MMTO Technical Memorandum #2009-02
Elevation Tracking for the 3rd Trimester of 2008

D. Clark

Introduction

The MMTO MySQL database was queried for routine tracking and weather data for the final trimester of 2008. This data is presented with discussion of data sources, their distributions over various dimensions of the data, and appropriate statistics are shown for the purposes of evaluation of the tracking performance of the latest iteration of the elevation servo (e.g. the version released after Summer 2008 Shutdown).

The database query returned 5064 entries from the tracking performance MySQL table[1]. The tracking performance table contains entries for the timestamp, source filename from the mount tracking logging software, position, RMS error, peak-to-peak error, and tracking rate. In addition, a Python application was written to acquire the wind sensor data from the database that matched the tracking data entries with similar (or the same) timestamps for study of the wind influence on tracking performance.

RMS Tracking Error

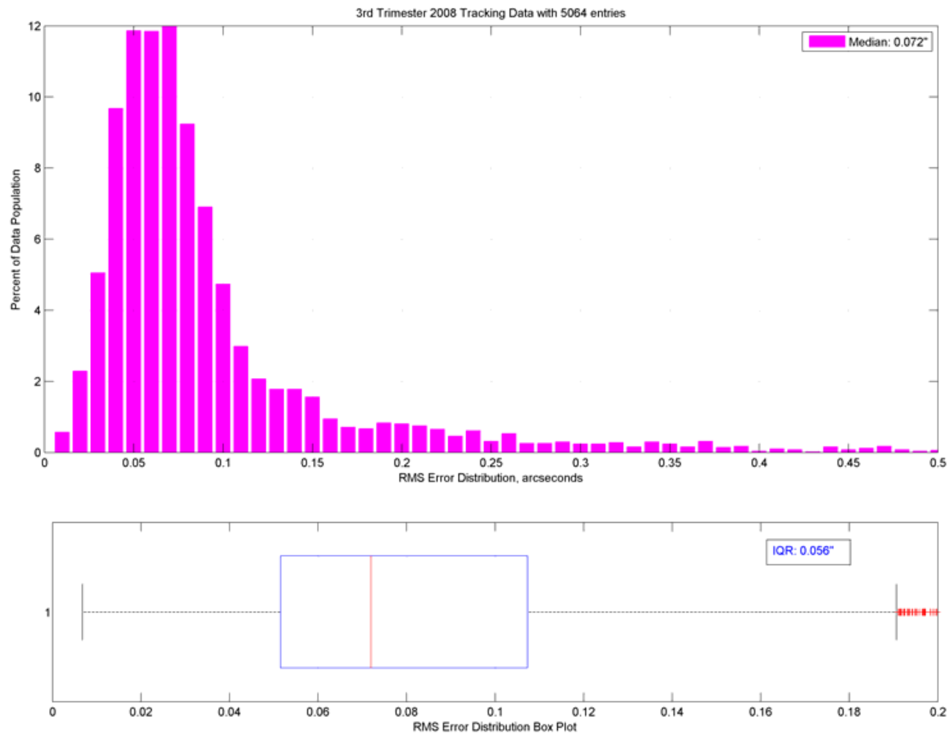
The RMS error and other statistics in arcseconds for the whole data population are:

Range	Median Value	Inter-quartile Range
1.75	0.072	0.056

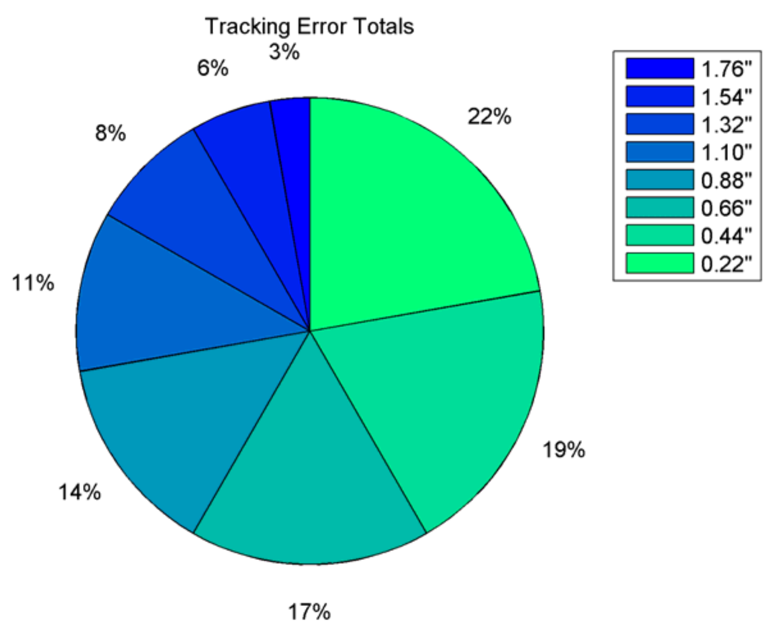
The inter-quartile range measures the width of the 50% of the data that lies between the 25th and 75th percentiles, and gives a better estimate of the spread of the data than the standard deviation (std), which can be sensitive to outliers.

Below we have a histogram of the RMS error data (top), and a box plot of the data zoomed over the range of interest. The histogram contains all of the data, binned into 0.01” sections, or ~1 encoder count. The box plot shows the IQR range as a blue box, with a red line inside at the median value of the data. The left-hand black line is the smallest data entry, while the right black line is set to 1.5 times the IQR value away from the median value box by the Matlab `boxplot` routine. Values outside this are marked with red crosses and are considered outliers. The `boxplot` routine returned 654 entries in the data as outliers (out of the 5064 total). With this, we see that 50% of the RMS error in the data lies between 0.05 and 0.107 arcseconds.

[1] See the appendix portion, “SQL Query and Python Data Collection” for details.

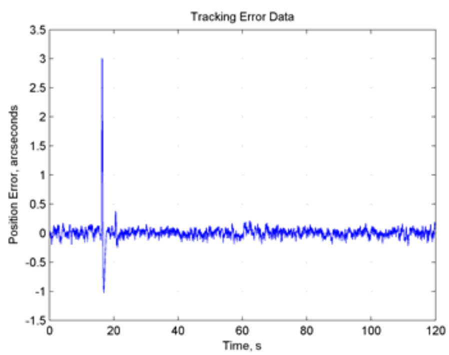


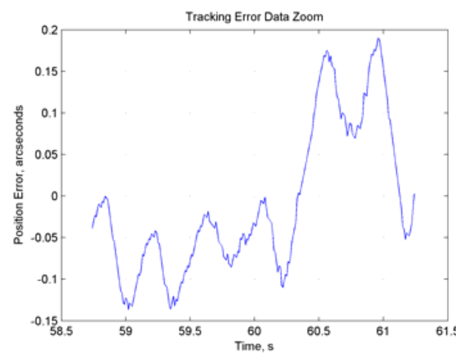
The pie chart below shows the distribution of the complete set of tracking error entries with 0.22" bin widths. The legend at right for the pie chart shows the center value for each bin.

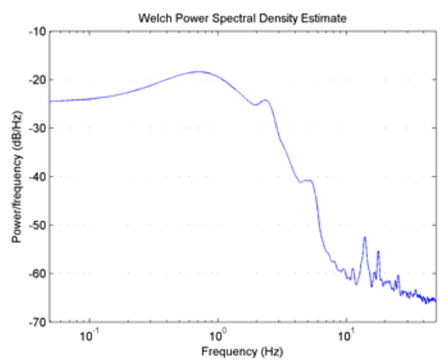


Data Reporting Issues
A known problem with the tracking error data collection is that it collects tracking data for each new object acquired just after completing the slew to the object; applications of offsets or other pointing corrections to the mount are often captured in the logging data. This means that large step responses in the error signal can be present in the data. Early versions of the logging software would often trigger the data collection before the slew completed, contaminating the data output. We continue to improve our logging facility to ensure data quality in the MySQL system.

A typical logging file from the 2008 3rd trimester data is shown below:

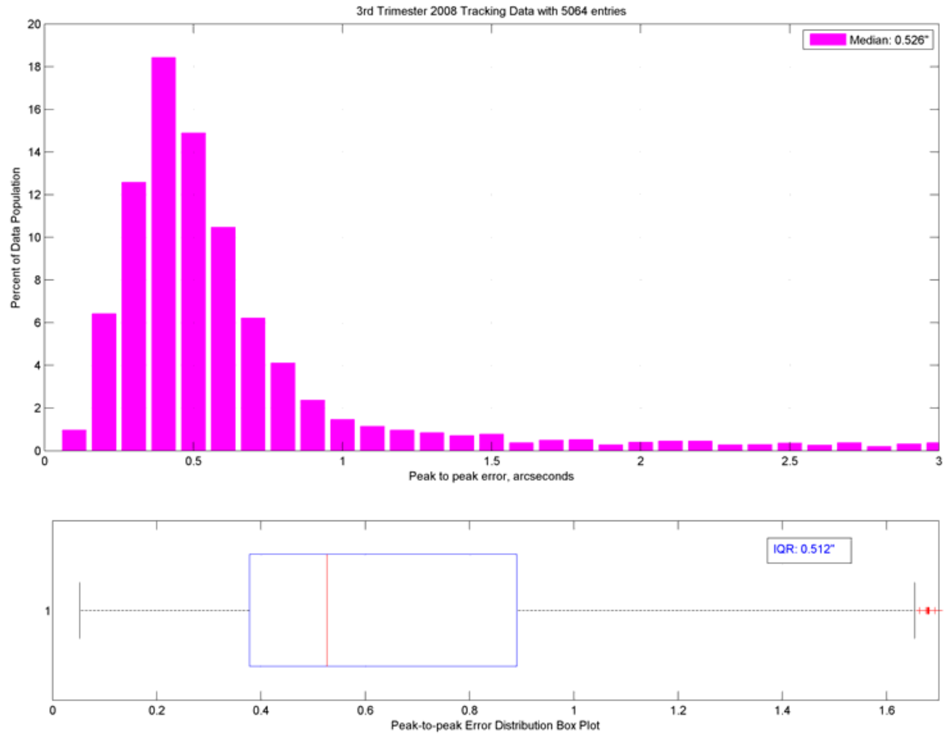




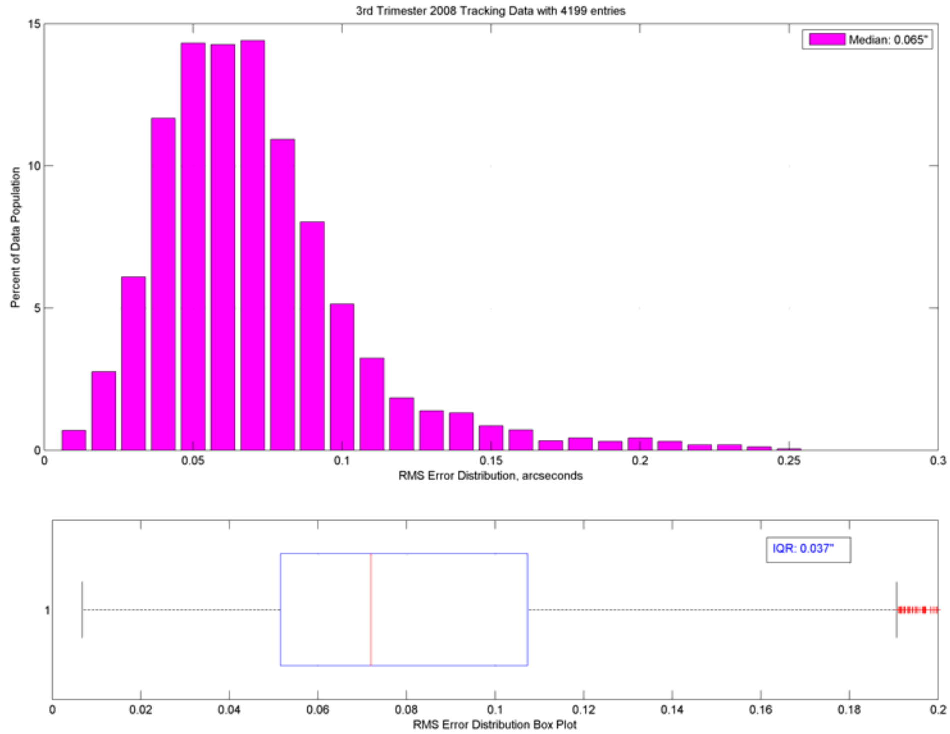


Data	Value	Units
File Name	rd_20081008_234501	
Tracking Rate	4.792	Arcseconds/s
Total RMS Error	0.1406	Arcseconds
5.6Hz Mode RMS	0.0024	Arcseconds
20Hz Mode RMS	0.0004	Arcseconds
0-3.5Hz Integrated Error	72.22	Percent Total...
5.6Hz Mode Integrated Error	0.80	Percent Total...
20Hz Mode Integrated Error	0.05	Percent Total...
Peak-to-peak Error	4.032	Arcseconds

This file reports a peak-to-peak error of just over 4 arcseconds, due to the offset step response at ~18s in the data. The RMS error seen in this file is reported as 0.14"; if the std of just the data from 20s to the end is calculated, the RMS error becomes 0.067" – a much more reasonable result, given the obviously smaller amplitude in the majority of the time history. For the peak-to-peak error data, we have the distribution plot below (zoomed a bit):



If we remove those data entries with a peak-to-peak value of more than 1.7" (the guard value for outliers), the RMS error distribution becomes as shown below; 865 entries were removed from the data population by this exclusion:



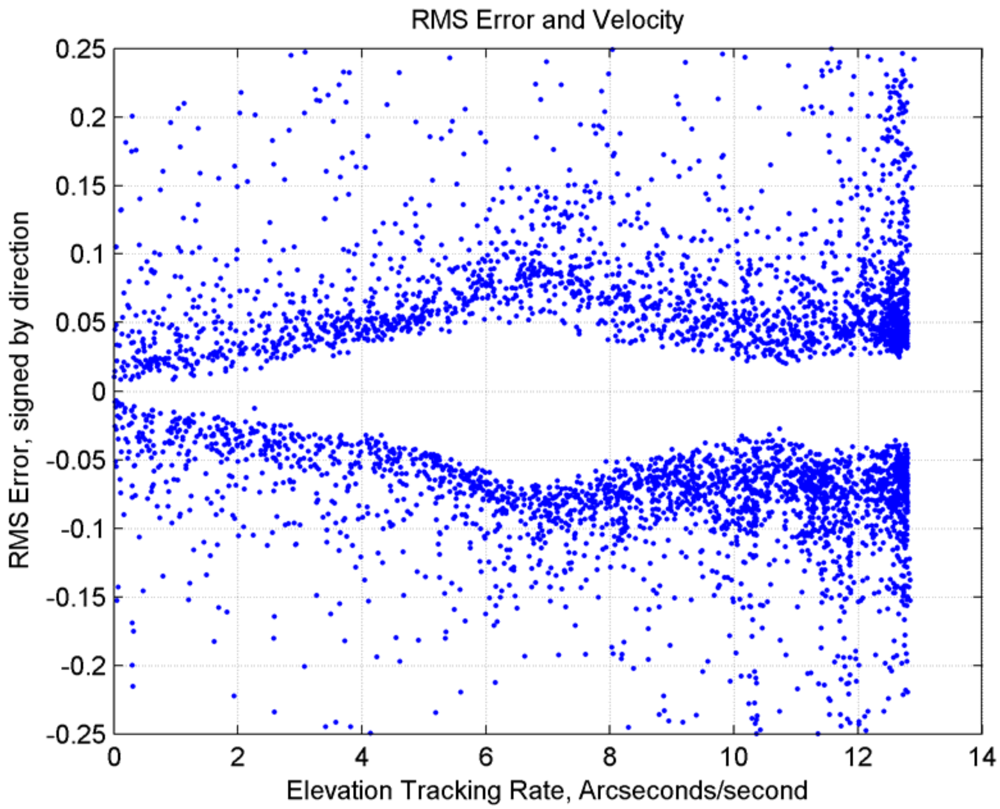
Now the median error is 0.065", with an IQR (spread) of 0.037", in line with the earlier result.

Error Distributions

Detailed visualizations of the error data help illuminate the dependencies of the tracking performance on position, velocity, and the environment. Evidence that the elevation controller experiences limit cycling based on the quantization of the encoder feedback is difficult to determine when using one, or few, tracking files. The large data set makes the existence of this limit cycle much easier to detect.

In the figure below, the absolute tracking rate is plotted on the x-axis, and the y-axis points are the RMS error values signed by the tracking direction – negative is tracking down to the horizon. The figure is zoomed in for clarity.

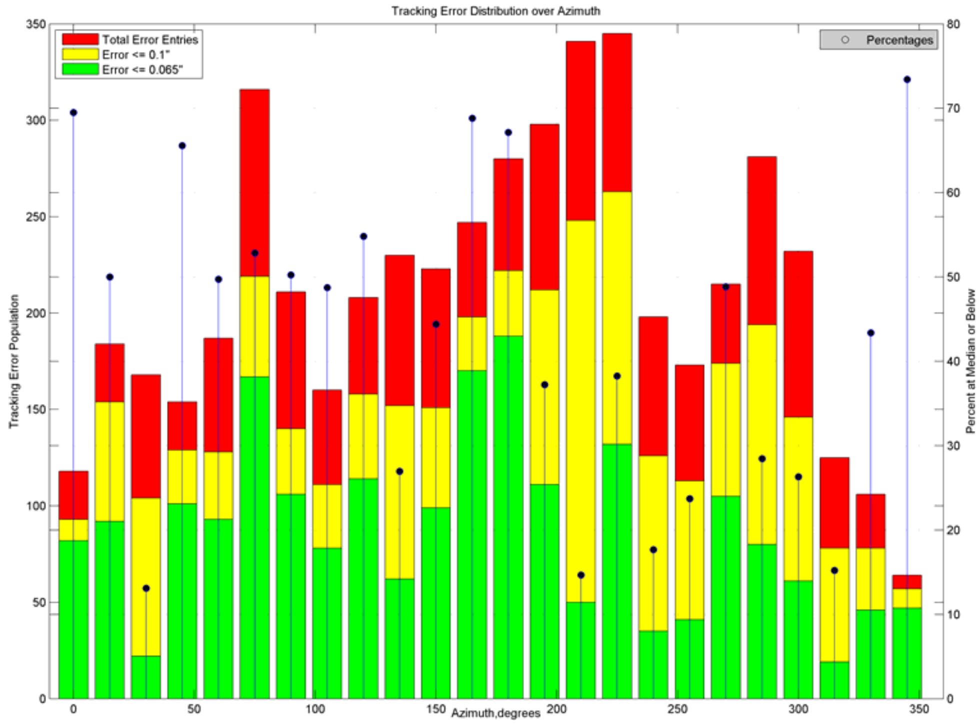
Tracking smoothness appears unaffected by the tracking direction, but cannot go below about ±2 encoder counts. In addition, the tracking error shows a non-linear dependence on the tracking rate. Work on encoder feedback improvements (i.e. improved alignment, period counting) would help make this lower limit on tracking error smaller.

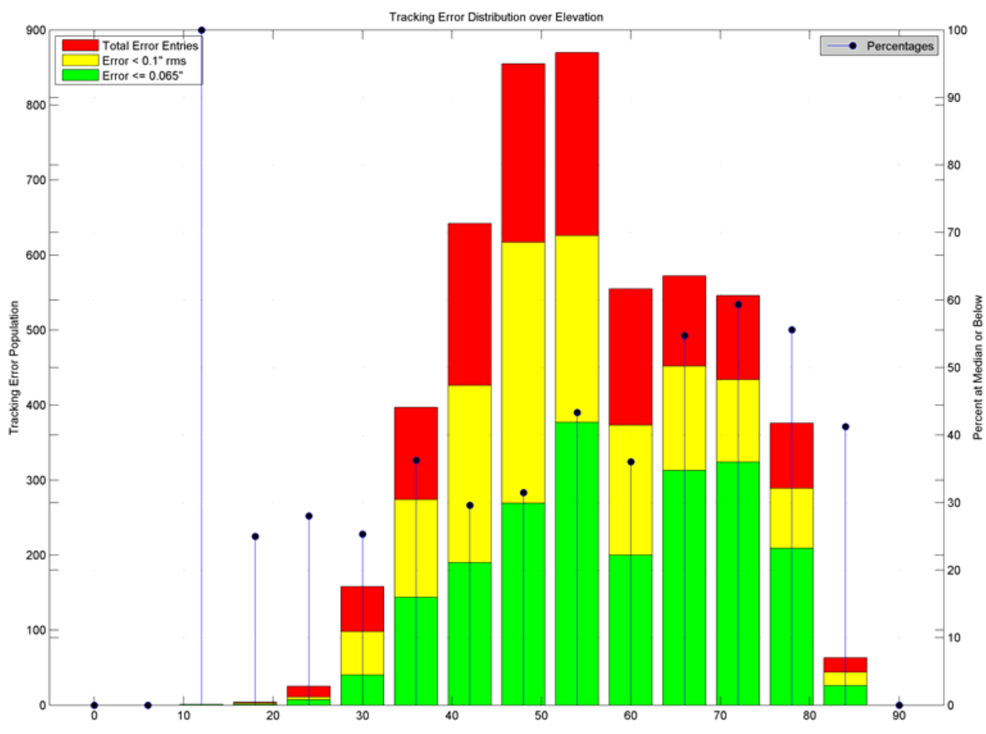


To investigate error dependence on position, the azimuth and elevation entries were separated into bins, and the population of error entries in the data were totaled into a) the total number of data entries, b) the number of entries where the RMS error was ≤ 0.1", and c) the number of entries where the RMS error was at the global median of 0.072" or better. The bar charts below show these totals in red, yellow, and green. A stem plot is overlaid showing the percentage of the total entries that are at the median tracking value or lower, with its y-value on the right axis for reference.

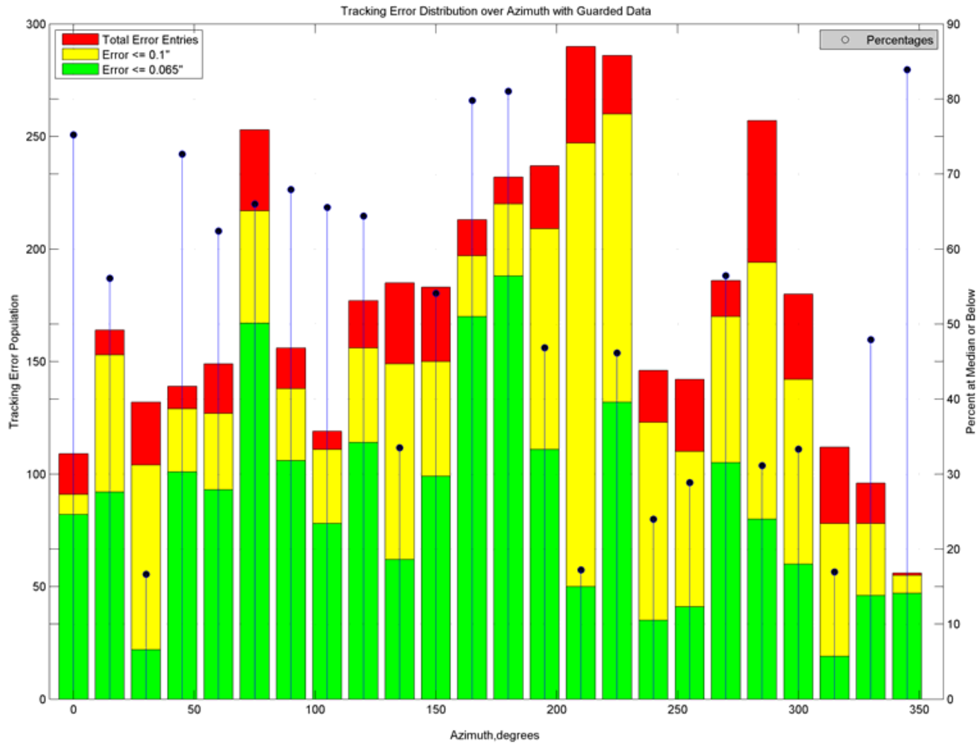
In the elevation data, a tiny number of samples at below 20° have 100% of their population at the "green" level; it cannot be determined from this sample size if this is an anomaly or if the tracking is really always that good at (very low) elevations. Since few observers are generally willing to work at such a high airmass, we await more data to settle the matter.

From the data, it appears there is weak correlation to lower tracking performance to the west, and generally better performance over the interval of 50 to 80° elevation. The azimuth variation may be explained by the direction of the prevailing winds to be generally from the southwest; wind influence is discussed in detail later.

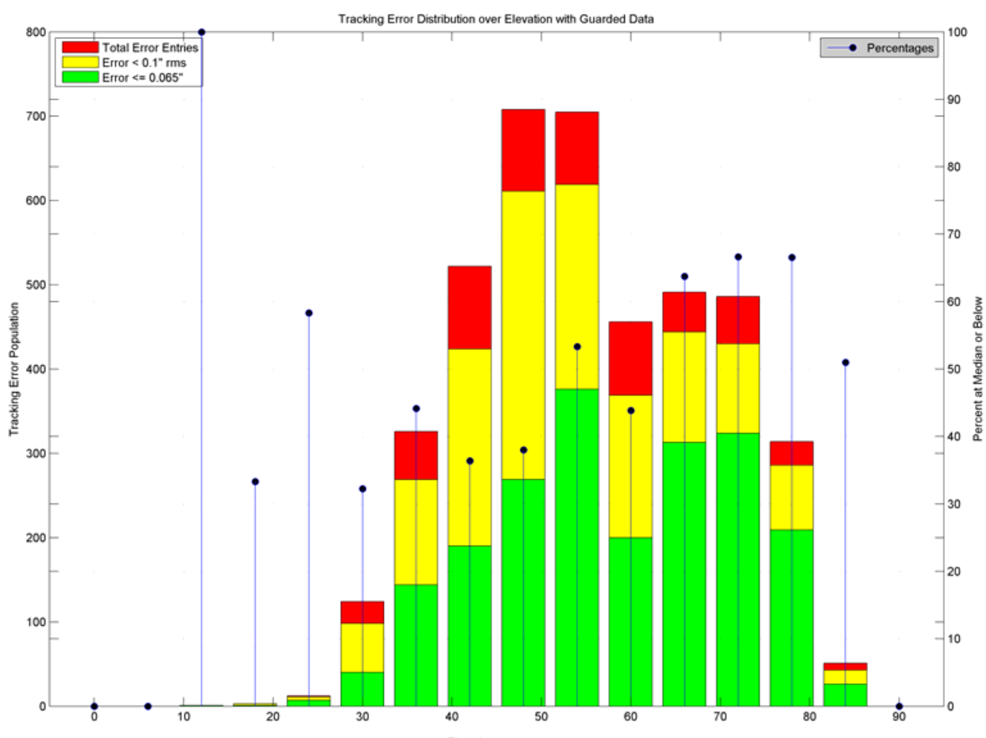




Using the guarded data, below are the same azimuth and elevation bar plots:



Tracking Error Distribution over Azimuth with Guarded Data
Total Error Entries
Error <= 0.1"
Error <= 0.065"
Percentages
Tracking Error Population
Percent at Median or Below
Azimuth,degrees

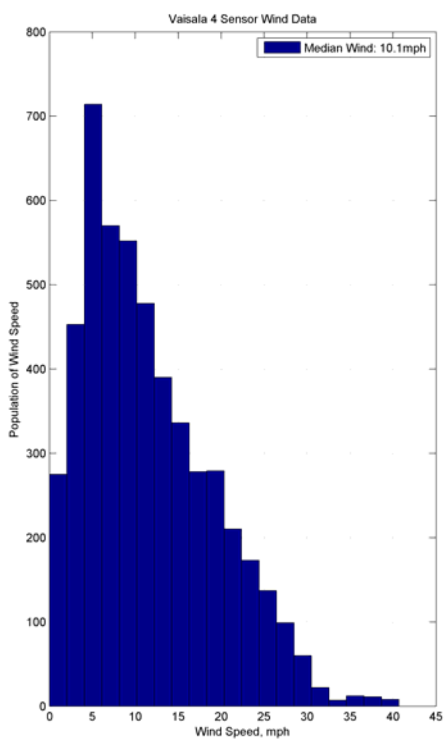


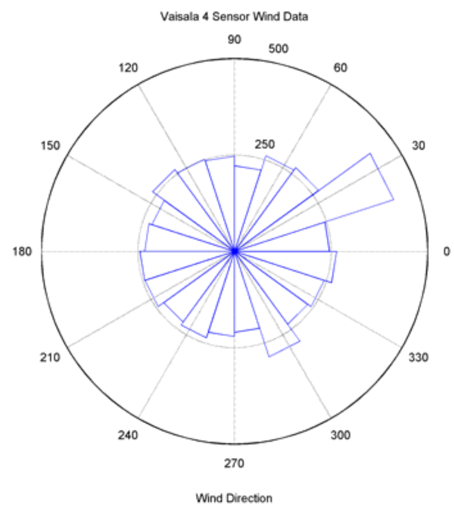
Tracking Error Distribution over Elevation with Guarded Data
Total Error Entries
Error < 0.1" rms
Error <= 0.065"
Percentages
Tracking Error Population
Percent at Median or Below
Elevation,degrees

Wind Data
A small Python application was written to acquire wind data from the *Vaisala 3* and *Vaisala 4* sensors, located on the east and west sides of the MMT building, respectively. This data was filtered to output data at or near the timestamps of the tracking file data used in this report.

Examination of the data from the *Vaisala 3* sensor shows poor data distributions when compared to that from the *Vaisala 4*, as well as bad data entries ("NaNs"). Many operational issues were encountered with the *Vaisala 3* unit during the 3rd trimester of 2008 (bird and water damage, calibration), so its data was discarded in favor of the *Vaisala 4's* output.

The wind speed distribution and wind azimuth distribution is shown below. Keep in mind that this data is *only for when tracking is active*. The global wind distribution is quite different (see T. Pickering's notes for details).

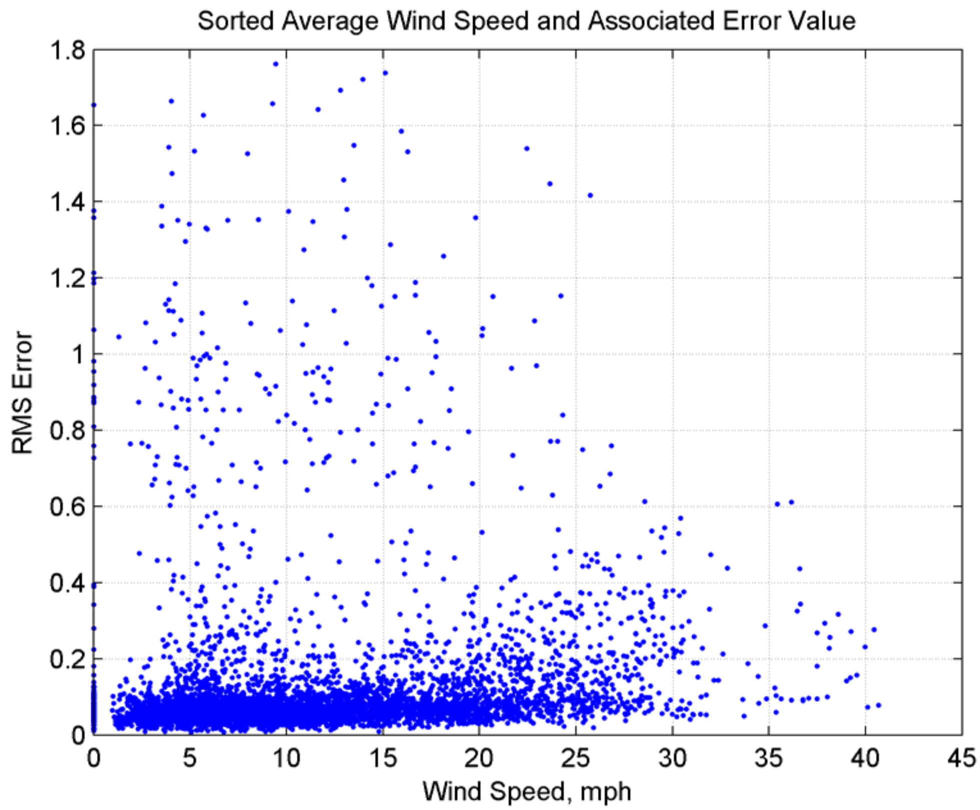




The wind data is fairly evenly distributed in azimuth, except for one bin to the NE; it's unclear why this is so, as the *Vaisala 3* data is useless for comparison. It can be safely assumed, however, that the MMT building doesn't appear to "shadow" the wind data from the west flag pole location, at least in azimuth. The *Vaisala 3* has been repaired and we await better data to compare the two sensors for a better long-term answer.

Wind Influence on Tracking

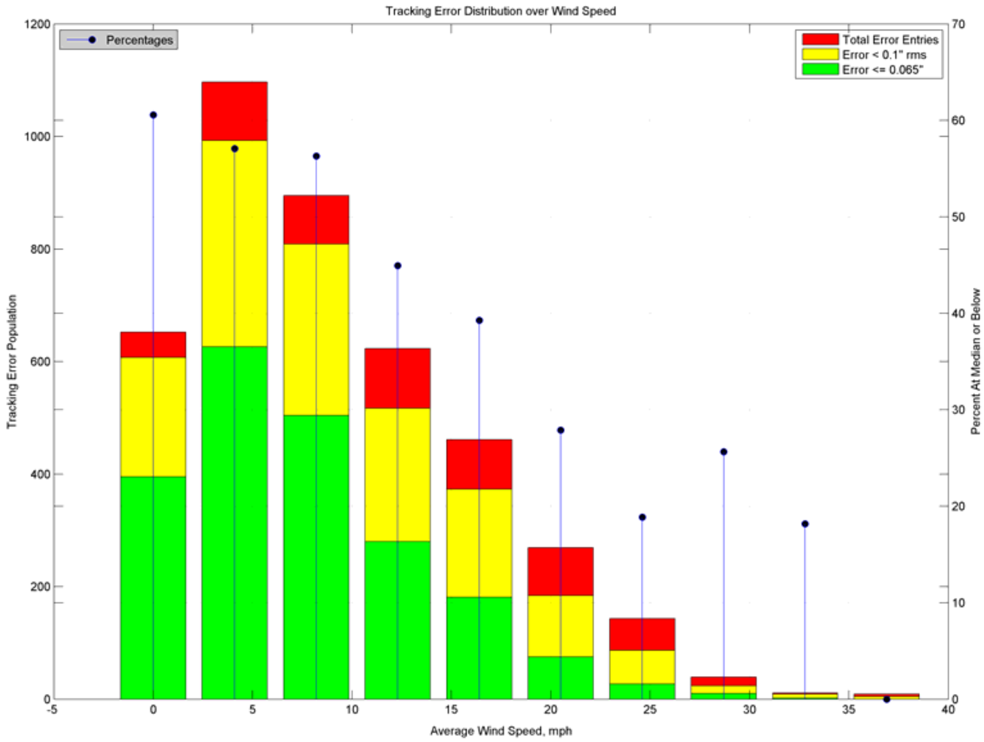
For all the data entries, the average wind speed was sorted in ascending order, and the corresponding RMS error entry for each wind speed value is shown in the plot below:



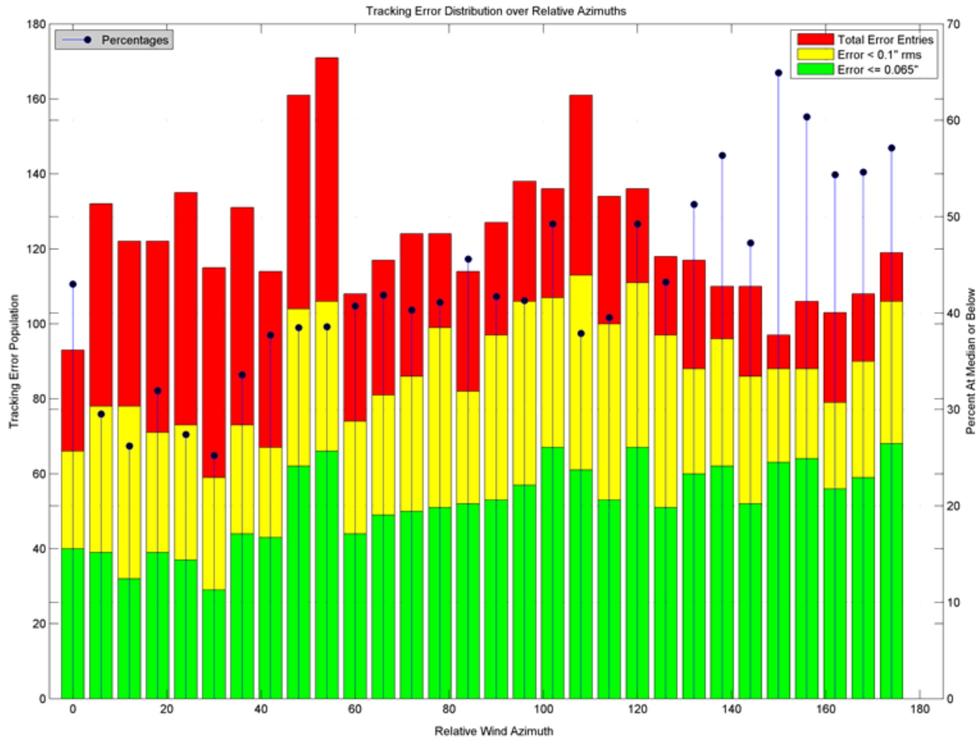
Clearly, a few poor tracking entries exist for all wind speeds in the data, and most of the good tracking is concentrated at wind speeds below ~15mph.

Sorting this data into a histogram provides a clearer picture. Using the data with the guarded data (again, only entries with a peak-to-peak error of ≤ 1.7”), we have below the tracking error distribution over wind speed, irrespective of the telescope position.

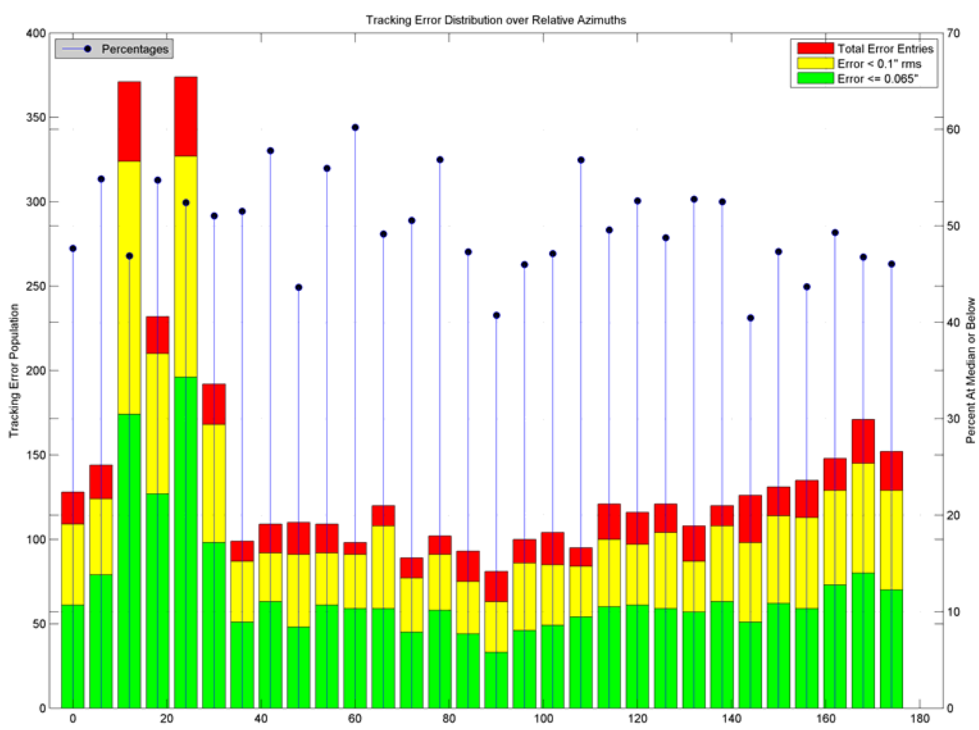
The distribution shape is influenced by the shape of the wind distribution and tracking error populations, but tracking error and wind speed as expected are inversely related.



How about the relative wind distribution? The wind azimuth data and the tracking azimuth were subtracted to produce a relative absolute azimuth angle and the distribution of RMS error is shown below; the top bar plot shows the distribution over the entire data population, and the bottom is the same plot with the outliers removed. The exhaustive, time consuming task of examining the data to determine why the distribution shape changes so much awaits the intrepid person with weeks to spend on the pursuit.



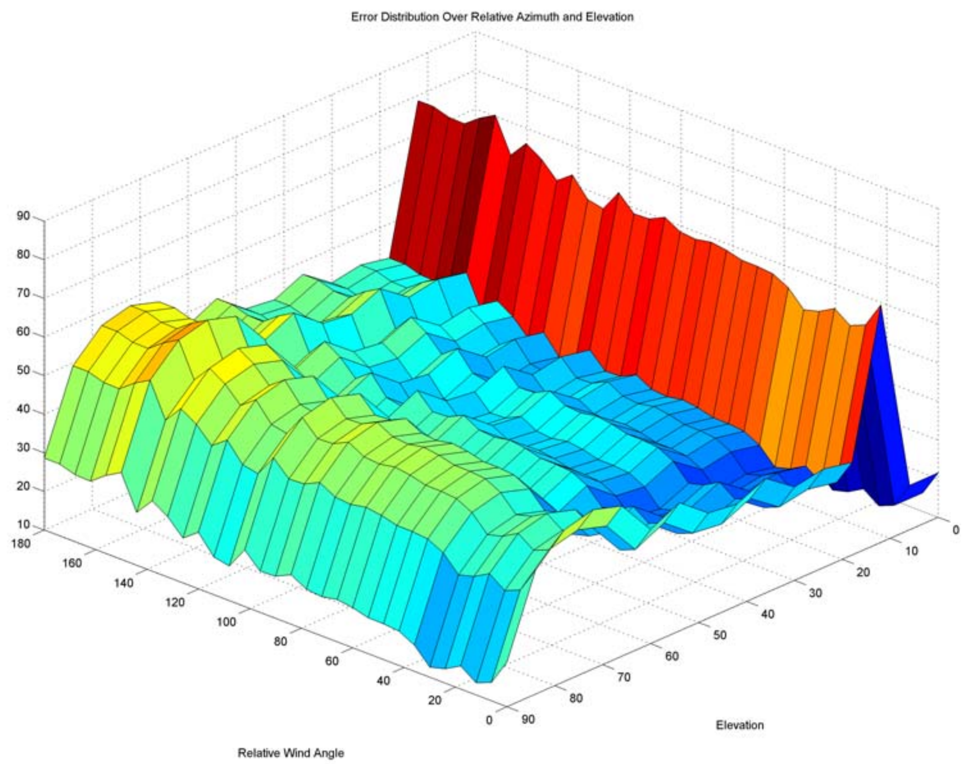
Tracking Error Distribution over Relative Azimuths
Percentages
Total Error Entries
Error < 0.1" rms
Error <= 0.065"
Tracking Error Population
Percent At Median or Below
Relative Wind Azimuth



Tracking Error Distribution over Relative Azimuths
Percentages
Total Error Entries
Error < 0.1" rms
Error <= 0.065"
Tracking Error Population
Percent At Median or Below
Relative Wind Azimuth

In the top plot above, correlation between azimuth angles away from the wind and tracking improvement is observed. Note also local maxima at 45° intervals away from directly into the wind (0°). The "red" portion of the guarded data shown in the lower plot is much smaller, as might be expected.

For another view, consider the following figure, which joins the relative wind azimuth, elevation angle, and RMS error in the range up to the median and below into a single 3D image for the complete data set:



As mentioned earlier, a small number of samples at low elevation had excellent tracking, so this throws off the surface mesh in the image at low elevation. However, this helps to show how tracking quality changes over elevation position and wind angle.

Conclusion

The MMT elevation tracking for the 3rd trimester of 2008 was at a median of 0.065", ±0.04". There is a lower limit to the tracking smoothness at about 0.02", or ±2 encoder counts, with a non-linear dependence on tracking rate. Wind rejection remains an issue, with tracking degradation a (nearly linear) function of the wind speed, regardless of the telescope position. Positions at high elevation angles away from the prevailing wind are more favorable, however. Further study of the reasons for poor tracking in the ~17% of the data population is needed. We plan to regularly repeat this data report going forward.

For the purpose of documenting the data queries and the software used in producing the data and figures in this report, a separate document was produced with this information. Interested readers are directed to the URL:
www.mmto.org/~dclark/Reports/El_Tracking2008_appendices.pdf.