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# EOS Technologies, Inc.

**UCO/Lick APF Telescope**

# Telescope Simulator Software
# User Manual

**SUM-5334-1**
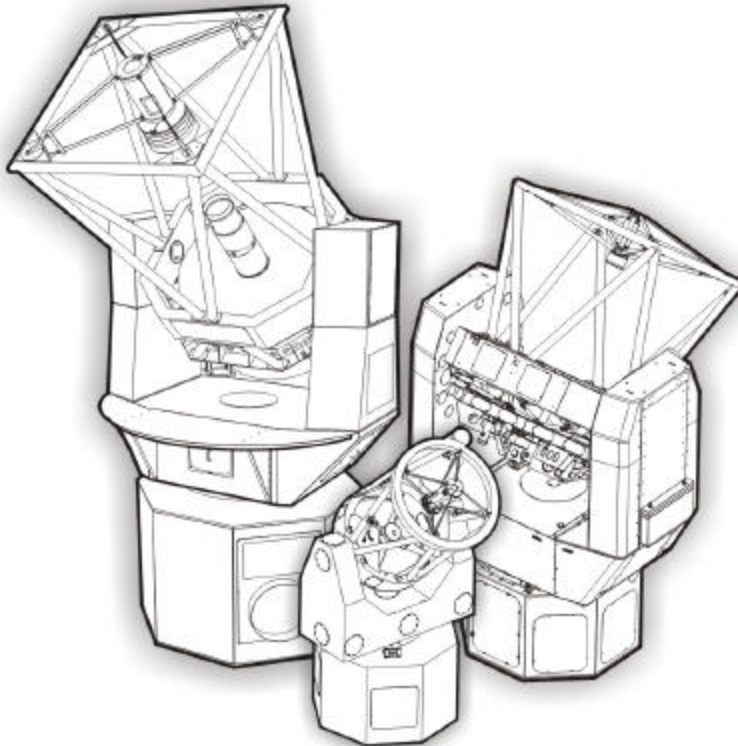
# DOCUMENT CONTROL

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**UCO/Lick APF Telescope**

# TELESCOPE SIMULATOR SOFTWARE USER MANUAL

## 1. INTRODUCTION

### 1.1 SCOPE

This document describes the Telescope Simulator software package provided for the UCO/Lick Automated Planet Finder Telescope project. This software has been released as CDE-5333-1.

This document has been configured as SUM-5334-1 and is a designated controlled document under the EOST Quality System.

## 2. INSTALLATION

This section describes how to install the Telescope Simulator software package.

### 2.1 MINIMUM SYSTEM REQUIREMENTS

The software is designed to run on a computer satisfying the following requirements:

Windows NT/2000/XP

Pentium II 450MHz processor

128 MB of RAM (256 MB for Windows XP)

300 MB free hard drive space on C: drive

The software can operate on a computer with fewer resources, but performance may be less than adequate.

### 2.2 PACKAGE CONTENTS

The software is provided as a single ZIP archive file containing all the files required for operation. These files are arranged in a directory hierarchy below a top-level directory called `Lick` as shown below:

`Lick\Configuration`

System configuration files.

`Lick\Keystone`

Legacy software.

`Lick\Servers`

Server applications.

`Lick\Utilities`

Client and utility applications.

## 2.3  INSTALLATION PROCEDURE

To install the simulator on a suitable computer, follow these steps:

1. Extract the contents of the ZIP file to the computer

2. Move the Lick subdirectory to `C:\Lick`

3. Move the `Lick\Keystone` subdirectory to `C:\Keystone`

4. Copy the two files in `Lick\Configuration` to the Windows directory on the computer

   The two configuration files are `CommonLocalConfig.dmx` and `KEYSTONE.INI`. These define some common parameters that all the software applications use.

   The Windows directory is usually `C:\Windows` or `C:\WINNT`.

# 3.  OPERATING INSTRUCTIONS

This section provides an overview of how to start the simulator software and shut it down.

## 3.1  STARTING THE SERVERS

The simulator consists of a number of components, which must be started in the following order:

1. ***Dispatcher***

   Set the current working directory to `C:\Lick\Servers\Dispatcher` and run `Dispatcher.exe`. This component provides inter-application messaging between clients and servers.

2. ***Config Server***

   Set the current working directory to `C:\Lick\Servers\ConfigServer` and run `ConfigServer.exe`. This component provides configuration information for the other applications.

3. ***Alerts Server***

   Set the current working directory to `C:\Lick\Servers\AlertsServer` and run `AlertsServer.exe`. This component handles exceptions.

4. **Log Server**

Set the current working directory to `C:\Lick\Servers\LogServer` and run `LogServer.exe`. This component provides an event logging service for the other applications.

5. **Telescope Server**

Set the current working directory to `C:\Lick\Servers\TelescopeServer` and run `Telescope.exe`. The **Telescope Server** controls the telescope hardware in response to requests from clients.

The command script `StartSimulator.bat` in the `C:\Lick` directory has been provided as a convenient means to start the software. This script starts both the server applications and the two telescope clients.

## 3.2 STARTING THE CLIENTS

Once the servers have been started, several client applications can be run that will interact with these services:

1. **Telescope VCP**

Set the current working directory to `C:\Lick\Utilities\TelescopeVCP` and run `TelescopeVCP.exe`. This application is a *virtual control panel* (VCP) that provides an engineering-level interface displaying low-level telescope diagnostics and controls to allow the user to drive the telescope.

For more details on operating **Telescope VCP**, please see the section of this document devoted to **Telescope VCP**.

2. **StarCal**

Set the current working directory to `C:\Lick\Utilities\StarCal` and run `StarCal.exe`. This application provides a higher level of interface than the **Telescope VCP** that allows the user to track stars. It also has functions for calibrating the pointing model used by the telescope.

For more details on operating **StarCal**, please see the section of this document devoted to **StarCal**.

3. **Device Browser**

Set the current working directory to `C:\Lick\Utilities\DeviceBrowser` and run `DeviceBrowser.exe`. This optional application provides real-time updates of server state.

The command script `StartSimulator.bat` in the `C:\Lick` directory has been provided as a convenient means to start the software. This script starts both the server applications and the two telescope clients.

## 3.3  UTILITY APPLICATIONS

Two utility applications are provided as part of the system.  These run independently of the servers and clients.

1. ***Log Viewer***

   This application can be used to view the event logs (*.elf) for the system.  Event logs are written by each application and can be found in that application's `Logs` subdirectory.

   To run ***Log Viewer***, set the current working directory to `C:\Lick\Utilities\Log Viewer` and run `Log Viewer.exe`.

2. ***DML Editor***

   This application can be used to view and edit the configuration files for several of the applications in the system.  These configuration files are either DML Extend files (*.dmx) or DML Schema files (Schema-*.dms) and are found in various locations in the `Lick` directory structure.

   To run the ***DML Editor***, set the current working directory to `C:\Lick\Utilities\DML Editor` and run `DMLFileEdit.exe`.

## 3.4  SHUTTING DOWN THE SYSTEM

To shut down the simulation follow these steps:

1. Shut down all client applications, i.e. ***StarCal***, ***Telescope VCP***, and ***Device Browser***.

2. Shut down the servers in reverse order, i.e. ***Telescope Server*** (this has two windows that need to be closed), ***Log Server***, ***Alerts Server***, ***Config Server***, and ***Dispatcher***.

The command script `StopSimulator.bat` in the `C:\Lick` directory has been provided as a convenient means to stop the software.  This script stops any clients that may be running (***Telescope VCP***, ***StarCal*** and ***Device Browser***) and then the server applications.

Any utility applications (***Log Viewer***, ***DML Editor***) can be shut down independently of the servers and clients.

# 4.  TELESCOPE VCP

***Telescope VCP*** is a client application of ***Telescope Server*** and serves as the primary user interface for the telescope.  It provides diagnostic information and control not normally available through other client applications and can be used to monitor the status of the telescope and drive it to specific positions.

To use ***Telescope VCP*** the system must be started up as described above and the ***Telescope Server*** application must be running.  Other client applications such as

*StarCal* or instances of **Telescope VCP** running on other computers can be attached to the telescope at the same time but only one can be in control.

## 4.1 QUICK START GUIDE

Set the current working directory to `C:\Lick\Utilities\TelescopeVCP` and run `TelescopeVCP.exe`. **Telescope VCP** will ask for a password to connect to the Lick telescope — enter `vcpuser` and click *OK*.

The polar plot should display an icon for the telescope at 0 degrees azimuth and 0 degrees elevation. Depending on the time of day, the Sun may also be visible.

Click the *Control* radio-button in the top left corner of the **Telescope VCP**. Below the *Control* radio-button are two edit boxes, *AZ* and *EL*. Enter `90` and `0` in these two boxes respectively to specify a commanded position of 90 degrees azimuth and 0 degrees elevation (due East) and then click the *Go* button. The telescope icon should begin to move as the telescope executes its homing procedure. After about 20 seconds it will reset to its starting position and then start moving to the right edge of the polar plot, which represents the eastern horizon.

## 4.2 APPLICATION STRUCTURE

### 4.2.1 Windows

The application is centered around the main display window which contains numerous controls separated into functional blocks. From here smaller dialog boxes can be opened to control the Secondary Focus mechanism, the Instrument Rotator and Data Logging, or to connect to a different telescope (not relevant for the Lick project).

Figure 4.1 shows the main window for **Telescope VCP**, while Figures 4.2–4.6 show the other dialogs available from within the application.
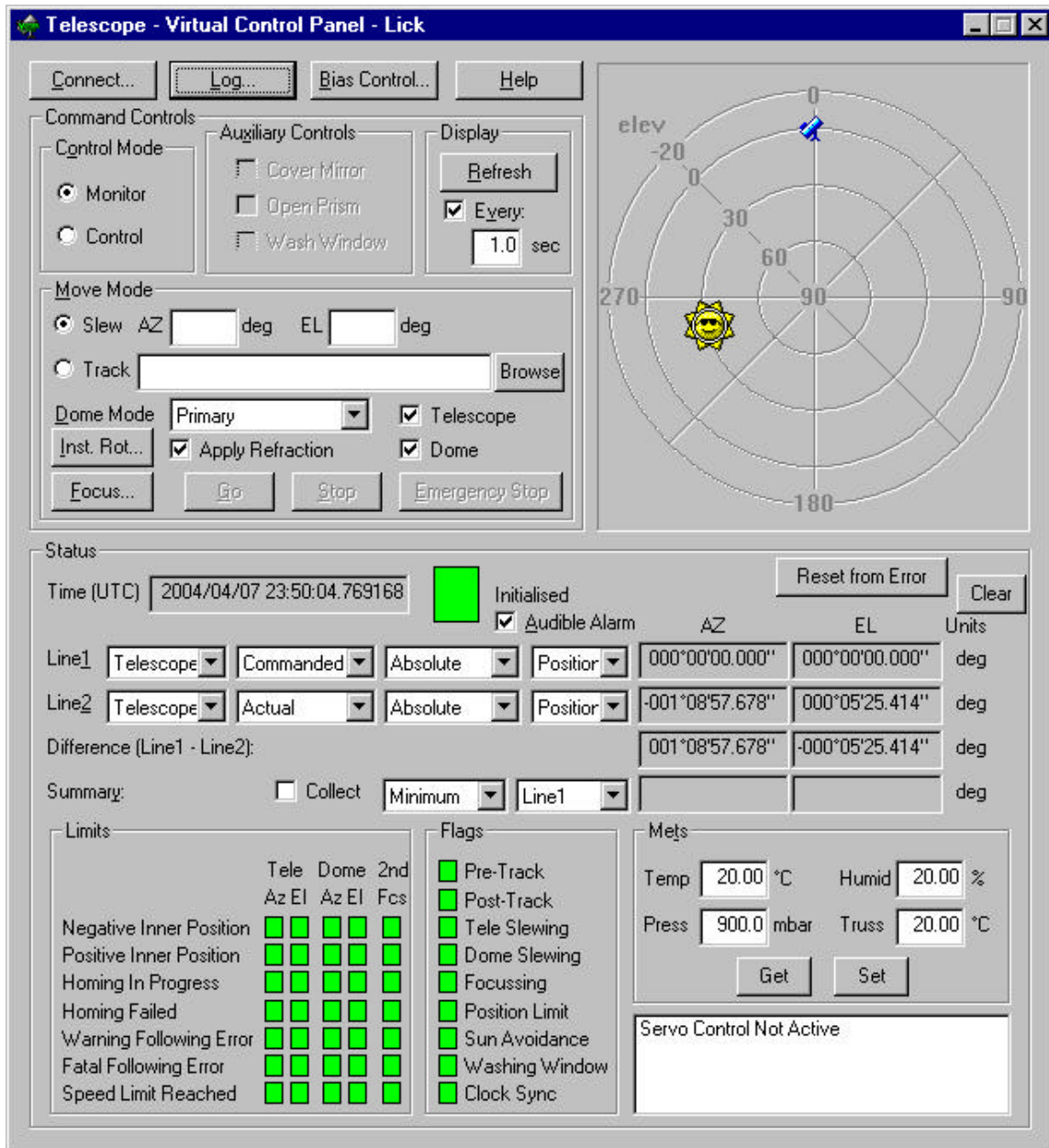
Figure 4.1: The **Telescope VCP** main window

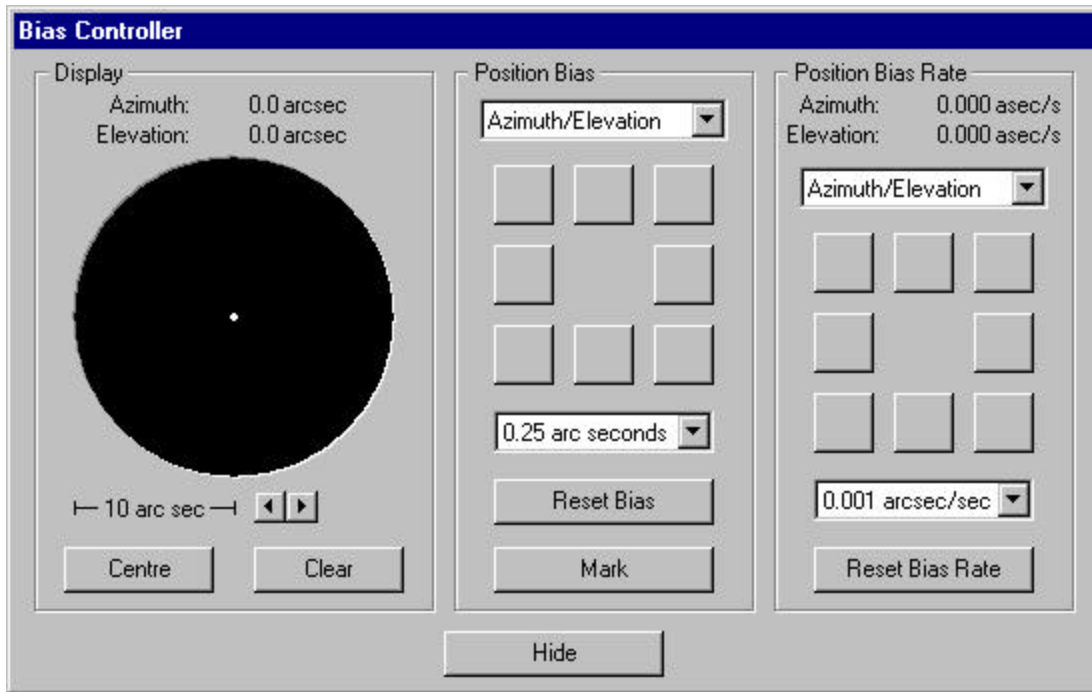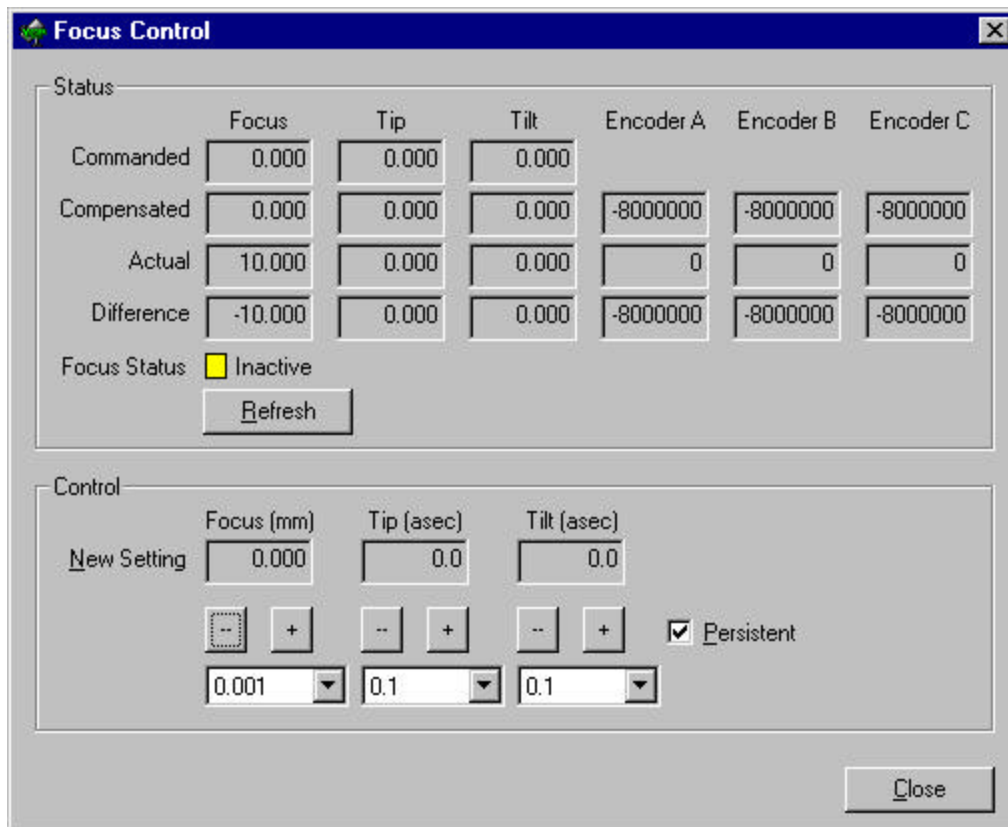Figure 4.2: The **Telescope VCP** *Bias Controller* dialog



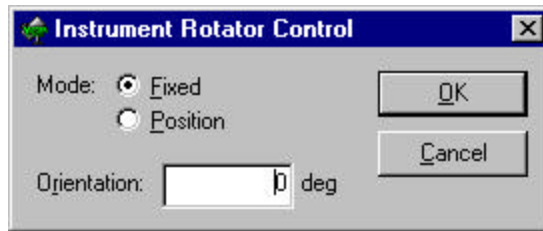Figure 4.3: The **Telescope VCP** *Focus Control* dialog

Figure 4.4: The **Telescope VCP** *Instrument Rotator Control* dialog
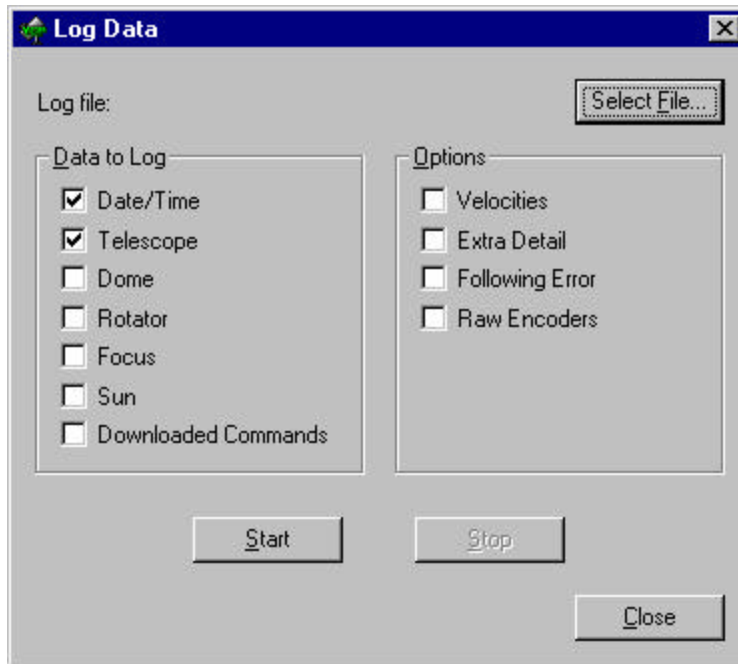


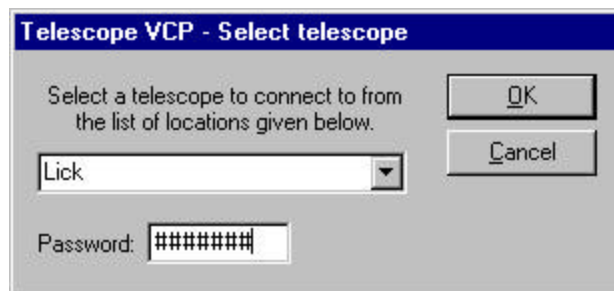Figure 4.5: The **Telescope VCP** *Data Logging* dialog



Figure 4.6: The **Telescope VCP** *Select Telescope* dialog

### 4.2.2  Guide to Controls

This section describes the various controls available in **Telescope VCP**.

### 4.2.2.1  Top Button Group

A group of four buttons in a row along the top of the display provide functions as follows:

*Connect...* button

> This displays the *Select Telescope* dialog box allowing the user to connect to a telescope at a specified site (see Figure 4.6).  This dialog box is also displayed automatically when **Telescope VCP** starts.

> Normally the telescope at the current site is displayed by default.  Some of the commands accessible via **Telescope VCP** are quite low level and while not potentially damaging could interfere with other telescope operations.  Therefore a password must be entered to connect to the telescope.  The password for Lick is `vcpuser`.

*Log...* button

> This opens up the *Log Data* dialog box that allows the user to log position data to a file (see Figure 4.5).  The user selects the file to be written to, the parameters to be logged, and can start and stop logging as required.  If the file doesn't exist it will be created.  If the file does exist new data will simply be added to it.  A recommended convention is to use the extension `.log` for log files.

> One record will be appended to the file each time the main window display is refreshed, either by pressing the *Refresh* button or enabling periodic refresh using the *Every* check box.  The data typically includes the current time as well as the commanded and actual positions of the telescope and dome, and is written in a format which can be imported into **Excel** for analysis.  See §4.4.2 Log Files for more details.

*Bias Control...* button

> This button brings up the *Bias Controller* dialog box (see Figure 4.2) which is also used in **StarCal**.  This allows the user to apply offsets to incrementally adjust the telescope position around the currently tracked point.

> The left side of the dialog displays the current offset applied to the telescope.  Both a digital and a graphical representation are given.  The graphical representation shows the history of offsets made to the telescope position — applying offsets leaves a trail of dots.  The buttons at the bottom of this half control the graphical display:

> > Arrow buttons

> > > These zoom the display in and out, which is useful for showing detail of small offsets or for getting a broad picture.  The left arrow reduces the scale of the display in fixed increments while the right arrow increases the scale of the display.  The current radius of the display is shown to the left of the arrow buttons.

*Centre* button

This centers the display on the current offset. This is useful if the current offset is off the display.

*Clear* button

This clears the historical trail of offsets from the display. After pressing this button only the current offset will be displayed.

The middle section of the dialog is used to enter new offsets:

Orientation listbox

This determines the orientation in which to apply offsets. Offsets can be applied in one of two orientations:

`Azimuth/Elevation` — left and right offsets correspond directly to azimuth, while up and down offsets correspond to elevation.

`Across/Along Track` — offsets are made with respect to the direction of motion of tracking. Left and right offsets are perpendicular to the current direction of the track, as looking out from the telescope, while up and down offsets are along the direction of the track: up moves in the direction of the track and down moves in the opposite direction. If the telescope is stationary then these correspond directly with `Azimuth/Elevation`.

Note that changing the orientation will clear any offset already applied.

Step buttons

These eight buttons each produce a single step in the corresponding cardinal direction.

Stepsize listbox

This controls the size of each step in offset. It also controls the units used in the digital display of the current offset on the left side of the dialog.

*Reset Bias* button

Pressing this button resets the offset to $(0, 0)$.

*Mark* button

This button is used to mark the current offset. For some applications this may have special meaning, such as recording the current telescope position when used in **StarCal**. However for **Telescope VCP** it simply colors the current offset red in the graphical display.

The right side of the dialog is used to enter offset rates, which are continuously varying offsets. The controls in this section operate in much the same way as the offset controls in the middle of the dialog. Note that offset rates are added to any constant offset that is currently applied.

The *Hide* button at the bottom right of the dialog closes the dialog.  This does not affect the currently applied offset.

This dialog also provides keyboard support:

| | |
|---|---|
| ‹Up arrow› | step up |
| ‹Down arrow› | step down |
| ‹Left arrow› | step left |
| ‹Right arrow› | step right |
| ‹Home› | step up and left |
| ‹End› | step down and left |
| ‹PageUp› | step up and right |
| ‹PageDn› | step down and right |
| ‹Ctrl-Home› | *Reset Bias* |
| ‹Insert› | *Centre* |
| ‹Delete› | *Clear* |
| ‹Space› | *Mark* |
| ‹Enter› | *Mark* |
| ‹Escape› | *Close* |
| ‹Ctrl-PageUp› | decrement orientation |
| ‹Ctrl-PageDn› | increment orientation |
| ‹Ctrl-Left arrow› | decrement display radius |
| ‹Ctrl-Right arrow› | increment display radius |
| ‹Ctrl-Up arrow› | decrement step size |
| ‹Ctrl-Down arrow› | increment step size |
| ‹Shift-Up arrow› | rate up |
| ‹Shift-Down arrow› | rate down |
| ‹Shift-Left arrow› | rate left |
| ‹Shift-Right arrow› | rate right |
| ‹Shift-Home› | rate up and left |
| ‹Shift-End› | rate down and left |
| ‹Shift-PageUp› | rate up and right |
| ‹Shift-PageDn› | rate down and right |
| ‹Ctrl-PageUp› | decrement orientation |

| ‹Shift-Ctrl-PageDn› | increment rate orientation |
| ‹Shift-Ctrl-Up arrow› | decrement rate step size |
| ‹Shift-Ctrl-Down arrow› | increment rate step size |
| ‹Shift-Ctrl-Home› | *Reset Bias Rate* |

Biasing can only be done if **Telescope VCP** has control of the telescope. The telescope position can be biased when it is idle and even when it is not operating (in which case bias commands will be ignored). Each time a new slew or track command is sent by pressing the *Go* button, position bias will be reset to zero.

In **Telescope VCP** the *Mark* button does nothing except highlight the current bias point in red. In other applications it may be used to signal an event or to take a data sample.

*Help* button

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

### 4.2.2.2 *Control Mode* Group

These two radio buttons are used to take or release control of the telescope.

*Monitor* radio button

To simply observe the telescope without driving it or changing its operating parameters select this button. This is the default selection when first connecting to the telescope. If the *Control* button was previously selected then control of the telescope will be released, allowing other applications to take control.

*Control* radio button

To take control of the telescope select this button. Only one application can be in control of the telescope at a time. If another application is in control when this button is selected, the status indicator in the center of the window will briefly flash red to signify that the request to take control was rejected by **Telescope Server**, and the *Monitor* button will automatically be re-selected.

When in control, those buttons which initiate actions requiring control, such as *Go*, *Stop* and *Emergency Stop*, will be enabled.

### 4.2.2.3 *Auxiliary Controls* Group

This group of controls provides functions which are not directly related to tracking.

*Cover Mirror*

The *Cover Mirror* checkbox is intended to open and close the primary mirror cover. This function is not available in this version of the software.

*Open Prism*

> The *Open Prism* checkbox allows the user to open the vertical ranging prism shutter. This function is not available on the Lick system.

*Wash Window*

> The *Wash Window* checkbox is used to start a dome window washing operation. This function is not available on the Lick system.

### 4.2.2.4 *Display* Group

These control the rate of display of time and position information in the **Telescope VCP** main window and in its focus dialog. They also control the rate at which records are written to the log file during data logging.

Note that status information, including the status of individual components and axes as well as the overall status of the telescope, is updated automatically whenever it changes, independent of the controls in this group.

*Refresh* button

> The *Refresh* button is used to update the time and position information displayed by **Telescope VCP**. Each time the button is pressed new data will be retrieved from the telescope and displayed. This may be useful for taking a snapshot of the telescope time and position coinciding with a particular event.

*Every* checkbox

> The *Every* checkbox and the associated edit field are used to poll the telescope continuously for time and position information. This provides a constantly refreshing display and is functionally equivalent to pressing the *Refresh* button at regular intervals.

> Enter the refresh period (in seconds) into the edit field and check the *Every* box to start refreshing the display at the specified rate. To change the rate type a new value into the edit field and then uncheck and recheck the *Every* box.

> The smallest supported refresh period is 0.1 seconds. Although telescope performance should not be affected, frequent polling of the telescope position can slow down other operations on the computer on which **Telescope VCP** is running. Network activity may also be affected. It is recommended that for routine purposes the maximum polling rate be limited to once per second (i.e. refresh period no less than 1 second). **Telescope VCP** starts up with a refresh period of 1 second by default.

### 4.2.2.5 Polar Plot

The polar plot in the top right quadrant of the main window displays the actual position of the telescope as a small telescope icon. The polar plot uses the convention that North is at 12 o'clock, East is at 3 o'clock, zenith is in the center, and the horizon

(0° elevation) forms a circle around the outside of the plot. This is similar to the view when looking down on the telescope from above.

A trail of the last 50 points is maintained to show where the telescope has been. The plot is updated each time the display is refreshed (see §4.2.2.4 *Display* Group). The actual position of the Sun is also displayed while it is above -5° elevation, providing a quick indication of whether the telescope is in danger of tracking too close to the Sun.

### 4.2.2.6 *Move Mode* Group

These controls are used to move the telescope.

*Slew* radio button

> This button is used to slew the telescope. A slew is a high-speed move to a new position in the shortest time possible.
>
> To slew the telescope, select this button and enter the coordinates of the new position (azimuth and elevation, in degrees) in the edit boxes labeled *AZ* and *EL*. Then press the *Go* button to commence the slew.
>
> Either azimuth or elevation (but not both) may be left blank, in which case the current azimuth or elevation of the telescope will be used.

*Track* radio button

> **Telescope VCP** also supports more complex moves than slews. Select the *Track* radio button and enter the full path name of a track file into the adjacent edit box. The *Browse* button can be used to easily find a file. Then press the *Go* button to start following the track specified in the file.
>
> Track files are described in §4.4.1 Track Files.

*Dome Mode* listbox

> The dome is not controlled by the current release of Lick software. This selection has no effect on the operation of the telescope.

*Apply Refraction* checkbox

> Correction for atmospheric refraction can be applied to any move by checking the *Apply Refraction* checkbox prior to pressing *Go*. The correction is applied to the elevation position only and depends on the current atmospheric conditions, which can be specified using the controls in the *Mets* group described in §4.2.2.10 *Mets* Group.

*Telescope* and *Dome* checkboxes

> The telescope, the dome or both can be held in their current position rather than following the current track or slew. This allows the telescope and dome to be driven independently. However the current release of Lick software does not control the dome so this feature is of little use. The *Telescope* checkbox should be checked at all times.

*Focus...* button

This will display the *Focus Control* dialog (see Figure 4.3). This allows the user to monitor or control the position of the secondary mirror. Note that **Telescope VCP** does not have to be in control in order to move the secondary focus. This allows the focus to be adjusted while **StarCal** is tracking a star.

The secondary mirror mechanism consists of three actuators which together provide the movements of focus (piston), tip (vertical) and tilt (horizontal). Focus position is represented in terms of millimeters, measured from the collimated position in the direction away from the primary mirror. Tip and tilt are each represented in terms of arcseconds movement of the image at the focal plane with respect to the collimated position. A positive tip moves the image up in elevation; a positive tilt moves the image right (clockwise) in azimuth.

The position of each axis can be controlled by selecting a step size for the axis from the drop down listboxes at the bottom of the dialog box. Each press of the '+' or '-' button above the step size will adjust the position by one step, as shown in the edit boxes labeled *New Setting*.

The *Persistent* checkbox controls whether the new setting will persist beyond the current session. Check this box to have the new settings maintained after the current controlling client releases control of the telescope. Clear this box to return the mirror to its collimated position when the client releases control.

The mirror position can be set even when the telescope is not operating. However, the mirror will not move to its commanded position until the telescope begins tracking.

A variety of position information is shown in the dialog. The *Commanded* position indicates the last focus command received by the **Telescope Server** application. The *Compensated* position represents the commanded position adjusted for flexure of the telescope structure due to temperature and zenith angle. The *Actual* position is read back from the servo control system and represents the true position of the mechanism. The *Difference* position is the *Commanded* position minus the *Actual* position. Just after a new setting is entered this shows how far the mechanism has left to move. Once the actuators have stabilized at the new position it gives an indication of the following error.

Encoder values are also given. The three actuators do not correspond directly to the three controllable axes but instead work together in complex ways to provide the required motion. The data displayed under *Encoder A*, *Encoder B* and *Encoder C* indicate the raw positions of the three actuators in encoder counts.

The display positions are updated whenever the position information on the main window is updated or when the *Refresh* button on this dialog is pressed. This button is identical in operation to the *Refresh* button on the main window (see §4.2.2.4 *Display* Group).

The status of the focus mechanism is shown by *Focus Status*. The box changes color to give a quick indication of the status while a message is displayed next to the box providing more information:

Green — `In Position`

The mirror has reached the last commanded position.

Yellow — `Focussing`

The mirror is moving to the last commanded position.

Yellow — `Inactive`

The servo loop for the mirror is currently open. This is usually the state which the focus is in when the **Telescope Server** application first starts up and means the telescope is not currently tracking.

Red — `Instrument Fault`

The **Telescope Server** application has detected an instrument fault and has entered the Error state. The fault may be unrelated to the focus mechanism.

Black — `Not Installed`

The secondary focus mechanism has been disabled in `Telescope.ini`. Note that this state may not be displayed until a command is given to drive the focus.

The status indicator is updated whenever the status changes, independent of when the display positions are updated.

*Inst. Rot...* button

This will display the *Instrument Rotator Control* dialog (see Figure 4.4). This allows the user to control the position and behavior of the instrument rotator. Note that **Telescope VCP** does not have to be in control in order to move the rotator. This allows the orientation of the image to be adjusted while **StarCal** is tracking a star.

The instrument rotator is a single controllable axis which rotates the instruments on the telescope to allow their orientation with respect to the tracked object to be adjusted. The rotator provides two modes of operation: Fixed mode and Position mode.

Fixed mode is selected using the *Fixed* radio button. In this mode the rotator will move to a position such that the image at the instrument will be oriented with respect to the telescope up-elevation direction by the angle specified in the *Orientation* edit box (in degrees). The rotator will remain stationary to hold this position regardless of which direction the telescope is pointing.

Position mode is selected using the *Position* radio button. In this mode the instrument rotator will move to a position where the image at the instrument will

be oriented with respect to Celestial North by the angle specified in the *Orientation* edit box (in degrees). The rotator will track to hold this orientation as the telescope moves.

After selecting the mode and specifying the angular orientation, press *OK* to execute the move and close the dialog. Choose *Cancel* to return to the main window without changing the rotator position.

The rotator mode and orientation can be set even when the telescope is not operating. However, the rotator will not move until the telescope begins tracking.

The current commanded and actual position of the rotator can be monitored from the main window (see §4.2.2.7 *Status* Group).

*Go* button

The *Go* button is used to execute a move command specified by the *Slew* and *Track* controls.

A new move can be started at any time provided **Telescope VCP** is in control of the telescope. If the telescope is currently in the middle of another move then it will cancel this move and smoothly transition into the new move.

If the telescope is not tracking when this button is pressed then power will be applied to the motor drives, the axes will be homed if necessary, and the telescope will carry out the new move. Also, the focus and rotator will move to their commanded positions if they are enabled.

This button is only enabled when **Telescope VCP** is in control of the telescope.

*Stop* button

Pressing this button will bring the telescope to a stop in a controlled manner. This is less harsh on the telescope than an emergency stop but takes longer and may not work if the telescope is out of control.

This button is only enabled when **Telescope VCP** is in control of the telescope.

*Emergency Stop* button

This button can be used to halt the telescope in an emergency. It should be used sparingly as it will bring the telescope to a jarring stop. This has the same effect as pressing and releasing the physical Emergency Stop button on the cabinet, although it relies on the software in order to work. The physical Emergency Stop button is preferable in an emergency as it connects directly to the hardware. To stop the telescope smoothly in non-emergency situations use the *Stop* button.

Pressing this button once will halt the telescope. The next slew or track command which is issued will cause the telescope to resume tracking from its current position.

Pressing this button twice will force the telescope to re-execute its homing procedures when it receives the next slew or track command.

This button is only enabled when **Telescope VCP** is in control of the telescope.

### 4.2.2.7  *Status* Group

This set of controls displays information about the telescope including time, status and position.  The information is displayed on initial connection.  Time and position are updated whenever the *Refresh* button is pressed or the telescope is being polled periodically (see §4.2.2.4 *Display* Group).  Status is updated whenever the telescope status changes.

#### *Time (UTC)* field

The telescope system clock time is shown in the *Time (UTC)* field.  This value is precise and accurate to 1 microsecond.

If the telescope time has been set to a simulated value then `(simulated)` will be displayed below the label.  This is not the same as running the **Telescope Server** application in Simulate mode.  This feature is not available in the Lick version of the software.

#### Status indicators

The general state of the **Telescope Server** application is shown by the colored box in the center of the main window and the message (if any) to its immediate right.  Green indicates everything working normally, yellow indicates a warning such as homing in progress, and red indicates a more serious error such as an instrument fault or failure to connect to the telescope.  Changes in **Telescope Server** state are automatically displayed regardless of whether continuous polling is in effect.

##### Green — `Initialised`

**Telescope Server** is ready to accept commands.  No power is applied to the telescope drives.

##### Green — `Standby`

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

##### Green — `Operate`

The telescope is currently executing a move.

##### Yellow — `Initialising`

**Telescope Server** is transitioning to the Initialised state.

##### Yellow — `Configuring`

**Telescope Server** is transitioning from the Initialised state to the Standby state.

Yellow — `Starting`

> ***Telescope Server*** is transitioning from the Standby state to the Operate state.

Yellow — `Stopping`

> ***Telescope Server*** is transitioning from the Operate state to the Standby state.

Yellow — `Terminating`

> ***Telescope Server*** is in the process of shutting down. No further communications with the application will be possible.

Red — `Error`

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

Red — `NotResponding`

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

Red — `Unknown`

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

Red — `Unknown state`

> ***Telescope Server*** returned an unrecognized state. This may indicate a fault in the ***Telescope Server*** or ***Telescope VCP*** applications.

Red — `Not connected`

> ***Telescope VCP*** was unable to establish a connection to ***Telescope Server***.

This indicator also displays the following error flags sent back by ***Telescope Server***. These messages are often overwritten a moment later by status indicators for the ***Telescope Server***. A future release of the software may display these messages in a different place.

Red — `Incorrect version`

> The ***Telescope VCP*** application is incompatible with the ***Telescope Server*** application. Either or both of these applications should be updated.

Red — `Communications error`

> A error occurred exchanging messages with the ***Telescope Server*** application. If this error persists seek technical support.

Red — `Instrument timeout`

The **Telescope Server** application took too long to respond to a message. The normal message timeout is 5 seconds. This may indicate the **Telescope Server** application has hung or that there is a problem with the network.

Red — `Operation parameters invalid`

**Telescope VCP** sent invalid parameters with a message. This may indicate a fault in **Telescope VCP**.

Red — `Nested call not allowed`

**Telescope Server** can only accept one message from each client at a time. This error may mean that the previous message had not been fully processed when another command was sent. Try pausing between issuing commands with **Telescope VCP**.

Red — `Operation requires control of telescope`

**Telescope VCP** tried to send a command without having control of **Telescope Server**. This error can occur if control was taken from **Telescope VCP** by another client. This should not occur in the current release of the software for Lick.

Red — `Instrument fault`

**Telescope Server** encountered a fatal error when processing a command.

Red — `Feature not enabled/installed`

This error appears when attempting to use a feature which has not been enabled or installed. The most common examples of this would be the secondary focus drives and the instrument rotator.

Red — `Instrument has been terminated`

**Telescope Server** is in the process of shutting down. No further communications with the application will be possible.

Red — `Operation has not been implemented`

**Telescope VCP** has attempted to use a feature which has not been implemented. With the current release of software this includes the mirror covers and the dome window washer.

Red — `Unrecognised command`

**Telescope VCP** sent a command to **Telescope Server** which it did not recognize. This may indicate a fault in the **Telescope Server** or **Telescope VCP** applications or a network error.

Red — `Unknown Telescope result status:` *number*

> ***Telescope Server*** returned a status from the last command which ***Telescope VCP*** did not recognize.  This may indicate a fault in the ***Telescope Server*** or ***Telescope VCP*** applications or the occurrence of a network error.  The indicated number should be reported when seeking technical support.

The status indicator is also used to display various error messages generated by ***Telescope VCP***.  Most of these are self-explanatory.  However, these messages are often obliterated by status indicators for the ***Telescope Server***.  A future release of the software may display these messages in a different place.

*Reset from Error* button

This button can be used to clear a fault condition (red status indicator) in the ***Telescope Server***.  The *Clear* button should be used to clear the status indicator after pressing *Reset from Error*.

*Clear* button

The most recent status message will remain displayed until the *Clear* button is pressed.  In practice this button is rarely used since the status changes frequently.

*Audible Alarm* checkbox

Whenever ***Telescope VCP*** displays a red status it will beep to provide an audible warning.  This feature can be turned off by clearing this checkbox.

*Line 1* and *Line 2*

These two lines display position information for the telescope.  Each line consists of a series of four listboxes which select the type of information to display, and two edit boxes labeled *AZ* and *EL* which display the selected information, plus a *Units* indicator which displays the measurement units.  Both lines can display the same information.  Two lines are provided so that comparisons can easily be made.

The display is updated as described in §4.2.2.4 *Display* Group.  Data for every possible combination of list box selections is collected and stored, so that the listbox selections can be changed to view different types of data even if the display is not being updated.

First listbox

The first listbox chooses whether to display information on the `Telescope`, the `Dome` (not relevant for Lick), the `Rotator`, or the `Sun`.

If `Rotator` is selected then data will only be displayed in the *AZ* edit box.

If `Sun` is selected then the next two list boxes are ignored.

Second listbox

This selects whether `Commanded` or `Actual` position information will be displayed. `Commanded` position is the target point that the telescope is being instructed to follow while `Actual` position is where it currently is. The difference between these two values, all other listboxes being equal, represents the following error.

Third listbox

This listbox is used to select the processing stage at which to report the position. Commanded positions go through several stages in the process of converting them from an ideal angular representation to encoder counts used by the low-level servo control system. Actual positions go through the same stages in reverse to convert them from encoder counts to an angular measure of direction.

The stages are:

`Absolute`

For `Telescope`, `Dome` and `Sun` this represents the ideal azimuth and elevation co-ordinates in degrees. For `Rotator` the angle of the axis with respect to zero orientation will be displayed in degrees.

`Normal`

This is equivalent to the `Absolute` co-ordinates mapped to 0° to 360° in azimuth, -90° to +90° in elevation, and 0° to 360° for the rotator.

`Sky`

For `Telescope`, `Dome` and `Sun` this represents the ideal celestial right ascension and declination co-ordinates (both in degrees). For `Rotator` the ideal orientation in degrees will be displayed.

`Refracted`

This is the `Absolute` position after atmospheric refraction, if any, is applied. Note that the azimuth axis is unaffected by atmospheric refraction.

`Biased`

This is the `Refracted` position after position bias entered by the user is applied (see §4.2.2.1 Top Button Group).

`Held`

This shows the position the axes are being held at if either the telescope, dome or both were not selected for the last track command (see §4.2.2.6 *Move Mode* Group). This stage is not relevant for Lick.

`Sun Avoided`

This shows the position of the axes after applying any offset to avoid the solar halo. This function is not implemented in this release of the software.

`Speed Limit`

This stage shows the position of the axes after any position or speed limits have been applied.

Note that although speed limits are implemented they are not correctly reported in this release of the software.

`Mount Model`

The mount model corrects for any small errors caused by mechanical imperfections in the telescope mount. Selecting this stage shows the angular position of the axes after the mount model has been applied. This is only relevant for `Telescope`.

`Focus Offset`

Small corrections may be made to the telescope to compensate for the position of the secondary mirror. This stage shows the angular position of the axes after the corrections have been applied. This is only relevant for `Telescope`.

`Encoder`

At the lowest level the position of each axis is converted to encoder counts and given to the servo control system. This stage is not applicable for `Sun`.

Fourth listbox

Each of the positions selected by the previous three list boxes has an associated velocity. The fourth list box selects either `Position` or `Rate` (velocity) information for display. Any mention of position in the preceding discussion should be replaced by velocity when `Rate` is selected.

*Difference (Line 1 – Line 2)*

This line displays the difference between the values displayed by *Line 1* and *Line 2*. This is useful for working out the effect that a particular stage has on the telescope position, e.g. the effect of atmospheric refraction, or for calculating the following error by comparing `Commanded` and `Actual` position.

In order for the difference to be calculated the two lines must be displaying data with the same units. If the units are not the same then the display will be blank and *Units* will be shown as `(incompatible)`.

*Summary*

This line is used to collect and display statistical information for any of the previous three lines. When the *Collect* checkbox is checked, statistics of the values displayed by the *Line 1*, *Line 2* and *Difference* will be calculated each time the display is refreshed.

The two listboxes on this line allow the user to select the type of statistics to display (`Minimum`, `Maximum`, `Average`, `RMS`) and from which line they should be taken (`Line1`, `Line2`, `Difference`).

To stop collecting statistics clear the *Collect* checkbox. Changing any of the list boxes in *Line 1* or *Line 2*, or checking the *Collect* checkbox again, will reset the statistical calculations.

## 4.2.2.8  *Limits* Group

The *Limits* group contains a series of indicators corresponding to various faults or warnings on the telescope and dome. During normal operation all indicators should be green. Any that are red, apart from *Homing in Progress*, indicate a fault or a warning condition.

A column of indicators is shown for each of the two telescope axes (*Tele Az* and *El*), the two dome axes (*Dome Az* and *El*, which are not used in Lick), and one for the secondary focus (*2nd Fcs*). In this release of the software the three secondary focus axes are combined into a single set of indicators and there are no indicators for the instrument rotator.

The indicators are updated instantaneously whenever any of the limits change, regardless of the settings in the *Display* group (see §4.2.2.4 *Display* Group).

*Negative Inner Position*

This indicates the axis is near the end of its physical range of movement in the negative direction.

*Positive Inner Position*

This indicates the axis is near the end of its physical range of movement in the positive direction.

*Homing In Progress*

The axis is currently homing.

*Homing Failed*

The axis failed in its last attempt to home.

*Warning Following Error*

The axis is failing to keep up with the servo control system.

*Fatal Following Error*

> The axis failed to keep up with the servo control system to the point where continued operation is considered dangerous. This should cause **Telescope Server** to abort tracking.

*Speed Limit Reached*

> The axis is operating at its maximum allowable speed in the servo control system. This should never occur as the **Telescope Server** application should enforce speed limits before sending commands to the servo control system.

### 4.2.2.9  *Flags* Group

The *Flags* group displays various status indicators for the telescope. The flags change from green to yellow to indicate the associated condition (*Clock Sync* shows red instead of yellow as a warning).

The indicators are updated instantaneously whenever any of the conditions change, regardless of the settings in the *Display* group (see §4.2.2.4 *Display* Group).

*Pre-Track*

> The currently loaded track hasn't started yet.

*Post-Track*

> The currently loaded track has expired.

*Tele Slewing*

> The telescope has reached its maximum speed or acceleration.

*Dome Slewing*

> The dome has reached its maximum speed or acceleration.

> This flag is not used in the current release of software for Lick.

*Focussing*

> The secondary mirror is currently moving towards its commanded focus position.

*Position Limit*

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

*Sun Avoidance*

> The telescope is inside the solar halo.

> The current release of the software does not include any form of Sun avoidance. However this indicator can be used to determine whether the telescope is pointing dangerously close to the Sun.

*Washing Window*

> **Telescope Server** is currently executing a dome window washing operation.

> This flag is not used in the current release of software for Lick.

*Clock Sync*

> The telescope clock has lost synchronization with UTC.  As a result tracking may not be accurate.

### 4.2.2.10  *Mets* Group

The *Mets* group is used to monitor and set the meteorological information used by **Telescope Server** to calculate the compensation required for atmospheric refraction during tracking.  It also includes a field for the temperature of the truss which is used to adjust the secondary mirror to correct for thermal expansion of the structure:

*Temp* edit box

> The temperature in degrees Celsius used for calculating the amount of atmospheric refraction.  This should be measured at the site of the telescope.

*Press* edit box

> The pressure in millibars used for calculating the amount of atmospheric refraction.  This should be measured at the site of the telescope.

*Humid* edit box

> The humidity in percentage relative condensing used for calculating the amount of atmospheric refraction.  This should be measured at the site of the telescope.

*Truss* edit box

> The temperature in degrees Celsius used for calculating the focus compensation to apply for expansion in the truss.  This should be measured by sensors attached to the telescope.

The values being used by the telescope are displayed when **Telescope VCP** initially connects to **Telescope Server**.  The values are not refreshed with the rest of the display, but only when the *Get* button is pressed.

To change the data used by **Telescope Server** enter new values into the edit boxes and press the *Set* button.  This can be done even if another client is in control.  The values should be updated periodically while tracking stars.

### 4.2.2.11  Warnings Indicator Box

The box at the lower right of the screen lists other system warning and fault indicators which are active.

### 4.2.3 Error Messages

Error messages from **Telescope VCP** can appear in several different forms: in a dialog displayed to the user, as a status message displayed in the main window (see §4.2.2.7 *Status* Group and §4.2.2.11 Warnings Indicator Box), or as an error event in the system event log. Errors recorded in the system event log are usually self-explanatory.

## 4.3 OPERATIONS

### 4.3.1 Driving the Telescope

As an example of how to use **Telescope VCP** the following procedure shows how to slew and track the telescope:

1. Start up **Telescope VCP** and connect to the telescope.

2. Select the *Control* radio button in the *Control Mode* group. This allows **Telescope VCP** to drive the telescope. If another application is already in control of **Telescope Server** the status box will momentarily display an error indicating that **Telescope VCP** is not in control.

3. To point in a particular direction, select *Slew* in the *Move Mode* group, enter the azimuth and elevation into the adjacent fields and press *Go*. The telescope should move to the specified position. If necessary it will carry out a homing operation first.

4. To execute a pre-programmed maneuver, select *Track* in the *Move Mode* group, click on the *Browse* button, choose a track file and press *Go*. Track files (see §7.4.1 Track Files) can be created to run the telescope through a predefined sequence of moves. This is useful for testing the performance of the system. Track files can also be set up to point the telescope in certain directions such as at fixed targets or a park position for the telescope. Several sample track files can be found in `C:\Keystone\Site\Logs`.

5. Click on the *Bias Control...* button to display the *Bias Controller* dialog box and use it to adjust the telescope position.

6. When finished, select the *Monitor* radio button in the *Control Mode* group to release control or exit **Telescope VCP**. This allows other clients to control the telescope. The telescope will remain at its current position.

## 4.4 FILE FORMATS

### 4.4.1 Track Files

The track files used by **Telescope VCP** are simple text files that contain a spline path for the telescope to follow. They usually have the extension `.TRK`, although any extension will suffice. Some sample track files can be found in `C:\Keystone\Site\Logs`.

A track file consists of a header followed by one or more spline segments in the format described below.  All fields except the epoch must be separated from one another by whitespace (spaces, tabs or carriage returns); the epoch must be on the first line of the file by itself.  There is no provision in the file for comments or other characters, except that text after the last spline segment will be ignored.

Epoch

The first line contains the epoch for the track file.  This fixes the track to a particular date and time which is necessary when tracking objects such as stars.  The format of the line is:

```
YYYY/MM/DD HH:MM:SS
```

This allows the epoch to be specified to the nearest second.  If a track must be specified more precisely this can be done using the time offset in the spline data itself, described below.

For some purposes it may be inconvenient or make no sense to have an epoch.  For example, tracking a stationary target such as a calibration point or performing a predefined maneuver for measuring system performance.  For these cases the epoch term can be disabled by making the first character of the line a zero:

```
0
```

Any text after the zero is ignored.

Number of spline segments

The next line contains an integer indicating the number of spline segments making up the track.  For a stationary track there is typically only one segment.  For tracks to measure telescope performance there could be dozens of segments.  Track files for tracking moving objects may consist of hundreds or even thousands of segments.

The remaining fields are repeated as a group for each spline segment:

Time Offset

This is the number of seconds since the epoch at the top of the file.  If the epoch was disabled then this is the number of seconds since the start of the track.  A track with a zero epoch starts when the *Go* button is pressed.

The time offset can be specified to very high precision, as much as 15 significant digits.  Time offsets must be increasing — the time offset of each spline segment must be greater than the time offset of the segment before it.

Azimuth A, B, C and D terms

The next part of the spline segment defines the azimuth position of the target.  The A term corresponds to the position, the B term to the velocity, C to half the acceleration and D to one sixth of the jerk (change in acceleration with respect to time) over the period of the segment.  The values are specified in degrees and seconds (i.e. A is in degrees, B is in degrees per second, C is in degrees per

second per second and D is in degrees per second per second per second).
Each can be specified to as much as 15 significant digits.

Elevation A, B, C and D terms

Following the azimuth terms are similar terms for the elevation.  These are also specified in degrees and seconds.

Range A, B, C and D terms

At the end of each spline segment are the terms for range.  These have the same format as those for azimuth and elevation but are specified in seconds (as a distance measurement corresponding to light travel time) instead of degrees. The range is used to determine whether to apply atmospheric refraction: a value larger than about 0.000667 (time for light to travel 200km) will cause atmospheric refraction to be applied.  This was a carryover from Keystone and is not really relevant to Lick.

Note that if consecutive spline segments are not carefully specified to run smoothly into each other then the telescope will slew between them at the maximum speed allowed.

For example, a track file for a stationary target at 180° azimuth and -10° elevation would be:

```
0
1
  0.0
    180 0.0 0.0 0.0
    -10 0.0 0.0 0.0
    0.0 0.0 0.0 0.0
```

This specifies that there is no epoch and the track consists of one spline segment.  This spline segment has zero time offset, an azimuth of 180° with zero velocity, acceleration and jerk, an elevation of -10° with zero velocity, acceleration and jerk, and a range of zero with zero velocity, acceleration and jerk.

### 4.4.2  Log Files

The *Telescope VCP* data logging function (see §4.2.2.1 Top Button Group) generates text files containing data in a simple format.  Each line is a single record, and fields in each record are separated by ‹Tab› characters.  The first line identifies the contents of each field.

The actual fields recorded in a log file depend on the options selected in the *Data Logging* dialog (see Figure 4.5).  Some examples are:

Date/Time

This is the actual date and time (UTC) at which the data sample was taken in the format `mm/dd/yyyy hh:mm:ss.ssssss`. The time is in 24-hour format and is accurate to 1 microsecond.

`Seconds In Day`

This single number, to six decimal places, represents the time of day of the sample, or the number of seconds elapsed since midnight at the start of the current day, accurate to 1 microsecond. This is useful as an X-axis value for spacing irregular data samples out correctly in plots, as *Excel* cannot easily interpret the date/time column.

`Commanded Track Position (Az)`

This is the commanded absolute position of the telescope azimuth axis at the sample time. The value is represented in degrees clockwise from True North and is accurate to 1 micro-degree (3.6 milli-arcseconds).

`Commanded Track Position (El)`

This is the commanded absolute position of the telescope elevation axis at the sample time. The value is represented in degrees up from horizontal and is accurate to 1 micro-degree (3.6 milli-arcseconds).

`Commanded Biased Position (Az)`

This is the commanded biased position of the telescope azimuth axis at the sample time, which corresponds to the commanded absolute position with position and time bias applied. The value is represented in degrees clockwise from True North and is accurate to 1 micro-degree (3.6 milli-arcseconds).

`Commanded Biased Position (El)`

This is the commanded biased position of the telescope elevation axis at the sample time, which corresponds to the commanded absolute position with position and time bias applied. The value is represented in degrees up from horizontal and is accurate to 1 micro-degree (3.6 milli-arcseconds).

`Commanded Telescope Encoder Position (Az)`

This is the commanded encoder position of the telescope azimuth axis at the sample time. This is the approximate position to which the servo control system was being driven at that time. The value is represented in encoder counts and is accurate to 1 micro-count. Note that this value is approximate: speed and acceleration limits are not taken into account, and the servo control system may have interpolated to a slightly different value. Also, the value sent to the servo control system is rounded to the nearest integer (accuracy is approximately 2.2 milli-arcseconds in the current version of the software).

`Commanded Telescope Encoder Position (El)`

This is the commanded encoder position of the telescope elevation axis at the sample time. This is the approximate position to which the servo control system was being driven at that time. The value is represented in encoder counts and is accurate to 1 micro-count. Note that this value is approximate: speed and acceleration limits are not taken into account, and the servo control system may have interpolated to a slightly different value. Also, the value sent to the servo

control system is rounded to the nearest integer (accuracy is approximately 2.5 milli-arcseconds in the current version of the software).

`Commanded Dome Encoder Position (Az)`

This is the commanded encoder position of the dome azimuth axis at the sample time.  This value is not relevant to Lick.

`Commanded Dome Encoder Position (El)`

This is the commanded encoder position of the dome elevation axis at the sample time.  This value is not relevant to Lick.

`Actual Telescope Position (Az)`

This is the actual absolute position of the telescope azimuth axis at the sample time, calculated from the actual encoder position.  The value is represented in degrees clockwise from True North and is accurate to 1 micro-degree (3.6 milli-arcseconds).

`Actual Telescope Position (El)`

This is the actual absolute position of the telescope elevation axis at the sample time, calculated from the actual encoder position.  The value is represented in degrees up from horizontal and is accurate to 1 micro-degree (3.6 milli-arcseconds).

`Actual Dome Position (Az)`

This is the actual absolute position of the dome azimuth axis at the sample time.  This value is not relevant to Lick.

`Actual Dome Position (El)`

This is the actual absolute position of the dome elevation axis at the sample time.  This value is not relevant to Lick.

`Actual Telescope Encoder Position (Az)`

This is the actual encoder position of the telescope azimuth axis at the sample time, read directly from the servo control system.  The value is represented in encoder counts and is accurate to 1 count, although six decimal places are reported (all 0).  The accuracy is approximately 2.2 milli-arcseconds in the current version of the software.

`Actual Telescope Encoder Position (El)`

This is the actual encoder position of the telescope elevation axis at the sample time, read directly from the servo control system.  The value is represented in encoder counts and is accurate to 1 count, although six decimal places are reported (all 0).  The accuracy is approximately 2.5 milli-arcseconds in the current version of the software.

```
Actual Dome Encoder Position (Az)
```

> This is the actual encoder position of the dome azimuth axis at the sample time. This value is not relevant to Lick.

```
Actual Dome Encoder Position (El)
```

> This is the actual encoder position of the dome elevation axis at the sample time. This value is not relevant to Lick.

The file is designed so that it can easily be read into **Excel**. From within **Excel 97** choose *File | Open...* and select the log file to be opened (you may have to choose `All Files (*.*)` from the *Files of type* dropdown list in order to see it).

The *Text Import Wizard* dialog box should then appear. Select the *Delimited* option, start import at row 1, and make sure *File Origin* is set to `Windows (ANSI)`, then click on *Next >*.

In the *Delimiters* group make sure *Tab* is the only option checked. Clear *Treat consecutive delimiters as one* if it is checked since only one tab separates each field. *Text Qualifier* can be left at its default value.

Click the *Finish* button to import the file. After a moment **Excel** should display the contents of the file in a new spreadsheet. Each column corresponds to a field, and the first row contains the field titles. Note that **Excel** allows a maximum of 65535 records to be loaded from a file.


# 5. STARCAL

The **StarCal** application is one of the clients of the **Telescope Server** and is the principal means of directing the telescope to track stars and other celestial objects.

**StarCal** is also 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.


## 5.1 QUICK START GUIDE

Set the current working directory to `C:\Lick\Utilities\StarCal` and run `StarCal.exe` (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 switch to the **Telescope VCP** and click the Reset from Error and Clear buttons. Then try the failed action again.

## 5.2  APPLICATION STRUCTURE

### 5.2.1  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 5.1 shows the four information pages which can be accessed using the tabs at the bottom of the main window. See §5.2.4 Information Pages for more information.
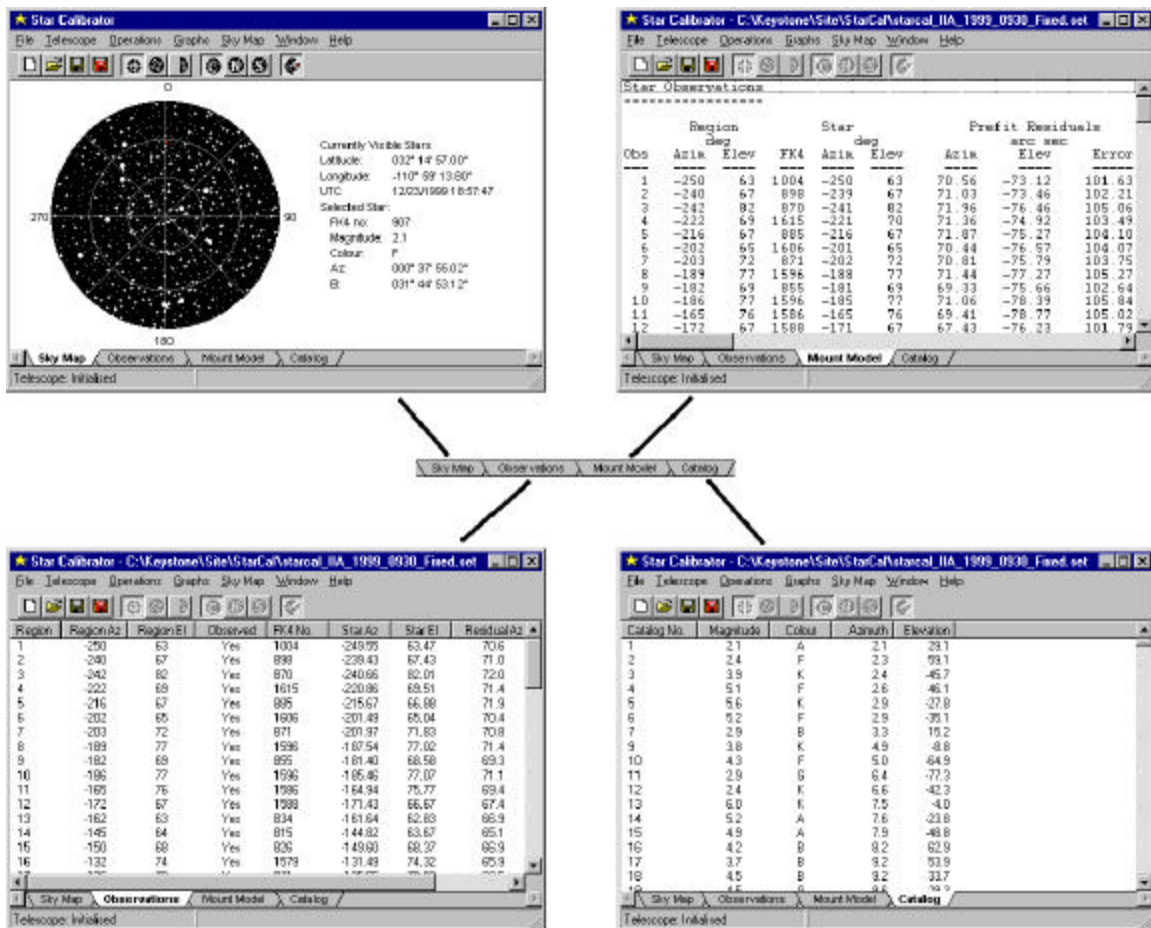


Figure 5.1: **StarCal**'s main window pages

### 5.2.2 Menus

5.2.2.1 *File* Menu

*File | New...*

Choose this menu item to begin a new observation sequence. The *New StarCal Dataset* dialog will be displayed (Figure 5.2) allowing the user to specify various parameters affecting the observation sequence.

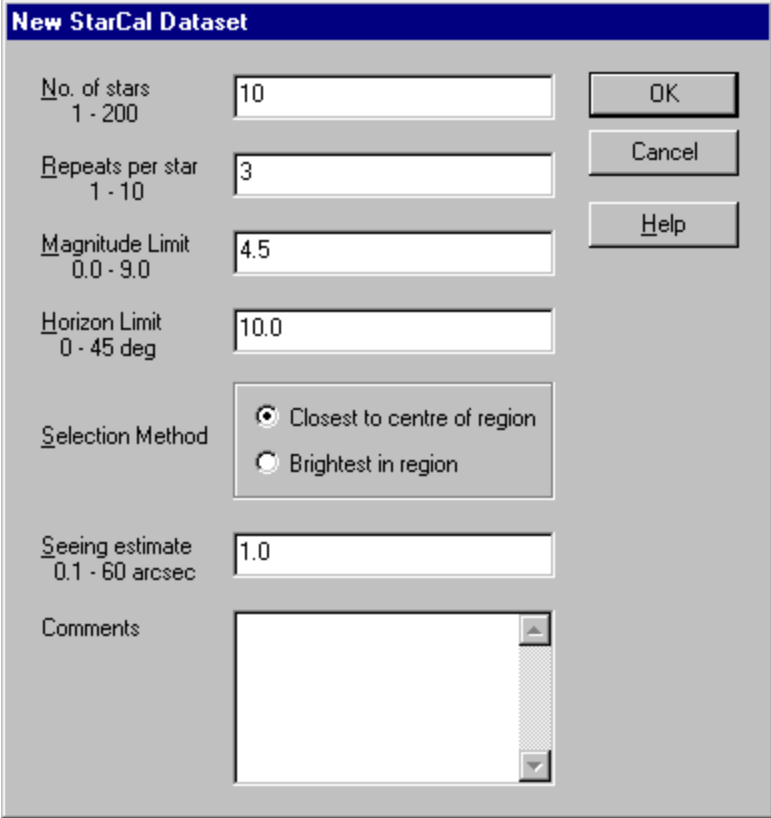The ‹Ctrl-N› key combination can be used as a shortcut to this menu item.



Figure 5.2: The *New StarCal Dataset* dialog

*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.

The ‹Ctrl-O› key combination can be used as a shortcut to this menu item.

*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.

The ‹Ctrl-S› key combination can be used as a shortcut to this menu item.

*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 ‹Alt-F4› key combination can be used as a shortcut to this menu item, and the close button (*X*) in the top right corner of the window can also be used to exit the application.

### 5.2.2.2  *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 (Figure 5.3) which allows the user to choose to which telescope (site) to connect.  `Lick` should already be selected as the site when the dialog appears.

This dialog is similar to the *Select Telescope* dialog box in **Telescope VCP** (see Figure 4.6) except that no password is required since **StarCal** does not provide access to low-level telescope functions.
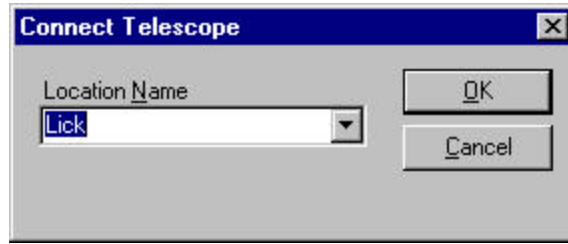
Figure 5.3: The *Connect Telescope* dialog

*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 VCP* 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 VCP* will be unable to move the telescope.

*Telescope | Dome Window...*

This menu item allows a different dome window to be used when tracking stars (see Figure 5.4).  Operation of the dome is not supported by the current release of the Lick software so this menu item will have no effect.
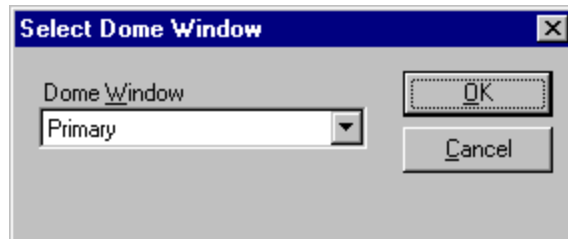


Figure 5.4: The *Select Dome Window* dialog

*Telescope | View Mount Model...*

This menu item displays the mount model parameters currently installed on the connected telescope (see Figure 5.5). **StarCal** must be connected to a telescope to be able to access this information, but need not be in control.
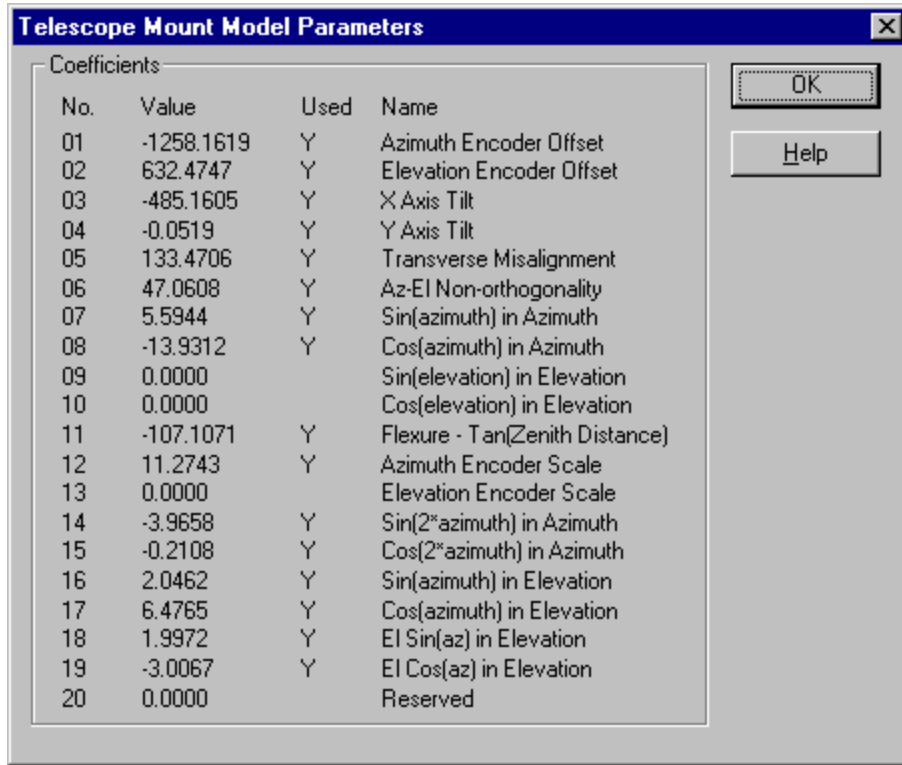
| No. | Value | Used | Name |
|-----|-------|------|------|
| 01 | -1258.1619 | Y | Azimuth Encoder Offset |
| 02 | 632.4747 | Y | Elevation Encoder Offset |
| 03 | -485.1605 | Y | X Axis Tilt |
| 04 | -0.0519 | Y | Y Axis Tilt |
| 05 | 133.4706 | Y | Transverse Misalignment |
| 06 | 47.0608 | Y | Az-El Non-orthogonality |
| 07 | 5.5944 | Y | Sin(azimuth) in Azimuth |
| 08 | -13.9312 | Y | Cos(azimuth) in Azimuth |
| 09 | 0.0000 | | Sin(elevation) in Elevation |
| 10 | 0.0000 | | Cos(elevation) in Elevation |
| 11 | -107.1071 | Y | Flexure - Tan(Zenith Distance) |
| 12 | 11.2743 | Y | Azimuth Encoder Scale |
| 13 | 0.0000 | | Elevation Encoder Scale |
| 14 | -3.9658 | Y | Sin(2*azimuth) in Azimuth |
| 15 | -0.2108 | Y | Cos(2*azimuth) in Azimuth |
| 16 | 2.0462 | Y | Sin(azimuth) in Elevation |
| 17 | 6.4765 | Y | Cos(azimuth) in Elevation |
| 18 | 1.9972 | Y | El Sin(az) in Elevation |
| 19 | -3.0067 | Y | El Cos(az) in Elevation |
| 20 | 0.0000 | | Reserved |

Figure 5.5: The *Telescope Mount Model Parameters* dialog

### 5.2.2.3 *Operations* Menu

This menu provides commands for carrying out various actions involving the telescope. See §5.3 Operations for examples.

*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 5.6). This dialog lists details about the region and the selected star, and provides buttons allowing the user to bring up the *Bias Controller* dialog (Figure 5.17), 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.
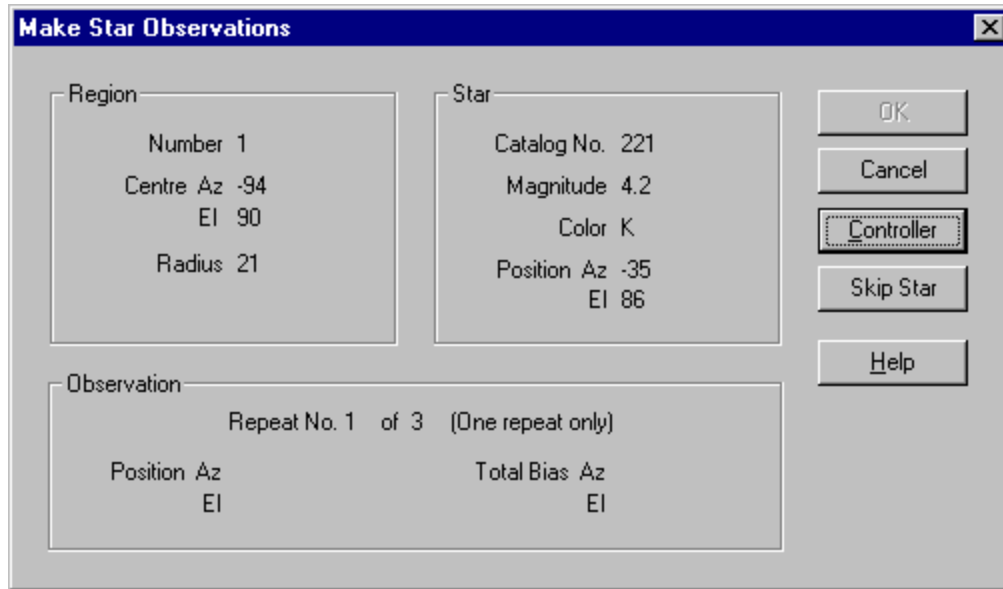


Figure 5.6: The *Make Star Observations* dialog

*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 5.7) 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 5.6), 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.
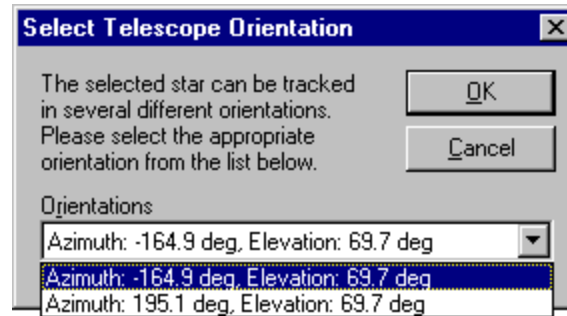


Figure 5.7: The *Select Telescope Orientation* dialog

*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 5.8) allowing the user to select which mount model parameters to calculate and which regions to use or discard. 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.
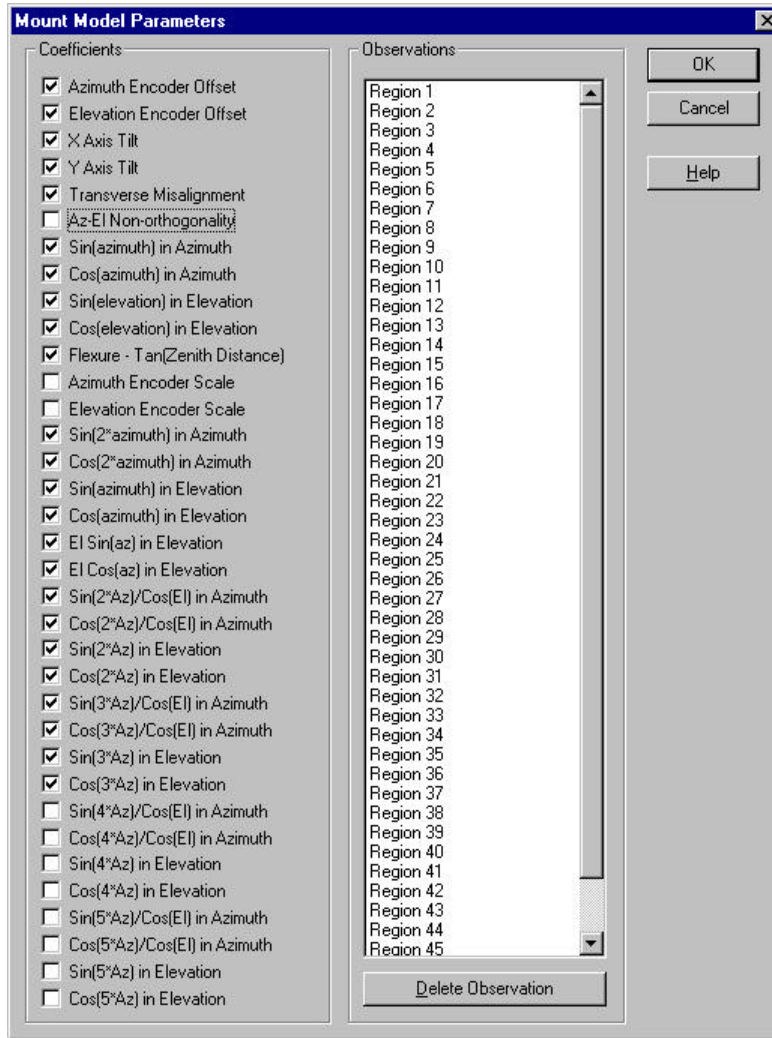
Figure 5.8: The *Mount Model Parameters* dialog

*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.

Note that the old mount model being used by the telescope, stored in `Telescope.ini`, will be overwritten. In case it may be necessary to restore the old mount model it is recommended that `Telescope.ini` 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 5.9), providing details about the selected star and buttons allowing the user to bring up the *Bias 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 VCP**) 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.
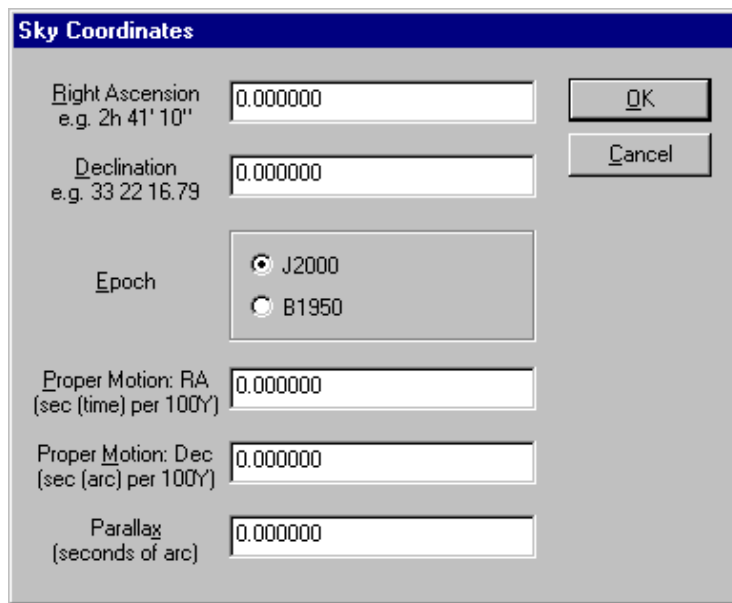


Figure 5.9: The *Observe Star* dialog


*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 5.10) 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 5.9), showing the celestial coordinates instead of the star magnitude and color normally shown. It also provides buttons allowing the user to bring up the *Bias Controller* dialog (Figure 5.17) or cancel tracking.

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 VCP*) 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 5.10: The *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 (Figure 5.9), providing details about the selected star and buttons allowing the user to bring up the *Bias 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 VCP*) 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 *Bias 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 (Figure 5.2).  Several of the parameters can be modified if desired.

### 5.2.2.4   *Graphs* Menu

### Graphs | Polar Plot of Error Vectors

This brings up the *Polar Plot* dialog (Figure 5.11) showing 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.
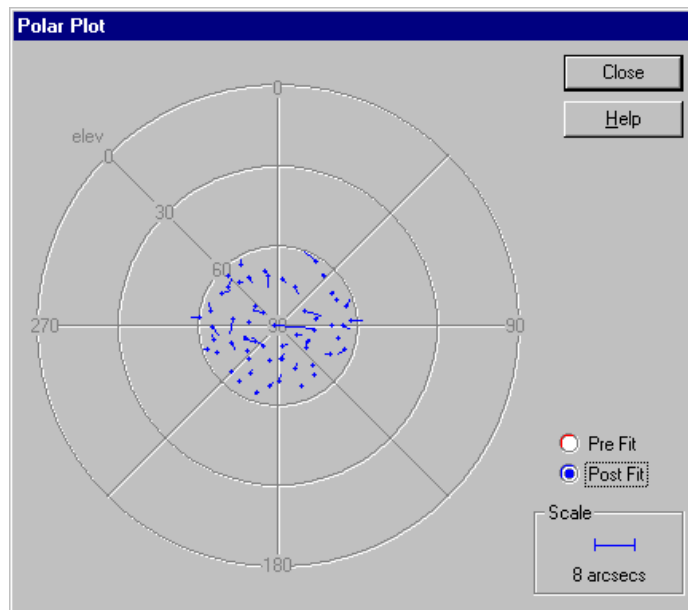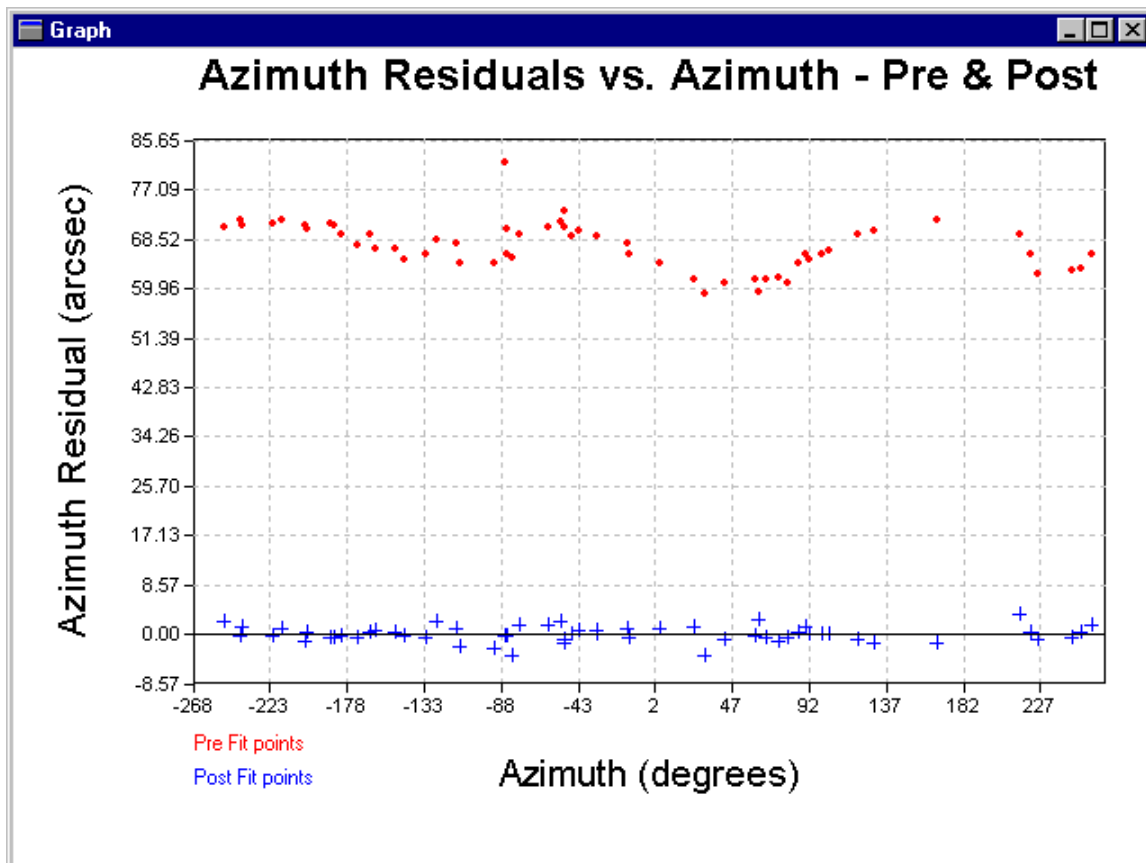


Figure 5.11: The *Polar Plot* graph, showing post-fit residuals

*Graphs | Azimuth Residuals vs. Azimuth*

This displays a graph showing the azimuth residual errors plotted against the azimuth axis (Figure 5.12). 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 5.12: The *Azimuth Residuals vs. Azimuth* graph, showing both pre-fit and post-fit residuals

*Graphs | Azimuth Residuals vs. Elevation*

This displays a graph showing the azimuth residual errors plotted against the elevation axis (Figure 5.13).  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.
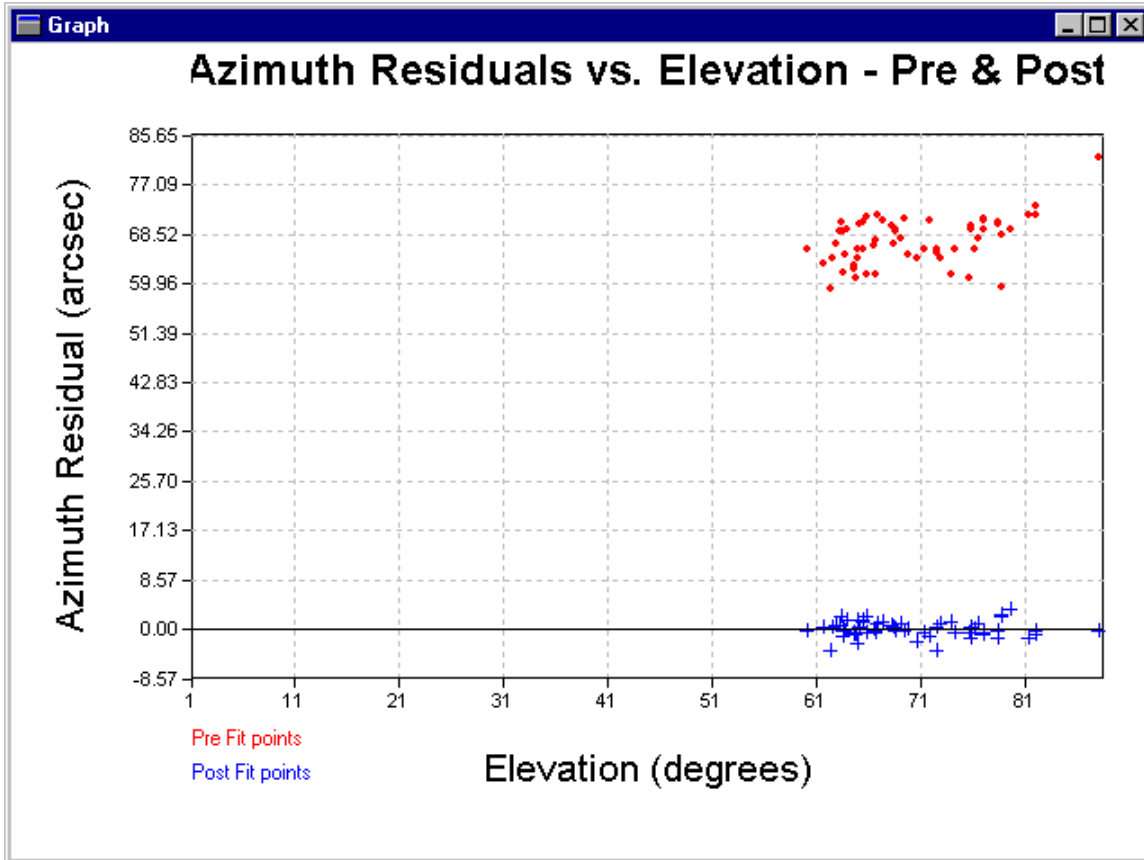


Figure 5.13: The *Azimuth Residuals vs. Elevation* graph, showing both pre-fit and post-fit residuals

*Graphs | Elevation Residuals vs. Azimuth*

This displays a graph showing the elevation residual errors plotted against the azimuth axis (Figure 5.14). 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.
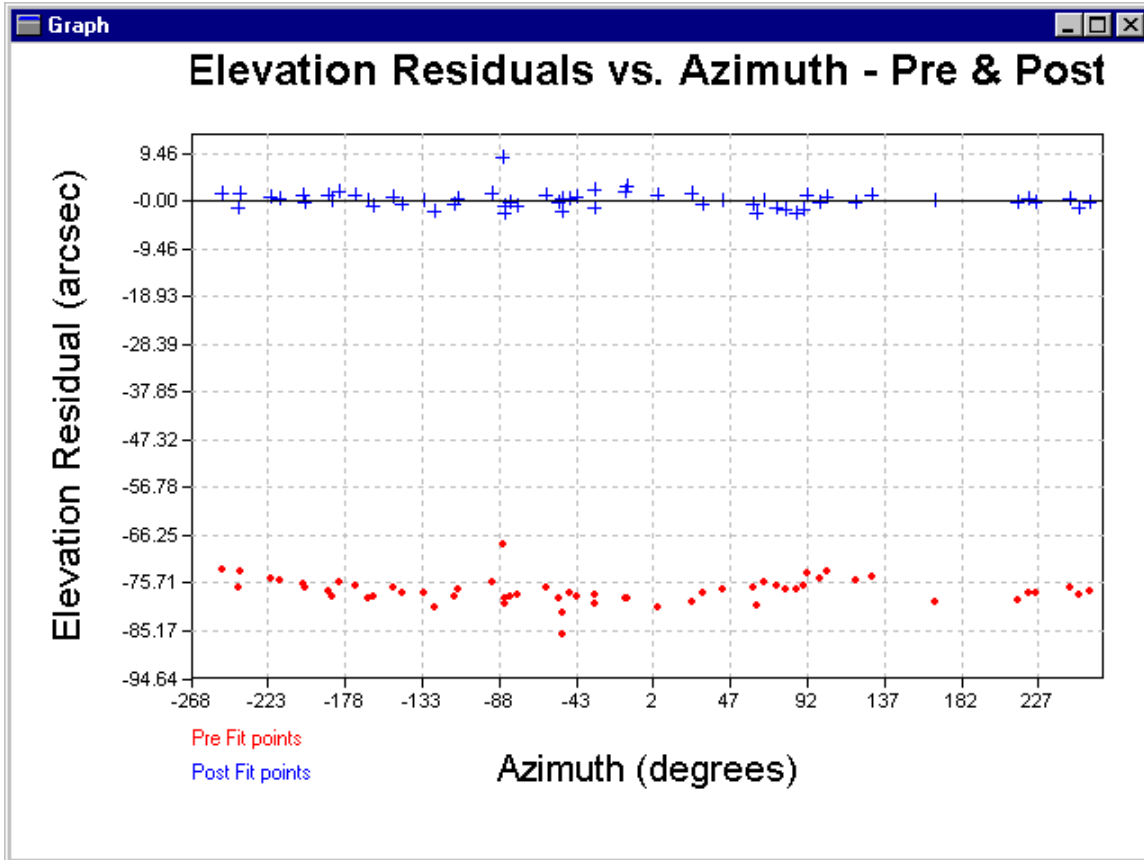


Figure 5.14: The *Elevation Residuals vs. Azimuth* graph, showing both pre-fit and post-fit residuals

*Graphs | Elevation Residuals vs. Elevation*

This displays a graph showing the elevation residual errors plotted against the elevation axis (Figure 5.15). 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.
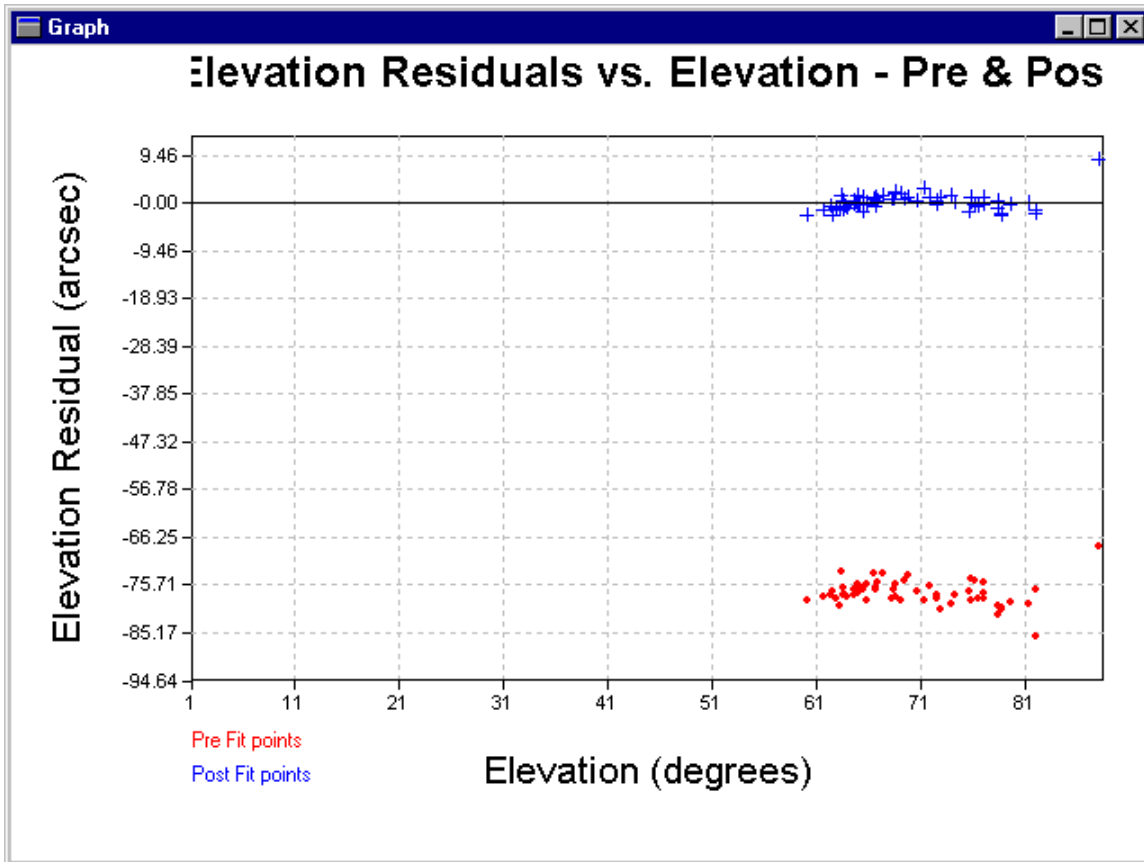


Figure 5.15: The *Elevation Residuals vs. Elevation* graph, showing both pre-fit and post-fit residuals

5.2.2.5   *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 | LowRegions*

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 5.16) which allows the user to specify a subset of the stars in the catalog to be displayed based on their magnitude.
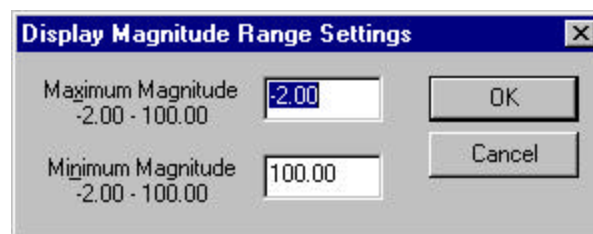
Figure 5.16: The *Magnitude Range Settings* dialog

*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.

5.2.2.6  *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.  See §5.2.4 Information Pages for more details.

*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.

5.2.2.7  *Help* Menu

*Help | Contents...*

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

*Help | Search...*

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

*Help | About Star Calibrator...*

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

## 5.2.3  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 as shown below.  Refer to §5.2.2 Menus for more details.

| Toolbar Button | Menu Command |
|---|---|
| *New* | *File | New...* |
| *Open* | *File | Open...* |
| *Save* | *File | Save* |
| *Save Report* | *File | Save Report* |
| *Grid Lines* | *Sky Map | Grid Lines* |
| *LowRegions* | *Sky Map | Low Regions* |
| *High Regions* | *Sky Map | High Regions* |
| *Current Time* | *Sky Map | Current Time* |
| *Northern Hemisphere* | *Sky Map | North Hemisphere* |
| *Southern Hemisphere* | *Sky Map | South Hemisphere* |
| *Refresh* | *Sky Map | Refresh* |
| *Remember Offsets* | *Operations | Remember Offsets...* |

### 5.2.4  Information Pages

The four main window information pages can be selected by clicking on the tabs at the bottom of the main window (Figure 5.1) 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.

5.2.4.1  *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.

### 5.2.4.2  *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.

### 5.2.4.3  *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 arcseconds, 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 arcseconds.

The parameters of the generated mount model are shown next.  The value of each parameter, in arcseconds, 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 arcseconds 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 arcseconds.

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.

### 5.2.4.4 *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).

## 5.2.5 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.

The current release of the software does not include any form of Sun avoidance. However this indicator can be used to determine whether the telescope is pointing dangerously close to the Sun.

`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.

### 5.2.6  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 §5.2.5 Status Bar), or as an error event in the system event log. Errors recorded in the system event log are usually self-explanatory.

### 5.3  OPERATIONS

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

### 5.3.1 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 VCP* currently attached to *Telescope Server* can be left connected but must not be in control if stars are to be tracked.

Generally *StarCal* is started up by setting the current working directory to `C:\Lick\Utilities\StarCal` and running `StarCal.exe`. *StarCal* does not support any command-line parameters.

When started a splash-screen should appear showing a satellite orbiting the Earth. Press any key to proceed to the main window shown in Figure 5.1. Note that the default sky map will be blank until *StarCal* is connected to a telescope.

### 5.3.2 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 (Figure 5.3).

2. Choose the telescope

   The current site (`Lick`) 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 Lick 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**.

### 5.3.3  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.

### 5.3.4  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.  If any other application is already in control of the telescope then this command will fail and will display a message indicating which other application has control.

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 (Figure 5.9).  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 (Figure 5.9).  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 (Figure 5.10) 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 (Figure 5.9), 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 *Bias Controller* dialog box shown in Figure 5.17.  This allows the telescope position to be adjusted in small increments around the current track.  Offsets can be applied in one of two orientations:

   `Azimuth/Elevation` — left and right offsets correspond directly to azimuth, while up and down offsets correspond to elevation.

   `Across/Along Track` — offsets are made with respect to the direction of motion of the stars.  In this case left and right offsets correspond to positive and negative declination, while up and down offsets correspond to decreasing or increasing right ascension.

   Note that changing the orientation will clear any offset already applied.

   If offsets are being remembered (see *Operations | Remember Offsets...*) then the *Bias Controller* dialog will start at the last offset that was used while tracking the previous star.
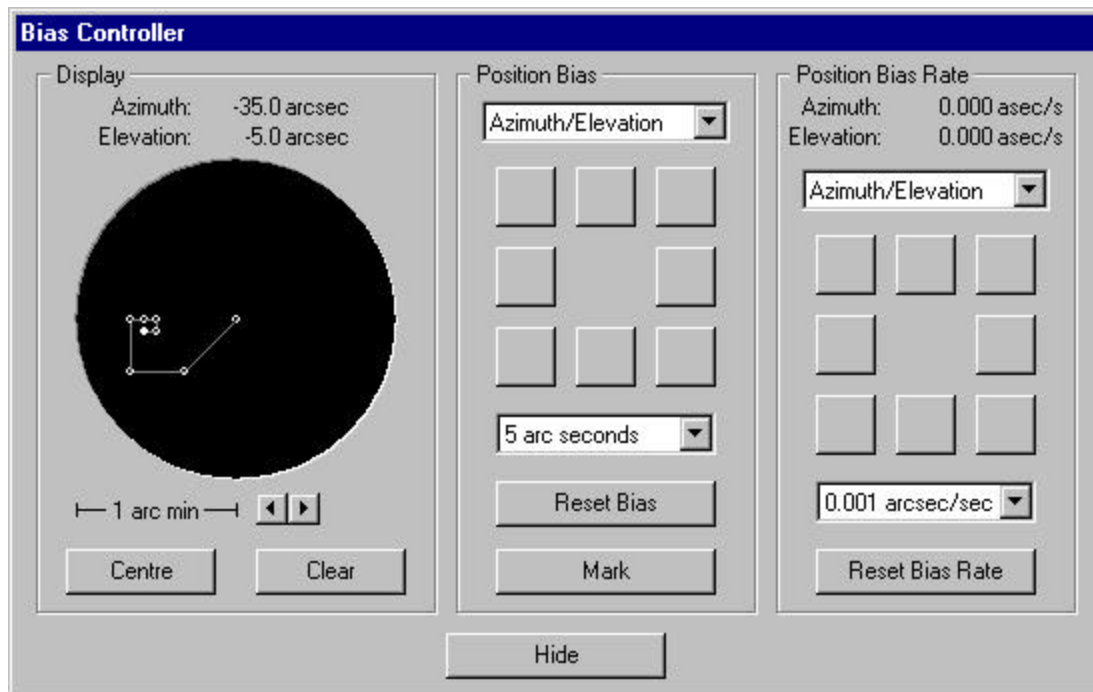
Figure 5.17: The *Bias Controller* dialog

10. Stop tracking

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

### 5.3.5  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 should be taken every few minutes and entered using ***Telescope VCP***.  See §4.2.2.10 *Mets* Group for more details.

2. Connect to a telescope

3. Start a new observation sequence

Choose *File | New...*.  This will bring up the *New StarCal Dataset* dialog box (Figure 5.2).  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 (Figure 5.6).

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 (Figure 5.7). 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 (Figure 5.6).

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 *Bias Controller* dialog box shown in Figure 5.17. Offsets can be applied in either of the two orientations: `Azimuth/Elevation` or `Across/Along Track`.

If offsets are being remembered (see *Operations | Remember Offsets...*) then the *Bias Controller* dialog will start at the last offset that was used while tracking the previous star.

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 *Bias Controller* dialog box.

The *OK* button will not be enabled until the *Mark* button in the *Bias 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...*).

### 5.3.6 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 §5.3.5 Star Calibrations 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 (Figure 5.8).

   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, the telescope will use this mount model until another one is installed.

Note that the old mount model being used by the telescope, stored in `Telescope.ini`, will be overwritten. In case it may be necessary to restore the old mount model it is recommended that `Telescope.ini` be copied to a backup directory before executing this command. Otherwise it can only be recovered if it was saved in another **StarCal** `.set` file.

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

# 6. KNOWN ISSUES

There are several known issues with this version of the software.

Creation of `C:\Temp\wobble.txt`

A diagnostic data file called `wobble.txt` is created in the `C:\Temp` directory by the **Telescope Server**. This file increases in size at a rate of about 2.5MB per minute. It should be deleted after the **Telescope Server** is shut down.

Note that the **Telescope Server** will not run if it can't create and write to this file.

**Device Browser** causes heavy CPU load when displaying **Telescope Server** state

If the **Device Browser** is running and is displaying the **Telescope Server** state, this may heavily load the CPU to the point where the computer will become unresponsive.

Reconnecting clients sometimes fails

If a client application such as **StarCal** is restarted after being shut down and disconnected from the **Telescope Server**, it may be unable to reconnect. Users should wait for approximately 1 minute before attempting to restart a client application that has been shut down.

Incorrect startup of servers causes errors

If the server applications are started up in the wrong order, or if an attempt is made to start them a second time, then various errors such as "assertion failure" will be reported in a dialog box. If this happens, shut down all the clients and servers and start from the beginning.

If a client application is started and the requisite servers are not yet running, then the client will report a Runtime Error and fail to start.

Control of telescope is not enforced

Normally only one client of the **Telescope Server** (**StarCal**, **Telescope VCP**) can be in control of the telescope at any time, in order to prevent confusion amongst simultaneous users. In this version of the simulation software client control is not enforced, so it is possible for **StarCal** to issue commands to the telescope while **Telescope VCP** is in control.