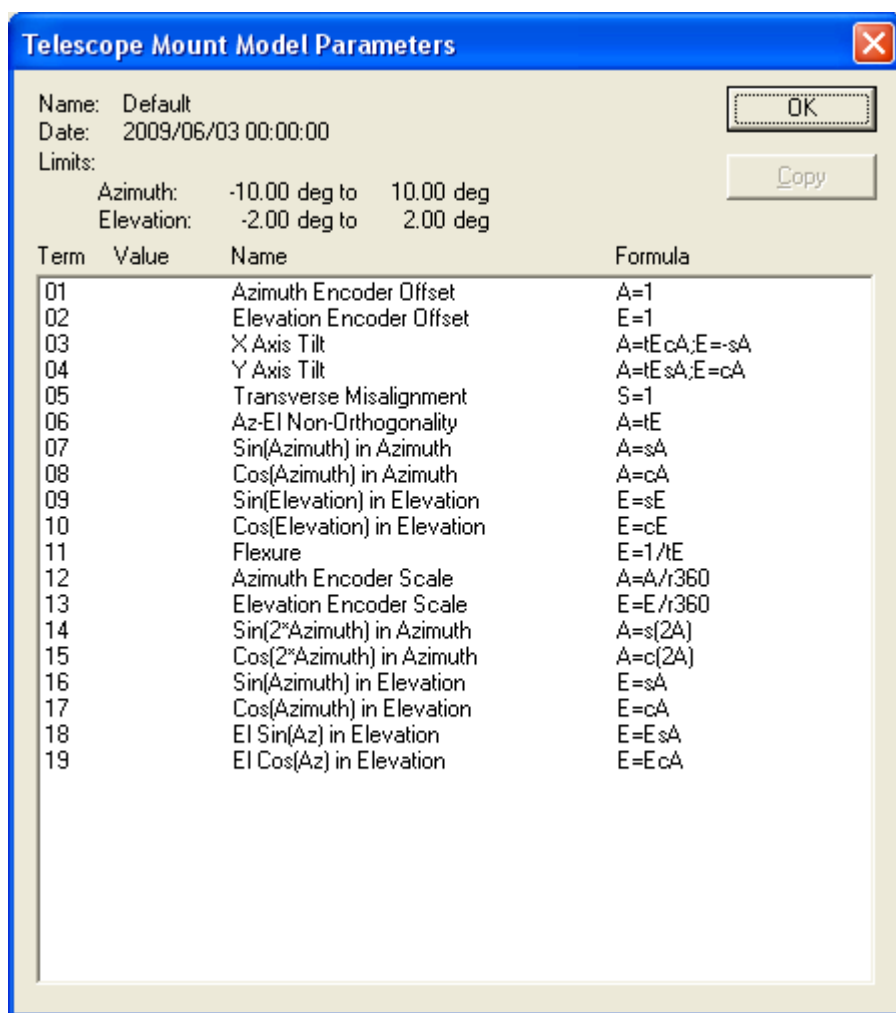This menu item displays each term of a mount model (see Figure 3).

Figure 3 Telescope mount model *dialog*

The OK button closes the dialog.

The Copy button retrieves the current model from the telescope. **StarCal** must be connected to a telescope to be able to access this information, but need not be in control. This list will be empty when starting a new model, so it is useful to copy the terms from the telescope rather than type them in by hand.

Each term is listed by name and the formula by which it is defined. See §2.6 for a description of the formula syntax.

2.2.3 Operations Menu

This menu provides commands for carrying out various actions involving the telescope.

Operations | Observe Stars...

Automatically select a star from the next observation region and track it. Observation regions are part of an observation sequence. Stars are selected according to criteria specified when the observation sequence was created.

When this menu item is selected the telescope will start to move to the selected star and the *Make Star Observations* dialog will appear (Figure 4). This dialog lists details about the region and the selected star, and provides buttons allowing the user to bring up the *Offset Controller* dialog, accept the marked position, skip the region, or cancel tracking.

The telescope will continue to track the star indefinitely. If the star moves outside the position range of the telescope it will stop at the limit and wait for the star to re-emerge.

The application must be in control of the telescope and have created or loaded an observation sequence for this option to be accessible. If all the regions in the sequence have been observed then this request will be rejected.
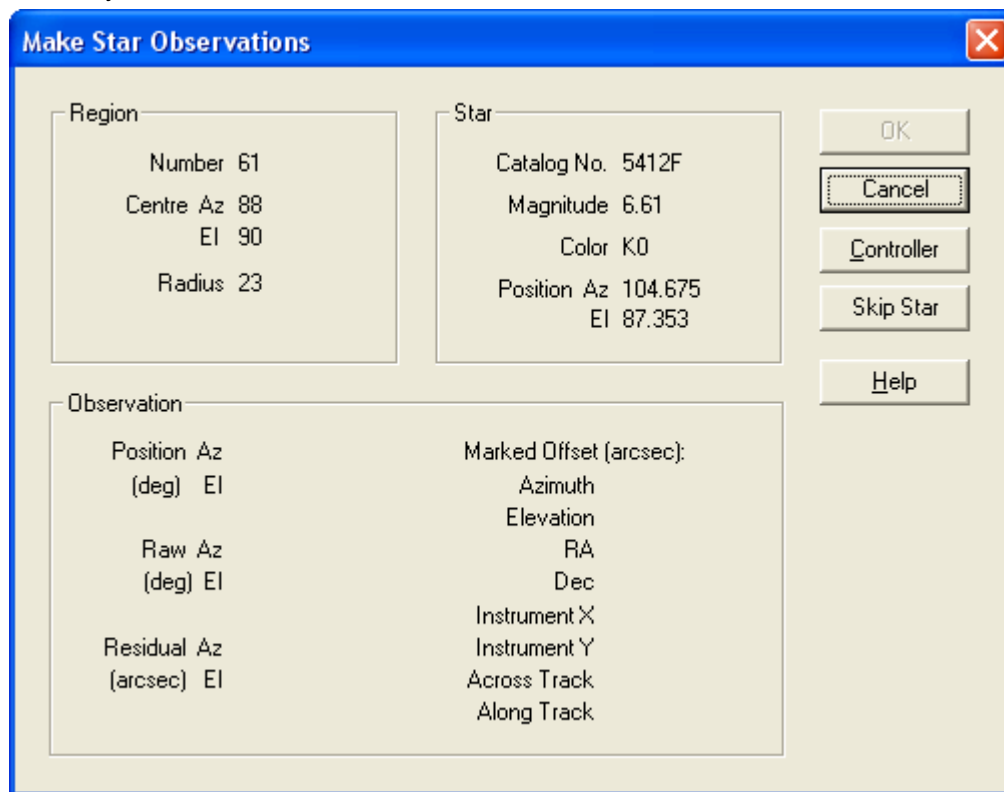
Figure 4 Make Star Observations *dialog*

Operations | Add New Observed Star...

This command allows the user to add a new region to the observation sequence using the currently selected star. The new region will be created with the currently selected star at its center and will be inserted into the observation sequence. The order in which regions occur in the observation sequence is immaterial.

Depending on the range of movement of the telescope it may be able to track the selected star in more than one orientation. In this case the *Select Telescope Orientation* dialog box will be displayed (Figure 5) allowing the user to specify which orientation to use. Note that the choice will

determine the spread of data points in the observation set, an important aspect affecting the quality of the mount model.

After the orientation is selected (if the option is given) the telescope then commences to track the star, the *Make Star Observations* dialog will be displayed (Figure 4) and the user continues as for *Operations | Observe Stars....* However, note that canceling out of this dialog will discard the new region rather than adding it to the observation sequence.

The telescope will continue to track the selected star indefinitely. If the star moves outside the position range of the telescope it will stop at the limit and wait for the star to re-emerge.

The application must be in control of the telescope and have created or loaded an observation sequence for this option to work. New regions can be added at any point in the sequence, even after all other regions have been observed.
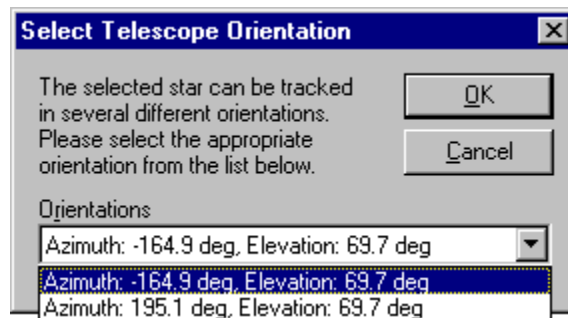
Figure 5 Select Telescope Orientation *dialog*

Operations | Generate Mount Model...

This option is used to generate a mount model from a set of observations. The *Mount Model Parameters* dialog box is displayed (Figure 6) allowing the user to select which mount model parameters to calculate and which regions to use or discard. Terms used in the model may be added, deleted or edited. See §2.6 for a description of the formula syntax.

The buttons Float, Fix and Zero determine how and whether the term will be utilized in the Fitting process. The usual approach is to the let each term Float, which allows it to be determined by the modeling process. But if desired a term can be Fixed so it will be used but not allowed to change value, or forced to Zero to effectively remove it from the model without deleting it from the table.

Pressing Fit will compute a new model using the formulas provided for each Floating or Fixed terms. The results of the operation are placed in the *Mount Model* page of the main window and replace any existing mount model.

Generation of a new mount model normally takes a second or less, but in some cases it may take up to 10 seconds or it may fail to converge to a solution at all. If this happens try removing some of the parameters from the solution.

StarCal does not have to be in control of the telescope or even attached to it in order to use this command. However, an observation sequence must be loaded. Mount models based on previously collected observation data can be generated and analyzed off-line.

Figure 6 Mount Model Parameters *dialog*

A new term may be added by clicking on Insert or an existing one may be Edited. Either of these buttons brings up the Mount Model Term Properties dialog; see Figure 7. This dialog allows you to edit the term's name and formula as well as set the value used for Fixed terms.
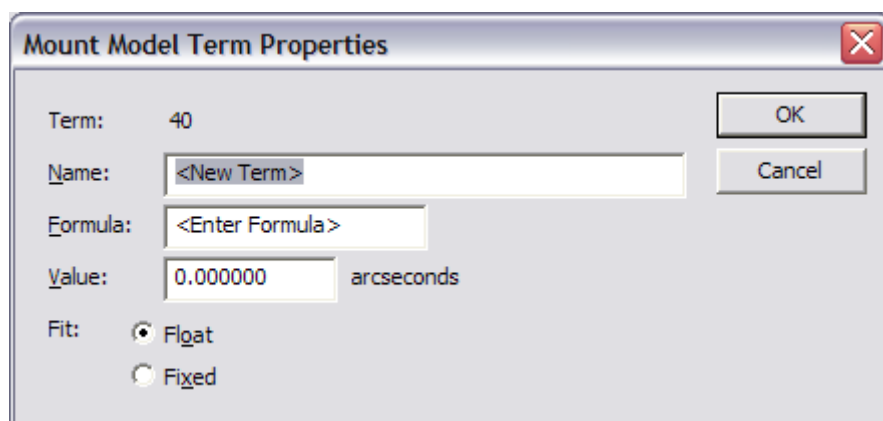
Figure 7 Mount Model Term Properties *dialog*

Operations | Install Mount Model...

This option installs the current mount model onto the telescope. **StarCal** must be in control of the telescope and must have a mount model loaded for this option to work.

The new model is typically stored in C:\EOST\Servers\ConfigFiles\SettableData\TelescopeMountModel.dmx. In case it may be necessary to restore the old mount model it is recommended that TelescopeMountModel.dmx be copied to a backup directory before executing this command.

Operations | Observe Selected Star...

When this menu item is selected the telescope will start to move to the currently selected on the *Sky Map* page and the *Observe Star* dialog will appear (Figure 8), providing details about the selected star and buttons allowing the user to bring up the *Offset Controller* dialog or cancel tracking.

Depending on the range of movement of the telescope it may be able to track the selected star in more than one orientation. With this command the telescope will always choose the shortest path to the star. If this is not the desired orientation then the telescope may have to be slewed manually to the general area of the sky (e.g. by selecting other stars in between, or by using **Telescope Interface**) and then choosing this command again.

The telescope will continue to track the selected star indefinitely. If the star moves outside the position range of the telescope it will stop at the limit and wait for the star to re-emerge.

The application must be in control of the telescope for this option to be available, but an observation sequence does not have to be loaded. This command will not in any way affect the observation sequence.
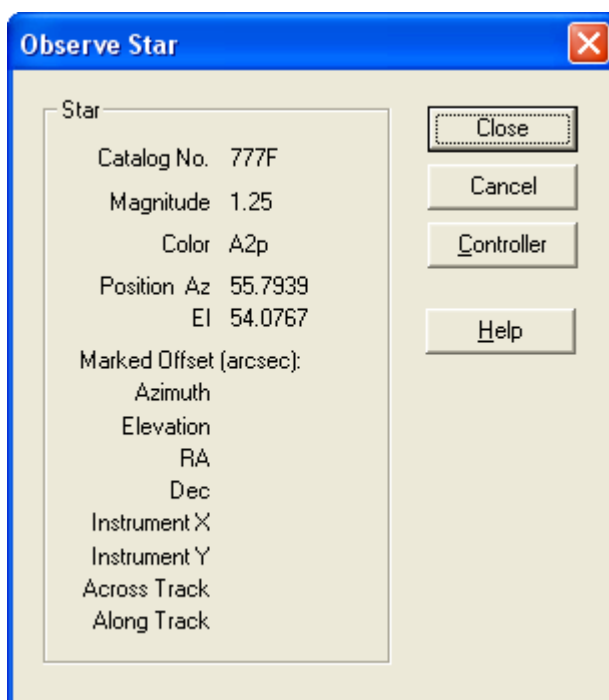
Figure 8 Observe Star *dialog*

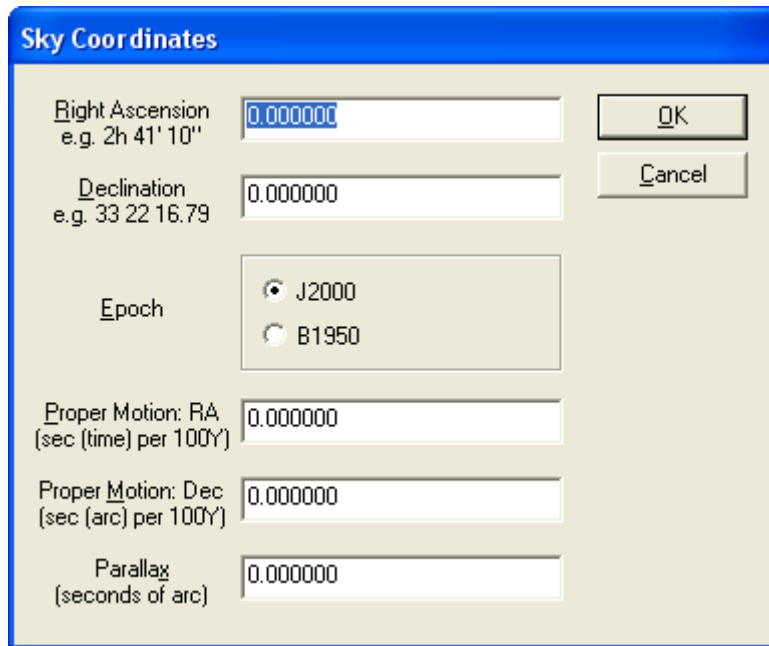*Operations | Observe RA/Dec...*

This menu item allows the user to specify celestial coordinates to be tracked. In this way objects other than the stars in the current catalog can be tracked.

The *Sky Coordinates* dialog will be displayed (Figure 9) allowing the user to enter right ascension (R.A.) and declination (Dec.), and to select the equinox for the coordinates. Parallax and proper motion can also be specified if desired.

Once the coordinates have been entered the telescope will start to move and the *Observe Star* dialog will appear (Figure 8), showing the celestial coordinates instead of the star magnitude and color normally shown.

Depending on the range of movement of the telescope it may be able to track the specified coordinates in more than one orientation. With this command the telescope will always choose the shortest path. If this is not the desired orientation then the telescope may have to be slewed manually to the general area of the sky (e.g. by selecting other stars or coordinates in between, or by using **Telescope Interface**) and then choosing this command again. The *Sky Coordinates* dialog remembers the previous settings, making it easy to repeat the command.

The application must be in control of the telescope for this option to be available, but an observation sequence does not have to be loaded. This command will not in any way affect the observation sequence.

Figure 9 Sky Coordinates *dialog*

Operations | Observe Star by Catalog ID...

This menu item allows the user to specify the identification number for a specific star in the catalog, rather than selecting it from the *Sky Map* page. Provided it can be found in the catalog, the telescope will start to move to the specified star and the *Observe Star* dialog will appear, providing details about the selected star and buttons allowing the user to bring up the *Offset Controller* dialog or cancel tracking.

Depending on the range of movement of the telescope it may be able to track the selected star in more than one orientation. With this command the telescope will always choose the shortest path to the star. If this is not the desired orientation then the telescope may have to be slewed manually to the general area of the sky (e.g. by selecting other stars in between, or by using **Telescope Interface**) and then choosing this command again.

The telescope will continue to track the selected star indefinitely. If the star moves outside the position range of the telescope it will stop at the limit and wait for the star to re-emerge.

The application must be in control of the telescope for this option to be available, but an observation sequence does not have to be loaded. This command will not in any way affect the observation sequence.

Operations | Remember Offsets...

This menu item controls whether offsets entered in the *Offset Controller* dialog will be re-used when tracking subsequent stars. Selecting this menu item toggles this function on and off.

Operations | Observation Parameters...

This menu item will display the parameters specified for the current observation sequence in the *New StarCal Dataset* dialog. Several of the parameters can be modified if desired.

2.2.4   Offset Controller

Figure 10 shows the *Offset Controller* dialog. This is used to input small changes in pointing to center a star while taking data for a mount model. The offsets may be in any of four coordinate systems. Az/El injects offsets in azimuth and elevation. RA/Dec injects offsets in RA and Declination. Instrument X/Y inject offsets along the axis of the instrument, as specified in the telescope configuration file. Along/Across track injects offsets in the same direction or in a direction perpendicular to the path of the target the telescope is currently following. The offsets can be injected using the square array of 8 buttons in the upper right of the dialog. The magnitude of the offset injected by each click of the button is set from the pulldown menu just below the array. The display in the upper left shows each offset and their net result at a scale determined by the selections beneath the graphic.
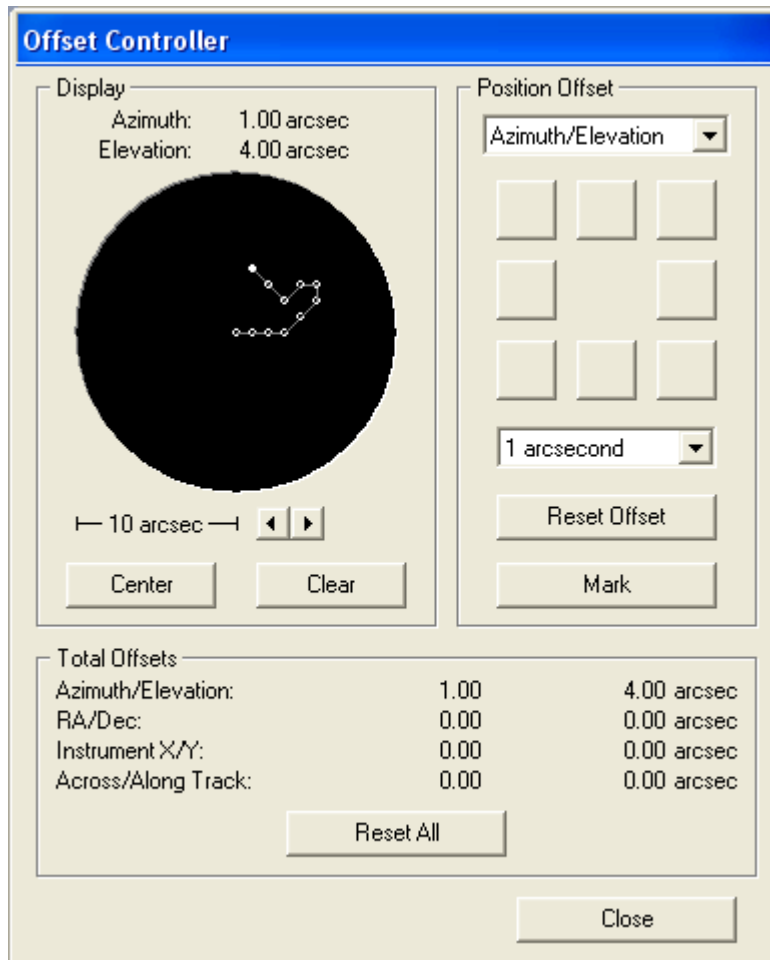

Figure 10 Offset controller *dialog*

2.2.5 Graphs Menu

Graphs | Polar Plot of Error Vectors

This brings up the *Polar Plot* dialog (Figure 11) showing a plot of the direction and magnitude of residual errors and the position of observed stars in azimuth and elevation. Either pre-fit or post-fit residual errors can be displayed.

StarCal does not have to be in control of the telescope or even attached to it in order to use this command. However, an observation sequence must be loaded and a mount model must have been generated.
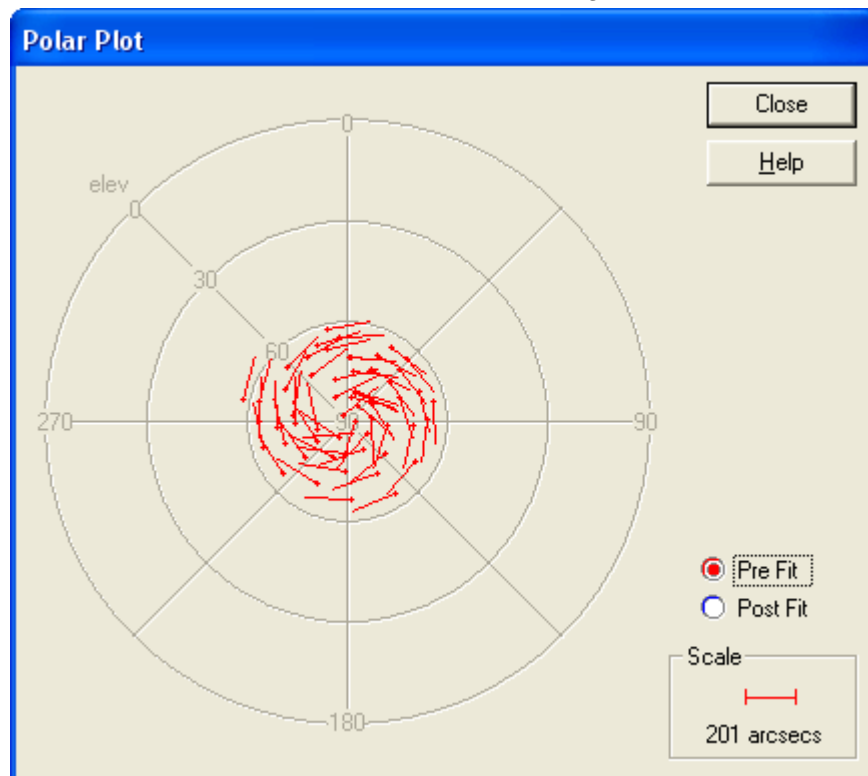

Figure 11 Polar Plot *graph, showing post-fit residuals*

Graphs | Azimuth On-Axis Residuals vs. Azimuth

This displays a graph showing the azimuth axis residual errors plotted against the azimuth axis (Figure 12). The menu item leads to three sub-items, each displaying a different set of the data.

The *Pre Fit* menu item will display only the pre-fit residuals. This may be useful if it is difficult to distinguish pre-fit residuals from post-fit residuals when both are displayed on the same plot.

The *Post Fit* menu item will display only the post-fit residuals. This may be useful to get additional detail since pre-fit residuals are normally larger and cause the axes to be scaled accordingly when both pre-fit and post-fit residuals are displayed on the same plot.

The *Pre & Post* menu item will display both pre-fit and post-fit residuals on the same plot. This is useful as a measure of the effect of the new mount model.

StarCal does not have to be in control of the telescope or even attached to it in order to use this command. However, an observation sequence must be loaded and a mount model must have been generated.
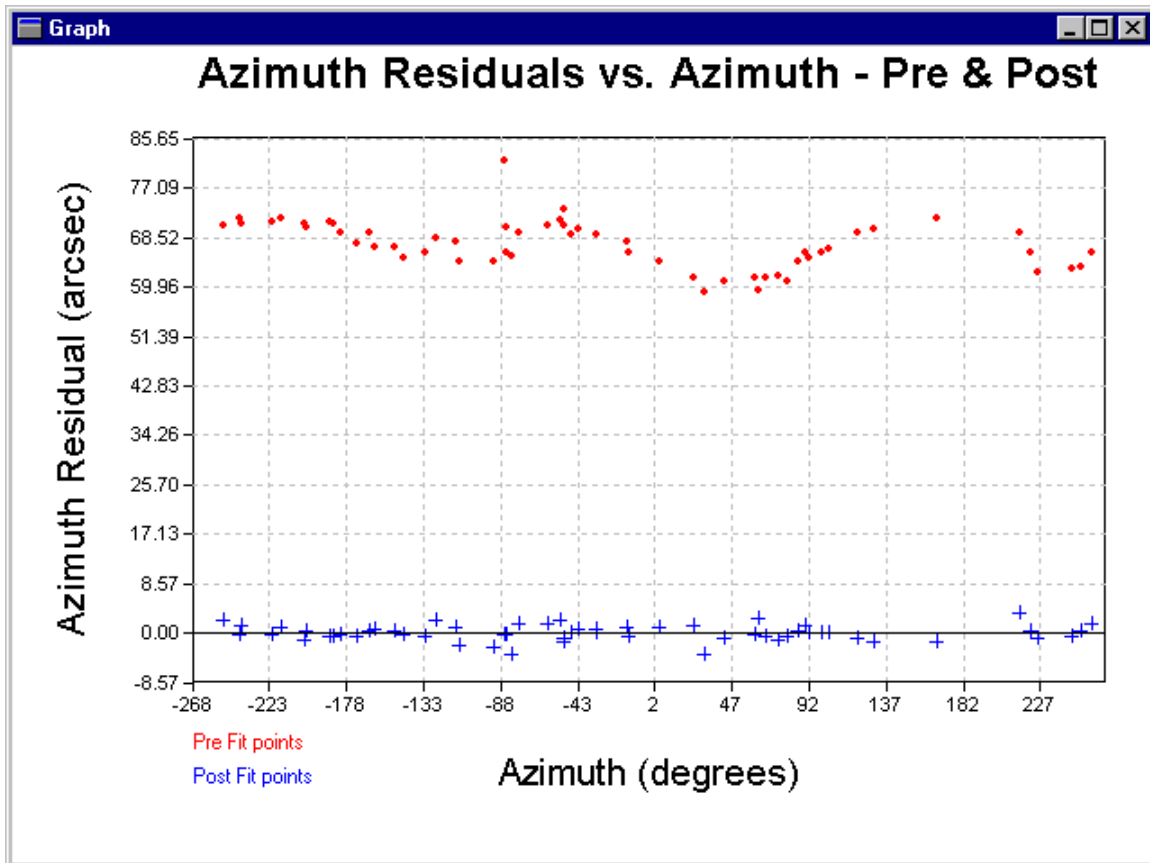

Figure 12 Azimuth Residuals vs. Azimuth *graph*

Graphs | Azimuth On-Axis Residuals vs. Elevation

This displays a graph showing the azimuth axis residual errors plotted against the elevation axis (Figure 13). The menu item leads to three sub-items, each displaying a different set of the data.

The *Pre Fit* menu item will display only the pre-fit residuals. This may be useful if it is difficult to distinguish pre-fit residuals from post-fit residuals when both are displayed on the same plot.

The *Post Fit* menu item will display only the post-fit residuals. This may be useful to get additional detail since pre-fit residuals are normally larger and cause the axes to be scaled accordingly when both pre-fit and post-fit residuals are displayed on the same plot.

The *Pre & Post* menu item will display both pre-fit and post-fit residuals on the same plot. This is useful as a measure of the effect of the new mount model.

StarCal does not have to be in control of the telescope or even attached to it in order to use this command. However, an observation sequence must be loaded and a mount model must have been generated.
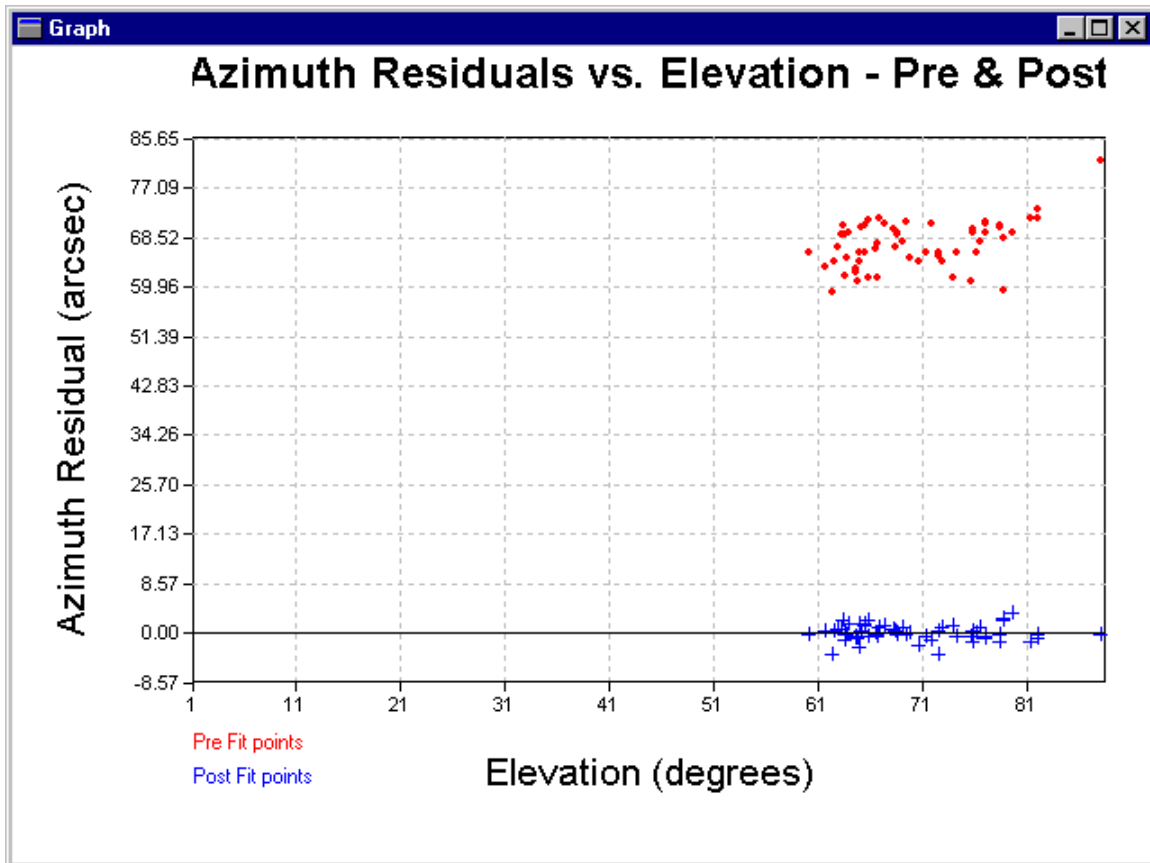

Figure 13 Azimuth Residuals vs. Elevation *graph*

Graphs | Azimuth On-Sky Residuals vs. Azimuth

This offers the same submenus and produces a graph similar to *Azimuth On-Axis vs. Azimuth* except the azimuth residuals values have been multiplied by cosine of elevation. In this way they reflect their extent on the celestial sphere, rather than changes in the azimuth axis.

Graphs | Azimuth On-Sky Residuals vs. Elevation

This offers the same submenus and produces a graph similar to *Azimuth On-Axis vs. Elevation* except the azimuth residuals values have been multiplied by cosine of elevation. In this way they reflect their extent on the celestial sphere, rather than changes in the azimuth axis.

Graphs | Elevation Residuals vs. Azimuth

This displays a graph showing the elevation residual errors plotted against the azimuth axis (Figure 14). The menu item leads to three sub-items, each displaying a different set of the data.

The *Pre Fit* menu item will display only the pre-fit residuals. This may be useful if it is difficult to distinguish pre-fit residuals from post-fit residuals when both are displayed on the same plot.

The *Post Fit* menu item will display only the post-fit residuals. This may be useful to get additional detail since pre-fit residuals are normally larger and cause the axes to be scaled accordingly when both pre-fit and post-fit residuals are displayed on the same plot.

The *Pre & Post* menu item will display both pre-fit and post-fit residuals on the same plot. This is useful as a measure of the effect of the new mount model.

StarCal does not have to be in control of the telescope or even attached to it in order to use this command. However, an observation sequence must be loaded and a mount model must have been generated.
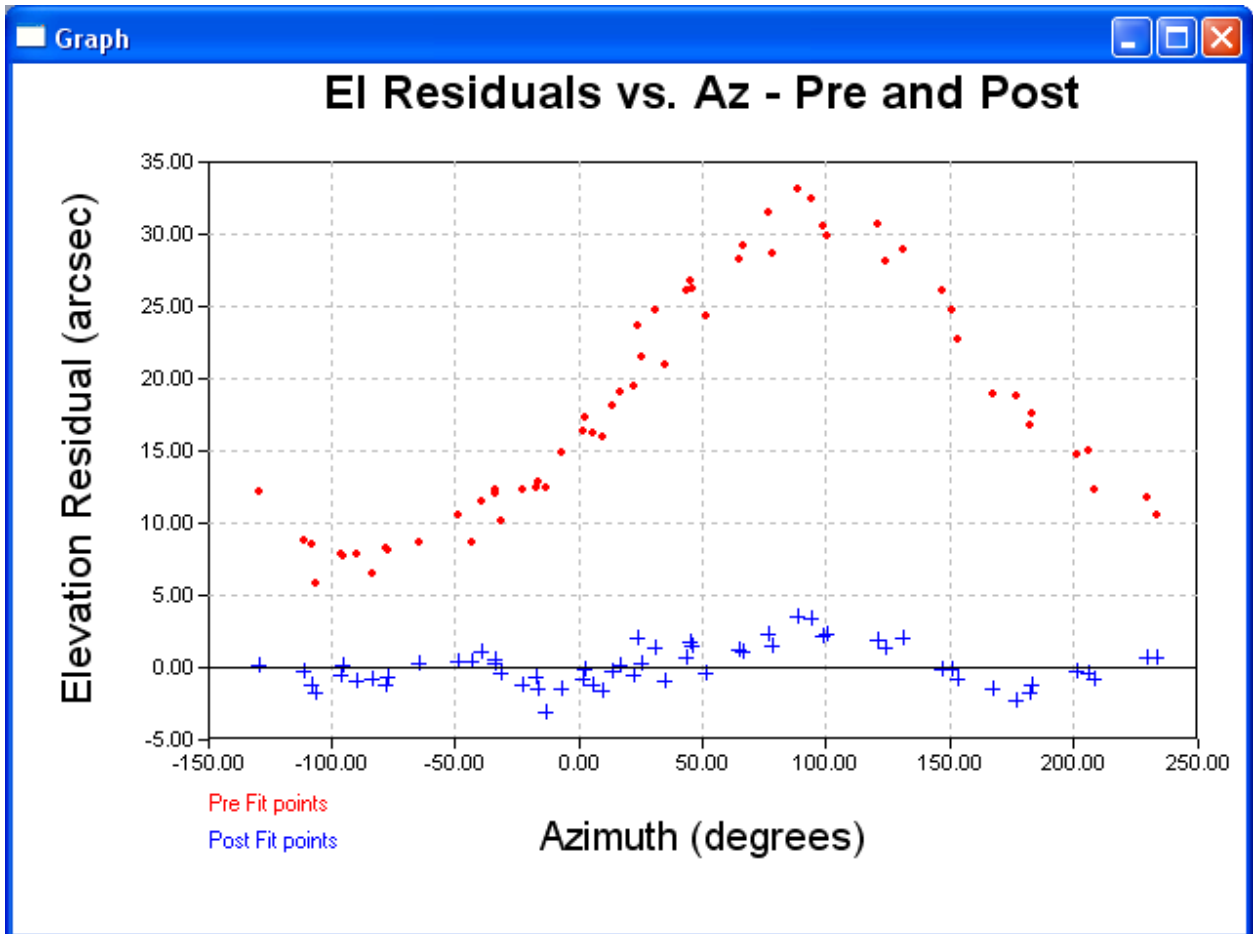

Figure 14 Elevation Residuals vs. Azimuth *graph*

Graphs | Elevation Residuals vs. Elevation

This displays a graph showing the elevation residual errors plotted against the elevation axis (Figure 15). The menu item leads to three sub-items, each displaying a different set of the data.

The *Pre Fit* menu item will display only the pre-fit residuals. This may be useful if it is difficult to distinguish pre-fit residuals from post-fit residuals when both are displayed on the same plot.

The *Post Fit* menu item will display only the post-fit residuals. This may be useful to get additional detail since pre-fit residuals are normally larger and cause the axes to be scaled accordingly when both pre-fit and post-fit residuals are displayed on the same plot.

The *Pre & Post* menu item will display both pre-fit and post-fit residuals on the same plot. This is useful as a measure of the effect of the new mount model.

StarCal does not have to be in control of the telescope or even attached to it in order to use this command. However, an observation sequence must be loaded and a mount model must have been generated.
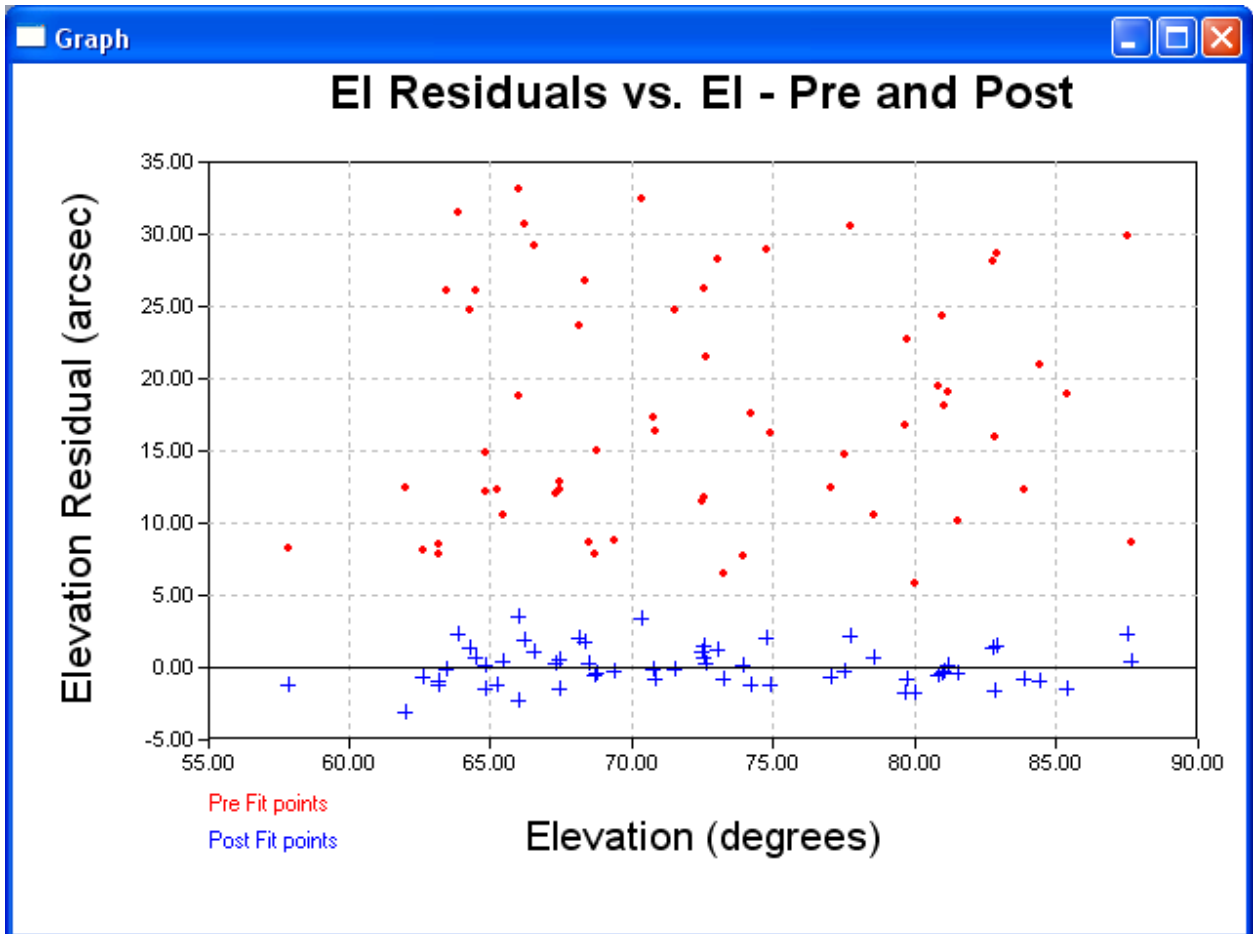

Figure 15 Elevation Residuals vs. Elevation

Graphs | Graph Options

This displays a table with several options to control the contents of and zoom in to specified areas of a graph. See Figure 16.

Figure 16 Graph Options *dialog*

2.2.6   Sky Map Menu

This menu is only available when the *Sky Map* screen is displayed.

Sky Map | Grid Lines

This menu item toggles the grid lines on and off the sky map display.

Sky Map | Low Regions

This displays circles indicating the position and approximate size of the regions in the current observation sequence which lie in the first 360° of the telescope azimuth range.

Sky Map | High Regions

This displays circles indicating the position and approximate size of the regions in the current observation sequence which lie in the range of telescope azimuth motion above the first 360°.

Sky Map | North Hemisphere

This displays the stars from the catalog which lie in the Northern hemisphere (positive declination).

Sky Map | South Hemisphere

This displays the stars from the catalog which lie in the Southern hemisphere (negative declination).

Sky Map | Current Time

This displays the stars which are currently visible from the connected telescope. If no telescope is connected then the sky map display will be blank.

Sky Map | Magnitude Range...

This displays the *Magnitude Range Settings* dialog (Figure 17) which allows the user to specify a subset of the stars in the catalog to be displayed based on their magnitude.
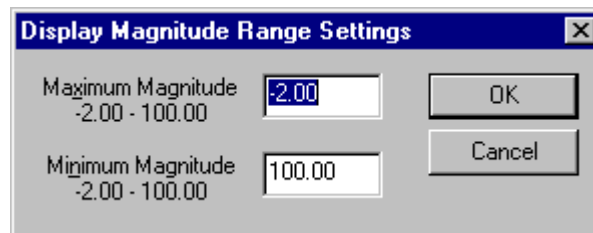
Figure 17 Magnitude Range Settings *dialog*

Sky Map | Refresh

This menu item toggles automatic refresh of the sky map display, which causes the display to be redrawn once per minute. By default automatic refresh is on.

2.2.7   Window Menu

The *Window* menu is used to select which information page to display in the main window. The tabs at the bottom of the main window can also be used.

Window | Sky Map

Display the *Sky Map* page.

Window | Observations

Display the *Observations* page.

Window | Mount Model

Display the *Mount Model* page.

Window | Catalog

Display the *Catalog* page.

2.2.8 *Help* Menu

Help | About Star Calibrator...

This displays a simple *About* box providing the version and date of the application.

2.3 Toolbar

A toolbar at the top of the main window provides quick access to some of the more common functions. Each of the toolbar buttons corresponds to a menu command. Hover over a toolbar button to see a description of its function.

2.4 Information Pages

The four main window information pages can be selected by clicking on the tabs at the bottom of the main window or by choosing the page from the *Window* menu.

The user can switch between these four pages at any time provided no dialog box is displayed.

2.4.1 Sky Map Page

The *Sky Map* page presents a graphical depiction of the night sky showing dots for stars currently visible from the telescope, or alternatively for the stars in the Northern or Southern hemisphere. If **StarCal** is not connected to a telescope then the sky map will be blank when showing the currently visible stars.

The magnitude of each star is represented by the size of its dot. Stars can be selected by clicking on them with the mouse. The selected star will be colored red and its details will be displayed to the right of the map. This star can then be tracked using *Operations | Observe Selected Star...* or added to an observation sequence using *Operations | Add New Observed Star...*.

Information on the current observation sequence is also shown. Stars that have been observed are colored green. Regions can be displayed as circles.

The *Sky Map* page can be updated automatically once a minute. This is only useful if it is set to display the currently visible stars, not the Northern or Southern hemisphere views.

2.4.2 Observations Page

This page lists the regions in the current observation set, showing which have been observed, which have been skipped, and which remain to be observed. Information includes the region location, the position of the star and the pre-fit residual error.

2.4.3 Mount Model Page

This page contains information about the mount model generated from the current observation set. Details on each observation are listed including the region center, the

star number and position, the pre-fit and post-fit residual errors in arc seconds, and the absolute error for each combining azimuth and elevation residuals into a single value.

Observations which were skipped or never made are listed as `<Not Observed>`. Observations which were deleted from the list when the user generated the mount model are shown as `<Not Selected>`.

The RMS errors for the pre-fit and post-fit residuals are calculated and shown at the end of the observation list. The post-fit RMS error is often taken as a measure of the quality of the new mount model, the lower the number the better. A good mount model has a post-fit RMS error of less than 3 arc seconds.

The parameters of the generated mount model are shown next. The value of each parameter, in arc seconds, indicates the magnitude of the compensation for that particular effect. This is useful when reviewing a history of mount models from the telescope to determine whether its mechanical characteristics are changing.

The standard deviation in arc seconds of each parameter is also shown. Standard deviations represent the amount of uncertainty in the value of the parameter. Parameters which are similar in nature may cause instability in the solution, and those parameters will have a high standard deviation indicating a high level of uncertainty in the value. The goal in generating a good mount model is to choose a set of parameters such that the standard deviations are all small, preferably less than 10 arc seconds.

Parameters which have been excluded from the mount model by the user have a value and standard deviation shown as `----`.

The covariance and correlation matrices are displayed below the mount model parameters. These matrices offer alternative representations of the interaction between parameters. Large numbers in the covariance matrix indicate stronger interactions. In the correlation matrix, values off the diagonal which are close to +1 or -1 identify parameters which are highly correlated. Either of these conditions suggests that the mount model may need to be refined by removing one or the other parameter.

The contents of this page can be written to a text file using *File | Save Report*.

The page will be blank if no mount model has been loaded or generated.

2.4.4   Catalog Page

The *Catalog* page lists the stars in the current star catalog (the FK5 catalog by default). These are shown on the sky map display and may be used for observations. All the relevant star details are shown: catalog number, magnitude, color, and celestial coordinates in right ascension and declination (both represented in degrees).

2.5   Status Bar

The status bar at the bottom of the main window displays the state of the connected telescope:

    Telescope disconnected

>   **StarCal** is not currently connected to any telescope.

    Telescope connected

>   A connection to the telescope has just been made.

`Telescope: Initialising`

> The telescope is transitioning to the `Initialised` state.

`Telescope: Initialised`

> The telescope is ready to accept commands. No power is applied to the telescope drives.

`Telescope: Homing`

> The telescope is transitioning from the `Initialised` state to the `Standby` state. This usually indicates that the telescope axes are being homed.

`Telescope: Standby`

> The telescope is ready to accept commands. Power has been applied to the telescope drives and they are being held in position.

`Telescope: Starting`

> The telescope is transitioning from `Standby` to `Tracking` where it will attempt to follow the currently loaded track.

`Telescope: Tracking`

> The telescope is following the currently loaded track.

`Telescope: Slewing...`

> The telescope has reached its maximum speed or acceleration. It may be slewing to the start of a newly loaded track, or the tracked object may be travelling too fast for it to keep up (e.g. a star passing very close to zenith).

`Telescope: Waiting for track to start...`

> The currently loaded track hasn't started yet.

`Telescope: Track has expired!`

> The currently loaded track has expired.

`Telescope: Telescope position limit!`

> The telescope has reached the edge of its allowable range of movement and cannot follow the currently loaded track.

`Telescope: Avoiding Sun`

> The telescope is inside the solar halo.

`Telescope: Stopping`

> The telescope is transitioning from the `Operate` state to the `Standby` state.

`Telescope: Error`

> The **Telescope Server** application has detected a serious error. Power has been removed from the telescope drives.

`Telescope: Terminating`

> The telescope is in the process of being shut down. No further communications with the **Telescope Server** application will be possible.

`Telescope: Unknown`

The telescope is in an unknown state. This may indicate a fault in the **Telescope Server** application.

```
Telescope: NotResponding
```

The **Telescope Server** application is not responding. This may indicate that it has crashed or that there is a problem with the network.

The status bar also displays a message describing the currently selected menu item.

2.6   Model equations

The terms in the mount model are defined using a simple symbolic notation. In this way, the tool allows for a wide range of possible terms, well beyond the typical set employed in standard analysis packages.

Each term uses any of several "input" values to compute any of several "output" values. The input values may be combined using the usual arithmetic operators and expressions, albeit with an abbreviated syntax that is designed for easy parsing. Inputs are the actual values, outputs are proportional to the *changes* in those values.

Table 1 Mount Model Output Values Notation

Input Value	*Notation*
Azimuth	*A*
Sky Azimuth	*S*
Elevation	*E*
Hour Angle	*H*
Declination	*D*

Table 2 Mount Model Input Values Notation

Output Value	*Notation*
Azimuth	*A*
Zenith Angle	*Z*
Elevation	*E*
Hour Angle	*H*
Declination	*D*
Parallactic Angle	*P*
Latitude	*L*
Pi	*p*

Table 3 Mount Model Operators Notation

Function	Notation
Constant	*1*
Separator	*;*
Assignment	*=*
Addition or unary plus	*+*
Subtraction, or unary minus	*-*
Multiplication	***
Division	*/*
Exponent	*^*
Begin expression	*(*
Close expression	*)*
Sine Function	*s*
Cosine Function	*c*
Tangent Function	*t*
Degrees-to-radians Function	*r*
Modulo Function	*m*

Multiplication is the assumed operator when two terms are adjacent.

Thus, we have the following examples:

A=1 means that the contribution to the modeled error in altitude from this term is to be proportional to a constant.

A=tEcA;E-sA means that the contribution to the modeled error in azimuth from this term is to be proportional to the product of the tangent of elevation and cosine of altitude; and that the contribution in elevation is to be proportional to the additive inverse of the sine of altitude.

A=s(2A) means that the contribution to the modeled error in azimuth from this term is to be proportional to the sine of twice the altitude.

2.7   Error Messages

Error messages from **StarCal** can appear in several different forms: in a dialog displayed to the user, displayed in the status bar at the bottom of the main window (see §2.5), or as an error event in the system event log. Errors recorded in the system event log are usually self-explanatory.

3   Operations

This section describes how to perform some typical operations using *StarCal*.

3.1   Starting the Application

StarCal can be run on any computer on the network. The *Dispatcher*, *Config Server*, *Alerts Server* and *Log Server* must be running in order to run *StarCal*, but depending on what is to be done it may not be necessary to connect to the *Telescope Server* application. In the standalone configuration with no connection to the telescope previously saved observation data can be loaded and mount models can be generated and analyzed.

To perform operations involving the telescope requires a connection to the *Telescope Server* application. Any other client applications such as *Telescope Interface* currently attached to *Telescope Server* can be left connected but be aware that a *StarCal* left unattended can suddenly cause the telescope to move or interfere with a track issued from another client.

Generally *StarCal* is started up by running StarCal.exe. When started a splash-screen should appear showing a satellite orbiting the Earth. Press any key to proceed to the main window. Note that the default sky map will be blank until *StarCal* is connected to a telescope.

3.2   Connecting to a Telescope

This operation is necessary before tracking stars or performing a set of observations. If the user tries to track a star before connecting to the telescope *StarCal* will prompt the user for a site to which to connect.

1. Choose *Telescope | Connect Telescope...*

    The *Connect Telescope* dialog box will appear.

2. Choose the telescope

    The current site from which you are running *StarCal* should already be selected in the list box. If you wish to use the telescope at another site select the other site from the list or type in the site name. Normally it will only be possible to connect to the local telescope.

3. Press *OK* to connect to the telescope

    StarCal will attempt to contact and connect to the *Telescope Server* application controlling the telescope. A remote connection sometimes takes several seconds to complete.

    A message will appear indicating whether the connection was successful or whether it failed. If it failed it could be for one of several reasons:

    • *Telescope Server* at the site is not running. Start up the *Telescope Server* application.

    • The site name was misspelt.

    • The computer you are using is not directly connected to the computer running *Telescope Server*.

    • The network is not operating.

• You are running an incompatible version of **StarCal**.

When connected the *Sky Map* page will display the stars currently visible from that telescope if the *Sky Map | Current Time* menu option is selected. This is selected by default when **StarCal** starts.

If **StarCal** is subsequently shut down it will automatically release control of and disconnect from the telescope. Note that the *Telescope | Disconnect Telescope...* menu command can be used to disconnect from the telescope without shutting down **StarCal**.

3.3   Displaying the Current Sky Map

1. Connect to a telescope

2. Display the *Sky Map* page

   Click on the *Sky Map* tab at the bottom of the main window or choose *Window | Sky Map*.

3. Select the Current Time display option

   Choose *Sky Map | Current Time* or select the *Current Time* button on the toolbar. The main window will show the stars currently visible (above the 0° horizon) using the latitude, longitude and clock of the connected telescope. If **StarCal** is not connected to a telescope then the map will be blank.

The sky map display automatically updates every minute. Toggle the *Refresh* button on the toolbar or the *Sky Map | Refresh* menu item to disable this feature.

The Northern or Southern hemisphere stars can be displayed if desired. The stars in the Northern and Southern hemispheres can be displayed by pressing the *Northern Hemisphere* or *Southern Hemisphere* buttons on the toolbar or by selecting the *Sky Map | North Hemisphere* or *Sky Map | South Hemisphere* menu commands. Note that these displays do not change with time or location and can be viewed without connecting to a telescope.

3.4   Tracking a Star

1. Connect to a telescope

2. Take control of the telescope

   In order to command the telescope to move **StarCal** must be in control. Choose *Telescope | Take Telescope Control* to take control of the telescope.

3. Display the current sky map

4. Select a star to track

   Click on one of the stars using the mouse. It can sometimes be difficult to select the desired star, especially if it is faint and represented by a small dot, or if it overlaps other stars. In these cases it can be helpful to expand the window to fill the entire screen, select the star, and then shrink the window back to its original size.

5. Command the telescope to start tracking

Choose *Operations | Observe Selected Star....* A track will be generated for the selected star and sent to **Telescope Server** and the *Observe Star* dialog box will appear. There is no limit to how long the star may be tracked.

StarCal will prompt the user if it is not connected to or does not have control of the telescope.

Be careful not to choose either of the first two options in this menu, *Operations | Observe Stars...* or *Operations | Add New Observed Star....* These will proceed to select and observe a star in the next region in the observation set. This mistake is easy to correct by clicking the *Cancel* button in the *Make Star Observations* dialog box (which is larger than the *Observe Star* dialog box) and then choosing the correct menu option.

6. Alternatively, track a star by catalog number

Rather than choosing a star from the sky map, the telescope can be instructed to track a specific star from the catalog by specifying its identification number.

Choose *Operations | Observe Star by Catalog ID....* and enter the catalog identification number of the desired star.

A track will then be generated and sent to **Telescope Server** and the *Observe Star* dialog box will appear. There is no limit to how long the position may be tracked.

StarCal will prompt the user if it is not connected to or does not have control of the telescope.

7. Alternatively, track a celestial coordinate

Instead of tracking one of the stars in the sky map, the telescope can be instructed to track a specific position on the celestial sphere.

Choose *Operations | Observe RA/Dec....* The *Sky Coordinates* dialog will appear allowing the user to enter right ascension (R.A.), declination (dec.) and equinox. Parallax and proper motion can also be specified if desired.

A track will then be generated and sent to **Telescope Server** and the *Observe Star* dialog box will appear, showing the celestial coordinates instead of the star magnitude and color normally shown. There is no limit to how long the position may be tracked.

StarCal will prompt the user if it is not connected to or does not have control of the telescope.

8. Wait for the telescope to reach the specified position

The telescope state is shown on the left side of the status bar at the bottom of the main window. If the telescope is not currently operating when the command is issued then it will automatically go through its power-up and homing sequence and the status bar will display `Telescope: Homing`. While moving into position it should show `Telescope: Slewing...` and when it reaches the specified position and begins tracking it should change to `Telescope: Tracking`. If an error occurs the message will change to `Telescope: Error`.

9. Adjust the pointing if desired

Position offsets can be entered to adjust telescope pointing. Click on the *Controller* button in the *Observe Star* dialog to bring up the *Offset Controller* dialog box shown in Figure 10.

10. Stop tracking

Choose *Close* or *Cancel* in the *Observe Star* dialog box to stop tracking. The telescope will stop at its current position.

3.5 Star Calibrations

StarCal is often used to calibrate or model the mechanical characteristics of the telescope mount. The name of the application in fact comes from "star calibration", the process whereby a series of star positions are used to collect data to build a model of mount pointing errors. Such mount models allow a precise mapping between theoretical and actual telescope pointing angles.

This procedure describes how to observe a set of stars and acquire data for later use in generating a mount model.

1. Set the current meteorological data

The meteorological information is used to calculate atmospheric refraction. It is important to have current values in order to get an accurate star calibration. Meteorological measurements are collected by the ***TelescopeMetsServer*** and can be checked using ***Telescope Interface***.

2. Connect to a telescope

3. Start a new observation sequence

Choose *File | New...*. This will bring up the *New StarCal Dataset* dialog box. Fill in the parameters for the new observation sequence. These include:

No. of stars

This is the number of regions in the observation sequence. The more regions which are included, the better the results will be. However it will also take longer to carry out the star calibration.

Repeats per star

To reduce the risk of operator error, or errors based on direction of motion of the telescope, repeat observations are made for each star.

Repeats are not implemented in this release of the software. Only a single observation of each star will be made.

Magnitude Limit

This specifies the maximum magnitude (minimum brightness) of stars which will be automatically selected by ***StarCal*** from each region. Set this according to the visibility of stars on the night. If the sky is clear then use the maximum value of 9. If conditions are hazy or somewhat cloudy then use a lower value such as 4 so that only the brighter stars will be selected.

This parameter does not affect stars which the user selects manually using *Operations | Add New Observed Star...*.

Horizon Limit

This determines the minimum region elevation and hence the lowest elevation of stars which will be automatically selected by **StarCal**. This value, specified in degrees, should correspond with the visible horizon of the telescope determined by nearby buildings or trees, atmospheric haze, operating limitations, etc.

This parameter does not affect stars which the user selects manually using *Operations | Add New Observed Star...*.

Selection Method

For each observation **StarCal** will automatically choose an appropriate star lying within the corresponding region, based on the magnitude and horizon limits specified above. If more than one star satisfies these conditions then it must pick which one to select according to the criterion specified by this parameter:

Closest to centre of region

This picks the star which is nearest to the center of the region, and will give a more even spread of points over the sky. However, because regions occur in rings of equal elevation this option may result in a mount model based on observations in a few narrow elevation bands. This provides a very poor spread of points in elevation.

Brightest in region

This will choose the brightest star (lowest magnitude) and is recommended during poor seeing conditions.

Because of the problem with banding in elevation when using *Closest to centre of region*, most star calibrations should instead use the *Brightest in region* option.

This parameter does not affect stars which the user selects manually using *Operations | Add New Observed Star...*.

Seeing estimate

An estimate of the quality of the atmosphere (seeing) should be entered here. This is a comment field which does not affect operation of the software.

Comments

Additional information pertaining to the star calibration should be entered here. For example the information may include the observer's name, the date, the reason for the star calibration, and anything unusual about the telescope.

This field does not affect operation of the software.

Press *OK* when the desired parameters have been entered. Regions will then be generated to evenly cover the sky above the specified horizon limit. Occasionally it may not be possible to provide even coverage using the requested number of regions, in which case a message will be displayed to inform the user that additional regions have been created.

4. Take control of the telescope

5. Start tracking the next star in the sequence

> To have StarCal automatically select a star from the next region choose *Operations | Observe Stars....* A star matching the selection criteria (magnitude, elevation, brightest or closest to center) will be selected, the telescope will begin moving to the star, and the *Make Star Observations* dialog box will appear showing the location of the region and information identifying the selected star.

> Alternatively, to manually select a star to be added to the observation sequence, click on a star on the *Sky Map* page and choose *Operations | Add New Observed Star....* A new region will be created with the selected star at its center and will be inserted into the observation sequence. If there is ambiguity in how the telescope can track the star the user will be prompted to select the appropriate orientation in the *Select Telescope Orientation* dialog box. The telescope will then begin moving to the star and the *Make Star Observations* dialog box will appear showing the location of the region and information identifying the selected star.

> Be careful not to choose *Operations | Observe Selected Star....* This will proceed to track the star currently selected in the sky map, but marking this star (see Step 8 below) will not add it to the data used to generate the mount model. The mistake is easy to correct by clicking the *Cancel* button in the *Observe Star* dialog box (which is smaller than the *Make Star Observations* dialog box and does not contain region information) and then choosing the correct menu option.

6. Wait for the telescope to reach the star

7. Center the star on the reference mark

> A reference mark must be established on the camera displaying the star images to represent the nominal center of the telescope's field-of-view. If the telescope includes an instrument rotator, this is normally defined as the center of rotation of the instrument rotator, the point where there is no translation of an image as the rotator is moved. Otherwise, any fixed reference point on a camera image is suitable.

> Position offsets may have to be entered to adjust telescope pointing to move the star image onto the reference mark. Click on the *Controller* button in the *Make Star Observations* dialog to bring up the *Offset Controller* dialog box shown in Figure 10.

8. Mark the star's position

> Click on the *Mark* button when the star is positioned appropriately. The current positions of the telescope and the star are taken and will be used later when generating the mount model. The current offset will be displayed on the *Make Star Observations* dialog box.

> The *Mark* button can be clicked as many times as desired. Only the information from the last click will be recorded and used.

9. Accept the observation

> Click on the *OK* button in the *Make Star Observations* dialog box to accept the observation. This will record the details of the observation and will close

both the *Make Star Observations* dialog box and the *Offset Controller* dialog box.

The *OK* button will not be enabled until the *Mark* button in the *Offset Controller* dialog box has been clicked.

10. OR Reject the observation

Click on the *Cancel* button in the *Make Star Observations* dialog box to reject the observation. This is useful if an error occurs with the telescope tracking or if the user wishes to interrupt the current observation sequence to perform some other task, perhaps returning later to continue the sequence.

Note that if a new region was created using *Operations | Add New Observed Star...* in Step 5, then rejecting the observation will cause the new region to be discarded instead of being inserted into the sequence.

11. OR Skip the region

Click on the *Skip Star* button in the *Make Star Observations* dialog box to reject the region altogether. This is useful if the star cannot be found, perhaps due to cloud or other interference. The region will be marked as `Skipped` and will not be included in mount model calculations.

12. Repeat for each region

Repeat Steps 5 to 11 until all regions in the sequence have been observed.

Note that it is possible to abort the sequence before observing all regions, and a sequence does not have to be completed in order to generate a mount model.

13. Save the data to file

Save the collected data to a file using *File | Save* or *File | Save As...*.

The observation details can be reloaded at any later time using *File | Open...*. Further observations can then be added to the sequence if desired (if all the regions have been observed then new regions will have to be added manually using *Operations | Add New Observed Star...*).

3.6   Generating a Mount Model

This procedure describes how to generate a mount model. An observation sequence must be loaded into *StarCal*, either by carrying out the procedure described in §3.5n §3.5 or by loading an observation sequence from a file using the *File | Open...* menu command.

1. Generate a mount model

Choose *Operations | Generate Mount Model...* and select the desired parameters (sometimes also known as *coefficients*) and regions from the *Mount Model Parameters* dialog box. The coefficients used in the current mount model will be selected by default.

Note that there must be at least one more region than the number of parameters to calculate. It is usually wise to have at least twice as many regions as parameters to ensure the calculations are not under-constrained.

Click the *OK* button to calculate the parameters and choose the *Mount Model* tab on the main window or *Window | Mount Model* to display details of the newly generated mount model.

2. Repeat until a suitable model has been generated

The aim is generally to produce a model consisting of as many parameters as possible using as many observations as possible and producing low post-fit RMS error and low standard deviation in all the parameters.

If the model does not appear to be very good it may help to remove some parameters or regions. Choose one of the parameters with the highest standard deviation to remove, and re-generate the mount model.

Parameters which are highly correlated can interfere with one another, so removing one often helps reduce the standard deviation for others. For example, `Sin(elevation) in elevation` and `Cos(elevation) in elevation` are particularly susceptible to this. However removing parameters makes it more difficult for the software to find a model which compensates for those mechanical anomalies, so the post-fit RMS usually increases.

Removing regions usually improves the post-fit RMS error. When choosing regions to remove the best results often come from choosing those with the highest post-fit RMS errors. However, regions should not be removed if it will leave a gap in the coverage of the sky. Complete and even coverage is important for ensuring the mount model is valid over the full range of telescope movement.

3. Save the mount model

Once an acceptable mount model is generated it should be saved to a file using *File | Save* or *File | Save As...*. The observation details and the last generated mount model are stored in the file and can be reloaded at any later time using *File | Open...*, allowing further models to be generated and even further observations to be made.

4. Install the mount model (optional)

Choose *Operations | Install Mount Model...* to download the new mount model to the telescope. After confirming the action with the user, from then on the telescope will use this mount model on the instrument port which is currently in use.

The new model is typically stored in C:\EOST\Servers\ConfigFiles\SettableData\TelescopeMountModel.dmx. In case it may be necessary to restore the old mount model it is recommended that TelescopeMountModel.dmx be copied to a backup directory before executing this command.

The accuracy of the new mount model should be tested by selecting and tracking individual stars.