

TPoint for Windows

A Telescope Pointing Analysis System

User's Guide

Revision 1.25



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Welcome!

Thank you for purchasing TPoint for Windows, the most advanced telescope analysis system available. The combination of TheSky and TPoint provides the tools necessary to analyze the polar alignment and pointing performance of your “go to” or robotic telescope, provide insight into the repeatable errors in your imaging system, and improve the telescope’s pointing.

Professional telescopes world-wide benefit from TPoint’s sophisticated error-modeling algorithms. Now, with TPoint for Windows and TheSky Astronomy software, you can discover the errors inherent in your telescope, and improve its pointing performance. With less time spent searching for objects, you’ll enjoy the increased productivity of your observing sessions.

As with other components of your imaging system, there is a significant learning curve with TPoint. However, when used in conjunction with TheSky Astronomy software, you should be able to complete a mapping run on the first night and start analyzing your imaging system the first night out.

What is TPoint?

TPoint is an interactive telescope-pointing analysis system. By logging the telescope’s position when it is pointed to known equatorial coordinates, much can be learned about the geometry of the optical tube assembly and the telescope mount system (including cameras, focusers, filter wheels, piers, optical tube mounting, etc.).

The process of collecting pointing data is called *mapping*.

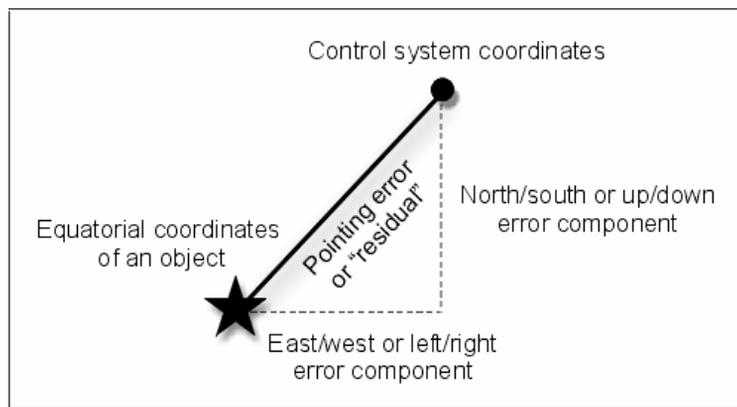


Figure 1: The telescope's control system typically does not point precisely to an object. The resulting difference is the pointing or “residual” error.

Mapping involves pointing the telescope at a series of stars distributed more or less evenly across the sky. When the telescope is centered on a star, both the star's coordinates and the telescope's position are recorded. The two coordinates differ by the *pointing error*, or *residual error*. Once these errors have been recorded for enough points (from a minimum of 6, to more than 1000 by some users), TPoint creates a set of values that are used in various mathematical formulae to compensate for the errors. Each time target coordinates are issued to the telescope they are adjusted by the amount of the computed error. The mathematical formulae for the various errors are called *terms*. A set of terms working together to improve telescope performance is called a *model*.

The model is used to improve the telescope system's ability to slew accurately to specified targets throughout the sky, or its *pointing*. The overall pointing of a system – taking into account all the residuals – is represented by the *Root Mean Square* (RMS) pointing. RMS is a statistical measurement whereby the square root of the mean of the squares of the errors is computed. In simpler terms, the computed RMS value provides a gauge from which one can estimate, with a high degree of confidence, how well a telescope system will point.

Once a model is established for a telescope, it is saved and can be used from night to night. As long as no adjustments are made to the telescope system, the model will remain valid. In situations where a telescope must be arbitrarily synchronized by pointing at a star each session, only a few of the terms must be re-established each night.

The “magic” of TPoint is in determining the values of the various terms from a set of mapped points, that is, *fitting* the data. If each term could be dealt with one at a time, the fit might not be difficult. However, when zero-points, polar alignment errors, non-perpendicular axes and various other pointing errors are all mixed together, untangling them becomes a daunting task that TPoint handles efficiently. The Fit Data command in TPoint automatically computes a new fit each time terms are added to or removed from the model.

The DOS/UNIX version of TPoint can digest data from either equatorial or alt-azimuth mounts. TPoint models have been applied to many telescopes, including IR, mm and radio, and are routinely used at the Gemini, AAO, UKST, UKIRT, LPO, Keck, WIYN, ARC and many other professional observatories.

TPoint is unique in that:

- (a) the telescope model can be changed during the interactive session, and
- (b) it contains a variety of graphical displays.

These two features allow for rapid exploration of the pointing possibilities of any given telescope and lead to the best model for that system.

TPoint for Windows works in concert with TheSky Astronomy Software to make collecting mapping data relatively simple. TheSky6 Professional Edition can even generate sets of evenly distributed azimuth and altitude coordinates that can be used with Orchestrate or Automapper II for automated mapping.

Sample of TPoint at Work

The best way to describe the ability of TPoint to improve telescope pointing is to show some actual “before and after” data.

The figures below show scatter diagrams of some data collected from an amateur telescope. Each of the diagrams shows the distribution of data plotted like a shooting target.

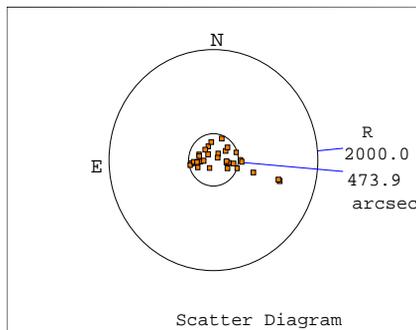


Figure 2: Before TPoint Model

Before the TPoint Model

The Root-Mean Square (RMS) pointing is about 8 arcminutes and a number of points fall well outside the 8-arcminute circle. It is easy to see that before the application of the TPoint model getting an object in the center of a 10x15 arcminute field of view is a hit-or-miss proposition.

Note the difference in scale between the top graph and the bottom graph.

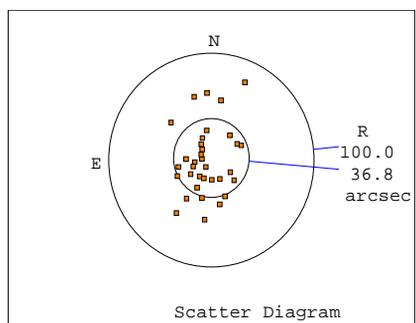


Figure 3: After TPoint Model

After the TPoint Model

The lower graph shows the same scatter diagram (at a magnified scale) after the application of a suitable TPoint model. The RMS pointing is under 40 arcseconds, with the worst points falling about one arcminute from center. The same 10x15 arcminute field of view is now “easy pickings.”

Minimum System Requirements

TPoint for Windows has the following software and hardware requirements.

Software Requirements

- Any computer capable of running Windows 98/Me/NT/2000/XP or later. A Pentium III or faster processor is recommended.
- At least 5 megabytes (MB) of free disk space is required for the TPoint installation.
- TheSky6 Serious Astronomer Edition or TheSky6 Professional Edition version 6.0.0.0 or later (or TheSky Level II, III or IV for Windows, version 5.00.014 or later) must also be installed on the same computer.

Hardware Requirements

TPoint requires an equatorially mounted robotic telescope with sufficient encoder resolution. The following equatorially mounted, robotic telescopes benefit from TPoint modeling.

- All ACL-compatible telescopes (DFM telescopes, ArchImage)
- All control systems that use the LX200/Autostar protocol and have sufficient encoder resolution. This includes virtually all telescopes from Meade Instruments Corporation.
- Astro-Physics GTO mounts.
- Losmandy Gemini.
- All Mountain Instruments telescope mounts (using the Astro-Physics control system).
- All NexStar GPS Series, CG, CGE, CPC, SLT Series and Advanced GT Series telescopes, or any NexStar-compatible model telescope using firmware version 4.1 or later.
- Paramount GT-1100.
- Paramount GT-1100S.
- Paramount ME.
- Parallax GTO telescopes (using the Astro-Physics control system).
- Takahashi Temma mounts.
- Vixen Sky Sensor 2000.

Performance

TPoint is a computation-intensive application that performs a many floating-point operations, especially when a “fit” is computed. A math coprocessor, included on all modern processors, is required.

Installing TPoint for Windows

TPoint for Windows is designed to run under Windows 98/Me/NT 4.0/2000/XP or later and take advantage of many of their features. TPoint is licensed as a single-user product – please do not install TPoint on a network. If you need a site-license, contact Software Bisque.

Before starting the installation...

If present, please read the ReadMe.htm file on the installation disk #1. It might have last-minute information we were not able to put in the manual.

Windows Installation

1. Insert the CD ROM in the CD ROM drive.
2. Wait for the installation to begin.
3. Follow the on-screen instructions to complete the installation.

The installation program prompts you for the information it needs, such as the hard drive and folder to install TPoint.

Uninstalling TPoint for Windows

Removal is easy under Windows 98/Me/NT/2000/XP – Windows does it for you.

1. Click **Start | Settings | Control Panel**.
2. Double-click **Add/Remove Programs**.
3. Highlight **Software Bisque TPoint (Remove Only)** in the list box.
4. Click **Add/Remove**.
5. In the Confirm File Deletion dialog box, click **Yes** to remove TPoint.

Technical Support

Telescope pointing analysis is not a trivial task. If you need help analyzing your telescope modeling data, consider posting your questions to the TPoint Community Forum on the Software Bisque Support Corner (<http://www.bisque.com/sc>). There are TPoint users on this forum who are willing to help.

Typographic Conventions

This manual uses the following typographic conventions.

Example of Convention	Description
<code>a:install</code>	Courier typeface is used for file and folder (directory) names, for text typed from the keyboard, and to display the contents of files and sample data.
<i>geometric</i>	<i>Italic</i> text is used to highlight new terms, for

CCDS*soft*
F1
ENTER

emphasis and to identify product names. Keystrokes are shown in caps. If two keys have a plus sign (+), *press and hold* the first key, then press the second.

Windows Conventions

This manual assumes you already have a basic understanding of how to use Windows. Here are a few reminders of mouse usage and Windows terminology.

Term	Description
Click	Point the mouse pointer (the on-screen arrow) to an object or command, then quickly press and release the left mouse button. “Click” always means click left. If you are supposed to press the right mouse button, it will say “Click right”.
Double-click	Point the mouse pointer (the on-screen arrow) to an object or command, then press the left mouse button twice, very quickly.
Select	Point the mouse cursor at a command or item in a list, then click the left mouse button.
Drag	Press <i>and hold</i> the left mouse button. Then move the mouse while continuing to hold the button down.
Dimmed	When a command or function is not available, it is shown in gray (rather than black). Unavailable functions are therefore said to be <i>dimmed</i> .
Marked; Clear	If a check box has a mark in it, it’s “marked”, if there is no mark, it’s “clear”.
Control button	The control button is the button on the upper left of a window or dialog box. Clicking it once displays the control menu.

Launching TPoint

Under Windows XP or later, the installation program adds TPoint to the Software Bisque menu in the All Programs menu. To run TPoint, click **Start | All Programs | TPoint**.

Quick Start

If you just want to gather some data from your telescope to see how well it can point, follow the steps below. You have to first promise to study the remainder of this documentation when you have more time.

1. Install TheSky (version 5.00.014 or later). To obtain the latest versions of all Software Bisque software, visit <http://www.bisque.com/download>.
2. Install TPoint and run it once by clicking **Start | All Programs** (or **Programs** on earlier operating systems) | **Software Bisque | TPoint | TPoint Telescope Pointing Analysis Software** (you must run it once to perform system-related initialization).
3. From TheSky, establish a link to the telescope.
4. From TheSky, click **Edit | Insert New Object**.
5. From the **Object Type** list, select TPoint model.
6. Begin collecting mapping data (see page 19 for details).

Introduction

How is TPoint used to investigate the pointing performance of your telescope?

A reticle eyepiece, low-light video camera, or CCD camera is used to establish a precise and consistent reference point in the focal plane of the telescope. Using this reference point, a sequence of stars of known coordinates is pointed to and centered on this reference point (with the aid of TheSky astronomy software). Once a series of observations have been logged, TPoint's Fit Data command is used to create a pointing model for the telescope based on the mapping data. Once created, the model is used each time a slew command is issued from TheSky to the telescope control system. TheSky adjusts the equatorial coordinates to automatically correct for repeatable telescope errors.

TPoint calculates the optimum value for each term in the model, such that the overall model is the best possible fit to the mapping data. Using TPoint's graphing commands, the remaining pointing errors can be inspected and any remaining obvious repeatable errors can be minimized by adding additional terms to the model.

The final result shows how well the telescope can point, and what coefficients need to be employed to achieve this result. The coefficients that TPoint produces (that is, the value of each pointing term) are then saved in the *TPoint Document*. The TPoint Document and included model is then used by TheSky to adjust the right ascension and declination coordinates issued to the telescope control system, so that the pointing accuracy is improved.

Another use of TPoint is to identify opportunities for mechanical adjustment. For example, TPoint enables the polar axis of an equatorial mount to be set up accurately even on telescopes that cannot, for some reason, see the pole.

What Kind of Pointing Can I Expect Using TPoint?

The pointing accuracy of your automated telescope is dependent on the integrity of your telescope mount and optical tube assembly. Even small mechanical errors

manifest themselves as pointing errors. If the mechanical errors are repeatable, then TPoint will most likely be able to determine the magnitude of the error and create a model that corrects for the error.

Random errors, such as mirror-flop, focusing shift, backlash and others, fall into the hysteresis category and must be dealt with separately. For example, locking the mirror on an SCT will virtually eliminate the random errors introduced by mirror flop.

Since these errors are random or somewhat random in nature, a model cannot be created that can correctly forecast the size of the errors at all pointing positions. Spending some time at the telescope with a simple video system can expose many of these non-repeatable errors. For example, if the focus is approached from both directions while the telescope is centered on an object, focus shift should become apparent.

On most amateur systems, root mean square (RMS) pointing of two arcminutes or better can be achieved without great difficulty. Robust amateur systems can achieve RMS pointing in the 10-20 *arcsecond* range using TPoint.

The TPoint Approach

The general approach taken by TPoint is the telescope model should describe real effects (geometrical misalignments, well understood flexures, etc.), and empirical functions should be used only to “mop up” any remaining systematic errors. There is a school of thought that advocates using empirical functions (for example polynomials or spherical harmonics) for the whole job. However, the TPoint approach has some advantages.

Simple geometrical misalignments might require very complicated empirical functions but are simple to deal with analytically. Direct manipulation of certain geometrical terms while the telescope is in operation can be very useful. An important application of this technique on professional telescopes is where a star is switched from one instrument aperture to another simply by changing the collimation parameters. Another example is where the polar axis of a wide field telescope is routinely raised and lowered as a function of declination, to minimize the field rotation effects of differential refraction. The polar axis elevation parameter in the pointing model can simply be changed by the same amount and accurate pointing is maintained.

A realistic model of a telescope frequently exposes mechanical deficiencies, which can then be diagnosed and cured. A realistic model is likely to require fewer terms, and the number of stars observed in a pointing test can be correspondingly smaller. Physically based models are less likely to misbehave when extrapolating outside the area covered by the available test data.

Interaction with TheSky

Mapping requires slewing the telescope to a number of known objects (or positions) in the sky. TPoint works with TheSky astronomy software to provide a set of software tools that make mapping telescope errors a straightforward procedure. The task of mapping these errors and reducing them to a model might otherwise require many nights of labor.

TheSky performs the following functions necessary to perform a mapping run.

- Generates databases of points that can be used for mapping. See TheSky6 Professional Edition's **Data Mapping Points** command for more information.
- Oversees telescope control by sending coordinates to the telescope.
- Records the star coordinates and telescope coordinates used by TPoint.
- Maintains a visual history of mapped points.
- Once a model is established, it makes adjustments to telescope coordinates so that pointing is improved.
- Acts as a “container” for the TPoint telescope model. The telescope model is used on subsequent observing sessions to improve the telescope's pointing.

Setting Up TPoint for Telescope Use

TheSky must be able to control the telescope (issue slew commands) in order to collect TPoint mapping data. At the time of this writing, TheSky supports most popular amateur telescopes and control systems, as well as many professional telescopes.

Telescopes Not Supported by TheSky

If you have a telescope or mount that is not supported by TheSky, you can still use TPoint for Windows to analyze your system by creating an appropriately formatted DOS text file and using TPoint's Import command. Unfortunately, the benefit of real-time adjustments to the coordinates sent to the telescope control system by TheSky is lost.

To achieve interaction of TheSky and TPoint on such systems, the following options should be considered:

1. Modify to the telescope control system such that it supports one of the existing communications protocols used by TheSky.
2. Contact Software Bisque regarding third-party programming options for telescope and CCD camera control.
3. Use the existing Telescope Applications Programmers Interface (Telescope API) available in TheSky version 5.0 or later.

How TheSky and TPoint Interact

TPoint must first collect mapping data in order to analyze and improve your telescope's pointing. This involves slewing the telescope to a number of different points in the sky, then recording the actual destination and the desired destination of the telescope. TheSky is a very efficient tool for gathering this data.

Once a sufficient number of mapping points are collected, TPoint generates a mathematical model of the telescope's pointing. TheSky uses this model to modify the telescope's destination coordinates each time a slew command is issued.

TPoint works "invisibly" in the background when controlling your telescope with TheSky. The only indication that TPoint is present is a small window on the Virtual Sky. This window represents the TPoint model, and is called a TPoint Document.

The TPoint window on the Virtual Sky also allows you to access the TPoint program. From the TPoint program, you may view or graph the mapping data, or modify the pointing model.

In order to understand the differences between running TPoint as a stand-alone program versus running TPoint as an embedded model on the Virtual Sky, first try launching TPoint by clicking Start, Programs, TPoint. On the File menu, click New.

A new TPoint document appears and resembles the familiar spreadsheet-like input. This holds mapping data that can be input manually, imported from a text file, or generated by TheSky. Now exit TPoint and launch TheSky.

The next step is to run TPoint as an "embedded document" in TheSky.

Inserting a TPoint document into a Sky Document

To insert a TPoint document into TheSky, from TheSky, click **Edit | Insert New Object**. The Windows Insert Object dialog box is displayed listing all of the embeddable objects available on your computer. Scroll the list until TPoint Model is displayed (pressing "T" will quickly move the highlighted selection to objects beginning with T). Choose **TPoint Model** and then click **OK**.

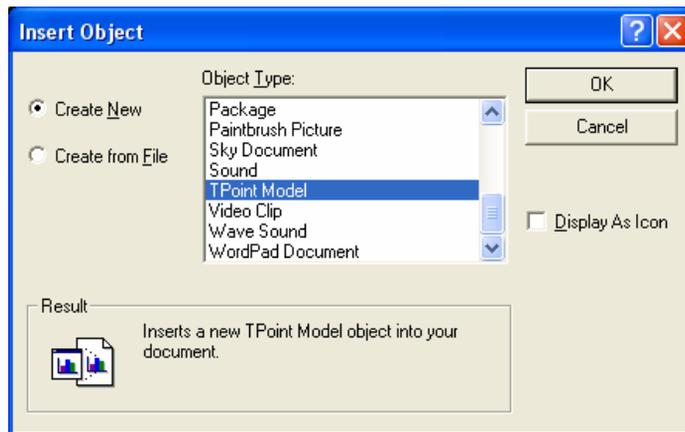


Figure 4: The Edit | Insert Object dialog box.

The Insert Object dialog box allows inserting a previously created model instead of starting with a new, empty model. If you wish to insert an existing model, click **File | Create** instead of the **Create New** command, and then click **OK**.

Note: On systems intended for permanent installation (such as the Paramount ME, GT-1100 or GT-1100S), a TPoint object is automatically inserted into TheSky when a link is established to the telescope.

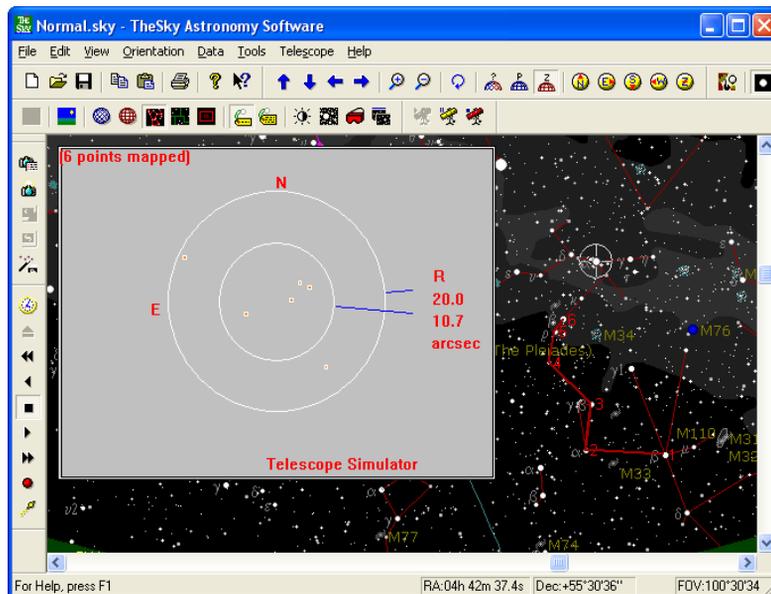


Figure 5: An embedded TPoint document.

Once inserted, the TPoint document appears as a large gray rectangle on the Virtual Sky, showing the number of mapped points. When a new model is created, a gray window with the text “(0 points mapped)” is shown. A scatter diagram similar to the one above will only be displayed *after* six or more points have been mapped and a TPoint model has been created.

This TPoint document window can be resized or moved to any part of the Virtual Sky. To resize the window, click once in the gray area. This displays eight small black sizing rectangles. Next drag one of these sizing rectangles to change the window’s size.

Right click on the TPoint model to display the options described below.

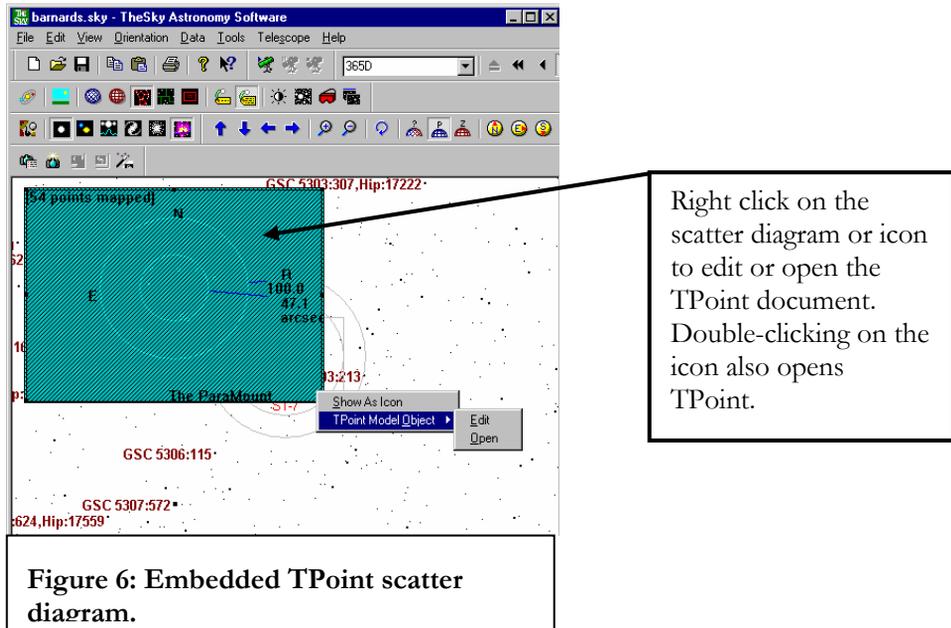


Figure 6: Embedded TPoint scatter diagram.

Right Click, Show as Icon Command

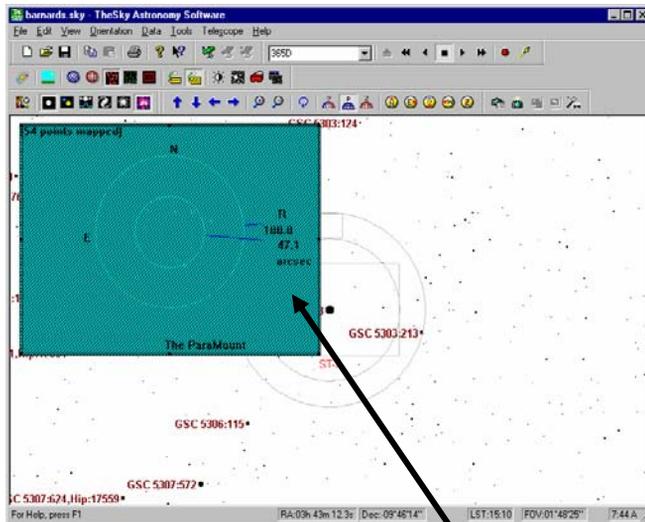
This command will toggle between displaying the TPoint model as graph or a smaller icon. The icon display is typically used once mapping is done and there is no longer a need to see the scatter diagram.

Right Click, TPoint Model Object | Edit Command

When this command is selected, the TPoint toolbar will be displayed along with the toolbars for TheSky, allowing editing of the TPoint data values without leaving TheSky. For example, if you misidentify a star and map it, this command allows you to mask the offensive point. To return to TheSky, simply click anywhere in TheSky display.

Right Click, TPoint Model Object | Open command

This command launches TPoint, and displays the TPoint window. Note that while the TPoint application is running, the model is not accessible from TheSky. That is, the icon representing the TPoint model on the Virtual Sky will be grayed and not editable. Also, a slew command is issued from TheSky while the TPoint application is running, the coordinates issued to the telescope will *not* be adjusted per the model. *Always make sure that you close the TPoint application by clicking File | Exit and Return to TheSky.*



#	Star RA	Star Dec	Scope RA	Scope Dec	LST	Ang. Sep.	*	AUX1	AUX2	Def
1	18 55 07.64	-26 17 48.6	18 55 07.50	-26 17 46.5	20 29.3	3		0.000	0.000	123
2	18 45 31.14	-26 59 23.8	18 45 33.30	-26 59 21.7	20 29.6	29		0.000	0.000	138
3	19 04 32.98	-21 44 30.7	19 04 32.65	-21 44 28.5	20 30.0	6		0.000	0.000	85
4	19 07 35.96	-21 06 24.4	19 07 36.30	-21 06 22.2	20 30.3	23		0.000	0.000	91
5	19 09 37.60	-21 01 26.0	19 09 37.00	-21 01 24.0	20 30.6	26		0.000	0.000	90
6	19 21 32.73	-17 50 55.4	19 21 33.30	-17 50 28.0	20 31.1	28		0.000	0.000	55
7	19 01 33.85	-05 44 22.3	19 01 34.35	-05 44 06.0	20 33.4	18		0.000	0.000	-31
8	18 47 03.66	-04 44 52.2	18 47 04.20	-04 44 51.0	20 34.0	8		0.000	0.000	-38
9	19 06 08.03	-04 53 01.4	19 06 07.96	-04 52 36.7	20 34.5	25		0.000	0.000	-37
10	19 25 23.34	+03 06 43.5	19 25 10.15	+03 06 45.0	20 34.0	70		0.000	0.000	-92
11	19 00 40.03	+00 51 49.0	19 50 33.60	+00 51 40.5	20 35.3	107		0.000	0.000	-130
12	19 05 18.81	+13 51 42.2	19 05 05.70	+13 52 36.8	20 35.8	199		0.000	0.000	-171
13	18 59 31.64	+15 03 59.6	18 59 14.70	+15 05 06.0	20 37.1	254		0.000	0.000	-181
14	18 07 16.02	+09 33 56.6	18 07 06.86	+09 34 39.0	20 37.6	142		0.000	0.000	-132
15	17 34 30.39	+09 35 14.3	17 34 26.10	+09 36 15.8	20 38.1	388		0.000	0.000	-125
16	17 34 50.32	+12 33 52.4	17 34 42.90	+12 35 01.5	20 39.5	129		0.000	0.000	-152
17	17 14 33.12	+14 23 46.2	17 14 23.40	+14 24 49.5	20 39.9	155		0.000	0.000	-160
18	16 30 07.67	+21 29 54.1	16 29 49.35	+21 32 08.2	20 39.4	289		0.000	0.000	-204
19	16 41 12.59	+31 36 39.8	16 40 40.05	+31 38 46.5	20 39.9	434		0.000	0.000	-310
20	17 00 12.79	+30 56 01.1	16 59 40.80	+30 57 54.0	20 40.3	427		0.000	0.000	-308
21	17 14 58.99	+36 48 54.8	17 14 11.85	+36 51 00.0	20 40.6	680		0.000	0.000	-388
22	16 42 49.70	+30 55 50.1	16 41 59.10	+30 57 47.3	20 41.1	603		0.000	0.000	-395
23										

Figure 7: Relationship between TPoint mapping data (in TPoint's spreadsheet) and Scatter Diagram (in TheSky).

Important!

When the TPoint program is open, the icon or scatter diagram changes to a cyan color with diagonal hatching on the Virtual Sky. This indicates that the TPoint document is currently in use. When the TPoint spreadsheet is visible as in the above diagram, TheSky cannot access TPoint functions such as mapping or improving telescope pointing. To give TheSky control of the TPoint document, from TPoint, click **File | Exit and Return to TheSky**.

Deleting a TPoint Model

When any physical changes are made to the telescope system (such as changing the polar alignment or changing the optical tube assembly) you must perform a new mapping run starting with an empty TPoint model.

To delete an existing model, click on the TPoint model in the Virtual Sky, and it will be highlighted. Note the presence of eight small black sizing rectangles around the scatter diagram indicating that it is selected.

Click on the scatter diagram or icon to select the TPoint document. Once selected, from the TheSky, click **Edit | Delete**.

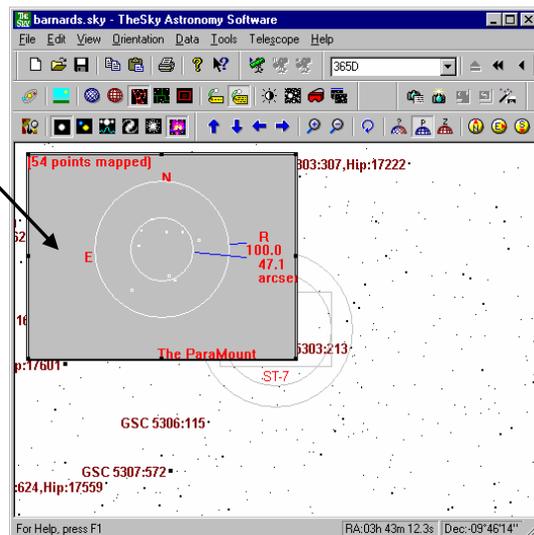


Figure 8: TPoint Scatter diagram embedded in TheSky.

Next, from TheSky, click **Edit | Delete**. Once you verify you wish to delete the model, it will be removed from the Sky Document. You can then click **Edit | Insert New Object** to add a new, empty TPoint model.

Mapping

When TheSky and TPoint are installed on your computer, each program is registered with Windows. This allows programs to “find each other” when needed. TheSky and TPoint share data during the mapping process, and when slew commands are issued from TheSky6.

To begin mapping, start TheSky and establish a link with the telescope by clicking **Telescope | Link | Establish**.

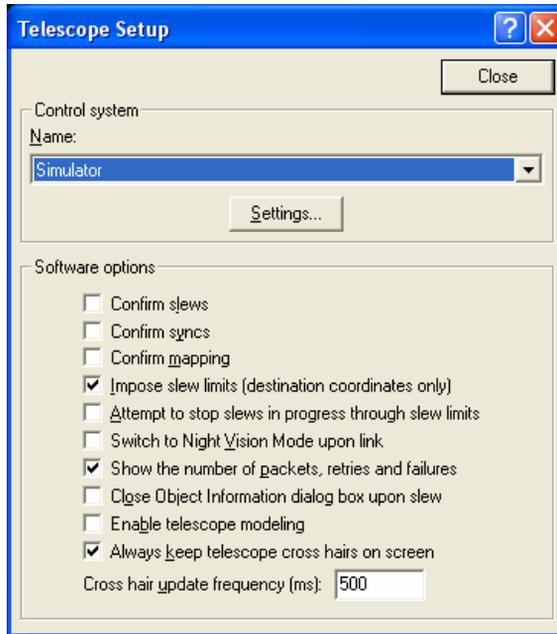


Figure 9: Telescope Setup dialog box (TheSky).

Make sure to check the **Enable TheSky Modeling** option on the Telescope Setup dialog box.

Next, perform any initialization or synchronization required by the telescope’s control system.

Once communication is established between TheSky and the telescope, you are ready to start mapping. You must map *at least* six points before TPoint is able perform a “fit” and begin to improve the pointing of the telescope. You should notice considerable improvement in pointing after six mapping points are collected. If you are using a German equatorial mount, continue mapping on one side of the meridian initially, since polar misalignment and errors dues to non-orthogonalities can make locating stars “on the other side of the meridian” difficult until a more thorough

model is established. See Using TPoint to Quantify Polar Alignment on page 27 for more information.

Centering Stars on the Sensor

There are a number of different methods that can be used to center a star once the telescope control system has been directed at the star's coordinates. Each method has particular advantages and disadvantages.

A commonly asked question is, "What focal length should be used for mapping?" Of course, the longer the focal length, the more accurately you will be able to center the target. However, using too much magnification can hinder the mapping process, especially when it is the first time a) the telescope has been mapped or b) you have used TPoint. If the telescope is pointing poorly, locating and centering objects at high magnification becomes an arduous task.

Reticle Eyepiece

The simplest method is using a reticle eyepiece. Many eyepieces are available with the reticle lines illuminated, making it much easier to center an object. This method has the benefits of requiring a minimum amount of hardware. However, it does require the user physically views and centers each star – which can be difficult on some telescopes.

Video Camera

A low-light video camera is generally the most efficient method of centering a star at a given location in the focal plane since the gymnastics of placing an eye in the telescope eyepiece is removed. As well, there is no integration and download time associated with each observation as there is with a CCD camera. Be sure to check the focal plane relationship between the video and CCD detector to insure they match satisfactorily.

CCD Camera

The goal of most mapping procedures is so that objects will fall on a CCD detector, so there are obvious advantages to using the CCD camera to perform a mapping run. If the video camera is not centered in the exact same position as the CCD, there will be a consistent pointing error once the video is replaced with the CCD. Of course this offset can be corrected using TPoint but this requires an additional step.

Automated Mapping

Once you become proficient with the mapping process, and understand your imaging system, the most efficient method of collecting mapping data is to automate the process. The free Automapper II software from New Astronomy Press (www.newastro.com/newastro/downloads/automap2) will automatically collect mapping data required by TPoint using your CCD camera, CCDSoft and TheSky.

Summary of Centering Methods

Centering Method	Advantages	Disadvantages
Reticle Eyepiece	Simple; no additional electronics are required.	Requires visual sighting at all telescope positions.
Video camera	Very efficient, no climbing around the telescope. No integration and download times associated with a CCD.	Equipment is expensive.
CCD Camera	Uses the same instrument for which the mapping is being performed; no additional collimation error adjustments are required.	Slowest method; must wait for integrating and downloading the CCD image.
Automapper II	<ul style="list-style-type: none"> Collects mapping data automatically. No centering of objects required. (Automapper II uses CCDSoft's AutoAstrometry to determine where the telescope is pointing.) 	This is an advanced feature, and requires a good understanding of mapping fundamentals, as well as CCDSoft's AutoAstrometry command.

Collecting Mapping Data Points

1. Initialize the telescope (see TheSky's documentation or visit www.bisque.com/telescope for details.)
2. Identify a star in TheSky by clicking on it (preferably one that is somewhere in the area near where the telescope is currently pointed so a long slew is not required).

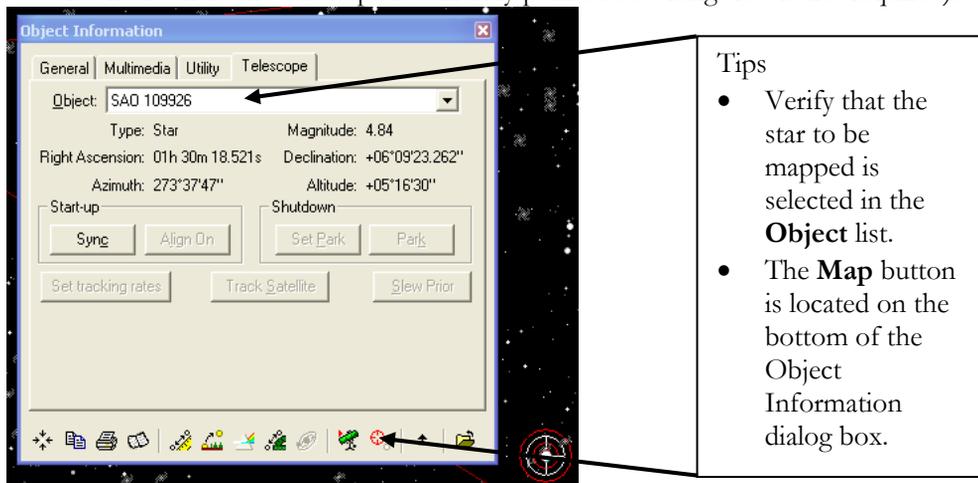


Figure 10: TheSky's Object Information dialog box.

3. Click **Slew** on the Object Information dialog box.



4. Center the star.
5. Once centered, click **Map** on the Object Information dialog box. (Verify the star to be mapped is highlighted in the **Object** list box; see Figure 10.) If the **Telescope | Setup | Confirm mapping** option is marked, you'll need to confirm that you really want to add this data to the current model. The Confirm Map dialog box shows the current object's coordinates and the telescope's coordinates.

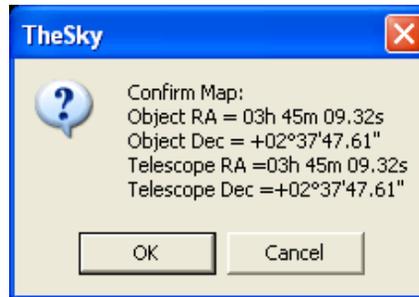


Figure 11: Confirm Map dialog box.

If the telescope's coordinates are more than 30 arcminutes from the telescope's coordinates, TheSky will post the following message:

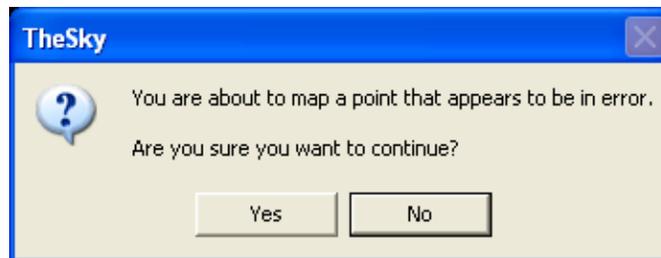


Figure 12: TheSky's warns you if the current map point appears to be erroneous.

Click **No** to reject the map point, **Yes** to accept it.

When the Map button is clicked (and all else is okay), the star's coordinates and the telescope's current coordinates are logged in the TPoint Document.

Mapping – How Many Points and Where?

The number and distribution of mapped points is dependent on the pointing goal for the system and the system itself. Permanently mounted telescopes are better suited for extensive pointing runs (that is, hundreds of points) since the pointing model will probably remain unchanged for a long period of time.

A preliminary assessment of a telescope's pointing capabilities can be made using perhaps 20-30 map points. More extensive pointing runs of 50-100 map points (or more) provide TPoint with the necessary data to create a model that contains the geometrical terms and any additional terms relevant to the telescope system.

On amateur systems, performing mapping runs of 30 to 100 points usually result in RMS pointing of one to two arcminutes; less than one arcminute RMS pointing is possible on robust systems.

The mapped points can be evenly distributed across the sky on an altitude and azimuth basis (but do not have to be so). Even though you might map a perfect distribution of equatorial positions (right ascension and declination), the stars are continually moving. This results in an uneven distribution of points on an altitude and azimuth basis. Conversely, the same star can be used multiple times as its horizon coordinates change during the mapping run.

Mapping Hint: Avoid stars close to the horizon, as refraction begins to cause large pointing offsets. Although TPoint makes refraction calculations, computing the exact positions of objects “down in the muck” is difficult.

TheSky6 Professional Edition can create a set of altitude and azimuth points that are plotted on the Virtual Sky for a visual template of where in the sky to map points (using the **Data | Mapping Points** command). See the web page below for details about generating these points.

<http://www.bisque.com/thesky/tom/auto-map/automap.asp>

For best results, use TheSky6's **Magnitude Limits** feature (to edit the magnitude of stars, right-click on any star, and then click **Display Properties of Star** command). TheSky Version 5 users should click **View | Filters** to exclude all non-stellar objects and all faint stars during a mapping session. The identification errors can be minimized if stars of sixth magnitude and brighter are displayed while mapping.

Software Bisque recommends that the first six stars selected for a mapping run be relatively close to one another, that is, within a few degrees. Then, the benefits of the model can be utilized as you migrate away from these stars, making the mapping of the remaining points easier.

Keep an eye on the scatter diagram that is updated as each point is mapped on the Virtual Sky. If you misidentify a star during the mapping run the RMS pointing will jump drastically into the thousands of arcseconds. When this happens, you need to open the TPoint model and mask the observation so that the model is not polluted by it.

As data points are mapped, they are added to TheSky's **Data | Add User-Defined Data** list as Reference Lines. These horizon-based lines provide a visual reference of where in the sky mapping has been performed. They are not part of the mapping data and can be hidden in TheSky6 by right-clicking the line, and then clicking the Toggle Reference Line command (or, from TheSky Version 5, by clicking **View | Filters** and then clearing the **Reference Line** option in the Celestial Object list).

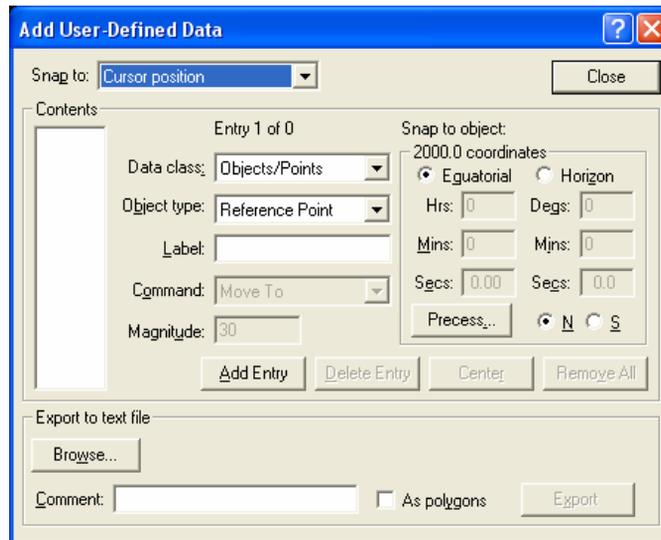


Figure 13: Add User-Defined Data dialog box (TheSky).

This data is added to show the mapping path only and does not affect the TPoint model in any way. The data present in the Add User-Defined Data section of TheSky can be deleted at any time, and you will probably want to do so once the mapping session is completed.

To Remove the Red “Map Path” Lines

1. From TheSky, click **Data | Add User-Defined Data**.
2. On the Add User-Defined Data dialog box, click **Remove All** and then click **Close**.

Printing a Video Target

When using a video camera for centering, the reference point employed is usually a mark somewhere on the video monitor. Though drawing directly on the monitor with a marker is one possible alternative, most will find that using a transparency with a cross hair pattern to be superior. TPoint provides a method for printing a cross hair with a set of concentric circles that, when printed on a transparency sheet, is well suited for use as a centering guide.

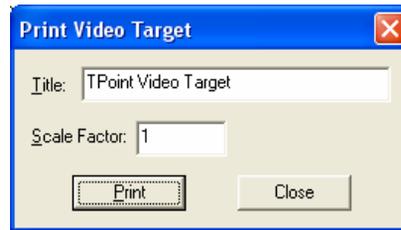


Figure 14: Print Video Target dialog box (TPoint).

To print a Video Target, on the File menu, click the Print Video Target command.

*Note: A TPoint document must be present. If one is not present, click **File | New**. Next, click **Print** to send the template to the printer.*

Title

The title entered will be printed on the transparency with the centering rings and cross hairs.

Scale Factor

Calibration of the circles printed on the transparency sheet is not necessary to accomplish a mapping run. However, it is instructive to calibrate such that each circle corresponds to an integral distance in arcminutes for quick estimation of pointing accuracy during a pointing run.

Because there are many factors that determine the final scale on the video monitor in say “arcseconds per millimeter,” using an empirical method determine the scale factor for a particular system is the best approach.

To calibrate the circles printed on the template with your system, the scale on the video monitor must be determined. Once the scale is known, the scale factor can be adjusted so that when printed on transparency paper, the various ring sizes correspond directly with arcminutes. At a scale factor of one, each circle is a multiple of 25.4 mm (1 inch) so the nominal scale is one arcminute per inch.

For example, if the scale on the video monitor is determined to be 0.80 arcminutes per inch, then the scale factor should be set to the reciprocal of 0.80, which is 1.25. Then, when the transparency is printed and attached to the video monitor, circles of 1, 2, 3, etc. arcminutes are available for quick estimation of pointing.

Using a TPoint Model

Once you have mapped at least six points from TheSky, TPoint’s Fit Data command is performed automatically each time a new map point is collected, and the model is updated with the new observation. The default model used in TPoint consists of the 6 geometric terms. By analyzing the mapping data, you can determine the additional

terms that should be used for your telescope. Click **Model | Fit Data** and then click the **More Terms** button to add them. If you're unsure which terms to use, click the "Suggest Terms" button to optimally add terms (page 60).

During a mapping run, the pointing data is continually supplied to TPoint and the pointing model is updated with each new point. Once a model is computed (and the Enable TheSky Modeling option is checked in TheSky's Telescope Setup dialog box), coordinates sent to the telescope are modified according to the terms in the model. Telescope pointing should start to improve, and continue to improve, as additional points are added to the model.

Once a reasonable sample of pointing data has been acquired (approximately 30 or more points), you can experiment with various other terms from within TPoint to possibly further improve the pointing performance. Two of the most obvious candidates are the TF tube flexure (TF) and the fork flexure (FF) terms (if your telescope has fork arms, that is. If not, don't include this term in the model).

When adding new terms, pay attention to the standard deviation of the new coefficient, the effect on other terms, and whether the population standard deviation (PSD) has gone down. A new term will almost always reduce the RMS, but population standard deviation is a better indication of whether the improvement is real. If the PSD increases, the new term has probably done more harm than good and should be rejected.

Gear errors, such as out of round gears, or not properly centered gears, are another common source of pointing errors. These can be modeled by adding the harmonic terms HDSD and HD CD for the declination gear or HSH and HHCH for the RA gear. On the Paramount ME, the DAF term is almost always recommended.

See the section titled "Generic Terms" on page 58 for information on the syntax of polynomial and harmonic terms.

Example: Adding Generic Terms for Gear Centering Errors

1. From TPoint, click **Model | Fit Data**.
2. Click the **More Terms**.
3. On the More Terms dialog box, in the Add Terms group, type HDSD (the sine component) in the **Abbreviation** text box. The **Add** button is undimmed if the term is not already part of the model.
4. Click **Add** to append this term to the list of terms. Note that the **Use** option (in the Current Term group) is marked when a new term is added.
5. Repeat steps one and two for the cosine component (HD CD).
6. Click **Close**.

When the new terms have been added, make note of the change in RMS pointing and population standard deviation to determine if the terms should be added to the model.

Hint: Click the **Suggest Term** button (page 60) to have TPoint analyze your data and list the most favorable terms for your telescope model.

Using TPoint to Quantify Polar Alignment

Equatorially mounted telescopes need to be aligned with the celestial pole before they can point and track accurately. Although there are many different techniques for aligning a mount with the pole, TPoint works best.

The telescope mapping data you collect can be used by TPoint to determine the magnitude (in arcseconds) of polar misalignment in altitude and azimuth. Once the misalignment has been determined, adjustments to the mount can be made and the process of mapping, analyzing and adjusting repeated until the desired polar alignment is attained.

Once you are familiar with the technique of telescope mapping you are ready to begin a mapping run. If the mount's polar alignment is way off, even short star-hopping slews may require the destination star to be re-centered in the eyepiece.

Testing Polar Alignment

After synchronizing the telescope on a known star, slew the mount to second star two or three degrees away. If the star does not fall near the field of view of a typical eyepiece, the polar alignment is probably way off.

Assessing Polar Alignment

Use TPoint to assess the polar alignment of your mount by centering and mapping six to ten well known, bright stars that are close to each other (the stars in the Big Dipper, for example). After six stars are mapped, the telescope's pointing should noticeably improve.

While mapping, filter fainter stars from the Sky Display (in TheSky) to minimize the chance of mapping the wrong star. We recommend filtering stars to about magnitude 2 or 3. To do so from TheSky6, right-click on any star on the Virtual Sky, and then click the **Display Properties of Star** command. On the Display Properties tab of the Properties dialog, enter **3** for the **Brightest** option. (For TheSky Version 5 users, click **View | Filters** and highlight **Stars** in the Object List and then enter the number 3 for the **Brightest** option.)

Procedure for Assessing Telescope Mapping and Polar Alignment

1. Accurately set the computer clock each night. Inaccurate time introduces errors in the TPoint model.
2. Insert a New TPoint model into TheSky (**Edit | Insert New Object | TPoint Model**).
3. Synchronize the telescope on a bright star. When performing a TPoint mapping run, synchronize the telescope *once* for each mapping run. Synchronizing more than once requires a new TPoint model.
4. After synchronizing the telescope on a known star, slew to a nearby star (by identifying the star in TheSky and clicking the **Slew To** button), center the actual star in the eyepiece, and then click the **Map** button on the Object Information dialog box in TheSky. This constitutes one map point.
5. When you have mapped six points, TPoint can begin correcting for errors in the mount and the pointing improves. Now, you're ready to begin mapping stars over a larger portion of the actual night sky.
6. After about 20 points are mapped, add terms to the TPoint model (see "Suggest Terms" on page 60) so that the RMS value is as small as possible, without increasing the PSD value.
7. From TPoint, determine the current polar alignment of the telescope by clicking **Model | Polar Alignment Information**.
8. Adjust the mount according to the information presented in the Polar Alignment Information dialog box.
9. Delete the existing TPoint model from TheSky and start over from Step 2. To remove the red Reference Lines that are created for each mapping run, from TheSky, click **Data | Add User-Defined Data** and then click **Remove All**.

Optimum Location of the Polar Axis

The optimum polar-axis setting depends on what declination and hour angle you're observing. For observations on the meridian, somewhere between the true and refracted pole is best. Ideally, one should shoot for the refracted pole. For typical users in the continental US the refracted pole is 1-1.5 arcminutes above the true pole. For observers in the northern hemisphere, this corresponds to ME = -60 to -90. For southern hemisphere observers it's plus not minus, so for Sydney Australia aim for ME = +90.

The following table shows the angular distance (in arcseconds) between the refracted and unrefracted poles for different latitudes and elevations.

Latitude (deg.)	0m	250m	500m	1000m	1500m	2000m	2500m	3000m
85	5	5	5	4	4	4	4	4
80	10	10	9	9	8	8	8	7
75	15	15	14	14	13	12	12	11
70	20	20	19	18	17	17	16	15

65	26	25	25	24	22	21	20	19
60	32	31	31	29	28	26	25	24
55	39	38	37	35	34	32	30	29
50	47	46	45	42	40	38	36	35
45	56	54	53	50	48	46	43	41
40	66	65	63	60	57	54	52	49
35	80	78	76	72	68	65	62	59
30	96	94	92	87	83	79	75	71
25	119	116	113	108	102	98	93	88
20	152	148	145	138	131	125	118	113
15	205	200	195	185	176	168	160	152
10	305	298	290	276	263	250	238	227

If you want to set your polar axis to the refracted pole, and you're in the northern hemisphere, aim for ME = minus the tabulated value. In the south aim for ME = plus the value.

Using a Model on Subsequent Sessions

Once a satisfactory model is created, you can use a working model on subsequent sessions without performing a complete mapping run, or without any mapping at all. The amount of work involved in preparing your telescope for accurate pointing each night depends on a number of variables in your system. For example, if you setup a portable mount each night, then a new mapping run must be performed as part of the setup.

Observations cannot be accumulated into a single TPoint model from night to night unless the telescope system remains completely unchanged. Typically, an arbitrary initialization is performed on a nightly basis by pointing at a star. This “pollutes” an existing TPoint model and data from one observing session is not compatible with data from another. A model can be carried forward to subsequent observing sessions, but pointing data from night to night *cannot* be combined.

Changing the CCD camera or optical configuration requires that only the offset terms be recomputed. When the need arises to establish the offset terms (IH, ID and CH), a Short Mapping Run (see “Performing a Short Mapping Run” on page 30) can be employed to provide TPoint the mapping data required. This is one example of using pointing data from two separate sessions without actually mixing the mapping data into one data set.

Absolute Encoders, Park, Unpark and Homing

If your telescope uses absolute encoders or an absolute positioning system (such as the Paramount ME or GT-1100S with AutoHome™ technology), a single TPoint model can be used night after night and does not require a Short Mapping Run.

Given that the telescope starts up each night with the telescope control system synchronized identically with the celestial sphere (through an accurate time base), a given model will remain valid for subsequent sessions. If the time base is not accurate, the pointing error is manifested as an Index error in right ascension (the IH term). If an accurate time base cannot be achieved, you must perform a Short Mapping Run at the start of the session to establish the terms IH, ID and possibly CH.

If your automated telescope does not have absolute encoders (true for most commercial mounts) and is initialized by pointing at one or more stars, then you will have to perform a Short Mapping Run each session to reestablish the IH, ID and possibly CH terms.

Performing a Short Mapping Run

A Short Mapping Run is a procedure that reestablishes the relationship between the telescope and an existing TPoint pointing model. This procedure is required whenever a telescope is “synchronized” from TheSky.

On a fixed-pier mount, most of the geometrical errors remain constant from night to night. Therefore, the terms in a working model can also remain fixed even if a telescope synchronization or “sync” is performed each night at an arbitrary position to initialize the system. For example, the polar misalignment terms, non-perpendicularity terms and tube flexure terms do not change unless there are physical adjustments to the telescope.

However, the terms representing the Hour Angle offset (IH) and the declination offset (ID) are “polluted” when telescope synchronization requires a star sighting. That is, the initialization of the control system is dependent on where in the sky the sync is performed. The errors for each term at this synchronization point are unknown. Even if a model exists that more closely estimates the pointing effects at the sync position, we do not know the exact magnitude of each term at this arbitrary position.

Additionally, the axis of the imaging device may change slightly when exchanging the CCD camera with an eyepiece. This will be manifested by a change in the CH term (OTA/Declination axis perpendicularity) when a new model is created. Therefore, Short Mapping Runs should also allow CH to vary along with IH and ID.

Note: Simply synchronizing the telescope on a single star while using an existing model can result in sufficient RMS pointing. If the goal for the evening is imaging just a few objects, the Short Mapping Run can be skipped.

To establish the value of these terms for subsequent observing sessions, a Short Mapping Run involving six or more points is performed, and then submitted to TPoint. Whereas the initial mapping run involved many more mapped points, and all pointing terms were subject to modification, short mapping runs require only 6 new map points. Only the offset terms (IH and ID, and possibly CH) are modified, while the other unchanged terms, (like polar alignment, etc.), are held constant in TPoint.

To perform a Short Mapping Run using an existing model, from TPoint, click **Model | Short Mapping Run**. All terms in the model that are not to be altered based on the new data points that will be collected are fixed.

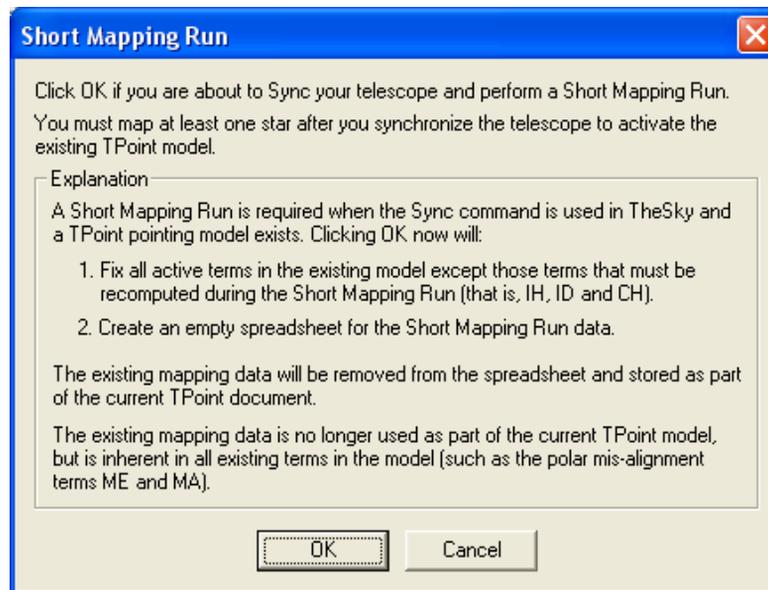


Figure 15: Short Mapping Run dialog box.

Clicking **OK** on the Short Mapping Run dialog box fixes all the terms in the base model and hides all of the existing data so that a “Short Mapping Run” model (which varies only IH, ID and CH) can be created. Note that the RMS and PSD values reported by TPoint during a short mapping run should be ignored, since they report the short mapping run’s pointing and not the base model’s pointing.

Short Mapping, a Step-By-Step Guide

A Short Mapping Run is required when using any telescope that must be re-synchronized each night (such as the LX200). This process can be completed fairly quickly since only a small number of observations are required to reestablish the relationship between the telescope and the TPoint model.

The following step-by-step instructions describe a Short Mapping Run procedure.

1. Start TheSky and load the Sky Document that contains the existing TPoint model.
2. From TheSky, click **Telescope | Link | Establish**.
3. Open the TPoint by double clicking on the TPoint icon on the Virtual Sky *or* right click on the TPoint icon, and then click **TPoint Model Object Open**.
4. From TPoint, click **Model | Short Mapping Run**.
5. On the Short Mapping Run dialog box, click **OK**.
6. Exit TPoint by clicking the **File | Exit and Return to TheSky**.
7. From within TheSky, synchronize the telescope on a known star.
8. Proceed to map one or more additional stars to complete the Short Mapping Run.

Hint: In order to really “pin down” the CH term during a Short Mapping Run, at least six stars should be mapped.

What is happening?

The procedure for a Short Mapping Run is used to establish the relationship between the telescope and the actual night sky. Re-synchronizing each night introduces new and different offset errors; therefore, the offset error terms (IH and ID) must be reestablished by pointing at a small number of stars.

Clicking **OK** on the Short Mapping Run dialog box hides the existing mapping points and masks these observations. *This does not mean that these observations are not employed!* These observations are used to establish the terms that remain static from night to night (such as polar alignment and non-perpendicularities in the mount). Since we have determined acceptable values for these telescope imperfections, we will lock them down and reuse them on subsequent nights.

For example, if the non-perpendicularity between the RA and Declination axis is computed to be 425 arcseconds when an extensive mapping is performed, then this term can be fixed at 425 arcseconds from that point on (barring any physical changes of course).

So the short mapping run does not alter or include any of these static terms. Only the offset terms (IH and ID) because they are changed upon re-synching and the CH term. The CH term is included because altering CCD cameras or rotating a diagonal mirror will affect this term. Swapping telescope assemblies will also certainly change the CH term, but will not change other static terms.

Note that each night short mapping run is performed, the handful of observations that are added go on the end of the TPoint spreadsheet.

If you wish to modify the terms used by the base TPoint model, click **Model | Edit Base Model**. Although no additional points can be added to the base model after a Short Mapping Run, the terms that define this model can be changed.

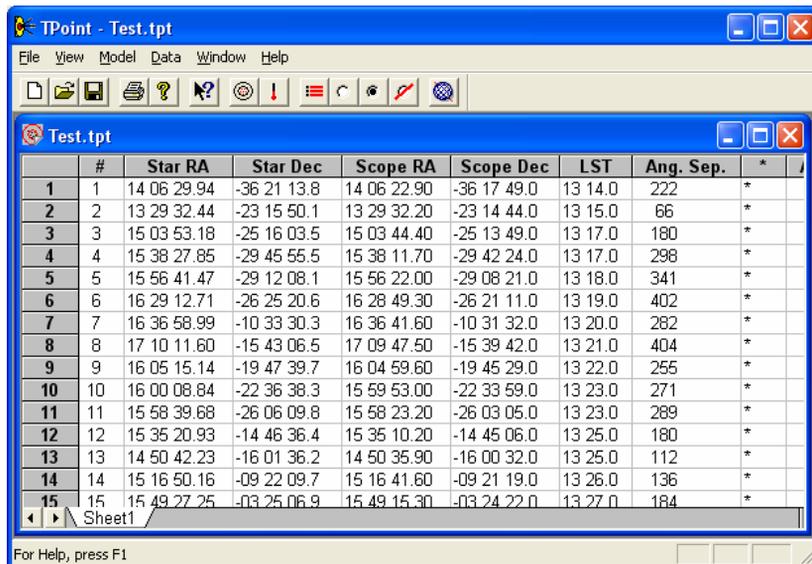
Using TPoint to Model the LX200 or Autostar

Make sure the Pressure and Height are set to zero in the Observing Parameters dialog. This forces TPoint to ignore its refraction calculations (the LX200 and Autostar's control system does refraction calculations automatically).

The TPoint Document

TPoint for Windows is a Multiple Document Interface (MDI) application, so several documents can be opened simultaneously, only one of which is active at a given time. This active document (which will have the title bar highlighted in its window) is used for all operations, such as the Fit command.

What is a TPoint Document?



#	Star RA	Star Dec	Scope RA	Scope Dec	LST	Ang. Sep.	*
1	14 06 29.94	-36 21 13.8	14 06 22.90	-36 17 49.0	13 14.0	222	*
2	13 29 32.44	-23 15 50.1	13 29 32.20	-23 14 44.0	13 15.0	66	*
3	15 03 53.18	-25 16 03.5	15 03 44.40	-25 13 49.0	13 17.0	180	*
4	15 38 27.85	-29 45 55.5	15 38 11.70	-29 42 24.0	13 17.0	298	*
5	15 56 41.47	-29 12 08.1	15 56 22.00	-29 08 21.0	13 18.0	341	*
6	16 29 12.71	-26 25 20.6	16 28 49.30	-26 21 11.0	13 19.0	402	*
7	16 36 58.99	-10 33 30.3	16 36 41.60	-10 31 32.0	13 20.0	282	*
8	17 10 11.60	-15 43 06.5	17 09 47.50	-15 39 42.0	13 21.0	404	*
9	16 05 15.14	-19 47 39.7	16 04 59.60	-19 45 29.0	13 22.0	255	*
10	16 00 08.84	-22 36 38.3	15 59 53.00	-22 33 59.0	13 23.0	271	*
11	15 58 39.68	-26 06 09.8	15 58 23.20	-26 03 05.0	13 23.0	289	*
12	15 35 20.93	-14 46 36.4	15 35 10.20	-14 45 06.0	13 25.0	180	*
13	14 50 42.23	-16 01 36.2	14 50 35.90	-16 00 32.0	13 25.0	112	*
14	15 16 50.16	-09 22 09.7	15 16 41.60	-09 21 19.0	13 26.0	136	*
15	15 49 27.25	-03 25 06.9	15 49 15.30	-03 24 22.0	13 27.0	184	*

Figure 16 – TPoint's spreadsheet-like user interface.

The TPoint document contains the following data:

- Mapping data, including the star's coordinates, the control system's coordinates when pointing at that star, and the Local Sidereal Time of the observation (LST).
- The Observing Parameters for the session, including the date, temperature pressure, etc.
- A telescope-pointing model that consists of any number of geometrical pointing terms.

TPoint documents become part of Sky Documents (documents created and used by TheSky) to create a "Compound Document." When a Compound Document is loaded into TheSky, the TPoint application is automatically run.

Saving a document

Normally, your TPoint document is saved with the Sky Document (.SKY file) in TheSky. However, you may wish to save a TPoint document (and the corresponding modeling data) independently from TheSky. To do so, from TPoint, **click File | Save As**, enter an appropriate name for the model and then click **OK**.

Printing a document

Click **File | Print** to print the data contained in a TPoint document. The printout contains the Observing Parameters followed by each of the mapped points.

Multiple documents

When multiple documents are loaded into TPoint, any of them can be made active by simply clicking anywhere in the document window.

Commands such as **Fit, Sort, Mask, Unmask**, etc. operate on the active document.

Data Selection and Manipulation

A number of commands are available for selecting only a portion of the available data as well as sorting the data based on a number of different criteria.

Masking Observations

Excluding certain parts of the data from consideration is often very useful when analyzing data from a pointing run. For example, you may have noticed a cable being stretched near the end of a pointing session which started to alter the pointing characteristics of your system, while all prior data was unaffected by the problem.

The *Mask* command is used to remove one or more mapped points from the data set as used by the Fit command.

The following steps are used to Mask observations from the Fit computations:

1. Click on the window containing the data to activate it.
2. On the left-most column in the window (which contains the gray row numbers) click on the observations which you wish to exclude. (You can drag over multiple rows if desired.)
3. Click **Mask**.

When the data is masked, the column with the question mark (?) in its header will change from an asterisk to a blank, indicating this data point is not in use.

Note: The Mask and Unmask commands do not change the state of observations marked as errors. These are *toggled* when the Mark as Error command is used.

Unmasking Observations

When data is masked using the Mask command, it can be included again in the Fit command by using the Unmask command.

To unmask the entire data set, place the cursor in the upper left corner of the data, and then press `Ctrl+Shift+End` to select all of the data. Next, click **Data | Unmask**.

Note: The Mask and Unmask commands do not change the state of observations marked as errors. These are *toggled* when the Mark as Error command is used.

Marking Observations as Errors

Pointing the telescope at an incorrect star when performing a mapping run is not uncommon, especially when many points are mapped using fainter stars. These errors tend to “stick out like a sore thumb” when the various graphs are used to examine the data.

To mark an observation as an error, highlight the corresponding row on the spreadsheet containing the data then click Mark as Error.

Once a data point is marked as an error, it will remain so unless the Mark as Error is again used to toggle it. Observations marked as errors are unaffected by the Mask and Unmask commands, effectively removing them from the data set.

Sorting the Data

Data analysis often involves working with a subset of the observation data based on its distribution across the sky. For example, there may be an unexplained pointing anomaly that is manifested only at high declinations.

The Sort Observations dialog box is used to change the order of the observations within the spreadsheet so that various ranges of data can quickly be masked or unmasked.



Figure 17: Sort Observations dialog box.

For example, to remove all observations at declinations higher than 75 degrees:

1. Click on the window containing the data.
2. Click **Sort**.
3. Choose the **Star Declination** option from the Sort Observations dialog.
4. Click **OK**.
5. After adjusting the spreadsheet so that all high declination observations are visible, select those higher than 75 degrees by dragging on the first row.
6. Click **Mask**.

Once the desired observations are excluded using the Mask command, use the Sort command to sort by Observation Number. Certain trends in the data become visible when sorted this manner.

Using TPoint to Suggest Telescope Modeling Terms

TPoint for Windows can suggest modeling terms to analyze the polar alignment and to minimize the RMS pointing of your telescope.

After mapping 15 to 20 stars, click **Model | Fit Data**. Click **More Terms** to display the More Terms dialog box.

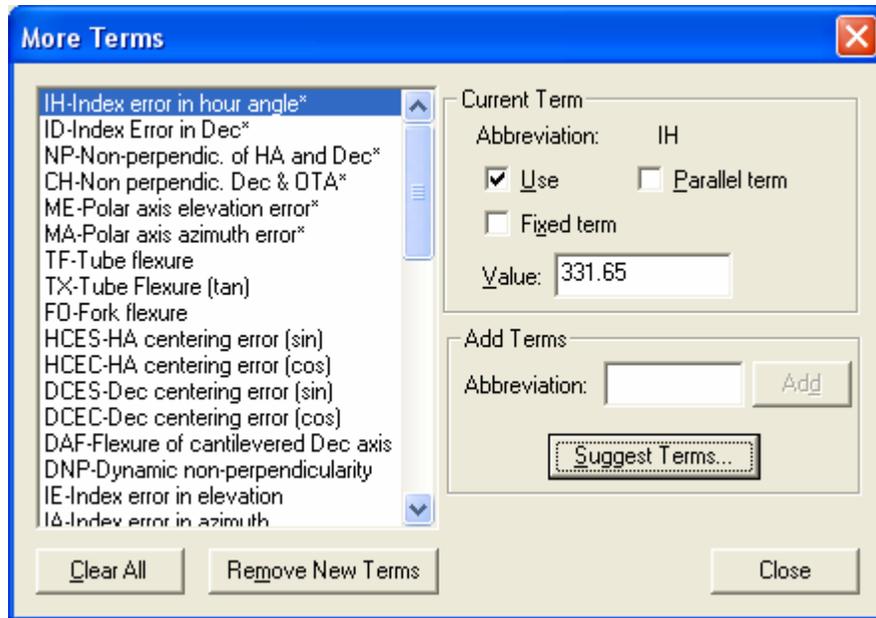


Figure 18: More Terms dialog box.

Click **Suggest Terms** to display the Add Harmonic Terms dialog box.

Click **Start** to compute the harmonic terms that will most significantly improve the current pointing data. You can continue adding additional terms as long as the overall RMS and the PSD values decrease.

When you get to the point where there is very little change in the RMS (less than about 20 percent) value, click **OK**. As a rule of thumb, adding six to eight harmonic terms is sufficient.

This capability is extremely powerful and will allow you to easily get 30 to 40 arcsecond RMS pointing without having to understand any of the complicated mathematics behind TPoint. The general rule of thumb is that fewer terms is always better and do not add terms if you are unsure.

Note that adding too many terms can “pollute” the model and lead to erroneous RMS pointing and polar alignment information.

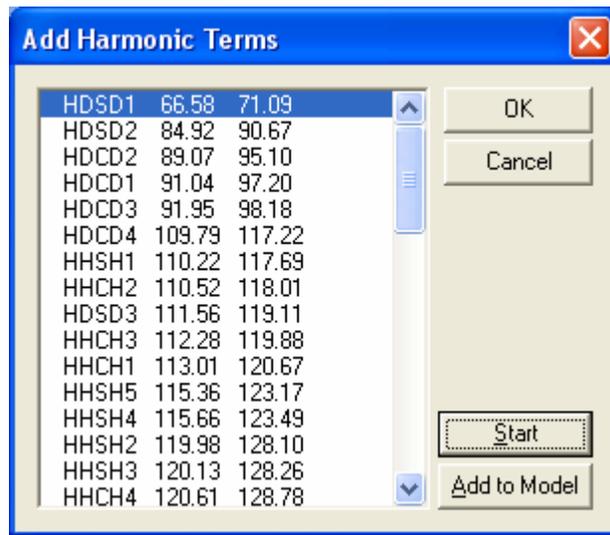


Figure 19: Add Harmonic Terms dialog box.

After adding six to eight harmonic terms, the polar alignment can be evaluated. From TPoint, click **Model | Polar Alignment Information**.

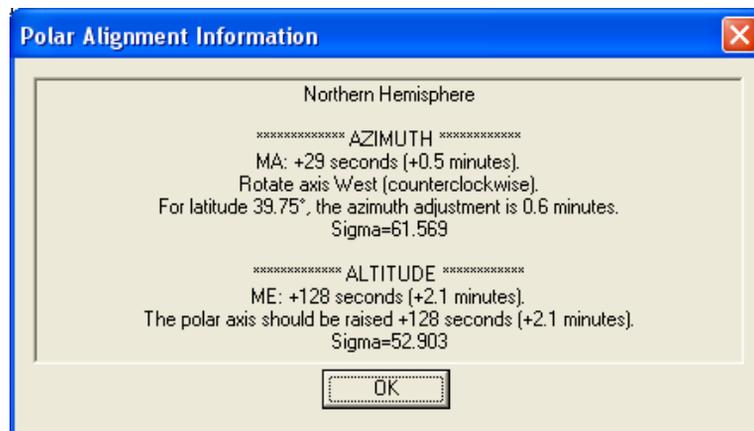


Figure 20: Example polar alignment data from TPoint.

Note: Additional harmonic terms must be added to the TPoint model for the polar alignment information to be accurate.

When you can achieve 30- to 40-arcseconds RMS value by using the **Suggest Terms** button (from TPoint, click **Model | Fit Data | More Terms button | Suggest Terms button** to view the Add Harmonic Terms dialog box) you will have accurate polar alignment information from TPoint.

Remember that it is actually best to shoot for the refracted pole, which is about 90 arcseconds high in elevation. This has the same effect as the “Kings Rate” in that it will somewhat average out the effects of atmospheric refraction.

Polar Alignment Hints

- Any adjustment to the mount requires a new TPoint mapping run. Collect small sets of data points (less than 30 points) in one area of the sky while determining polar alignment.
- Stay on one side of the Meridian and start in a small area of the sky. This helps minimize errors when collecting data.
- Choose a constellation with bright stars and “star hop.”
- From TheSky6, right-click on any star on the Virtual Sky, and then click the **Display Properties of Star** command. On the Display Properties tab of the Properties dialog, enter **3** for the **Brightest** option. From TheSky Version 5, click **View | Filters** and set the brightest magnitude for stars to about 3. This hides the fainter stars that may be mapped inadvertently.
- After mapping the first six bright stars, increase the area of the sky that is mapped since the pointing improves once six stars are added to the pointing model.

DOS Text File Format

Note: If you are using TPoint under Windows 95/98/Me/NT 4.0/2000/XP and TheSky, the DOS text file functions are unnecessary.

To maintain compatibility with other versions of TPoint, the Windows version allows importing and exporting TPoint data files in the form of ASCII text files. The data format used is compatible with the DOS/Unix versions of TPoint.

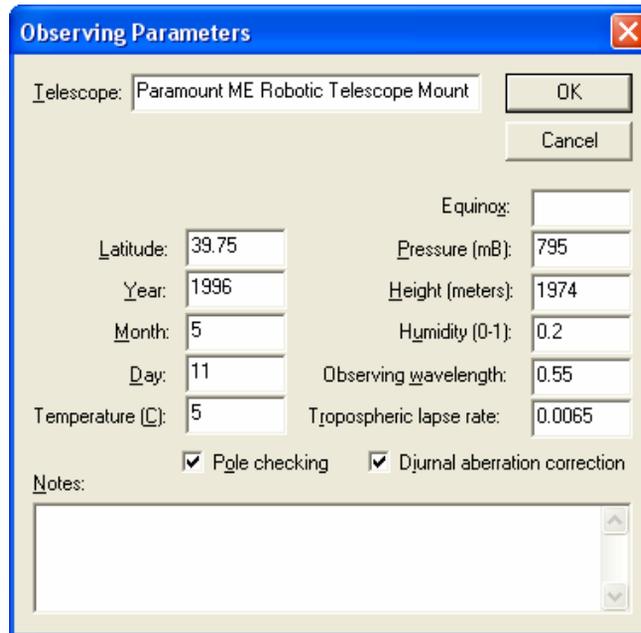
When the File Export Text File command is used, only the Pointing Data and the Observing Parameters are saved in the text file. When the File Save command is used, all of the model information as well as the pointing data and observing parameters are saved in the current TPoint Document.

The DOS file format follows:

Line 1: [Telescope Name]

Line 2: The table below lists all of the entries for the second line:

Parameter	Format	Example
Latitude	Degrees Minutes Seconds	53 24 55.0
Date	Year Month Day	1996 12 20
Temperature	Degrees Celsius	5



Observing Parameters

Telescope: Paramount ME Robotic Telescope Mount

OK

Cancel

Equinox:

Latitude: 39.75

Pressure (mB): 795

Year: 1996

Height (meters): 1974

Month: 5

Humidity (0-1): 0.2

Day: 11

Observing wavelength: 0.55

Temperature (C): 5

Tropospheric lapse rate: 0.0065

Pole checking Djurnal aberration correction

Notes:

Figure 21: Observing Parameters dialog box (TPoint)

Telescope

Enter the name of the telescope in the Telescope edit box. This will appear on the various graphs generated by TPoint.

Type

Specify the type of telescope mount used in gathering the observations.

Latitude

Enter the Latitude of the observing site as a floating-point number. If imbedding an object into a Sky document starts TPoint, this data will be extracted from the site location information in TheSky. It can, of course, be changed at any time.

Date

Enter the date of the start of the observations as three integer values: year, month and day.

Temperature

Enter the approximate temperature during the observations, in degrees Celsius.

Equinox

Enter the equinox of the telescope coordinates. This is only required if the recorded telescope positions are “mean” positions (If TheSky is used to collect the data, leave

this blank). Only one equinox (typically, it is B1950 or J2000) may be specified, and this applies to all map points.

Pressure

Enter the approximate atmospheric pressure in mB. LX200 users should enter 0 here because the LX200 control system automatically computes and accounts for refraction.

Height

Enter the height of your observatory above sea level, in meters.

Humidity

Enter the relative humidity in the range 0.0 (zero percent) to 1.0 (100 percent).

Observing Wavelength

Observing wavelength in micrometers, default 0.55. The default value can be used in nearly all circumstances.

Tropospheric Lapse Rate

In degrees K/meter, default 0.0065. The default value can be used in nearly all circumstances.

Pole Checking

Pole checking rejects stars in places that may cause problems – very close to the celestial pole, for instance. This option should be checked unless specific circumstances require turning pole checking off.

Diurnal Aberration Correction

The correction for diurnal aberration (maximum 0.3") should be disabled if the telescope control system itself omits it.

Notes

This edit box can be used to enter any notes that are important to the observing session such as weather conditions, the state of the telescope hardware, etc.

The Geometrical Terms

The six standard geometrical terms used by TPoint are described below. These terms quantify the various mechanical inaccuracies of the optical tube assembly (OTA) and telescope mount. Even the best of telescope mounts exhibit mechanical errors that ultimately affect the telescope pointing performance. Often adjustments can be made to the telescope system to minimize the size of these misalignments. However,

eliminating them entirely is impossible, so telescope pointing can be improved by considering these terms in a telescope-pointing model.

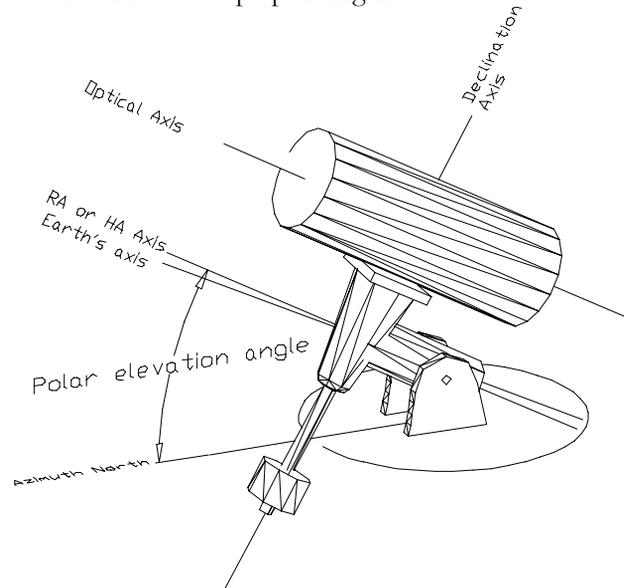


Figure 22: German equatorial Mount

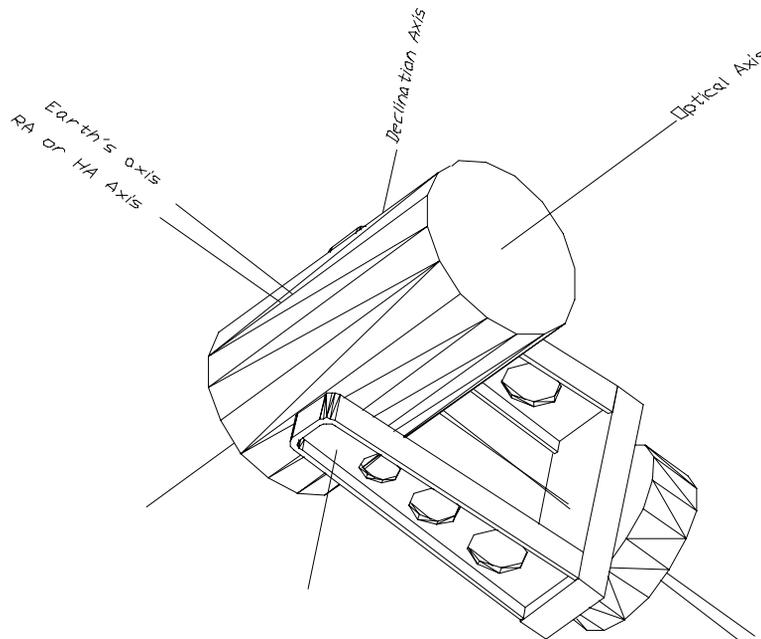
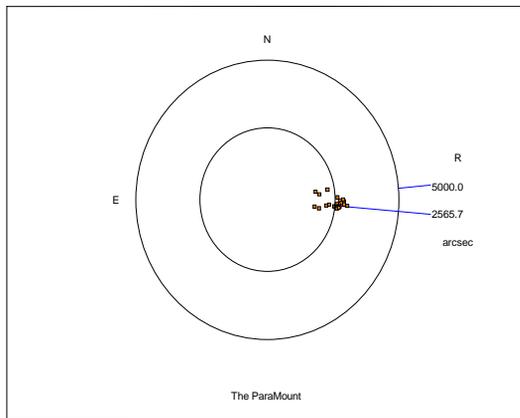


Figure 23: Fork Mounted Telescope

The diagrams above show the two most popular telescope mount designs with various axes labeled. The following discussions relate to equatorial mounted telescopes. The Right Ascension (RA) or Hour Angle (HA) axis is pointed closely to the celestial pole.

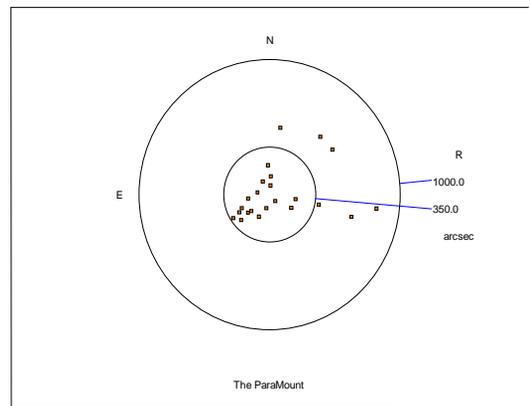
Index Errors in Hour Angle (IH) and Declination (ID)

The index errors are simply offsets to the hour angle and declination values such that the distribution of pointing errors across the sky is best fit. Looking at the scatter diagrams below, you can see that adding index error terms to the model moves the entire data set towards the center, thereby improving the overall pointing. Since the control system is typically synchronized on a star by a sighting through the optical path of the telescope, this initial sighting is “polluted” by all errors in the system at the time of the sighting. An average from all mapped points results in better system pointing.



Sky RMS = 2565.69 PSD = 2565.69

Figure 25: Data without Index Error term.



Sky RMS = 350.04 PSD =
IH-Index Error in HA
ID-Index Error in Dec

Figure 24: Data with Index Error term.

Declination/Optical Axis Non-Perpendicularity

In order to achieve repeatable pointing, the Optical Tube Assembly (OTA) must be rigidly attached to the mount so that no motion occurs between the two as the OTA is slewed about the sky. Ideally, the optical axis should also be perpendicular to the declination axis. In practice, this can be difficult to achieve by simple mechanical means since the true optical path probably does not coincide with the physical telescope tube.

The following diagrams graphically illustrate the OTA/Declination axis term (CH) for two different telescope mounts.

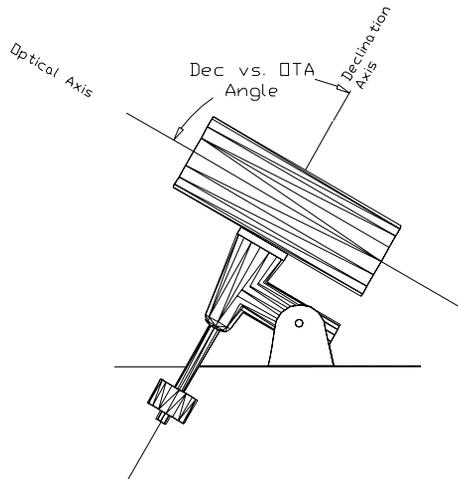


Figure 26: Side view of a German equatorial telescope mount.

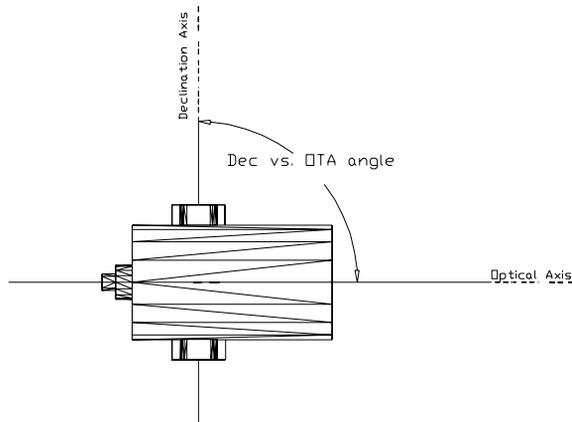


Figure 27: Top view of a fork mount.

After sufficient TPoint pointing data is collected, the magnitude of the OTA/declination non-perpendicularity can be quantified, and if it is large, mechanical adjustments can be (but *do not necessarily have to be*) made to minimize the non-perpendicularity.

While this source of *pointing error* can make centering stars difficult initially, it does not affect the *tracking performance* of the mount. In general, if the telescope is permanently mounted, and the pointing data can be collected automatically (for example, using Automapper II), then no adjustment is necessary; once a model is established, TPoint will automatically correct for this error when the telescope is slewed. If the telescope is used in a portable setup, and stars are located visually, then you may wish to minimize this error so that unmodeled pointing is improved.

Change EW on the sky equal to coefficient CH. For a fork mount operating above the pole, or for a GEM observing stars east of the meridian, positive CH displaces the pointing axis to the west of where it would otherwise be.

Note that CH and IH both move stars east or west in the field of view. The difference is that the displacement is constant for CH whereas the displacement due to IH shrinks as you approach the pole.

RA or HA axis/Declination Axis Non-perpendicularity

For north declinations, for a fork mount operating above the pole, or for a GEM observing stars east of the meridian, positive NP displaces the pointing axis to the west of where it would otherwise be.

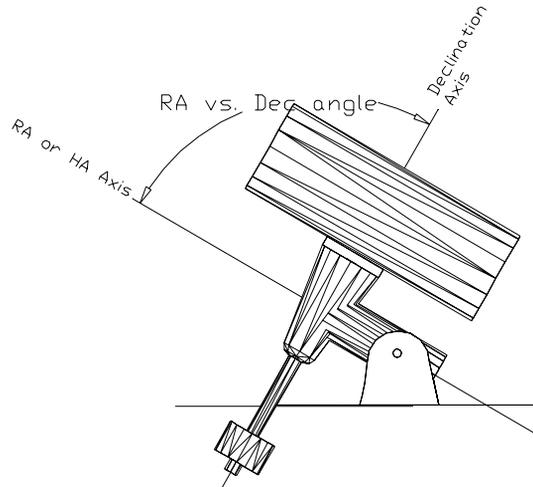


Figure 28: Side view of GEM.

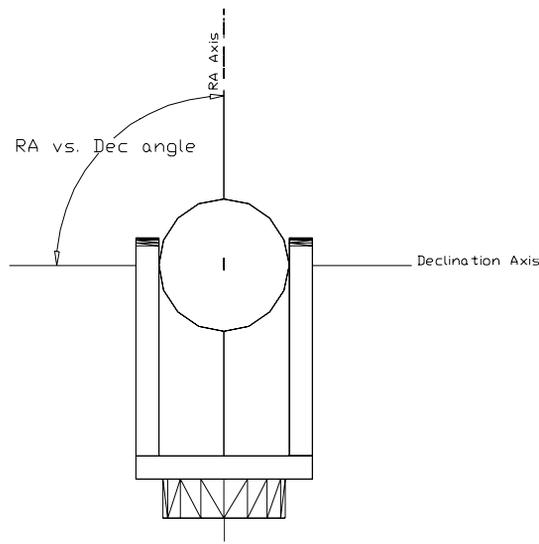


Figure 29: Front view of fork mount.

Polar Alignment Error in Azimuth

In the Northern Hemisphere, a positive MA means that the pole of the mounting is to the right of due north. In the Southern Hemisphere, a positive MA means that the pole of the mounting is to the right of due south.

When making adjustments to correct for the MA term (polar misalignment in azimuth) you need to rotate about a vertical axis through a larger angle than MA itself. This is because MA is really a rotation about the point Hour Angle = 0, Declination = 0. The factor to inflate MA by before rotating the mount is $1/\cos(\text{latitude})$.

Polar Alignment Error in Elevation

In the Northern Hemisphere, a positive ME means that the pole of the mounting is below the true (unrefracted) pole. A mounting aligned on the refracted pole will have a negative ME. In the Southern Hemisphere, a positive ME means that the pole of the mounting is above the true (unrefracted) pole. A mounting aligned on the refracted pole will have a positive ME.

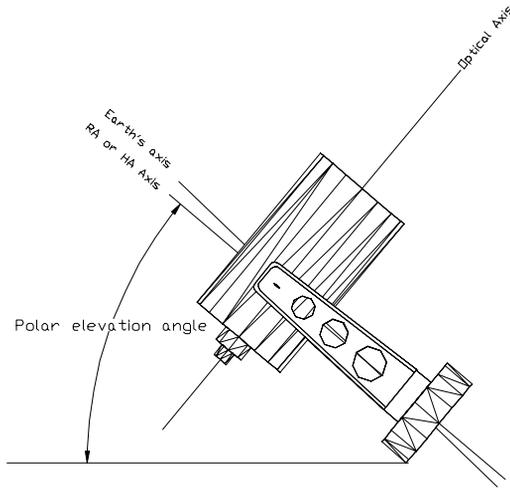


Figure 30: Fork mount.

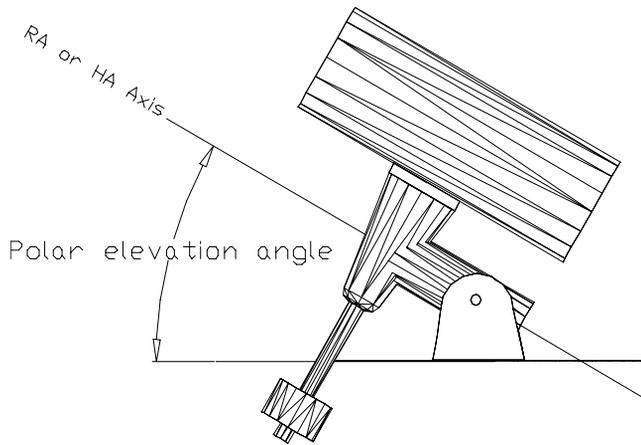


Figure 31: Equatorial mount.

The Fit Data Dialog Box

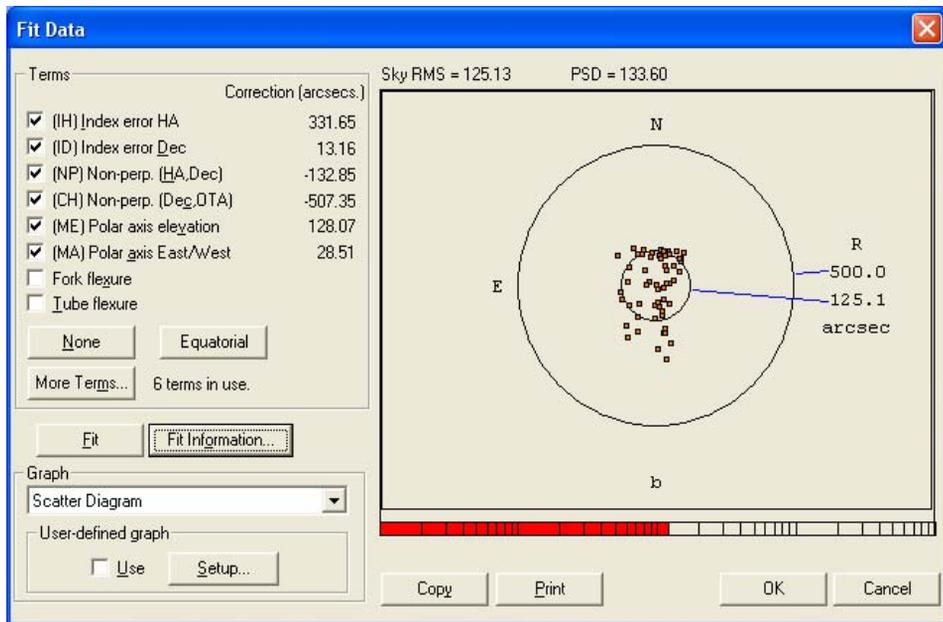


Figure 32: Fit Data dialog box.

When examining the pointing performance of a telescope, most of the activity will occur in the Fit Data dialog box. In addition to providing the prompts for adding and removing terms to the telescope-pointing model, numerous graphs are available that can quickly point out telescope system errors.

Selecting Terms

Once you have collected pointing data from your telescope, analyzing the pointing performance typically starts by turning on the six geometric terms. On an equatorial telescope, these are the first six terms listed on the Fit dialog. Click Equatorial in the Terms group to quickly mark these six terms.

Each time new terms are selected, the Fit Data command is automatically called and TPoint reduces the pointing data and determines the best-fit model using all of the terms currently in use. Once the computations are completed, the resulting RMS pointing value and population standard deviation are displayed in above the currently selected graph.

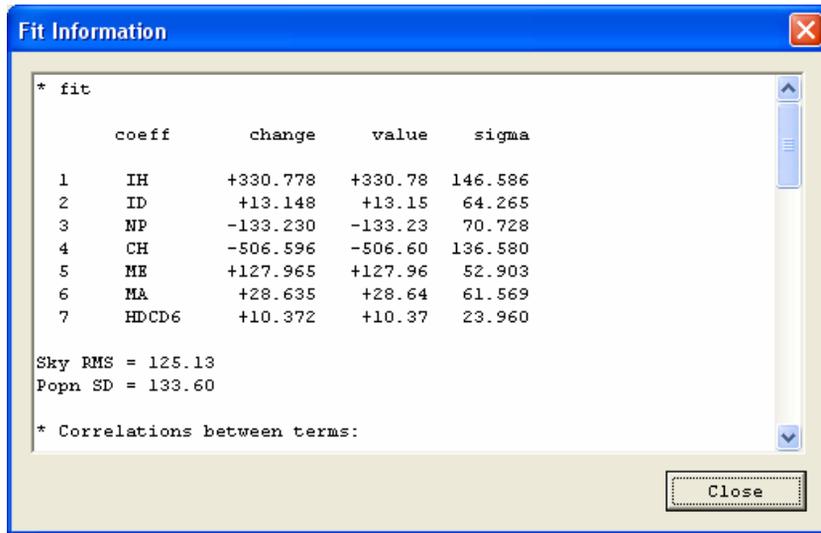


Figure 33: The Fit Information dialog box.

Fit Information

The Fit Information dialog box displays additional information about each of the terms. When adding new terms to a model, pay close attention to the standard deviation of the new coefficient (sigma), the effect on other terms, and whether the population standard deviation has been reduced. With the exception of the six standard geometrical terms, it is wise to reject any terms that are not at least 2 sigma in size.

For each fit, a table of correlation between every pair of terms is also displayed in the Fit Information dialog box for inspection after the TPoint session. Values close to unity show terms that are not easily distinguishable given the current data.

Selecting a Graph

A number of different graphs are available for plotting the pointing data to reveal systematic errors in the telescope system.

The general strategy is to plot different components of the residuals against the various coordinates. Terms can then be added to the model to target any systematic effects that are seen. Some plots are more likely than others to have a mechanical interpretation, and attention should be initially confined to these plots.

Files of pointing observations are normally written in time order. Therefore, graphing y-data vs. N plots are useful for exposing shifts or drifts that have occurred during the

pointing run. Other x-axis meanings can be contrived by appropriately sorting the observation file.

The numerous plots have a variety of presentation and diagnostic roles.

Scatter Plot

The scatter plots residuals as a scatter diagram, like a shooting target. As well as being a good way of presenting overall pointing performance, the scatter plot exposes errant observations and abnormal distributions.

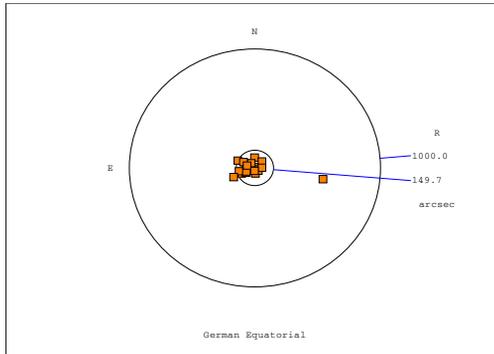


Figure 34: Scatter Plot Example 1

The above Scatter diagram contains a single star identification error. This type of error, mapping an incorrect star, is more likely to occur with a large number of data points since using fainter stars increases the possibility of misidentification. Note how the errant star causes a misleading tight clustering of the remaining stars by changing the overall plotting scale.

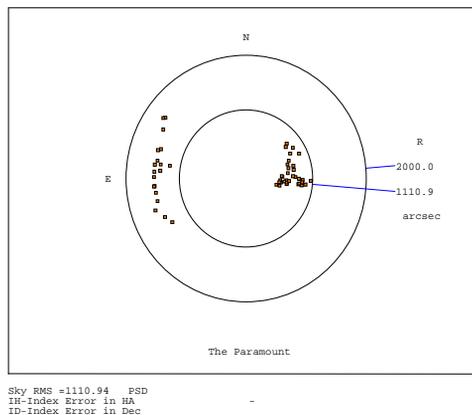


Figure 35: Scatter Plot Example 1 (continued)

In the above scatter plot there are two distinct distributions of stars. This is the result of a very large Declination axis and OTA non-perpendicularity on a German Equatorial mount. On the East side, the angle causes observations to be misplaced in one direction while on the West side, they are misplaced in the opposite direction.

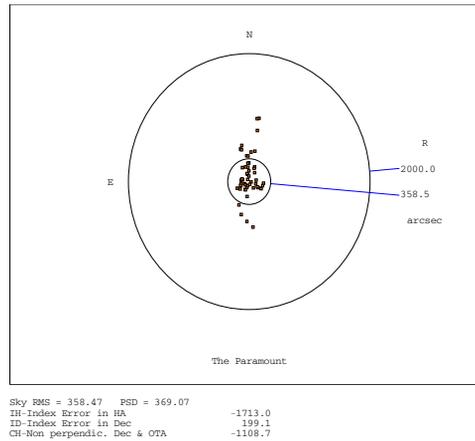


Figure 36: Scatter Plot Example 1 (continued)

The scatter plot above shows the same data after the Dec/OTA term has been added.

Error Vectors – Orthographic

Figure 37 displays the residuals as error vectors on an orthographic projection (a distant view of the celestial sphere looking down on the zenith from above). The vectors (lines projecting from the square symbols that mark star positions) are the great circle continuations of the pointing residuals.

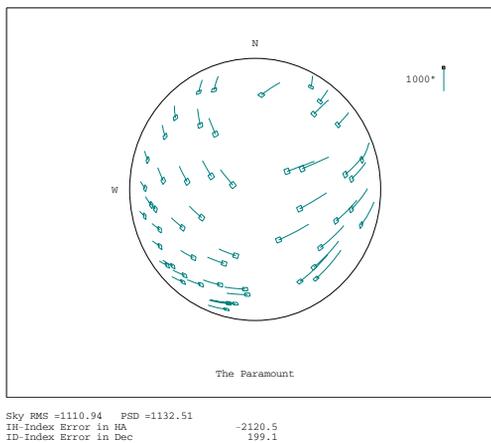


Figure 37: Error vectors graphed using an orthographic projection.

Error Vectors – Cartesian

Figure 38 plots error vectors on a Cartesian Cylindrical projection, either HA/Dec or Az/El.

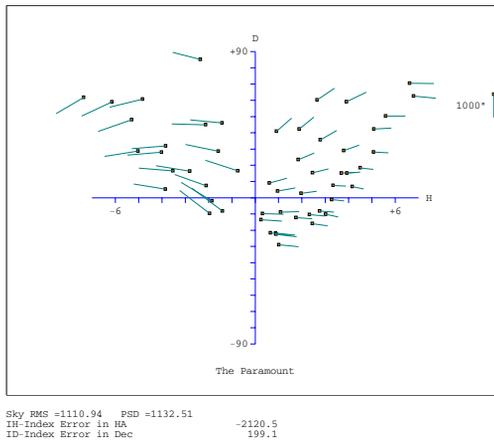


Figure 38: Error vectors on a Cartesian Cylindrical projection.

Hysteresis

Figure 39 looks for hysteresis by drawing the error vector at a position that indicates the direction from which the telescope has come. This assumes that the data file contains all the observations in the correct order, and that hysteresis is related to the direction of the large-scale movements in cylindrical coordinates (either HA/Dec or Az/El). Summing the residuals oriented relative to the telescope movements makes a numerical estimate of the hysteresis.

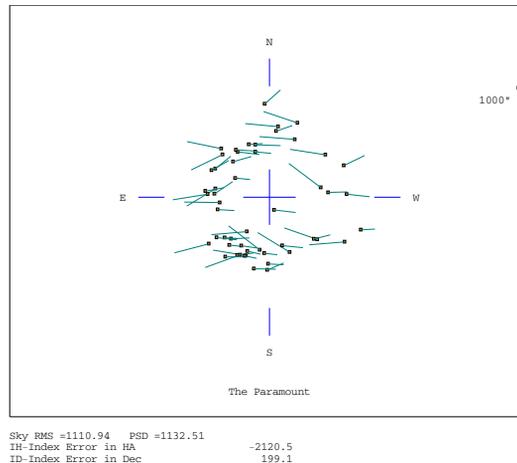


Figure 39: Error vectors vs. telescope direction.

Changing Axis Alignment

This graph looks for changing polar/azimuth axis misalignment. Each residual is interpreted as being due to a misalignment of the specified “roll” axis—either polar or azimuth as specified. A histogram is plotted to show if the residuals do, in fact, favor one particular direction. The mean direction is calculated and reported, and then the component of each residual in the direction of this misalignment is plotted.

Error Distribution

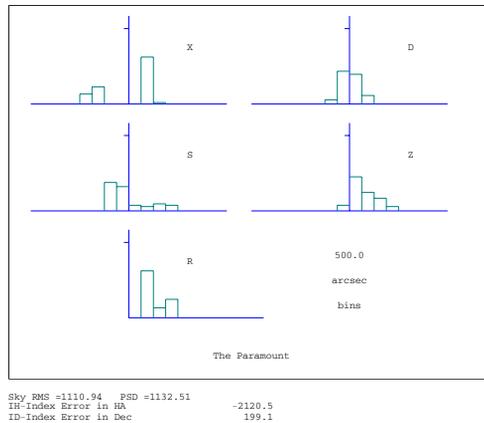


Figure 40: Error Distribution graph

Figure 40 plots multiple histograms that show various sorts of error distribution, and is useful for testing whether the residuals are reasonably normal. In the example the X (east-west) plot shows a suspicious double peak.

Other Graphs

Any of the following graphs can be selected from the Graph list on the Fit Data dialog:

- Observation number vs. Declination
- Observation number vs. Hour Angle
- Hour Angle vs. EW on sky
- Declination vs. Declination
- Zenith Distance vs. Zenith Distance
- Declination vs. EW on sky
- Hour Angle vs. Dec
- Hour Angle vs. HA/Dec non-perpendicularity

Creating a User-Defined Graph

In addition to the graphs available in the Graph list box, you can plot one component of the residuals against one coordinate.

Following is a list of the various components of the residuals that will be plotted on the Y-axis:

- Hour Angle
- East-West on the sky
- Declination
- HA/Dec non-perpendicularity
- Azimuth
- Horizontally on the sky
- Zenith Distance
- Az/Elev non-perpendicularity
- Total residual

The Y data is plotted against one of the following coordinates on the X-axis of the User-Defined graph:

- Hour Angle
- Declination
- Azimuth
- Zenith distance
- Parallax angle
- Observation number

Figure 41 shows TPoint's multiple graph display capabilities.

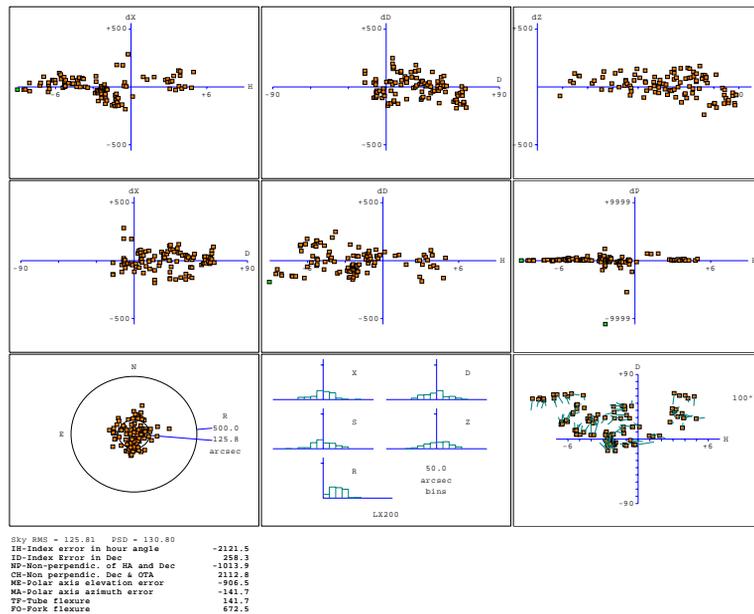


Figure 41: Multiple graphs.

Determining an Observation Number from a Graph

If one or more errant observations are present in the mapping data, these points will usually stand out in one or more of the graphs. For example, in the scatter diagram below, most of the observations are clustered tightly, while there appears to be a single observation that is inconsistent with the remaining data.

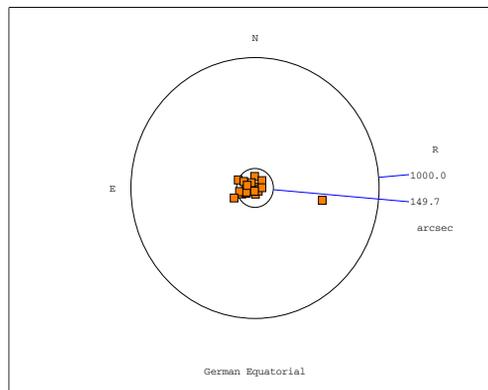


Figure 42: Scatter diagram with erroneous data point.

To determine the observation number of this errant point, click on it and the following will occur. In the upper right of the Fit Data dialog, the observation number

is printed and the mapping data window (behind the Fit Data dialog) will be adjusted so that this observation is shown on the top line.

The mapped point in the actual mapping data presented above is in fact a star identification error as verified during the mapping run. Once the observation number is known, it can be marked as an error so that it is not included in the fitting procedure.

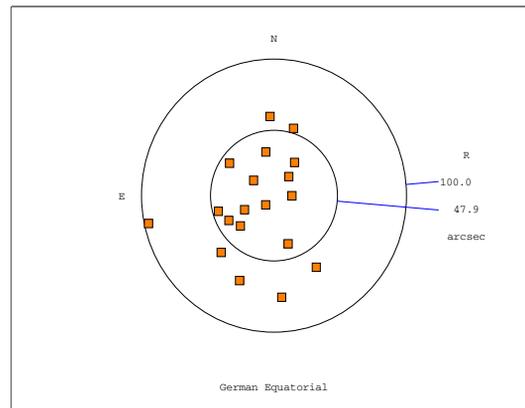


Figure 43: Scatter diagram without erroneous data point.

Printing a Graph

To print a graph, select the desired graph using the Graph list box on the Fit Data dialog. When the graph is displayed, click the Print button. The graph will be sent to the default printer. If a model is present, each of the terms that are in use will be printed below the graph.

Copying a Graph to the Windows Clipboard

If you wish to use a graph in another Windows application, such as a word processor, the Copy command can be used to copy the graph as a metafile to the Windows clipboard. Once copied, use the Paste command (CTRL+V) while in the other application to insert the graph in its document.

The More Terms Dialog Box

The More Terms dialog box provides access to many additional terms that can be added to a telescope model. It is important to realize that many terms do not make sense for a particular telescope or they may be redundant. Therefore all terms should not be recklessly turned on with hopes of accounting for any and all possible telescope problems. Before additional terms are used in a model, the review the Advanced Modeling section as it describes an overall strategy for creating more complex models.

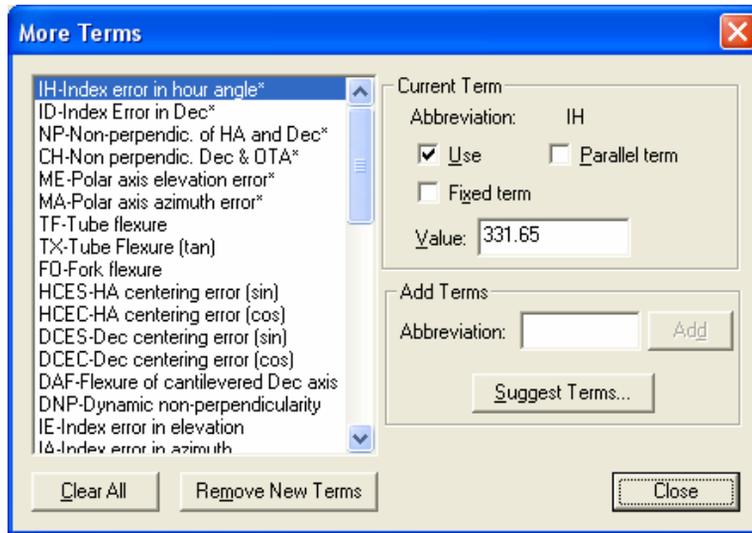


Figure 44: More Terms dialog box (TPoint)

The list box on the left of the More Terms dialog displays a list of terms that can be used when creating telescope models. Within the list box are the short descriptions of each of the terms. When a particular term is highlighted, the TPoint abbreviation for the term is shown at the top of the dialog, as well as other status information about the term.

The Use option in the Current Term group is marked when the selected term is used in the model. Each term can be toggled on and off using this option. This option is the same option for the common terms listed on the Fit Data dialog box.

The Fixed Term option is used to fix a term at a certain value, even when new fits are calculated. Fixing terms is useful once a model has been established for a given system and only certain terms require adjustment, for example, when a control system must be reinitialized (See the *“Performing a Short Mapping Run”* section) or CCD equipment is changed. In these cases, probably only the Index Error terms and the collimation error term need to be adjusted.

Generic Terms

There are two types of Generic terms, where the name of the coefficient spells out the required polynomial or harmonic formula.

Polynomial Terms

Polynomial terms have names in the form:

$$Pr[i^c [i]]$$

One example is a term PXH2D1, which models an effect that produced an east-west shift on sky (X) proportional to $h^2\delta$ (H2D1).

The initial P identifies the term as a polynomial.

The *r* field describes the result, and is one of the following:

H	Result is in hour angle.
X	Result is east west on the sky.
D	Result is in declination.
U	Result tilts polar axis up or down.
L	Result tilts polar axis left or right.
P	Result changes HA/Dec non-perpendicularity.
A	Result is in azimuth.
S	Result is left-right shift on the sky.
Z	Result is in zenith distance.
N	Result azimuth axis north or south.
W	Result tilts azimuth axis east or west.
V	Result changes Azimuth/El non-perpendicularity.

The two *i* fields indicate the independent variables and their powers. Each *i* is in the range 0-9; each *c* can be any of:

H	Hour Angle.
D	Declination.
A	Azimuth.
Z	Zenith distance.
Q	Parallactic angle.

Harmonic Terms

Harmonic terms have names of the forms:

or
$$H r f c [j] [f c [j]]$$

$$H r f c i i$$

Once example might be the term HXSH2, which would model an effect that produced an East-West shift on the sky (X) proportional to the sine (S) of 2h (H2).

The initial 'H' identifies this term as a harmonic.

The *r* and *c* fields describe the result and an independent variable respectively, and are as for polynomials, above.

Each *fci*, *fcii* and *fciii* indicates a function of an integer multiple of an independent variable *c*. The *f* field is either S for sine or C for cosine. Each *i* is in the range 0-9, allowing frequencies from 0 to 999 cycles per revolution in the case of simple one-coordinate harmonics, and 0 to 9 cycles per revolution in the case of compound two-coordinate harmonics. An omitted *i* defaults to unity, as does an omitted trailing *fci*.

Adding a Generic Term

To add a polynomial or harmonic term to a model, enter the term using the forms described above into the edit box located in the Create New Term group box. The Add Term button will remain grayed until a legitimate term has been typed into the edit box. Legitimate terms are unique terms that follow the form described above.

Once the desired term is entered, click Add Term to add the term to the current model. The Use check box will automatically be marked when a new term is added. The new term is placed at the end of the Terms list box.

For example, to model a gear-centering error in declination, a harmonic term must be created. The result *r* and the independent variable *c* are in declination. Both the sine and cosine components must be accounted for in order to allow arbitrary phase, so the two necessary terms are as follows:

HDSD and HDSD.

To add these to a model, type in HDSD in the Add Term edit box, then click Add Term. Do the same for HDSD. You will now see these new terms listed at the end of the terms list box.

Suggest Terms

Click this button to have TPoint analyze the existing pointing data, then list all the possible terms that may be added, sorted by magnitude of the correction. This option is a handy way to determine which terms have the greatest impact on the RMS pointing.

Sizes of the Coefficients

The mathematical expressions used by TPoint are rather simple and designed to give results of adequate accuracy when not too close to the pole of the mounting and *when the pointing errors of the telescope are small*. Flexures and misalignments of up to a few arcminutes are unlikely to give problems; they will not interact significantly with one another, and will be calculated by TPoint to sufficient accuracy. However, terms with larger coefficients may not be so well behaved, especially near a pole.

In practice, a particular source of problems is collimation error, the non-perpendicularity of the chosen pointing axis with respect to the declination or elevation axis of the mounting. If the measuring device – eyepiece, video, CCD etc. – is offset too far, there may be unmodeled pointing errors due to such effects as optical distortion. The best plan is to ensure that the measuring device is offset no more than a few minutes of arc. If this is impossible try to pre-process pointing observations to remove the bulk of the offset before the TPoint run. This might involve rigorous calculation of the tangent-plane projection and optical distortions.

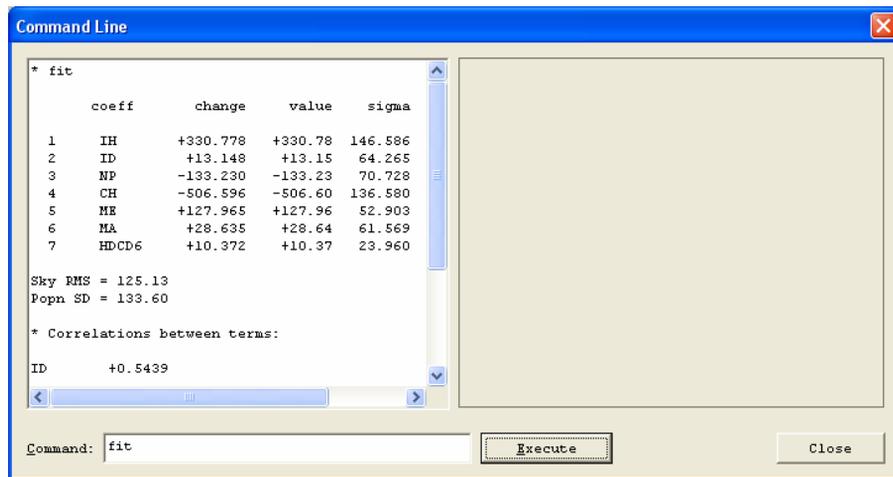


Figure 45: Command Line dialog box (TPoint)

TPoint Command Line

The command line dialog provides an area where experienced TPoint DOS or Unix users can type in commands in the same manner as on those platforms. The command line interface is not documented in this manual since all of the functionality of TPoint can be reached using the available dialogs. However, in the Advanced Modeling discussions below, a few additional commands are presented which can only be reached from the command line.

Advanced Modeling

TPoint allows a straightforward model for a telescope to be generated easily and without requiring great cunning or insight, but also provides the tools more experienced and determined users will need when conducting more exhaustive analyses.

As already described, the general strategy for modeling a telescope from scratch is to load a data file, set up the basic geometrical model (clicking Equatorial on the Fit Data dialog) and watching the term values and selected graph.

With the various graphs, plots of residuals can then be made and inspected for signs of systematic error. Plausible flexure terms can be tried, and any others that the particular telescope design suggests.

When adding new terms, pay attention to the standard deviation of the new coefficient, the effect on other terms, and whether the population standard deviation has gone down. A new term will almost always reduce the RMS pointing but population standard deviation is a better indication of whether the improvement is real.

If an attempt is made to use two terms that are more or less indistinguishable (for example, the identical terms, CH and PXH0), the condition will be reported. If this occurs, eliminate one of them. In such ill-conditioned cases, the singular value decomposition (SVD) methods used by FIT will normally return a meaningful model, with the “true” value of a duplicated term being shared out between the two (or more) coefficients involved. Two common cases are (i) if two inseparable terms are present from the start, they each receive an equal share of the value, and (ii) where a new term is added to an already fitted model, and that term is inadequately distinguished from something already present, then the new term will be left close to zero.

Do not try to extract more information from a given sample of data than the size of the sample justifies. A preliminary assessment of a telescope's capabilities can be made using perhaps 20-30 stars. Routine fitting of a typical operational telescope model, consisting of six geometrical terms, two or three flexures, and perhaps a few scale adjustments, centering corrections, etc., calls for 50-100 stars, well-distributed

over the whole observable sky. A campaign to expose high-frequency flexures and bumps should not be embarked upon without a sample of 500-1500 stars. Even with this large number of stars, fitting a full set of polynomials or harmonics up to the required degree in one go is impractical, and new terms must be tried out in groups of no more than about 20.

When first analyzing a new telescope, it is not uncommon to see obvious systematic residuals on the simple graphs of error in one coordinate plotted against that or another one--plotting error in zenith distance versus against zenith distance (Z Z plot) for example. However, once these straightforward effects have been treated, systematic errors can still hide in what looks like noise. Some of these can be exposed by using more specialized plots -- zenith distance errors against parallactic angle (Z Q plot), errors in HA/Dec non-perpendicularity plotted against HA (P H plot), and so on. However, certain effects that depend simultaneously on two coordinates may prove more stubborn; given a data set of adequate size, the solution is to use the MASK and UNMASK commands to select bands in one coordinate, allowing the residuals for that one band to be plotted.

At various stages the Hysteresis plot should be examined to assess whether the current pointing accuracy seems to be limited by hysteresis.

When pursuing low-level flexures and irregularities, difficult questions may arise. To what extent is the model physically meaningful? Has adding empirical terms affected the supposedly well-understood underlying model? Is it worth trying to keep a grip on physical reality, or wouldn't it be just as good to fit a massive set of polynomials or harmonics?

An approach that seems to preserve the considerable advantages of having a model firmly based on mechanical reality, yet allows all the power of empirical modeling to be unleashed, is to construct a model that includes both physical and empirical terms. At no stage should both sets be free to float during fitting.

Finding Harmonics: An Example

Often times after the geometric terms have been added to a model, other systematic errors present themselves in the various graphs generated by TPoint. Though not always obvious, close examination of the various graphs reveal patterns that provide insight into which additional terms should be added. The following example illustrates how adding two harmonic terms to the pointing model below improved the RMS pointing from two arcminutes to about one arcminute.

First, examine the "Multiple" graphs below generated from the Fit Data Dialog. Taking a close look at the top-middle graph (the delta-declination vs. declination

graph) shows a strong pattern in the form of the cosine function. The frequency appears to be 1-1/2 cycles per 90 degrees or 6 cycles per revolution.

A harmonic term that produces a declination shift on the sky proportional to the cosine (C) of $6d$ (D6) should be added to the model. The term name is HD C D6 (i.e. **H**armonic **D**eclineation **p**roportional to the **C**osine of **D**eclineation*6).

In the Terms Dialog, add the term HD C D6 to the edit box next to the Add Term button. Once the term you have added has the correct syntax and is unique (i.e. the term is not already present in the list of terms) the Add Term button will become undimmed. Click Add Term to include this new term in the model.

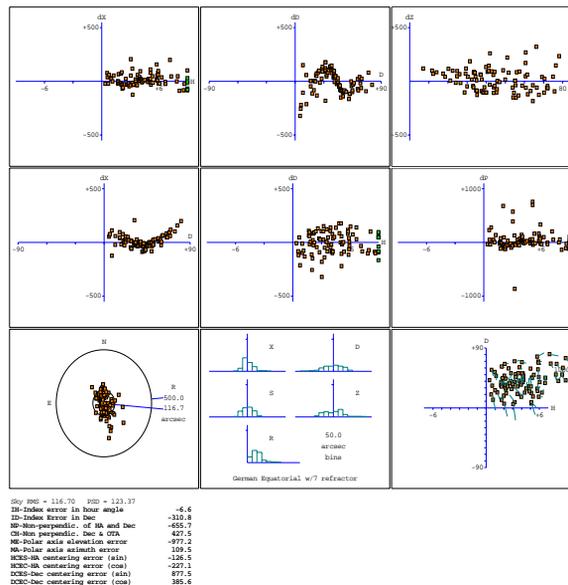


Figure 46: Multiple graphs.

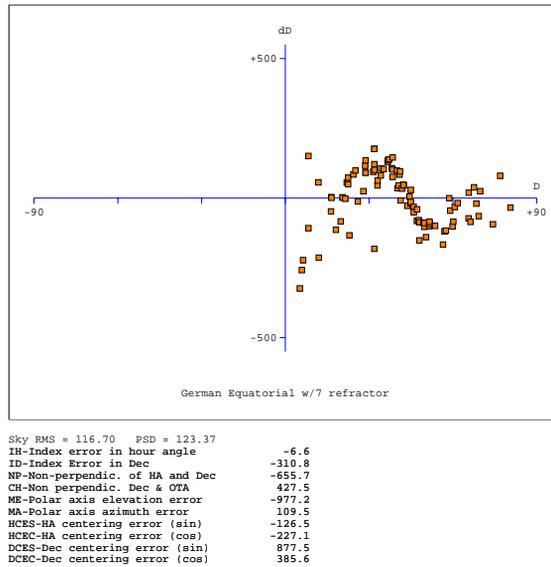


Figure 47: Graph of dD vs. Declination Before Adding the HDCC6 Term (RMS Pointing = 116 arcseconds)

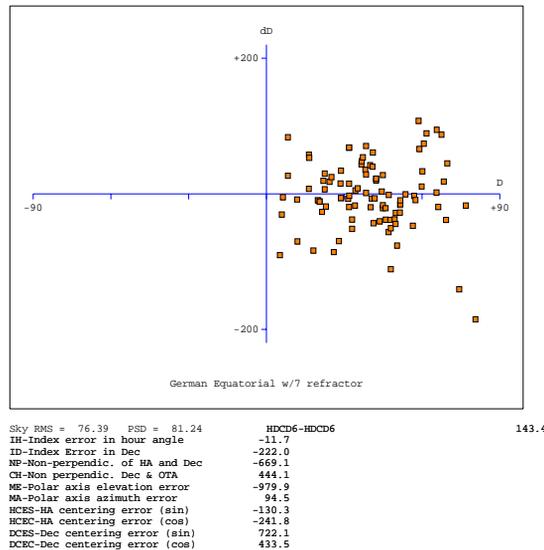


Figure 48: Graph of dD vs. Declination After Adding the HDCC6 Term (RMS Pointing = 76 arcseconds)

Note the RMS pointing decreases from 117 arcseconds to 76 arcseconds. Also note the scale of the Y-Axis changes from +/- 500 to +/- 200 arcseconds.

Examining the various graphs on the terms dialog shows another harmonic present in the dX vs. Declination graph.

In this case, a harmonic term that produces an east-west shift on the sky proportional to the cosine (C) of $2d$ (D2) should be added to the model. The term name is HXCD2 (i.e. **H**armonic **X** (east-west shift) proportional to the **C**osine of **D**eclication***2**).

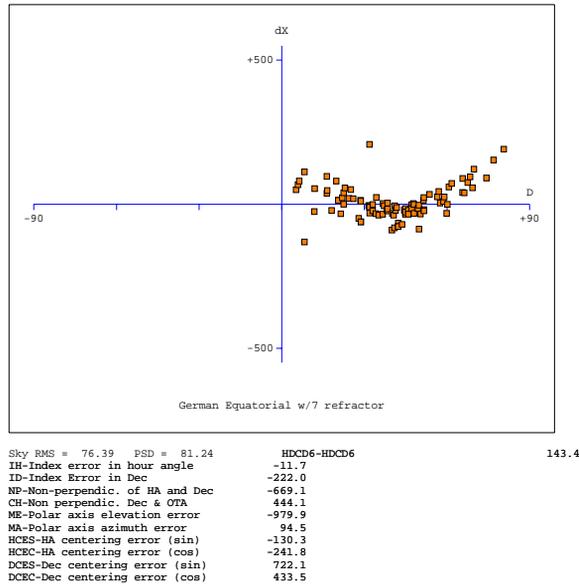


Figure 49: Before Adding the HXCD2 Term (RMS = 76 arcseconds).

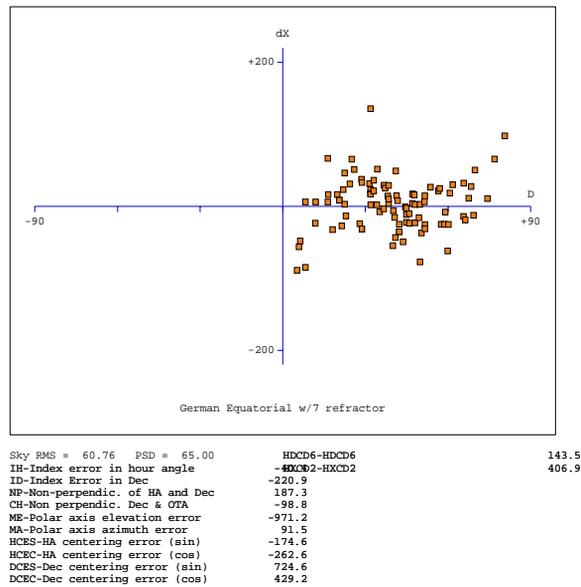


Figure 50: After Adding the HXCD2 Term (RMS = 61 arcseconds).

Appendix A – The Pointing Terms

This appendix contains a listing of the TPoint pointing terms. The pointing terms obey the following nomenclature and sign conventions:

- Hour angle: h is positive west of the meridian.
- Declination: δ is positive north of the equator.
- Parallax angle: q is positive west of the meridian.
- Azimuth: TPoint's internal convention such that A is zero for due south and 90 degrees for due east.
- Zenith distance: ζ the distance from 90 degrees altitude.
- Elevation: $E = 90 - \text{zenith distance}$.
- Hour angle and east-west corrections: Δh and $\Delta X (= \Delta h \cos \delta)$ are positive when corrected telescope position is west of the uncorrected position.
- Declination corrections: Δd is positive when corrected telescope position is north of the uncorrected position.
- Azimuth and left right corrections: ΔA and $\Delta S (= \Delta A \cos E)$ are positive when the corrected telescope position is to the left of the uncorrected position as seen by someone standing at the telescope looking at the sky.
- Elevation corrections: ΔE is positive when the corrected telescope position is above the uncorrected position.

TheSky provides the sequence of transformations and corrections needed to bridge the gap between (i) the cataloged object's position and (ii) where the telescope needs to be pointed to see the object, that is, transforming them to the "observed place."

Term: ACEC

The cosine component of the once-per-revolution cycle errors produced by a mis-centered azimuth setting-circle.

Notes: The sine component is ACES.

Term: ACES

The sine component of the once-per-revolution cycle errors produced by a mis-centered azimuth setting-circle.

Notes: The cosine component is ACEC.

Term: AN

In an alt-azimuth mount, misalignment of the azimuth axis north south: rotation about a horizontal east-west axis equal to coefficient AN.

Notes: AN is one of the six purely geometrical terms that affect all alt-azimuth mounts, the others being IA, IE, CA, NPAE, AW.

If AN is positive, the pole of the mounting is north of the zenith.

The other (that is east-west) component of the azimuth axis misalignment is the term AW.

Term: AW

In an alt-azimuth mount, misalignment of the azimuth axis east west: rotation about a horizontal north-south axis equal to coefficient AW.

Notes: AW is one of the six purely geometrical terms that affect all alt-azimuth mounts, the others being IA, IE, CA, NPAE, AN.

If AN is positive, the pole of the mounting is west of the zenith.

The other (that is north-south) component of the azimuth axis misalignment is the term AN.

Term: CA

In an alt-azimuth mount, the collimation error is the non-perpendicularity between the nominal pointing direction and the elevation axis. It produces a left-right shift on the sky that is constant for all elevations.

Notes: CA is one of the six purely geometrical terms that affect all alt-azimuth mounts, the others being IA, IE, AW, NPAE, AN.

A non-zero CA on its own means there is an area round the zenith inside which the telescope cannot point (irrespective of velocity and acceleration limits close to the zenith).

Collimation error has many causes—misalignment of the optics, an inaccurately centered eyepiece reticle and so on.

Term: CH

In an equatorial mount, the collimation error is the non-perpendicularity between the nominated pointing direction and the declination axis. It produces an east-west shift on the sky that is constant for all declinations.

CH is one of the six purely geometrical terms that affect all equatorial mounts, the others being IH, ID, NP, ME and MA.

A non-zero CH on its own means there is an area around the pole inside which the telescope cannot point.

Collimation error has many causes -- misalignment of the optics, an inaccurately centered eyepiece reticle and so on.

Term: DAF

Downward sag of cantilevered declination axis. English cross-axis and German equatorial mountings), proportional to the sine of the zenith distance of the declination axis.

Note: The sign convention corresponds to a declination axis that emerges from the polar axis towards the west when the telescope points at the meridian.

Term: DCEC

The cosine component of the once-per-revolution cyclic errors produced by a mis-centered declination setting-circle.

The sine component is the term DCES.

Term: DCES

The sine component of the once-per-revolution cyclic errors produced by a mis-centered declination setting-circle.

The cosine component is the term DCEC.

Term: DNP

For an equatorial mount, a change in the non-perpendicularity proportional to $\sin h$.

Notes: The static form is the term NP.

Term: ECEC

The cosine component of the once-per-revolution cyclic errors produced by a mis-centered elevation setting-circle.

Term: ECES

The sine component of the once-per-revolution cyclic errors produced by a mis-centered elevation setting-circle.

Term: FO

Flexure in an equatorial fork mounting: change in declination proportional to $\cos h$.

Notes: This model of fork flexure is based in the idea that the flexure is at a maximum on the meridian, that it affects only declination, and that at $h = 6^{\text{h}}$ the flexural displacement leaves the pointing direction unaffected. These assumptions are usually borne out well in practice.

Term: HCEC

The cosine component of the once-per-revolution cyclic errors produced by a mis-centered hour angle setting-circle.

Term: HCES

The sine component of the once-per-revolution cyclic errors produced by a mis-centered hour angle setting-circle.

Term: IA

Azimuth index error in an alt-azimuth mount: the zero-point error in A.

Take care with sign conventions: inside TPoint, azimuth increases counterclockwise.

Notes: On many alt-azimuth telescopes, IA is arbitrarily set at the start of each night by pointing at a calibration star, and on telescopes without absolute encoders or readouts there is no choice; under these circumstances the IA value returned by TPoint has no lasting significance. However, note that IA is not the same thing as a horizontal error on the sky, such as might be caused by a badly adjusted primary mirror; the latter, addressed by the CA term, would produce the same image displacement at all elevations, whereas IA has a lessening effect as the zenith is approached.

IA is one of the six purely geometrical terms that affect all equatorial mounts, the others being IE, CA, NPAE, AN and AW.

Term: ID

Declination index error in an equatorial mount: the zero-point error in declination.

Notes: ID produces a fixed offset of the image north south. On many telescopes, it is arbitrarily set at the start of each night by pointing at a calibration star, and on telescopes without absolute encoders or readouts, there is no choice; under these circumstances the ID value returned by TPoint has no lasting significance. It is indistinguishable from other north-south shifts, such as those caused by a badly adjusted primary mirror.

ID is one of the six purely geometrical terms that affect all equatorial mounts, the others being IH, CH, NP, ME and MA.

Term: IE

Elevation index error in an alt-azimuth mount: the zero-point error in E.

IE produces a fixed vertical offset of the image. On many alt-azimuth telescopes IE is arbitrarily set at the start of each night by pointing at a calibration star, and on telescopes without absolute encoders or readouts there is no choice; under these circumstances the IE value returned by TPoint has no lasting significance. It is indistinguishable from various other vertical shifts, such as those caused by a badly adjusted primary mirror.

IE is one of the six purely geometrical terms that affect all alt-azimuth mounts, the others being IA, CA, NPAE, AN and AW.

Term: IH

Hour angle index error in an equatorial mount.

Notes: IH has the same effect on pointing as an error in the clock or using an inaccurate value for the site longitude. On many telescopes, it is arbitrarily set at the start of each night by pointing at a calibration star, and on telescopes without absolute encoders or readouts, there is no choice; under these circumstances the IH value returned by TPoint has no lasting significance. However, note that it is not the same thing as an east-west error on the sky, such as might be caused by a badly adjusted primary mirror; the latter, addressed by the CH term, would produce the same image displacement at all declinations, whereas IH has a lessening effect as the pole is approached.

IH is one of the six purely geometrical terms that affect all equatorial mounts, the others being ID, CH, NP, ME and MA.

Term: MA

Misalignment of the polar axis of an equatorial mount to the left or right of the true pole: a rotation about an axis through $h = \delta = 0$ equal to coefficient MA.

Notes: In the Northern Hemisphere, positive MA means that the pole of the mounting is to the right of due north.

In the Southern Hemisphere, positive MA means that the pole of the mounting is to the right of due south.

To avoid unwanted field rotation effects it is best to eliminate MA mechanically by an appropriate azimuth adjustment. To eliminate MA arcseconds of polar axis azimuth error, rotate the mounting $MA \sec \phi$ arcseconds counterclockwise as seen from above.

The other (that is, up and down) component of the polar axis misalignment is the term ME.

Term: ME

Vertical misalignment of the polar axis of an equatorial mount: a rotation about an east-west axis equal to coefficient ME.

Notes: In the Northern Hemisphere, positive ME means that the pole of the mounting is below the true (unrefracted) pole. A mounting aligned the refracted pole (for most telescopes probably the simplest and best thing to aim for in order to avoid unwanted field rotation effects) will have negative ME.

In the southern hemisphere, positive ME means that the pole of the mounting is above the true (unrefracted) pole, and a mounting aligned the refracted pole will have positive ME.

The other (that is left-right) component of the polar axis misalignment is the term MA.

Term: NP

In an equatorial mount, if the polar axis and declination axis are not exactly at right angles, east-west shifts of the image occur that are proportional to $\sin \delta$.

Notes: NP is one of the six purely geometrical terms that affect all equatorial mounts, the others being IH, ID, CH, ME and MA.

The image displacement produced by NP is zero on the celestial equator and reaches a maximum at the pole.

Most telescope sites lie well away from the equator of the Earth and hence the correction for NP tends to be the same sign most of the time. Furthermore, because there is more sky at lower declinations than near the pole there are likely to be fewer pointing observations in a given declination-band near the pole than in a similar band nearer the equator. These two effects conspire so that the NP effect tends to be poorly sampled when pointing tests are made, and hence the NP coefficient is apt to be poorly determined. In some cases, it can be better to omit NP from the model and rely on other terms mopping up any NP-like effects that are preset.

A non-zero NP on its own means there is an area around the pole inside which the telescope cannot point.

Term: NPAE

NPAE is one of the six purely geometrical terms that affect all alt-azimuth mounts, the others being IA, IE, CA, AN and AW.

The image displacement produced by NPAE is zero on the horizon and reaches a maximum at the zenith.

Just as E is always positive, the correction for NPAE never changes sign. Furthermore, because there is more sky at lower elevations than near the zenith there are likely to be fewer pointing observations in a given elevation-band near the zenith than in a similar band nearer the horizon. These two effects conspire so that the NPAE effect tends to be very poorly sampled when pointing tests are made, and hence the NPAE coefficient is apt to be poorly determined. In some cases, it can be better to omit NPAE from the model and rely on other terms mopping up any NPAE-like effects that are preset.

A non-zero NPAE on its own means there is an area around the zenith inside which the telescope cannot point (irrespective of velocity and acceleration limits close to the zenith).

Term: NRX

In a Nasmyth alt-azimuth mount, a horizontal displacement between the elevation axis of the mount and the rotation axis of the Nasmyth instrument-rotator produces an image shift on the sky with a horizontal component proportional to cosine elevation and a vertical component proportional to minus sine elevation.

(Take care with sign conventions: inside TPoint, azimuth increases counterclockwise.)

Notes: The same corrections apply even if there is no Nasmyth rotator, except that the displacement is between the elevation axis and the nominated pointing-origin in the Nasmyth focal-plane.

NRX is positive when the elevation axis emerges from the Nasmyth focal plane to the right of the rotator axis.

Term: NRY

In a Nasmyth alt-azimuth mount, a vertical displacement between the elevation axis of the mount and the rotation axis of the Nasmyth instrument-rotator produces an image shift on the sky with a horizontal component proportional to sine elevation and a vertical component proportional to cosine elevation. (Take care with sign conventions: inside TPoint, azimuth increases counterclockwise.)

Notes: The same corrections apply even if there is no Nasmyth rotator, except that the displacement is between the elevation axis and the nominated pointing-origin in the Nasmyth focal-plane. NRY is positive when the elevation axis emerges from the Nasmyth focal plane above the rotator axis.

The NRY correction has an identical form to the two terms NPAE and TF acting in combination. This unfortunately prevents simultaneous fitting of pointing observations to a model containing all three terms. The recommended procedure for Nasmyth telescopes is to determine a canonical value of TF from observations at a non-Nasmyth focus (prime, Cassegrain, Newtonian etc., and then to fit Nasmyth pointing observations to a model which includes TF fixed at this value.

Term: TF

Classical tube flexure: change in zenith distance proportional to $\sin \zeta$.

Notes: This is the classic tube flexure model, which assumes that the telescope obeys Hooke's Law. In practice there is often a rapid increase in the vertical displacement towards the horizon, and it is sometimes found that a tangent law is a better approximation than a sine law: see the TX term.

Term: TX

Empirical tube flexure: change in zenith distance proportional to $\tan \zeta$.

Notes: The classical tube flexure model, TF, which assumes that the telescope obeys Hooke's Law, is a sine rather than tangent law. In practice there is often a rapid increase in the vertical displacement towards the horizon, and it is sometimes found that the present term, TX, is a better approximation than TF.

Note that TX will compensate for any scaling error in the refraction corrections.

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