MMTO Internal Technical Memorandum #09-3

MMT Observatory

Smithsonian Institution &
The University of Arizona®

**Azimuth Tracking for the 3rd Trimester of 2008
(September – December, 2008)**

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Introduction

The MMTO MySQL database was queried for routine tracking and weather data for the final trimester of 2008 (Sept-Dec). These data are presented with discussion of data sources, their distribution over various dimensions of the data, and appropriate statistics are shown for the purposes of evaluation of the tracking performance of the legacy azimuth-axis servo (e.g. using an LM628-based velocity loop inside a mode-switching software PID position loop). This document is a companion to the previously released report for the elevation tracking, MMT Technical Memorandum #2009-02. Information about the control loop itself can be found at **http://tinyurl.com/c4axze** , the azimuth-axis topology is unchanged since that document was written and is still relevant, although the loop tuning has changed since then, which affects the closed-loop response.

For this report, the database query returned 5014 entries from the tracking performance MySQL table. 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 by Tom Trebisky 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. All of the figures that follow are available via the web at **http://tinyurl.com/dfdmg7** if closer study is desired, as with the previous elevation-axis report.

The reader is encouraged to study the previous report for details concerning the data collection system, and various web-based utilities for viewing the data on an ad-hoc basis. The web page for daily tracking data visualization has recently been updated to add the azimuth and rotator axes and is available at **http://tinyurl.com/cupa85**.
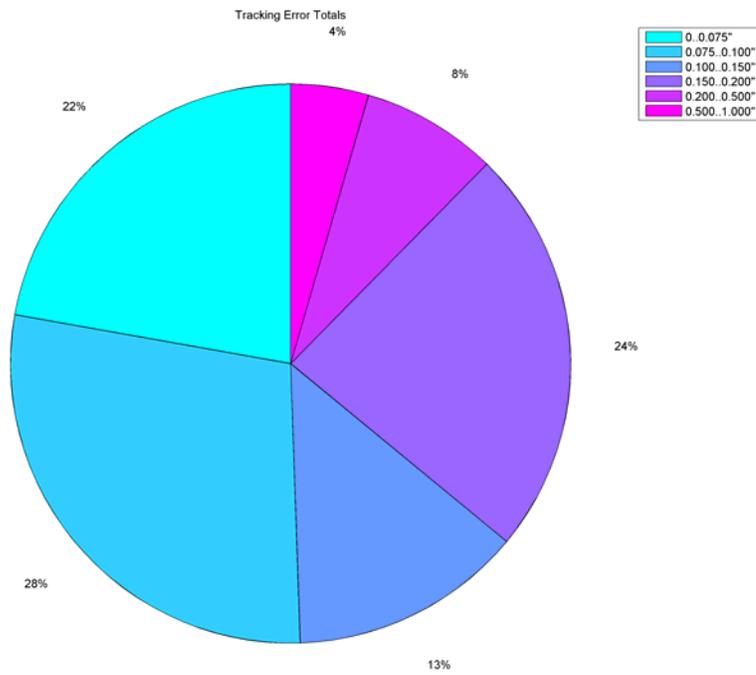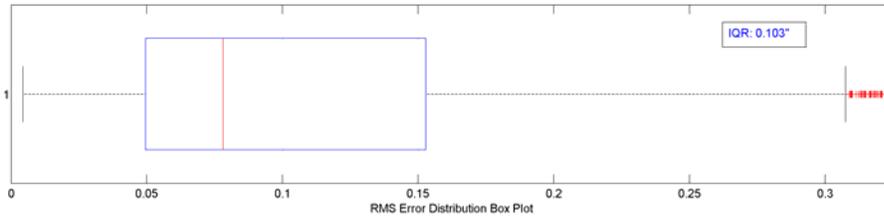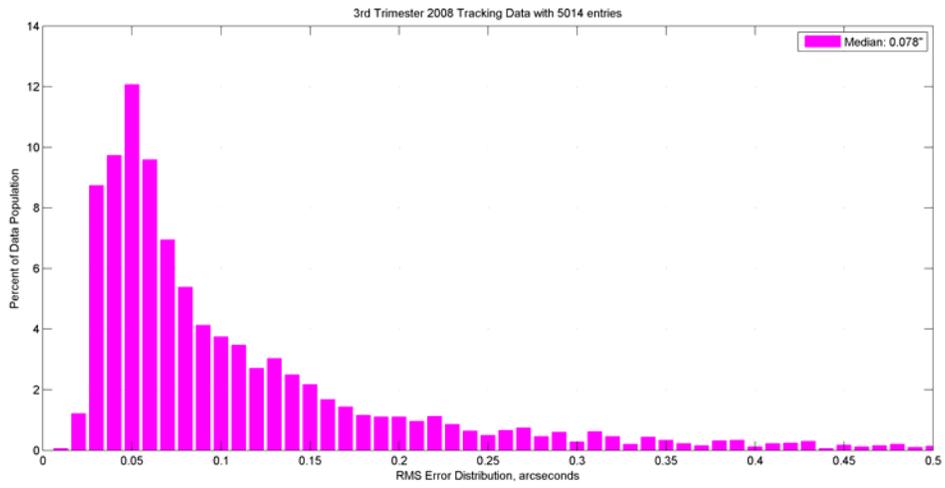
RMS Tracking Error

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

Min	Max	Median	Inter-quartile Range
0.0044	1.997	0.078	0.103

The inter-quartile range (IQR) 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 are a histogram and pie chart of the RMS error distribution for the data population.

3rd Trimester 2008 Tracking Data with 5014 entries

Median: 0.078"

IQR: 0.103"

Tracking Error Totals

	0..0.075"
	0.075..0.100"
	0.100..0.150"
	0.150..0.200"
	0.200..0.500"
	0.500..1.000"

The peak to peak error histogram appears below:

3rd Trimester 2008 Tracking Data with 5014 entries

Median: 0.657"

Percent of Data Population

Peak to peak error, arcseconds

IQR: 1.081"

Peak-to-peak Error Distribution Box Plot
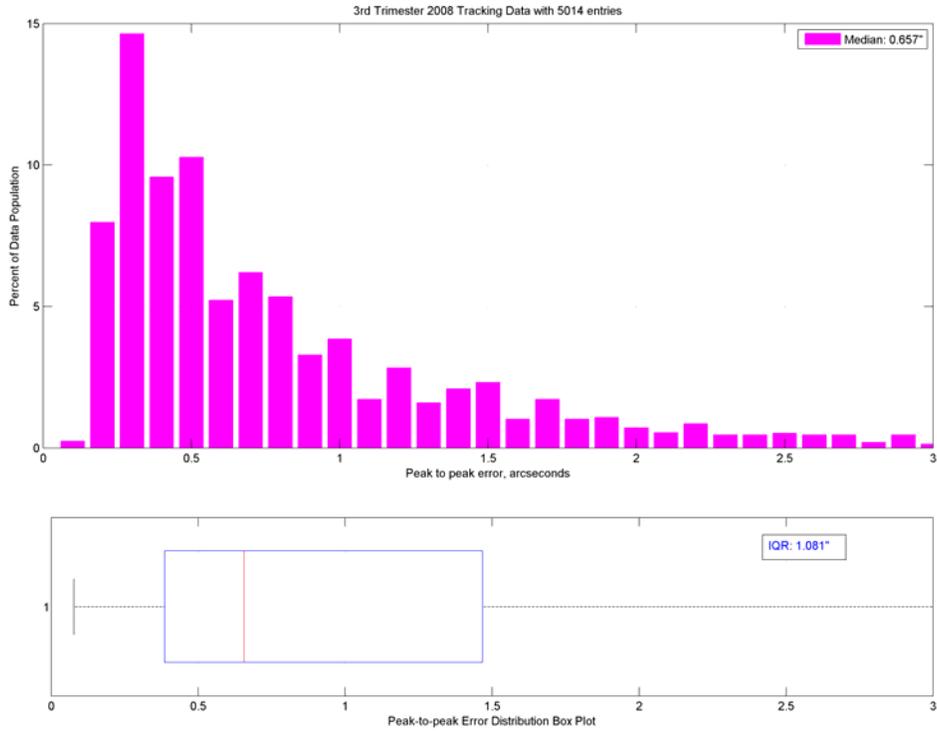
The boxplot routine records the outlier value for the RMS data as ~0.307", so guarding the data by exclusion of those entries removes 557 members from the data set. This changes the RMS error distribution somewhat; the median RMS error then becomes 0.069", with an IQR of 0.074". Clearly, there is still significant "tail" to the right of the median, seen below:

3rd Trimester 2008 Tracking Data with 4455 entries
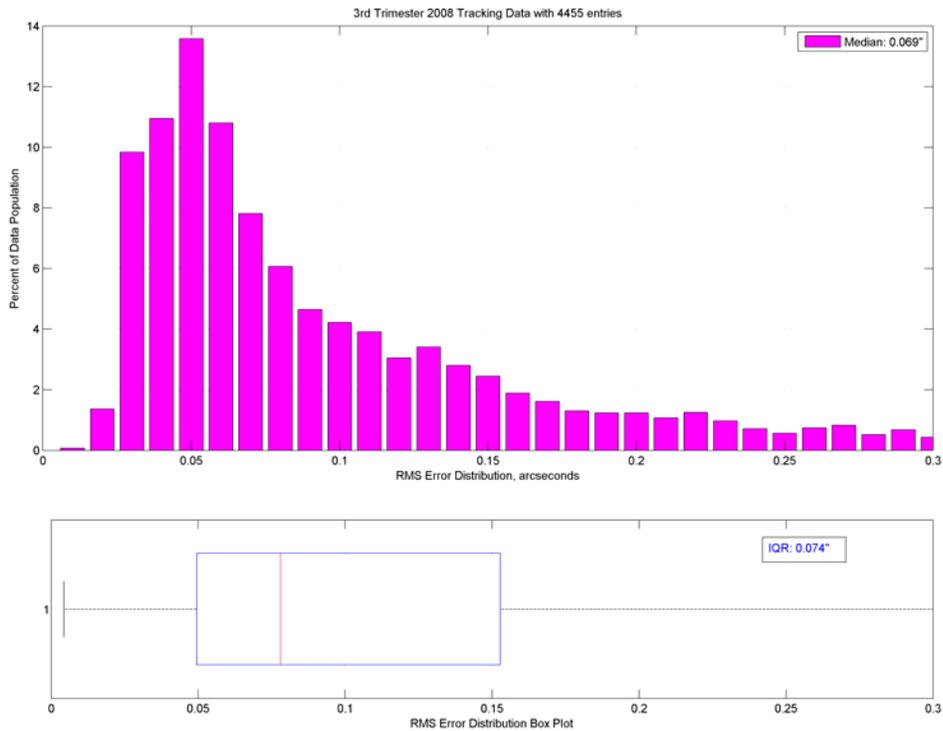
Error Distributions

Below are detailed analyses of the tracking error over variables of tracking rate, wind speed and direction, and telescope position, as in the previous report on the elevation axis.

The figure on the next page shows the RMS error for the entire data population, with the velocity for each entry signed by the tracking direction. Positive directions indicate tracking in azimuth clockwise from north, and negative directions indicate tracking past north due to the need to disambiguate the azimuth angle in the tracking software – the MMT has a ±270° azimuth range from the "repose", or zero-strain position in the utility cable maypole. Since the total azimuth motion exceeds 360°, the mount control software must distinguish the current angle in a unique way that prevents exceeding the cable wrap limit.
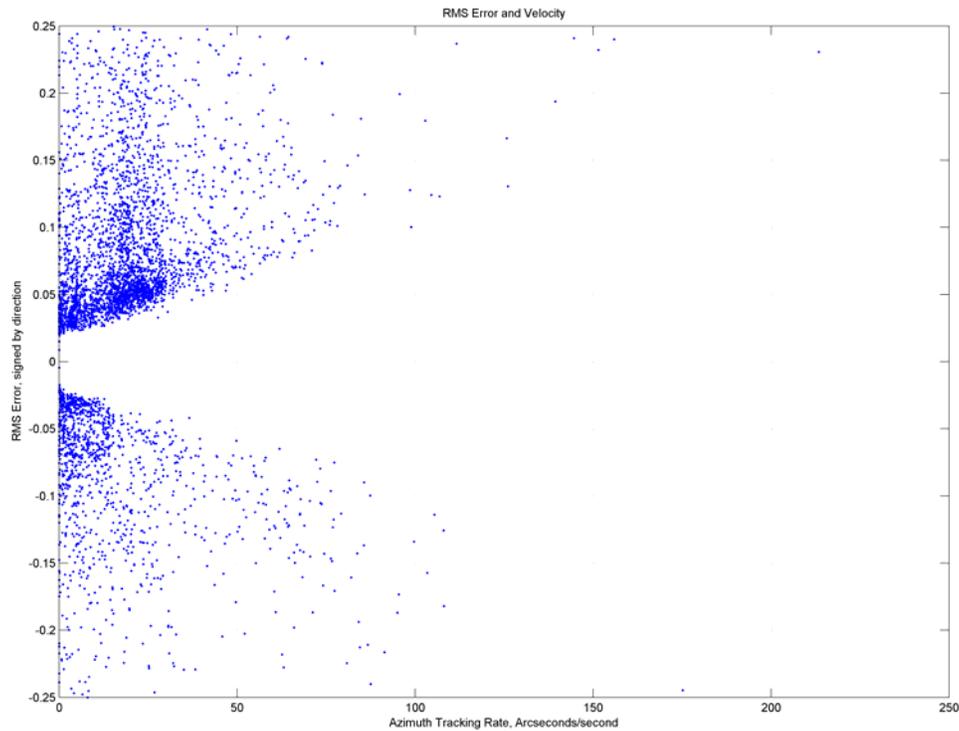
The azimuth tracking smoothness has a lower limit related to the absolute encoder quantization of 0.0386"/count that has a strong dependence on velocity. Further study is needed to understand the reasons for the tracking degradation over velocity seen above.

Next, we have the RMS error distributions over the azimuth position using both guarded and unguarded data. The distributions are influenced by not only the prevailing wind direction, but by the shape of the observing position(s) over the course of the trimester. However, it appears there is no particular advantage to favoring any azimuth over another from these data. There also appears to be little difference between using the guarded and unguarded data.

The 0th bin covers the azimuth range of 0 to 15° (1hr) in the bar plots below. A consequence of the matlab *bar* plot routine is that it centers the bar by the bin indices, not their edges. Each bar in the distribution plots is 1hr wide.

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Tracking Error Distribution over Azimuth, Unguarded Data

Tracking Error Distribution over Azimuth, Guarded Data
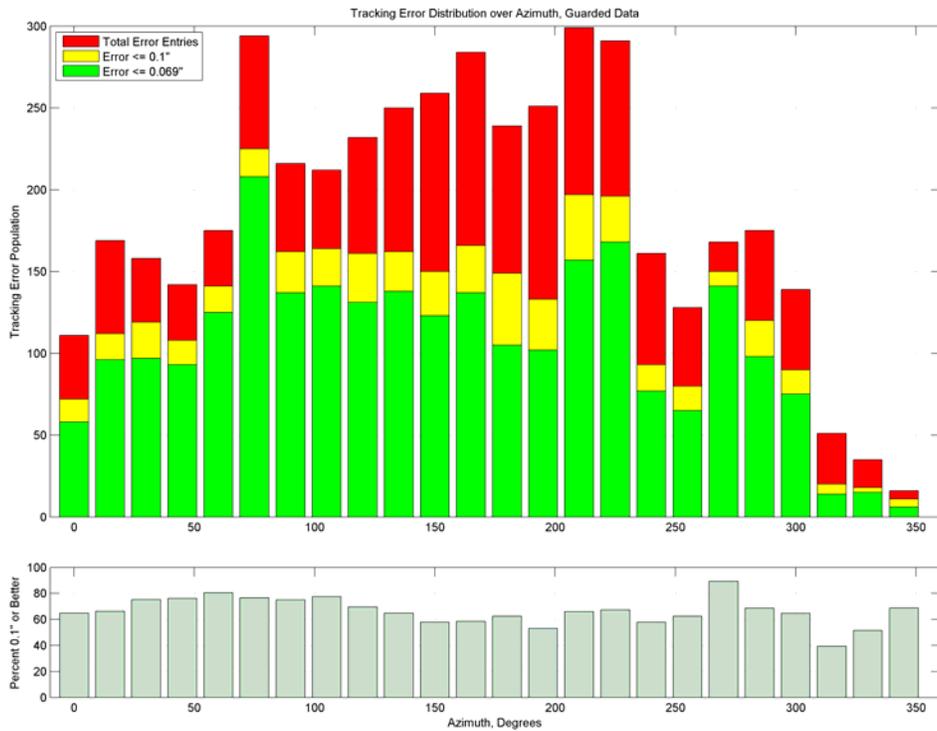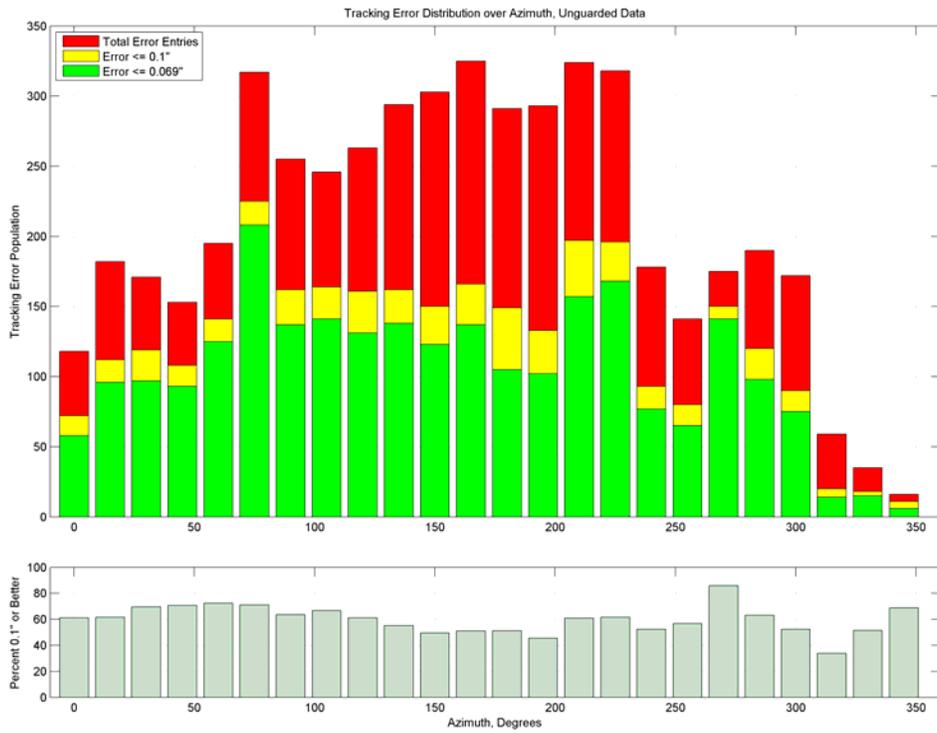
To investigate the influence of the elevation angle on the azimuth tracking error, we have the histograms below. The degradation in tracking performance at higher elevations (implying higher azimuth velocities) is consistent with the velocity-dependence figure above.
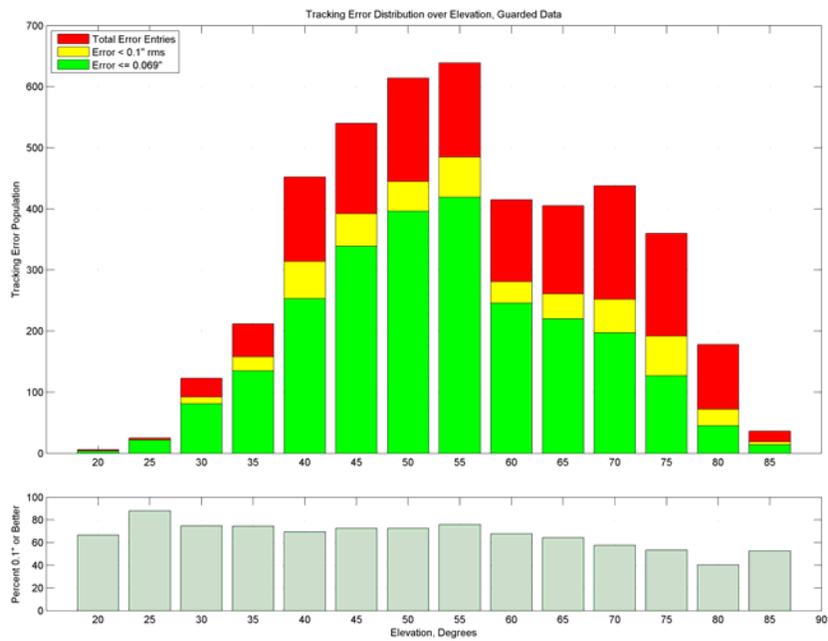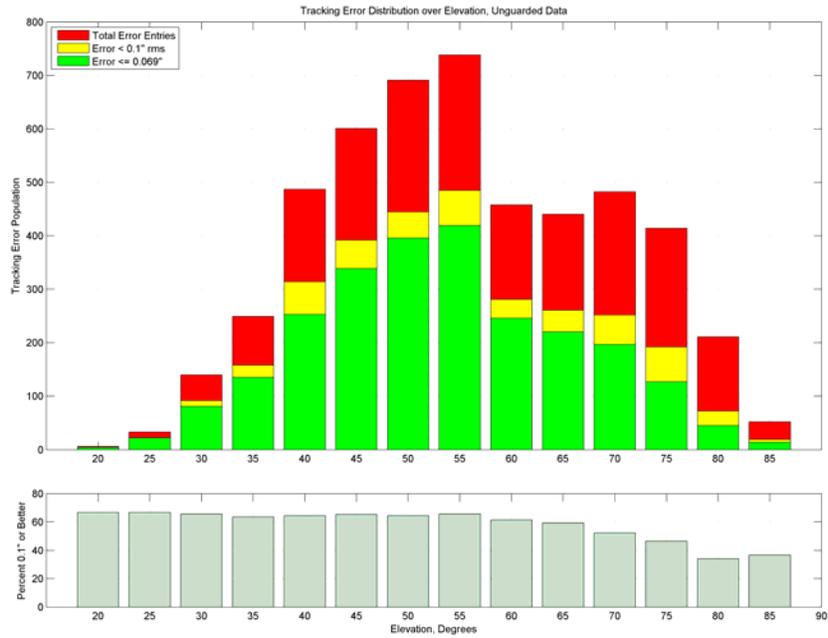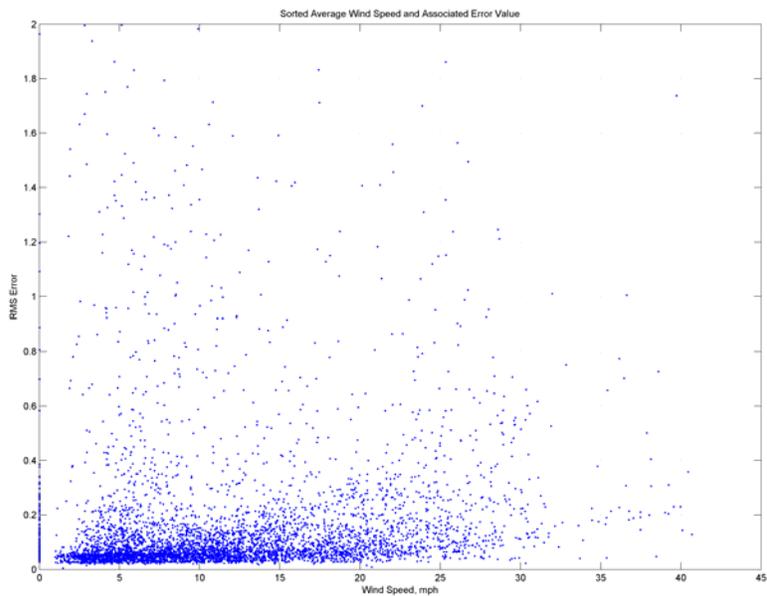
Wind Influence on Tracking

We repeat the wind-intensity rose plot from the elevation report below; the length of the bars is the total population at that azimuth angle, while the colors represent the velocity distribution for each azimuth:
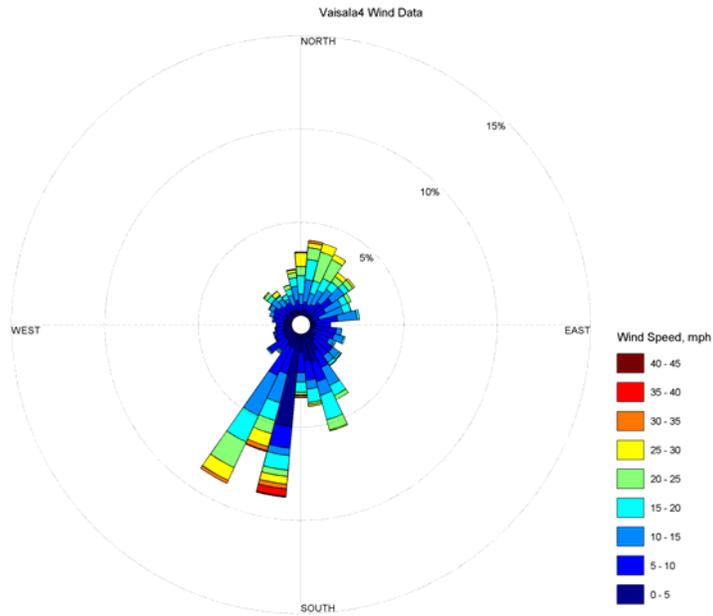

Below, we have the wind speed data points sorted by magnitude, and their associated RMS tracking error:

Clearly, poor tracking was experienced over all wind speeds, and there are relatively few instances of tracking data entries where the wind speed was more than about 35mph. Much of this can be explained by the tracking data collection triggering issue discussed in the elevation report; the rest will need more careful study.

Below, we have the RMS error distribution over wind speed, for both unguarded and guarded data:
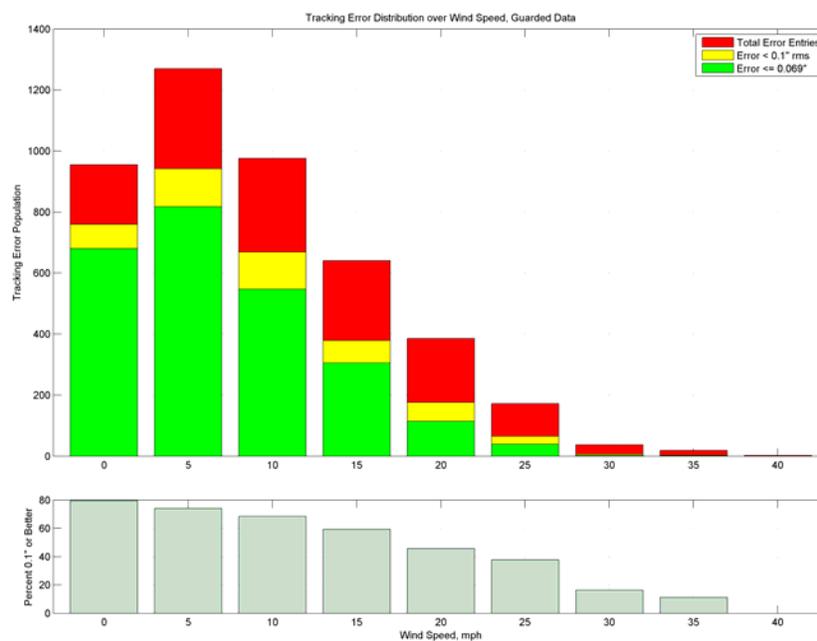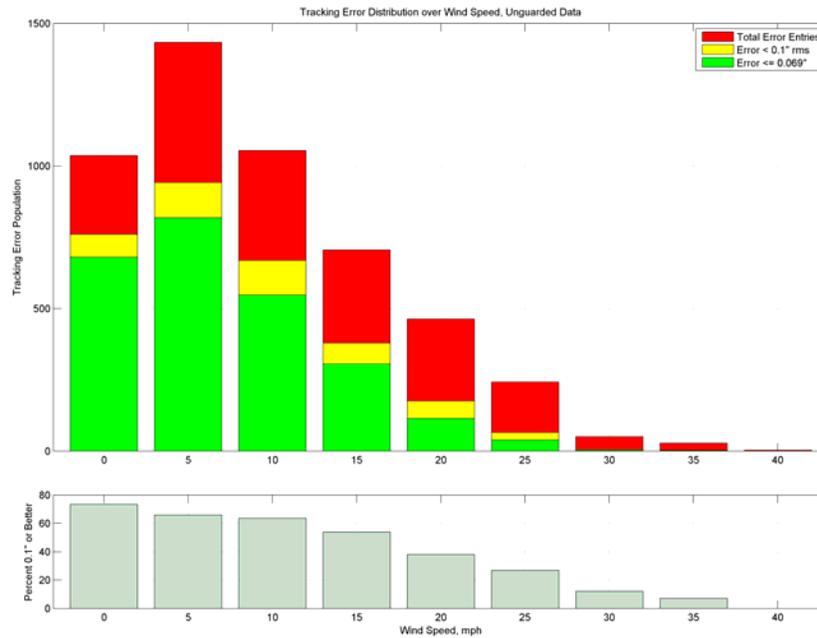
The relative wind azimuth, e.g. the absolute difference between the average wind direction and telescope azimuth, constrained to the domain of 0 to 180°, is used to produce the histograms below for the RMS error over the wind direction:
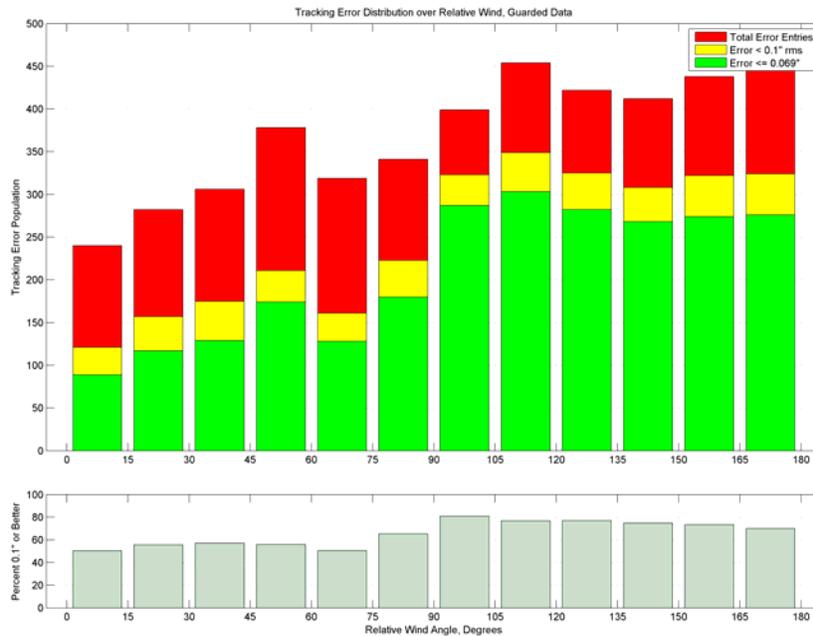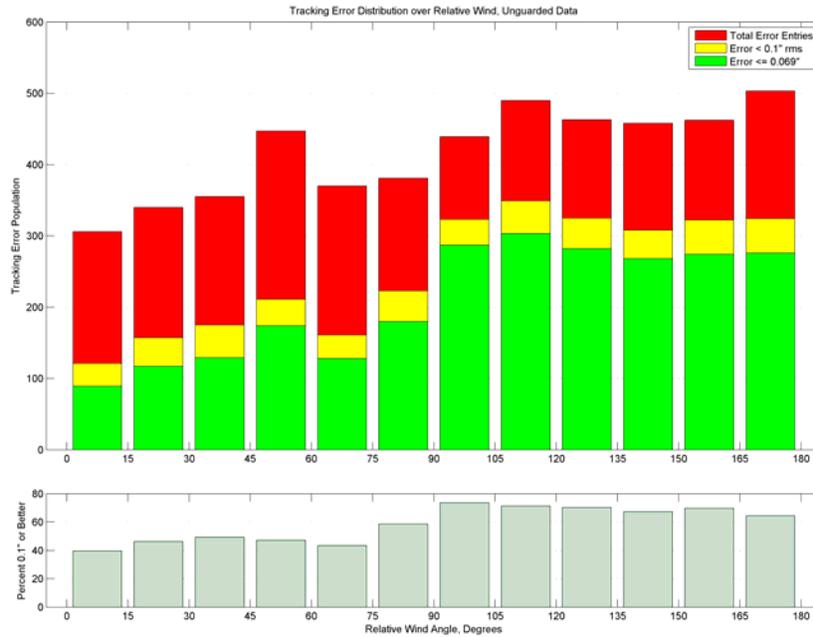
Finally, consider the following 3-D plots that join the RMS error over wind angle, wind speed, and azimuth position, using the full unguarded data populations:
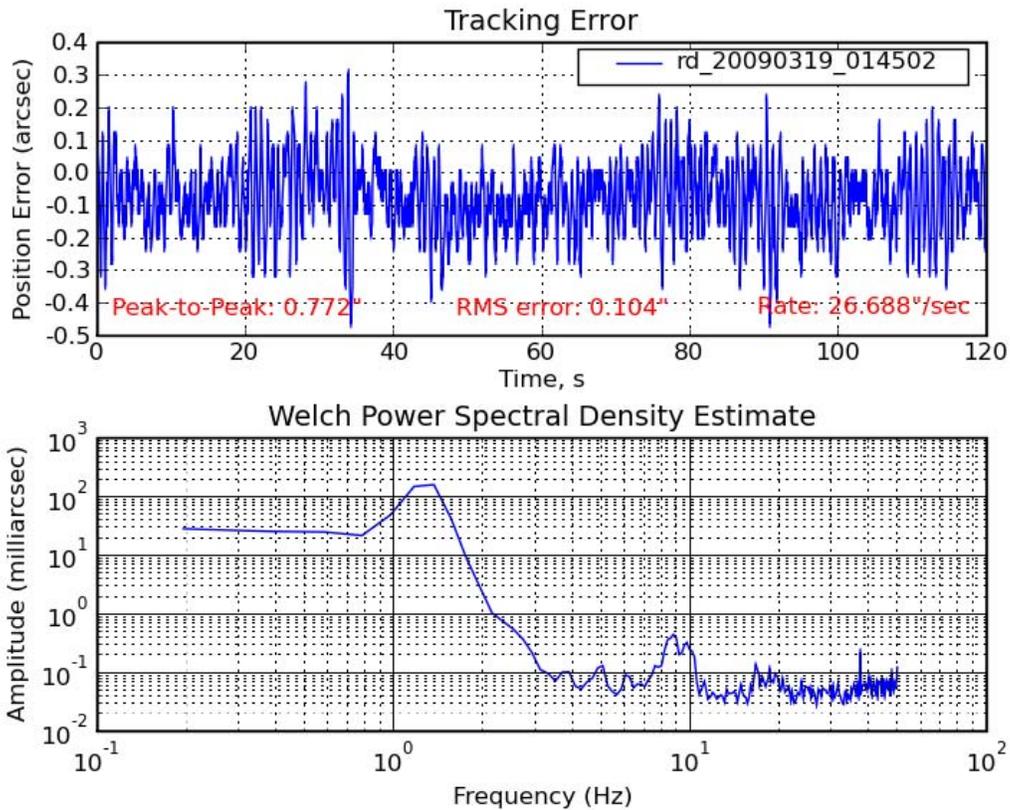

Error Distribution Over Relative Azimuth and Wind Speed, Unguarded Data

Error Distribution Over Relative Wind Angle and Azimuth Position, Unguarded Data
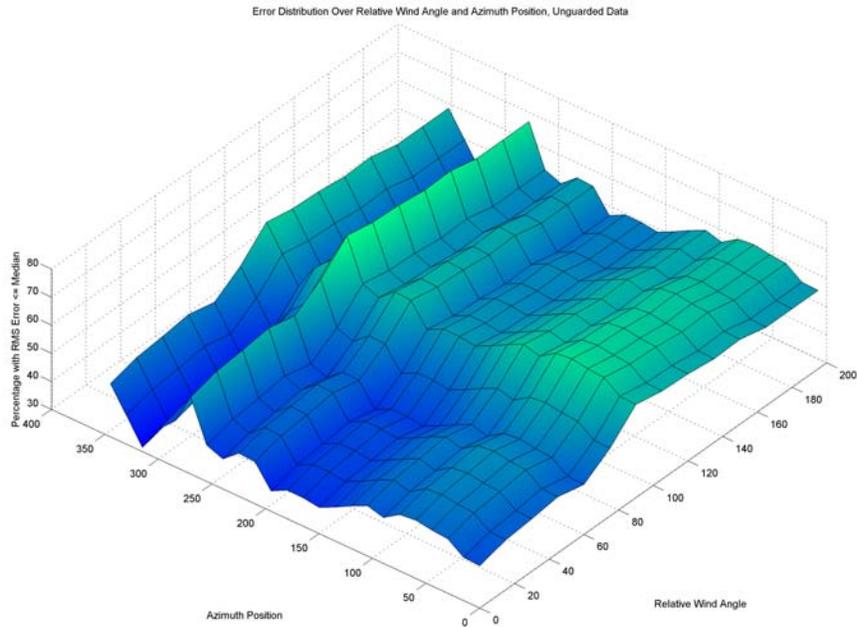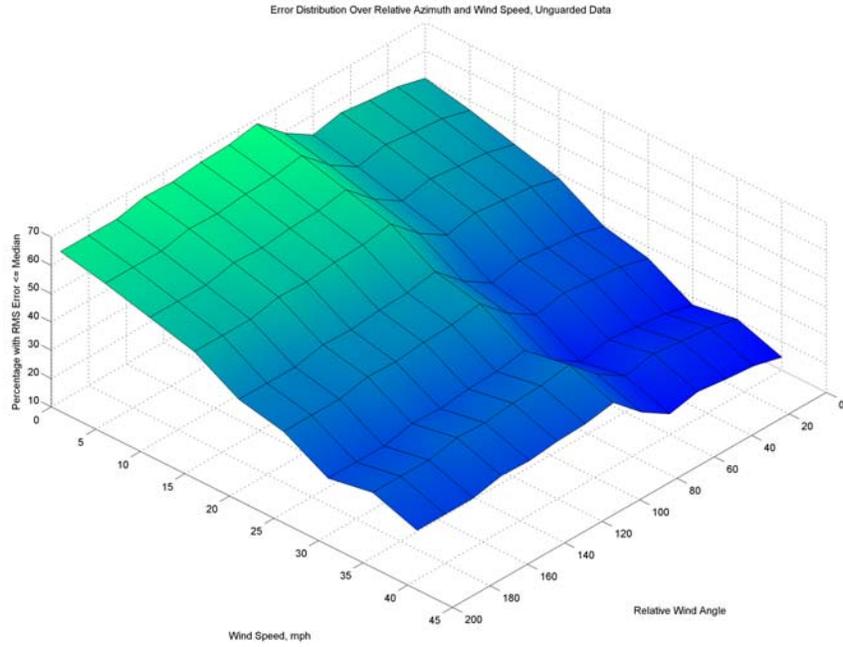
For the above, the difference between using guarded versus unguarded data was considered too subtle to be useful so those graphs are excluded.

Remarks

The azimuth controller is known to have considerable low-frequency gain peaking. The connection between this closed-loop gain peaking and tracking error is shown by inspection of the closed-loop servo Bode plot from testing reported in MMTO Internal Technical Memorandum #03-5:
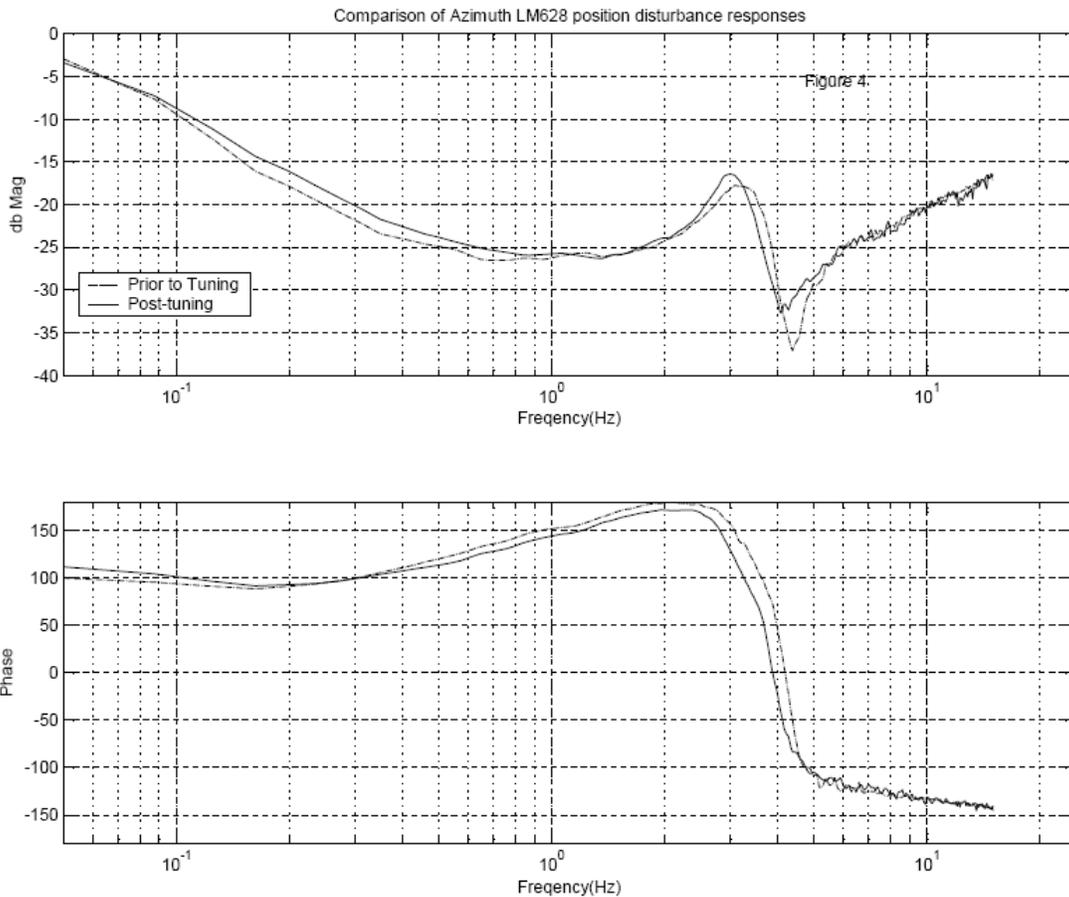
Now compare the disturbance response shape to the shape of the position error PSD (Power Spectral Density) from one of our routine tracking-data logging files, shown below:

Tracking Error — rd_20090319_014502

Peak-to-Peak: 0.772"   RMS error: 0.104"   Rate: 26.688"/sec

Welch Power Spectral Density Estimate

As can be seen here, a large part of the tracking error budget is oscillatory in nature. This jitter, excited in part by external influences (mainly wind), helps explain why the RMS error histogram exhibits nearly twice the IQR as the elevation axis (0.103" versus 0.056"), but is perhaps not the whole story. Recall that the loop tuning has been changed since the 2003 report; it is suspected that the current azimuth closed-loop response shape now includes a peak at ~1.5Hz. There currently exists no way within the mount control software for the azimuth and rotator axes to perform closed-loop frequency response measurements as is available for the new elevation servo. Revival of the ancient DSA-based measurements will be necessary to confirm this.

Conclusion

The azimuth tracking for the 3rd trimester of 2008 was at median of ~0.07", ±0.05". Wind shake remains an issue, with tracking degradation becoming significant above 10-15mph. There is a lower limit to tracking smoothness that exhibits a strong dependence on the tracking velocity. There is clear evidence of gain peaking, excited by wind buffeting, contributing noticeable jitter to the tracking error budget. Observing angles away from the prevailing wind direction tend to be more favorable, as earlier reported.

Further study for the reasons for poor tracking over all wind speeds, as well as detailed investigation of the reasons for the increasing error over increasing tracking velocity is

warranted. An effort to quantify and prepare the azimuth axis for servo upgrades should be mounted.

We plan to regularly repeat this series of reports.