Attachment 1. Baselining Analysis 2012

Baselining Analysis 2012

Discovery Across Texas Project

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External Version

1. INTRODUCTION

The Center for Commercialization of Electric Technologies (CCET) was awarded contract DE-OE0000194 by the Department of Energy to perform the Discovery Across Texas demonstration project. Electric Power Group, LLC (EPG) received a subaward from CCET to provide professional services to perform, among other things, a substation cluster analysis, comparison of phasor data versus state estimator data, and voltage and angle difference baselining. The goal of this particular analysis was to, using 2012 data: (1) group substations having Phasor Measurement Units (PMUs) which are geographically close to each other and perform a voltage and angle difference analysis for each group (cluster analysis); (2) perform a comparison of voltage and angle differences obtained using phasor measurements versus similar results using state estimator data (phasor vs. state estimator comparison); and, (3) perform a baseline analysis for voltages and angle differences for selected pairs of substations. Alarm limits will be established and documented based on the baseline analysis.

2. PROJECT SCOPE

A. Cluster Analysis

Activities to be performed as part of this item:

1. Obtain state estimator data from ERCOT, solve cases received and extract data for analysis.
2. Group geographically close substations equipped or to be equipped with PMUs.
3. Using state estimator data analyze voltage angle differences for these groups and document results for two selected days of 2012.
4. Prepare voltage angle difference graphs for the selected substations and pairs.
5. Summarize results.

B. Phasor versus {tate 9stimator /omparison

Activities to be performed as part of this item:

1. In addition to state estimator data from ERCOT obtained for part (1) above, obtain phasor data from ERCOT, download it, down-sample to one sample per second and process it for analysis.
2. Use extracted phasor and state estimator data to develop comparison graphs for phasor and for state estimator results. Comparison was performed for three days in 2012: August 1 (peak load), November 23 (low load), and December 25 (high wind output). For days where both data was not available, a third day, December 2, was selected for comparison.
3. Summarize results.

C. Baseline !nalysis for ±oltage and !ngle 5ifferences

Analyze historical performance of ERCOT grid, using State Estimator data plus phasor data to identify normal and abnormal voltages and angle limits across the grid. In this analysis, EPG leveraged its experience in performing similar analyses for CAISO in California and four Independent System Operators (ISOs) in the Eastern Interconnection. Activities to be performed as part of this item:

1. Develop and utilize software to process provided state estimator (SE) data and extract key metric information (i.e., voltage, angles and angle differences).
2. Analyze extracted data and develop baseline understanding of voltage, phase angle and angle difference patterns for key substations and key pairs of substations. Substations were selected based on current or projected availability of PMUs at those substations.
3. Monitor voltages and angle differences (pairs) and develop patterns and statistics in the form of box-whisker plots and load duration curves. Substations selected for analysis of voltages are listed in Table 1 below and pairs of substations selected for analysis of angle differences are listed in Table 2 below.
4. Prepare baselining analysis results for the selected substations and pair of substations as excel spreadsheet and charts, including:
   a. Voltage statistics (mean, maximum and minimum).
   b. Voltage phase angle difference statistics (mean, maximum and minimum).
   c. Voltage and phase angle distribution functions.
5. Prepare baselining analysis summary for discussion with ERCOT and the Synchrophasor Team.

D. Establishing Alarm Limits for Use in Operations

Based on the baselining analysis, recommend key substations and angle pairs for monitoring in Real Time Dynamics Monitoring System[1] (RTDMS), and recommend voltage and angle difference alarm settings for use in RTDMS to alert operators when grid stress is approaching limits. Guidelines will be linked to observed metrics using synchrophasor data and corresponding operator actions. EPG will leverage experience gained from analysis performed on phasor and SE data to establish alarm limits for a California utility in establishing alarm limits for use in the ERCOT RTDMS.

This section will not be completed in this report. A massive number of new 345 kV lines will be added to the ERCOT system in 2013 as part of the CREZ project, changing significantly the distribution of power among the existing and future transmission lines. This will result in change in limits for voltages, voltage angles, and particularly angle differences. Recommending alarm limits based in 2012 results will not be practical. EPG will conduct an analysis with 2013 data to determine the voltage and angle difference limits that will be more likely to represent current and future system conditions. Voltage and angle difference limits for use by operators will be recommended once the 2013 analysis is completed.

3. DATA SOURCES

Two sources of data were utilized to perform the analysis of voltage and angle differences in the ERCOT network: phasor data and state estimator cases. A description of these sources of data is provided below.

A. Phasor Data

[1] ®Electric Power Group. Built upon GRID-3P platform, US Patent 7,233,843, US Patent 8,060259, and US Patent 8,401,710.

Initially, ERCOT, the Synchrophasor Team, and EPG agreed to use data for the 12 months of 2012. ERCOT provided EPG phasor data for these 12 months with a resolution of 30 samples per second. EPG downloaded the phasor data provided by ERCOT via hard drive and using an in-house software tool, down-sampled the data received to 1 sample per second. Due to the amount of data this process took several days to complete.

A program was developed by EPG to extract the data and compile it into a summary table, and two series of graphs. One graph (box-whisker) shows daily summaries of data, and the other time duration curves, shows values versus percent time for each study variable. The time duration curves were used to obtain the metric values corresponding to 1% and 99% exceedance (the value which was less than 1% plus inflection or greater than 99% minus inflection).

Phasor Measurement Units (PMUs) Installed and Planned in ERCOT

As of January 30, 2013 there were 26 PMUs installed in 19 locations across the ERCOT service area. Also there are another 44 PMUs planned for installation in the future at 14 additional locations.

The base analysis completed with 2012 data included state estimator data analysis for locations for which PMUs are installed and for which PMUs are planned. However, six of the locations are new and therefore there was no state estimator data available for those substations or pair of substations that included any one of these six new substations.

PMU Commitment Status

As of January 30, 2013

TDSP	PMU Signal Name	PMU Station Name	Number of PMUs In-Service	Additional PMUs Planned	Voltage (kV)	Existing or New Substation
AEP	Line 1	West 10	1		69	Existing
AEP	Line 1	Coast 1	1		138	Existing
AEP	Line 1	South 14		1	138	Existing
AEP-ETT	Line 1	West 14	1		345	Existing
AEP-ETT	Line 2	West 14	1		345	Existing
AEP-ETT	Line 3	West 14	1		345	Existing
AEP-ETT	Line 4	West 14	1		345	Existing
AEP-ETT	Line 1	West 15		1	345	New
AEP-ETT	Line 1	West 16		1	345	New
AEP-ETT	Line 1	West 3		1	345	New
AEP	Line 1	FarWest 9	1		138	Existing
AEP	Line 1	Coast 4	1		345	Existing
AEP	Line 2	Coast 4		1	345	Existing
AEP	Line 3	Coast 4		1	345	Existing
AEP	Line 1	West 4	1		138	Existing
AEP	Line 2	West 4	1		138	Existing
AEP	Line 3	West 4	1		138	Existing
AEP	Line 4	West 4		1	138	Existing
AEP	Line 1	South 6		1	138	Existing
AEP	Line 1	Coast 2		1	69	Existing
AEP	Line 1	South 10		1	138	Existing
AEP	Line 1	Coast 3	1		345	Existing
AEP	Line 2	Coast 3	1		345	Existing
ONCOR	Line 1	FarWest 7	1		345	Existing
ONCOR	Line 1	West 6	1		345	Existing
ONCOR	Line 1	FarWest 4	1		345	Existing
ONCOR	Line 1	North 7	1		138	Existing
ONCOR	Line 1	North 4	1		138	Existing
ONCOR	Line 1	North 5	1		138	Existing
ONCOR	Line 1	North 6	1		138	Existing
ONCOR	Line 1	North 2	1		138	Existing
ONCOR	Line 1	FarWest 8	1		138	Existing
ONCOR	Line 1	West 11	1		345	Existing
ONCOR	Line 1	West 9		1	345	Existing
ONCOR	Line 1	West 12		1	345	
ONCOR	Line 1	West 5		1	345	Existing
ONCOR	Line 1	West 1		7	345	Existing
ONCOR	Line 1	West 2		4	345	Existing
ONCOR	Line 1	North 1	1		345	Existing
Sharyland	Line 1	South 13	1		138	Existing
Sharyland	Line 2	South 13	1		138	Existing
Sharyland	Line 1	West 13		1	345	New
Sharyland	Line 1	West 17		1	345	New
LCRA	Line 1	South 2		4		Existing
LCRA	Line 1	South 4		3		Existing
LCRA	Line 1	South 7		1		Existing
LCRA	Line 1	South 9		3		Existing
LCRA	Line 1	South 11		2		Existing
LCRA	Line 1	South 15		5		Existing
			In-Service	**Planned**	**Total Planned & In-Service**	
	Totals	**PMUs**	**26**	**44**	**70**	
		Locations	**19**	**20**	**39**	

B. State Estimator (SE) Data

As per the case of phasor data, ERCOT provided EPG SE data for the 12 months of 2012. EPG used the Power World simulator provided by ERCOT via Power World, to extract about 16,000 SE cases. There were several days for which SE data was not available as shown below:

<u>Dates for which SE data was not available</u>

1/10/2012 – 1/17/2012	8 days
1/25/2012	1 day
2/01/2012 – 3/13/2012	13 days
5/03/2012 – 7/08/2012	67 days
9/13/2012 – 9/17/2012	5 days
9/28/2012 – 10/01/2012	4 days
10/05/2012 – 10/09/2012	5 days
10/24/2012 – 10/31/2012	8 days
11/04/2012 – 11/06/2012	3 days
Total	114 days

Estimate of SE availability: 2.7 cases per hour of data available

C. Data Availability

Data availability for phasor data source varied from substation to substation; the summary table of phasor-based results shows the percent viability for each substation or each pair analyzed. As shown in Table A-1, availability varies from substation to substation and ranges from 10.4% for FarWest 7 and North 1 to greater than 95% for North 4, North 5, North 6, North 7, FarWest 4 and West 6. Box whisker plots in Appendix C provide a view of data availability on a day by day basis.

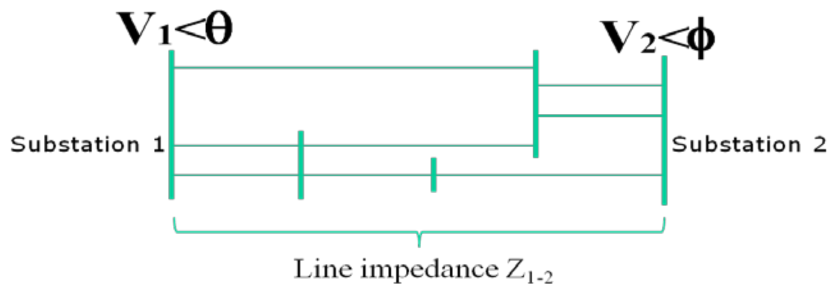
Data availability for state estimator data was low. ERCOT produces state estimator cases every 5 minutes for a total of 105,120 possible cases per year. EPG received about 16,000 cases which represent about 15.22 % data availability. Even though SE cases were available approximately 15.2% of the time, SE data was not available all of this time. The availability of SE data was approximately 13%.

Below a summary of phasor data availability from Table A-1 below:

<40%	41% to 60%	61% to 80%	>80%
West 14	West 4	West 11	West 10
North 1	Coast 4	Coast 1	North 7
Coast 2	Coast 3	FarWest 8	North 2
South 6	South 13		North 4
FarWest 7	FarWest 9		North 5
			West 6
			North 6
			FarWest 4

4. CLUSTER ANALYSIS

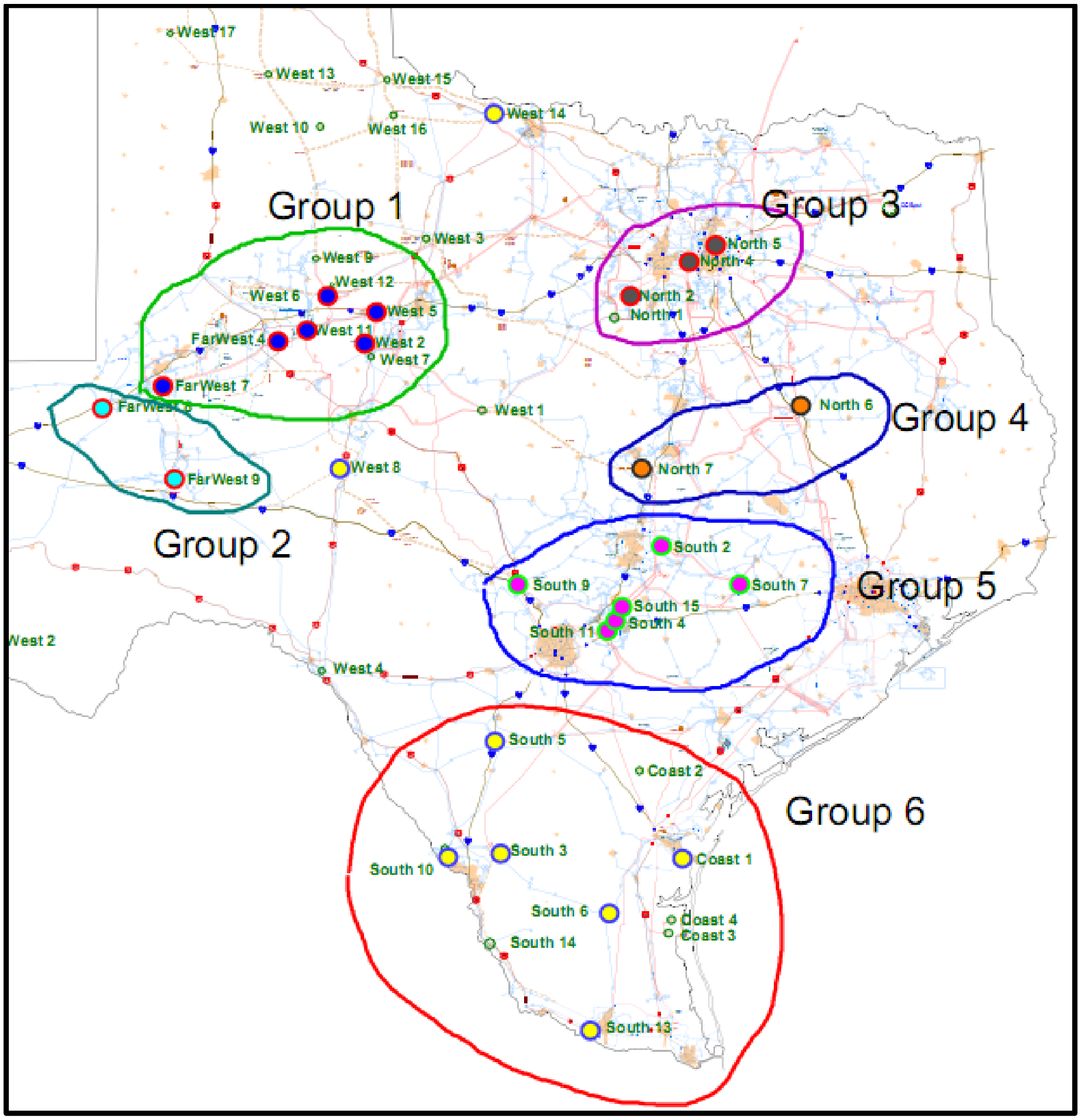
Phase angles differences are indicators of power flow and direction. Power flow follows voltage angle difference as per the following diagram and equation:



Power flow: $P = V_1 V_2 \sin(\theta - \phi)/Z$

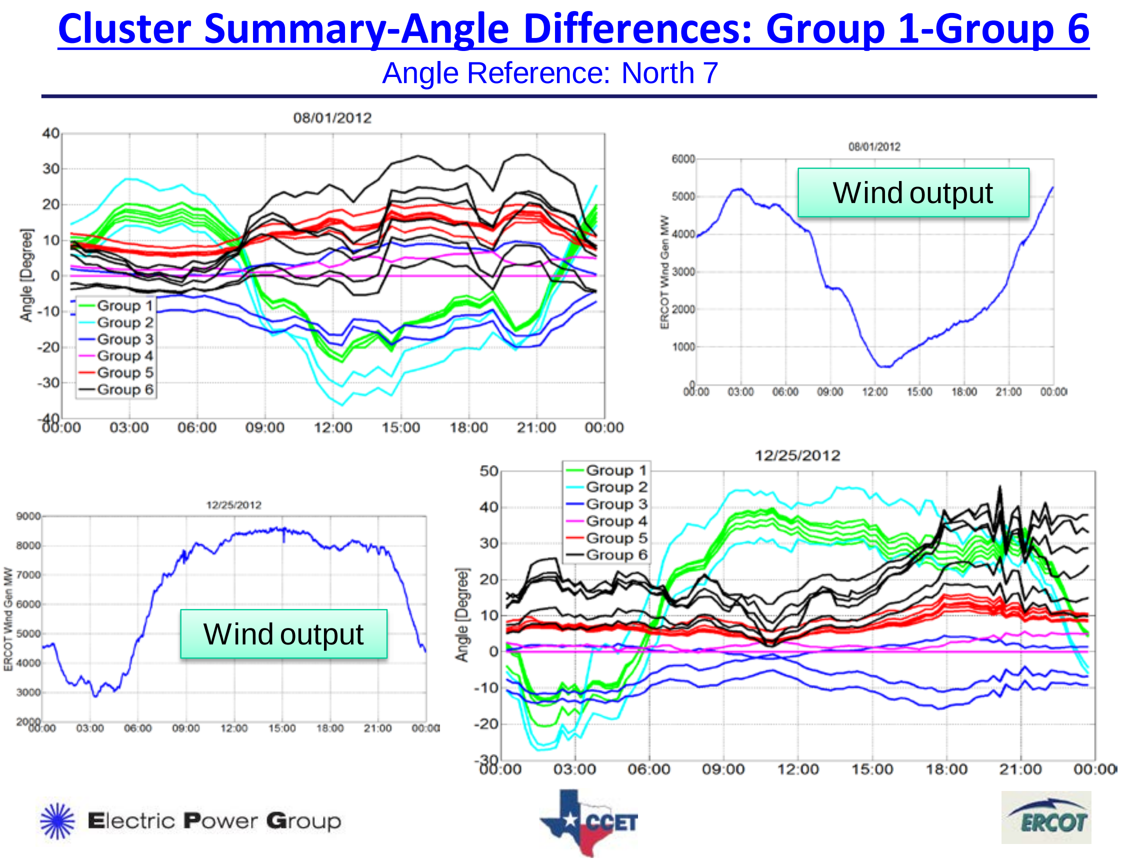
Any change in Power flow or impedance will be reflected in a change in voltage phase angle difference between two locations.

EPG grouped substation based on geographical proximity as shown in the map and table below in order to find trends regarding angle differences referenced to North 7.



GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6
a. FarWest 4	a. FarWest 8	a. North 2	a. North 6	a. South 2	a. Coast 1
b. FarWest 7	b. FarWest 9	b. North 4	b. North 7	b. South 4	b. South 3
c. West 2		c. North 5		c. South 7	c. South 5
d. West 5				d. South 9	d. South 6
e. West 6				e. South 11	e. South 10
f. West 11				f. South 15	f. South 13

A summary of angle difference plots by groups is shown below:



Review of this graph shows that the angle differences for the substations in Groups 1 and 2, which are close to the wind farms follow the pattern of the wind output shown next to the angle difference curves. Further, it appears that the angles for the substations in Groups 1 and 2, referenced to North 7, turn negative for wind output levels of about 4,000 MW or less. Of course this may change depending on where wind farms are developed in the state or what wind farms are online. Note also the high range in angle difference for the days analyzed for the substations in Groups 1 and 2, it fluctuates from -35 degrees when wind output is low to approximately 45 degrees when wind output is at max.

The angles for the substations in Group 6 under low wind conditions share similar patterns but are separated from each other by several degrees, this is a reflection from the fact they are also physically separated and subject to different levels of generation and load.

More detailed information for each group is presented in Appendix A attached to this report.

5. COMPARISON OF PHASOR DATA WITH STATE ESTIMATOR DATA – DATA QUALITY

The results obtained using SE data received from the ERCOT were compared against those obtained using phasor data at one sample per second. Phasor data was compared with SE data by plotting results for the following three days:

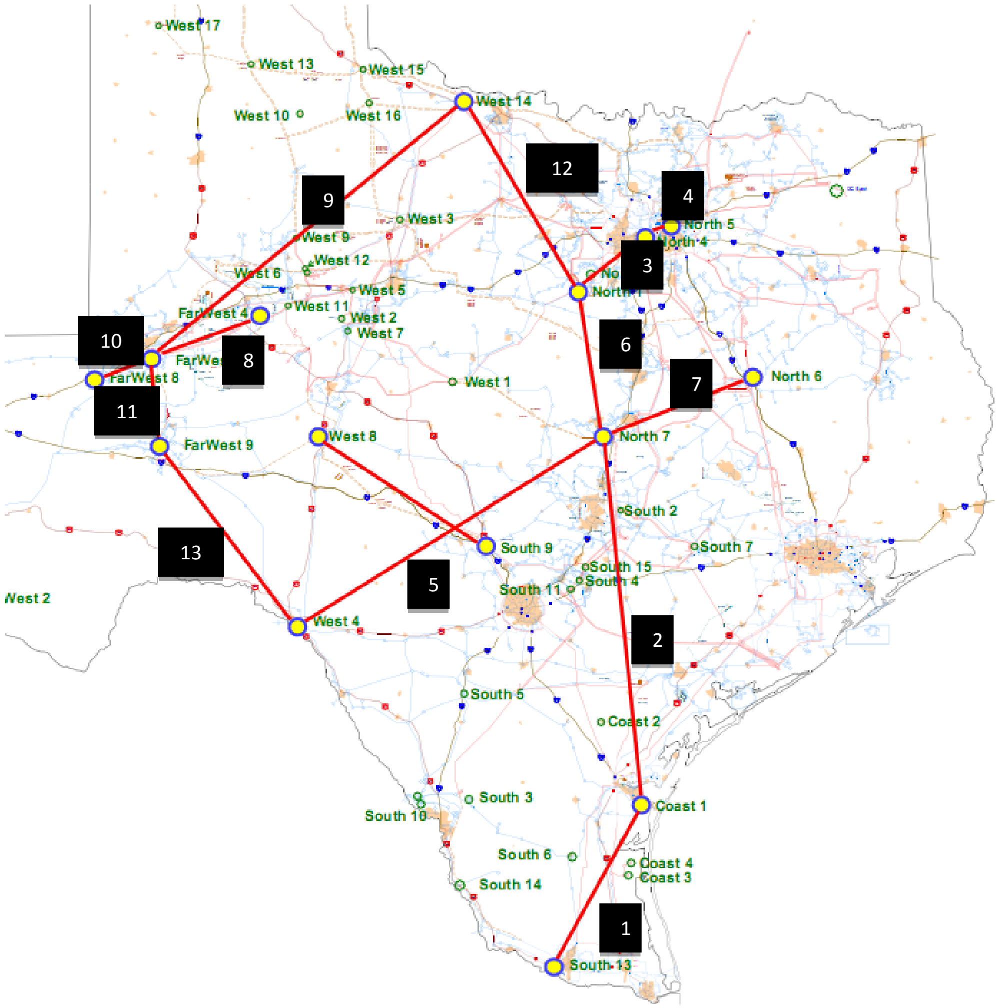
1. August 1, 2012 – Peak load day
2. November 23, 2012 – Low load day
3. December 25, 2012 – Maximum wind Day

This comparison was performed for the following 13 pairs of substations:

Index	Substation A	Substation B
1	Coast 1	South 13
2	Coast 1	North 7
3	North 1	North 4
4	North 4	North 5
5	West 4	North 7
6	North 7	North 1
7	North 7	North 6
8	FarWest 7	FarWest 4
9	FarWest 7	West 14
10	FarWest 7	FarWest 8
11	FarWest 7	FarWest 9
12	West 14	North 1
13	FarWest 9	West 4

The location of these pairs is shown in the map below.

Location of Angle Pairs with PMUs in service



Individual comparison can be seen in the Appendix B attached to this report. State estimator data was available except for the cases for West 4 and FarWest 4. Data for these two stations was either not available, partially available, or the names of the substation changed for some of the cases provided. When possible, EPG made an effort to obtain data for those substations for which the name had been changed.

The results of this comparison indicate that the results obtained with phasor data track very well with those obtained using SE data. It seems that the PMUs under analysis are reasonable well calibrated.

Observation of the graphs in Appendix B which show phasor data for only three out of 365 days indicate that that there was no phasor data for North 1 for two of the three days. For the day that was available (December 25, 2012), the phasor data coordinated reasonable well with the SE data (within one degree). One reason why there was no data for the two days is because the availability of phasor data at North 1 was the lowest of all active PMUs. The availability for North 1 was only 10.4%. North 1 is located in a central location near Dallas; it is desirable to have high availability and high quality phasor data at this substation, it does not have the first but seems to have the second characteristic.

Similarly, FarWest 7 PMU had no data for either August 1 or November 23 and as in the case of North 1 is was because the data availability for this PMU was also only 10.4%. Phasor data was available for December 2 and the phasor data for this day coordinated reasonable well with state estimator data. There was no SE data for December 25. FarWest 7 is located near the wind farms and is very desirable to have as much phasor data for this location to track system variables with wind output.

Further observation of Appendix B graphs shows that for West 4 phasor data was not available on November 23 and was available only five hours for December 25. It was available on peak load day, August 1, and tracked very well with SE data this day. The data availability for West 4 for 2012 was 41.3%.

6. BASELINE ANALYSIS FOR VOLTAGE AND ANGLE DIFERENCES

The baseline analysis for voltages and angle differences was performed using the phasor data and state estimator data obtained from ERCOT for 2012. This data was processed to extract voltage magnitude and voltage angles. Min and max for these variables were documented in summary tables; box–whiskers plots and time duration curves were developed for each variable and for each type of data used. Below is an analysis of voltage magnitudes and voltage angles.

7. METHODOLOGY

For the pairs selected for study, the following work was performed:

1. Obtain and process phasor data and state estimator data.
2. Extract information to identify max, min and average values from these data sources. Prepare summary tables showing results of all data, including data saved during events.
3. Use phasor and SE data to develop weekly box-whisker graphs and time duration curves for angle differences.
4. Identify limits corresponding to normal operation; excluding events and outages. To exclude extreme values corresponding to outliers and to events, values corresponding to the metrics exceeding 1% and 99% percent of the time were identified for the entire study period, to be identified as normal operating limits. A summary showing these normal operation limits were obtained using phasor and SE data and tabulated in the same table for comparison.
5. Analyze results, identify limits, and report results for each pair selected.

8. STUDY APPROACH

Electric Power Group used the following approach:

1. Obtain available phasor data and state estimator data from ERCOT.
2. Extract phasor data and condition it for processing.
3. Solve state estimator cases and save solved cases.

4. Select substations and angle pairs of interest to ERCOT and the synchrophasor team members choosing substations that have or soon will have PMUs installed.
5. Identify the substations and subset of substations and pairs for which phasor data is available.
6. Develop statistical charts including time duration curve and box-whisker graphs for voltage magnitudes and angles and for angle pairs.
7. Perform statistical analysis to identify angle differences limits for the pairs selected under all conditions. Summarize angle difference limits.
   - Establish limits for normal operation based on the criteria described in the corresponding methodology. Summarize angle difference limits.
   - The limits for angle differences identified in this report shall be compared with ERCOT's criteria, if any, that apply to angle differences for the paths selected for this study.

9. BASELINE ANALYSIS FOR VOLTAGES MAGNITUDES

A. Substations Identified For Voltage Monitoring

EPG in consultation with ERCOT and the Synchrophasor team identified the following substations for monitoring.

	Table 1		SUBSTATIONS
	FOR VOLTAGE MONITORING		
	SUBSTATION	kV	REGION
1	West 10	69	Panhandle
2	West 14	345	Panhandle
3	West 11 Switch	345	Central
4	West 6	345	Central
5	North 7	138	Central-East
6	North 2	138	Dallas
7	North 4	138	Dallas
8	North 5	138	Dallas
9	North 1	345	Dallas
10	North 6	138	East
11	West 4	138	SouthWest
12	Coast 1	138	Valley
13	South 13	138	Valley
14	Coast 3	345	Valley
15	Coast 4	345	Valley
16	FarWest 8	138	West Texas
17	FarWest 9	138	West Texas
18	FarWest 4	345	West Texas
19	FarWest 7	345	West Texas
20	West 16*	345	Panhandle
21	West 17*	345	Panhandle
22	West 13*	345	Panhandle
23	West 15*	345	Panhandle
24	West 8*	345	Central
25	West 1*	345	Central
26	West 2*	345	Central
27	West 3*	345	Central
28	West 9*	345	Central
29	West 12*	345	Central
30	West 5*	345	Central
31	South 15*	345	Central
32	FarWest 2*	69	Central-East
33	South 2*	345	Central-East
34	South 4*	345	Central-East
35	South 7*	345	Central-East
36	South 9*	345	Central-East
37	South 11*	345	Central-East
38	Coast 2*	69	Valley
39	South 3*	138	Valley
40	South 5*	138	Valley
41	South 6*	138	Valley
42	South 10*	138	Valley

B. Analysis of Data and Results

Data availability was approximately 13% for all SE cases; phasor data availability varies from bus to bus. As shown in the Table A-1 below phasor data availability varies from substation to substation and ranges from 10.4% for FarWest 7 and North 1 to greater than 95% for North 4, North 5, North 6, North 7, FarWest 4and West 6.

Table A-1 below summarizes the min, max, and average values for voltage magnitude for the selected substations. The maximum voltage spreads observed were: 29.5 kV at the Coast 4 345 bus and 19.9 kV at the West 4 138 kV bus. The maximum voltage observed were: 368.91 kV at Coast 4 and 152.46 kV at West 4. The highest average voltages observed were: 357.3 kV at West 2 and 142.27 kV at South 6.

The voltage spreads and actual voltages obtained from phasor data were lower than those form state estimator data. However they also indicate that the highest spreads and voltages occurred at Coast 4 and West 4. As in the case of SE data results, phasor data indicates the highest average 138 kV voltage occurred at South 6 with 142.51 kV. The highest 345 kV voltage occurred at West 14 at 357.62 kV. No phasor data was available for West 2.

The summary shown in Table A-1 below shows the results for all data, including events and outages. EPG made an attempt to exclude values corresponding to events and outages by isolating the values that lie in the lower one percent and in the higher 1 percent plus minus a point f inflection in the time duration curve. The values in these regions are assumed to be extreme values resulting from outage or events. The results are summarized in Table A-2 below.

Table A-1 _ ERCOT DISCOVERY ACROSS TEXAS PROJECT - SUMMARY OF VOLTAGE MAGNITUDES - ALL DATA JANUARY 1 TO DECEMBER 31, 2012

				PHASOR DATA					STATE ESTIMATOR DATA			
No	Substation	Base kV	Region	Min	Max	Average	Max-Min Spread	Percent Data Available	Min	Max	Average	Max-Min Spread
1	West 10	69	Panhandle	68.00	74.68	71.18	6.68	84.43	66.99	71.64	69.33	4.7
2	West 14	345	Panhandle	346.64	366.44	357.62	19.80	33.82	348.07	364.84	357.09	16.8
3	West 11	345	Central	344.28	359.24	353.04	14.96	77.72	346.17	361.28	355.01	15.1
4	West 6	345	Central	343.80	360.44	353.37	16.64	96.11	346.73	364.08	356.04	17.4
5	North 1	345	Dallas	341.28	354.29	349.75	13.01	10.37	340.69	358.94	349.64	18.3
6	North 2	138	Dallas	137.38	144.64	141.55	7.26	94.04	138.01	142.37	140.30	4.4
7	North 4	138	Dallas	138.68	144.12	141.99	5.44	96.61	137.34	147.26	141.65	9.9
8	North 5	138	Dallas	137.94	145.68	141.04	7.74	96.42	136.92	148.05	139.82	11.1
9	North 6	138	East	137.76	144.32	141.73	6.56	95.70	137.57	144.82	141.61	7.3
10	North 7	138	Central-East	138.08	145.08	142.34	7.00	96.03	135.35	144.93	140.96	9.6
11	West 4	138	SouthWest	133.30	147.48	141.76	14.19	41.27	132.52	152.46	141.38	19.9
12	Coast 2+	69	Valley	66.56	72.92	70.15	6.36	39.61	65.81	72.33	69.67	6.5
13	Coast 1	138	Valley	138.44	144.60	142.27	6.16	61.92	132.78	144.93	141.58	12.2
14	Coast 4	345	Valley	342.00	367.44	354.25	25.45	40.21	339.45	368.91	354.48	29.5
15	Coast 3	345	Valley	342.37	362.88	353.91	20.51	47.96	339.10	368.36	354.39	29.3
16	South 6+	138	Valley	138.08	149.08	142.51	11.00	24.05	138.40	145.07	142.27	6.7
17	South 13	138	Valley	135.76	146.60	141.91	10.84	40.64	135.53	145.69	141.75	10.2
18	FarWest 4	345	West Texas	347.16	360.56	354.31	13.40	95.52	344.59	363.15	355.63	18.6
19	FarWest 7	345	West Texas	341.75	354.57	350.52	12.82	10.37	342.79	360.59	351.78	17.8
20	FarWest 8	138	West Texas	137.36	145.48	138.56	8.12	73.53	135.41	143.00	139.80	7.6
21	FarWest 9	138	West Texas	133.84	146.48	141.25	12.64	51.65	134.84	148.92	141.00	14.1
22	West 16*	345	Panhandle	No phasor data available. PMUs are planned for installation at these substations.					NOT IN SERVICE			
23	West 17*	345	Panhandle						NOT IN SERVICE			
24	West 13*	345	Panhandle						NOT IN SERVICE			
25	West 15*	345	Panhandle						NOT IN SERVICE			
26	West 8*	345	Central						342.58	364.29	353.39	21.7
27	West 1*	345	Central						343.17	363.08	354.00	19.9
28	West 2*	345	Central						346.59	366.11	357.30	19.5
29	West 3*	345	Central						NOT IN SERVICE			
30	West 9*	345	Central						346.93	365.53	356.67	18.6
31	West 12*	345	Central						NOT IN SERVICE			
32	West 5*	345	Central						346.59	365.77	356.78	19.2
33	South 15*	345	Central						347.86	361.80	355.65	13.9
34	FarWest 2*	69	Central-East						66.93	72.33	69.32	5.4
35	South 2*	345	Central-East						345.90	360.77	353.85	14.9
36	South 4*	345	Central-East						348.69	361.42	355.97	12.7
37	South 7*	345	Central-East						345.52	366.15	354.01	20.6
38	South 9*	345	Central-East						342.31	364.29	353.69	22.0
39	South 11*	345	Central-East						348.52	360.97	355.50	12.5
40	South 3*	138	Valley						138.25	148.81	142.51	10.6
41	South 5*	138	Valley						135.90	145.74	141.61	9.8
42	South 10*	138	Valley						138.54	144.90	141.84	6.4

Note: The availability of state estimator cases was in the order of 13%. One substation, West 8, had an availability of only 3.3%. We believe this to be an anomaly, ERCOT to provide feedback. The two substations with + came on line during the second half of 2012 and the substations with * did not have PMUs installed in 2012.

TABLE A-2_CCET_DISCOVERY ACROSS TEXAS - LIMITS FOR VOLTAGES - NORMAL CONDITIONS

			Phasor Data			State Estimator Data								SE Data		
No.	Bus Names	Base kV	Normal Min	Normal Max	Max-Min Spread	Normal Min-100%	100% or POI	99% Min	99% - POI	1% Max	1% + POI	Normal Max-0%	0% or POI	Normal Min	Normal Max	Max-Min Spread
1	West 10	69	68.0	72.40	4.40	67.05	99.99%	68.09	98.99%	70.64	1.01%	71.59	0.01%	67.05	71.59	4.55
2	West 14	345	346.6	361.40	14.76	348.43	100.00%	351.89	99.00%	360.22	1.01%	363.97	0.01%	348.43	363.97	15.54
3	West 11	345	344.3	356.50	12.22	347.38	99.99%	351.62	98.99%	358.04	1.01%	360.92	0.01%	347.38	360.92	13.55
4	West 6	345	343.8	358.20	14.40	347.61	99.99%	351.02	98.99%	360.31	1.03%	363.32	0.03%	347.61	363.32	15.71
5	North 1	345	341.3	353.40	12.12	342.54	99.99%	344.89	98.99%	355.09	1.02%	358.78	0.02%	342.54	358.78	16.24
6	North 2	138	137.4	143.70	6.32	138.04	99.99%	138.83	98.99%	141.49	1.01%	142.34	0.01%	138.04	142.34	4.29
7	North 4	138	138.7	143.70	5.02	137.34	100.00%	138.71	99.00%	143.37	1.01%	146.08	0.01%	137.34	146.08	8.74
8	North 5	138	137.9	143.00	5.06	137.11	99.97%	138.02	98.97%	141.46	1.01%	145.66	0.01%	137.11	145.66	8.56
9	North 6	138	137.8	143.40	5.64	138.95	99.98%	140.20	98.98%	142.92	1.11%	144.49	0.11%	138.95	144.49	5.54
10	North 7	138	138.1	144.20	6.12	135.75	99.99%	137.90	98.99%	143.47	1.01%	144.80	0.01%	135.75	144.80	9.05
11	West 4	138	133.3	146.50	13.21	133.27	99.98%	136.81	98.98%	145.54	1.02%	151.60	0.02%	133.27	151.60	18.32
12	Coast 2+	69	66.6	72.92	6.36	65.81	100.00%	67.26	99.00%	71.50	1.05%	72.12	0.05%	65.81	72.12	6.31
13	Coast 1	138	138.4	144.10	5.66	138.83	99.99%	139.91	98.99%	143.97	1.01%	144.85	0.01%	138.83	144.85	6.02
14	Coast 4	345	342.0	362.40	20.40	341.07	99.99%	347.69	98.99%	362.07	1.01%	368.81	0.01%	341.07	368.81	27.74
15	Coast 3	345	342.4	361.50	19.13	340.84	100.00%	347.36	99.00%	361.72	1.11%	366.89	0.11%	340.84	366.89	26.06
16	South 6+	138	138.08	144.50	6.42	139.51	99.99%	140.60	98.99%	143.67	1.01%	145.06	0.01%	139.51	145.06	5.55
17	South 13	138	135.8	144.20	8.44	137.06	99.98%	138.76	98.98%	144.03	1.01%	145.59	0.01%	137.06	145.59	8.53
18	FarWest 4	345	347.2	357.70	10.54	345.27	99.98%	352.29	98.98%	358.57	1.01%	362.57	0.01%	345.27	362.57	17.30
19	FarWEst 7	345	341.7	353.90	12.15	343.25	99.99%	346.22	98.99%	356.89	1.01%	359.88	0.01%	343.25	359.88	16.62
20	FarWest 8	138	137.4	144.30	6.94	136.22	99.99%	137.34	98.99%	142.05	1.01%	142.92	0.01%	136.22	142.92	6.70
21	FarWest 9	138	133.8	144.10	10.26	136.13	99.97%	138.05	98.97%	143.11	1.05%	147.68	0.05%	136.13	147.68	11.55
22	West 16*	345	NOT IN SERVICE													
23	West 17*	345	NOT IN SERVICE													
24	West 13*	345	NOT IN SERVICE													
25	West 15*	345	NOT IN SERVICE													
26	West 8*	345				342.85	100.00%	345.01	99.00%	362.57	1.02%	364.29	0.02%	342.85	364.29	21.44
27	West 1*	345	N/A			343.77	99.99%	346.72	98.99%	359.73	1.01%	363.03	0.01%	343.77	363.03	19.26
28	West 2*	345				348.15	99.99%	352.15	98.99%	361.14	1.01%	365.70	0.01%	348.15	365.70	17.55
29	West 3*	345	NOT IN SERVICE													
30	West 9*	345	N/A			348.24	99.99%	351.60	98.99%	361.72	1.03%	364.86	0.03%	348.24	364.86	16.62
31	West 12*	345	NOT IN SERVICE													
32	West 5*	345				347.36	99.99%	351.93	98.99%	360.66	1.03%	364.10	0.03%	347.36	364.10	16.74
33	South 15*	345				348.26	99.99%	350.38	98.99%	360.04	1.01%	361.60	0.01%	348.26	361.60	13.34
34	FarWest 2*	69				66.93	100.00%	67.74	99.00%	71.16	1.01%	72.32	0.01%	66.93	72.32	5.39
35	South 2*	345				346.30	99.98%	348.21	98.98%	358.20	1.02%	360.34	0.02%	346.30	360.34	14.04
36	South 4*	345				348.82	100.00%	350.78	99.00%	360.15	1.00%	361.42	0.00%	348.82	361.42	12.60
37	South 7*	345	N/A			346.17	99.98%	348.04	98.98%	361.66	1.02%	365.80	0.02%	346.17	365.80	19.63
38	South 9*	345				343.11	99.95%	346.27	98.95%	360.04	1.01%	364.21	0.01%	343.11	364.21	21.10
39	South 11*	345				349.44	99.99%	350.82	98.99%	359.55	1.01%	360.77	0.01%	349.44	360.77	11.33
40	South 3	138				138.30	100.00%	140.34	99.00%	145.88	1.01%	148.55	0.01%	138.30	148.55	10.25
41	South 5*	138				136.52	99.99%	138.24	98.99%	144.15	1.01%	145.47	0.01%	136.52	145.47	8.95
42	South 10*	138				138.59	99.99%	139.73	98.99%	143.86	1.01%	144.85	0.01%	138.59	144.85	6.25

Note: The two substations with + came on line during the second half of 2012 and the substations with * did not have PMUs installed in 2012.

Note that the voltage spreads at Coast 4 - 345 kV and West 4 - 138 kV buses are down to 27.74 and 18.32 kV respectively. For each SE data and phasor data, box-whisker plots and time duration curves were developed for each of the substations listed above and were used to obtain the values in the Table A-2 above. Summaries of SE-based voltage angle pairs with their corresponding box-whisker and time duration curves as well as summaries of phasor-based voltage angle pairs with their corresponding box-whisker and time duration curves are presented in Appendix C.

C. Observations

a. Data availability: the availability for state estimator data was approximately 13%; for phasor data was greater overall but varied from 10.37% at FarWest 7 to 96.61% at North 4. Ten out of twenty one substations had data availability greater than 70%

b. Maximum voltages obtained from phasor data were overall lower than those obtained with state estimator data; however, the average voltages were within 1% from each other with the only exception being West 10 whose state estimator average voltage was 97.4% of that obtained with phasor data..
c. Both phasor data and state estimator data point to West 4 and Coast 4 as having the highest voltage and voltage spread in their class. Voltage at these substations is more volatile than at the other substations. Note Coast 3 also has high voltage spread but South 13 and South 6 which are in the neighborhood have a much lower spread.
d. Fifteen substations out of a total of forty one show voltage spreads of higher than 15 kV and 24 substations show voltage spreads higher than 10 kV
e. Voltage spreads for normal conditions went down by up to 5 kV (phasor) from those under all conditions.

D. Proposed Alarm Limits for Voltages

The limits summarized in the two tables above will change due to the massive addition of new 345 kV lines in the ERCOT system in 2013. EPG will update these results with the data collected in 2013 and then develop alarm limits for recommendation to ERCOT.

E. Criteria to Set Alarm Limits For Voltages

At the time when EPG has all 2013 data, EPG will use the voltage results from the SE data as the main source of information for determining alarm limits. Also, EPG will establish alarm limits only for those substations that have or will soon have PMUs associated with them as listed in the table in section 6-A.

The following criteria are proposed to be used to later determine the alarm limits for the substations selected for analysis.

a. Determine four alarm limits for voltages: two based on maximum values obtained from SCADA data results and from System Operating Bulletin 17 (SOB-17) and the other based on minimum values obtained from the SCADA data results and from SOB-17.
b. For high voltages, the Maximum Alarm value shall represent the highest voltage, and the Maximum Alert shall represent the second highest voltage, based on the following selection criteria:
    i. Based on SE results, the voltage which is exceeded only 1 % of the time, if the box-whisker and time duration plots show no extreme values (outliers or values due to events in the system). If extreme values or outliers are present, a point of inflection will be determined, and the alarm will be based on the voltage corresponding to the time represented by the point of inflection plus 1% of time, based on the time duration curve.
    ii. The maximum voltage pre-established by ERCOT operations.
c. For low voltages, the minimum alarm value shall represent the lowest voltage, and the minimum alert shall represent the second lowest voltage, based on the following selection criteria:
    i. Based on SE results, the voltage which is exceeded 99 % of the time, if the box-whisker and time duration plots show no extreme values (outliers or values due

to events in the system). If extreme values or outliers are present, a point of inflection will be determined, and the alarm will be based on the voltage corresponding to the time represented by the point of inflection minus 1% of time, based on the time duration curve.

  ii. The minimum voltage pre-established by ERCOT operations.

d. Phasor data will be used for voltage alarm limits if necessary.

10. BASELINE ANALYSIS FOR VOLTAGE ANGLES (REFERENCE: North 7 Bus)

A. Substations Identified for Voltage Angle Analysis

The following substations were selected for voltage angle analysis; the substation selected as reference was North 7.

	Table 2 SUBSTATIONS FOR VOLTAGE ANGLE MONITORING		
	SUBSTATION	kV	REGION
1	West 10	69	Panhandle
2	West 14	345	Panhandle
3	West 11 Switch	345	Central
4	West 6	345	Central
5	North 2	138	Dallas
6	North 4	138	Dallas
7	North 5	138	Dallas
8	North 1	345	Dallas
9	North 6	138	East
10	West 4	138	SouthWest
11	Coast 1	138	Valley
12	South 13	138	Valley
13	Coast 3	345	Valley
14	Coast 4	345	Valley
15	FarWest 8	138	West Texas
16	FarWest 9	138	West Texas
17	FarWest 4	345	West Texas
18	FarWest 7	345	West Texas
19	West 16*	345	Panhandle
20	West 17*	345	Panhandle
21	West 13*	345	Panhandle
22	West 15*	345	Panhandle
23	West 8*	345	Central
24	West 1*	345	Central
25	West 2*	345	Central
26	West 3*	345	Central
27	West 9*	345	Central
28	West 12*	345	Central
29	West 5*	345	Central
30	South 15*	345	Central
31	FarWest 2*	69	Central-East
32	South 2*	345	Central-East
33	South 4*	345	Central-East
34	South 7*	345	Central-East
35	South 9*	345	Central-East
36	South 11*	345	Central-East
37	Coast 2*	69	Valley
38	South 3*	138	Valley
49	South 5*	138	Valley
40	South 6*	138	Valley
41	South 10*	138	Valley

B. Summary of Results – All Data Included

The voltage angle results obtained from all data available, all solved SE cases, and all phasor data are summarized in Table B-1 below.

These results were obtained using all data available including event and outage conditions; under these conditions, voltage angles would be expected to be larger than under normal conditions because during event and outages conditions the angles tend to increase to reflect the changes in system conditions or changes in system configuration. The maximum Max-Min spreads observed were 112.8 degrees for FarWest 9 138 kV substation and 87.7 degrees for West 11 345 kV substation. Note also that the substations close to the wind farms in groups 1 and 2 shown in yellow have over 80 degrees Max-Min spreads.

Table B-1: CCET DISCOVERY ACROSS TEXAS- BASELINING ANALYSIS - VOLTAGE ANGLES - ALL CONDITIONS (Reference: North 7)

			Phasor Data - 1/1/12 to 12/31/12					State Estimator Data - 1/1/12 to 12/31/12				
No	Angle Pair FROM - TO	Base kV	Min	Max	Average	Percent Positive	% Data Available	Min	Max	Average	Percent Positive	Max-Min Spread
1	West 10	69/138	-50.62	86.46	12.32	64.09	80.76	-28.51	28.34	2.81	64.31%	56.9
2	West 14	345/138	-30.47	51.50	7.85	71.45	31.78	-23.22	39.09	9.05	76.65%	62.3
3	West 11	345/138	-38.23	58.28	9.70	61.95	76.97	-31.81	56.01	12.55	67.98%	87.8
4	West 6	345/138	-35.80	57.41	11.45	66.36	95.24	-29.90	55.56	13.02	69.46%	85.5
5	North 1	345/138	-14.24	27.29	8.28	88.37	10.08	-14.55	31.48	9.48	89.13%	46.0
6	North 2	138	-19.38	26.35	4.13	70.45	93.11	-7.76	10.35	-0.87	29.72%	18.1
7	North 4	138	-22.68	21.60	-0.54	47.73	95.72	-21.23	21.44	0.70	55.43%	42.7
8	North 5	138	-24.71	19.82	-2.14	37.84	95.55	-23.62	19.56	-1.31	43.93%	43.2
9	North 6	138	-13.81	46.79	6.81	98.58	94.80	-5.17	20.77	7.04	98.92%	25.9
10	West 4	138	-45.26	34.93	-7.81	25.60	39.21	-33.40	22.27	-4.06	38.69%	55.7
11	Coast 2+	69/138	-22.42	22.92	-1.19	39.75	18.37	-27.54	23.55	0.79	54.64%	51.1
12	Coast 1	138	-39.23	54.52	8.06	76.87	60.29	-30.80	43.67	10.25	82.02%	74.5
13	Coast 4	345/138	-39.98	49.99	8.78	79.82	13.38	-29.65	50.16	11.37	84.36%	79.8
14	Coast 3	345/138	-29.61	55.00	7.41	74.96	43.91	-29.68	49.39	11.11	84.27%	79.1
15	South 6+	138	-35.85	36.26	6.01	70.64	22.60	-29.81	38.97	5.82	72.86%	68.8
16	South 13	138	-40.88	49.78	4.40	65.31	39.03	-35.35	50.24	6.80	71.58%	85.6
17	FarWest 4	345/138	-40.52	60.74	11.87	65.16	94.71	-31.74	57.44	13.27	68.16%	89.2
18	FarWest 7	345/138	-30.34	54.40	13.05	67.91	10.08	-37.07	54.99	10.51	64.72%	**92.1**
19	FarWest 8	138	-53.36	52.46	-0.96	48.35	72.29	-46.71	49.75	3.32	54.01%	96.5
20	FarWest 9	138	-67.76	86.98	7.92	57.32	49.62	-47.32	65.44	9.37	59.06%	**112.8**

No	Angle Pair FROM - TO	Base kV	Phasor Data	Min	Max	Average	Percent Positive	Max-Min Spread
19	West 16*	345/138	No phasor data available for these substations for 2012	NOT IN SERVICE IN 2012				
20	West 17*	345/138		NOT IN SERVICE IN 2012				
21	West 13*	345/138		NOT IN SERVICE IN 2012				
22	West 15*	345/138		NOT IN SERVICE IN 2012				
23	West 8*	345/138		-23.93	40.46	8.31	64.12%	64.4
24	West 1*	345/138		-26.45	47.04	9.52	68.03%	73.5
25	West 2*	345/138		-28.82	54.09	12.27	69.34%	82.9
26	West 3*	345/138		NOT IN SERVICE IN 2012				
27	West 9*	345/138		-29.90	55.56	13.00	69.43%	85.5
28	West 13*	345/138		NOT IN SERVICE IN 2012				
29	West 5*	345/138		-29.36	54.10	12.74	69.82%	83.5
30	South 15*	345/138		-7.68	18.78	4.00	86.89%	26.5
31	FarWest 2*	69/138		-15.18	7.87	-2.77	19.34%	23.1
32	South 2*	345/138		-2.44	16.93	5.70	98.37%	19.4
33	South 4*	345/138		-8.58	19.88	4.08	84.80%	28.5
34	South 7*	345/138		-3.35	20.21	6.71	96.98%	23.6
35	South 9*	345/138		-10.48	17.30	3.63	84.37%	27.8
36	South 11*	345/138		-10.00	20.79	4.13	83.30%	30.8
12	South 3*	138		-25.96	36.98	4.06	67.68%	62.9
13	South 5*	138		-24.34	19.00	-3.40	26.49%	43.3
16	South 10*	138		-28.50	26.26	-2.32	35.91%	54.8

Note: The two substations with + came on line during the second half of 2012 and the substations with * did not have PMUs installed in 2012.

C. Summary of Results – Normal Conditions (Events and Outages Excluded)

The voltage angle results obtained from excluding extreme values based on analysis of the box-whiskers plots and time duration curves are shown in Table B-2 below.

Table B-2: CCET DISCOVERY ACROSS TEXAS- BASELINING ANALYSIS - VOLTAGE ANGLES - NORMAL CONDITIONS
(Reference: 138 kV North 7)

			DATA RESULTS														
			Phasor-Normal			State Estimator Data									SE Data-Normal		
No	Angle Pair FROM - TO	Base kV	Min Angle	Max Angle	Max-Min Spread	Percent Positive	Min Angle at POI or 100%	Percent (POI or 100%)	Min Angle at 99% or POI - 1%	Percent (99% or POI - 1%)	Max Angle at 1% or POI +1%	Percent (1% or POI +1%)	Max Angle at POI or 0%	Percent (POI or 0%)	Min Angle	Max Angle	Max-Min Spread
1	West 10	69	-42.66	74.90	117.6	64.31%	-27.18	99.99%	-14.48	98.99%	20.70	1.00%	28.34	0.00%	-27.18	28.34	55.5
2	West 14	345	-25.30	39.97	65.3	76.65%	-21.73	99.98%	-14.99	98.98%	31.14	1.01%	38.71	0.01%	-21.73	38.71	60.4
3	West 11	345	-34.48	56.02	90.5	67.98%	-31.81	100.00%	-24.79	99.00%	47.41	1.08%	54.43	0.08%	-31.81	54.43	86.2
4	West 6	345	-31.53	51.34	82.9	69.46%	-29.90	100.00%	-22.81	99.00%	46.71	1.08%	53.51	0.08%	-29.90	53.51	83.4
5	North 1	345	-13.47	23.04	36.5	89.13%	-13.46	99.98%	-8.02	98.98%	25.22	1.02%	31.48	0.02%	-13.46	31.48	44.9
6	North 2	138	-17.71	25.01	42.7	29.72%	-7.50	99.97%	-5.99	98.97%	7.13	1.01%	10.28	0.01%	-7.50	10.28	17.8
7	North 4	138	-19.82	19.41	39.2	55.43%	-19.96	99.96%	-15.44	98.96%	14.81	1.00%	21.44	0.00%	-19.96	21.44	41.4
8	North 5	138	-23.86	17.02	40.9	43.93%	-22.47	99.97%	-17.74	98.97%	13.25	1.02%	19.09	0.02%	-22.47	19.09	41.6
9	North 6	138	-2.74	18.30	21.0	98.92%	-2.98	99.89%	0.08	98.89%	14.94	1.02%	20.76	0.02%	-2.98	20.76	23.7
10	West 4	138	-36.24	21.75	58.0	38.69%	-31.73	99.93%	-26.26	98.93%	16.39	1.09%	21.74	0.09%	-31.73	21.74	53.5
11	Coast 2+	69	-18.46	21.27	39.7	54.64%	-26.32	99.99%	-15.64	98.99%	17.32	1.00%	23.55	0.00%	-26.32	23.55	49.9
12	Coast 1	138	-24.50	40.36	64.9	82.02%	-26.93	99.96%	-13.84	98.96%	34.02	1.00%	43.67	0.00%	-26.93	43.67	70.6
13	Coast 4	345	-29.32	37.42	66.7	84.36%	-25.84	99.96%	-11.87	98.96%	36.80	1.00%	50.16	0.00%	-25.84	50.16	76.0
14	Coast 3	345	-23.22	35.88	59.1	84.27%	-24.11	99.96%	-11.79	98.96%	35.91	1.01%	48.14	0.01%	-24.11	48.14	72.3
15	South 6+	138	-19.78	33.86	53.6	72.86%	-28.62	99.99%	-13.42	98.99%	27.32	1.01%	38.12	0.01%	-28.62	38.12	66.7
16	South 13	138	-27.63	45.42	73.1	71.58%	-34.00	99.99%	-18.44	98.99%	35.70	1.00%	50.24	0.00%	-34.00	50.24	84.2
17	FarWest 4	345	-37.15	55.41	92.6	68.16%	-31.25	100.00%	-25.69	99.00%	49.19	1.10%	55.90	0.10%	-31.25	55.90	87.1
18	FarWest 7	345	-29.15	50.17	79.3	64.72%	-37.07	100.00%	-30.00	99.00%	45.65	1.12%	52.53	0.12%	-37.07	52.53	89.6
19	FarWest 8	138	-50.58	49.05	99.6	54.01%	-46.71	100.00%	-37.26	99.00%	40.08	1.00%	49.75	0.00%	-46.71	49.75	96.5
20	FarWest 9	138	-51.72	64.41	116.1	59.06%	-47.32	100.00%	-40.02	99.00%	55.41	1.04%	64.58	0.04%	-47.32	64.58	111.9
21	West 16*	345				NOT IN SERVICE IN 2012											
22	West 17*	345				NOT IN SERVICE IN 2012											
23	West 13*	345				NOT IN SERVICE IN 2012											
24	West 15*	345				NOT IN SERVICE IN 2012											
25	West 8*	345				64.12%	-21.86	99.97%	-16.88	98.97%	36.56	1.09%	39.95	0.09%	-21.86	39.95	61.8
26	West 1*	345				68.03%	-24.66	99.97%	-19.51	98.97%	37.85	1.04%	45.52	0.04%	-24.66	45.52	70.2
27	West 2*	345				69.34%	-26.19	99.88%	-21.56	98.88%	45.40	1.07%	52.14	0.07%	-26.19	52.14	78.3
28	West 3*	345				NOT IN SERVICE IN 2012											
29	West 9*	345				69.43%	-29.90	100.00%	-22.80	99.00%	46.70	1.08%	53.51	0.08%	-29.90	53.51	83.4
30	West 12*	345				NOT IN SERVICE IN 2012											
31	West 5*	345	No Phasor Data Available in 2012			69.82%	-28.65	99.99%	-22.77	98.99%	45.43	1.08%	51.84	0.08%	-28.65	51.84	80.5
32	South 15*	345				86.89%	-5.71	99.94%	-3.50	98.94%	14.42	1.05%	18.36	0.05%	-5.71	18.36	24.1
33	FarWest 2*	69				19.34%	-14.42	99.98%	-10.63	98.98%	5.51	1.04%	7.79	0.04%	-14.42	7.79	22.2
34	South 2*	345				98.37%	-2.25	99.99%	-0.38	98.99%	14.06	1.01%	16.86	0.01%	-2.25	16.86	19.1
35	South 4*	345				84.80%	-6.53	99.94%	-4.11	98.94%	15.39	1.05%	19.36	0.05%	-6.53	19.36	25.9
36	South 7*	345				96.98%	-3.02	99.94%	-1.19	98.94%	17.44	1.10%	19.77	0.10%	-3.02	19.77	22.8
37	South 9*	345				84.37%	-10.09	99.99%	-4.48	98.99%	13.04	1.05%	16.72	0.05%	-10.09	16.72	26.8
38	South 11*	345				83.30%	-9.29	99.99%	-4.78	98.99%	16.13	1.04%	20.10	0.04%	-9.29	20.10	29.4
39	South 3*	138				67.68%	-24.42	99.99%	-13.21	98.99%	23.70	1.06%	34.13	0.06%	-24.42	34.13	58.6
40	South 4*	138				26.49%	-23.46	99.99%	-17.30	98.99%	9.46	1.07%	17.85	0.07%	-23.46	17.85	41.3
41	South 10*	138				35.91%	-27.98	100.00%	-18.12	99.00%	14.96	1.00%	26.26	0.00%	-27.98	26.26	54.2

Note: The two substations with + came on line during the second half of 2012 and the substations with * did not have PMUs installed in 2012.

Summaries of SE-based voltage angle pairs with their corresponding box-whisker and time duration curves as well as summaries of phasor-based voltage angle pairs with their corresponding box-whisker and time duration curves are presented in Appendix D.

D. Observations – Voltage Angles

a. The voltage angles with respect to North 7 for West 10 and North 2 obtained with phasor data were significantly higher than those obtained with state estimator data. The angle spread obtained from phasor data for West 10 and North 2 were 117.7 and 42.7 degrees; whereas the same spreads obtained from SE data were 55.5 and 17.8 degrees. EPG checked historical information and found that on January 9, 2012 the angle at West 10 with reference to North 7 reached 70 degrees at approximately 2:00 a.m.
b. Voltage angles vary over a wide range for several substations. The highest variation of 111.9 degrees (-47.3 to 64.6) occurred at FarWest 9 138 kV substation. Among the 345 kV substations, the highest angle variation over the year 2012 occurred at FarWest 7 with a range of 89.6 (-37.1 to 52.5) degrees.
c. The highest variations occurred among the substations in the western part of the state namely: FarWest 7, West 11, West 6, FarWest 8, FarWest 9, FarWest 4, West 2, West 9 and West 5.
d. The next highest angle variation occurred in the south part of the state namely: South 13, Coast 3, Coast 4 and Coast 1.
e. The two highest normal angles observed were at West 10 and FarWest 9 with 74.9 and 64.4 degrees respectively.

11. BASELINE ANALYSIS FOR ANGLE DIFFERENCES

A. Pairs of Substations Identified for Angle Difference Analysis

The following pairs of substations were selected to perform the angle difference analysis (ALSO SEE MAP BELOW):

TABLE 3: ANGLE PAIRS FOR BASELINE ANALYSIS

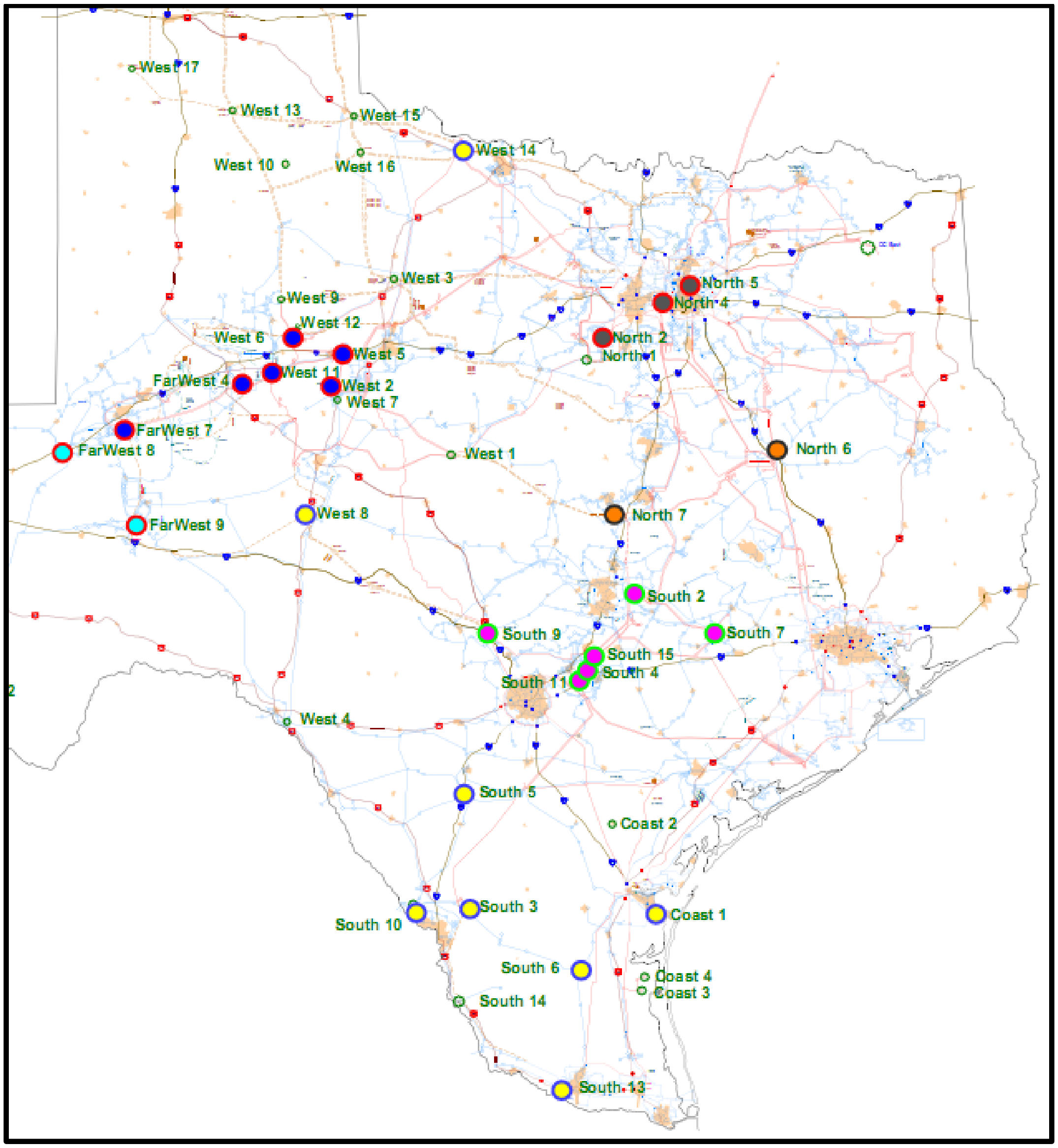
PAIRS WITH PHASOR DATA AVAILABLE

Substation A	Substation B	From Region	To Region
Coast 1	South 13	Valley	Valley
Coast 1	North 7	Valley	Central-East
North 1	North 4	Central	Central
North 4	North 5	Central	Central
West 4	North 7	SouthWest	Central-East
North 7	North 1	Central-East	Dallas
North 7	North 6	Central-East	East
FarWest 7	FarWest 4	West Texas	West Texas
FarWest 7	West 14	West Texas	Panhandle
FarWest 7	FarWest 8	West Texas	West Texas
FarWest 7	FarWest 9	West Texas	West Texas
West 14	North 1	Panhandle	Dallas
FarWest 9	West 4	West Texas	Southwest

PAIRS WITHOUT PHASOR DATA AVAILABLE

Coast 1	South 10*	Valley	Valley
Coast 1	South 14*	Valley	Valley
North 7	South 7*	Central-East	Central-East
North 7	South 9*	Central-East	Central-East
North 7	South 11*	Central-East	Central-East
West 8	South 9*	Central	Central-East
West 11	West 8*	Central	Central
West 5*	North 1	Central	Central
West 5*	FarWest 4	Central	West Texas
West 5*	West 10	Central	Panhandle
West 5*	North 7	Central	Central-East
West 14	West 16*	Panhandle	Panhandle
West 14	West 13*	Panhandle	Panhandle
West 14	West 15*	Panhandle	Panhandle
West 14	West 5*	Panhandle	Central
West 14	West 17*	Panhandle	Panhandle
FarWest 9	South 9*	West Texas	Central-East

* Denotes substations without existing PMUs or w/o data stream



B. Summary of wesults – !ll 5ata Lncluded

Table C-1 below contains angle difference results for all those angle pairs selected for study. This Table shows min, max and average values for angle differences obtained from all data received (all solved SE cases and all phasor data, normal and contingency conditions). Because phasor data was not available for many of the pairs selected for study, no phasor results are provided for those pairs.

Table C-1 -CCET DISCOVERY ACROSS TEXAS- BASELINING ANALYSIS- SUMMARY OF ANGLE DIFFERENCES - ALL DATA

			Phasor Data - 1/1/12 to 12/31/12					State Estimator Data - 1/1/12 to 12/31/12				
	Angle Pair	Base kV	Min	Max	Average	Percent Positive %	% Data Available	Min	Max	Average	Percent Positive %	Max-Min Spread
1	Coast 1-South 13	138kV	-14.96	24.97	2.84	65.96	24.07	-16.41	26.69	3.45	66.7%	43.1
2	Coast 1-North 7	138kV	-39.23	54.52	8.06	76.87	60.29	-30.80	43.67	10.25	82.0%	74.5
3	North 1-North 4	345/138kV	6.05	13.73	9.93	100.00	9.13	2.33	13.80	8.78	100.0%	11.5
4	North 4-North 5	138kV	-4.93	6.99	1.60	82.27	95.09	-2.71	6.05	2.01	89.8%	8.8
5	West 4-North 7	138kV	-45.26	34.93	-7.81	25.60	39.21	-33.40	22.27	-4.06	38.7%	55.7
6	North 1-North 7	345/138 kV	-14.24	27.29	8.28	88.37	10.08	-14.55	31.48	9.48	89.1%	46.0
7	North 4-North 7	138kV	-22.68	21.60	-0.54	47.73	95.72	-21.23	21.44	0.70	55.4%	42.7
8	North 7-North 6	138kV	-46.79	13.81	-6.81	1.42	94.80	-20.77	5.17	-7.04	1.1%	25.9
9	FarWest 7-FarWest 4	345kV	-6.83	3.67	-2.69	6.86	9.12	-17.72	5.71	-2.69	13.9%	23.4
10	FarWest 7-West 14	345kV	-16.79	23.20	0.73	47.43	2.92	-26.82	26.07	0.04	49.1%	52.9
11	FarWest 7-FarWest 8	345/138kV	4.19	12.68	8.52	100.00	7.28	1.11	13.87	7.19	100.0%	12.8
12	FarWest 7-FarWest 9	345/138kV	-19.89	19.66	2.93	64.83	9.09	-22.95	24.51	1.15	56.9%	47.5
13	FarWest 7-North 7	345/138kV	-30.34	54.40	13.05	67.91	10.08	-37.07	54.99	10.51	64.7%	92.1
14	West 14-North 1	345kV	-8.53	16.03	3.98	74.93	2.92	-16.14	17.13	0.99	56.4%	33.3
15	FarWest 9-West 4	138kV	-39.88	60.00	9.75	64.05	33.39	-40.32	85.11	13.71	71.7%	125.4
16	Coast 1-South 10*	138kV	Phasor data is not available for these pairs					-8.29	31.57	12.66	96.8%	39.9
17	North 7-South 7*	138/345kV						-20.21	3.35	-6.71	3.0%	23.6
18	North 7-South 9*	138/345kV						-17.30	10.48	-3.63	15.6%	27.8
19	North 7-South 11*	138/345kV						-20.79	10.00	-4.13	16.6%	30.8
20	West 5*-North 1	345kV						-25.30	28.24	3.28	56.1%	53.5
21	West 5*-FarWest 4	345kV						-9.17	9.25	-0.42	43.3%	18.4
22	West 5*-West 10	345/69kV						-49.84	61.89	9.73	64.0%	111.7
23	West 5*-North 7	345/138kV						-29.36	54.10	12.74	69.8%	83.5
24	West 14-West 16*	345kV						* Substation not yet in service in 2012				
25	West 14-West 13*	345kV										
26	West 14-West 15*	345kV										
27	West 14-West 5*	345kV						-20.57	16.08	-2.13	45.4%	36.7
28	West 14-West 17*	345kV						* Substation not yet in service in 2012				
29	West 11-West 8*	345kV						-11.52	4.01	0.44	65.6%	15.5
30	West 8*-South 9*	345kV						-35.64	42.66	4.98	58.4%	78.3
31	FarWest 9-South 9*	138/345kV						-56.70	66.69	5.73	55.6%	123.4

* Denotes substations without existing PMUs or w/o data stream

C. Criteria to Identify Normal Operations Limits for Angle Differences

The data received, both phasor and state estimator, provide information for all conditions during the study period including those conditions where the system experienced outages of lines or generators. This study is intended to provide angle difference limits that can be expected during normal operations, that is, when all facilities are in service. The following criteria were used to determine the angle difference limits expected during normal operations for the selected substation pairs.

i. If the angle difference time duration curves show only positive angles, then two limits will be identified: one corresponding to the angle difference that occurred at about one percent of the time, and the other corresponding to the maximum value observed.

ii. If the angle difference time duration curves show positive as well as negative angles, then four limits will be identified, two for one direction of flow and two for the opposite direction of flow, based on the criteria below:

    i. The first limit in either direction will be set using state estimator results by selecting the maximum (or minimum) angle difference observed on the corresponding time duration curves if the box-whisker and time duration plots show no extreme values (outliers or extreme values due to events in the system). If extreme values or outliers are present, a point of inflection will be determined and the maximum or minimum angle will be set at the angle corresponding to the point of inflection.

ii. The second maximum limit will be set at the angle difference which occurred 1% more time than the time corresponding to the selected maximum limit, based on the time duration curve. The second minimum limit will be set at the angle difference corresponding to 1% less time than the time corresponding to the selected minimum limit.

iii. In some cases such as the cases when there was extended outage, EPG reproduced the load duration curve excluding those days when the extended outage occur to determine the angle differences corresponding to normal conditions.

iv. The 1% values can be used to set alarms for the operators to be notified of impending maximum angle differences. The maximum and minimum values can be used to set up alarms notifying the operator that expected maximum or minimum values has been reached.

v. The alarms so determined should be monitored for a year against actual values observed during operation. If maximum values are exceeded, the observed values should be logged and documented for further analysis.

vi. Maximum and minimum angle differences will change as major changes occur in the system such as return to service of a large generating station such as SONGS. This analysis shall be revised based on historical information obtained with the new facility in place. Maximum and minimum values can also be estimated from many power flow cases representing different system conditions of the year.

D. Summary of Wesults – bormal /onditions

The angle difference results for normal conditions are summarized in Table C-2 below.

Table C-2 -CCET DISCOVERY ACROSS TEXAS- BASELINING ANALYSIS- SUMMARY OF ANGLE DIFFERENCES - NORMAL CONDITIONS

			DATA RESULTS														
			Phasor Data			State Estimator Data									SE Data-Normal		
No	Angle Pair FROM - TO	Base kV	Min Angle	Max Angle	Max-Min Spread	Percent Positive	Min Angle at POI or 100%	Percent (POI or 100%)	Min Angle at 99% or POI - 1%	Percent (99% or POI - 1%)	Max Angle at 1% or POI +1%	Percent (1% or POI +1%)	Max Angle at POI or 0%	Percent (POI or 0%)	Min Angle	Max Angle	Max-Min Spread
1	Coast 1-South 13	138	-10.30	21.98	32.28	66.69%	-14.47	99.95%	-10.27	98.95%	19.79	1.05%	25.33	0.05%	-14.47	25.33	39.79
2	Coast 1-North 7	138	-24.50	40.36	64.86	82.02%	-25.13	99.95%	-13.81	98.95%	34.01	1.01%	42.49	0.01%	-25.13	42.49	67.62
3	North 1-North 4	345/138	6.62	13.65	7.03	100.00%	2.33	100.00%	3.90	99.00%	12.41	1.02%	13.62	0.02%	2.33	13.62	11.29
4	North 4-North 5	138	-3.44	5.65	9.09	89.84%	-2.33	99.95%	-1.42	98.95%	5.13	1.01%	6.02	0.01%	-2.33	6.02	8.35
5	West 4-North 7	138	-36.24	21.75	57.99	38.69%	-31.73	99.93%	-26.26	98.93%	16.41	1.08%	21.82	0.08%	-31.73	21.82	53.55
6	North 1-North 7	345/138	-13.47	23.04	36.51	89.13%	-13.46	99.98%	-8.02	98.98%	25.22	1.02%	31.48	0.02%	-13.46	31.48	44.94
7	North 4-North 7	138	-19.82	19.41	39.23	55.43%	-19.96	99.96%	-15.44	98.96%	14.78	1.02%	20.77	0.02%	-19.96	20.77	40.73
8	North 7-North 6	138	-18.30	2.74	21.04	1.08%	-20.31	99.98%	-14.94	98.98%	0.03	1.02%	4.57	0.02%	-20.31	4.57	24.87
9	FarWest 7-FarWest 4	345	-5.91	2.26	8.17	13.91%	-16.35	99.98%	-8.79	98.98%	2.27	1.02%	4.11	0.02%	-16.35	4.11	20.46
10	FarWest 7-West 14	345	-15.35	22.05	37.40	49.10%	-25.14	99.99%	-19.49	98.99%	18.13	1.03%	24.58	0.03%	-25.14	24.58	49.72
11	FarWest 7-FarWest 8	345/138	4.79	12.56	7.77	100.00%	1.66	99.95%	3.42	98.95%	11.70	1.03%	13.05	0.03%	1.66	13.05	11.38
12	FarWest 7-FarWest 9	345/138	-13.43	16.35	29.78	56.95%	-22.95	100.00%	-17.89	99.00%	15.86	1.04%	23.81	0.04%	-22.95	23.81	46.76
13	FarWest 7-North 7	345/138	-29.15	50.17	79.32	64.72%	-37.07	100.00%	-30.00	99.00%	45.67	1.11%	52.64	0.11%	-37.07	52.64	89.71
14	West 14-North 1	345	-7.36	14.50	21.86	56.42%	-15.68	99.95%	-11.70	98.95%	12.80	1.02%	16.01	0.02%	-15.68	16.01	31.69
15	FarWest 9-West 4	138	-33.73	58.22	91.95	71.73%	-34.27	99.90%	-25.12	98.90%	59.85	1.01%	84.19	0.01%	-34.27	84.19	118.46
16	Coast 1-South 10*	138	No phasor data is available for these pairs			96.75%	-6.61	99.95%	-1.96	98.95%	26.77	1.00%	31.57	0.00%	-6.61	31.57	38.18
17	North 7-South 7*	138/345				3.01%	-20.05	99.98%	-17.56	98.98%	1.19	1.06%	3.16	0.06%	-20.05	3.16	23.21
18	North 7-South 9*	138/345				15.57%	-16.96	99.97%	-13.06	98.97%	4.49	1.00%	10.48	0.00%	-16.96	10.48	27.44
19	North 7-South 11*	138/345				16.59%	-19.61	99.95%	-16.12	98.95%	4.80	1.00%	10.00	0.00%	-19.61	10.00	29.61
20	West 5*-North 1	345				56.08%	-25.21	100.00%	-19.75	99.00%	24.51	1.01%	27.94	0.01%	-25.21	27.94	53.15
21	West 5*-FarWest 4	345				43.31%	-7.52	99.99%	-5.18	98.99%	5.35	1.00%	9.25	0.00%	-7.52	9.25	16.77
22	West 5*-West 10	345/69				64.00%	-48.21	99.99%	-38.30	98.99%	52.04	1.02%	61.12	0.02%	-48.21	61.12	109.33
23	West 5*-North 7	345/138				69.82%	-28.45	99.98%	-22.75	98.98%	45.46	1.07%	52.41	0.07%	-28.45	52.41	80.86
24	West 14-West 16*	345				ONE BUS NOT IN SERVICE IN 2012**									N/A		
25	West 14-West 13*	345				ONE BUS NOT IN SERVICE IN 2012**									N/A		
26	West 14-West 15*	345				ONE BUS NOT IN SERVICE IN 2012**									N/A		
27	West 14-West 5*	345				45.42%	-19.86	99.96%	-16.56	98.96%	11.15	1.00%	16.08	0.00%	-19.86	16.08	35.94
28	West 14-West 17*	345				ONE BUS NOT IN SERVICE IN 2012**									N/A		
29	West 11-West 8*	345				65.61%	-2.43	99.25%	-2.01	98.25%	2.84	1.03%	3.99	0.03%	-2.43	3.99	6.42
30	West 8*-South 9*	345				58.37%	-33.22	99.93%	-27.45	98.93%	36.45	1.03%	42.48	0.03%	-33.22	42.48	75.70
31	FarWest 9-South 9*	345				55.64%	-55.06	99.98%	-46.11	98.98%	53.63	1.00%	66.69	0.00%	-55.06	66.69	121.75

NOTE: These results were obtained with 2012 data; ** West 16, West 13, West 15, West 17 and West 8 were not in service in 2012.

Box-whisker and time duration curves were developed for each of the pairs analyzed. Angle differences that may be the result of contingencies were excluded by reviewing points of inflection, that is, points that significantly deviated from the normal operation trend observed in the box-whisker plots. The value of angle difference at the point of inflection was considered to be the maximum angle during normal conditions. If no outlier points were identified, then the angle corresponding to the 0% or 100% time points will represent the maximum and minimum angles reached during normal operations in either direction of flow. Summaries of SE-based voltage angle pairs with their corresponding box-whisker and time duration curves as well as summaries of phasor-based voltage angle pairs with their corresponding box-whisker and time duration curves are presented in Appendix E.

E. Observations – Angle Differences

a. The maximum Max-Min angle spreads under normal conditions occurred at FarWest 9-West 4 and FarWest 7-North 7 with 118.5 and 89.7 degrees respectively.
b. The maximum voltage angles under normal conditions also occurred at FarWest 9-West 4 and FarWest 7-North 7 with 84.2 and 52.6 degrees respectively.
c. Under normal conditions the maximum angles and the Max-Min spreads for these three pairs are:

FarWest 9-West 4	84.2	118.5
FarWest 7-North 7	52.6	89.7
West 5-North 7	52.4	80.9

d. Another three pairs had a Max-Min spreads of over 60 degrees under normal conditions: West 5-West 10 with 109.33 degree, West 8-South 9 with 75.7 degrees and Coast 1-North 7 with 67.6 degrees.
e. The remaining pairs had Max-Min spreads of less than 60 degrees, most of them significantly less.
f. In general the maximum angle differences and the Max-Min spreads obtained using phasor data are lower than those obtained with state estimator data.
g. The angle differences are 100% positive (power flow in one direction only) for two pairs: North 1-North 4 and FarWest 7-FarWest 8.

12. CONCLUSIONS

a. **Data Availability was Limited**: ERCOT provided phasor and state estimator data for 2012. Phasor data availability ranged from 10% to 96%. State estimator data availability was low (13%).

b. **Phasor and State Estimator Data Assessment**: Comparison of phasor and SE data shows phasor data seems well calibrated and the two data sets are well coordinated.

c. **Angle Differences Track Wind Output**: Cluster analysis reveal angle differences plots for the substations close to the wind farms track well with the wind output graphs.

d. **Highest Voltage Spreads at Two Locations**: Both phasor data and state estimator data point to West 4 and Coast 4 as having the highest voltage and voltage spread in their class. Note Coast 3 also has high voltage spread but South 13 and South 6 which are in the neighborhood have a much lower spread.

f. **Substations with High Voltage Spreads**: Fifteen substations out of a total of forty one show voltage spreads of higher than 15 kV and 24 substations show voltage spreads higher than 10 kV.

g. **Discrepancy Between SE and Phasor Data**: The voltage angles with respect to North 7 for West 10 and North 2 obtained with phasor data were significantly higher than those obtained with state estimator data. Phasor data for West 10 and North 2 were 117.7 and 42.7 degrees; SE data were 55.5 and 17.8 degrees. Historical on January 9, 2012 the angle at West 10 with reference to North 7 reached 70 degrees at about 2 AM.

h. **Voltage Angle Variability at 345kV and 138kV Substations**: Voltage angles vary over a wide range for several substations. The highest variation of 112.8 degrees (-47.3 to 65.4) occurred at FarWest 9 138 kV substation. Among the 345 kV substations, the highest angle variation over the year 2012 occurred at FarWest 7 with a spread of 92.1 (-37.1 to 55) degrees.

    a. The highest variations occurred among the substations in the western part of the state namely: FarWest 7, West 11, West 6, FarWest 8, FarWest 9, FarWest 4, West 2, West 9 and West 5.

    b. The next highest angle variation occurred in the south part of the state namely: South 13, Coast 3, Coast 4 and Coast 1.

    c. The two highest normal angles observed were at West 10 and FarWest 9 with 74.9 and 64.4 degrees respectively.

    d. The maximum Max-Min angle spreads under normal conditions occurred at FarWest 9-West 4 and FarWest 7-North 7 with 118.5 and 89.8 degrees respectively.

i. **Voltage Angles Under Normal Conditions**: The maximum voltage angles under normal conditions also occurred at FarWest 9-West 4 and FarWest 7-North 7 with 84.2 and 52.6 degrees respectively.

j. **a l·ÈǀYdzY !yƎƚŜă ¦yŘŜǋ bƵǋYl·f /ƵyŘǜǔƵyã**Y Under normal conditions the maximum angles and the Max-Min spreads for these three pairs are:

FarWest 7-North 7	52.6	89.7
West 5-North 7	52.4	80.9

k. **DŝyŜǊl-ƒ wŜădzƚűăY** In general the maximum angle differences and the Max-Min spreads obtained using phasor data are lower than those obtained with state estimator data

l. **[ʎYʎűăY** No limits are recommended for voltage magnitudes or voltage angles at this time since current limits will change due to the addition of many 345 kV transmission lines to the ERCOT system in 2013 as part of the CREZ project. Limits shall be recommended once all these lines are added and an updated baseline analysis is conducted.

13. RECOMMENDATIONS

a. **Study Updates to Reflect New Lines**: EPG recommends that every four months an update of this study be performed to track the changes in voltages and angles and assess how the new transmission lines are affecting the system performance in response to wind output.

b. **Improve Data Availability**: EPG recommends efforts are made to improve phasor data availability, if not already done, for those PMUs with less than 80% availability, particularly FarWest 7, North 1, and West 14. Coast 2 and South 6 also show availability of less than 40% but EPG believes these PMUs were only installed in the latter part of 2012.

c. **Need for Additional SE Cases**: EPG recommends a greater number of state estimator base cases be provided by ERCOT for 2013 to improve the quality of future baseline analysis. Future baseline analysis will be provide angle differences that are more representative of future system behavior since most new CREZ lines will be completed in 2013.

d. **Monitoring**: Actual voltage magnitudes and voltage angles should be collected while the new lines are being added to monitor change in angle differences which will provide insights into synchronization issue and solutions.

e. **Simplifying Analysis**: Baseline analysis in the future can be simplified if two or more PMUs show very similar behavior and result in similar voltages and angle differences. EPG will prepare a proposal of reduce variables for use in future baseline analysis.

f. **Monitoring Locations**: EPG recommends the development of a master list of substations and pairs of substations for monitoring the performance of the system in response to wind output changes and based on this analysis identify sites where it would be desirable to have PMUs installed

Appendix A

CCET Discovery Across Texas

Cluster Analysis – Angle Differences

External Version

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Cluster Analysis – Cluster Groups

Group 1- 345 Central:

- FarWest 4
- FarWest 7
- West 2
- West 5
- West 6
- West 11

Group 2- W. Texas:

- FarWest 8
- FarWest 9

Group 3 - Dallas:

- North 2
- North 4
- North 5

Group 4 – East & CE:

- North 6
- North 7

Group 5 – 345 C. East:

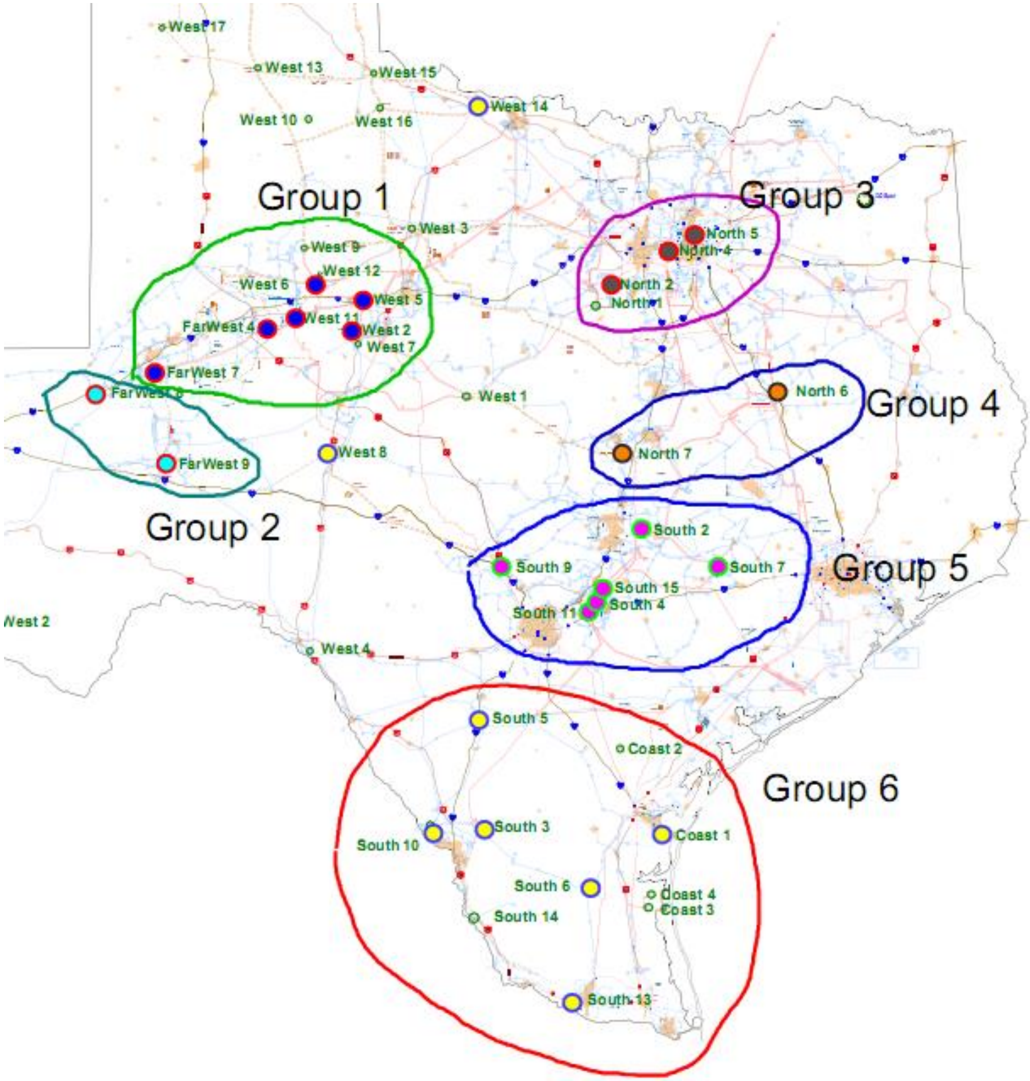
- South 2
- South 4
- South 7
- South 9
- South 11
- South 15

Group 6 - Valley:

- Coast 1
- South 3
- South 5
- South 6
- South 10
- South 13

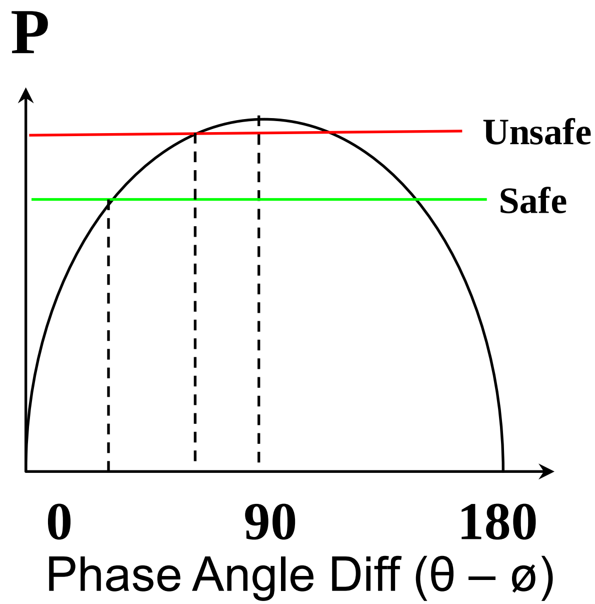
Note: This list includes existing and planned PMU locations from Oncor, AEP, Sharyland and LCRA

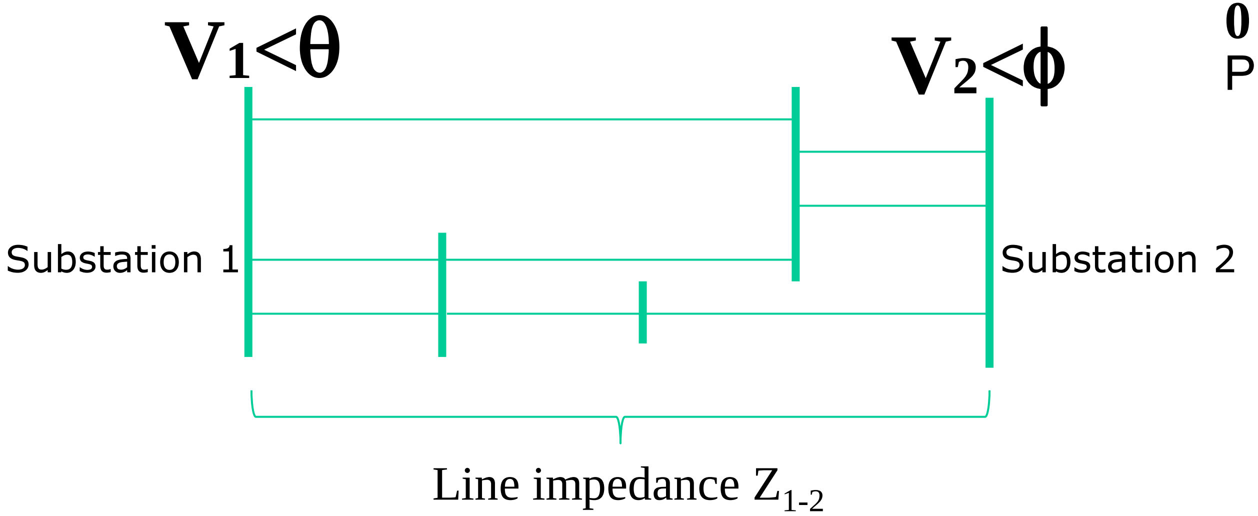
Cluster Locations: Group 1-Group 6



Phase angles differences as indicators of power flow

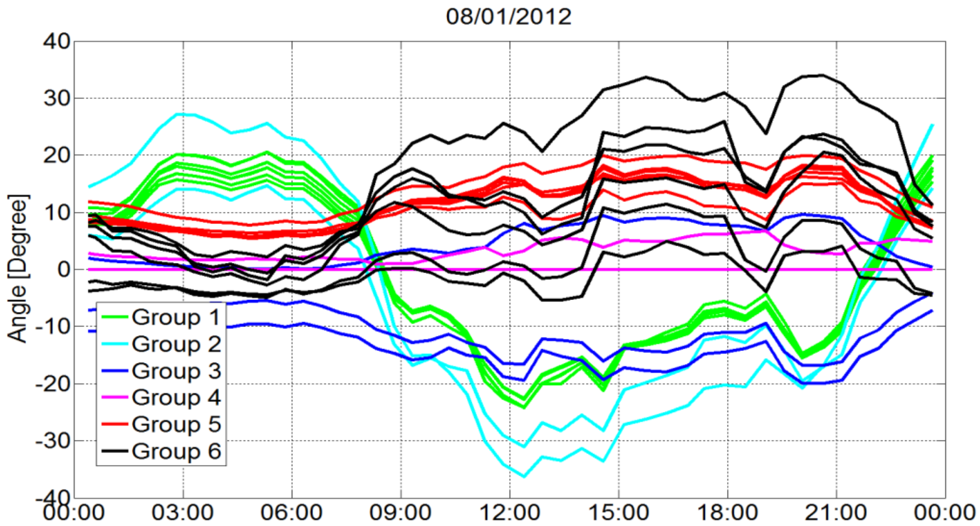
- Power flow follows voltage angle difference
  - Power flow: $P = V_1 V_2 \sin(\theta - ø)/Z$
- Any change in Power flow or impedance will be reflected in a change in voltage phase angle difference between two locations

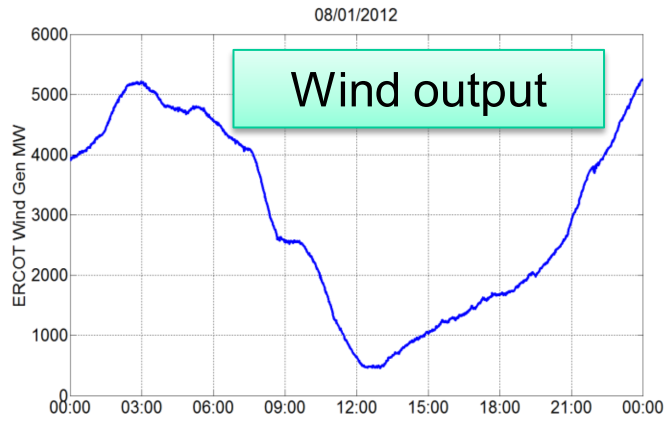


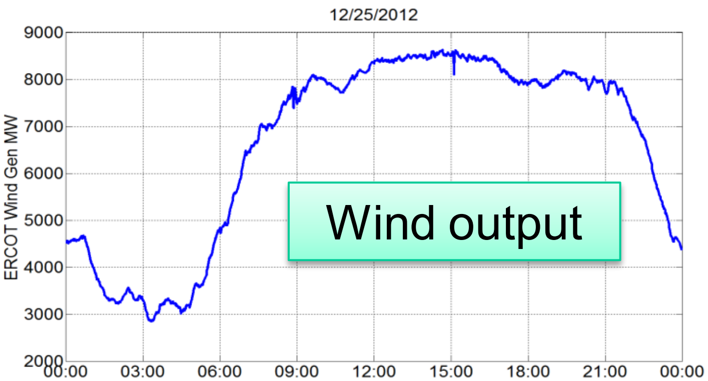


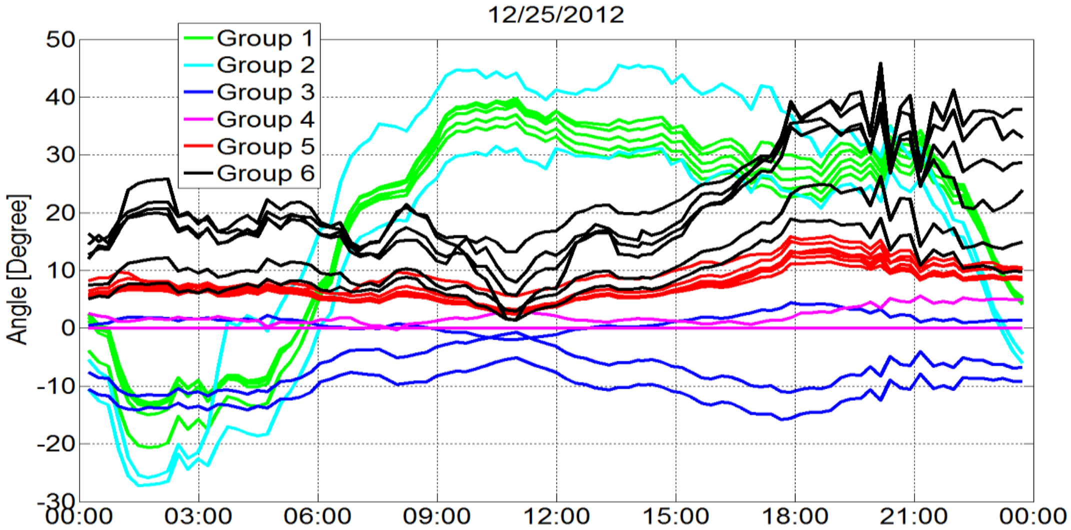
Cluster Summary-Angle Differences: Group 1-Group 6

Angle Reference: North 7









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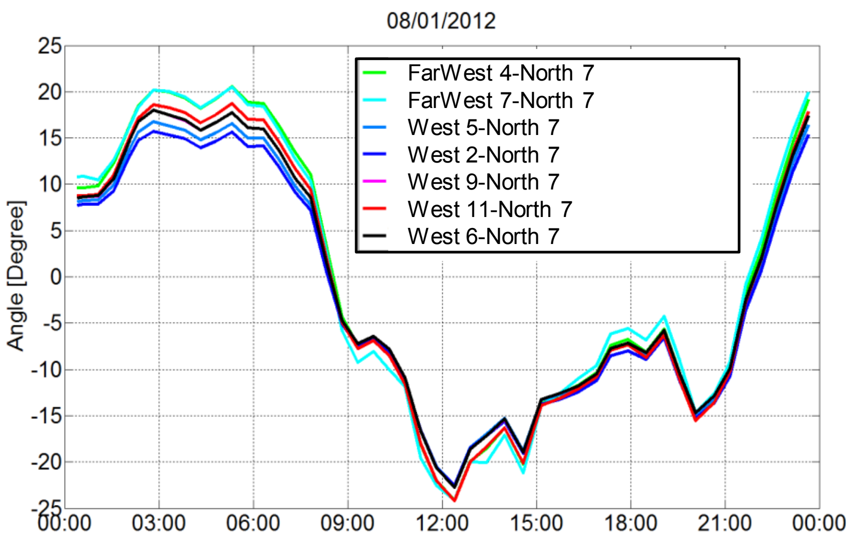
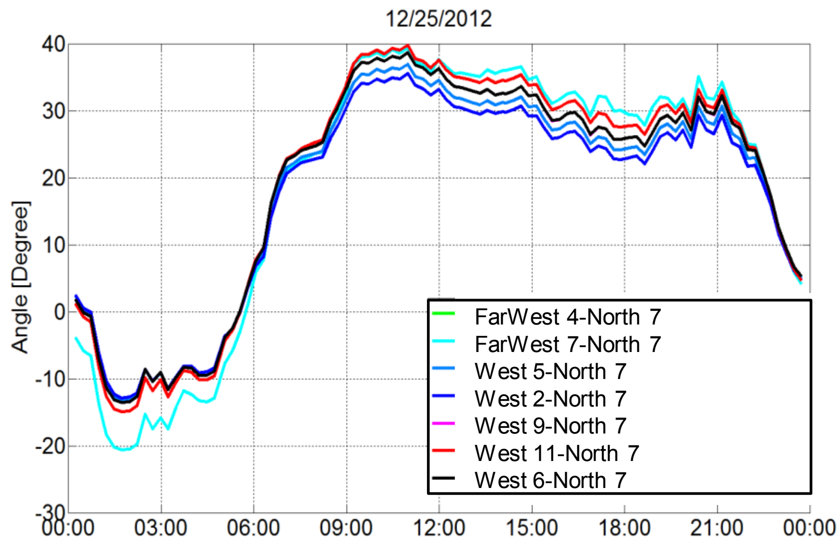
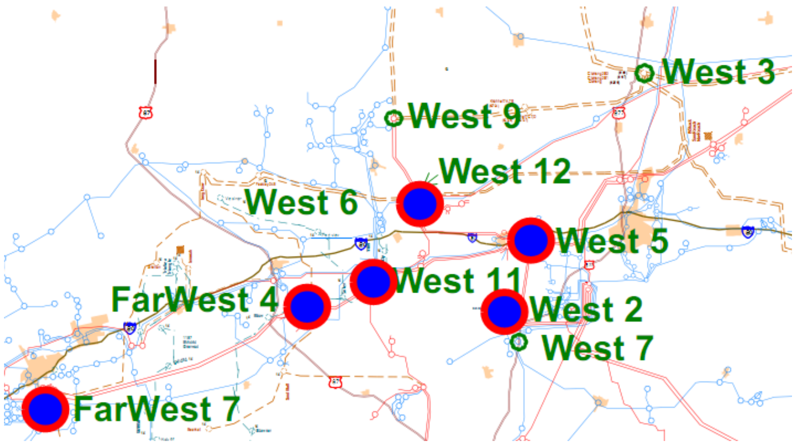
Group 1: Central







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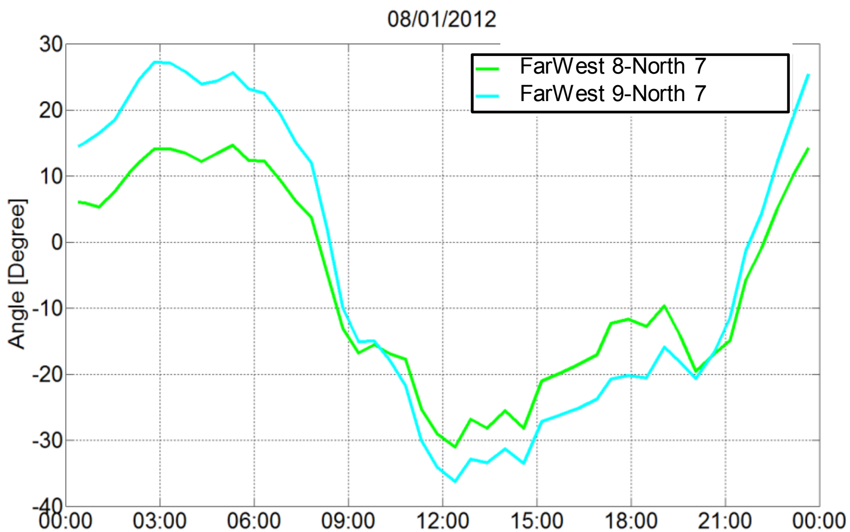
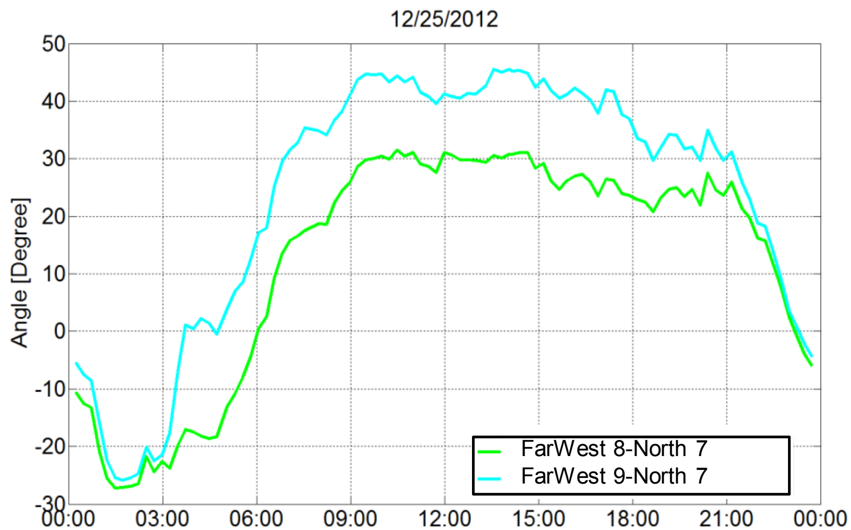
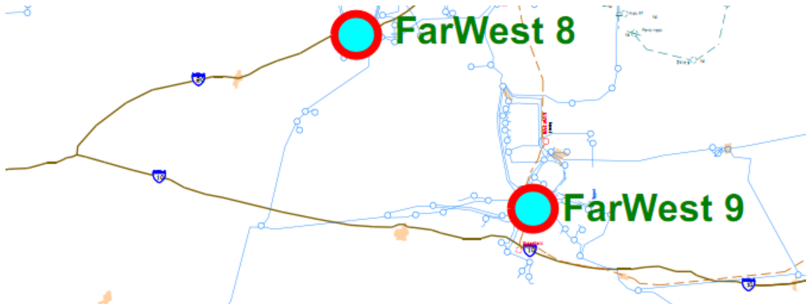
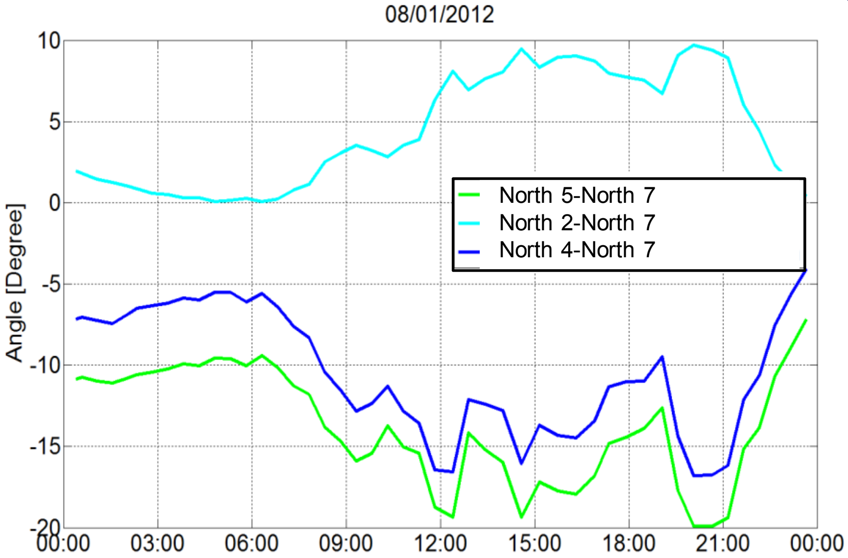
Group 2: West Texas

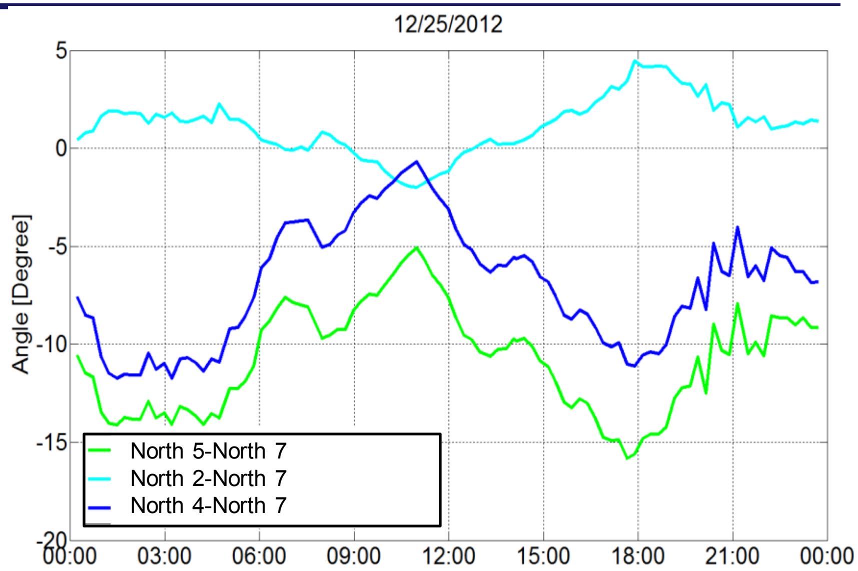


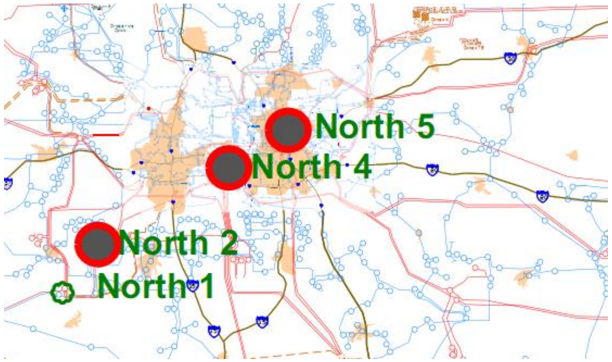




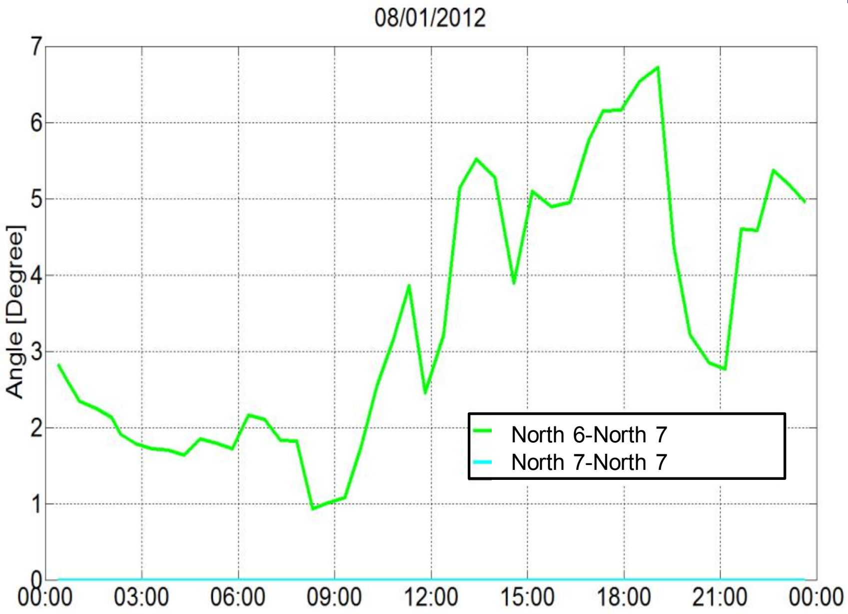
Group 3: Dallas

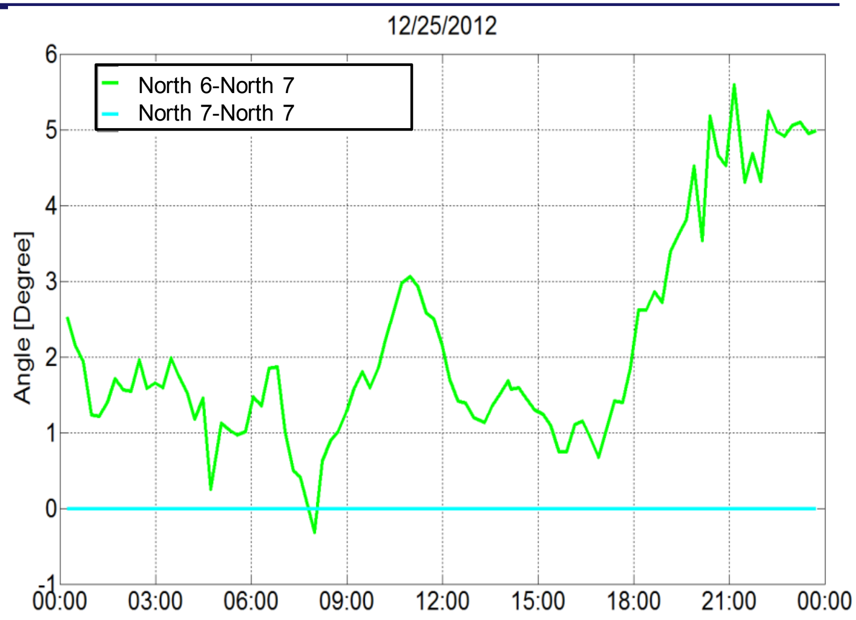


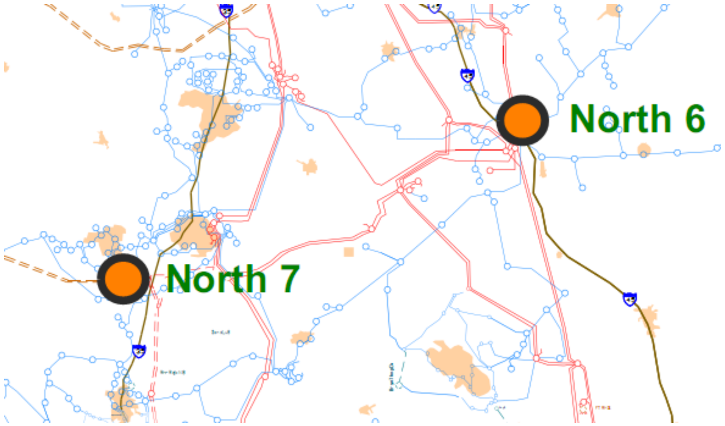




Group 4: East and Central East







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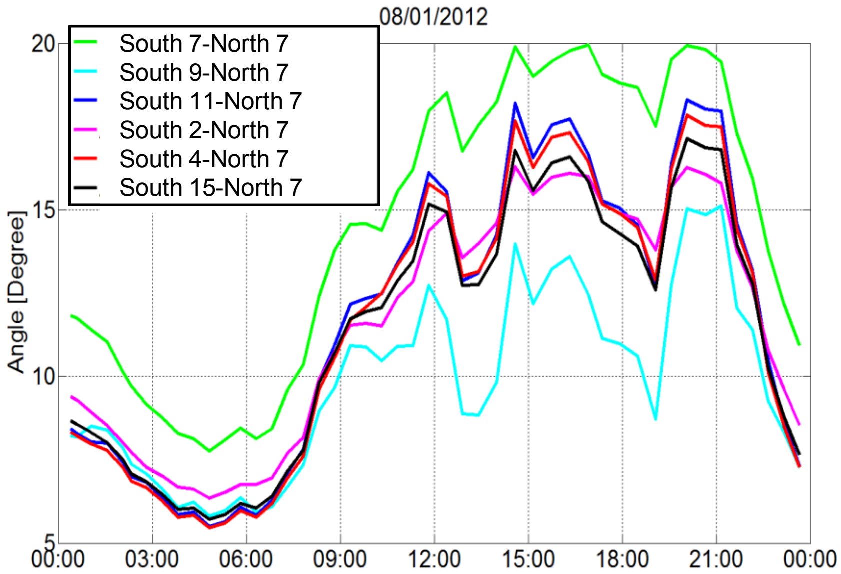
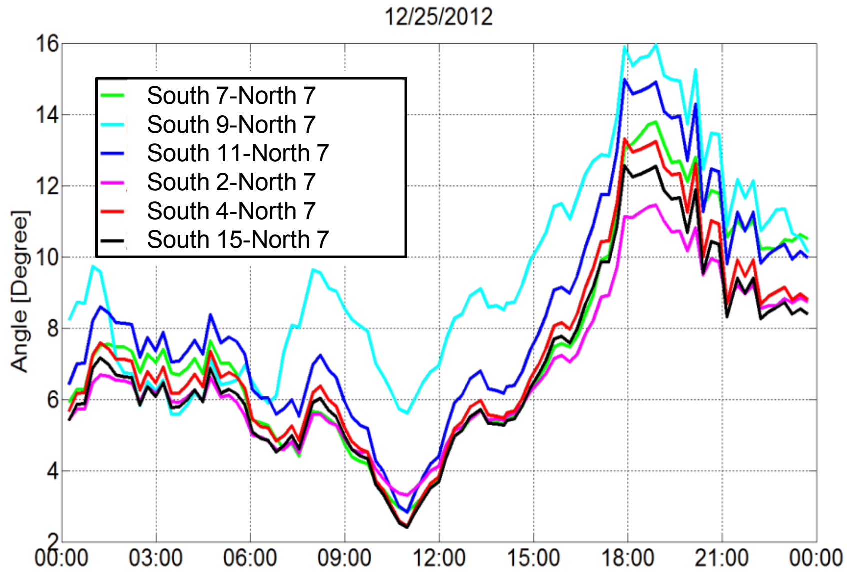
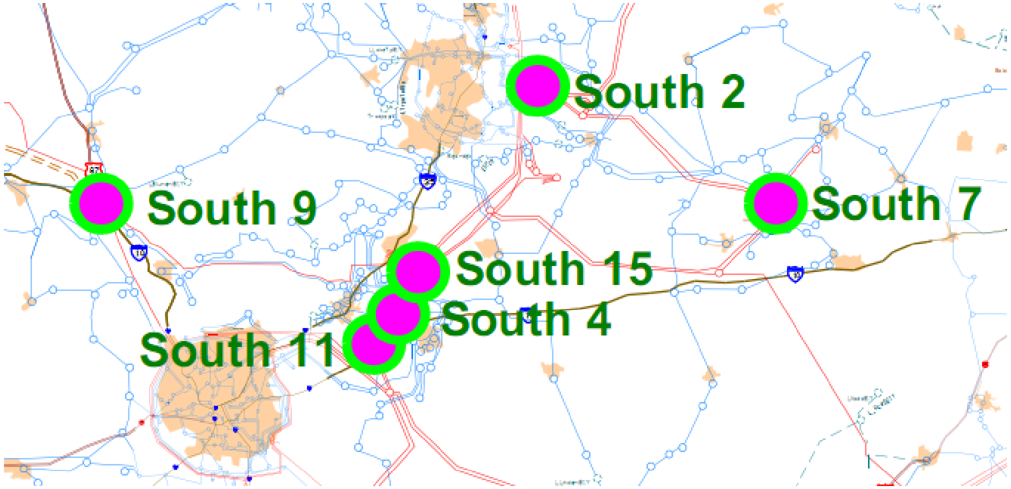
Group 5: Central East







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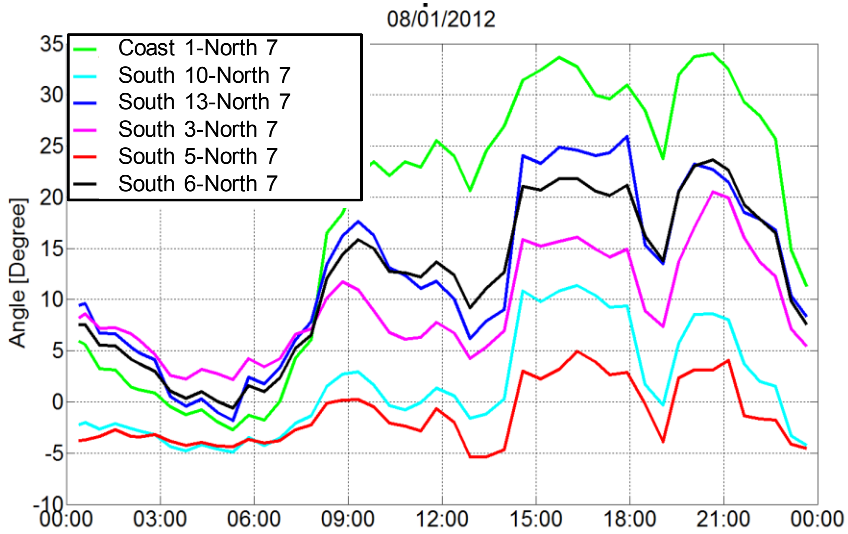
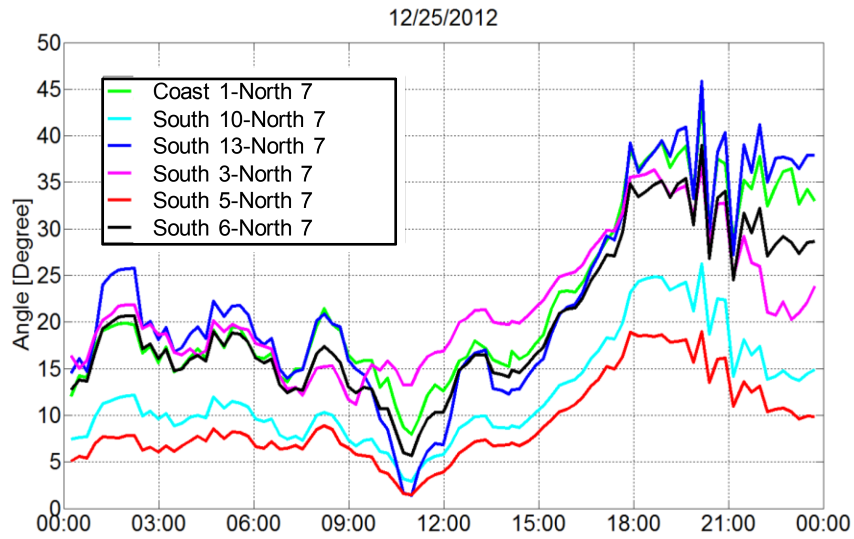
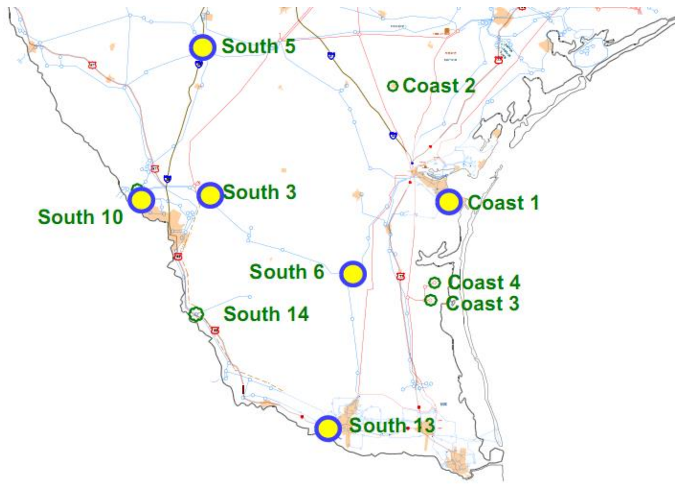
Group 6: Valley







Appendix B

CCET Discovery Across Texas

State Estimator versus Phasor Comparison

External Version

Phasor vs. State Estimator Comparison

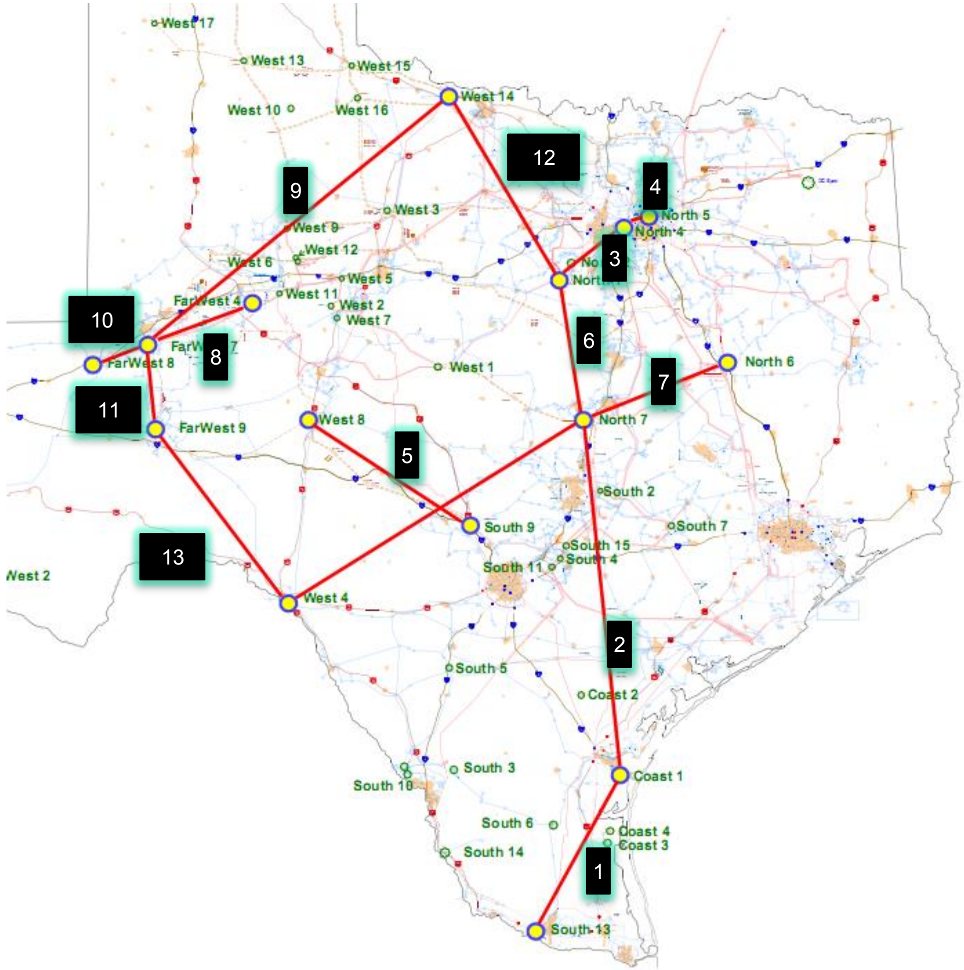
- Thirteen angle pairs were selected for comparison based on phasor measurement unit availability
- Three days were selected for comparison:
  - August 1: peak load
  - November 23: low load
  - December 25: maximum wind
- Phasor data missing for one or more of the days selected: South 13, North 1, West 4, West 8, West 14 and FarWest 7
- Where both phasor and SE data was available, the comparisons show a close correlation (within 1 degree) except for the North 4- North 5 pair (1.5 degrees of separation during about 7 hours on 8/1/2012).
- Observations:
  - The phasor and SE voltage angles compare very well across a wide range of locations and loads
  - The PMUs are apparently reasonably calibrated

Phasor vs. State Estimator Comparison

Angle Pairs with PMUs in Service

Index	Substation A	Substation B
1	Coast 1	South 13
2	Coast 1	North 7
3	North 1	North 4
4	North 4	North 5
5	West 4	North 7
6	North 7	North 1
7	North 7	North 6
8	FarWest 7	FarWest 4
9	FarWest 7	West 14
10	FarWest 7	FarWest 8
11	FarWest 7	FarWest 9
12	West 14	North 1
13	FarWest 9	West 4

Location of Angle Pairs with PMUs in Service



Days Analyzed:

1. August 1, 2012 (Peak load)
2. November 23, 2012 (low load)
3. December 25, 2012 (Maximum wind)

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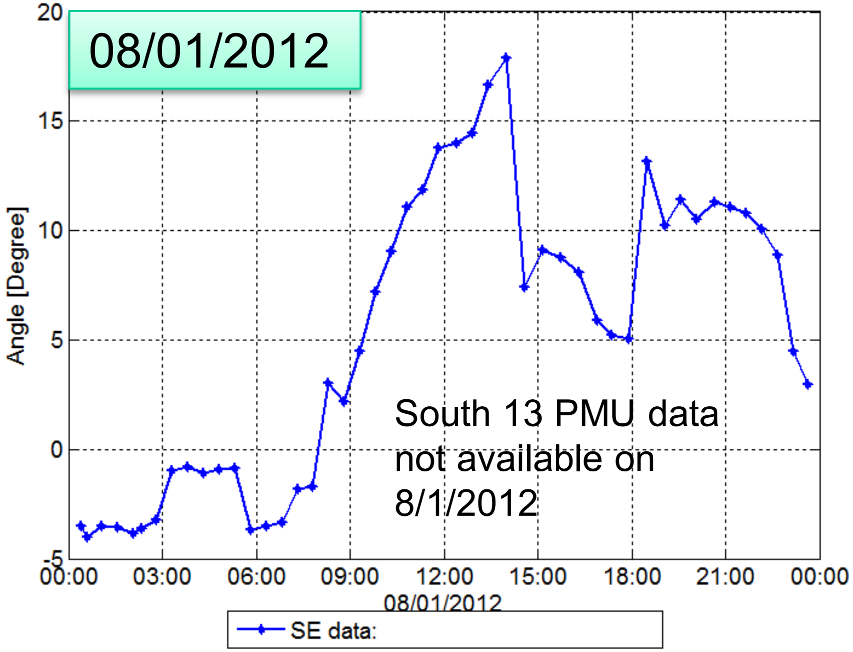
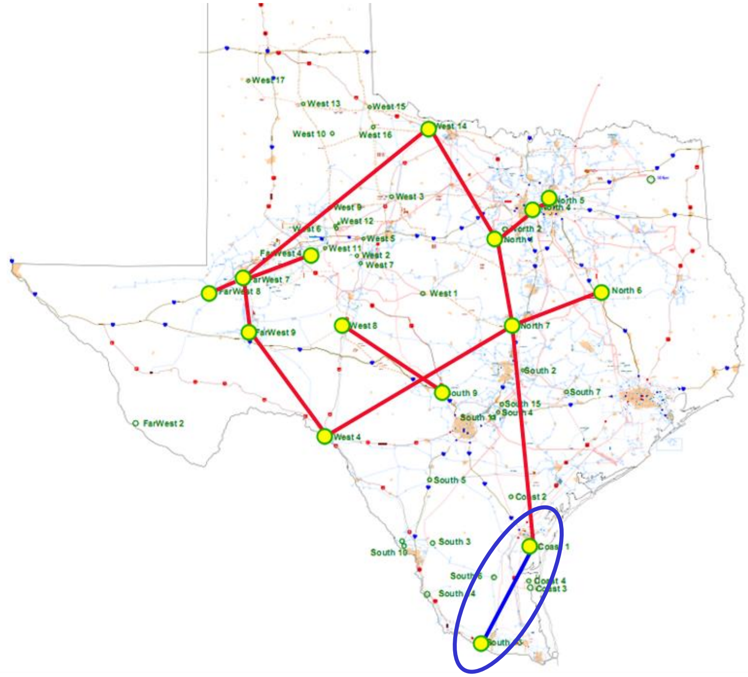
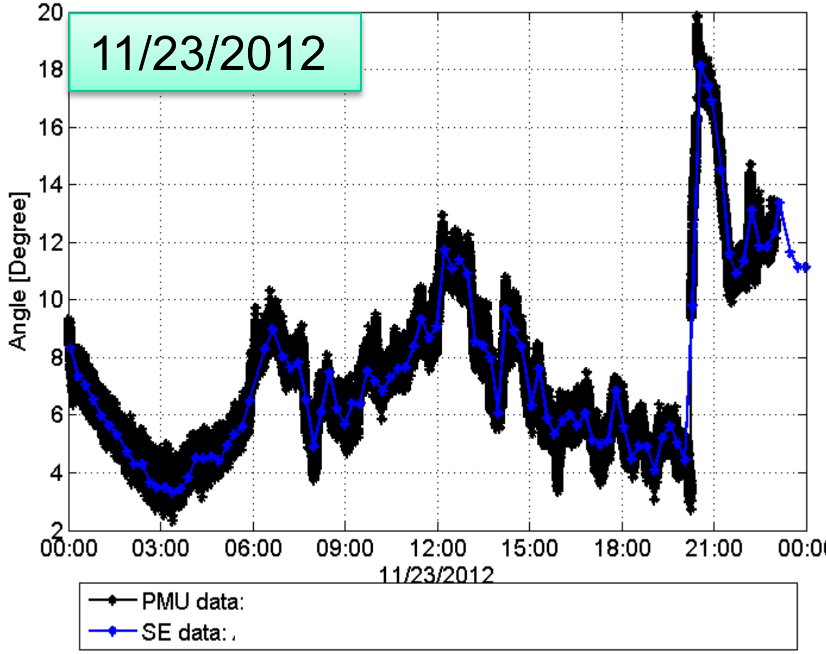
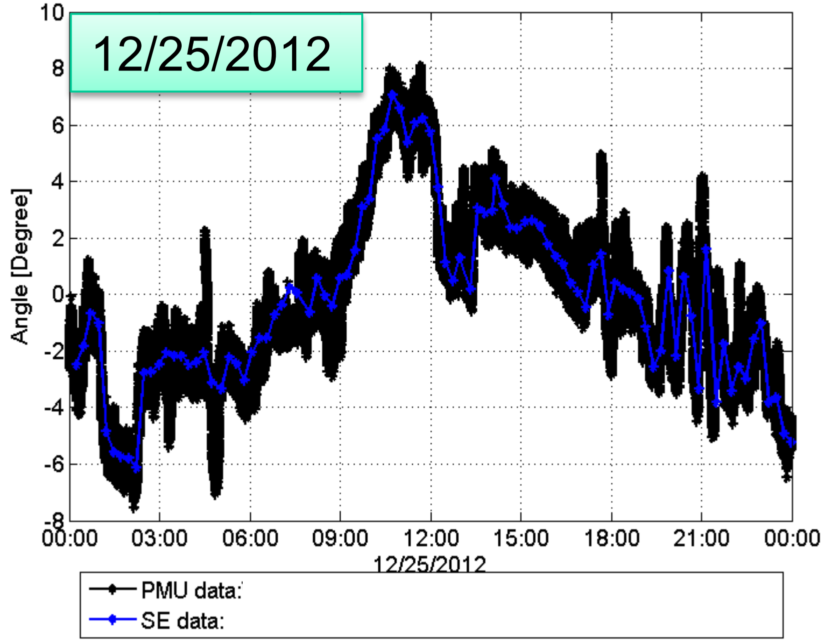
Coast 1-South 13

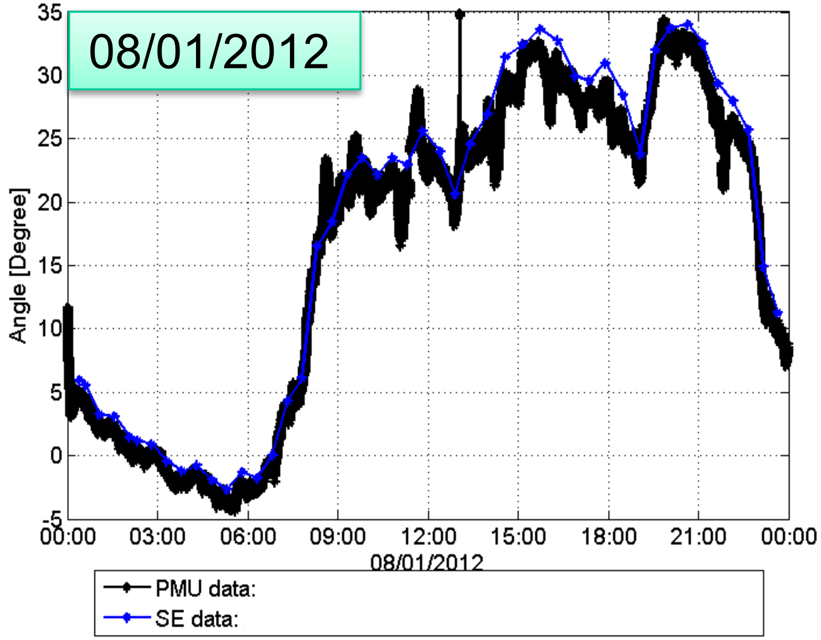


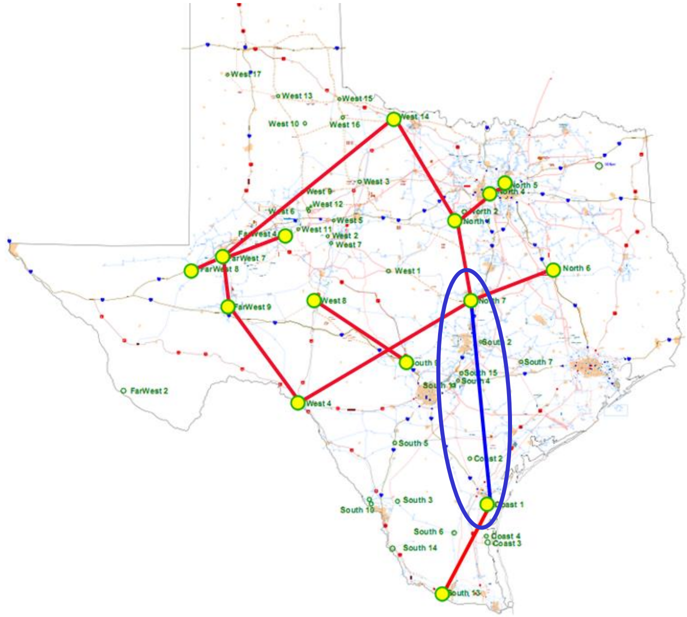


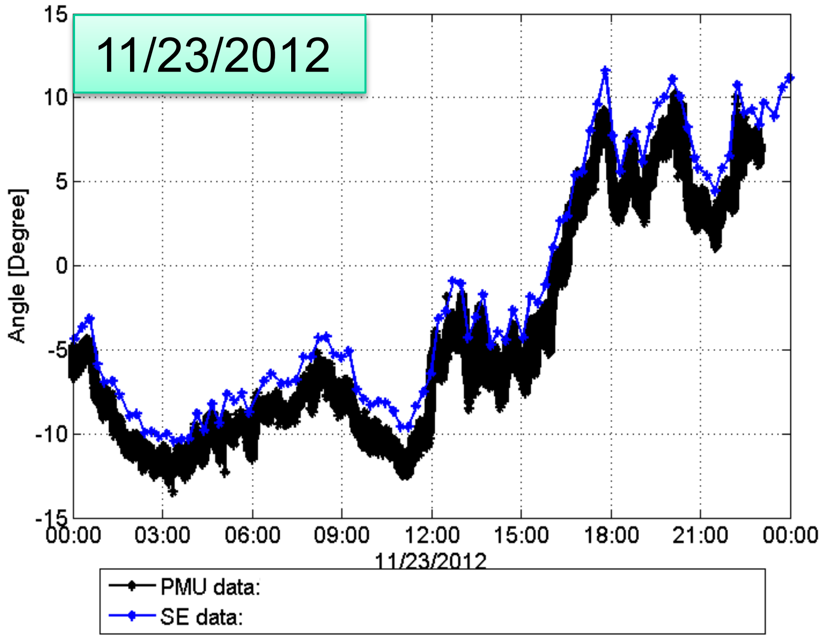


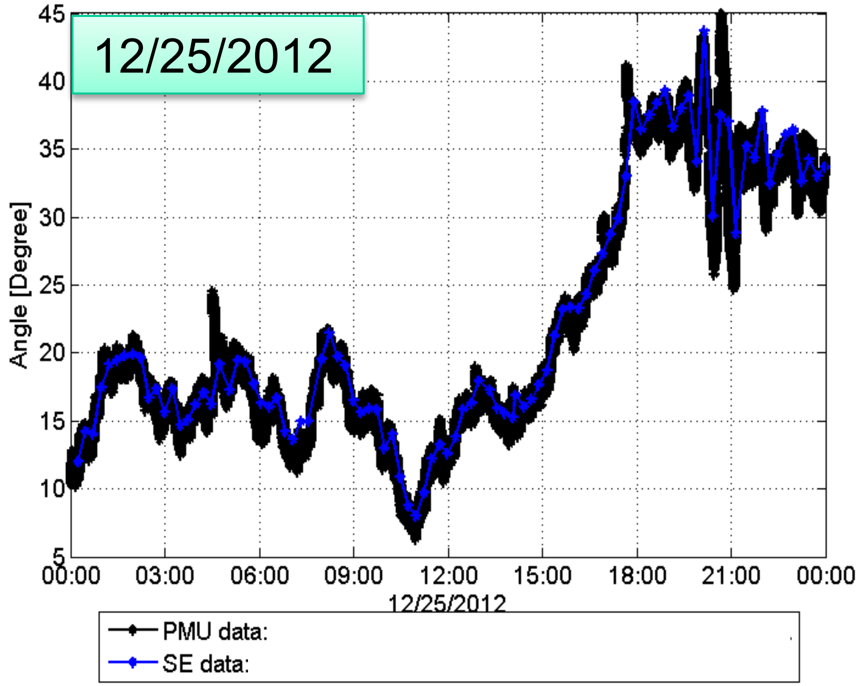


Coast 1-North 7

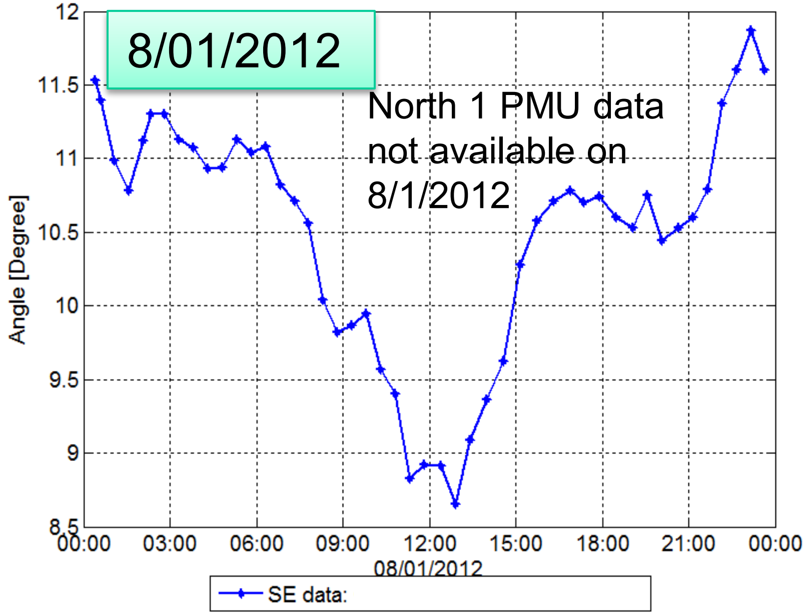


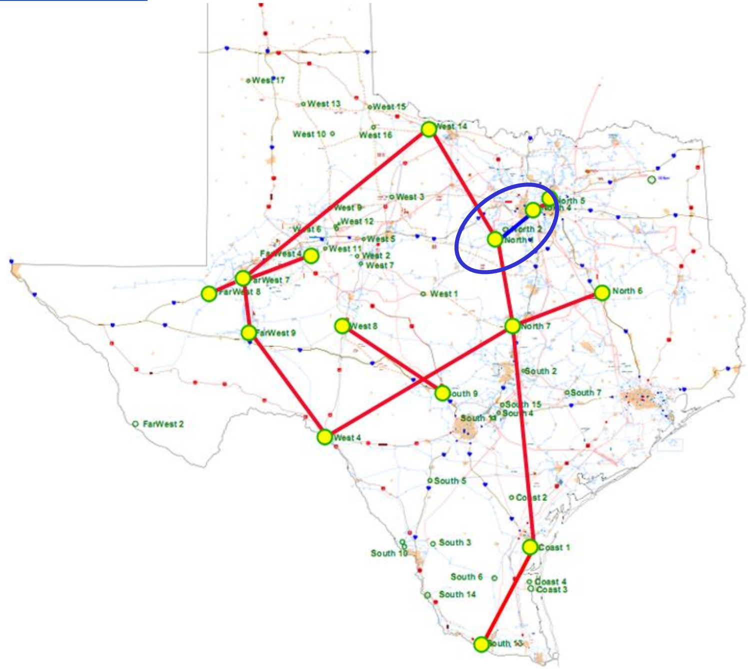


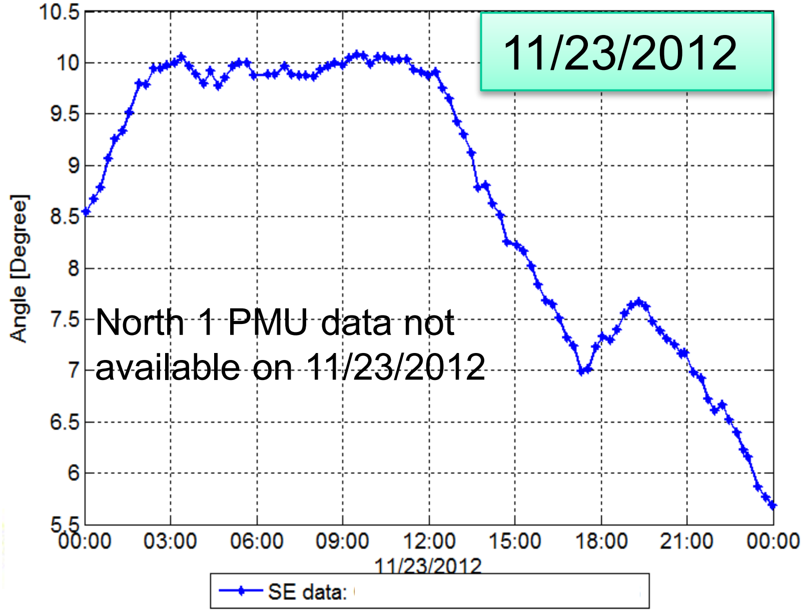


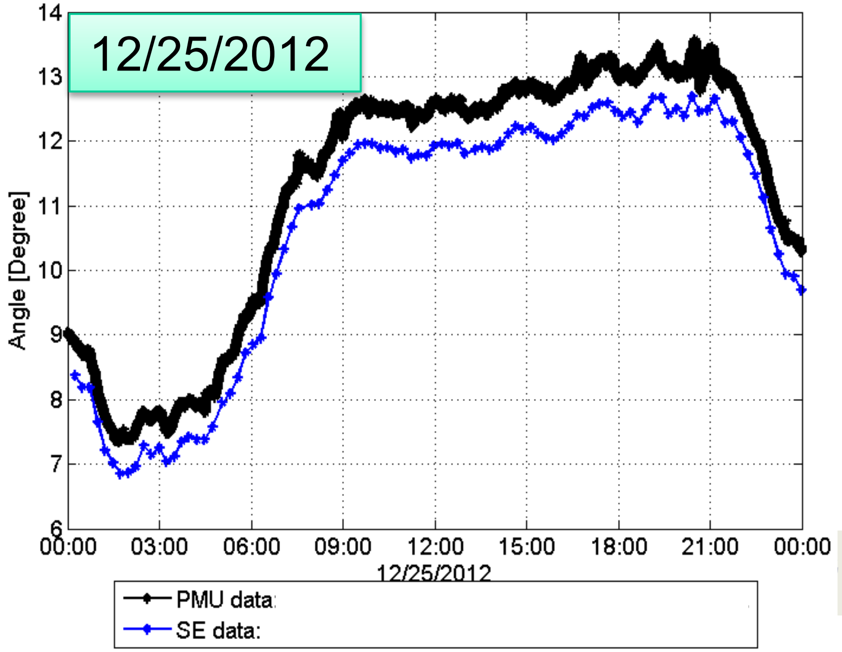


North 1-North 4

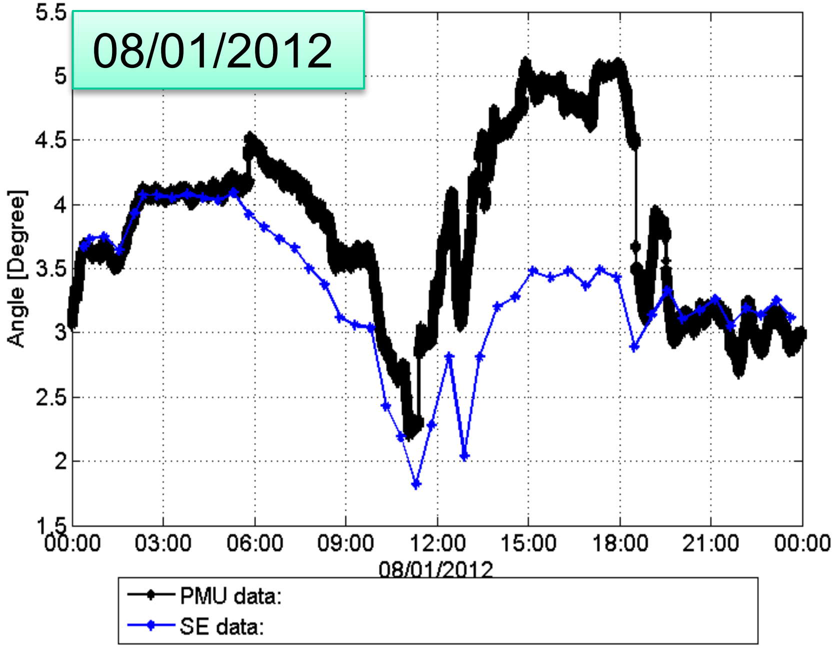


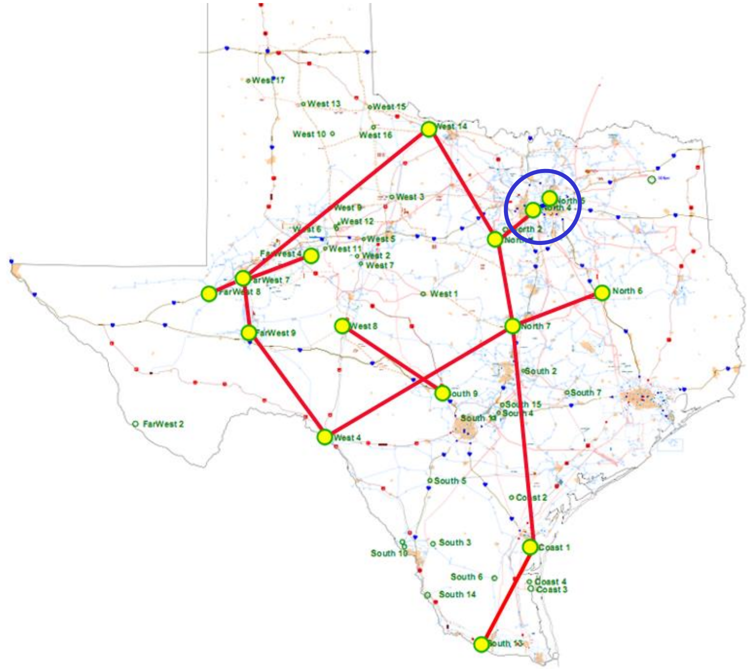


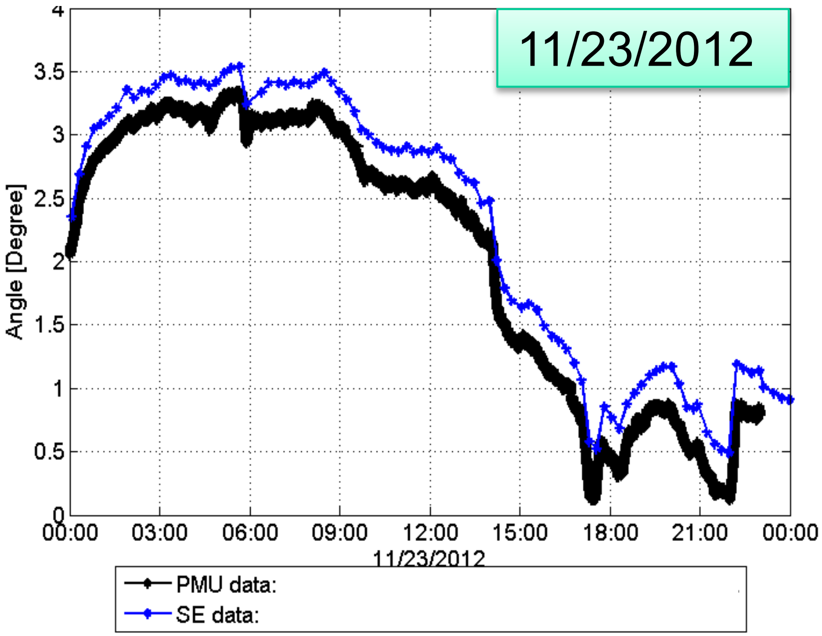


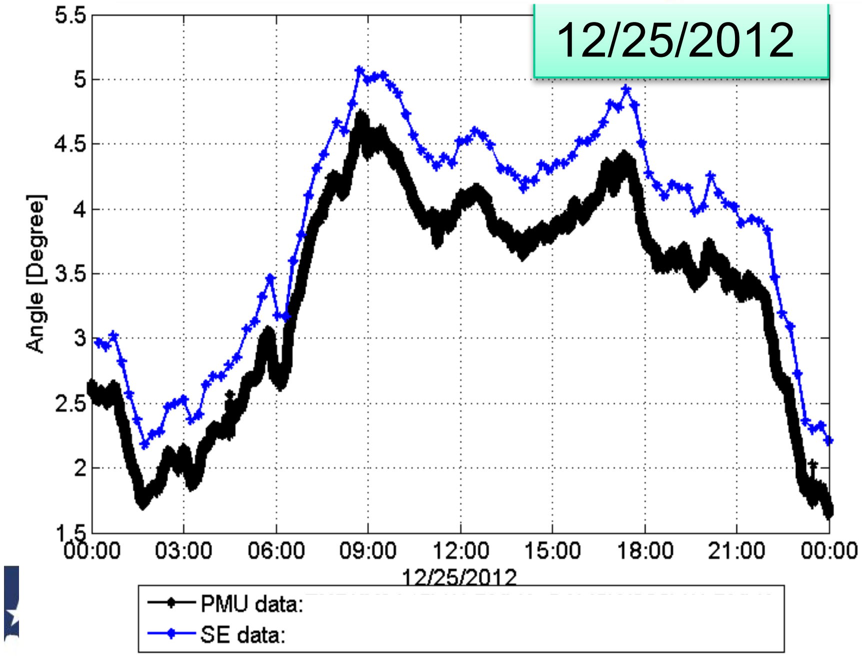


North 4-North 5

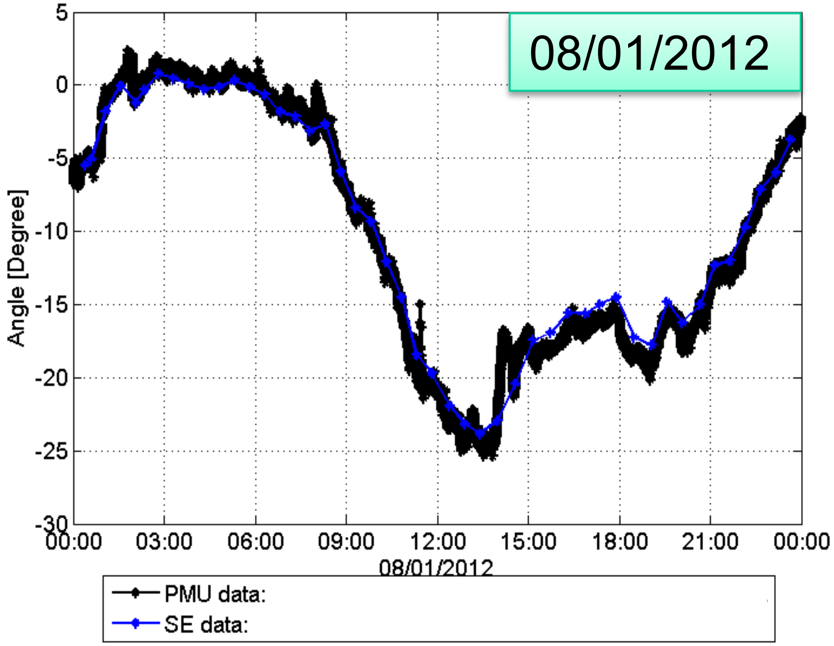


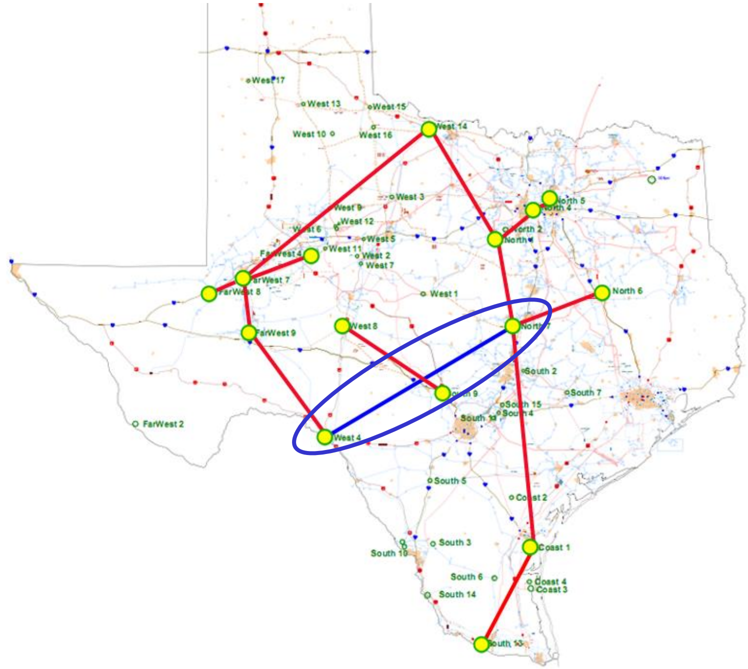


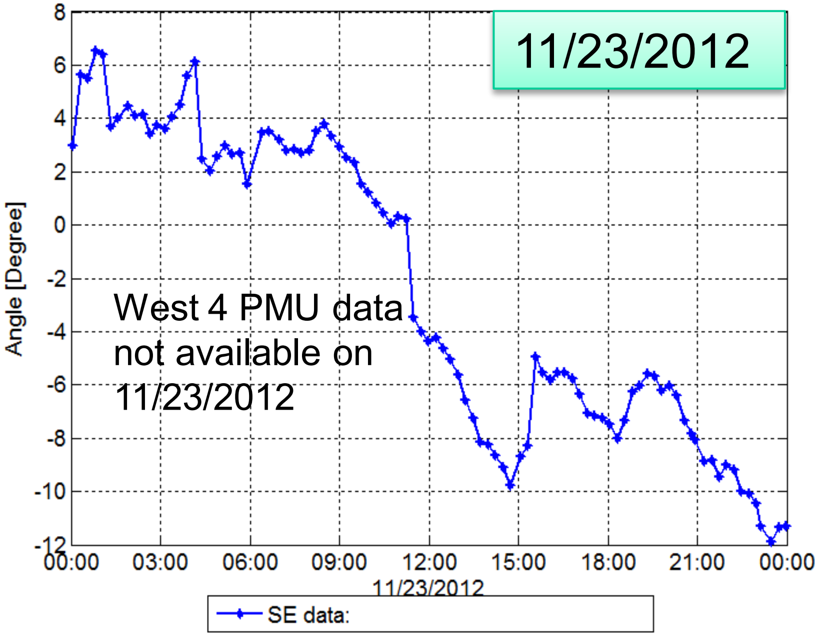


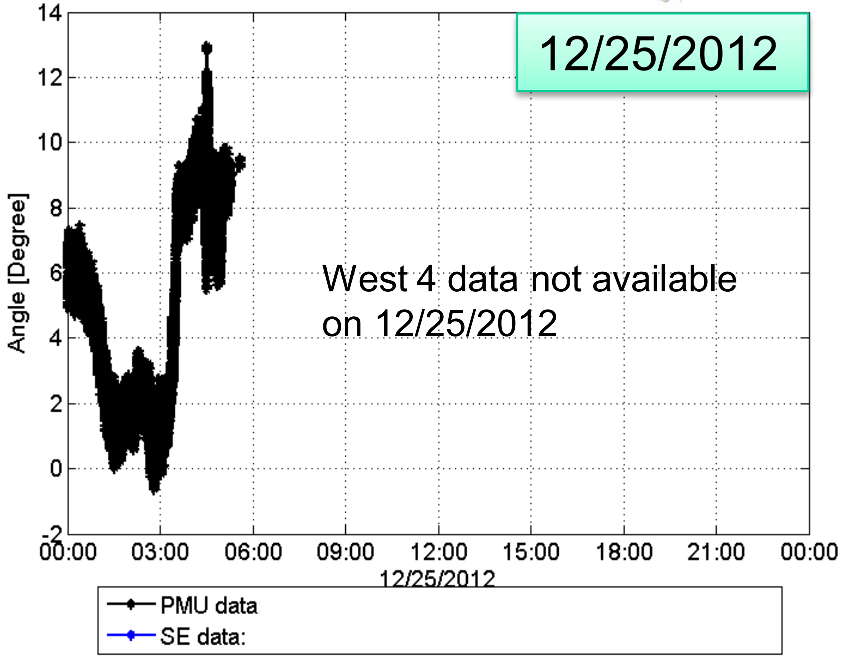


West 4-North 7

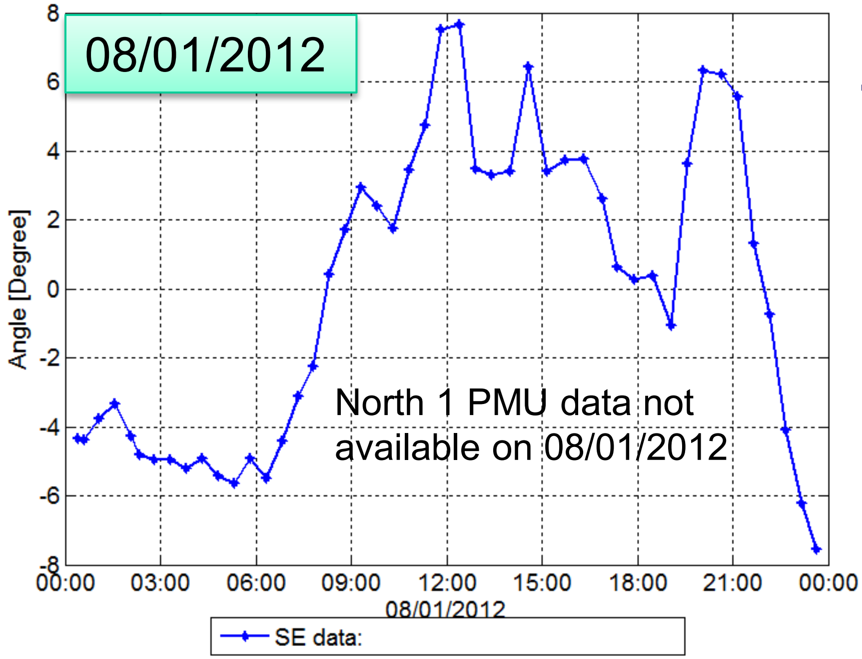


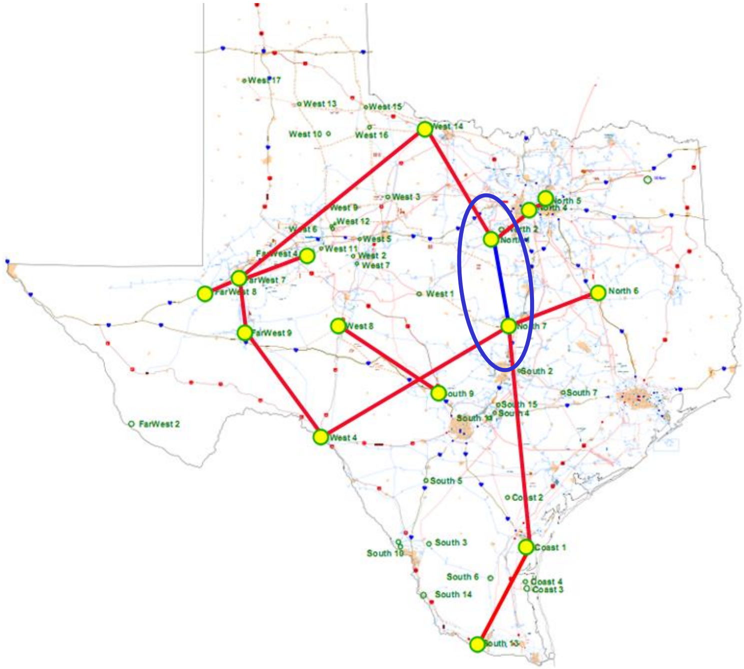


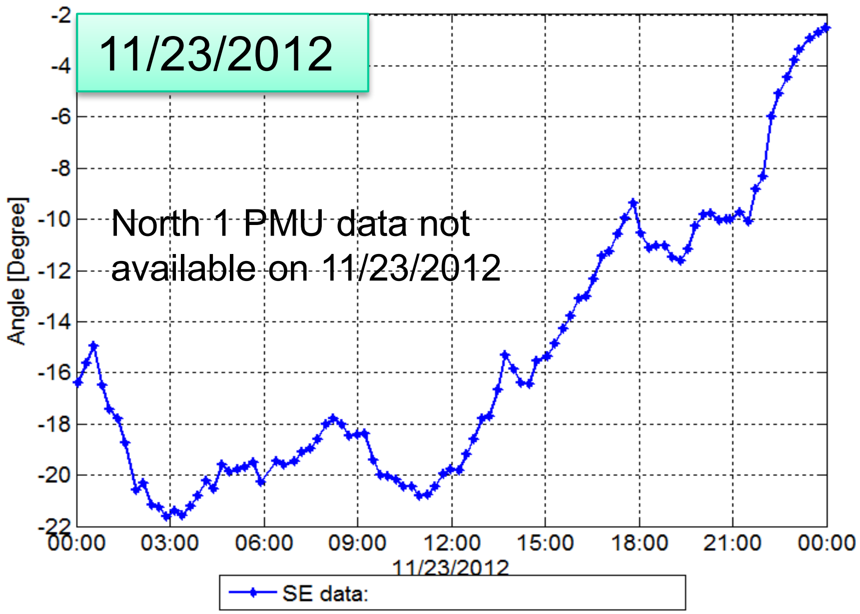


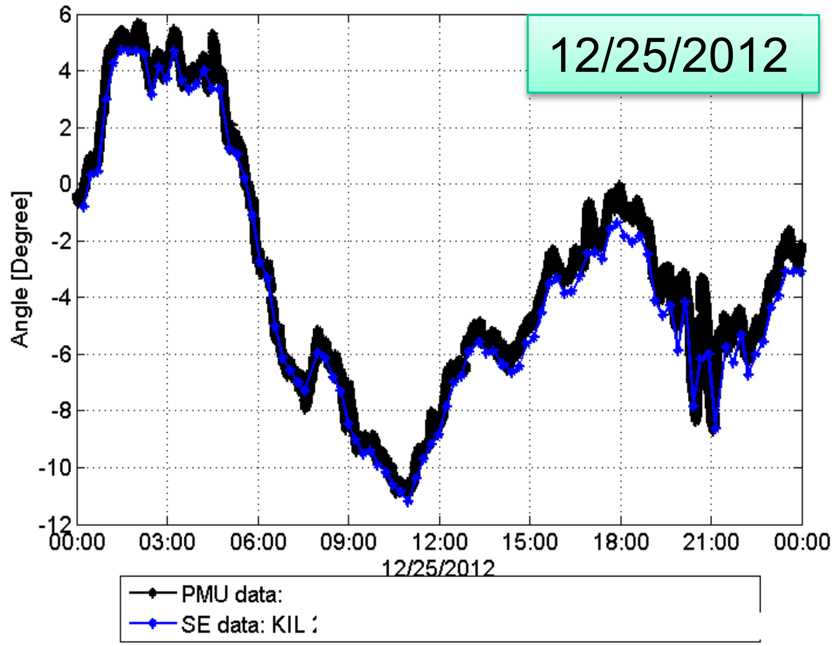


North 7-North 1

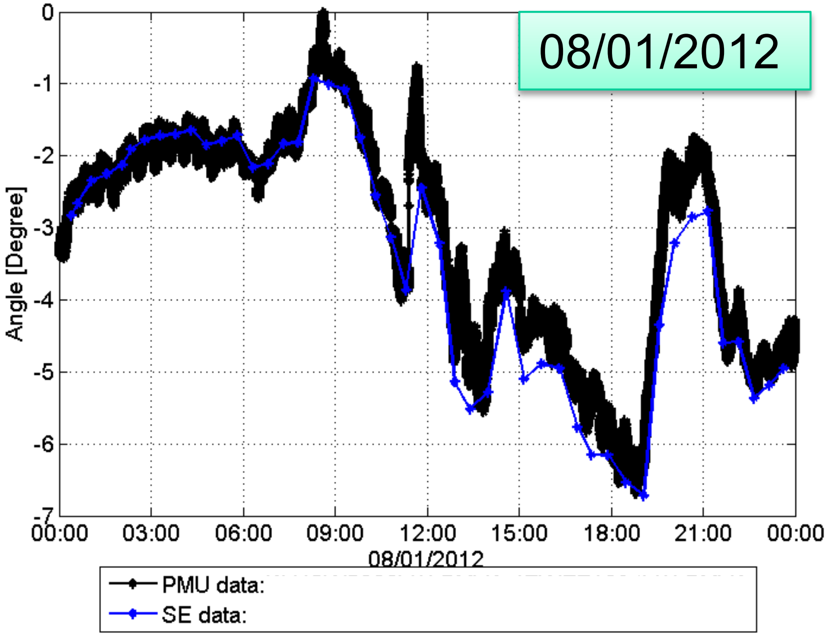


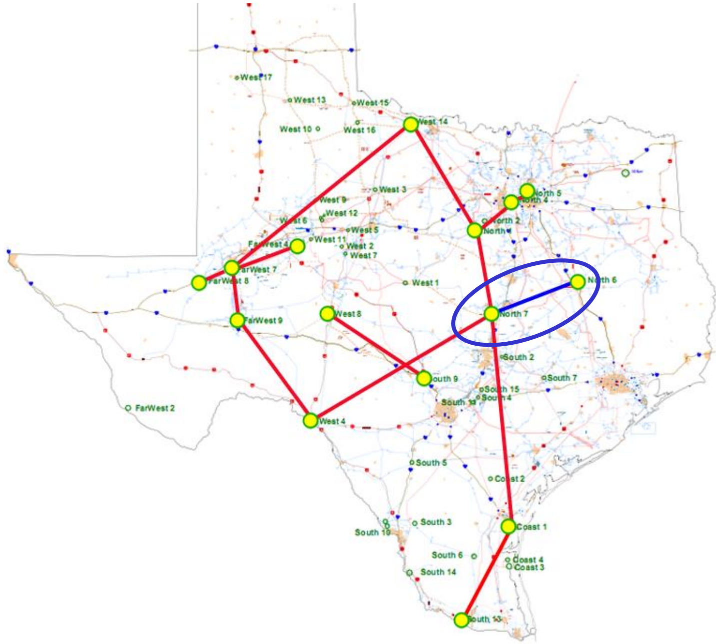


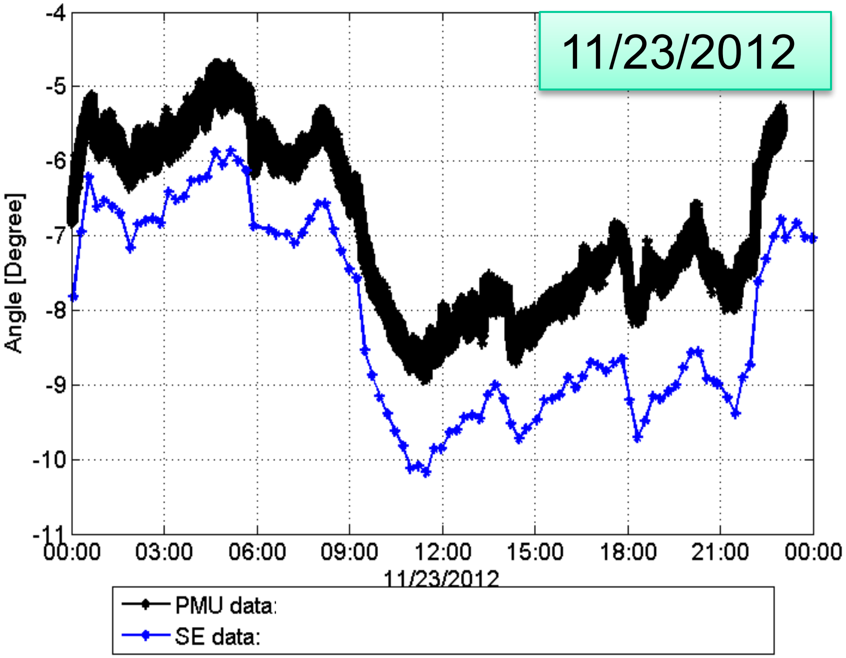


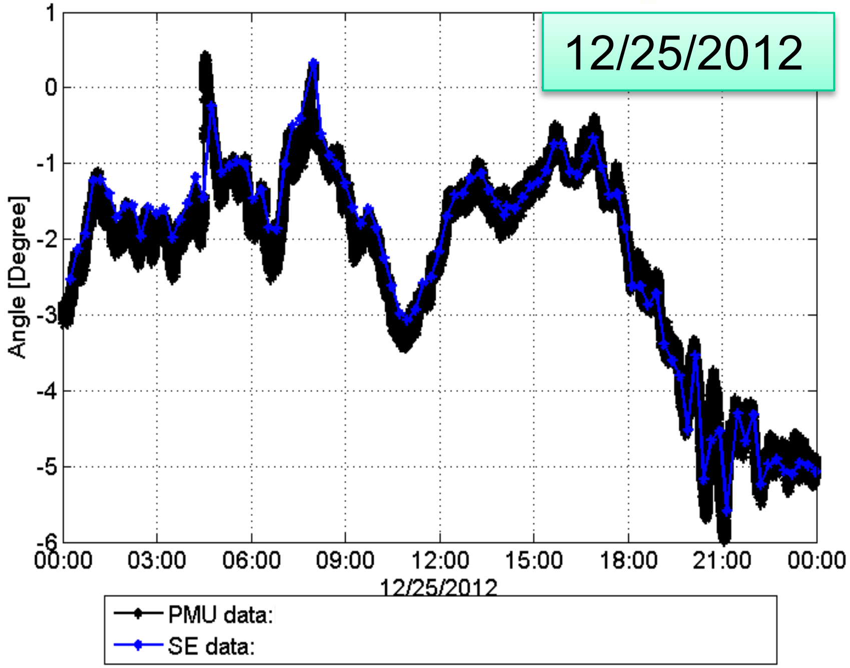


North 7-North 6

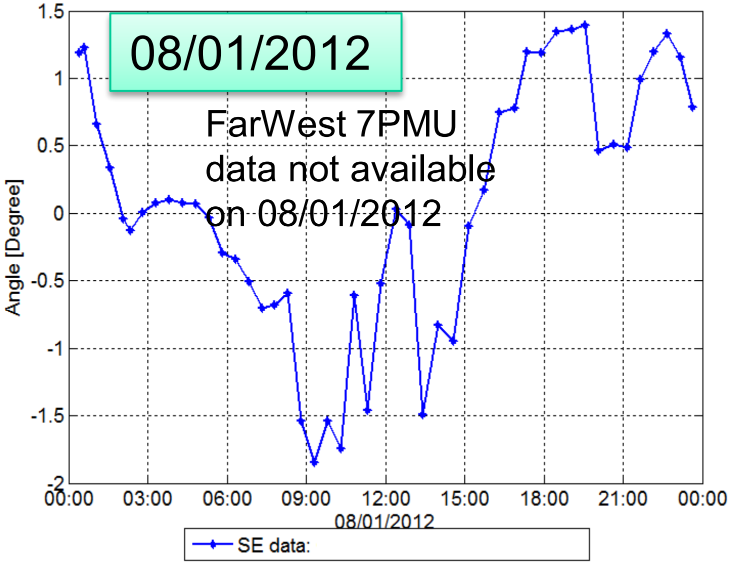


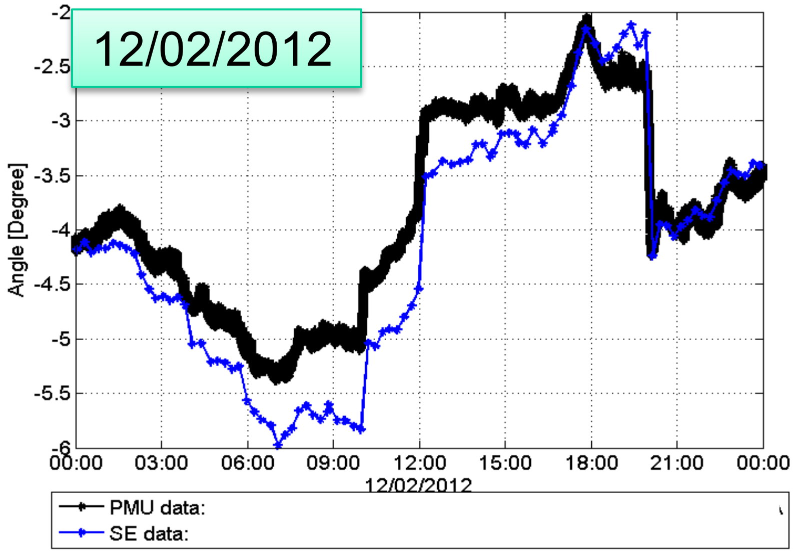


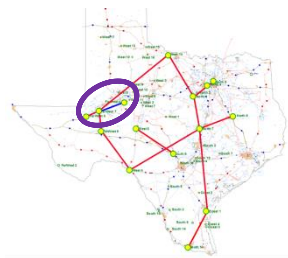


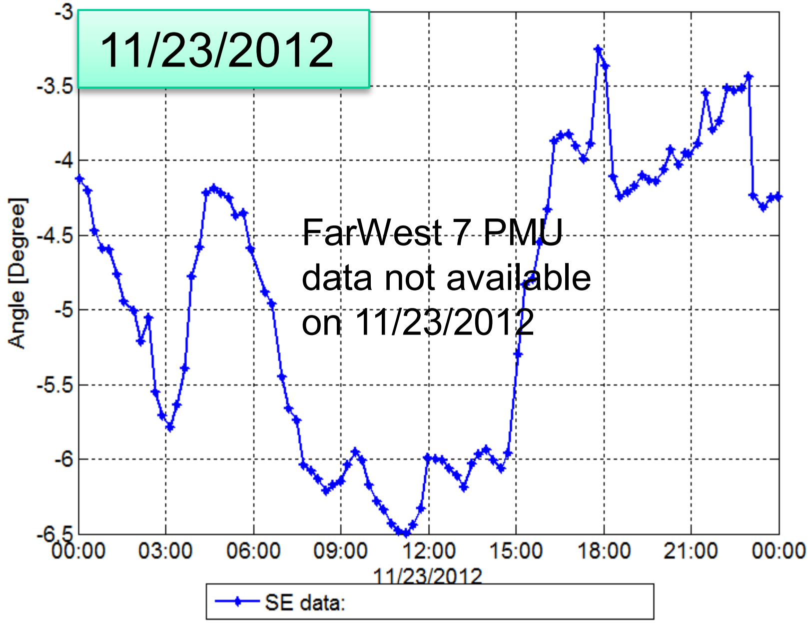


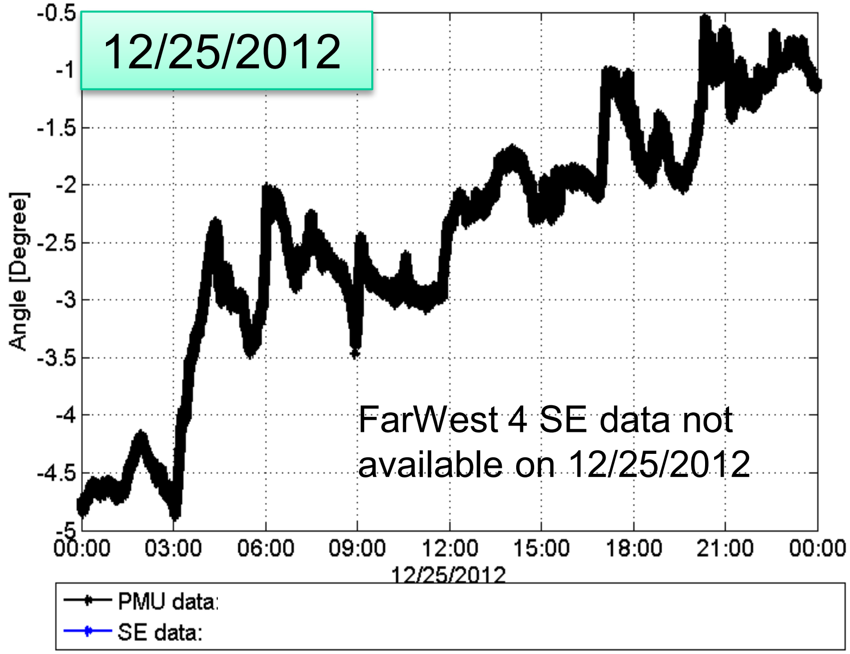
FarWest 7-FarWest 4











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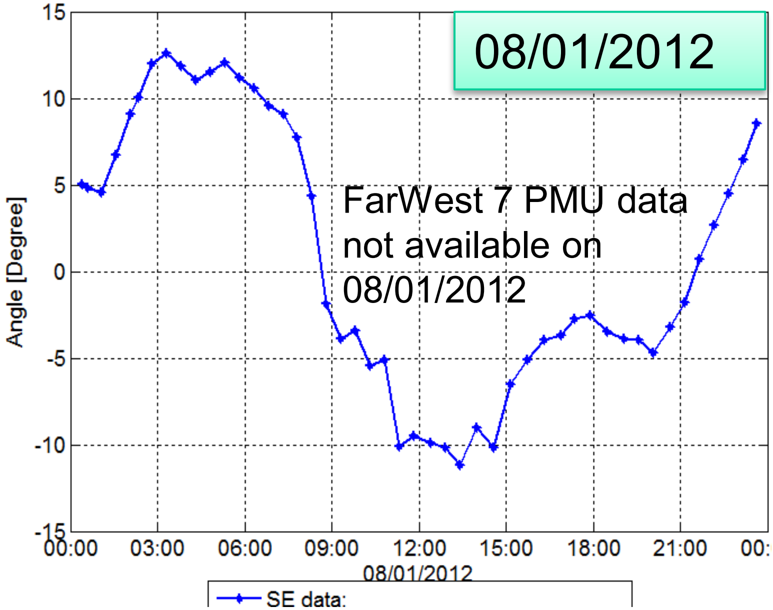
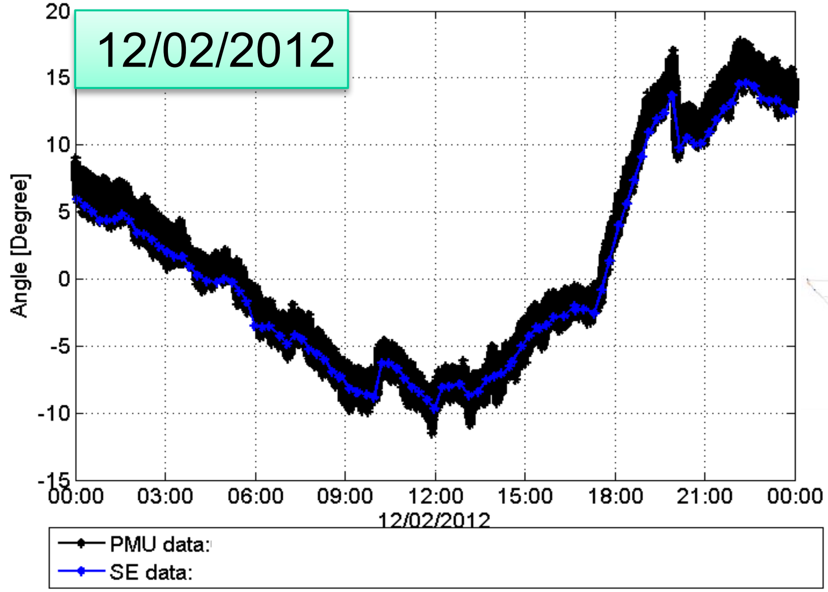
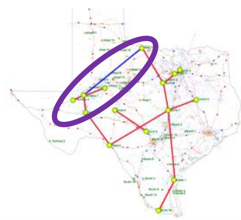
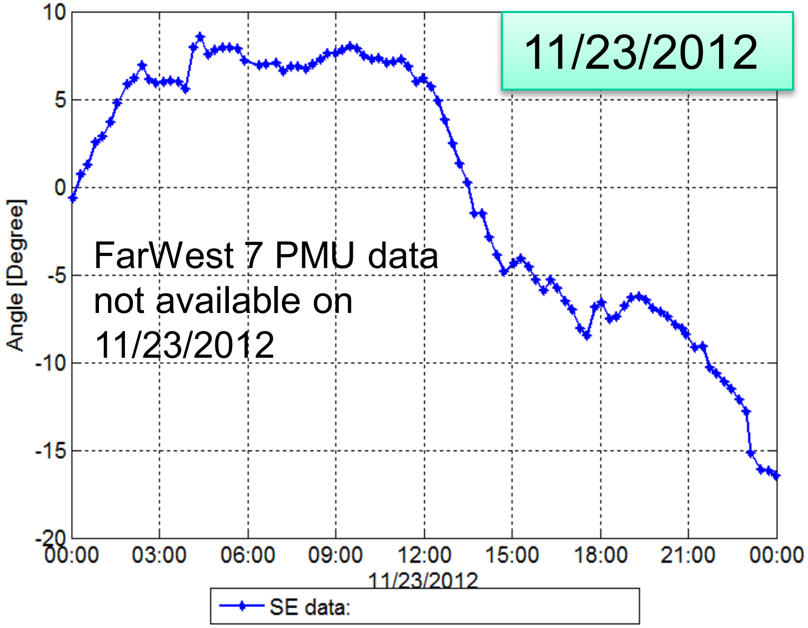
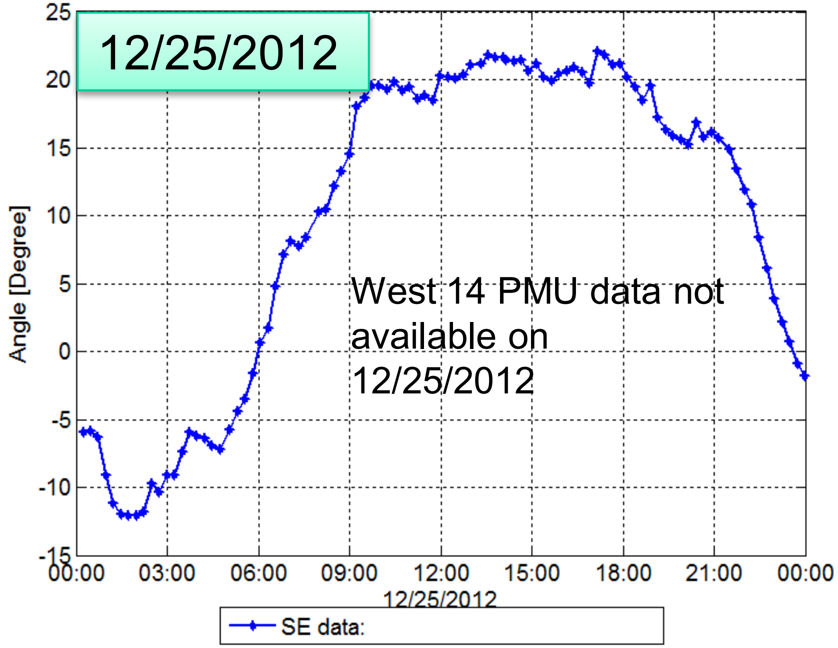
FarWest 7-West 14



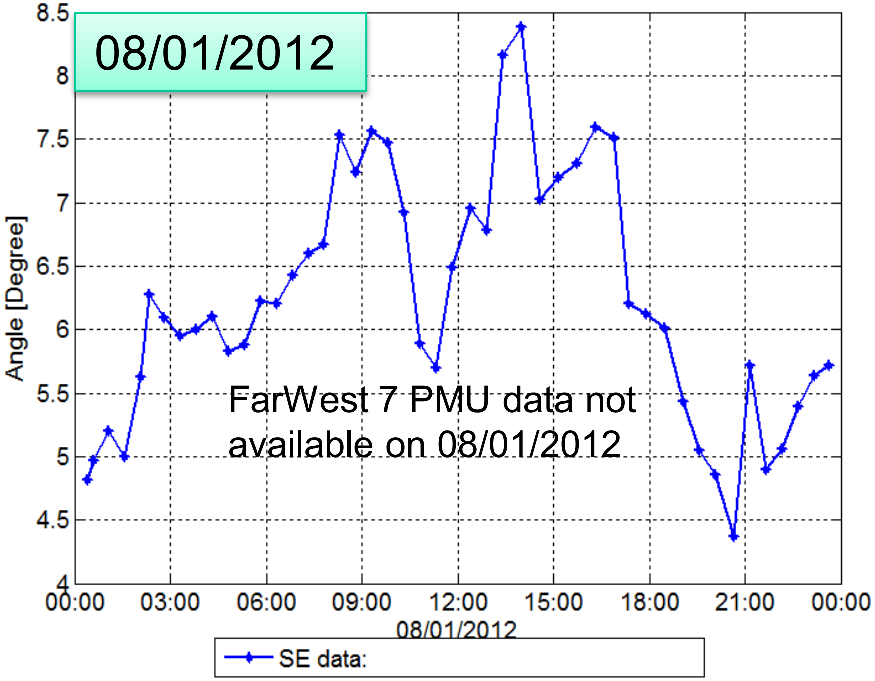


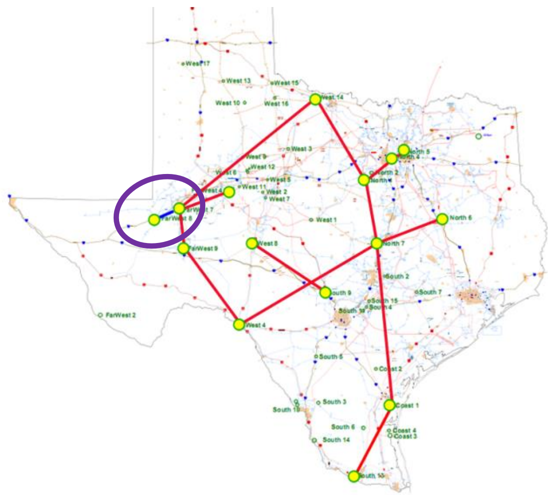


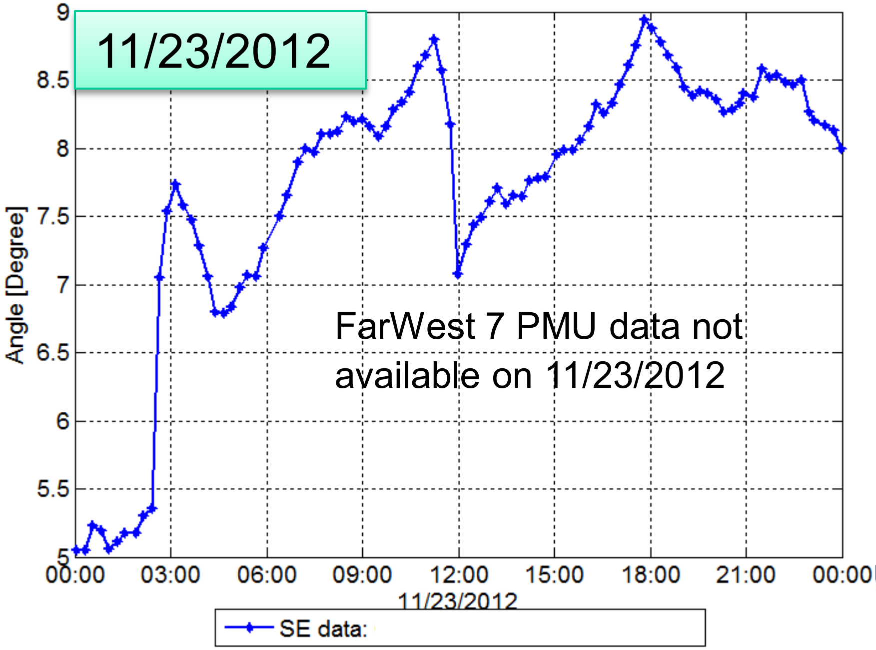


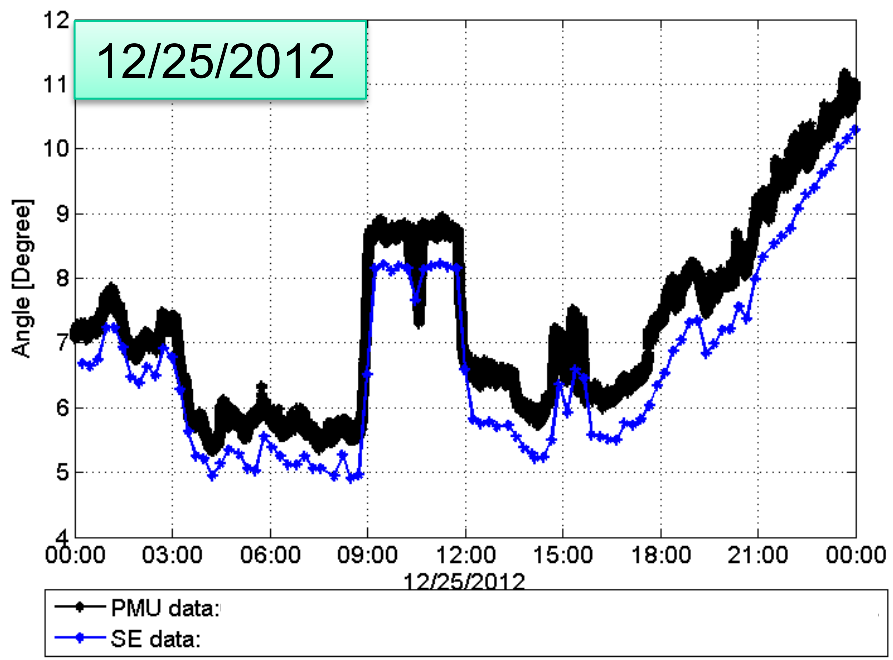


FarWest 7-FarWest 8









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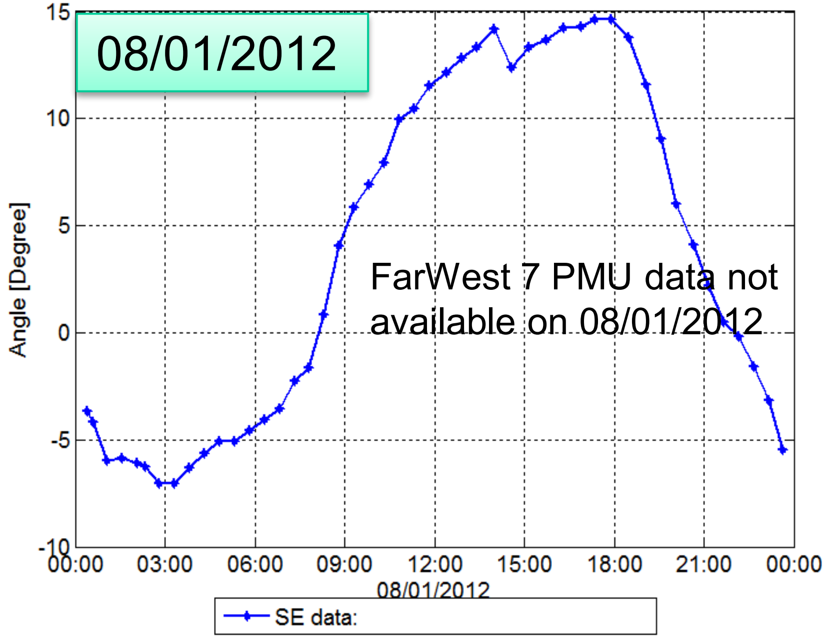
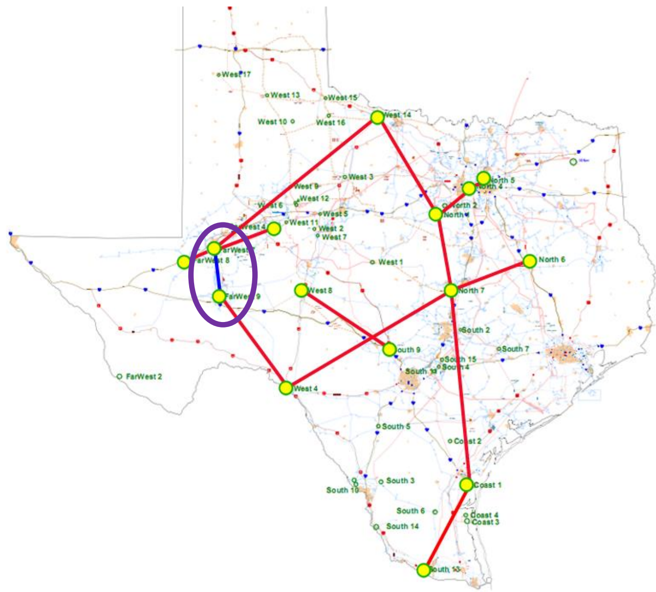
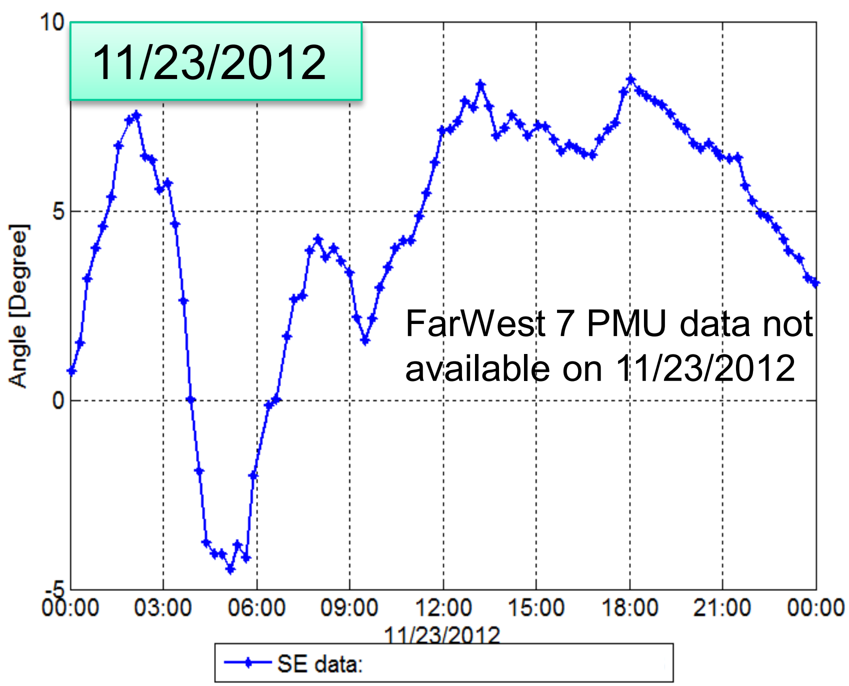
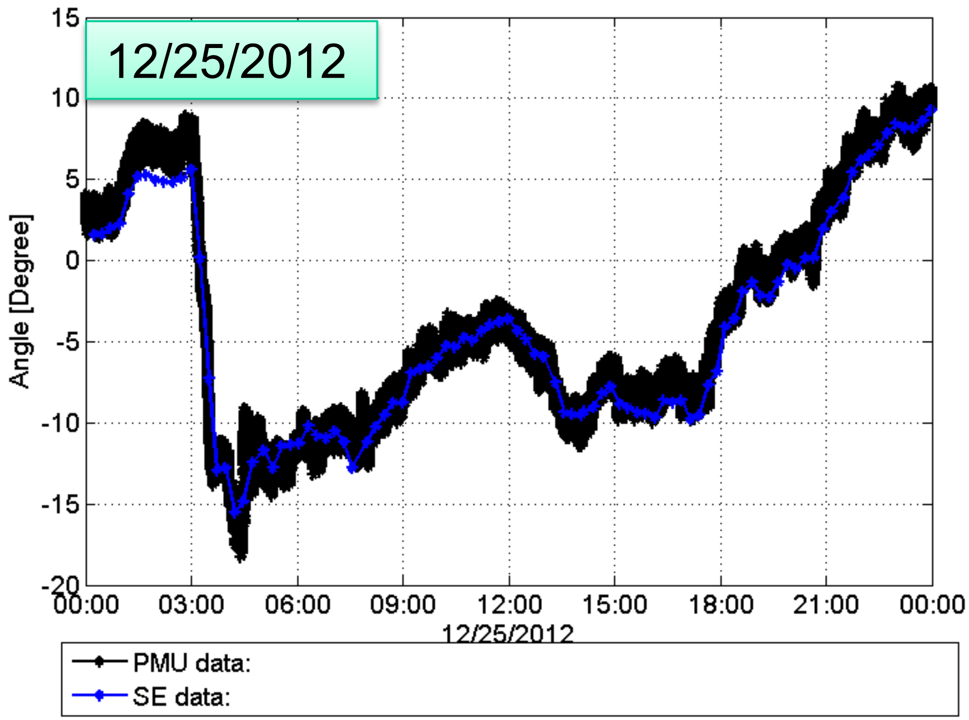
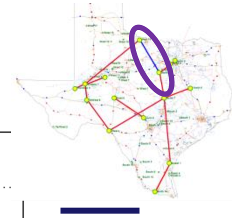


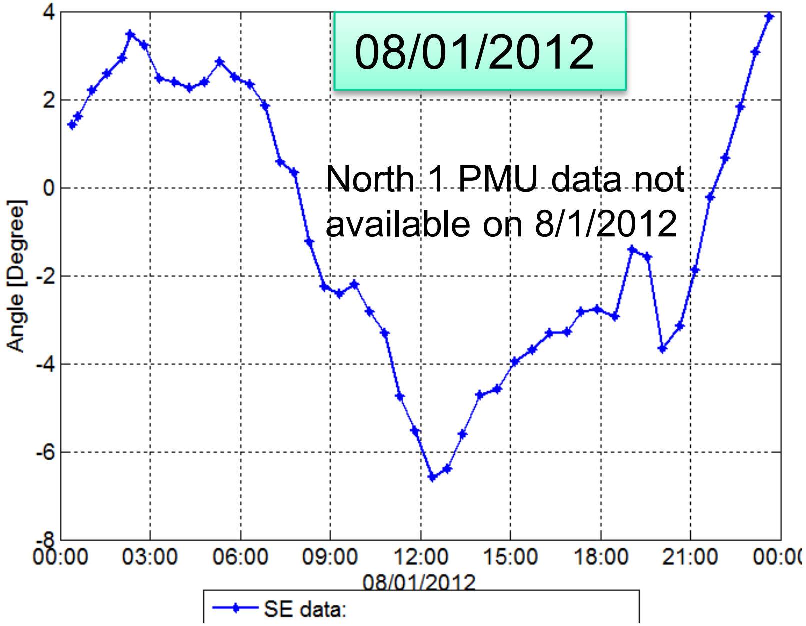


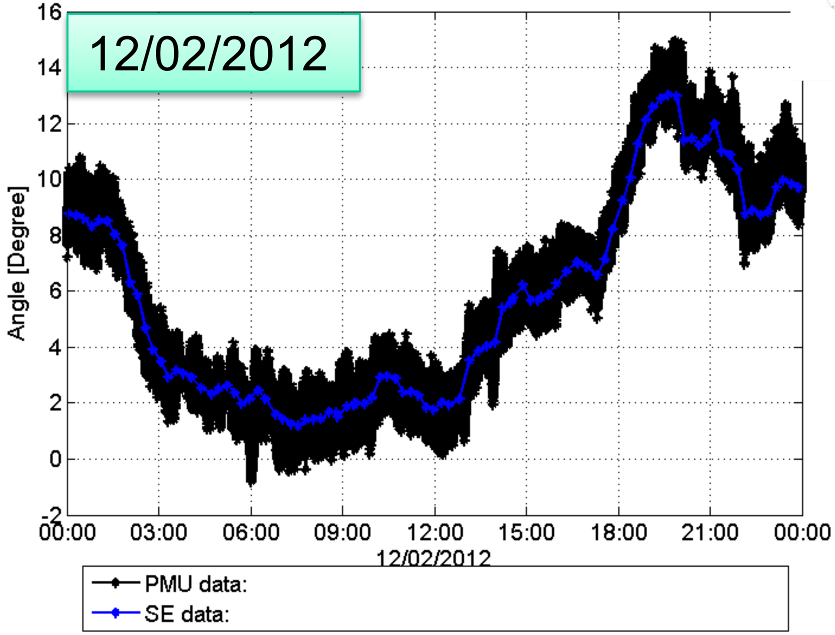


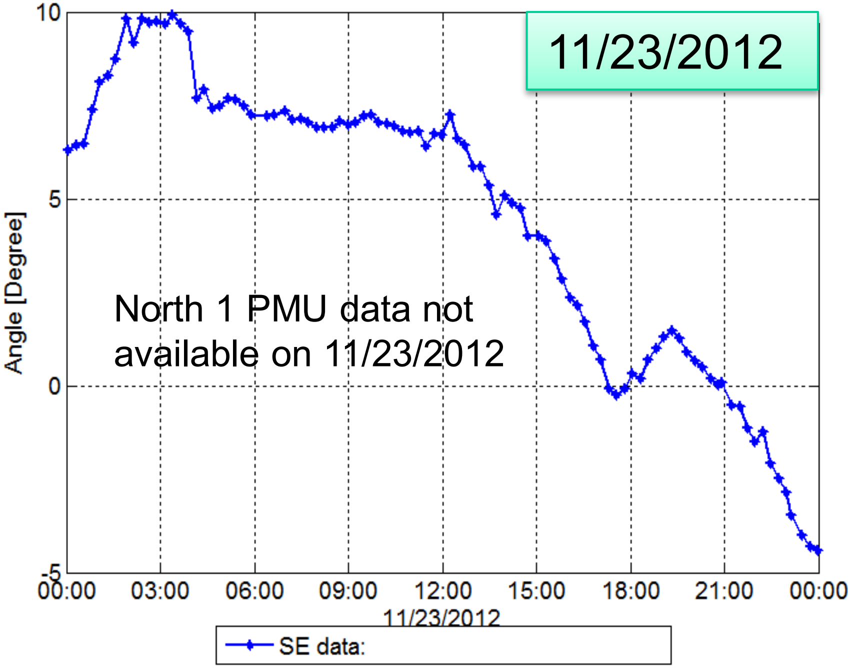


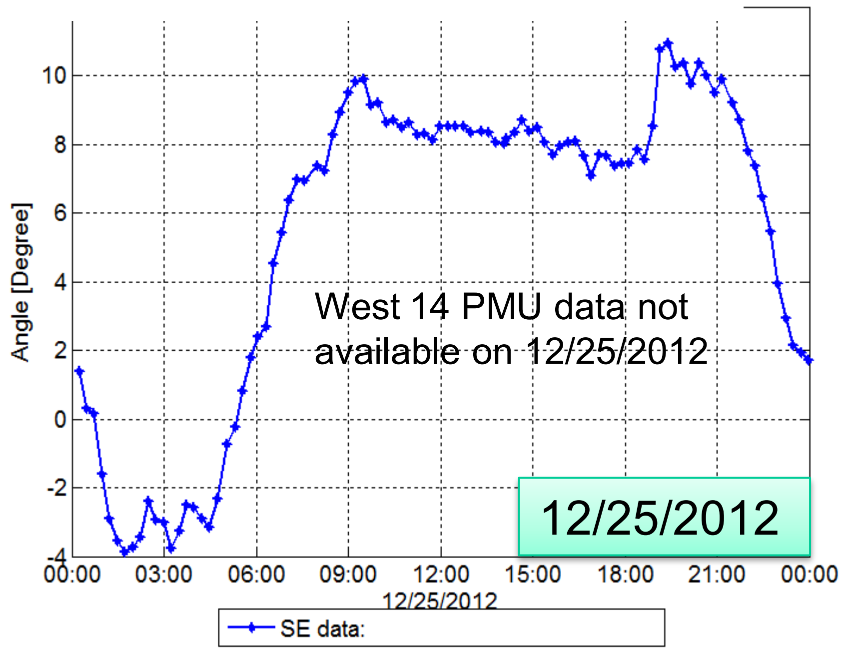
West 14-North 1



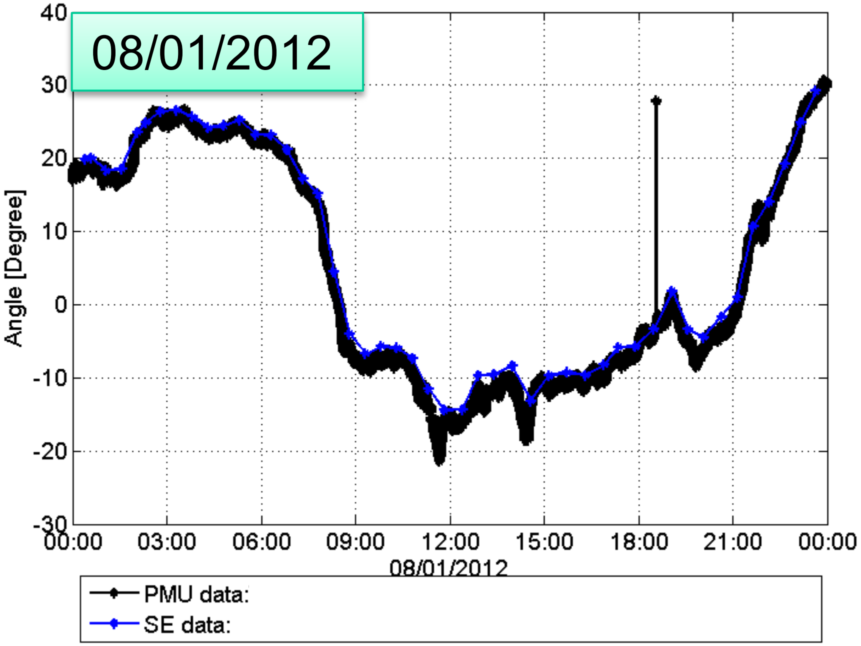


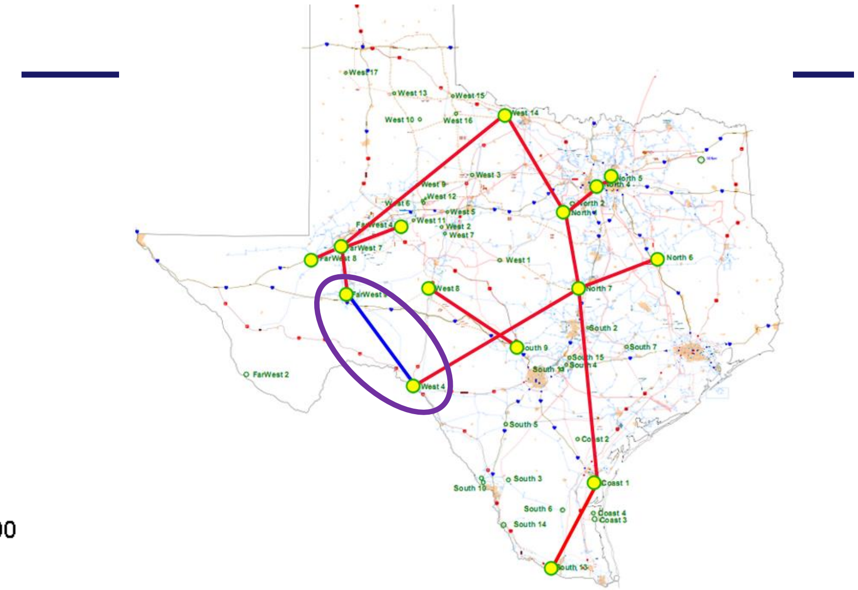


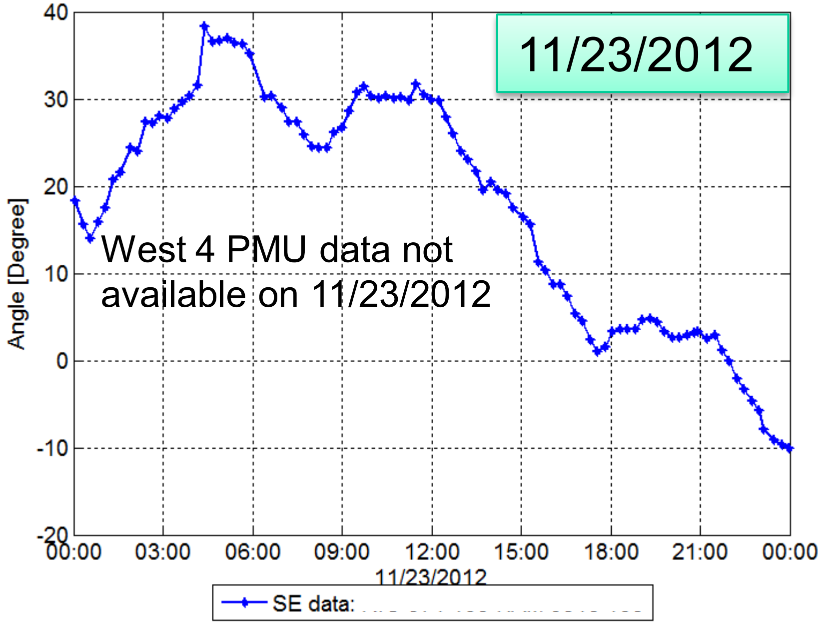


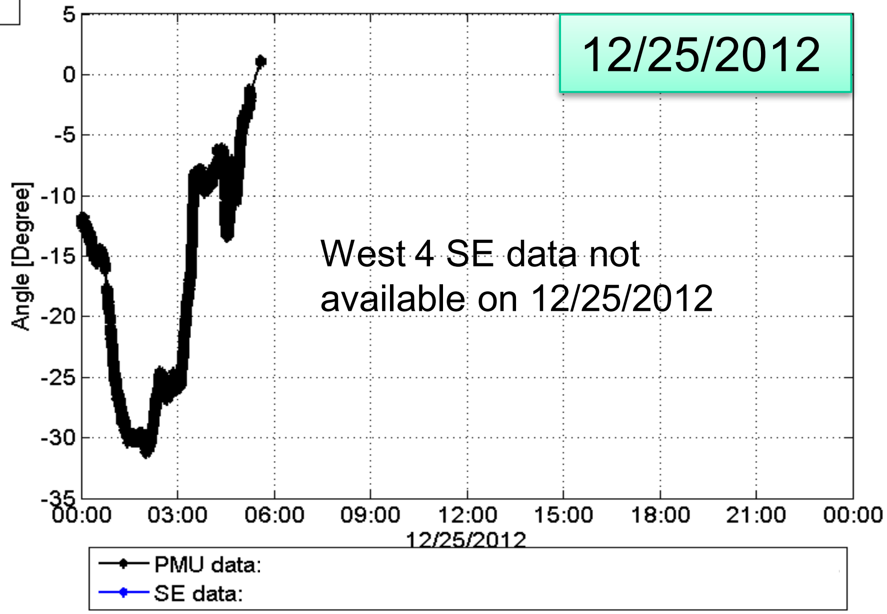


FarWest 9-West 4

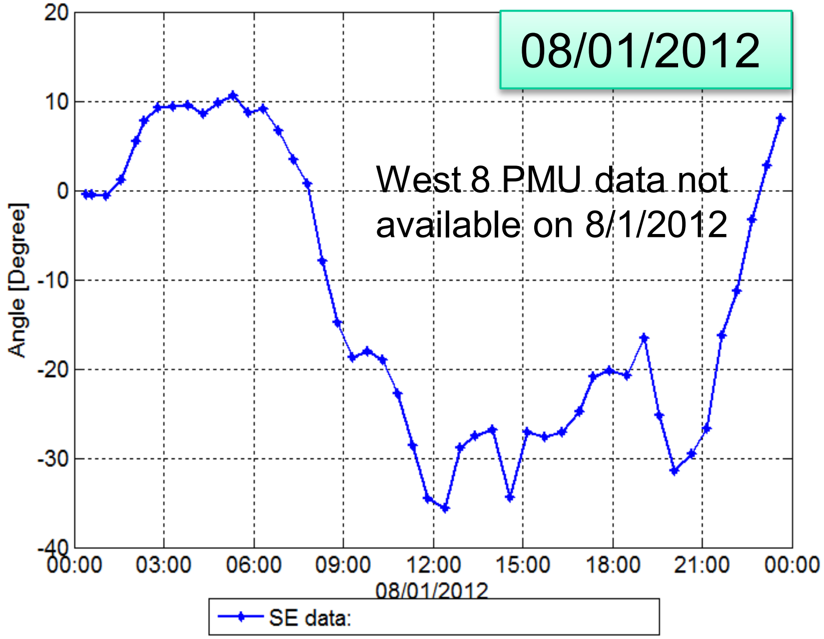


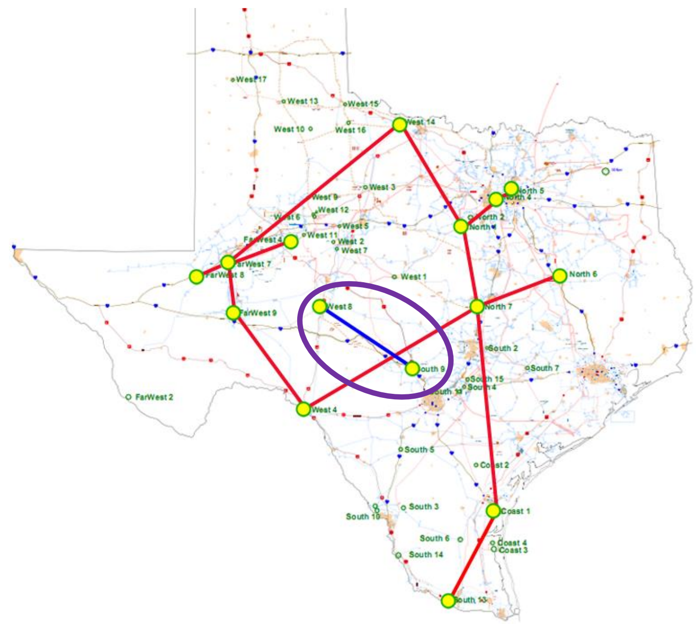






West 8-South 9





West 8 PMU and SE data not available on 11/23/2012

West 8 PMU and SE data not available on 12/25/2012

Appendix C

Baseline Analysis - Voltage Magnitudes Box Whiskers and Time Duration Curves

For: CCET Discovery Across Texas Project

Available Upon Request

External Version

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Appendix D

Baseline Analysis - Voltage Angles (Reference: North 7) Box Whiskers and Time Duration Curves

Phasor Data

Available Upon Request

External Version

Appendix E

Baseline Analysis – Angle Differences Box Whiskers and Time Duration Curves

For: CCET Discovery Across Texas Project

Available Upon Request

Attachment 2. Updated Cluster Analysis for First Half of 2013

Center for Commercialization of Electric Technologies -- Discovery Across Texas

Cluster Analysis Update
Period of January - June, 2013

Submitted By:

Electric Power Group

Romulo Barreno
Ajay Das
Song Xue

August 20, 2013

External Version

TABLE OF CONTENTS

1. INTRODUCTION

Electric Power Group, LLC (EPG) was awarded a portion of contract DE-FOA-0000036 by the Center for the Commercialization of Electric Technologies (CCET) Discovery Across Texas project to provide professional services to, among other things, perform cluster analysis, comparison of phasor data versus state estimator data, and voltage and angle difference baselining. In June 2013, EPG completed a Baselining Study using 2012 data that included the following: (1) grouped substations having phasor measurement units (PMUs) which are geographically close to each other, and performed a voltage and angle difference analysis for each group (cluster analysis); (2) performed a comparison of voltage and angle differences obtained using phasor measurements versus similar results using state estimator data (phasor vs. state estimator comparison); and, (3) performed a baseline analysis for voltages and angle differences for selected pairs of substations (cluster analysis). When all the 2013 data is analyzed, alarm limits will be established and documented based on the baseline analysis.

This report summarizes the cluster analysis results obtained using the January to June 2013 data. This study update was prepared with the addition of new available PMUs (substation) to the groups to cover a wider geographical area.

2. PROJECT SCOPE

The baselining study using 2012 data showed that phase angle differences for lines in Group 1 and some in Group 5 (South 2, South 4, South 11, and South 15) followed each other closely. This update will perform analysis of the six groups to confirm if the results from the 2012 analysis are also true with 2013 data. Activities to be performed as part of this item:

1. Obtain 2013 state estimator data from ERCOT, solve cases received, and extract data for analysis.
2. Group geographically close substations equipped or to be equipped with PMUs; add or subtract substations as necessary.
3. Using state estimator data, analyze voltage angle differences for these groups and document results for two selected days of 2013.
4. Prepare voltage angle difference graphs for the selected substations and pairs.
5. Summarize results.

3. DATA SOURCES

State estimator data was utilized to perform the study update of the cluster analysis of angle differences in the ERCOT network. A description of this data is provided below.

A. State Estimator (SE) Data

ERCOT provided EPG with SE data for the first six months of 2013. EPG used the Power World simulator provided by ERCOT via Power World, to extract approximately 15,330 SE cases. There were eight days for which SE data was not available as shown below:

Dates for which SE data was not available (First six months of 2013)

03/23 to 03/26/2013		4 Days
03/28 to 03/31/2013		<u>4 Days</u>
	Total	**8 days**

B. Data Availability

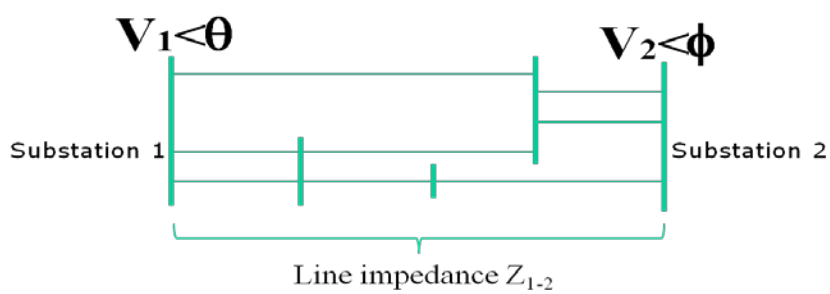
ERCOT produces state estimator cases every 5 minutes for a total of 105,120 possible cases per year. For six months, the total number of possible cases is 52,560; EPG received approximately 15,330 cases, which means the availability of SE data for the first six months of 2013 was approximately 29.2 % of the maximum available data. SE data availability for these six months improved to approximately double that of the 2012 SE data.

The estimated SE data availabilities for the two days of study were:

May 2, 2013	29.5%
June 27, 2013	27.8%

4. CLUSTER ANALYSIS – PHASE ANGLE DIFFERENCES

Voltage phase angle differences are indicators of power flow and direction. Power flows from the higher voltage phase angle to the lower phase angle. Power flow follows voltage angle difference as per the following diagram and equation:



Power flow: $P = V_1 V_2 \sin(\theta - \o)/Z$

Any change in power flow or impedance will be reflected in a change in voltage phase angle difference between two locations.

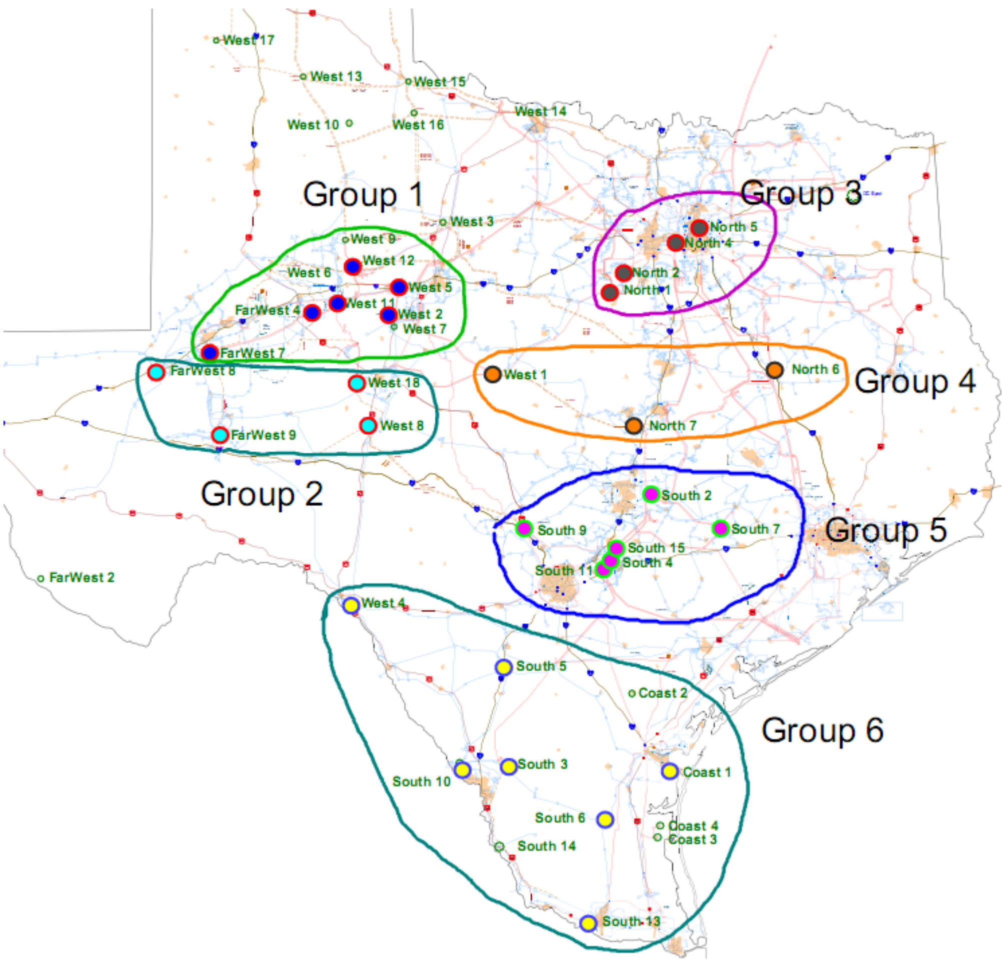
In the 2012 Baselining Study, EPG grouped substations based on geographical proximity as shown in the map and table below in order to find trends regarding angle differences referenced to North 7. The results of the 2012 study showed that there was strong correlation between the substations in Group 1 and between several substations in group 5 (South 2, South 4, South 11, and South 15). The angle difference plots for substations in Group 6 followed similar shapes but were not as close to each other as the substations in Groups 1 and 5. Angle difference plots for the other groups/substations have different, individual patterns. This baselining study update includes a cluster analysis for the same groups with some additions as follows:

Group 1	Add West 12 and remove West 9 and West 6
Group 2	Add West 8 and West 18

Group 3	Add North 1
Group 4	Add West 1
Group 5	No change
Group 6	Add West 4

The cluster analysis update was prepared for two days during the first six months of 2013: May 2, maximum wind output, and June 27, maximum ERCOT system load. The results of this cluster analysis update are shown below. These results corroborate the findings of the 2012 cluster analysis except for South 2. The angle curves for substations in Group 1 track very well with each other and the curves for South 4, South 11, and South 15 substations in Group 5 also track very well with each other (this time South 2 did not track all that well with these three substations). All other substations in this Group 5 and in other groups have their own unique behavior.

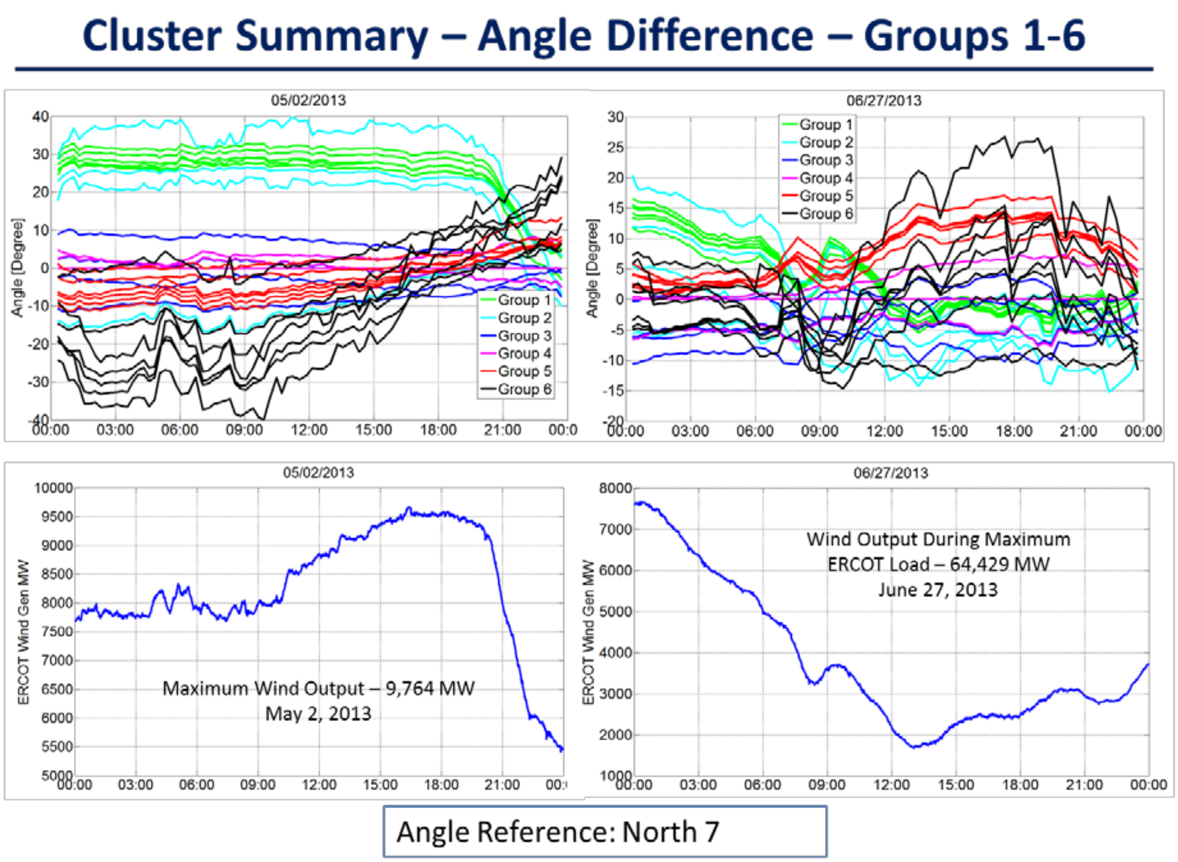
Below is a map with the geographical location of the substations in the groups and below it are listed the six groups and the substations in each group.



GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6
a. FarWest 4	a. FarWest 8	a. North 1	a. North 6	a. South 2	a. Coast 1
b. FarWest 7	b. FarWest 9	b. North 2	b. North 7	b. South 4	b. South 3
c. West 2	c. West 8	c. North 4	c. West 1	c. South 7	c. South 5
d. West 5	d. West 18	d. North 5		d. South 9	d. South 6
e. West 11				e. South 11	e. South 10
f. West 12				f. South 15	f. South 13
					g. West 4

5. RESULTS

A summary of angle difference plots by groups is shown below:



Review of this graph shows that the angle differences for the substations in Groups 1 and 2, which are close to the wind farms, follow the pattern of the wind output curves shown at the bottom of the graph. Further, it appears that the angles for the substations in Group 6 begin increasing after 9 a.m. on both days, presumably to meet the increasing load for the day. On May 2, these angles keep steadily increasing to follow the load but, at the end of the day, when the load goes down, these angles are still growing, probably to compensate for the reduction in wind output which started at about 8 p.m. that day (5,000 MW by midnight). On June 27 the angle for substations in Group 6 began increasing at about noon time, but this time began to come back down at about 8 p.m. when the load decreased and wind output increased to about 3,700 MW at midnight that day. Note also the wind curve for May 2 shows a bump of almost 2,000 MW between 10:30 a.m. and 8 p.m. which is not reflected in the angle curves for Groups 1 and 2 which stay constant for most of the day and begin to come down at about 8 p.m. This observed behavior seems to be the result of interaction between wind production in west Texas, load in Texas, and conventional generation in the south and other parts of Texas.

The angles for the substations in Group 6 share similar patterns, but are separated from each other by several degrees. This is a reflection of the fact they are also physically separated and subject to different levels of generation and load.

More detailed information for each group is presented in Appendix A attached to this report.

6. SUMMARY OF RESULTS – ANGLE DIFFERENCES

a. **Data Availability Improved**: ERCOT provided state estimator data for the first six months of 2013. This time the average availability improved from about 13% for 2012 data to 29.2% for the six months in 2013.
b. **Angle Differences Track Wind Output**: Cluster analysis for 2013 confirms that the angle difference plots for the substations close to the wind farms track well with the wind output graphs.
c. The angles for the substations near the wind farms in the western part of Texas for the maximum wind output day of May 2, 2013, were in the 25 to 33 degree range most of the day. All of these angles dropped to 5 degrees or below by the end of the day as the wind generation decreased.
d. In Group 2, the FarWest 9 to North 7 pair operated between 30 to 40 degrees most of the day on May 2, 2013; at the end of the day it dropped to about -7 degrees. The shape of the West 8 to North 7 pair was different in the plot for May 2; in the plot for June 27 it was closer to the other plots in the group. The West 18-West 8 line went in service on May 23, 2013, which is in between these two dates, and could have affected the relationship between West 8 and North 7. On June 27, this pair operated in the -10 to 0 degree range.
e. In Group 3, the North 2 to North 7 pair behaves different from the other pairs in the group. Its behavior is more like those curves in Group 5; this difference could be caused by power deliveries across the East DC tie near North 8.
f. In Group 4, the North 6 to North 7 pair is always positive (always providing power to North 7) whereas the West 1 to North 7 pair varies from positive to negative during the high wind day and is always negative during the high load day.
g. The angle pairs in the San Antonio-Austin area began the high wind day with negative angles and ended with positive angles by the end of the day when the wind output went down. During the peak load day (June 27), these pairs were all positive indicating the power was flowing northbound from these substations.
h. For Group 6, most of the curves in this group, except for West 4, were negative at the beginning of the day on May 2 when the wind output was strong; South 13 at the southern end of Texas fluctuated widely from -40 degrees at about 10 a.m. to about 22 degrees by the end of the day. During the peak load day, the pairs in this group seem to be responding to wind output in the

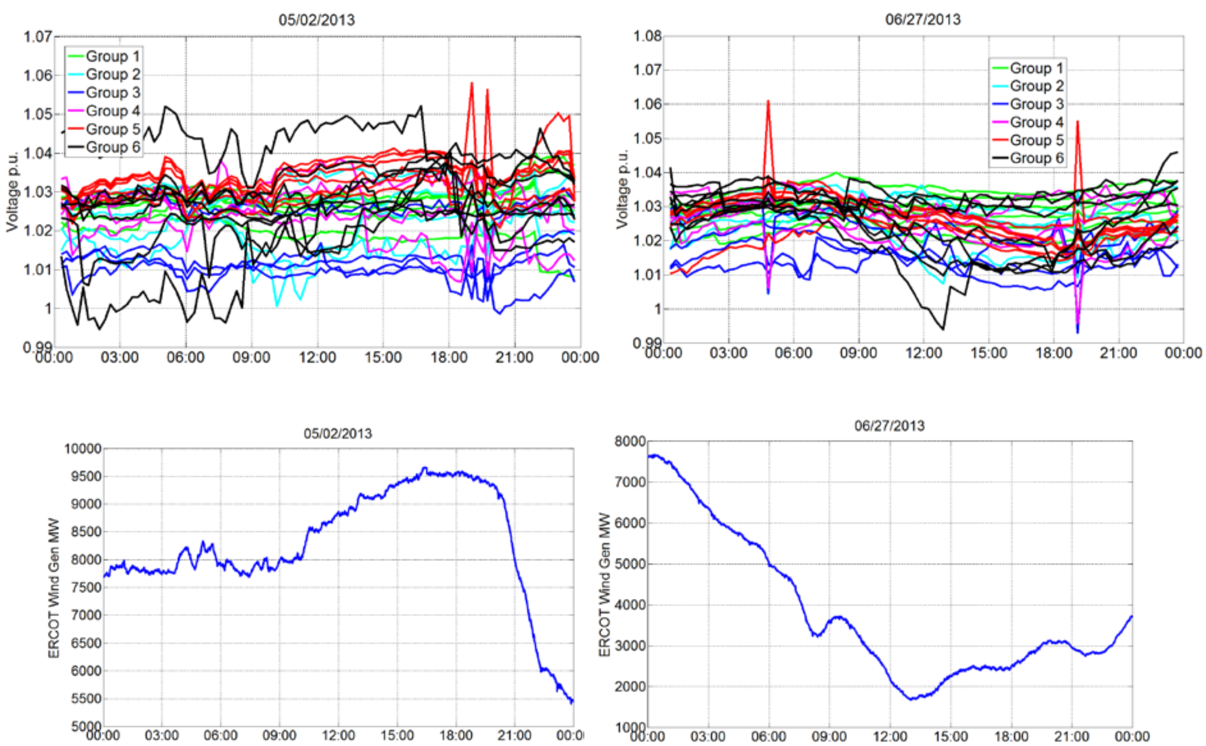
morning, to load increase in late morning to late afternoon, and to load decrease and mild wind increase in the evening.

7. CLUSTER ANALYSIS – VOLTAGE MAGNITUDES

Using the same six groups as for the phase angle difference analysis, EPG performed a voltage magnitude cluster analysis. The cluster analysis update for voltage magnitudes was prepared for the two days used in the angle difference analysis: May 2, maximum wind output, and June 27, 2013, maximum ERCOT system load. A summary of the resulting graphs of this voltage magnitude cluster analysis update are shown below. More detailed graphs are shown in Appendix B.

Observation of these graphs show that most of the voltages during the peak load day (June 27) fluctuated in the 1.01 to 1.04 per unit (pu) range whereas for the maximum wind output, low load day (May 2), the voltages operated within a wider range: 1 pu to 1.05 pu. South 7 experienced upward spikes of up to 8 kV during both days, reaching 366 kV at times. West 1, North 4, and FarWest 8 experienced downward spikes of lesser magnitude.

Cluster Summary-Voltage Magnitudes: Groups 1-6



8. SUMMARY OF RESULTS – VOLTAGE MAGNITUDES

a. **Group 1**: All voltages, except FarWest 7 in group 1, operated between 1.02 to 1.032 most of the day on May 2; at the end of the day, FarWest 7 voltage went down 1% and the rest of the voltages went up by about 1%. On June 27, the voltages in this group operated in the 1.017 and 1.04 range. The highest voltages were at West 2 and the lowest voltages at FarWest 7.

b. **Group 2**: On May 2, voltages in this group operated in the 1.00 to 1.03 pu range with FarWest 9 fluctuating the most between 1.027 and 1.00 pu. On June 27, the voltage at FarWest 8 spiked down 1% at about 5 a.m. The West 8 voltage stayed high until 9 a.m. and then went down to about 1.015 in the early afternoon and stayed low until about 7 p.m.
c. **Group 3**: On May 2, the North 4 voltage stayed at around 1.026 and experienced a couple of spikes down about 2% in the late afternoon. On June 27, the North 4 voltage stayed at around 1.026 and experienced a couple of spikes down about 2.5%, one in the morning and one in the afternoon.
d. **Group 4**: Voltages at West 1 spiked down in both days, May 2 and June 27. On May 2, the voltage at North 7 experienced a sudden drop from 1.037 to 1.015.
e. **Group 5**: The voltages at South 7 experienced upward spikes of up to 2.7% in both days of study.
f. **Group 6**: West 4 in May, and South 13 in June, experienced the lowest voltages in the group. In both cases, the voltages fell below 1.0 pu.
g. **Voltage Magnitude Averages**: Below is a table of voltage magnitude averages for the two days analyzed.

Groups 1-6 Daily Average Voltages

		5/2/2013		6/27/2013	
		Average(kV)	Average(p.u.)	Average(kV)	Average(p.u.)
Group 1	FarWest 4	355.15	1.03	354.67	1.03
	FarWest 7	351.85	1.02	352.35	1.02
	West 5*	355.07	1.03	355.43	1.03
	West 2*	355.17	1.03	357.14	1.04
	West 11	354.20	1.03	353.60	1.02
	West 12*	353.43	1.02	355.87	1.03
Group 2	FarWest 8	140.75	1.02	141.49	1.03
	FarWest 9	140.38	1.02	141.62	1.03
	West 8*	142.04	1.03	141.11	1.02
	West 18	142.01	1.03	142.30	1.03
Group 3	North 5	139.65	1.01	140.17	1.02
	North 1	139.64	1.01	140.22	1.02
	North 2	139.21	1.01	139.96	1.01
	North 4	141.64	1.03	141.32	1.02
Group 4	North 6	142.05	1.03	142.40	1.03
	North 7	140.96	1.02	141.79	1.03
	West 1*	141.41	1.02	140.83	1.02
Group 5	South 7*	355.45	1.03	355.29	1.03
	South 9*	355.76	1.03	351.98	1.02
	South 11*	357.15	1.04	354.68	1.03
	South 2*	354.61	1.03	353.50	1.02
	South 4*	357.00	1.03	354.70	1.03
	South 15*	356.73	1.03	354.26	1.03
Group 6	Coast 1	140.74	1.02	142.57	1.03
	West 4	140.56	1.02	141.62	1.03
	South 10*	141.57	1.03	142.35	1.03
	South 13	141.29	1.02	140.61	1.02
	South 3*	143.82	1.04	142.44	1.03
	South 5*	142.12	1.03	140.82	1.02
	South 6*	142.37	1.03	141.68	1.03

Conclusions from the above table include:

a. The lowest average voltage among 138 kV substations occurred in Group 3 which includes the Dallas load and the North 1 substation. The average voltage magnitude for this group was 140.04 kV.
b. The lowest average voltage among 345 kV substations occurred in Group 1 which includes the substations near wind farms. The average voltage magnitude for this group was 354.15 kV.
c. Maximum group average voltages observed were in Group 6 (141.78kV) and Group 5 (356.12 kV).
d. Average voltages during peak wind conditions and peak load conditions were very close to each other, except for Group 5 which experienced average voltage of 2.06 kV lower during peak load conditions.
e. The highest substation average voltages observed were at South 11 with 357.12 kV and at South 3 with 143.82 kV.

Appendix A

Center for Commercialization of Electric Technologies -- Discovery Across Texas

Updated Cluster Analysis – Angle Differences

(Ref: North 7)

January-June 2013 Data

Prepared by:

Romulo Barreno
Ajay Das
Song Xue

August 15, 2013

External Version

Electric Power Group

ERCOT

Cluster Analysis – Cluster Groups

Group 1- 345 Central:
- FarWest 4
- FarWest 7
- West 5
- West 2
- West 12
- West 11

Group 2- W. Texas:
- FarWest 9
- FarWest 8
- West 8
- West 18

Group 3 - Dallas:
- North 5
- North 4
- North 2
- North 1

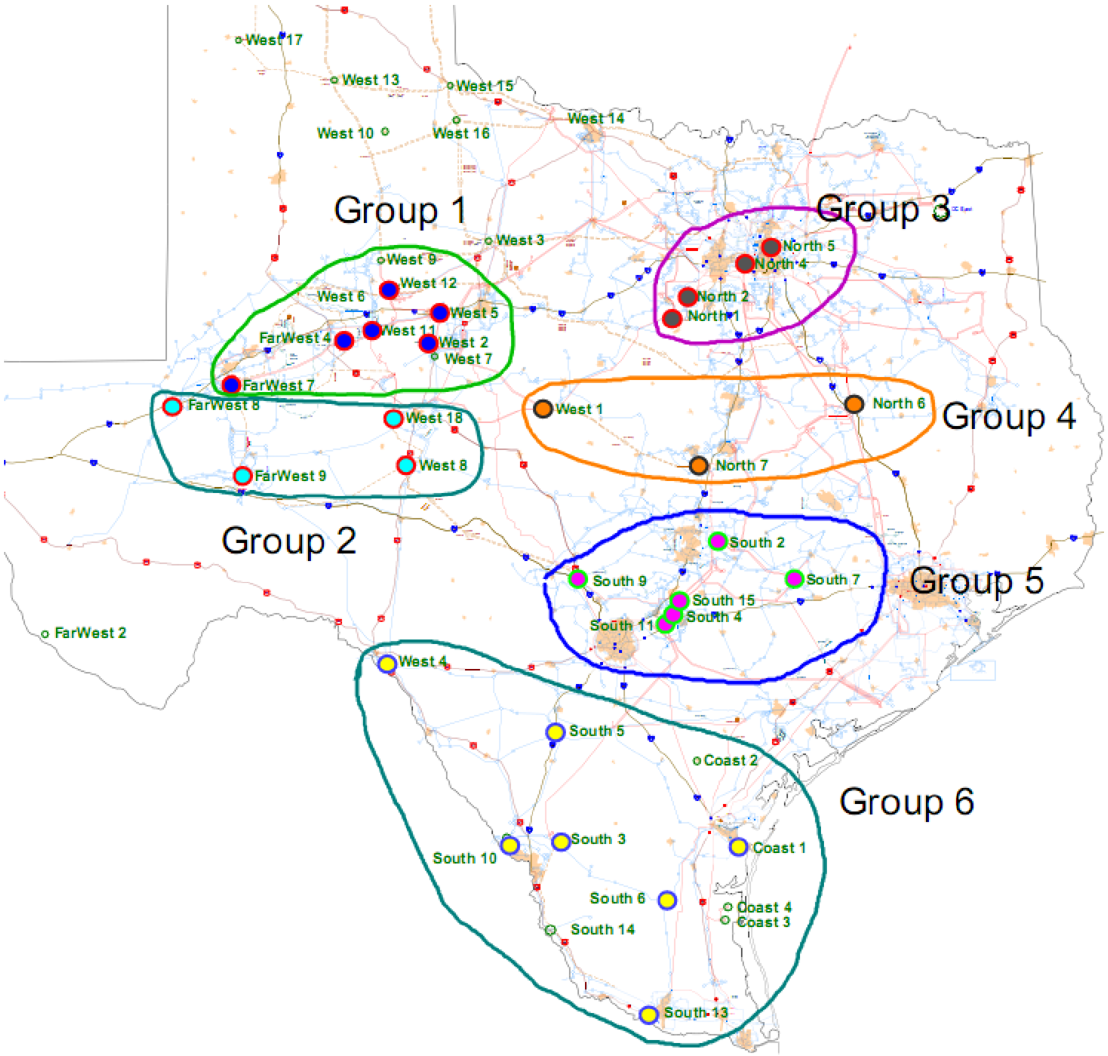
Group 4 – East & CE:
- West 1
- North 6
- North 7

Group 5 – 345 C. East:
- South 7
- South 9
- South 11
- South 2
- South 4
- South 15

Group 6 - Valley:
- Coast 1
- West 4
- South 10
- South 13
- South 3
- South 5
- South 6

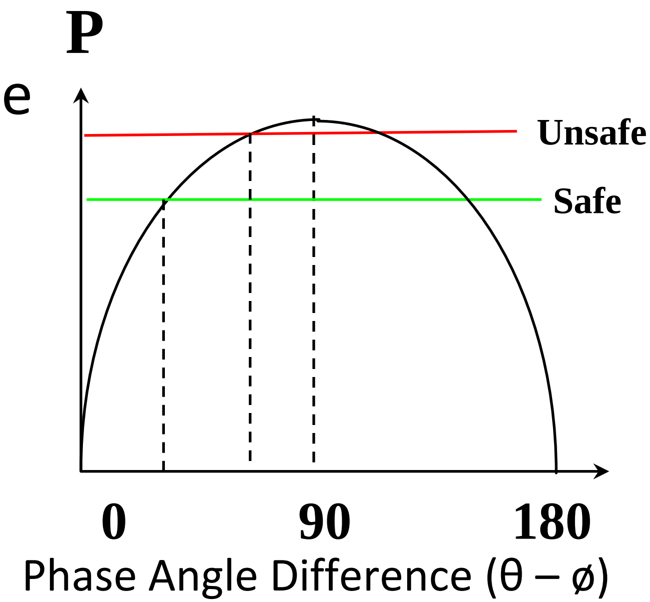
Note: This list includes existing and planned PMU locations from Oncor, AEP, Sharyland and LCRA

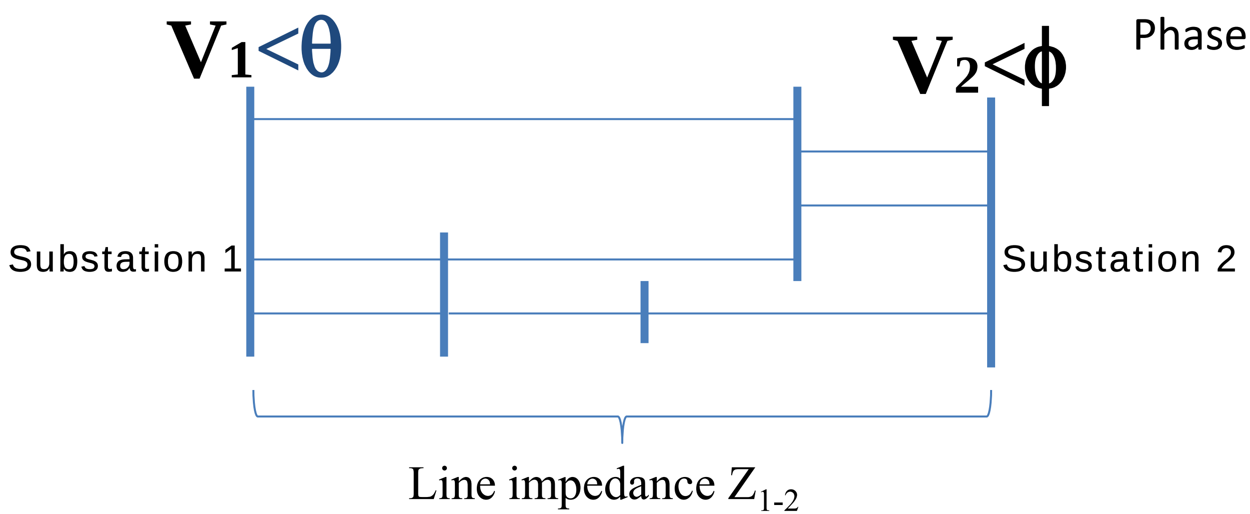
Cluster Locations: Groups 1-6



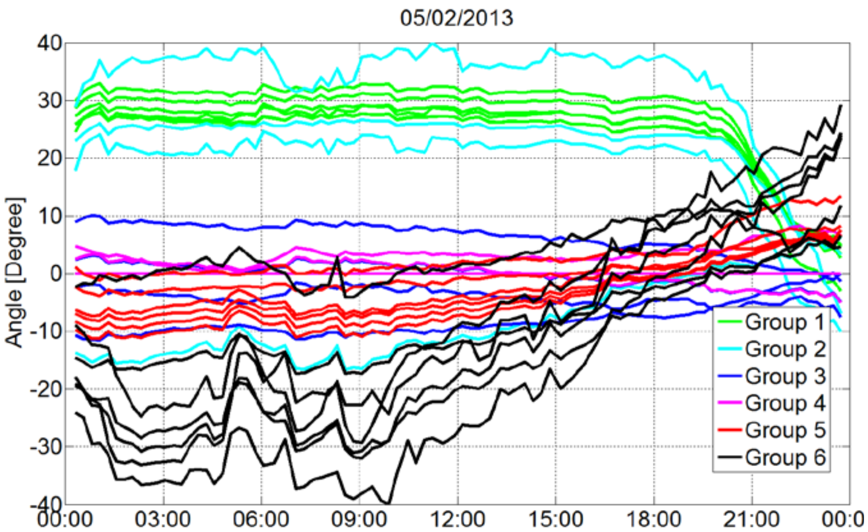
Phase Angles Differences as Indicators of Power Flow

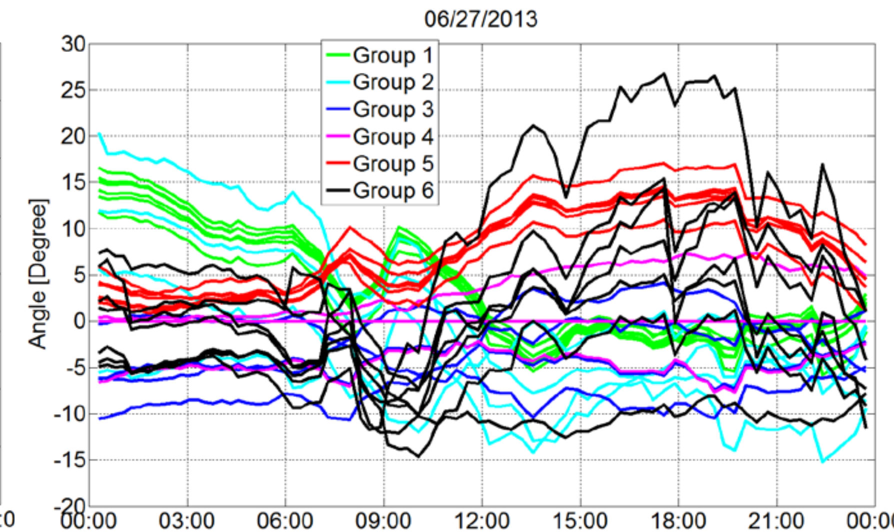
- Power flow follows voltage angle difference
  - Power flow: $P = V_1 V_2 \sin(\theta - \phi)/Z$
- Any change in power flow or impedance will be reflected in a change in voltage phase angle difference between two locations

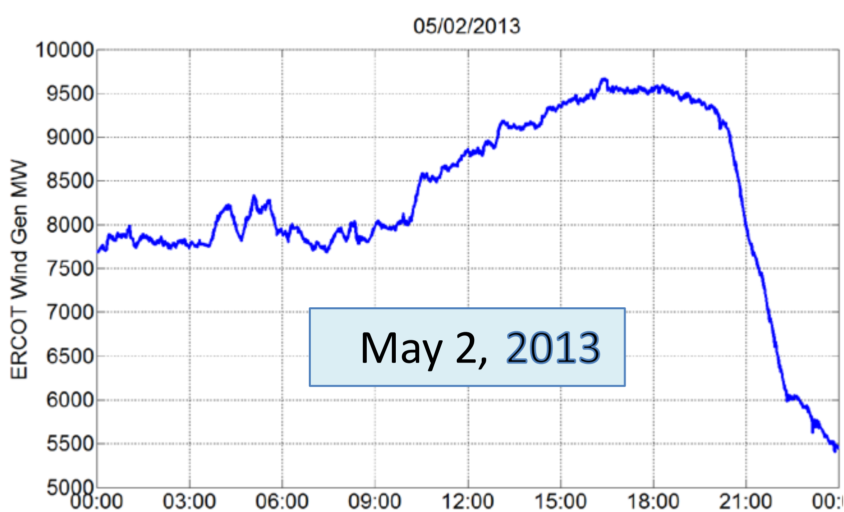


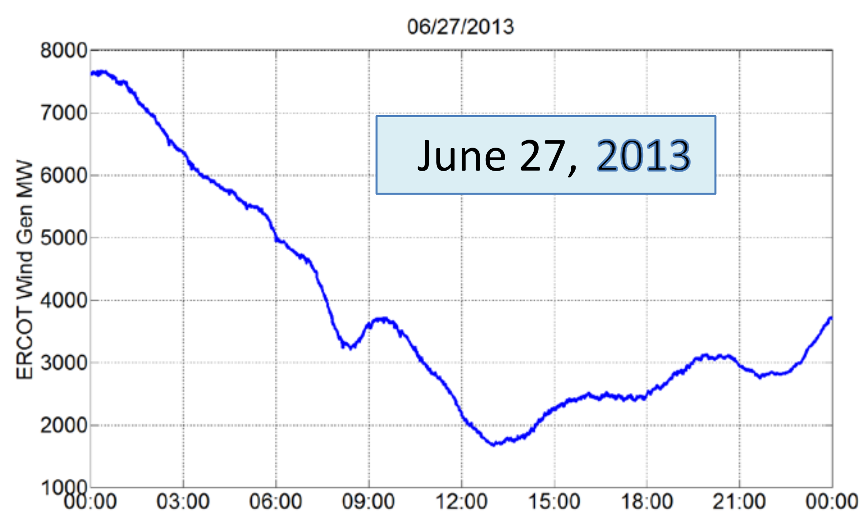


Cluster Summary – Angle Difference – Groups 1-6



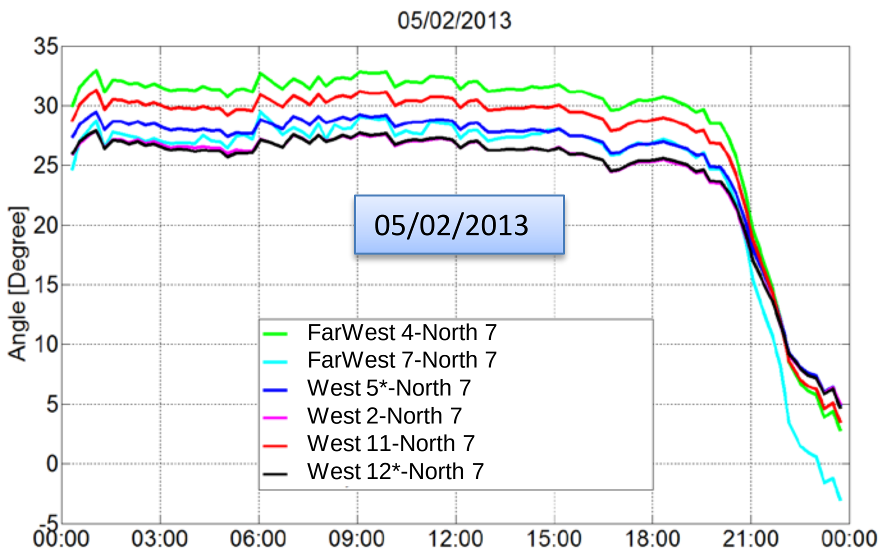


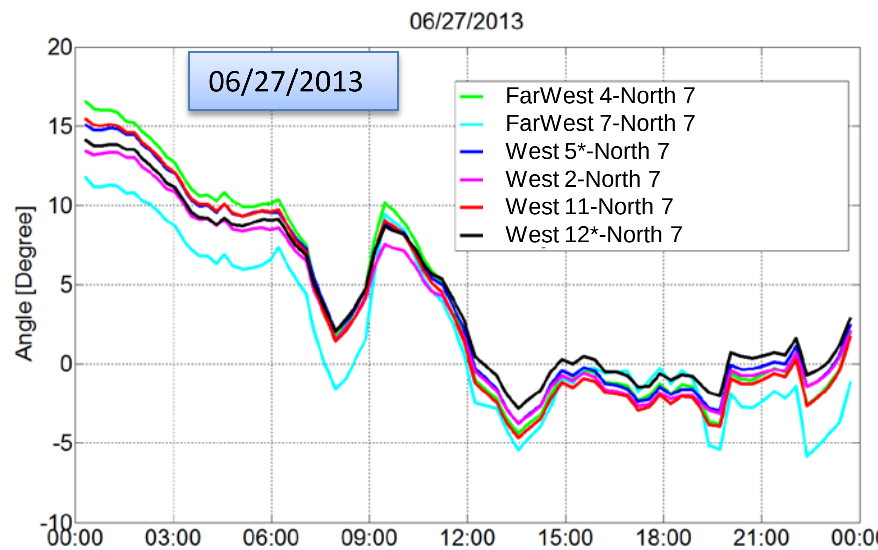


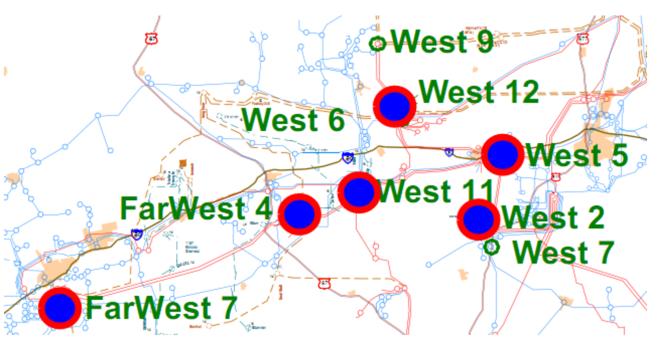


Angle Reference: North 7

Group 1 – West Texas



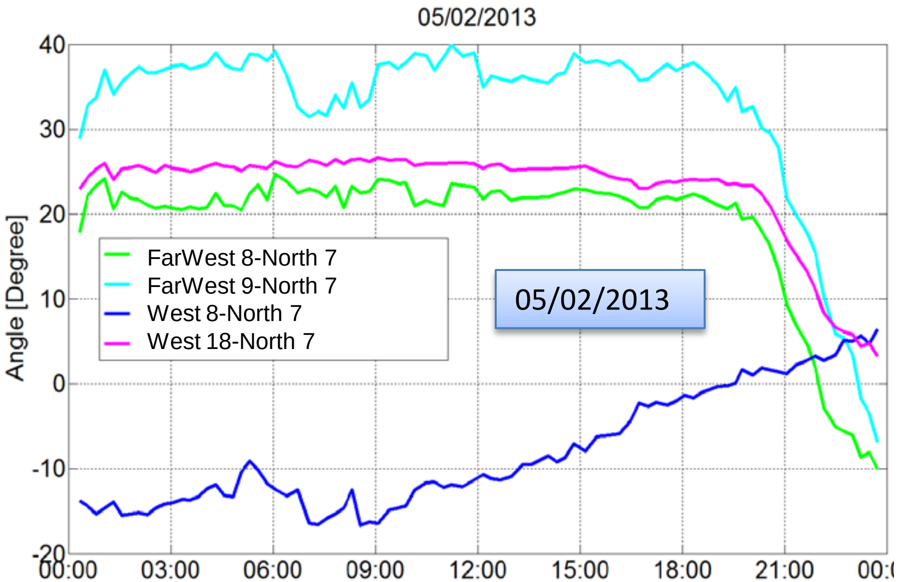


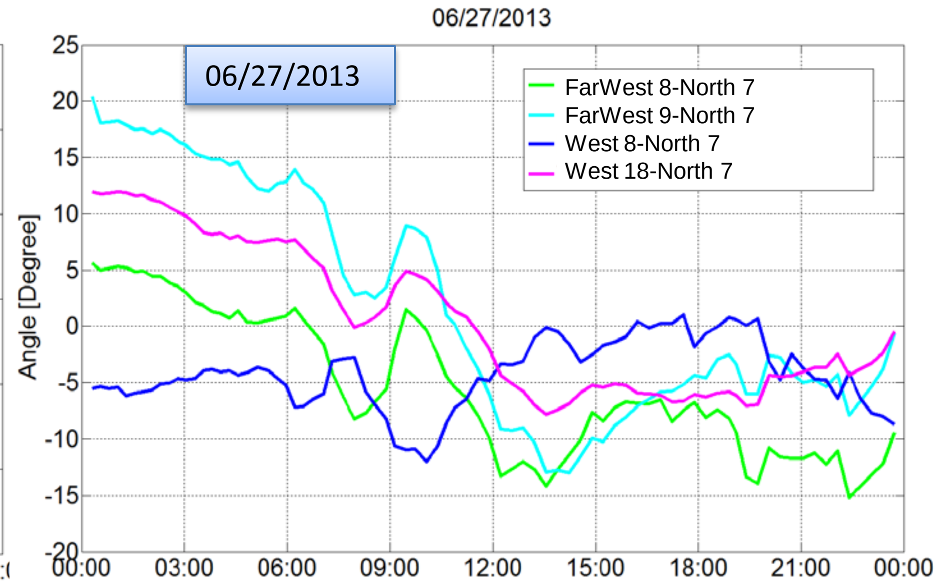


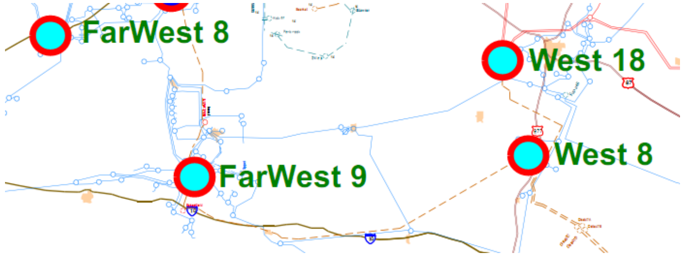
New lines in the area:

1.	West 12-West 21	3/06/13
2.	West 21-North 9	3/20/13
3.	North 9-North 8	3/21/13
4.	West 19-West 20	4/15/13
5.	West 13-West 19	4/29/13

Group 2 – West Texas







New lines in the area:

1. West 18-West 8 5/23/13

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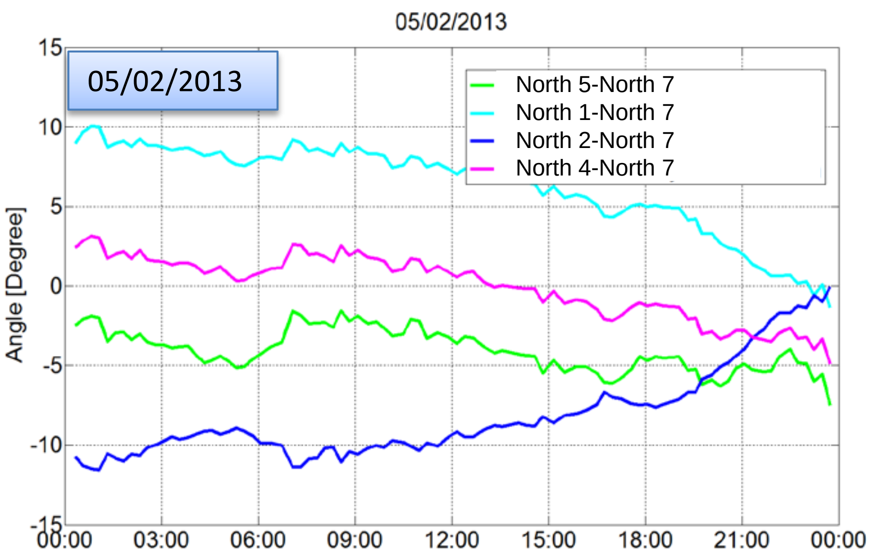
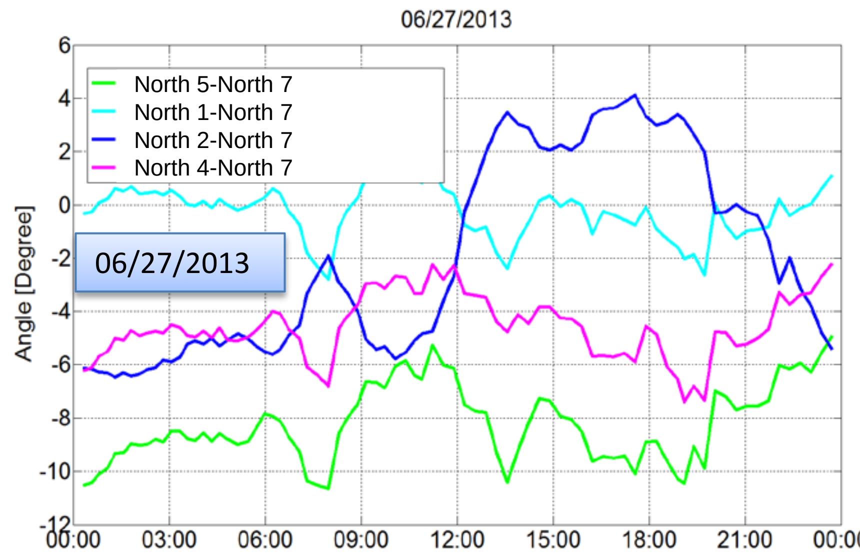
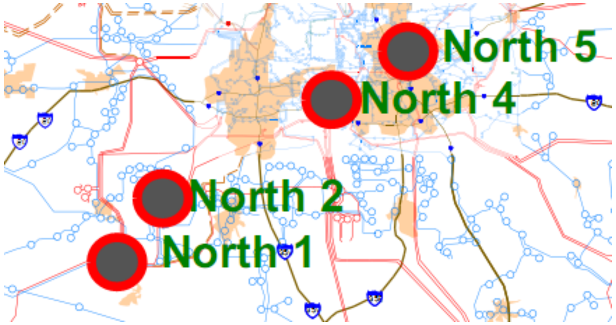
Group 3 - Dallas







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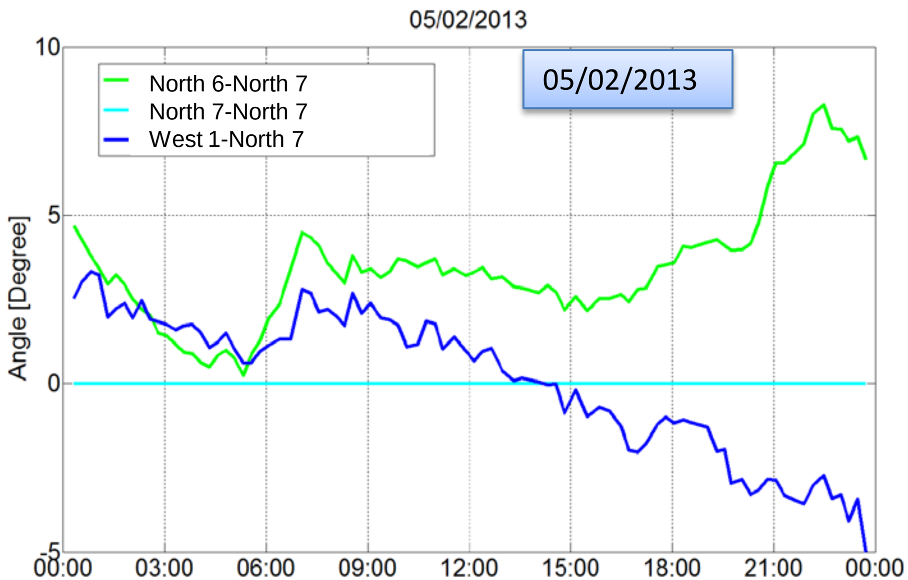

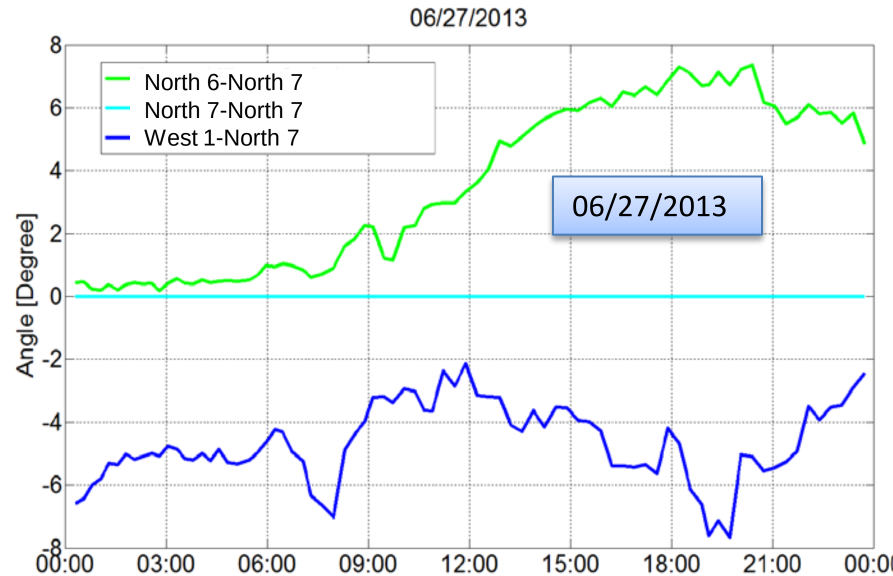

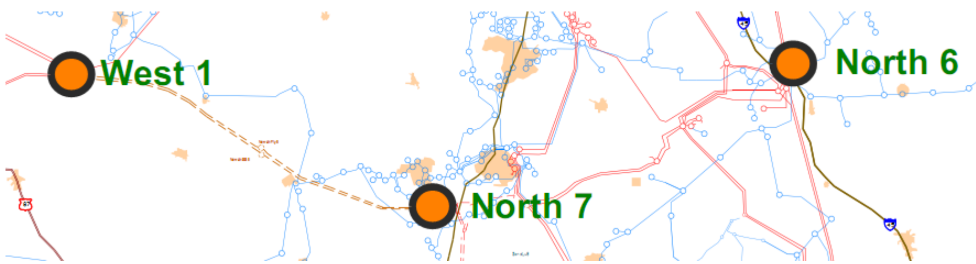

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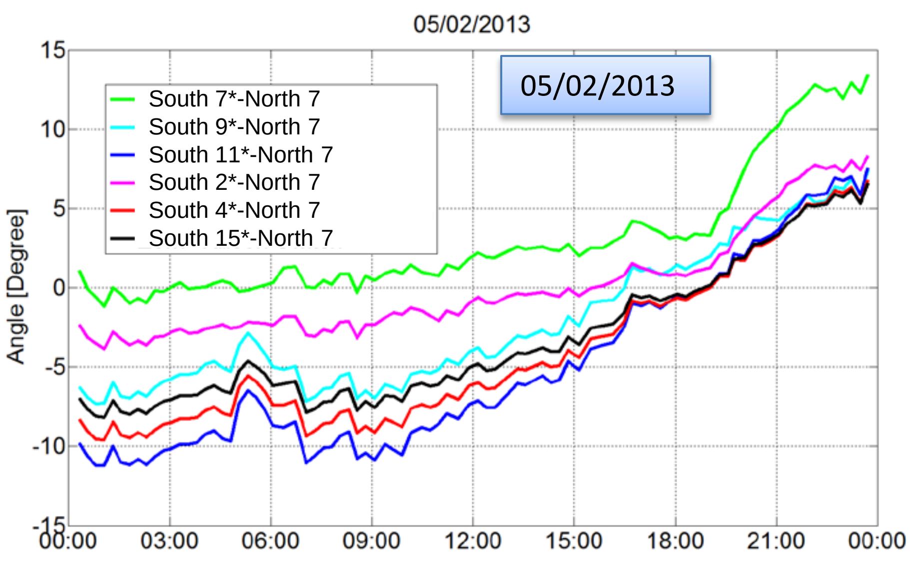

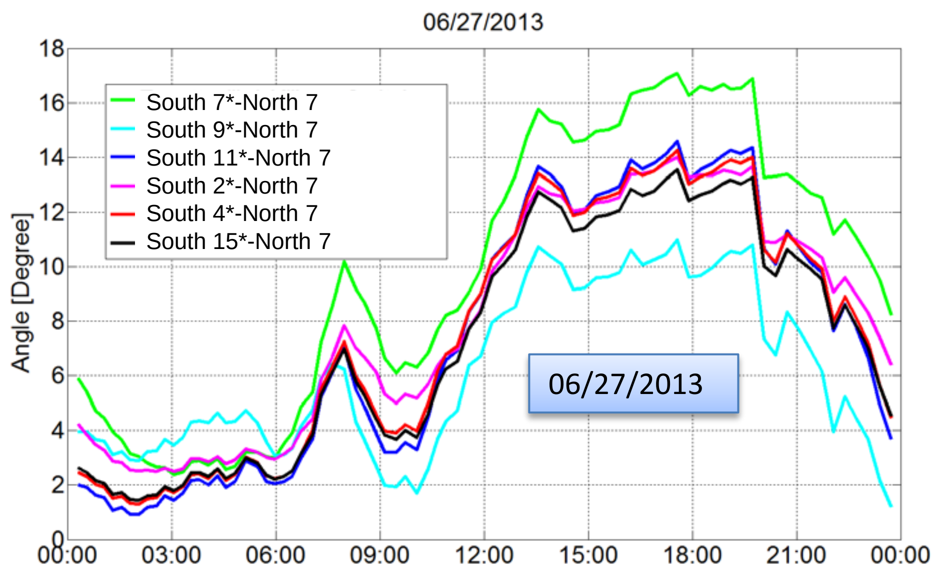

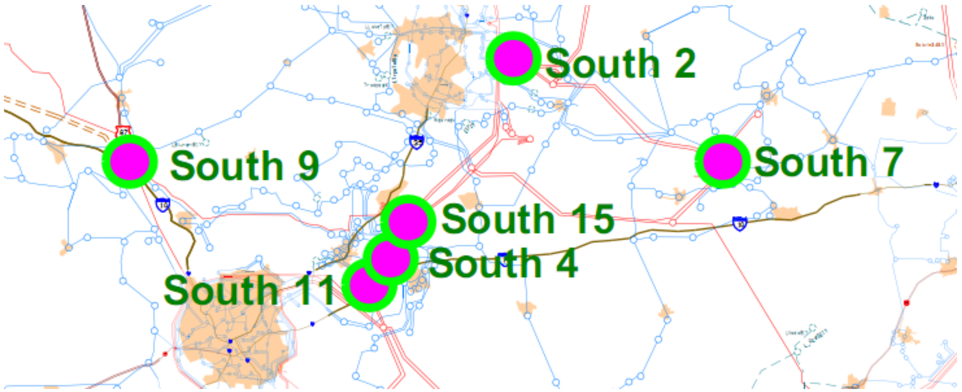

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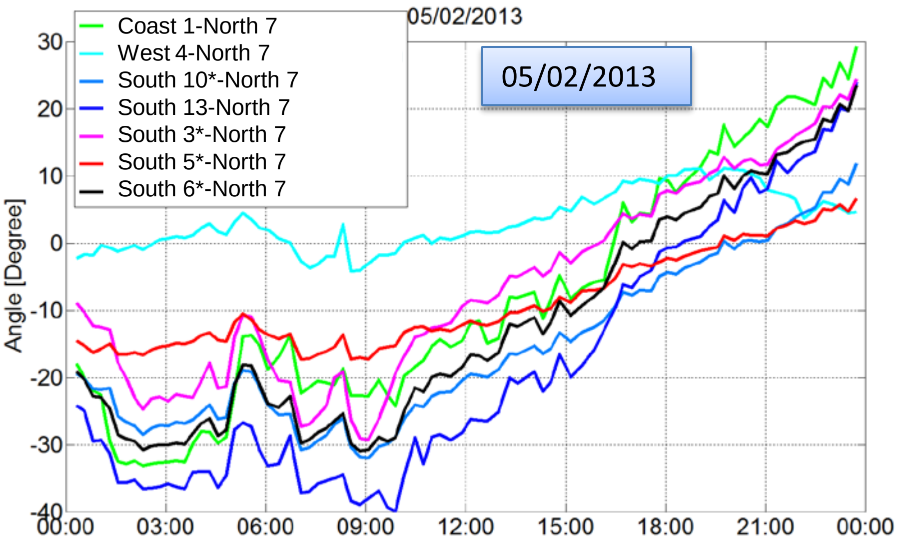
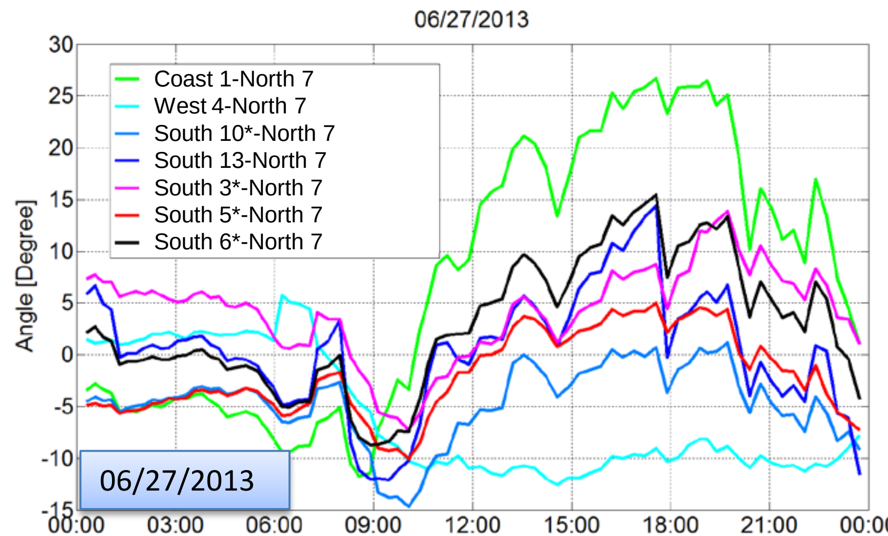
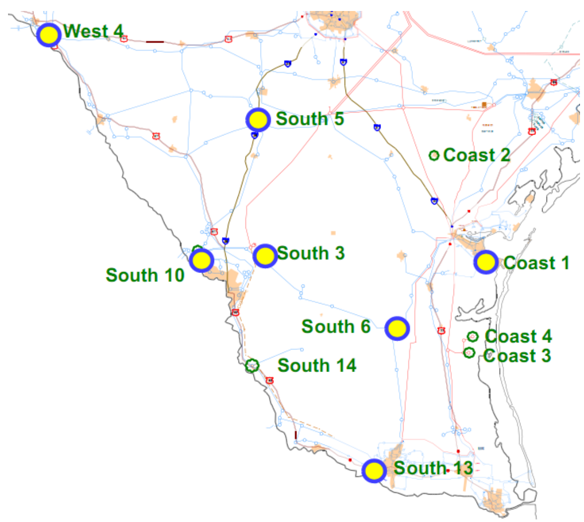
Group 6 – Valley (South)







Appendix B

Center for Commercialization of Electric Technologies -- Discovery Across Texas

Updated Cluster Analysis – Voltage Magnitudes

January-June 2013 Data

Prepared by:

Romulo Barreno
Ajay Das
Song Xue

August 15, 2013

External Version

Electric Power Group

ERCOT

Cluster Groups

Group 1- 345 Central:
- FarWest 4
- FarWest 7
- West 5
- West 2
- West 12
- West 11

Group 2- WŜăú Texas:
- FarWest 9
- FarWest 8
- West 8
- West 18

Group 3 - Dallas:
- North 5
- North 4
- North 2
- North 1

Group 4 – East & CŜýúǁl·ƭ 9l·ăú:
- West 1
- North 6
- North 7

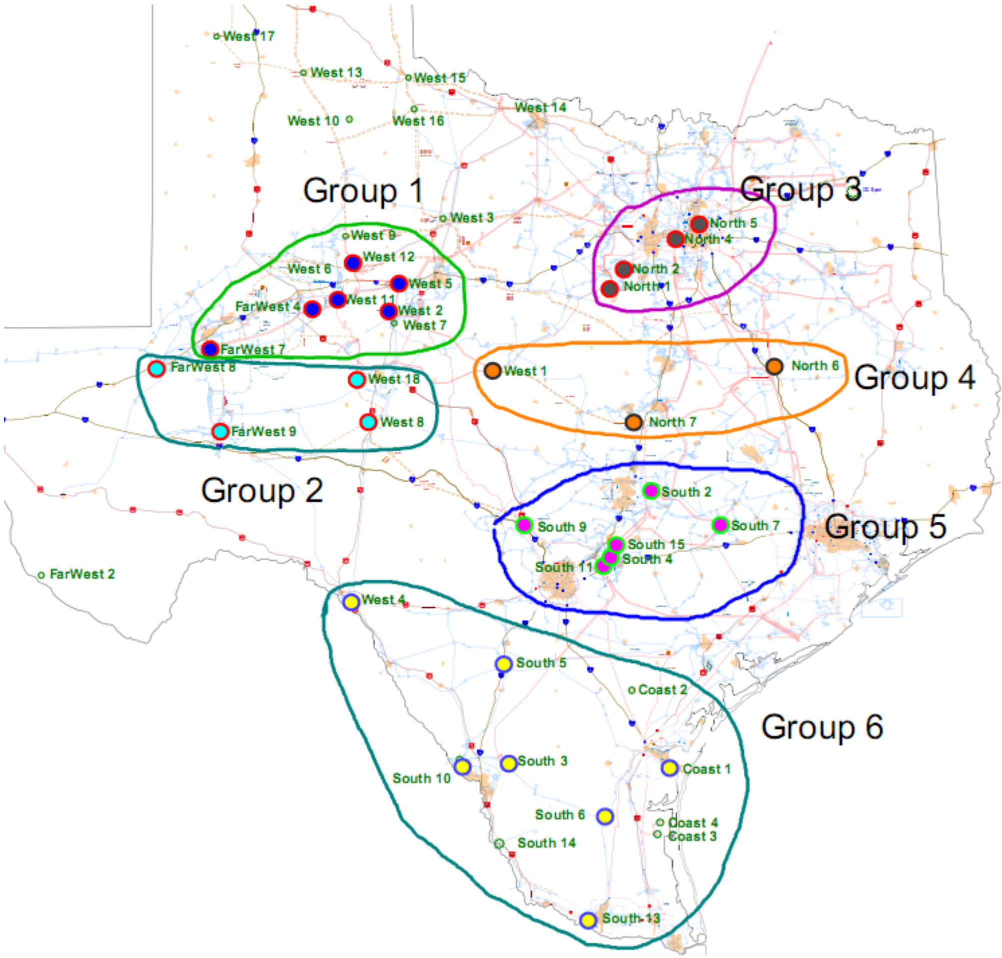
Group 5 – 345 CŜýúǁl·ƭ East:
- South 7
- South 9
- South 11
- South 2
- South 4
- South 15

Group 6 - Valley:
- Coast 1
- West 4
- South 10
- South 13
- South 3
- South 5
- South 6

Note: This list includes existing and planned PMU locations from Oncor, AEP, Sharyland and LCRA

8.15.13

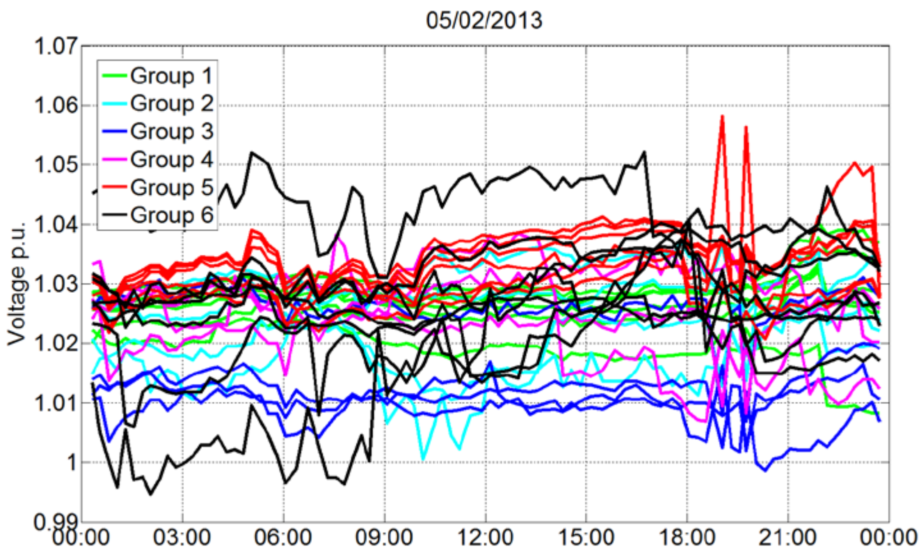
Cluster Locations: Groups 1-6

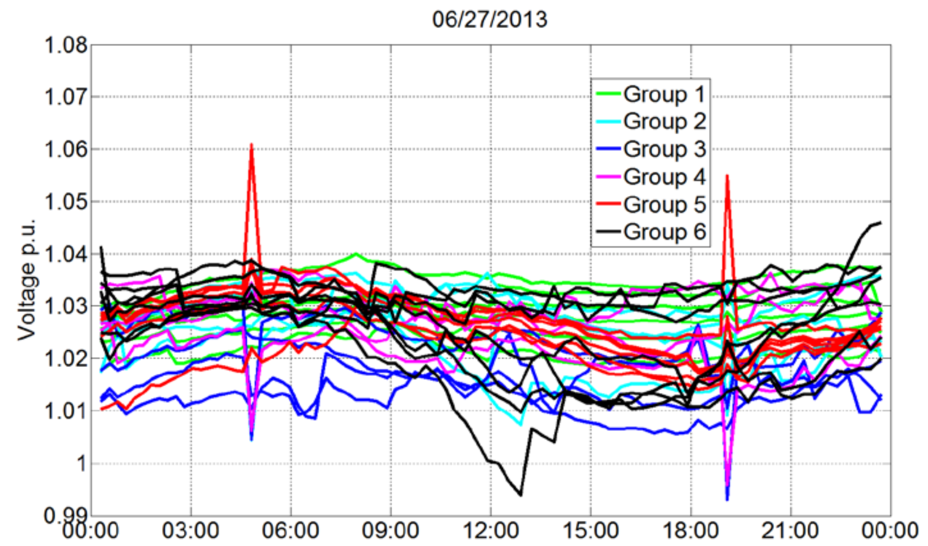


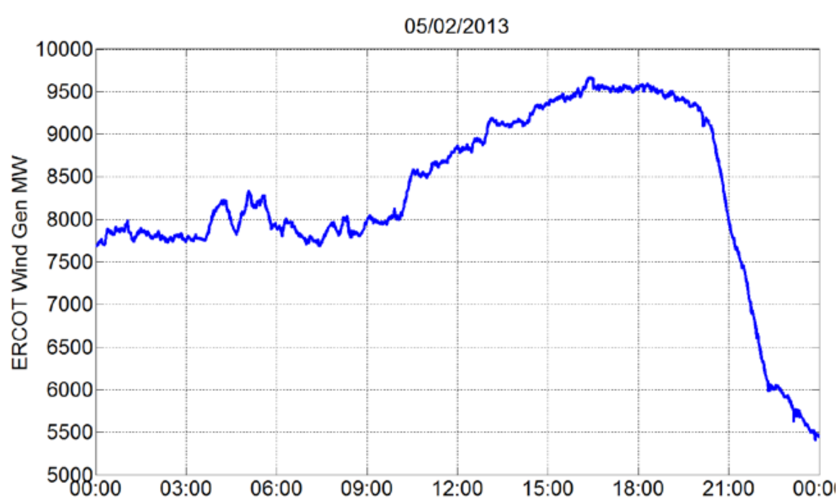
Groups 1-6 - Daily Average Voltages

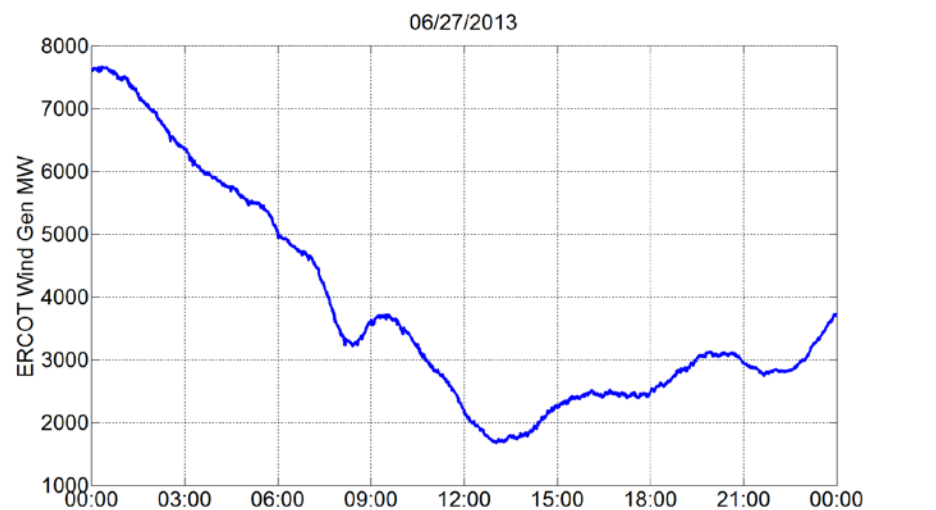
		5/2/2013		6/27/2013	
		Average(kV)	Average(p.u.)	Average(kV)	Average(p.u.)
Group 1	FarWest 4	355.15	1.03	354.67	1.03
	FarWest 7	351.85	1.02	352.35	1.02
	West 5*	355.07	1.03	355.43	1.03
	West 2*	355.17	1.03	357.14	1.04
	West 11	354.20	1.03	353.60	1.02
	West 12*	353.43	1.02	355.87	1.03
Group 2	FarWest 8	140.75	1.02	141.49	1.03
	FarWest 9	140.38	1.02	141.62	1.03
	West 8*	142.04	1.03	141.11	1.02
	West 18	142.01	1.03	142.30	1.03
Group 3	North 5	139.65	1.01	140.17	1.02
	North 1	139.64	1.01	140.22	1.02
	North 2	139.21	1.01	139.96	1.01
	North 4	141.64	1.03	141.32	1.02
Group 4	North 6	142.05	1.03	142.40	1.03
	North 7	140.96	1.02	141.79	1.03
	West 1*	141.41	1.02	140.83	1.02
Group 5	South 7*	355.45	1.03	355.29	1.03
	South 9*	355.76	1.03	351.98	1.02
	South 11*	357.15	1.04	354.68	1.03
	South 2*	354.61	1.03	353.50	1.02
	South 4*	357.00	1.03	354.70	1.03
	South 15*	356.73	1.03	354.26	1.03
Group 6	Coast 1	140.74	1.02	142.57	1.03
	West 4	140.56	1.02	141.62	1.03
	South 10*	141.57	1.03	142.35	1.03
	South 13	141.29	1.02	140.61	1.02
	South 3*	143.82	1.04	142.44	1.03
	South 5*	142.12	1.03	140.82	1.02
	South 6*	142.37	1.03	141.68	1.03

Cluster Summary-Voltage Magnitudes: Groups 1-6

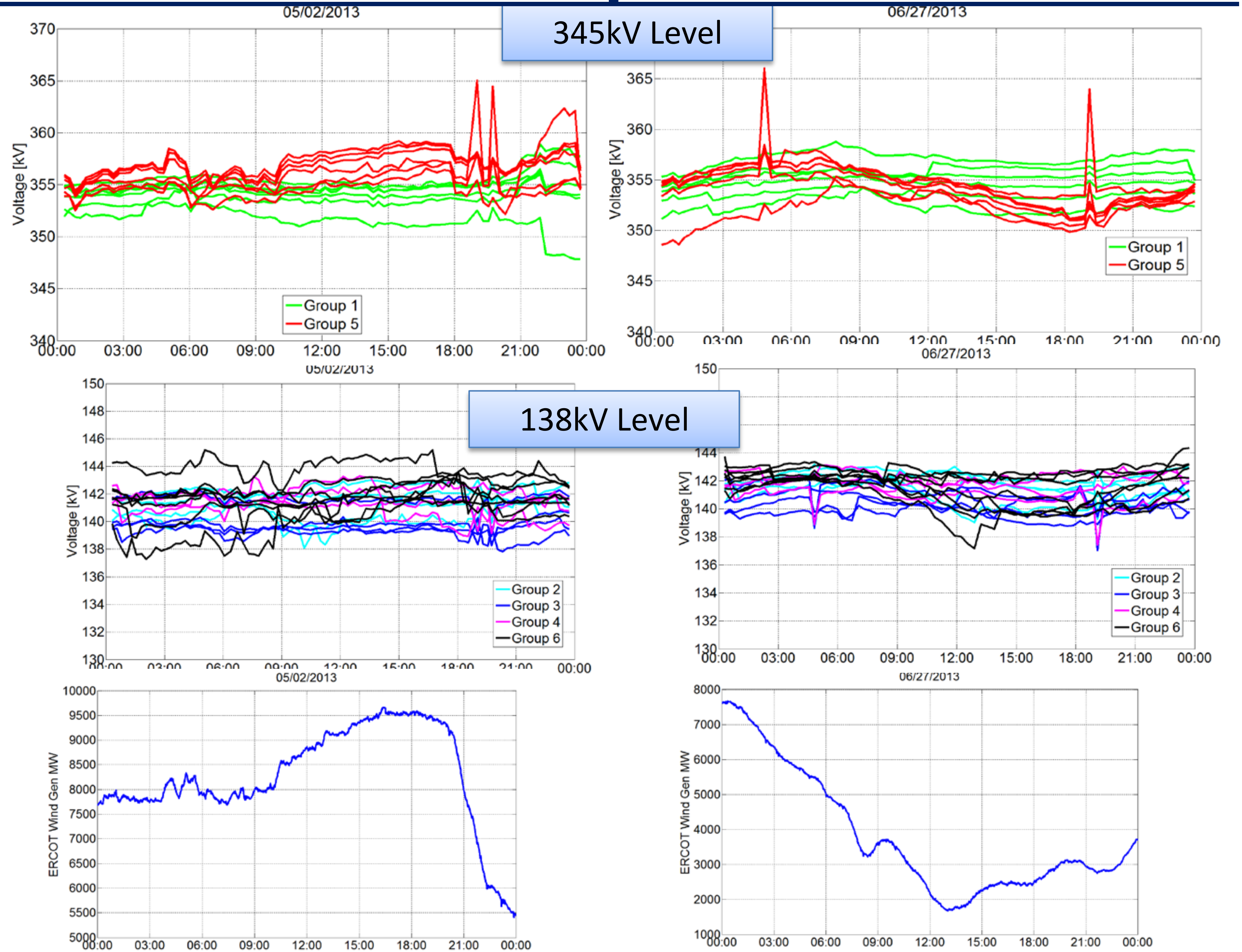






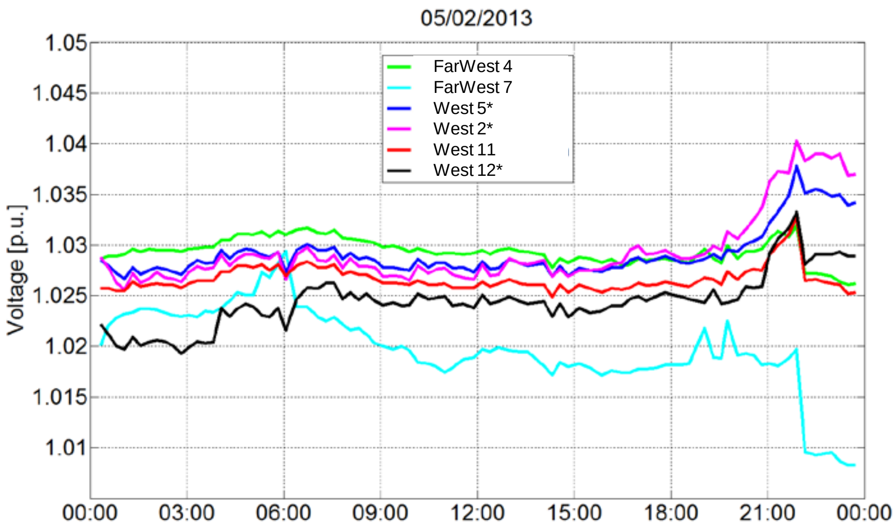


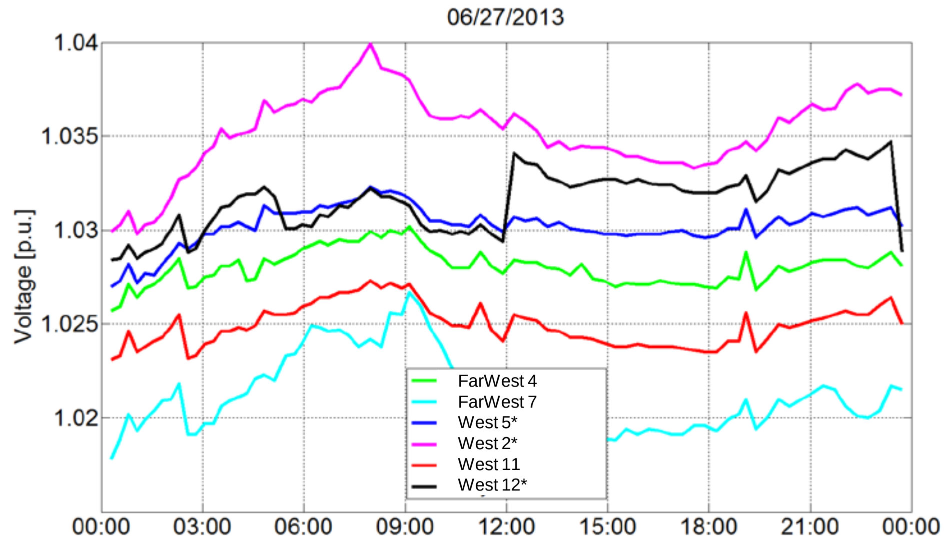
Groups 1-6

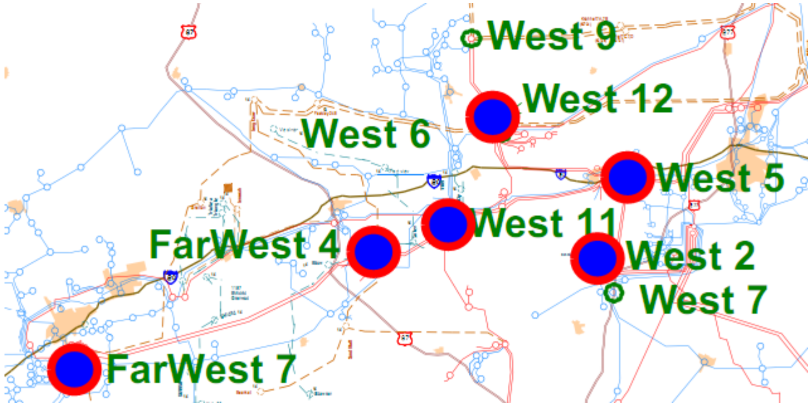


345kV Level
05/02/2013
Voltage [kV]
Group 1
Group 5
06/27/2013
Voltage [kV]
Group 1
Group 5
138kV Level
05/02/2013
Voltage [kV]
Group 2
Group 3
Group 4
Group 6
06/27/2013
Voltage [kV]
Group 2
Group 3
Group 4
Group 6
05/02/2013
ERCOT Wind Gen MW
06/27/2013
ERCOT Wind Gen MW

Group 1 – West Texas







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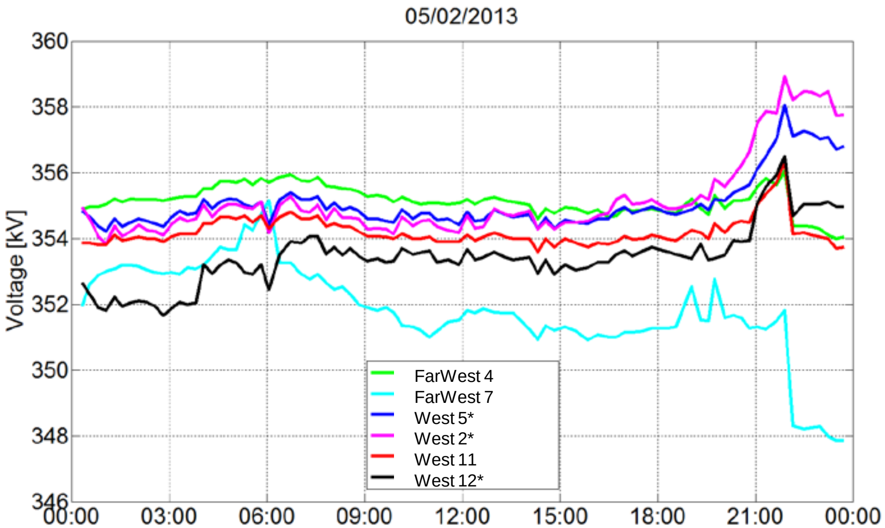

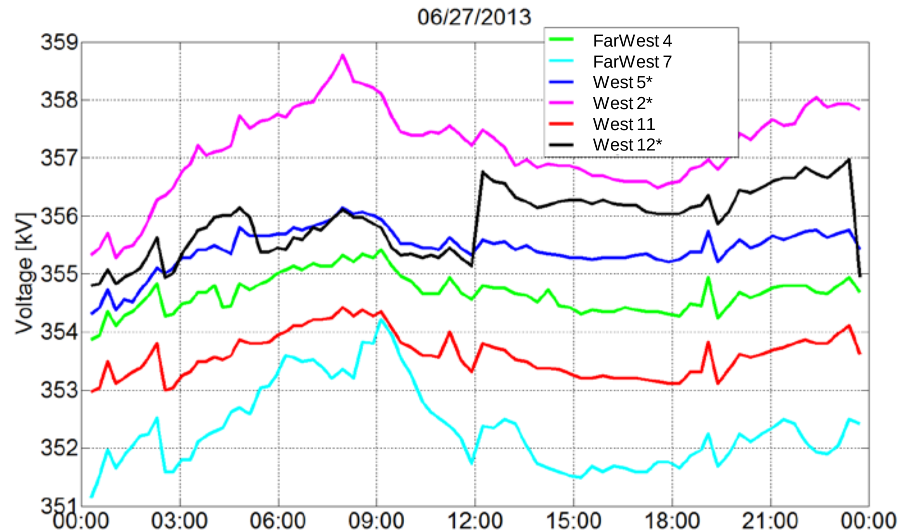

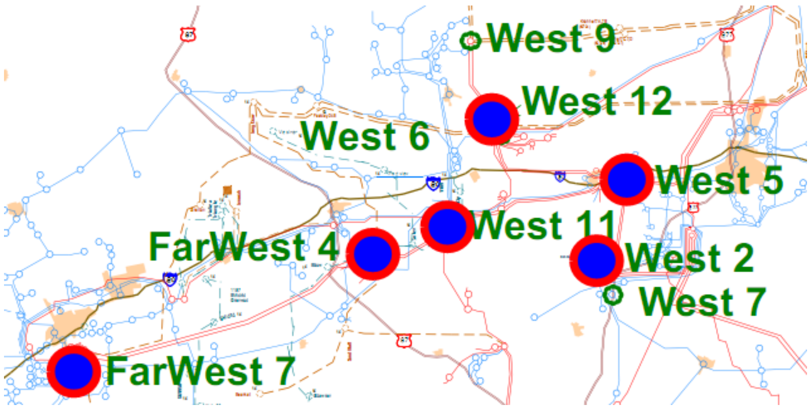

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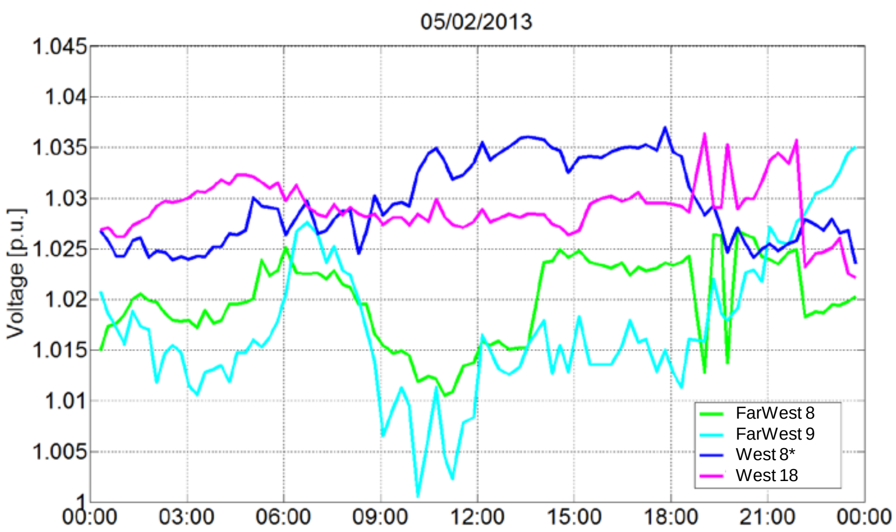

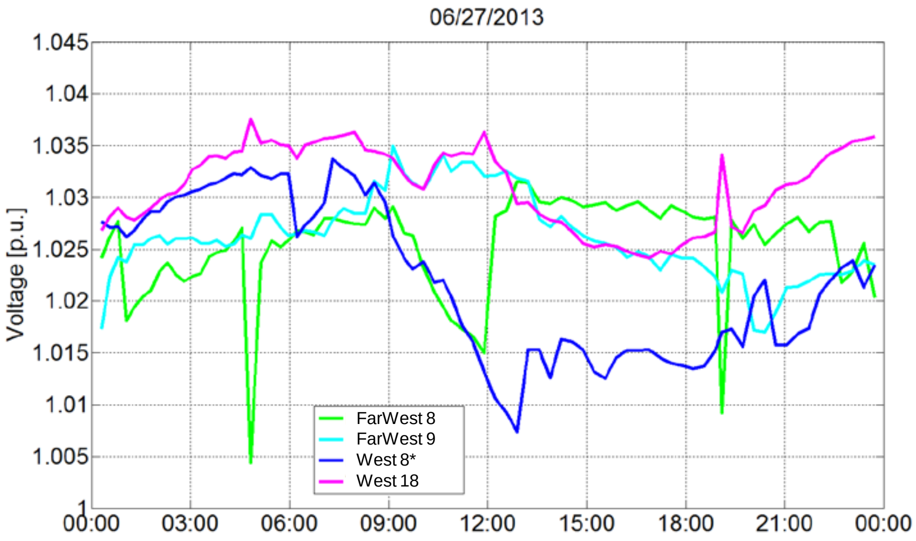

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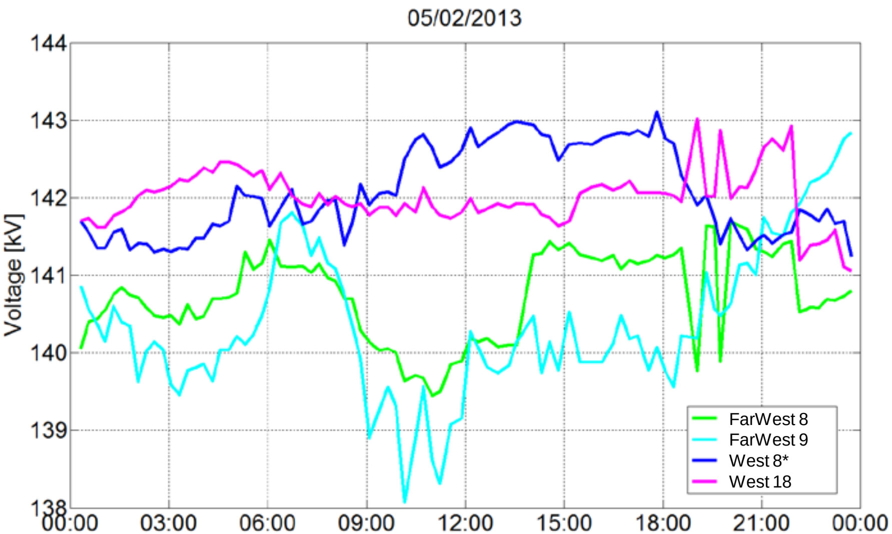

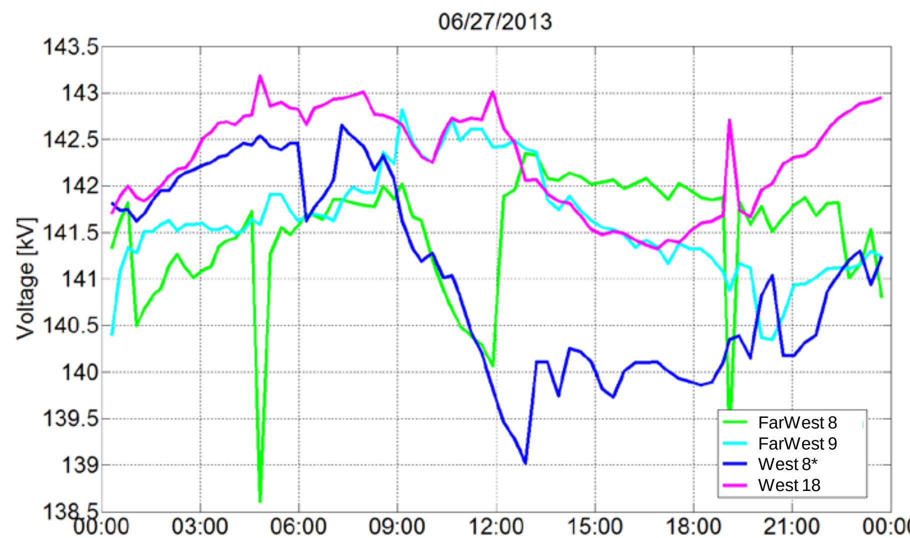

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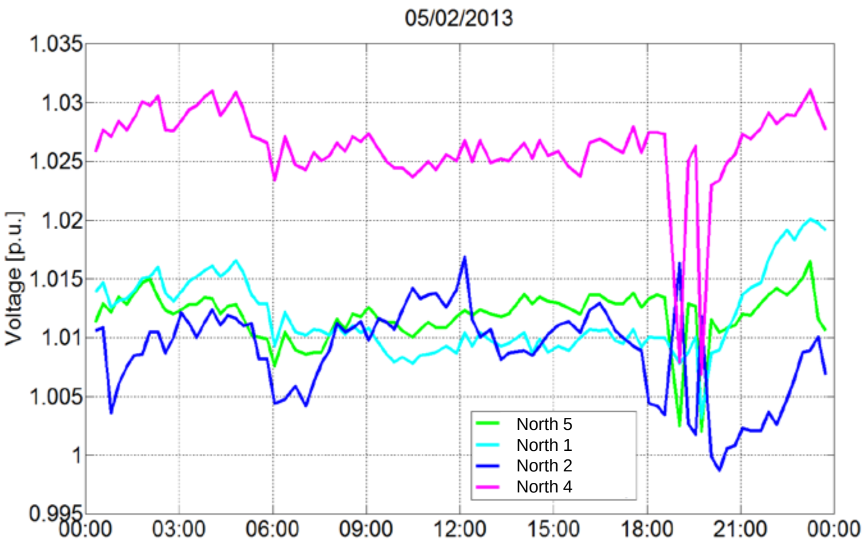

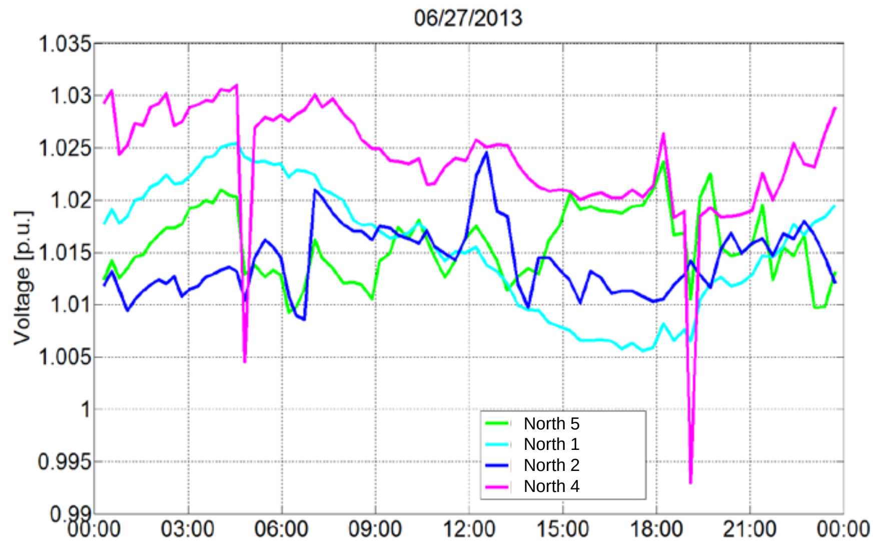

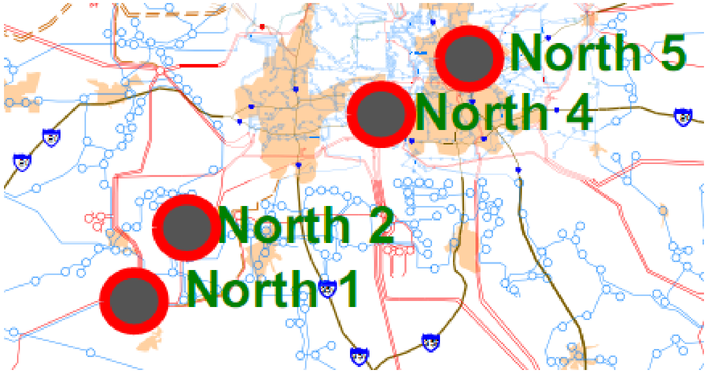

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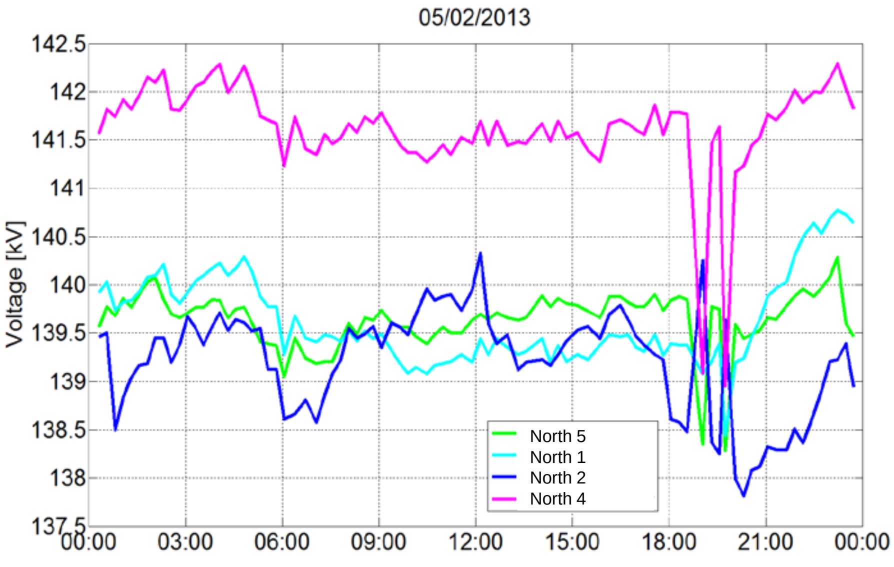

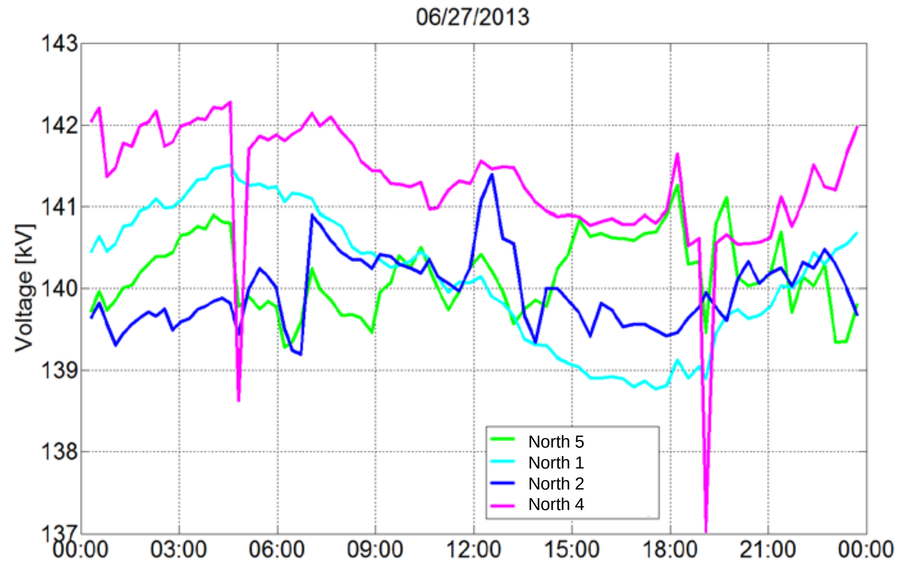

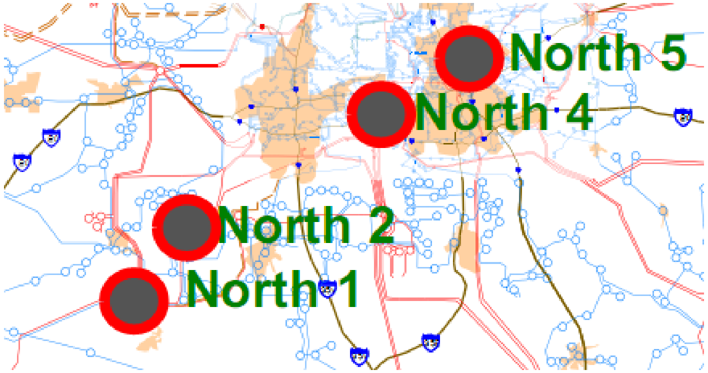

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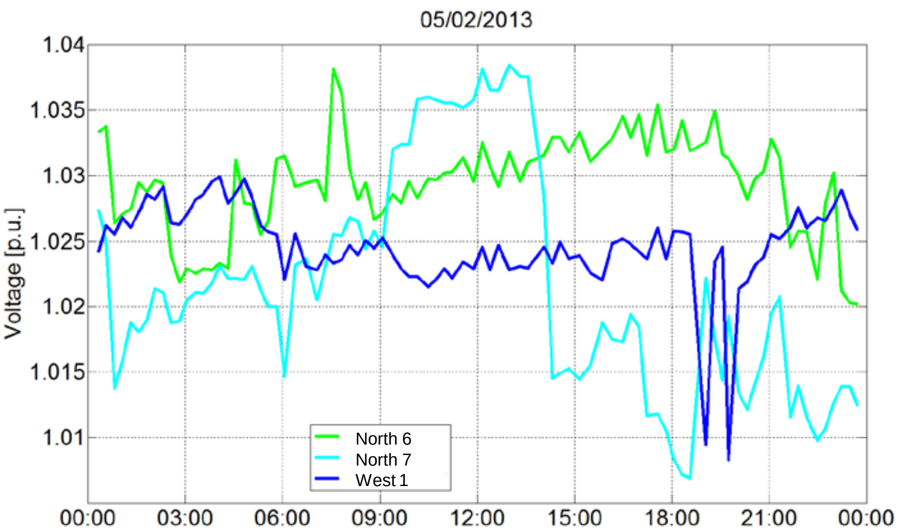

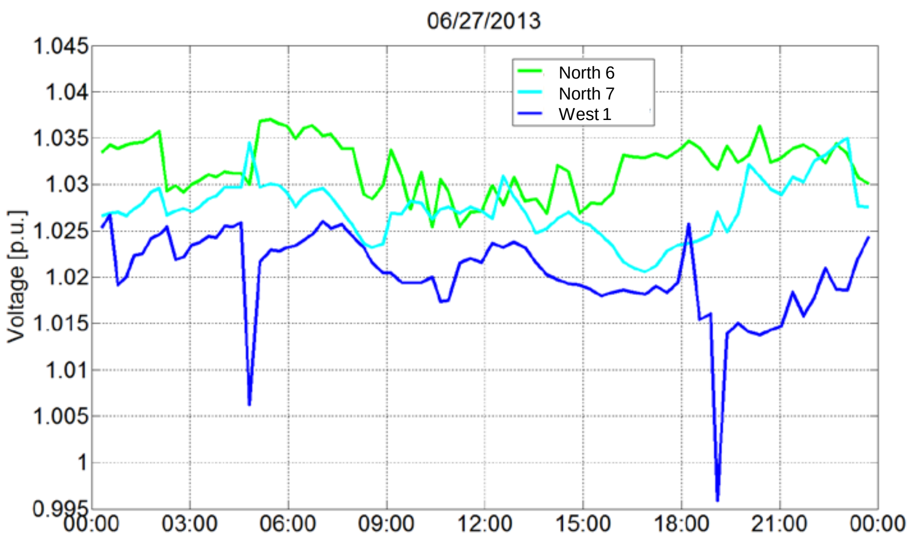

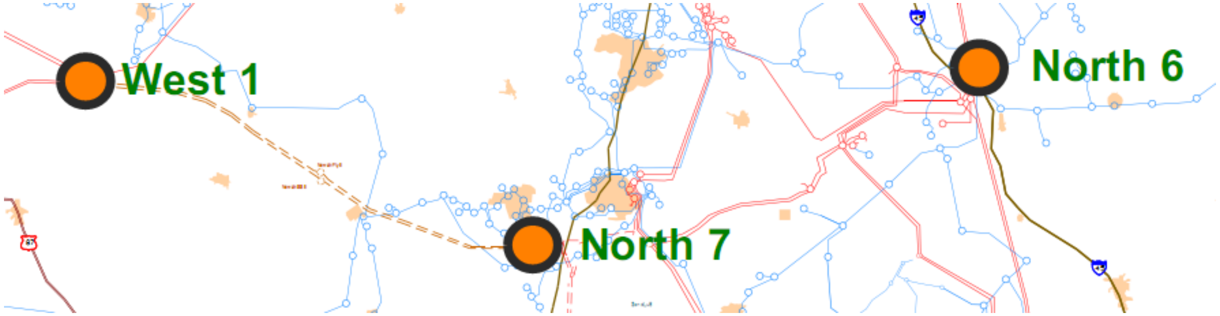

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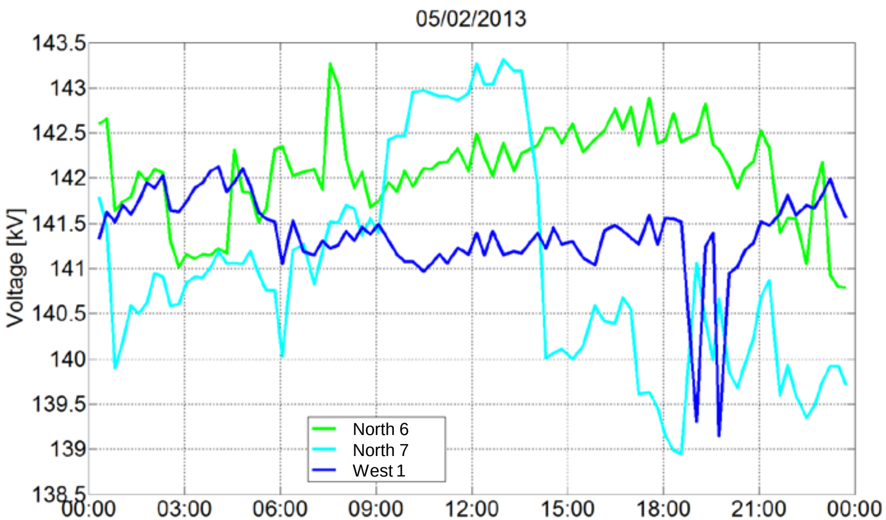

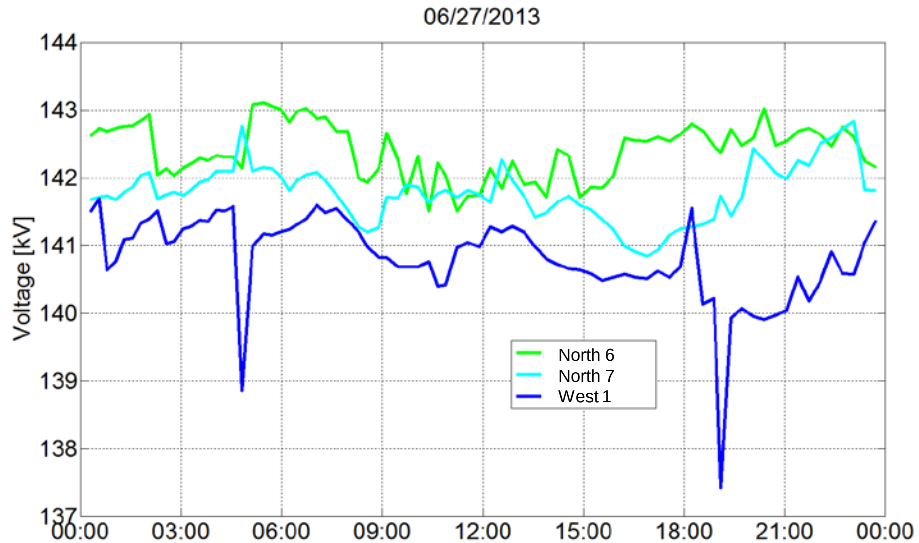

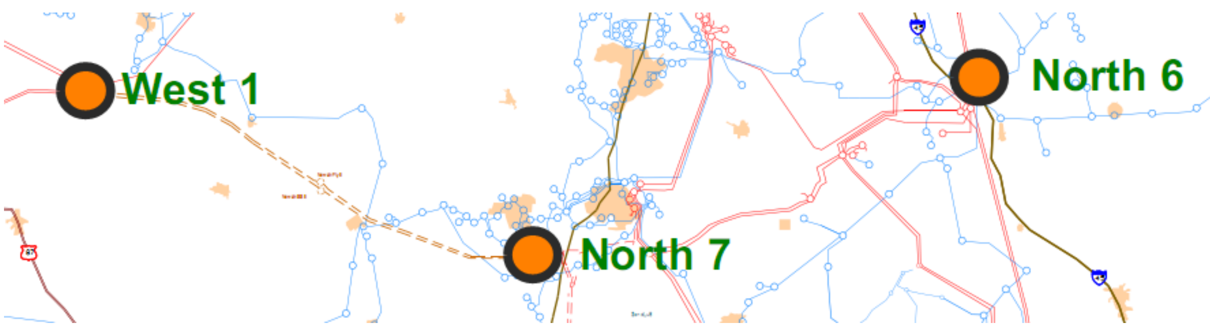

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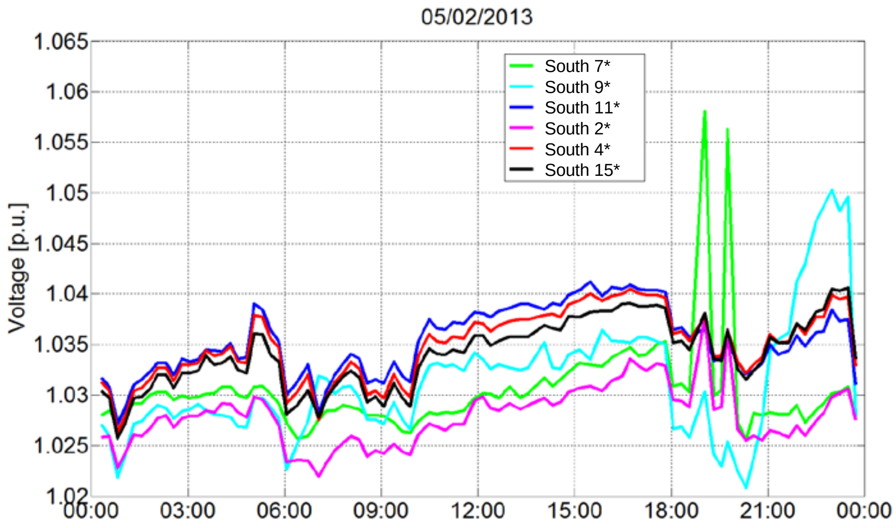

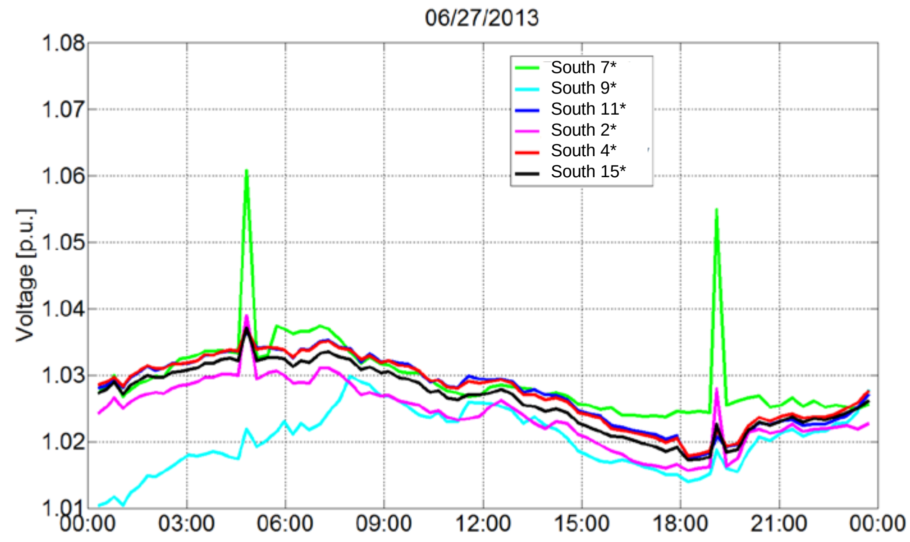

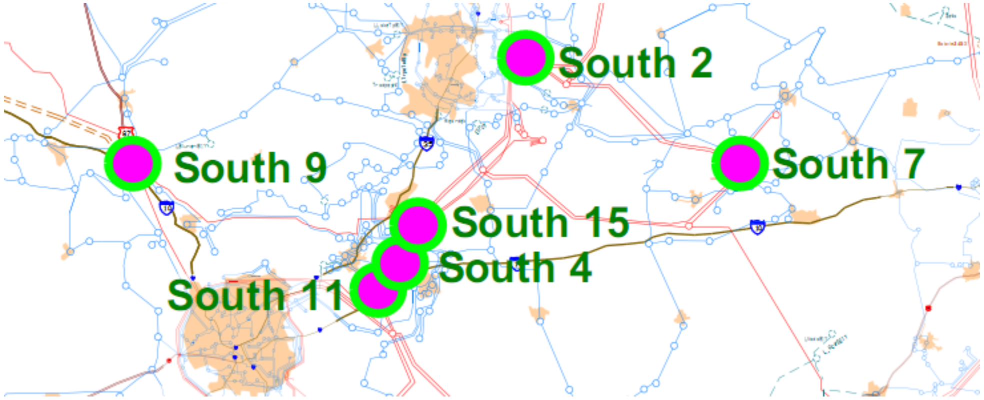

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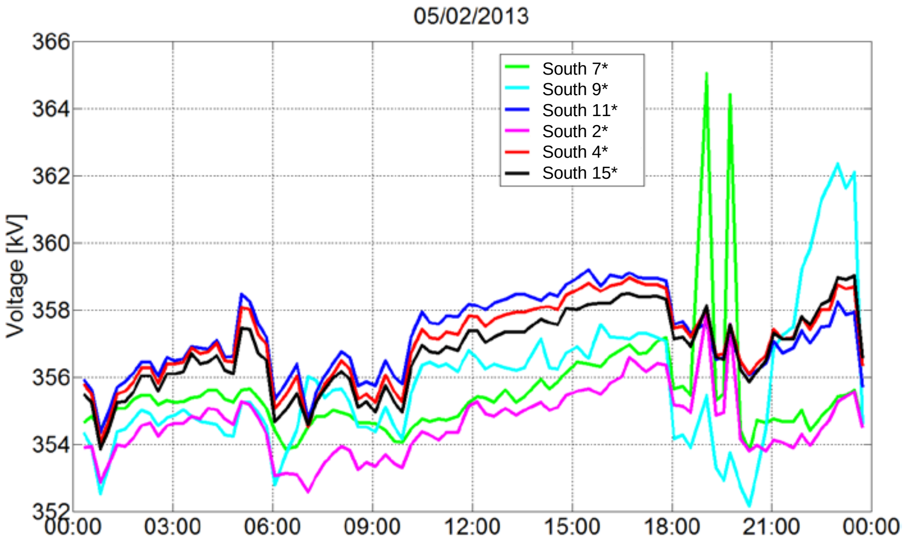
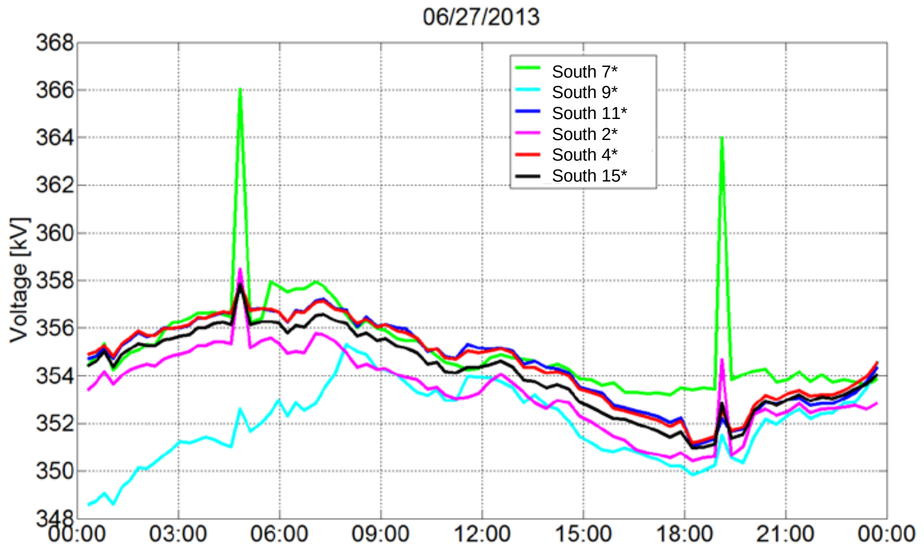
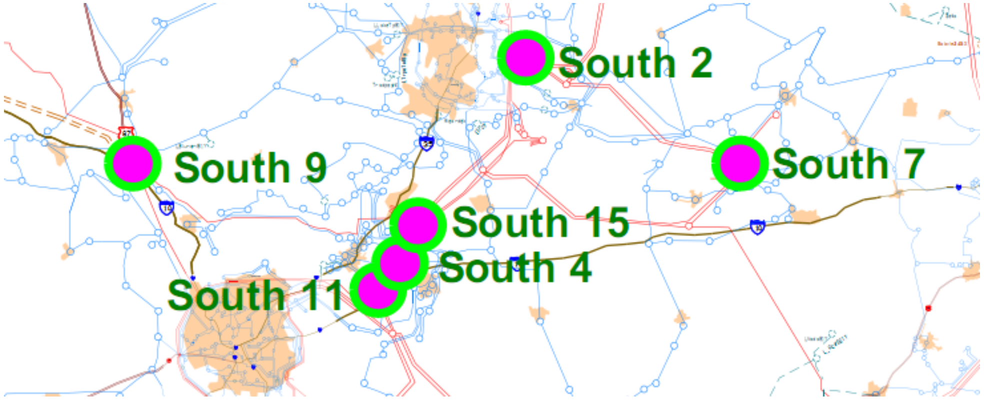
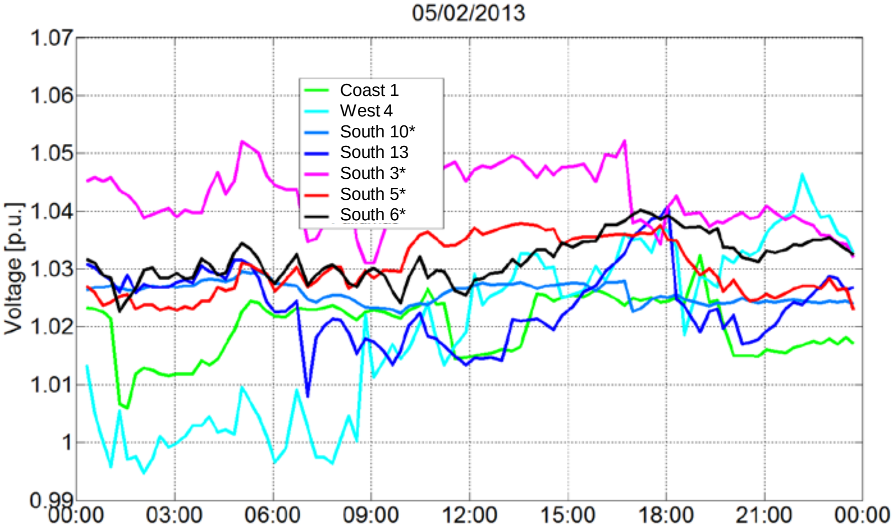
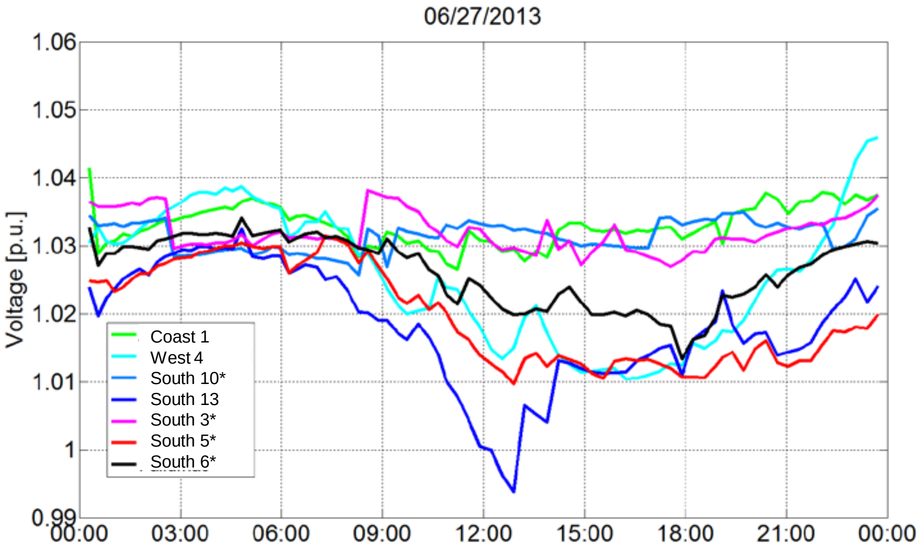


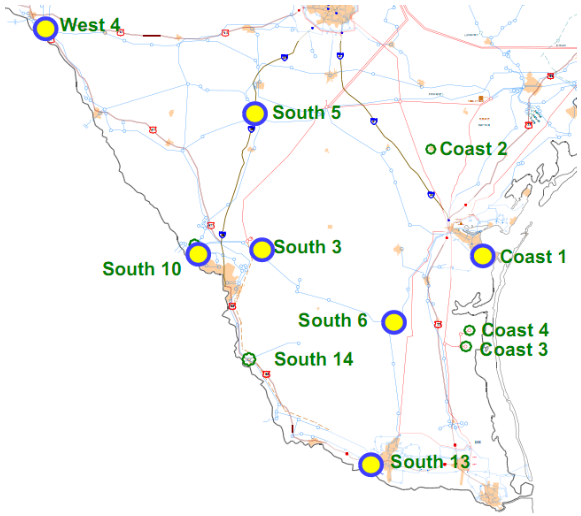




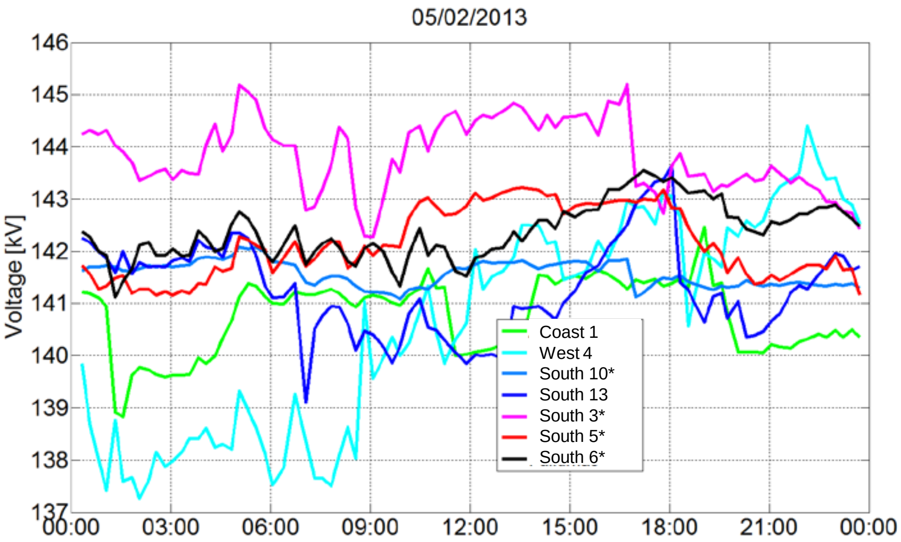
Group 6 – Valley (South)

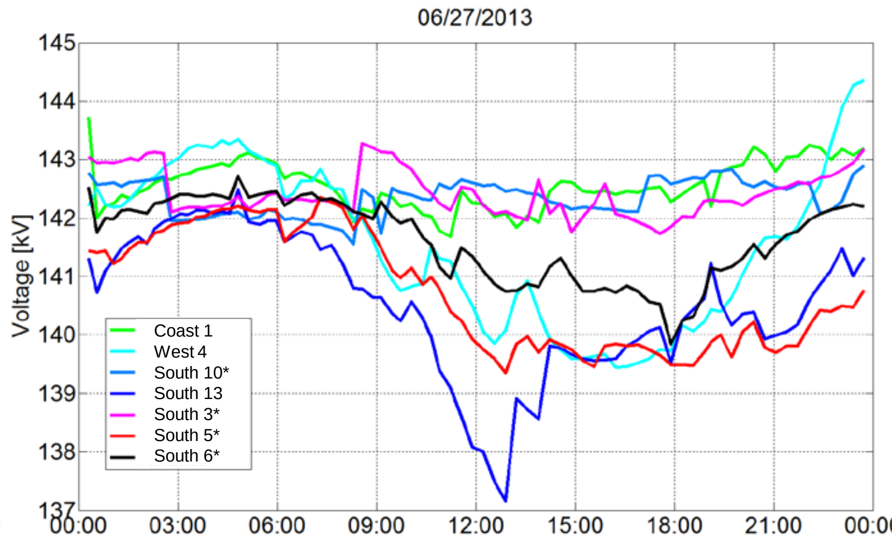


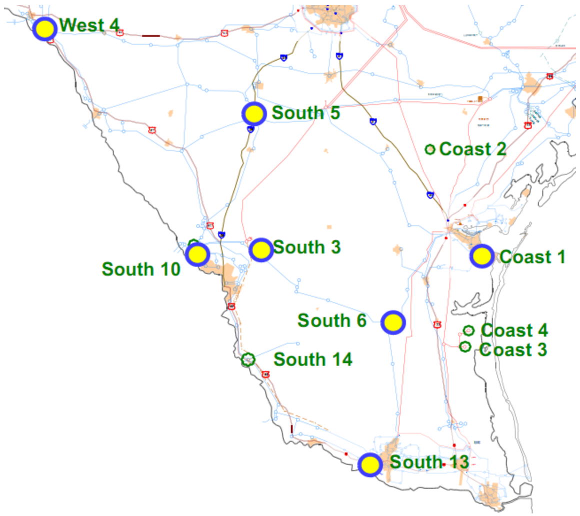




Group 6 – Valley (South)







Attachment 3. Updated Baselining Study for First Half of 2013

Baselining Analysis Update #1: January-June 2013 Data

Discovery Across Texas Project

Submitted By:

Electric Power Group

John Ballance
Romulo Barreno
Ajay Das
Song Xue

October 10, 2013

APPENDICES (attached as separate documents)

1. INTRODUCTION

Electric Power Group, LLC (EPG) was awarded contract DE-FOA-0000036 by the Center for the Commercialization of Electric Technologies (CCET) Discovery Across Texas project to provide professional services to, among other things, perform cluster analysis, comparison of phasor data versus state estimator data, and voltage and angle difference baselining. In June 2013, EPG completed a Baselining study using 2012 data that included the following: (1) grouped substations having phasor measurement units (PMUs) which are geographically close to each other, and performed a voltage and angle difference analysis for each group (cluster analysis); (2) performed a comparison of voltage and angle differences obtained using phasor measurements versus similar results using state estimator data (phasor vs. state estimator comparison); and, (3) performed a baseline analysis for voltages and angle differences for selected pairs of substations. Alarm limits were established and documented based on the baseline analysis.

A large number of CREZ 345 kV lines were dded to the ERCOT system in 2013 which will alter the results obtained with the 2012 data. Updates are being completed to corroborate the results of the 2012 study for the a) Cluster Analysis, b) Comparison Analysis and c) Baselining Analysis. Reports with updates for the Cluster and Comparison analysis have been completed and forwarded to ERCOT for their comments. Final reports will be posted in the CCET website.

This third and final report provides results from the update analysis to track the changes in voltage magnitudes and in voltage angles caused by the addition of several 345 kV lines added to the ERCOT system during the January to June 2013 time period.

2. PROJECT SCOPE

A. Baseline Analysis for Voltage and Angle Differences

This study update analyzed historical performance of the ERCOT grid, using State Estimator data plus phasor data for January to June 2013 to identify normal and abnormal voltages and angle limits across the grid. In this analysis, EPG compared the results obtained using 2013 data with those obtained using 2012 data and summarized the differences, if any, due to addition of the 345 kV lines added during the first six months of 2013. Activities performed as part of this item:

1. Extract key metric information (i.e., voltage, angles and angle differences).
2. Analyze extracted data and develop baseline understanding of voltage, phase angle, and angle difference patterns for key substations and key pairs of substations. Substations were selected based on current or projected availability of PMUs at those substations.
3. Monitor voltages and angle differences (pairs), and develop patterns and statistics in the form of box-whisker plots and load duration curves. Substations selected for analysis of voltages are listed in Table 1 below and pairs of substations selected for analysis of angle differences are listed in Table 2 below.
4. Prepare baselining analysis results for the selected substations and pairs of substations as Excel spreadsheet and charts, including:
   a. Voltage statistics (mean, maximum, and minimum).
   b. Voltage phase angle difference statistics (mean, maximum, and minimum).
   c. Voltage and phase angle distribution functions.

5. Develop a comparison table to show the differences in results for voltages and angle differences using 2012 and 2013 data.
6. Prepare baselining analysis summary for discussion with ERCOT and the Synchrophasor Team.

B. Establishing Alarm Limits for Use in Operations

Based on the baselining analysis, EPG will prepare a preliminary recommendation of key substations and angle pairs for monitoring in Real Time Dynamics Monitoring System[1] (RTDMS), and voltage and angle difference alarm settings for use in RTDMS to alert operators when grid stress is approaching limits.

This results from this report should be considered preliminary. A large number of new 345 kV lines will be added to the ERCOT system in the second half of 2013 as part of the CREZ project, changing significantly the distribution of power among existing and future transmission lines. This will result in changes in limits for voltages, voltage angles, and particularly angle differences. Recommending alarm limits based on only six months data will only be preliminary. EPG will conduct an analysis with the entire 2013 data to determine the voltage and angle difference limits that will be more likely to represent current and future system conditions. Final voltage and angle difference limits for use by operators will be recommended once the 2013 analysis is completed.

3. DATA SOURCES

Two sources of data were utilized to perform the study update analysis of voltage and angle differences in the ERCOT network: phasor data and state estimator cases. A description of these sources of data is provided below.

A. Phasor Data

ERCOT provided EPG phasor data for the first six months of 2013 with a resolution of 30 samples per second (SPS). EPG performed the following actions before the phasor data provided by ERCOT could be used for statistical analysis:

1. Downloaded the ERCOT data provided in MySQL format
2. Converted ERCOT binary format data into alphanumeric format
3. Converted MySQL data to CSV data files for use in Matlab data analysis programs.
4. Linked ERCOT data though the MySQL server to the EPG local ePDC database tool to allow downloading as CSV files to the local computer.
5. Down-sampled phasor data from 30 SPS to 1 SPS, and downloaded it to the local computer for analysis.
6. Applied status flag filtering to perform the first step in data cleaning
7. Developed data filtering algorithms and wrote code in Matlab to perform the second step of data filtering.
8. Addressed small data dropouts by interpolation techniques or filled dropouts with blanks.

[1] ®Electric Power Group. Built upon GRID-3P platform, US Patent 7,233,843, US Patent 8,060259, and US Patent 8,401,710.

This process of data setup, downloading, cleaning and fixing data dropouts takes several weeks due to the labor-intensive nature of the process.

This process is being automated to reduce the time taken to process the data from the time it is received to the time when the data is suitable for analysis. However, for this update, the manual process was used.

A program was developed by EPG to, once the data is setup, extract the information and display it in a summary table and two series of graphs. One graph (box -whisker) shows daily summaries of data, and the other, time duration curves, shows values versus percentage time for each study variable. The time duration curves were used to obtain the metric values corresponding to 1% and 99% exceedance (the value which was less than 1% plus inflection or greater than 99% minus inflection).

Phasor Measurement Units (PMUs) Installed and Planned in ERCOT

As of July 1, 2013, there were 41 PMUs installed in 28 locations across the ERCOT service area. Please see Table 1 below.

The baselining study update #3 was completed using data from the first six months of 2013 that included state estimator data analysis for locations for which PMUs are installed and for which PMUs are planned. However, five of the locations for which PMUs are planned are new and, therefore, there was no state estimator data available for those substations or pair of substations.

Table 1 – List of PMUs Currently Connected to the ERCOT Network as of July 1, 2013

#	Company	PMU Signal Name	PMU Station Name	Voltage (kV)	Existing or New Substation
1	AEP	Line 1	Coast 1	138	Existing
2	AEP	Line 1	Coast 2	69	Existing
3	AEP	Line 1	Coast 3	345	Existing
4	AEP	Line 2	Coast 3	345	Existing
5	AEP	Line 1	Coast 4	345	Existing
6	AEP	Line 2	Coast 4	345	Existing
7	AEP	Line 1	FarWest 2	69	Existing
8	AEP	Line 1	FarWest 9	138	Existing
9	AEP	Line 1	South 3	138	Existing
10	AEP	Line 1	South 5	69	Existing
11	AEP	Line 1	West 10	69	Existing
12	AEP	Line 1	West 4	138	Existing
13	AEP	Line 2	West 4	138	Existing
14	AEP	Line 3	West 4	138	Existing
15	AEP	Line 4	West 4	138	Existing
16	AEP	Line 5	West 4	138	Existing
17	AEP	Line 1	West 7	138	Existing
18	AEP-ETT	Line 1	West 14	345	Existing
19	AEP-ETT	Line 2	West 14	345	Existing
20	AEP-ETT	Line 3	West 14	345	Existing
21	AEP-ETT	Line 4	West 14	345	Existing
22	AEP-ETT	Line 5	West 15	345	Existing
23	ONCOR	Line 1	FarWest 4	345	Existing
24	ONCOR	Line 1	FarWest 7	345	Existing
25	ONCOR	Line 1	FarWest 8	138	Existing
26	ONCOR	Line 1	North 1	345	Existing
27	ONCOR	Line 1	North 4	138	Existing
28	ONCOR	Line 1	North 5	138	Existing
29	ONCOR	Line 1	North 6	138	Existing
30	ONCOR	Line 1	North 7	138	Existing
31	ONCOR	Line 1	West 1	345	Existing
32	ONCOR	Line 2	West 1	345	Existing
33	ONCOR	Line 1	West 11	345	Existing
34	ONCOR	Line 1	West 12	345	Existing
35	ONCOR	Line 1	West 2	345	Existing
36	ONCOR	Line 2	West 2	345	Existing
37	ONCOR	Line 1	West 5	345	Existing
38	ONCOR	Line 1	West 6	345	Existing
39	ONCOR	Line 1	West 9	345	Existing
40	Sharyland	Line 1	South 13	138	Existing
41	Sharyland	Line 2	South 13	138	Existing

B. State Estimator (SE) Data

ERCOT provided EPG with SE data for the first six months of 2013. EPG used the Power World simulator, provided by ERCOT, to extract approximately 15,330 SE cases. There were eight days for which SE data was not available as shown below:

Dates for which SE Data was Not Available (First Six Months of 2013)

03/23 to 03/26/2013		4 Days
03/28 to 03/31/2013		4 Days
	Total	**8 days**

C. Data Availability

Data availability for the phasor data varied from substation to substation. The summary table of phasor-based results shows the percent availability for each substation or each pair analyzed. As shown in Table A-1, availability varies from substation to substation, and ranges from 19.7% for West 1, West 2, West 9, West 12, and West 5, to greater than 95% for thirteen PMUs. No data was reported for North 2 and South 6. Box-whisker plots in Appendix A provide a view of data availability on a day-by-day basis.

For state estimator data availability, ERCOT produces state estimator cases every 5 minutes for a total of 105,120 possible cases per year. For six months, the total number of possible cases is 52,560; EPG received approximately 15,330 cases, which means the availability of SE data for the first six months of 2013 was approximately 29.2 % of available data. SE data availability for these six months improved to approximately double that of the 2012 SE data.

Below a summary of phasor data availability from Table A-1 below for 2012 and for 2013:

Phasor Data Availability

<40%	41% to 60%	61% to 80%	>80%
2013			
West 1	None	Coast 4	West 10
West 2			West 14
West 9			West 11
West 12			West 6
West 5			North 1
FarWest 2			North 4
South 3			North 5
South 5			North 6
			North 7
			West 4
			Coast 2
			Coast 1
			Coast 3
			South 13
			FarWest 4
			FarWest 7
			FarWest 8
			FarWest 9
2012			
West 14	West 4	West 11	West 10
North 1	Coast 4	Coast 1	North 7
Coast 2	Coast 3	FarWest 8	North 2
South 6	South 13		North 4
FarWest 7	FarWest 9		North 5
			West 6
			North 6
			FarWest 4

4. BASELINE ANALYSIS FOR VOLTAGE AND ANGLE DIFERENCES

This baseline analysis update for voltages and angle differences was performed using the phasor data and state estimator data obtained from ERCOT for the first six months of 2013. This data was processed to extract voltage magnitude and voltage angles. Minimum and maximum values for these variables were documented in summary tables; box-whisker plots and time duration curves were developed for each variable and for each type of data used. Below is an analysis of voltage magnitudes and voltage angles.

B. Methodology

For the pairs selected for study, the following work was performed:

1. Obtained and processed phasor data and state estimator data.
2. Extracted information to identify max, min, and average values from these data sources. Prepared summary tables showing results of all data, including data saved during events.
3. Used phasor and SE data to develop weekly box-whisker graphs and time duration curves for angle differences.
4. Identified limits corresponding to normal operation, excluding events and outages. To exclude extreme values corresponding to outliers and to events, values corresponding to the metrics exceeding 1% and 99% percent of the time were identified as normal operating limits. A summary showing these normal operation limits were obtained using phasor and SE data, and tabulated in the same table for comparison.
5. Analyzed results, identified limits, and reported results for each pair selected.

C. Study Approach

Electric Power Group used the following approach:

1. Obtained available phasor data and state estimator data from ERCOT.
2. Extracted phasor data and conditioned it for processing.
3. Solved state estimator cases and saved solved cases.
4. Selected substations and angle pairs of interest to ERCOT and the synchrophasor team members by choosing substations that have or soon will have PMUs installed.
5. Identified the substations and subsets of substations and pairs for which phasor data is available.
6. Developed statistical charts including time duration curve and box-whisker graphs for voltage magnitudes and angles, and for angle pairs.
7. Performed statistical analysis to identify angle difference limits for the pairs selected under all conditions. Summarized angle difference limits.
    - Established limits for normal operation based on the criteria described in the corresponding methodology. Summarized angle difference limits.
    - The limits for angle differences identified in this report shall be compared with ERCOT's criteria, if any, that apply to angle differences for the paths selected for this study.

5. BASELINE ANALYSIS FOR VOLTAGES MAGNITUDES

A. Substations Identified For Voltage Monitoring

EPG, in consultation with ERCOT and the Synchrophasor team, identified the following substations for monitoring.

	Table 2 SUBSTATIONS FOR VOLTAGE MONITORING		
	SUBSTATION	**kV**	**REGION**
1	West 10	69	Panhandle
2	West 14	345	Panhandle
3	West 1	345	Central
4	West 2	345	Central
5	West 9	345	Central
6	West 11	345	Central
7	West 12	345	Central
8	West 5	345	Central
9	West 6	345	Central
10	North 1	345	Dallas
11	North 2	138	Dallas
12	North 4	138	Dallas
13	North 5	138	Dallas
14	North 6	138	East
15	FarWest 2	69	West Texas
16	North 7	138	Central-East
17	West 4	138	SouthWest
18	Coast 2*	69	Valley
19	Coast 1	138	Valley
20	South 3	138	Valley
21	South 5	138	Valley
22	Coast 4	345	Valley
23	Coast 3	345	Valley
24	South 6	138	Valley
25	South 13	138	Valley
26	FarWest 4	345	West Texas
27	FarWest 7	345	West Texas
28	FarWest 8	138	West Texas
29	FarWest 9	138	West Texas
30	West 8*	345	Central
31	South 15*	345	Central
32	South 2*	345	Central-East
33	South 4*	345	Central-East
34	South 7*	345	Central-East
35	South 9*	345	Central-East
36	South 11*	345	Central-East
37	South 10*	138	Valley
38	West 16*	345	Panhandle
39	West 17*	345	Panhandle
40	West 13*	345	Panhandle
41	West 15*	345	Panhandle
42	West 3*	345	Central

B. Analysis of Data and Results

Availability of SE data for the first six months of 2013 was approximately 29.2%. SE data availability for these six months improved to approximately double that of the 2012 SE data. Data availability was approximately 13% for all SE cases in 2012. Phasor data availability varies from bus to bus. Data availability for 8 new PMUs was low because these PMUs were connected to the grid between late April and late May. On the other hand, there are 17 PMUs with data availability of 90 or better percent. Two PMUs have no data: North 2 and South 6.

Table A-1 below summarizes the min, max, and average values for voltage magnitude for the selected substations. The largest max-min voltage spreads observed were 28.1 kV at the Coast 4 345 bus and 10.7 kV at the West 4 138 kV bus. The maximum voltages observed were 368.56 kV at Coast 4 and 148.42 kV at South 3. The highest average voltages observed were 357.14 kV at West 14 and 142.43 kV at South 6.

As in the case of SE data results, phasor data indicated the highest average 138 kV voltage occurred at North 7 with 142.52 kV. The highest 345 kV voltage occurred at West 2 with 355.98 kV.

The summary shown in Table A-1 below shows the results for all data, including events and outages.

Normal Conditions: EPG made an attempt to exclude values corresponding to events and outages by isolating the values that lie in the lower one percent and in the higher 1 percent at the point of inflection in the time duration curve. The values of voltages obtained this way are considered to be the “normal points of operation”, and are summarized in Table A-2 below.

Table A-1 ERCOT DISCOVERY ACROSS TEXAS PROJECT - SUMMARY OF VOLTAGE MAGNITUDES - ALL DATA JANUARY 1 TO JUNE 30, 2013

No	Substation	Base kV	Region	PHASOR DATA Min	Max	Average	Max-Min Spread	Percent Data Available	STATE ESTIMATOR DATA Min	Max	Average	Max-Min Spread
1	West 10	69	Panhandle	67.92	73.16	70.72	5.24	97.57	67.50	72.31	69.95	4.8
2	West 14	345	Panhandle	344.76	362.03	355.87	17.27	94.11	351.76	364.91	357.14	13.2
3	West 1+	345	Central	343.66	361.94	355.66	18.28	19.65	344.48	362.80	354.24	18.3
4	West 2+	345	Central	346.92	360.41	355.98	13.49	19.67	349.31	361.28	356.33	12.0
5	West 9+	345	Central	341.68	361.94	352.99	20.26	19.67	345.52	364.04	354.07	18.5
6	West 11	345	Central	346.23	358.37	352.89	12.14	97.39	349.69	358.01	353.88	8.3
7	West 12+	345	Central	346.40	362.85	353.92	16.45	19.67	346.38	362.22	354.20	15.8
8	West 5+	345	Central	346.81	359.88	355.41	13.08	19.67	349.52	360.56	355.66	11.0
9	West 6	345	Central	345.78	360.56	353.85	14.78	97.18	348.10	361.35	354.75	13.3
10	North 1	345	Dallas	341.37	354.89	348.91	13.51	97.75	344.31	356.76	350.19	12.5
11	North 2	138	Dallas					0.00	137.30	142.43	139.81	5.1
12	North 4	138	Dallas	137.99	144.31	142.00	6.32	97.94	138.21	143.44	141.25	5.2
13	North 5	138	Dallas	136.51	143.83	141.15	7.32	97.78	137.35	141.73	139.70	4.4
14	North 6	138	East	137.24	145.80	141.92	8.56	97.78	138.77	145.95	142.02	7.2
15	FarWest 2+	69	Central-East	65.54	74.88	69.97	9.34	35.58	66.02	71.79	69.39	5.8
16	North 7	138	Central-East	138.24	145.04	142.52	6.80	95.87	137.85	145.02	141.46	7.2
17	West 4	138	SouthWest	134.99	148.22	142.30	13.23	91.52	136.07	146.75	141.76	10.7
18	Coast 2	69	Valley	65.32	72.85	70.14	7.53	96.51	66.86	73.24	70.19	6.4
19	Coast 1	138	Valley	138.46	144.25	142.32	5.79	97.79	137.93	144.20	141.49	6.3
20	South 3+	138	Valley	141.81	142.78	142.31	0.97	37.42	139.01	148.42	143.15	9.4
21	South 5+	69	Valley	68.44	71.73	70.51	3.29	35.44	67.44	73.46	70.67	6.0
22	Coast 4	345	Valley	345.00	364.31	354.16	19.31	74.61	340.48	368.56	354.50	28.1
23	Coast 3	345	Valley	342.88	363.81	353.50	20.93	89.29	340.38	367.87	354.23	27.5
24	South 6	138	Valley					0.00	139.85	144.42	142.43	4.6
25	South 13	138	Valley	133.92	146.88	141.67	12.96	97.29	137.02	146.43	141.92	9.4
26	FarWest 4	345	West Texas	347.71	357.53	354.06	9.82	93.77	350.35	358.56	354.43	8.2
27	FarWest 7	345	West Texas	342.38	355.85	350.45	13.46	97.90	344.38	356.04	350.80	11.7
28	FarWest 8	138	West Texas	137.51	145.47	141.95	7.96	92.56	136.85	143.52	140.44	6.7
29	FarWest 9	138	West Texas	135.72	144.17	141.15	8.45	95.79	137.20	144.47	140.99	7.3
30	West 8*	345	Central						343.21	367.11	354.68	23.9
31	South 15*	345	Central						349.14	363.46	356.01	14.3
32	South 2*	345	Central-East						348.28	362.39	355.02	14.1
33	South 4*	345	Central-East						349.66	363.70	356.33	14.0
34	South 7*	345	Central-East						348.93	361.94	355.11	13.0
35	South 9*	345	Central-East	**PMUs are planned for installation at these substations. No phasor data available for the January to June 2013 period.**					343.34	365.32	354.50	22.0
36	South 11*	345	Central-East						349.69	363.56	356.03	13.9
37	South 10*	138	Valley						139.05	144.83	141.74	5.8
38	West 16*	345	Panhandle						**These substations were not in service during the January to June 2013 period. No PSSE data available for this period.**			
39	West 17*	345	Panhandle									
40	West 13*	345	Panhandle									
41	West 15*	345	Panhandle									
42	West 3*	345	Central									

Note: The availability of state estimator cases was on the order of 13%.
The substations with + came on line during the second half of 2012 and the substations with * did not have PMUs installed by June 30, 2013.

TABLE A-2_CCET_DISCOVERY ACROSS TEXAS - LIMITS FOR VOLTAGES - NORMAL CONDITIONS

			Phasor Data			State Estimator Data - January 1 To June 30, 2013								SE Data		
No.	Bus Names	Base kV	Normal Min	Normal Max	Max-Min Spread	Normal Min-100%	100% or POI	99% Min	99% - POI	1% Max	1% + POI	Normal Max-0%	0% or POI	Normal Min	Normal Max	Max-Min Spread
1	West 10	69	69.36	71.72	2.36	68.03	99.90%	68.49	98.90%	71.43	1.03%	72.16	0.03%	68.49	71.43	2.94
2	West 14	345	350.90	359.80	8.90	352.21	99.96%	353.16	98.96%	359.96	4.56%	360.24	3.56%	353.16	359.96	6.79
3	West 1+	345	349.30	360.10	10.80	345.37	99.93%	347.23	98.93%	359.39	1.06%	361.04	0.06%	347.23	359.39	12.16
4	West 2+	345	351.60	358.70	7.10	350.68	99.83%	351.91	98.83%	359.42	1.04%	360.71	0.04%	351.91	359.42	7.51
5	West 9+	345	349.00	357.10	8.10	346.84	99.84%	348.40	98.84%	358.12	5.40%	358.40	4.40%	348.40	358.12	9.72
6	West 11	345	350.20	355.50	5.30	350.24	99.92%	351.23	98.92%	356.31	1.03%	357.73	0.03%	351.23	356.31	5.08
7	West 12+	345	350.30	358.10	7.80	347.00	99.97%	349.25	98.97%	358.99	1.07%	361.46	0.07%	349.25	358.99	9.73
8	West 5+	345	351.10	358.30	7.20	349.87	99.97%	351.73	98.97%	358.85	1.05%	359.92	0.05%	351.73	358.85	7.13
9	West 6	345	350.40	357.00	6.60	349.75	99.79%	350.84	98.79%	358.62	1.07%	359.63	0.07%	350.84	358.62	7.79
10	North 1	345	345.30	353.10	7.80	344.76	99.92%	345.59	98.92%	354.38	5.22%	354.54	4.22%	345.59	354.38	8.79
11	North 2	138				137.68	99.93%	138.30	98.93%	141.23	1.01%	142.37	0.01%	138.30	141.23	2.93
12	North 4	138	140.45	143.30	2.85	139.78	96.38%	139.92	95.38%	142.66	1.02%	143.40	0.02%	139.92	142.66	2.75
13	North 5	138	139.65	142.50	2.85	138.66	95.51%	138.75	94.51%	140.95	1.04%	141.46	0.04%	138.75	140.95	2.20
14	North 6	138	140.15	143.75	3.60	139.20	99.94%	140.03	98.94%	143.97	3.98%	144.20	2.98%	140.03	143.97	3.95
15	FarWest 2+	69	68.34	71.98	3.64	67.38	99.35%	67.65	98.35%	71.12	1.03%	71.72	0.03%	67.65	71.12	3.47
16	North 7	138	140.51	143.99	3.48	139.83	95.49%	139.96	94.49%	143.50	2.85%	143.68	1.85%	139.96	143.50	3.54
17	West 4	138	138.60	145.69	7.09	136.88	99.91%	138.05	98.91%	145.00	1.11%	145.81	0.11%	138.05	145.00	6.96
18	Coast 2	69	68.39	71.76	3.37	67.39	99.89%	68.24	98.89%	72.05	1.07%	72.59	0.07%	68.24	72.05	3.81
19	Coast 1	138	140.70	143.41	2.71	139.92	95.18%	139.97	94.18%	143.32	1.09%	143.85	0.09%	139.97	143.32	3.34
20	South 3+	138	142.14	142.43	0.29	139.51	99.97%	140.38	98.97%	146.17	2.00%	146.66	1.00%	140.38	146.17	5.79
21	South 5+	69	69.55	71.36	1.81	69.27	96.97%	69.38	95.97%	72.22	2.77%	72.31	1.77%	69.38	72.22	2.84
22	Coast 4	345	349.00	359.70	10.70	347.74	97.17%	348.28	96.17%	360.05	3.75%	360.67	2.75%	348.28	360.05	11.77
23	Coast 3	345	348.30	359.10	10.80	347.50	97.35%	348.10	96.35%	359.72	3.96%	360.30	2.96%	348.10	359.72	11.62
24	South 6	138				140.52	99.75%	140.89	98.75%	143.78	1.05%	144.15	0.05%	140.89	143.78	2.89
25	South 13	138	139.30	143.70	4.40	138.33	99.83%	139.03	98.83%	144.48	1.08%	145.39	0.08%	139.03	144.48	5.45
26	FarWest 4	345	351.06	355.93	4.87	350.49	99.97%	351.55	98.97%	355.95	4.02%	356.13	3.02%	351.55	355.95	4.40
27	FarWest 7	345	346.30	353.80	7.50	345.15	99.93%	346.45	98.93%	354.42	1.10%	355.34	0.10%	346.45	354.42	7.97
28	FarWest 8	138	140.06	143.80	3.74	138.71	97.69%	138.86	96.69%	142.40	1.08%	143.15	0.08%	138.86	142.40	3.54
29	FarWest 9	138	138.80	143.13	4.33	137.25	99.95%	138.49	98.95%	143.13	1.07%	143.60	0.07%	138.49	143.13	4.64
30	West 8*	345	PMUs are planned for installation at these substations. No phasor data available for the January to June 2013 period.			346.09	99.65%	346.73	98.65%	359.16	1.25%	359.88	0.25%	346.73	359.16	12.43
31	South 15*	345				350.08	99.90%	351.37	98.90%	359.87	1.05%	361.16	0.05%	351.37	359.87	8.49
32	South 2*	345				349.04	99.92%	350.24	98.92%	359.31	1.07%	360.89	0.07%	350.24	359.31	9.06
33	South 4*	345				350.14	99.93%	351.64	98.93%	360.15	1.03%	361.39	0.03%	351.64	360.15	8.51
34	South 7*	345				350.05	99.90%	351.53	98.90%	358.15	3.39%	358.38	2.39%	351.53	358.15	6.62
35	South 9*	345				343.88	99.95%	346.03	98.95%	361.44	1.09%	364.22	0.09%	346.03	361.44	15.40
36	South 11*	345				350.69	99.74%	351.56	98.74%	359.62	1.04%	360.70	0.04%	351.56	359.62	8.05
37	South 10*	138				139.23	99.93%	139.87	98.93%	143.81	1.09%	144.41	0.09%	139.87	143.81	3.94
38	West 16*	345				These substations were not in service during the January to June 2013 period. No PSSE data available for this period.								No PSSE data available for this period.		
39	West 17*	345														
40	West 13*	345														
41	West 15*	345														
42	West 3*	345														

Note: The eight substations with + came on line late in June 2013 and the substations with * did not have PMUs installed in first half of 2013.

Note that the greater Max-Min voltage spreads now occur at South 9 345 kV bus with 15.4 kV, and West 4 138 kV bus with 6.95 kV.

For both the SE data and the phasor data, box-whisker plots and time duration curves were developed for each of the substations listed above, and were used to obtain the values in the Table A-2 above. Summaries of SE-based voltage pairs with their corresponding box-whisker and time duration curves as well as summaries of phasor-based voltage pairs with their corresponding box-whisker and time duration curves are presented in Appendix A.

C. Observations

i. **Data availability:** the availability for state estimator data was approximately 29.2%; the availability for phasor data was greater overall but varied from 19.7% at West 12 to 97.94% at North 4. Nineteen PMUs out of 29 substations had data availability greater than 70%.

ii. Both phasor data and state estimator data point to West 4 and Coast 4 as having the highest voltage and voltage spreads in their class. Voltages at these substations are more volatile than at the other substations. Note that Coast 3 also has high voltage spread, but South 13 and South 6, which are in the neighborhood, have a much lower spread.

iii. Fifteen substations out of a total of 41 show voltage spreads higher than 15 kV, and 24 substations show voltage spreads higher than 10 kV.

iv. Voltage spreads for normal conditions went down by up to 5 kV (phasor) from those under all conditions.

D. Comparison of Alarm Limits for Voltages – 2012 vs. 2013 Data

The limits summarized in the two tables above reflect system performance after the addition of the CREZ lines in the first six months of 2013. EPG has prepared a comparison table to indentify the changes in voltages due to the addition of the new 345 kV lines. Table 3 shows a comparison of voltage magnitude averages as well as Max-Min spreads for 2012 and 2013.

Table 3 CCET DISCOVERY ACROSS TEXAS PROJECT - VOLTAGE MAGNITUDES - ALL DATA COMPARISON 2012 vs. 2013 - JANUARY 1 TO JUNE 30

				STATE ESTIMATOR DATA - 2012				STATE ESTIMATOR DATA-2013			
No	Substation	Base kV	Region	Min	Max	Average	Max-Min Spread	Min	Max	Average	Max-Min Spread
1	West 10	69	Panhandle	68.03	73.13	71.03	5.1	67.15	74.15	71.89	7.0
2	West 14	345	Panhandle	348.07	362.15	355.89	14.1	351.76	364.91	357.14	13.2
3	West 1+	345	Central					344.48	362.80	354.24	18.3
4	West 2+	345	Central	348.17	366.11	357.56	17.9	349.31	361.28	356.33	12.0
5	West 9+	345	Central	346.93	365.53	357.31	18.6	345.52	364.04	354.07	18.5
6	West 11	345	Central	347.73	361.28	355.14	13.6	349.69	358.01	353.88	8.3
7	West 12+	345	Central	346.17	364.70	356.50	18.5	346.38	362.22	364.20	15.8
8	West 5+	345	Central	347.83	365.77	356.95	17.9	349.52	360.56	355.66	11.0
9	West 6	345	Central	346.73	364.08	356.46	17.4	348.10	361.35	354.75	13.3
10	North 1	345	Dallas	340.69	353.14	347.70	12.5	344.31	356.76	350.19	12.5
11	North 2	138	Dallas	138.30	141.79	140.37	3.5	137.30	142.43	139.81	5.1
12	North 4	138	Dallas	138.55	144.07	142.13	5.5	138.21	143.44	141.25	5.2
13	North 5	138	Dallas	137.34	141.75	139.80	4.4	137.35	141.73	139.70	4.4
14	North 6	138	East	138.88	143.53	141.59	4.7	138.77	145.95	142.02	7.2
15	FarWest 2+	69	Central-East	67.32	71.53	69.27	4.2	66.02	71.79	69.39	5.8
16	North 7	138	Central-East	139.23	144.46	142.21	5.2	137.85	145.02	141.46	7.2
17	West 4	138	SouthWest	132.52	151.74	141.17	19.2	136.07	146.75	141.76	10.7
18	Coast 2	69	Valley	66.58	71.94	69.61	5.4	66.86	73.24	70.19	6.4
19	Coast 1	138	Valley	138.69	143.18	141.20	4.5	137.93	144.20	141.49	6.3
20	South 3+	138	Valley	138.25	146.38	142.11	8.1	139.01	148.42	143.15	9.4
21	South 5+	69	Valley	67.14	72.67	70.56	5.5	67.44	73.46	70.67	6.0
22	Coast 4	345	Valley	341.96	363.32	353.39	21.4	340.48	368.56	354.50	28.1
23	Coast 3	345	Valley	341.62	363.39	353.27	21.8	340.38	367.87	354.23	27.5
24	South 6	138	Valley	139.61	144.00	142.03	4.4	139.85	144.42	142.43	4.6
25	South 13	138	Valley	137.74	145.48	141.72	7.7	137.02	146.43	141.92	9.4
26	FarWest 4	345	West Texas	349.45	360.63	355.81	11.2	350.35	358.56	354.43	8.2
27	FarWest 7	345	West Texas	345.38	360.59	352.86	15.2	344.38	356.04	350.80	11.7
28	FarWest 8	138	West Texas	135.41	142.35	139.39	6.9	136.85	143.52	140.44	6.7
29	FarWest 9	138	West Texas	136.10	146.85	141.20	10.8	137.20	144.47	140.99	7.3
30	West 8*	345	Central					343.21	367.11	354.68	23.9
31	South 15*	345	Central	349.49	359.46	354.82	10.0	349.14	363.46	356.01	14.3
32	South 2*	345	Central-East	348.80	358.52	354.07	9.7	348.28	362.39	355.02	14.1
33	South 4*	345	Central-East	349.17	359.83	354.80	10.7	349.66	363.70	356.33	14.0
34	South 7*	345	Central-East	348.59	359.04	354.33	10.5	348.93	361.94	355.11	13.0
35	South 9*	345	Central-East	343.17	358.90	352.20	15.7	343.34	365.32	354.50	22.0
36	South 11*	345	Central-East	348.52	358.46	354.22	9.9	349.69	363.56	356.03	13.9
37	South 10*	138	Valley	138.59	144.49	141.46	5.9	139.05	144.83	141.74	5.8
38	West 16*	345	Panhandle	**These substations were not in service during the January to June 2012 period. No PSSE data available for this period.**				**These substations were not in service during the January to June 2013 period. No PSSE data available for this period.**			
39	West 17*	345	Panhandle								
40	West 13*	345	Panhandle								
41	West 15*	345	Panhandle								
42	West 3*	345	Central								

Note: The substations with + came on-line during the second half of 2012 and the substations with * did not have PMUs installed by June 30, 2013.

Evaluation of Table 3 shows a few substations had voltage spreads with difference greater than 5 kV, but the average voltages were not that much different. Several substations experienced slightly higher voltage magnitudes in 2013 than in 2012. No clear trends were observed for voltage magnitudes from this summary table.

E. **Analysis of the Box- ² hisker ±oltage ƚlots - 2013 Data**

a. For one day, January 10, the voltage at West 14 went up by about 5 kV, and again in mid-March the voltage at this substation went up by about 3 kV. By mid-April, the voltage at this substation came down and was operating mostly in the 354 to 358 kV range.
b. The voltage at West 9 fluctuated within a 16 kV range; the voltages at this substation reached the lowest points during the month of May.
c. West 12 substation also experienced voltages operating within a wide range of 12 kV.
d. The voltage at North 1 behaved somewhat wildly during the first six months of 2013. During the month of April, the voltage jumped up 4 kV and operated in the neighborhood of 354 kV for most of the month. By the end of May, the voltage came down drastically to around 347 kV and then day-by-day went up and ended up operating around 354 kV by the end of June.
e. The North 4 box-whisker plot exhibits what appears to be a large number of outlier points in the lower part of the plot.
f. The voltage at North 6 was steady during the months of January to April and then, at the beginning of May, jumped up a couple of kVs before coming down again in late June.
g. Around 20 February, the voltage at FarWest 2 dipped almost 4 kV to 64 kV.
h. Voltage fluctuations at Coast 2 were more pronounced during May and June.
i. The voltage at Coast 1 came down around 1.5 kV by the middle of March, before going back up to 142.5 kV by the end of June.
j. South 3: the voltage at this substation operated within a wide margin from 139.5 to 148 kV. In mid-January, the voltage went up to as high as 148 kV before coming down to around 143kV. In June, the voltage operated in the 141 to 143 kV range.
k. South 5: the voltage took a dip to around 68 kV around 12 February.
l. Coast 4: the voltage spiked up to about 368 kV in late January, and spiked down to about 341 kV in early March.
m. Coast 3: similar to Coast 4, the voltage spiked up to about 368 kV in late January, and spiked down to about 341 kV in early March.
n. FarWest 4: one spike up (358.5 kV) and three spikes down (340.5 kV).
o. FarWest 7: operates within a 10 kV range (345 to 355 kV) with large daily swings.
p. South 2: operated within a 12 kV range (349 to 361 kV).
q. South 9: voltage fluctuated within a wide range, from 344 to 365 kV, with a spike up around March 2.
r. South 10: the median changes constantly with a few spikes up and down.

6. BASELINE ANALYSIS FOR VOLTAGE ANGLES (REFERENCE: North 7 Bus)

D. Substations Identified for Voltage Angle Analysis

The following substations were selected for voltage angle analysis; the substation selected as reference was North 7.

Table 4: SUBSTATIONS FOR VOLTAGE ANGLE MONITORING			
#	SUBSTATION	kV	REGION
1	West 10	69	Panhandle
2	West 14	345	Panhandle
3	West 1	345	Central
4	West 2	345	Central
5	West 9	345	Central
6	West 11	345	Central
7	West 12	345	Central
8	West 5	345	Central
9	West 6	345	Central
10	North 1	345	Dallas
11	North 2	138	Dallas
12	North 4	138	Dallas
13	North 5	138	Dallas
14	North 6	138	East
15	FarWest 2	69	West Texas
16	West 4	138	SouthWest
17	Coast 2	69	Valley
18	Coast 1	138	Valley
19	South 3	138	Valley
20	South 5	138	Valley
21	Coast 4	345	Valley
22	Coast 3	345	Valley
23	South 6	138	Valley
24	South 13	138	Valley
25	FarWest 4	345	West Texas
26	FarWest 7	345	West Texas
27	FarWest 8	138	West Texas
28	FarWest 9	138	West Texas
29	West 8+	345	Central
30	South 15+	345	Central
31	South 2+	345	Central-East
32	South 4+	345	Central-East
33	South 7+	345	Central-East
34	South 9+	345	Central-East
35	South 11+	345	Central-East
36	South 10+	138	Valley
37	West 16*	345	Panhandle
38	West 17*	345	Panhandle
39	West 13*	345	Panhandle
40	West 15*	345	Panhandle
41	West 3*	345	Central

+ Means no PMUs installed as of June 30, 2013

* Means substations were not in service as of June 30, 2013

E. Summary of Results - All 5ata Lncluded

The voltage angle results obtained from all solved SE cases, and all phasor data, are summarized in Table B-1 below.

These results were obtained using all data available, including event and outage conditions. Under these conditions, voltage angles would be expected to be larger than under normal conditions because, during event and outage conditions, the angles tend to increase to reflect the changes in system conditions or changes in system configuration. The maximum Max-Min spreads observed were 104.1 degrees, for FarWest 9 138 kV substation, and 90.8 degrees, for FarWest 4 345 kV substation. Note also that the substations close to the wind farms in groups 1 and 2, shown in yellow, have over 80 degree Max-Min spreads, and the angles for these substations are positive more than 74% of the time; that is, the power flows from these substations towards North 7 most of the time. These spreads are lower than those maximum spreads found in the 2012 baselining study, but this is expected since the grid is now tighter with the addition of several 345 kV lines.

Table B-1: CCET DISCOVERY ACROSS TEXAS- BASELINING ANALYSIS UPDATE - VOLTAGE ANGLES - ALL CONDITIONS (Reference: North 7)

			Phasor Data - 1/1/13 to 6/30/13					State Estimator Data - 1/1/13 to 6/30/13				
No	Angle Pair FROM - TO	Base kV	Min	Max	Average	Percent Positive	% Data Available	Min	Max	Average	Percent Positive	Max-Min Spread
1	West 10	69	-40.45	70.08	10.62	66.29	96.70	-32.72	28.12	-4.27	33.51%	60.8
2	West 14	345	-21.43	37.65	8.48	85.89	92.23	-18.97	32.46	7.54	87.87%	51.4
3	West 1+	345	-15.92	33.07	6.01	81.58	19.63	-24.06	56.73	7.01	79.85%	80.8
4	West 2+	345	-10.52	27.27	8.20	78.33	19.66	-26.31	55.73	9.24	77.77%	82.0
5	West 9+	345	-12.37	33.07	9.43	80.11	19.67	-27.52	57.18	10.15	78.59%	84.7
6	West 11	345	-30.72	62.04	9.68	74.37	97.23	-29.63	58.64	9.98	74.94%	88.3
7	West 12+	345	-12.39	33.07	9.42	79.97	19.67	-27.52	57.19	10.15	78.59%	84.7
8	West 5+	345	-11.58	29.97	9.00	79.10	19.67	-26.90	55.73	9.92	78.04%	82.6
9	West 6	345	-28.43	60.40	10.00	77.52	97.04	-27.52	57.20	10.33	78.31%	84.7
10	North 1	345	-12.33	26.41	6.76	92.69	97.55	-11.84	25.11	6.96	94.67%	37.0
11	North 2	138						-24.64	10.28	-6.48	4.76%	34.9
12	North 4	138	-18.85	14.43	-2.80	24.37	97.74	-17.84	13.60	-2.18	28.33%	31.4
13	North 5	138	-20.35	14.99	-4.81	13.69	97.59	-19.99	11.56	-4.58	13.75%	31.6
14	North 6	138	-8.67	17.99	4.44	87.88	97.56	-10.70	17.25	3.78	83.10%	28.0
15	FarWest 2+	69	-160.79	-78.92	-122.15	0.00	35.31	-28.75	10.39	-7.82	5.64%	39.1
16	West 4	138	-32.04	18.95	-5.08	25.21	90.40	-29.75	16.94	-4.93	25.46%	46.7
17	Coast 2	69	-31.96	24.48	-6.28	23.13	95.66	-31.46	24.53	-6.13	24.26%	56.0
18	Coast 1	138	-36.75	50.83	2.59	57.68	96.44	-35.89	44.81	2.16	56.10%	80.7
19	South 3+	138	-31.70	50.46	-2.67	39.89	36.98	-31.00	32.95	-0.06	50.88%	64.0
20	South 5+	138	-25.25	14.95	-10.34	7.44	35.05	-29.57	14.27	-7.40	10.35%	43.8
21	Coast 4	345	-39.53	49.50	3.63	61.24	64.51	-33.40	50.50	5.20	64.94%	83.9
22	Coast 3	345	-34.93	46.65	4.51	62.39	87.52	-33.40	49.75	4.87	64.07%	83.2
23	South 6	138						-34.06	37.63	-0.63	48.46%	71.7
24	South 13	138	-54.93	50.00	-1.74	46.40	96.71	-51.34	46.50	-1.67	46.57%	97.8
25	FarWest 4	345	-32.57	60.00	10.32	74.15	93.61	-30.54	60.24	10.74	75.08%	90.8
26	FarWest 7	345	-35.49	59.79	8.23	70.29	97.71	-34.04	55.59	8.26	70.86%	89.6
27	FarWest 8	138	-44.79	54.96	0.00	49.63	92.37	-42.34	51.30	0.43	50.69%	93.6
28	FarWest 9	138	-44.80	59.98	5.27	57.85	94.74	-40.92	63.14	5.76	59.32%	104.1
29	West 8*	345/138	No phasor data available for these substations for the first half of 2013					-11.24	27.27	8.87	78.96%	38.5
30	South 15*	345/138						-20.01	15.63	-0.60	42.74%	35.6
31	South 2*	345/138						-16.81	18.32	1.85	67.25%	35.1
32	South 4*	345/138						-20.47	16.74	-0.81	41.31%	37.2
33	South 7*	345/138						-17.89	21.19	3.23	73.36%	39.1
34	South 9*	345/138						-19.23	16.37	-1.17	37.69%	35.6
35	South 11*	345/138						-21.08	17.78	-1.03	40.50%	38.9
36	South 10*	138						-35.17	24.79	-7.31	18.65%	60.0
37	West 16*	345/138						Substations not in service during the January to June 2013 period.				
38	West 17*	345/138										
39	West 13*	345/138										
40	West 15*	345/138										
41	West 3*	345/138										

Note: The eight substations with + came on line late in June of 2013 and the substations with * did not have PMUs installed in the first half of 2013.

F. Summary of Results – Normal Conditions (events and outages excluded)

The voltage angle results obtained from excluding extreme values based on analysis of the box-whisker plots and time duration curves are shown in Table B-2 below.

Table B-2: CCET DISCOVERY ACROSS TEXAS- BASELINING ANALYSIS UPDATE- VOLTAGE ANGLES - NORMAL CONDITIONS

(Reference: 138 kV North 7)

			DATA ANALYSIS RESULTS													
			Phasor-Normal			State Estimator Data - 1/1/13 to 6/30/13								SE Data-Normal		
No	Angle Pair FROM - TO	Base kV	Min Angle	Max Angle	Max-Min Spread	Min Angle at POI or 100%	Percent (POI or 100%)	Min Angle at 99% or POI - 1%	Percent (99% or POI - 1%)	Max Angle at 1% or POI +1%	Percent (1% or POI +1%)	Max Angle at POI or 0%	Percent (POI or 0%)	Min Angle	Max Angle	Max-Min Spread
1	West 10	69	-36.57	53.16	89.7	-27.69	99.04%	-21.75	98.04%	46.66	1.04%	59.74	0.04%	-27.69	59.74	87.4
2	West 14	345	-17.56	33.24	50.8	-17.62	99.98%	-12.26	98.98%	23.68	1.00%	32.46	0.00%	-17.62	32.46	50.1
3	West 1+	345	-6.64	18.88	25.5	-22.84	99.96%	-16.95	98.96%	32.04	1.06%	40.40	0.06%	-22.84	40.40	63.2
4	West 2+	345	-9.30	26.74	36.0	-24.97	99.96%	-18.79	98.96%	35.97	1.02%	46.03	0.02%	-24.97	46.03	71.0
5	West 9+	345	-11.67	32.00	43.7	-26.00	99.97%	-19.57	98.97%	37.84	1.02%	48.04	0.02%	-26.00	48.04	74.0
6	West 11	345	-27.34	49.97	77.3	-27.67	99.96%	-21.07	98.96%	38.74	1.02%	48.96	0.02%	-27.67	48.96	76.6
7	West 12+	345	-11.67	31.98	43.7	-26.02	99.97%	-19.53	98.97%	37.87	1.01%	49.60	0.01%	-26.02	49.60	75.6
8	West 5+	345	-10.42	29.30	39.7	-25.31	99.95%	-19.11	98.95%	36.85	1.02%	45.85	0.02%	-25.31	45.85	71.2
9	West 6	345	-25.24	49.50	74.7	-26.00	99.97%	-19.60	98.97%	38.02	1.02%	47.23	0.02%	-26.00	47.23	73.2
10	North 1	345	-10.05	21.40	31.5	-9.90	99.98%	-5.63	98.98%	17.45	1.02%	23.22	0.02%	-9.90	23.22	33.1
11	North 2	138				-22.69	99.98%	-17.51	98.98%	2.67	1.02%	8.80	0.02%	-22.69	8.80	31.5
12	North 4	138	-17.65	9.92	27.6	-16.29	99.95%	-12.02	98.95%	7.27	1.03%	11.37	0.03%	-16.29	11.37	27.7
13	North 5	138	-18.07	10.01	28.1	-19.39	99.96%	-14.37	98.96%	6.15	1.02%	11.55	0.02%	-19.39	11.55	30.9
14	North 6	138	-7.60	14.69	22.3	-10.25	99.98%	-5.15	98.98%	12.28	1.02%	16.90	0.02%	-10.25	16.90	27.1
15	FarWest 2+	69	-155.40	-85.97	69.4	-26.74	99.98%	-20.54	98.98%	3.53	1.02%	9.79	0.02%	-26.74	9.79	36.5
16	West 4	138	-26.08	14.73	40.8	-27.94	99.98%	-21.80	98.98%	10.48	1.04%	15.35	0.04%	-27.94	15.35	43.3
17	Coast 2	69	-30.28	18.03	48.3	-31.46	99.99%	-25.46	98.99%	14.11	1.02%	24.20	0.02%	-31.46	24.20	55.7
18	Coast 1	138	-31.72	35.82	67.5	-33.15	99.89%	-25.49	98.89%	29.77	1.02%	41.56	0.02%	-33.15	41.56	74.7
19	South 3+	138	-27.42	28.39	55.8	-28.67	99.98%	-22.67	98.98%	22.53	1.02%	31.96	0.02%	-28.67	31.96	60.6
20	South 5+	138	-23.39	12.95	36.3	-28.42	99.98%	-20.97	98.98%	8.05	1.03%	13.85	0.03%	-28.42	13.85	42.3
21	Coast 4	345	-32.91	40.48	73.4	-32.78	99.98%	-25.35	98.98%	35.72	1.02%	49.95	0.02%	-32.78	49.95	82.7
22	Coast 3	345	-30.16	42.98	73.1	-33.05	99.98%	-25.43	98.98%	35.08	1.02%	49.06	0.02%	-33.05	49.06	82.1
23	South 6	138				-33.67	99.98%	-26.96	98.98%	25.31	1.00%	37.63	0.00%	-33.67	37.63	71.3
24	South 13	138	-44.74	42.58	87.3	-48.36	99.98%	-36.11	98.98%	33.56	1.02%	45.94	0.02%	-48.36	45.94	94.3
25	FarWest 4	345	-28.82	51.33	80.2	-28.52	99.96%	-21.56	98.96%	39.99	1.02%	50.47	0.02%	-28.52	50.47	79.0
26	FarWest 7	345	-30.90	46.24	77.1	-32.14	99.97%	-23.88	98.97%	35.70	1.02%	46.35	0.02%	-32.14	46.35	78.5
27	FarWest 8	138	-40.57	41.77	82.3	-40.77	99.95%	-32.53	98.95%	29.79	1.02%	41.50	0.02%	-40.77	41.50	82.3
28	FarWest 9	138	-40.43	55.18	95.6	-39.76	99.97%	-32.70	98.97%	41.94	1.02%	52.47	0.02%	-39.76	52.47	92.2
29	West 8*	345	No Phasor Data Available the first half of 2013			-11.13	99.97%	-8.94	98.97%	25.71	1.22%	26.73	0.22%	-11.13	26.73	37.9
30	South 15*	345				-18.31	99.97%	-13.47	98.97%	11.50	1.00%	15.63	0.00%	-18.31	15.63	33.9
31	South 2*	345				-14.96	99.99%	-9.91	98.99%	12.54	1.01%	18.19	0.01%	-14.96	18.19	33.2
32	South 4*	345				-18.97	99.98%	-14.11	98.98%	12.02	1.04%	16.00	0.04%	-18.97	16.00	35.0
33	South 7*	345				-15.85	99.98%	-10.16	98.98%	15.29	1.00%	21.19	0.00%	-15.85	21.19	37.0
34	South 9*	345				-17.70	99.95%	-13.10	98.95%	9.98	1.02%	16.01	0.02%	-17.70	16.01	33.7
35	South 11*	345				-19.91	99.98%	-14.72	98.98%	12.29	1.05%	16.74	0.05%	-19.91	16.74	36.6
36	South 10*	138				-34.65	99.98%	-26.92	98.98%	13.60	1.02%	21.84	0.02%	-34.65	21.84	56.5
37	West 16*	345				Substations not in service during the January to June 2013 period.								PSSE data not available during the January to June 2013 period.		
38	West 17*	345														
39	West 13*	345														
40	West 15*	345														
41	West 3*	345														

Note: The substations with + came on line during the second half of 2012 and the substations with * did not have PMUs installed in the first half 2013.

NOTE: The PMUs noted with a + have very limited amount of phasor data because these PMUs were connected to the ERCOT grid in the later weeks of the study period.

Summaries of voltage angle pairs with their corresponding box-whisker and time duration curves based on state estimator data and phasor data are presented in Appendix B.

G. Observations

1. Voltage angles vary over a wide range for several substations. The largest variation of 94.3 degrees (-48.36 to 45.94) occurred at South 13 138 kV substation. Among the 345 kV substations, the largest angle variation over the first six months of 2013 occurred at Coast 4 with a range of 82.7 (-32.78 to 49.95) degrees.

2. The largest variations occurred among the substations in the western part of the state, namely: FarWest 7, West 11, West 6, FarWest 8, FarWest 9, FarWest 4, West 2, West 9, and West 5.
3. The next largest angle variation occurred in the south part of the state, namely: South 13, Coast 3, Coast 4, and Coast 1.
4. The two largest normal angles observed were at FarWest 4 and FarWest 9, with 50.47 and 52.47 degrees, respectively.

7. COMPARISON OF VOLTAGE ANGLES (Ref.: North 7) – 2012 vs. 2013

A. Goal

EPG performed a comparison of voltage angles for a number of pairs to determine the effect the new CREZ lines had on the performance of the ERCOT grid. Following are the results of that comparison.

B. Pairs Selected for Comparison

Twelve pairs were selected to compare voltage angles between 2012 and 2013 conditions. They are listed in Table 5 below.

TABLE 5: ANGLE PAIRS FOR VOLTAGE ANGLE COMPARISON

#	Substation A	Substation B	From Region	To Region
1	West 10	North 7	Panhandle	Central-East
2	West 14	North 7	Panhandle	Central-East
3	West 11	North 7	Central	Central-East
4	West 6	North 7	West Texas	Central-East
5	North 4	North 7	Dallas	Central-East
6	North 5	North 7	Dallas	Central-East
7	North 6	North 7	East	Central-East
8	Coast 1	North 7	Valley	Central-East
9	Coast 3	North 7	Valley	Central-East
10	FarWest 4	North 7	West Texas	Central-East
11	FarWest 8	North 7	West Texas	Central-East
12	FarWest 9	North 7	West Texas	Central-East

C. Procedure

This comparison was completed using median values to avoid, as much as possible, distortions in the comparison. Phasor data was collected for the six months of 2012 and 2013, and daily median values plotted for each pair for the six-month period.

In addition to these daily median graphs, box-whisker plots were developed for each pair using median values. These box-whisker plots produced a new median for the six-month period for 2012 and 2013.

D. Results

The results of the comparison are shown in Appendix C. Results for 2012 are shown in blue and results for 2013 are shown in red. Some pairs had insufficient data in 2012; in these cases, EPG completed the comparison using only the periods of time when data was available for BOTH years.

The daily median graphs show that, for most of the days, the 2013 median voltage angle difference (relative to North 7) was lower than the 2012 median. The overall six-month box-whisker plots were more conclusive: the median of the medians for every pair for 2013 was lower than the median of the medians for 2012. See Table 6 below.

TABLE 6: VOLTAGE ANGLE COMPARISON (Median) - 2012 vs. 2013

			VOLTAGE ANGLE - MEDIAN		
#	**Substation A**	**Substation B**	**2012**	**2013**	**Difference**
1	West 10	North 7	21.70	12.30	-9.40
2	West 14	North 7	10.24	8.51	-1.73
3	West 11	North 7	15.67	10.20	-5.47
4	West 6	North 7	16.44	9.00	-7.44
5	North 4	North 7	2.50	-2.40	-4.90
6	North 5	North 7	0.91	-4.57	-5.48
7	North 6	North 7	7.38	4.65	-2.73
8	Coast 1	North 7	7.33	2.85	-4.48
9	Coast 3	North 7	4.57	1.28	-3.29
10	FarWest 4	North 7	17.03	9.51	-7.52
11	FarWest 8	North 7	4.60	2.15	-2.45
12	FarWest 9	North 7	10.92	10.01	-0.91

Review of this table shows the following:

i. The largest difference occurred on the West 10, FarWest 4, and West 6 to North 7 pairs. All of these substations are located in west Texas.

ii. The FarWest 9 and West 14 to North 7 pairs had the lowest reduction: 0.91 and 1.73 degrees, respectively.

iii. Coast 1 and Coast 3 to North 7 pairs had reductions of 4.48 and 3.29 degrees. These reductions seem significant, though EPG is not aware of new lines added between the Valley and the North 7 area in the first half of 2013.

E. Conclusions

i. The new transmission lines added since July, 2012, have tightened the ERCOT system which is reflected in the reduced voltage angle differences for the twelve pairs being lower in 2013 than in 2012.

ii. These voltage angles will likely change again with the addition of the 345 kV CREZ transmission lines planned for the second half of 2013.

iii. This analysis should be revised once all CREZ lines are added to the ERCOT system by the end of 2013.

8. BASELINE ANALYSIS FOR ANGLE DIFFERENCES

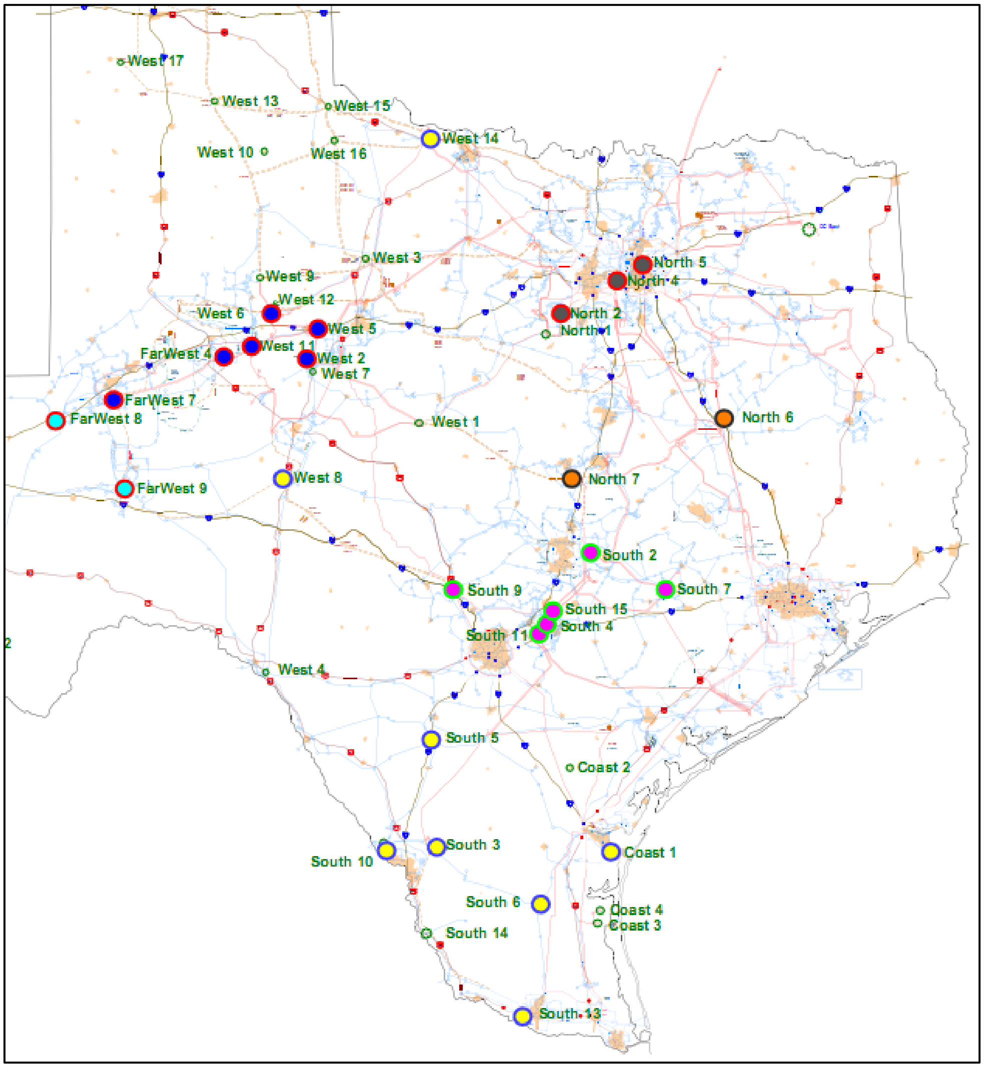
A. Pairs of Substations Identified for Angle Difference Analysis

The following pairs of substations were selected to perform the angle difference analysis (ALSO SEE MAP BELOW):

TABLE 7: ANGLE PAIRS FOR ANGLE DIFFERENCES ANALYSIS UPDATE

#	Substation A	Substation B	From Region	To Region
	PAIRS WITH PHASOR DATA AVAILABLE			
1	Coast 1	South 13	Valley	Valley
2	Coast 1	North 7	Valley	Central-East
3	West 5*	West 10	Central	Panhandle
4	West 5*	FarWest 4	Central	West Texas
5	West 5*	North 1	Central	Central
6	West 5*	North 7	Central	Central-East
8	North 1	North 7	Dallas	Central-East
7	North 1	North 4	Dallas	Central
9	North 4	North 7	Central	Central-East
10	West 4	North 7	SouthWest	Central-East
11	North 7	North 6	Central-East	East
12	FarWest 7	FarWest 4	West Texas	West Texas
13	FarWest 7	West 14	West Texas	Panhandle
14	FarWest 7	FarWest 8	West Texas	West Texas
15	FarWest 7	FarWest 9	West Texas	West Texas
16	FarWest 7	North 7	West Texas	Central-East
17	West 9	FarWest 7	Central	West Texas
18	West 9	West 1	Central	Central-East
19	West 9	North 1	Central	Dallas
20	West 14	West 5*	Panhandle	Central
21	West 14	North 1	Panhandle	Dallas
22	FarWest 9	West 4	West Texas	Southwest
	PAIRS WITHOUT PHASOR DATA AVAILABLE			
23	Coast 1	South 10*	Valley	Valley
24	South 3	South 11*	Valley	Central-East
25	South 11*	North 7	Valley	Central-East
26	North 7	South 7*	Central-East	Central-East
27	North 7	South 9*	Central-East	Central-East
28	West 11	West 8*	Central	Central
29	West 8	South 9*	Central	Central-East
30	FarWest 9	South 9*	West Texas	Central-East
31	West 14	West 16*	Panhandle	Panhandle
32	West 14	West 13*	Panhandle	Panhandle
33	West 14	West 15*	Panhandle	Panhandle
34	West 14	West 17*	Panhandle	Panhandle

The + sign means the PMU was recently added to the ERCOT grid
* denotes substations without existing PMUs or w/o a data stream



B. Summary of Results – All Data Included

Table C-1 below contains angle difference results for all those angle pairs selected for study. Several PMUs were connected to the ERCOT grid during the first six months of 2013 and were streaming phasor data. As a result, EPG had 22 pairs with phasor data included in the analysis (total of 34). This table shows min, max, and average values for angle differences obtained from all data received for the first six months of 2013 (all solved SE cases and all phasor data, normal and contingency conditions). Phasor data was not available for some of the pairs selected for study, so no phasor results are provided for those pairs.

Data availability for those pairs which had at least one PMU recently added (see those designated with a + sign) shows low values because the availability is calculated based on the entire six months.

Four pairs show positive angles greater than 80 degrees (high degree of one direction flow): North 1 to North 4 (100%), North 1 to North 7 (94.7%), FarWest 7 to FarWest 8 (100%), and Coast 1 to South 10 (84.8%).

Observation of Table C-1 results shows the following:

1. Five pairs show Max-Min angle spreads greater than 80 degrees: Coast 1-North 7, West 5 -North 7, FarWest 7-North 7, FarWest 9-West 4, and FarWest 9-South 9.
2. The lowest Max-Min angle spreads occurred on the following pairs: North 1 to North 4, FarWest 7 to FarWest 8, and West 11 to West 8.
3. Pairs with angles higher than 50 degrees are: West 5-North 7, FarWest 7-North 7, FarWest 9-West 4, and FarWest 9-South 9.

Table C-1 CCET DISCOVERY ACROSS TEXAS- BASELINING ANALYSIS- SUMMARY OF ANGLE DIFFERENCES - ALL DATA

			Phasor Data - 1/1/13 to 06/30/13					State Estimator Data - 1/1/13 to 06/30/13				
	Angle Pair	Base kV	Min	Max	Average	Percent Positive	% Data Available	Min	Max	Average	Percent Positive	Max-Min Spread
1	Coast 1-South 13	138kV	-19.98	49.99	4.28	66.61	95.27	-19.37	31.69	3.86	66.7%	51.1
2	Coast 1-North 7	138kV	-36.75	50.83	2.59	57.68	96.44	-35.89	44.81	2.16	56.1%	80.7
3	West 5-West 10	345/69kV	-21.91	16.21	-1.64	46.34	17.32	-23.88	15.46	-1.27	49.0%	39.3
4	West 5-FarWest 4	345kV	-8.26	5.75	-0.60	47.10	15.75	-10.15	6.36	-0.69	43.6%	16.5
5	West 5-North 1	345kV	-19.30	25.72	2.24	50.94	17.34	-18.64	36.19	2.94	56.9%	54.8
6	West 5-North 7	345/138kV	-11.58	29.97	9.00	79.10	19.67	-26.90	55.73	9.92	78.0%	82.6
7	North 1-North 7	345/138 kV	-12.33	26.41	6.76	92.69	97.55	-10.38	24.01	6.96	94.7%	34.4
8	North 1-North 4	345/138kV	4.46	16.34	9.58	100.00	97.43	4.07	15.49	9.13	100.0%	11.4
9	North 4-North 7	138kV	-18.85	14.43	-2.80	24.37	97.74	-17.84	13.60	-2.18	28.3%	31.4
10	West 4-North 7	138kV	-32.04	18.95	-5.08	25.21	90.40	-29.75	16.94	-4.93	25.5%	46.7
11	North 7-North 6	138kV	-17.99	8.67	-4.44	12.07	93.60	-17.25	10.70	-3.78	16.8%	28.0
12	FarWest 7-FarWest 4	345kV	-15.00	3.43	-2.36	8.69	93.24	-11.36	6.63	-2.47	11.3%	18.0
13	FarWest 7-West 14	345kV	-27.18	28.17	-0.17	47.79	91.86	-25.16	21.19	-0.96	43.9%	46.4
14	FarWest 7-FarWest 8	345/138kV	2.00	13.05	8.19	100.00	92.03	1.42	13.22	7.83	100.0%	11.8
15	FarWest 7-FarWest 9	345/138kV	-19.98	29.94	3.08	61.78	94.45	-17.09	26.89	2.53	60.2%	44.0
16	FarWest 7-North 7	345/138kV	-35.49	59.79	8.23	70.29	97.71	-34.04	55.59	8.26	70.9%	89.6
17	West 9-FarWest 7	345kV	-7.65	10.29	1.57	69.15	17.34	-10.45	13.94	1.89	74.9%	24.4
18	West 9-West 1	345kV	-19.35	23.71	3.42	76.84	17.31	-6.26	14.61	3.14	76.1%	20.9
19	West 9-North 1	345kV	-20.51	28.80	2.67	51.01	17.34	-19.60	37.64	3.18	57.1%	57.2
20	West 14-West 5	345kV	-21.62	12.32	-0.23	58.24	17.13	-21.33	12.24	-0.70	49.8%	33.6
21	West 14-North 1	345kV	-12.27	16.81	1.80	63.23	91.69	-9.70	14.86	2.24	67.5%	24.6
22	FarWest 9-West 4	138kV	-33.87	51.99	10.80	72.04	89.56	-30.09	60.11	10.63	72.7%	90.2
23	Coast 1-South 10*	138kV	Phasor data is not available for these pairs					-10.38	32.91	9.46	84.8%	43.3
24	South 3-South 11	138kV						-21.35	21.54	0.96	55.3%	42.9
25	South 11-North 7	345/69kV						-21.08	17.78	-1.03	40.5%	38.9
26	North 7-South 7*	138/345kV						-21.19	17.89	-3.23	26.6%	39.1
27	North 7-South 9*	138/345kV						-16.37	18.41	1.17	62.2%	34.8
28	West 11-West 8*	345kV						-2.84	5.75	1.27	75.7%	8.6
29	West 8*-South 9*	345kV						-22.35	30.69	7.87	71.2%	53.0
30	FarWest 9-South 9*	138/345kV						-44.29	64.43	6.85	59.9%	108.7
31	West 14-West 16*	345kV						* Substation not yet in service in first half of 2013				
32	West 14-West 13*	345kV										
33	West 14-West 15*	345kV										
34	West 14-West 17*	345kV										

* Denotes substations without existing PMUs or w/o data stream

C. Criteria to Identify Normal Operations Limits for Angle Differences

The data received, both phasor and state estimator, provide information for all conditions during the study period including those conditions where the system experienced outages of lines or generators. This study is intended to provide angle difference limits that can be expected during normal operations, that is, when all facilities are in service. The following criteria were used to determine the angle difference limits expected during normal operations for the selected substation pairs.

i. If the angle difference time duration curves show only positive angles, then two limits will be identified: one corresponding to the angle difference that occurred at about one percent of the time, and the other corresponding to the maximum value observed.

ii. If the angle difference time duration curves show positive as well as negative angles, then four limits will be identified, two for one direction of flow and two for the opposite direction of flow, based on the criteria below:
    1. The first limit in either direction will be set using state estimator results by selecting the maximum (or minimum) angle difference observed on the corresponding time duration curves if the box-whisker and time duration plots show no extreme values (outliers or extreme values due to events in the system). If extreme values or outliers are present, a point of inflection will be determined and the maximum or minimum angle will be set at the angle corresponding to the point of inflection.
    2. The second max limit will be set at the angle difference which occurred 1% more time than the time corresponding to the selected maximum limit, based on the time duration curve. The second minimum limit will be set at the angle difference corresponding to 1% less time than the time corresponding to the selected minimum limit.

iii. In some cases such as when there was an extended outage, EPG reproduced the load duration curve excluding those days when the extended outage occurred to determine the angle differences corresponding to normal conditions.

iv. The 1% values can be used to set alarms for the operators to be notified of impending maximum angle differences. The maximum and minimum values can be used to set alarms notifying the operator that expected maximum or minimum values have been reached.

v. The alarms so determined should be monitored for a year against actual values observed during operation. If maximum values are exceeded, the observed values should be logged and documented for further analysis.

vi. Maximum and minimum angle differences will change as major changes occur in the system such as the addition of the 345 kV CREZ lines to the ERCOT system. This analysis should be revised based on historical information obtained with the new facilities that are in place. Maximum and minimum values can also be estimated from many power flow cases representing different system conditions of the year. Once ALL the CREZ lines are added to the ERCOT system, expected to occur by the end of 2013, this study and conclusions should be updated to reflect the impact of those significant additions.

D. Summary of results – normal conditions

The angle difference results for normal conditions are summarized in Table C-2 below. This table was developed based on the criteria described above.

Table C-2 -CCET DISCOVERY ACROSS TEXAS- BASELINING ANALYSIS- SUMMARY OF ANGLE DIFFERENCES - NORMAL CONDITIONS

			DATA RESULTS														
			Phasor Data			State Estimator Data - 1/1/13 to 06/30/13									SE Data-Normal		
No	Angle Pair FROM - TO	Base kV	Min Angle	Max Angle	Max-Min Spread	Percent Positive	Min Angle at POI or 100%	Percent (POI or 100%)	Min Angle at 99% or POI - 1%	Percent (99% or POI - 1%)	Max Angle at 1% or POI +1%	Percent (1% or POI +1%)	Max Angle at POI or 0%	Percent (POI or 0%)	Min Angle	Max Angle	Max-Min Spread
1	Coast 1-South 13	138kV	-16.84	33.55	50.39	66.73%	-18.95	99.98%	-11.88	98.98%	21.61	1.02%	28.42	0.02%	-18.95	28.42	47.4
2	Coast 1-North 7	138kV	-31.72	35.82	67.54	56.10%	-35.10	99.99%	-25.75	98.99%	29.78	1.01%	42.08	0.01%	-35.10	42.08	77.2
3	West 5-West 10	345/69kV	-17.61	15.49	33.10	48.99%	-17.57	98.32%	-17.01	97.32%	13.04	1.08%	14.67	0.08%	-17.57	14.67	32.2
4	West 5-FarWest 4	345kV	-7.49	5.20	12.69	43.62%	-10.01	99.97%	-5.58	98.97%	3.46	1.01%	5.90	0.01%	-10.01	5.90	15.9
5	West 5-North 1	345kV	-17.01	24.45	41.46	56.90%	-17.85	99.98%	-14.98	98.98%	22.16	1.00%	36.19	0.00%	-17.85	36.19	54.0
6	West 5-North 7	345/138kV	-10.42	29.30	39.72	78.04%	-26.30	99.99%	-19.21	98.99%	36.87	1.01%	47.99	0.01%	-26.30	47.99	74.3
7	North 1-North 7	345/138 kV	-10.05	21.40	31.45	94.68%	-9.92	99.99%	-5.64	98.99%	17.46	1.01%	23.39	0.01%	-9.92	23.39	33.3
8	North 1-North 4	345/138kV	5.47	15.37	9.90	100.00%	4.43	99.95%	5.45	98.95%	13.58	1.00%	15.49	0.00%	4.43	15.49	11.1
9	North 4-North 7	138kV	-17.65	9.92	27.57	28.33%	-16.81	99.98%	-12.03	98.98%	7.29	1.01%	12.66	0.01%	-16.81	12.66	29.5
10	West 4-North 7	138kV	-26.08	14.73	40.81	25.46%	-28.46	99.99%	-21.88	98.99%	10.56	1.00%	16.94	0.00%	-28.46	16.94	45.4
11	North 7-North 6	138kV	-14.62	7.77	22.39	16.81%	-16.88	99.99%	-12.29	98.99%	5.16	1.01%	10.59	0.01%	-16.88	10.59	27.5
12	FarWest 7-FarWest 4	345kV	-8.35	2.66	11.01	11.25%	-10.99	99.98%	-8.57	98.98%	2.37	1.00%	6.63	0.00%	-10.99	6.63	17.6
13	FarWest 7-West 14	345kV	-19.50	20.45	39.95	43.87%	-24.66	99.98%	-16.31	98.98%	15.86	1.03%	21.00	0.03%	-24.66	21.00	45.7
14	FarWest 7-FarWest 8	345/138kV	3.74	12.47	8.73	100.00%	2.94	99.96%	4.07	98.96%	11.41	1.01%	12.63	0.01%	2.94	12.63	9.7
15	FarWest 7-FarWest 9	345/138kV	-12.89	18.93	31.82	60.16%	-15.74	99.99%	-11.77	98.99%	16.29	1.02%	26.80	0.02%	-15.74	26.80	42.5
16	FarWest 7-North 7	345/138kV	-30.90	46.24	77.14	70.86%	-32.14	99.97%	-23.88	98.97%	35.70	1.01%	48.09	0.01%	-32.14	48.09	80.2
17	West 9-FarWest 7	345kV	-5.83	9.53	15.36	74.88%	-9.16	99.98%	-5.80	98.98%	8.74	1.02%	13.30	0.02%	-9.16	13.30	22.5
18	West 9-West 1	345kV	-5.84	14.82	20.66	76.09%	-6.13	99.98%	-4.34	98.98%	12.75	1.01%	14.57	0.01%	-6.13	14.57	20.7
19	West 9-North 1	345kV	-18.05	27.45	45.50	57.15%	-18.90	99.98%	-15.48	98.98%	24.34	1.01%	29.26	0.01%	-18.90	29.26	48.2
20	West 14-West 5	345kV	-15.12	10.90	26.02	49.76%	-16.47	99.99%	-13.88	98.99%	9.54	1.03%	11.90	0.03%	-16.47	11.90	28.4
21	West 14-North 1	345kV	-9.48	13.00	22.48	67.50%	-8.95	99.99%	-6.69	98.99%	11.22	1.01%	13.78	0.01%	-8.95	13.78	22.7
22	FarWest 9-West 4	138kV	-26.26	48.28	74.54	72.75%	-29.69	99.99%	-20.41	98.99%	41.67	1.01%	51.61	0.01%	-29.69	51.61	81.3
23	Coast 1-South 10*	138kV	No phasor data is available for these pairs			84.82%	-6.81	98.10%	-5.98	97.10%	23.50	2.61%	24.58	1.61%	-6.81	24.58	31.4
24	South 3-South 11	138kV				55.34%	-13.71	97.58%	-12.88	96.58%	14.49	2.71%	15.35	1.71%	-13.71	15.35	29.1
25	South 11-North 7	345/69kV				40.50%	-9.16	95.46%	-8.58	94.46%	8.26	4.03%	9.21	3.03%	-9.16	9.21	18.4
26	North 7-South 7*	138/345kV				26.59%	-12.34	96.56%	-11.95	95.56%	6.18	3.14%	7.08	2.14%	-12.34	7.08	19.4
27	North 7-South 9*	138/345kV				62.20%	-5.41	94.86%	-4.93	93.86%	8.43	4.00%	9.31	3.00%	-5.41	9.31	14.7
28	West 11-West 8*	345kV				75.74%	-1.57	97.67%	-1.47	96.67%	5.12	1.25%	5.47	0.25%	-1.57	5.47	7.0
29	West 8*-South 9*	345kV				71.18%	-14.84	97.23%	-13.84	96.23%	27.90	1.60%	28.78	0.60%	-14.84	28.78	43.6
30	FarWest 9-South 9*	138/345kV				59.87%	-30.05	97.44%	-28.08	96.44%	42.07	2.17%	44.39	1.17%	-30.05	44.39	74.4
31	West 14-West 16*	345kV				* Substation not yet in service in first half of 2013									N/A		
32	West 14-West 13*	345kV													N/A		
33	West 14-West 15*	345kV													N/A		
34	West 14-West 17*	345kV													N/A		

NOTE: These results were obtained with January-June, 2013 data; ** West 16, West 13, West 15, West 17, and West 8 were not in service during this period.

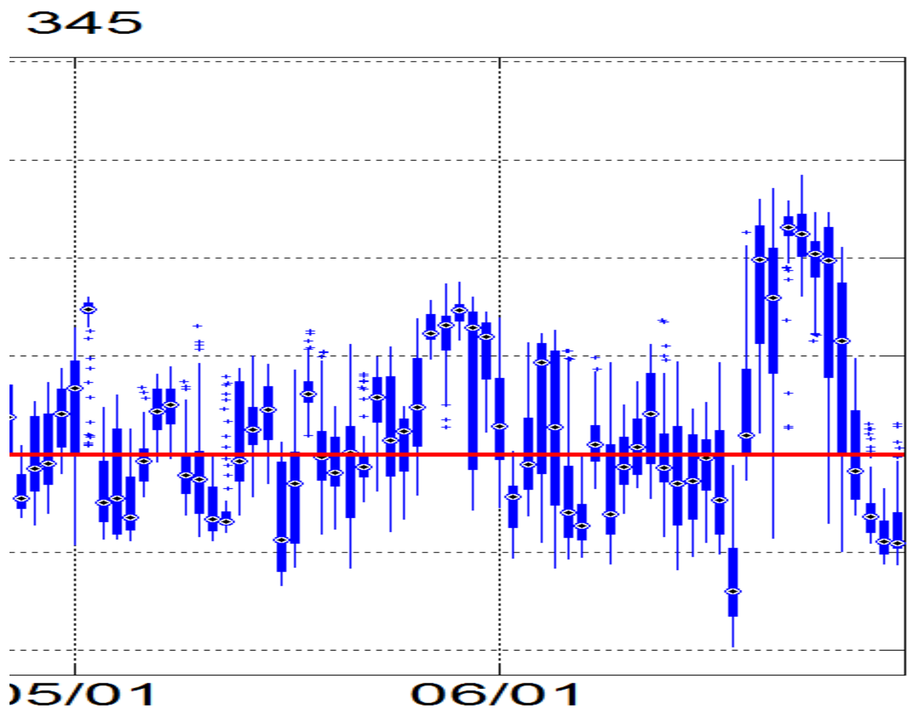
Box-whisker and time duration curves were developed for each of the pairs analyzed. Angle differences that may be the result of contingencies were excluded by reviewing points of inflection, that is, points that significantly deviated from the normal operation trend observed in the box-whisker plots. The value of angle difference at the point of inflection was considered to be the maximum angle during normal conditions. If no outlier points were identified, then the angle corresponding to the 0% or 100% time points will represent the maximum and minimum angles reached during normal operations in either direction of flow. Summaries of SE-based voltage angle pairs with their corresponding box-whisker and time duration curves, as well as summaries of phasor-based voltage angle pairs with their corresponding box-whisker and time duration curves, are presented in Appendix D.

E. Observations from Table C-2 !bove

a. The maximum Max-Min angle spreads under normal conditions occurred at FarWest 9-West 4 (81.3), FarWest 7-North 7 (80.2), Coast 1-North 7 (77.2), FarWest 9-South 9 (74.4), and West 5-North 7(74.3).
b. The angle pairs with Max-Min spreads less than 10 degrees are: FarWest 7-FarWest 8 (9.7) and West 11-West 8 (7.0)
c. The maximum voltage angles under normal conditions occurred at FarWest 9-West 4 (51.6) and FarWest 7-North 7 (48.09).
d. Seventeen pairs had maximum angles less than 20 degrees, and the rest had angles between 20 and 52 degrees. Seven substations had minimum angles lower than -20 degrees: Coast 1-North 7 (-31.1), West 5-North 7 (-26.3), West 4-North 7 (-28.5), FarWest 7-West 14 (-24.7), FarWest 7-North 7 (-32.1), FarWest 9-West 4 (-29.7), and FarWest 9-South 9 (30.1).
e. Three pairs had positive angle differences greater than 90 degrees: North 1-North 4 (100), FarWest 7-FarWest 8 (100), and North 1-North 7 (94.7).

F. Observations from Box-² hisker tlots

a. Several angle pairs exhibited abrupt changes in angle that may be due to outages or construction work. Some of these changes lasted several days before returning to the original values. If this is the case, the “normal operations” angle differences may need to be revisited with feedback from ERCOT operation personnel.
b. If there were extended outages, EPG would need to know so that those angles are excluded when calculating the “normal limits”.
c. Examples of those abrupt angle changes are:
    1. Coast 1-South 13 (late February)
    2. Coast 1-North 7 (early June)
    3. West 5-West 10 (angle changes often, large jump in early May and late June)
    4. West 5-FarWest 4 (angle drops in April and in June)
    5. West 5-North 7 (drops twice in mid-January and jumps up once in late January)
    6. North 1-North 7 (angle changes abruptly several times)
    7. North 1-North 4 (significant jump in mid-May)
    8. North 4-North 7 (experienced several changes up and down)
    9. North 7-North 6 (two jumps in mid-February: one up and one down)
    10. West 9-West 1 (three jumps: early January, early April and late June)
    11. Several pairs experienced similar jumps up in late June, perhaps due to a common event. See graph below (red line is zero degrees and lines are in increments of 10).
    12. EPG suggests that ERCOT operators review Appendix D, State Estimator Box-Whisker Plots, and identify what angle difference changes were due to events in the system.



9. PAIRS FOR REAL TIME MONOTORING

A. Criteria for {election of !ngle tairs for wealπ¢ime aonitoring

1. Choose a few transmission paths (pairs) from the wind areas to monitor wind power delivery.
2. Choose load center, such as North 1, and select transmission paths serving such loads.
3. Choose transmission paths delivering power from the Valley and from the Houston area.
4. Choose transmission paths connecting the Dallas area with the Houston and San Antonio areas.

NOTE: Because there are not enough PMUs installed in the system, EPG will choose pairs that meet the criteria as close as possible.

B. Transmission Paths (Pl·ǐǐǎú Selected for RealπTime Monitoring

The transmission paths selected for monitoring are shown below:

TABLE 8: ANGLE PAIRS SELECTED FOR REAL-TIME MONITORING

PAIRS WITH PHASOR DATA AVAILABLE

#	Substation A	Substation B	From Region	To Region
1	Coast 1	South 13	Valley	Valley
2	Coast 1	North 7	Valley	Central-East
3	Coast 3	North 7	Valley	Central-East
4	South 5*	North 7	Valley	Central-East
5	West 4	North 7	Southwest	Central-East
6	North 6	North 7	East	Central-East
7	West 1*	North 7	Central	Central-East
8	North 1	North 7	Dallas	Central-East
9	North 1	North 4	Dallas	Central
10	North 4	North 7	Central	Central-East
11	West 5*	North 1	Central	Central
12	West 5*	North 7	Central	Central-East
13	West 5*	West 10	Central	Panhandle
14	West 5*	FarWest 4	Central	West Texas
15	FarWest 7	FarWest 4	West Texas	West Texas
16	FarWest 7	FarWest 9	West Texas	West Texas
17	FarWest 9	West 4	West Texas	Southwest
18	West 9	West 1*	Central	Central-East
19	West 9	North 1	Central	Dallas
20	West 14	West 5*	Panhandle	Central
21	West 14	North 1	Panhandle	Dallas

* means PMU recently added to the ERCOT grid

C. Proposed Alarm Limits

Table 9 below shows the proposed angle limits for the paths (pairs) selected for real time monitoring. These proposed limits were selected from the results for normal conditions shown in Tables B-2 and C-2 of this report. These results are based on the data for the first six months of 2013 provided by ERCOT. Several CREZ 345 kV lines were added during this period of time which have tightened electrically the ERCOT grid. Additional 345 kV lines are being added to the ERCOT system during the second half of 2013 which will further tighten the ERCOT system. EPG expects that the alarm limits proposed in this section will be wider than those expected in 2014 when all the CREZ lines have been added to the ERCOT system.

By monitoring these angle pairs, the ERCOT grid operators should have a good overview of power flow from generation centers to the load centers. It will also provide them with a good idea of ongoing power flows among the different regions of the ERCOT grid.

EPG suggests that operators document any time these limits are exceeded, noting the reason if known for the deviations.

Table 9 -CCET DISCOVERY ACROSS TEXAS- BASELINING ANALYSIS- ALARM LIMITS FOR REAL TIME MONITORING

			ALARM LIMITS - NORMAL CONDITIONS								
			Phasor Data		RECOMMENDED ALARM LIMITS				SE Data-Normal		
No	Proposed Angle Pairs FROM - TO	Base kV	Min Angle	Max Angle	Minimum Angle Limit	Minimum Angle Alert	Maximum Angle Alert	Maximum Angle Limit	Min Angle	Max Angle	Max-Min Spread
1	Coast 1-South 13	138	-16.84	33.55	-18.95	-11.88	21.61	28.42	-18.95	28.42	47.4
2	Coast 1-North 7	138	-31.72	35.82	-35.10	-25.75	29.78	42.08	-35.10	42.08	77.2
3	Coast 3-North 7	345	-30.16	42.98	-33.05	-25.43	35.08	49.06	-33.05	49.06	82.1
4	South 5-North 7	138	-23.39	12.95	-28.42	-20.97	8.05	13.85	-28.42	13.85	42.3
5	West 4-North 7	138	-26.08	14.73	-27.94	-21.80	10.48	15.35	-27.94	15.35	43.3
6	North 6-North 7	138	-7.60	14.69	-10.25	-5.15	12.28	16.90	-10.25	16.90	27.1
7	West 1-North 7	345	-6.64	18.88	-22.84	-16.95	32.04	40.40	-22.84	40.40	63.2
8	North 1-North 7	345	-10.05	21.40	-9.90	-5.63	17.45	23.22	-9.90	23.22	33.1
9	North 1-North 4	345/138kV	5.47	15.37	4.43	5.45	13.58	15.49	4.43	15.49	11.1
10	North 4-North 7	138	-17.65	9.92	-16.29	-12.02	7.27	11.37	-16.29	11.37	27.7
11	West 5-North 1	345	-17.01	24.45	-17.85	-14.98	22.16	36.19	-17.85	36.19	54.0
12	West 5-North 7	345	-10.42	29.30	-25.31	-19.11	36.85	45.85	-25.31	45.85	71.2
13	West 5-West 10	345/69kV	-17.61	15.49	-17.57	-17.01	13.04	14.67	-17.57	14.67	32.2
14	West 5-FarWest 4	345	-7.49	5.20	-10.01	-5.58	3.46	5.90	-10.01	5.90	15.9
15	FarWest 7-FarWest 4	345	-8.35	2.66	-10.99	-8.57	2.37	6.63	-10.99	6.63	17.6
16	FarWest 7-FarWest 9	345/138kV	-12.89	18.93	-15.74	-11.77	16.29	26.80	-15.74	26.80	42.5
17	FarWest 9-West 4	138	-26.26	48.28	-29.69	-20.41	41.67	51.61	-29.69	51.61	81.3
18	West 9-West 1	345	-5.84	14.82	-6.13	-4.34	12.75	14.57	-6.13	14.57	20.7
19	West 9-North 1	345	-18.05	27.45	-18.90	-15.48	24.34	29.26	-18.90	29.26	48.2
20	West 14-West 5	345	-15.12	10.90	-16.47	-13.88	9.54	11.90	-16.47	11.90	28.4
21	West 14-North 1	345	-9.48	13.00	-8.95	-6.69	11.22	13.78	-8.95	13.78	22.7

Note that all the pairs in the above table have two negative numbers and two positive numbers. The negative numbers apply in the TO to FROM direction, and the positive numbers apply in the FROM to TO direction. One pair, the North 1 to North 4 pair, have all positive numbers which means that all the flow is in the FROM to TO direction, and only two alarm limits are needed to monitor this path under normal conditions (13.6 degrees alert and 15.5 degrees limit).

10. CONCLUSIONS

a. **Data Availability was Improved in 2013**: State estimator data provided by ERCOT for 2013 had availability of 29% which was more than double the availability rate for 2012. Phasor data availability ranged from 20% to 98%. Those substations with the lower availability rates were those that began transmitting data to ERCOT at the end of the six-month study period.

b. **Highest Voltage Spreads at Two Locations**: Both phasor data and state estimator data point to West 4 and Coast 4 as having the greatest voltage and voltage spread in their class. Note that Coast 3 also has a high voltage spread, but South 13 and South 6, which are in the neighborhood, have a much lower spread.

c. **Substations with High Voltage Spreads**: In the first six months of 2013, seven substations out of a total of 37 showed voltage spreads of greater than 15 kV.

d. **Voltage Angle Variability at 345kV and 138kV Substations**: Voltage angles vary over a wide range for several substations. The greatest variation of 104.1 degrees (-40.9 to 63.2) occurred at FarWest 9 138 kV substation. Among the 345 kV substations, the greatest angle variation over the first six months of 2013 occurred at FarWest 4, with a spread of 90.8 (-30.6 to 60.2) degrees.
    a. The greatest variations occurred among the substations in the western part of the state, namely: FarWest 7, West 11, West 6, FarWest 8, FarWest 9, FarWest 4, West 2, West 9, West 12, and West 5.
    b. The next greatest angle variation occurred in the south part of the state, namely: South 13, Coast 3, Coast 4, South 6, and Coast 1.
    c. The two greatest normal angles observed were at West 10 and FarWest 9 with 59.74 and 52.47 degrees, respectively.
    d. The maximum Max-Min angle spreads under normal conditions occurred at FarWest 9-South 9 and Coast 4-North 7 with 121.8 and 82.7 degrees, respectively.

e. **Maximum Voltage Angles Under Normal Conditions:** The maximum voltage angles under normal conditions occurred at FarWest 9-West 4 and FarWest 7-North 7 with 51.6 and 48.1 degrees, respectively.

f. **Voltage Spreads are Smaller in 2013:** The voltage spreads obtained with six months of 2013 data are smaller than those obtained with 2012 data. This is a result of the ERCOT system's increased tightness due to the addition of the many 345 kV new CREZ lines.

g. **Alarm Limits for Voltage Angles:** EPG expects the voltage angles to change with the addition of many 345 kV CREZ lines in the second half of 2013, but has prepared a preliminary list of alarm limits, based on results of this baselining update which was based on data from the first six months of 2013 provided by ERCOT, to monitor in real time with the understanding that these limits will most likely change by 2014.

11. RECOMMENDATIONS

a. **Ongoing Monitoring**: Actual voltage magnitudes and voltage angles should be collected while additional new lines are being added to monitor change in angle differences which will provide insights into synchronization issues and solutions.

b. **Monitoring Locations**: EPG recommends monitoring the angle pairs shown in section 9.C. The proposed alarm limits shown in this section should be used for monitoring purposes.

c. **Need for a Second update**: A new baselining update should be completed, once all the CREZ 345 lines are added to the ERCOT system, to obtain a more accurate set of alarm limits to be used during real-time conditions.

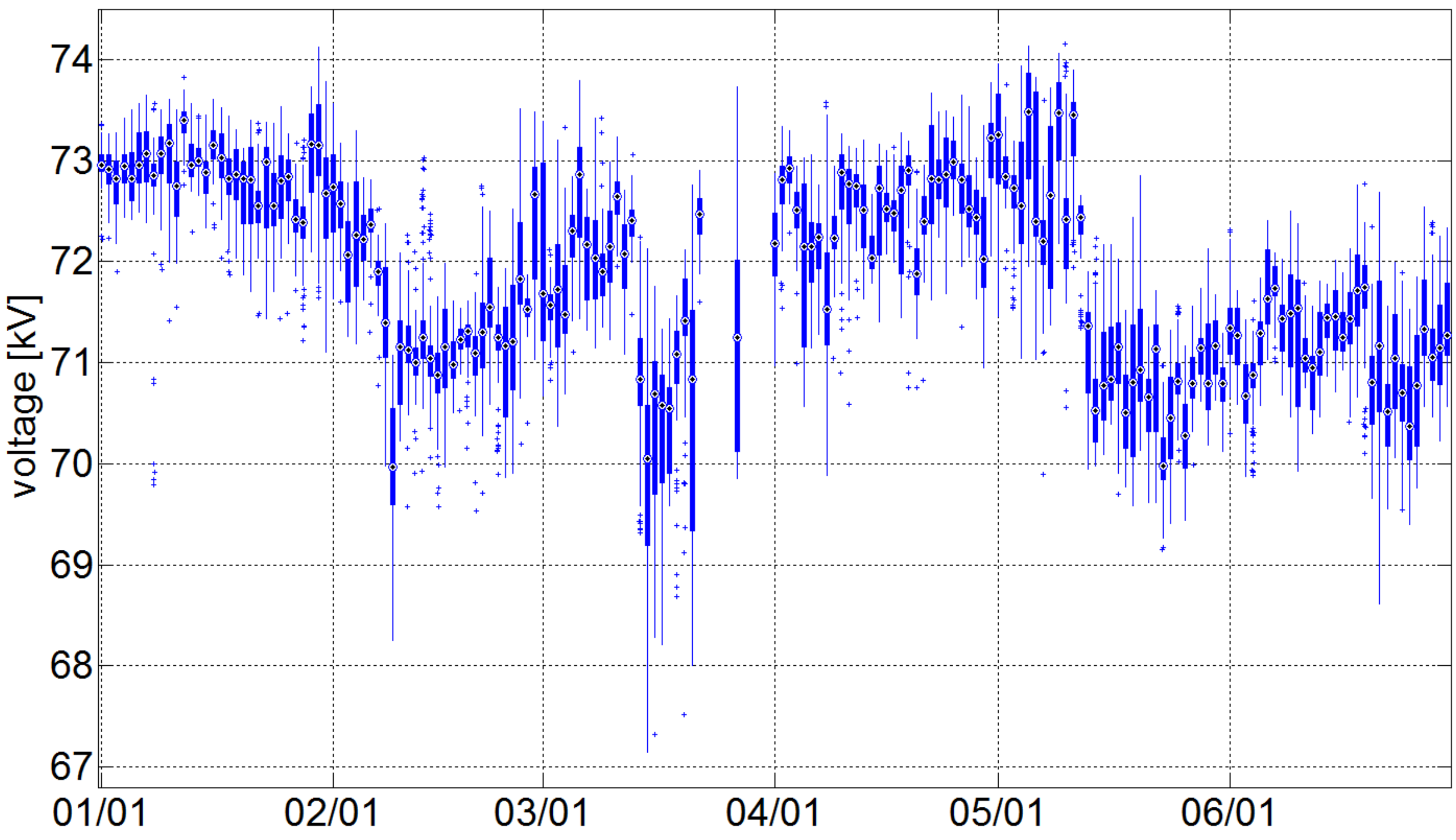
Appendix A – Part 1
CCET Discovery Across Texas project

Baseline Analysis Update - Voltage Magnitudes

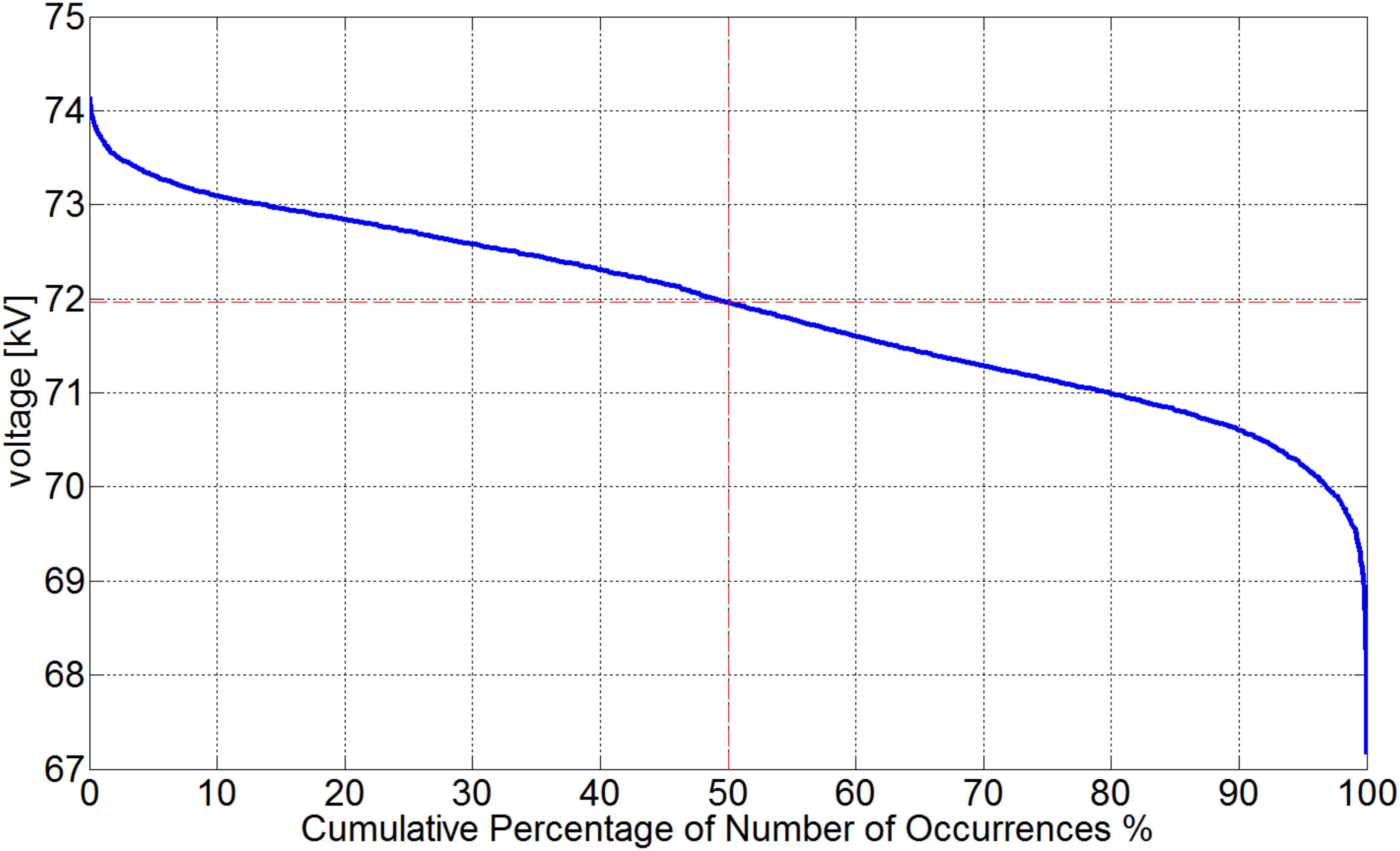
State Estimator Data: January to June 2013
Box-Whisker Plots and Time Duration Curves

External Version

West 10

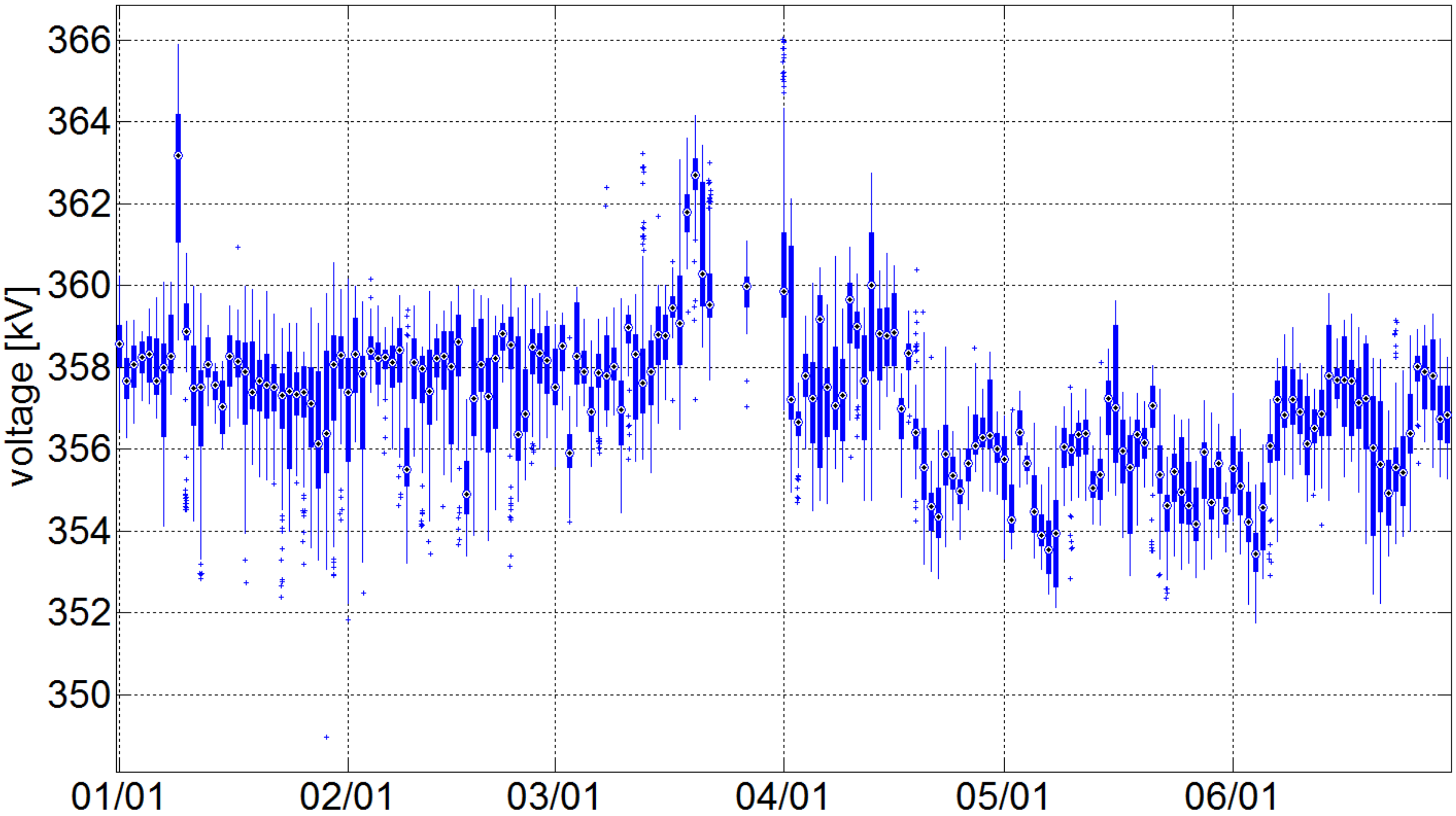


West 10



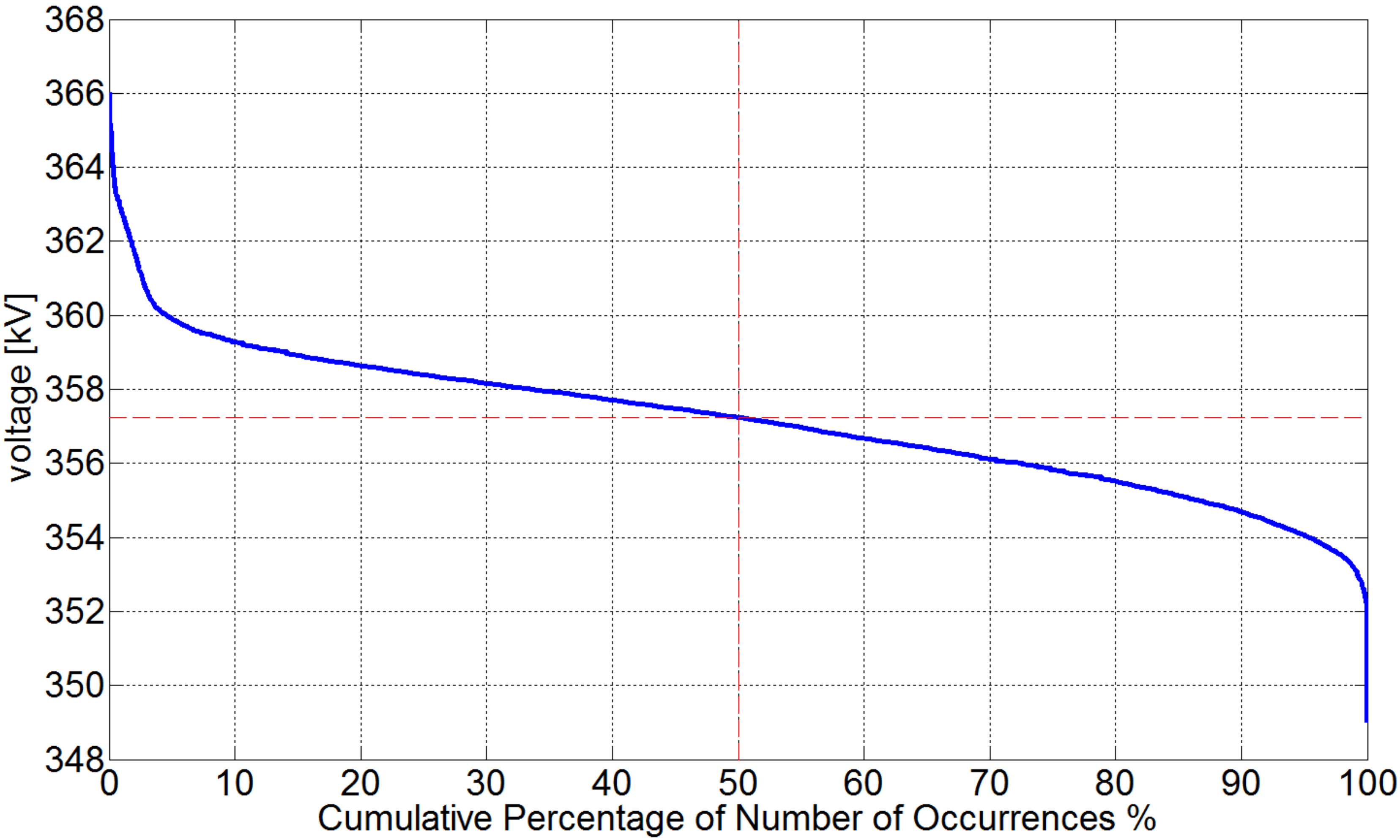
75
74
73
72
71
70
69
68
67
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

West 14



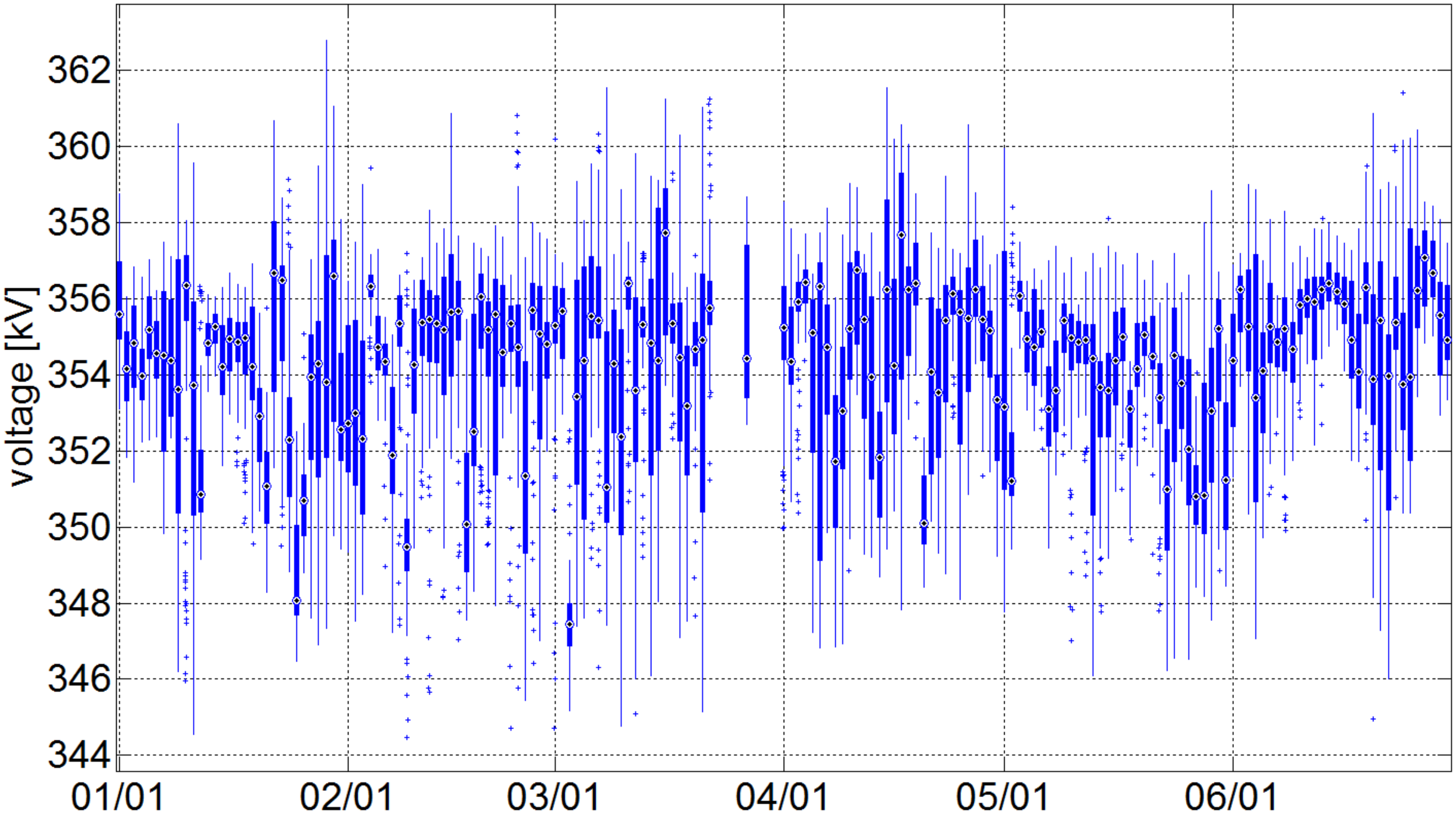
366
364
362
360
358
356
354
352
350
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01

West 14



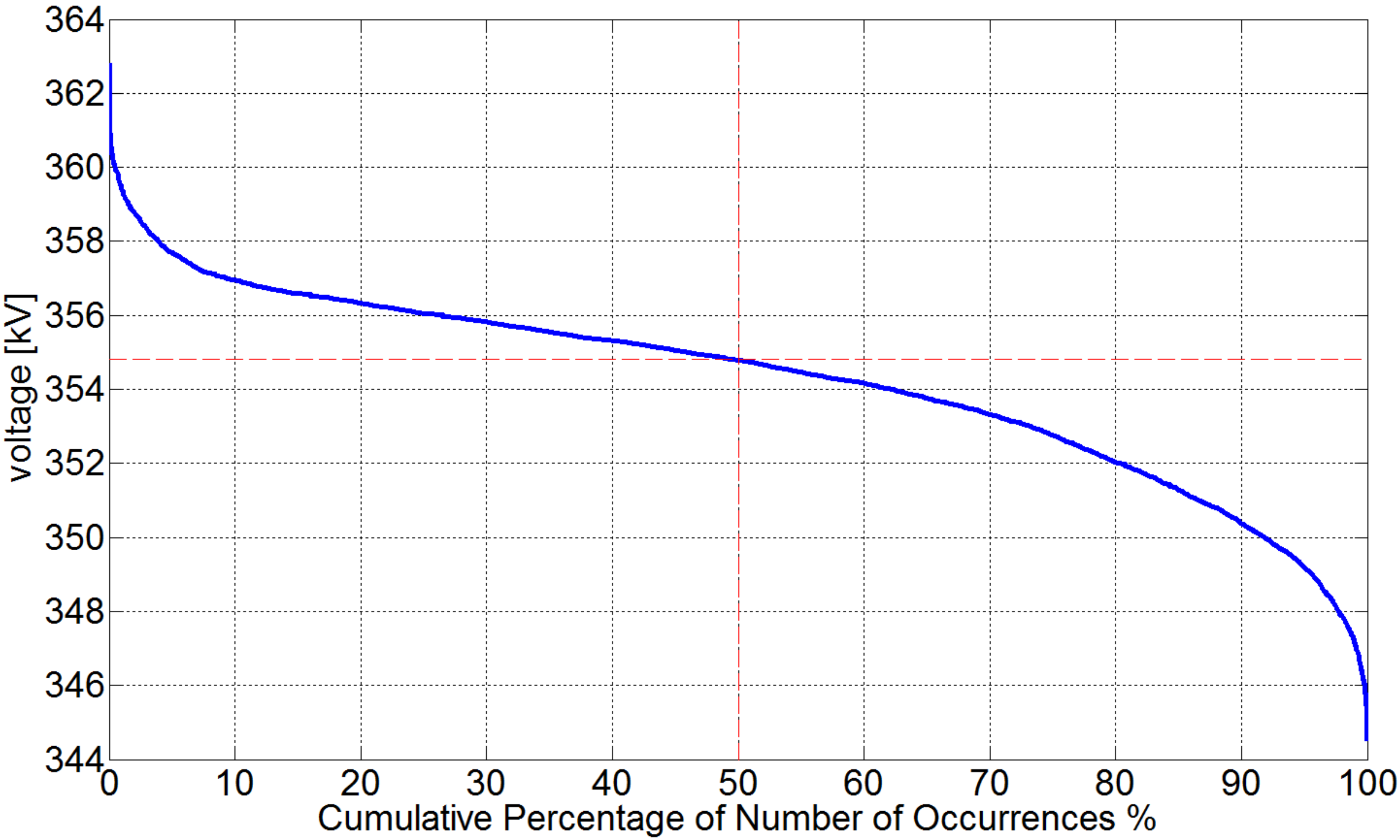
368
366
364
362
360
358
356
354
352
350
348
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

West 1*



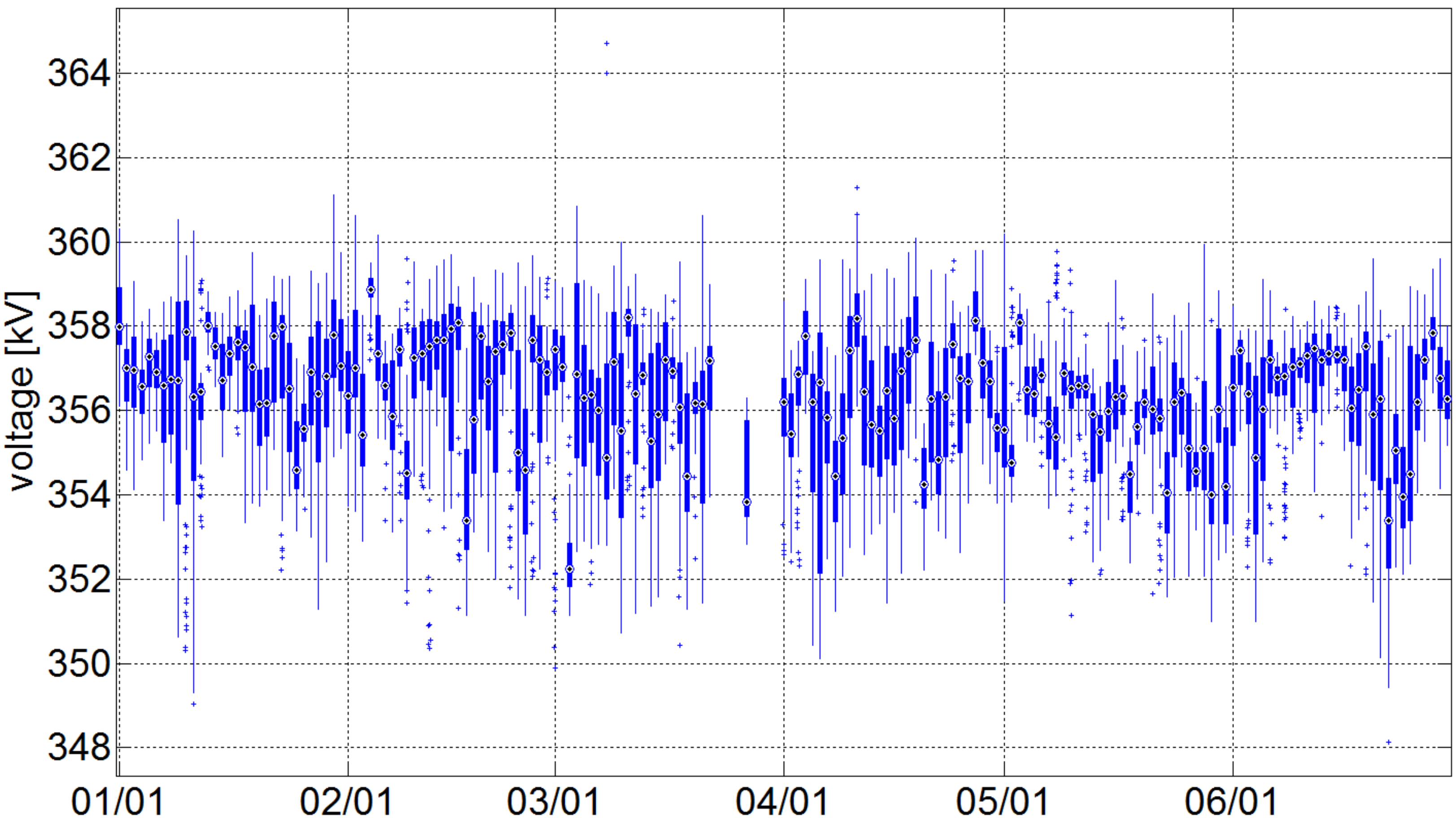
voltage [kV]
362
360
358
356
354
352
350
348
346
344
01/01
02/01
03/01
04/01
05/01
06/01

West 1*



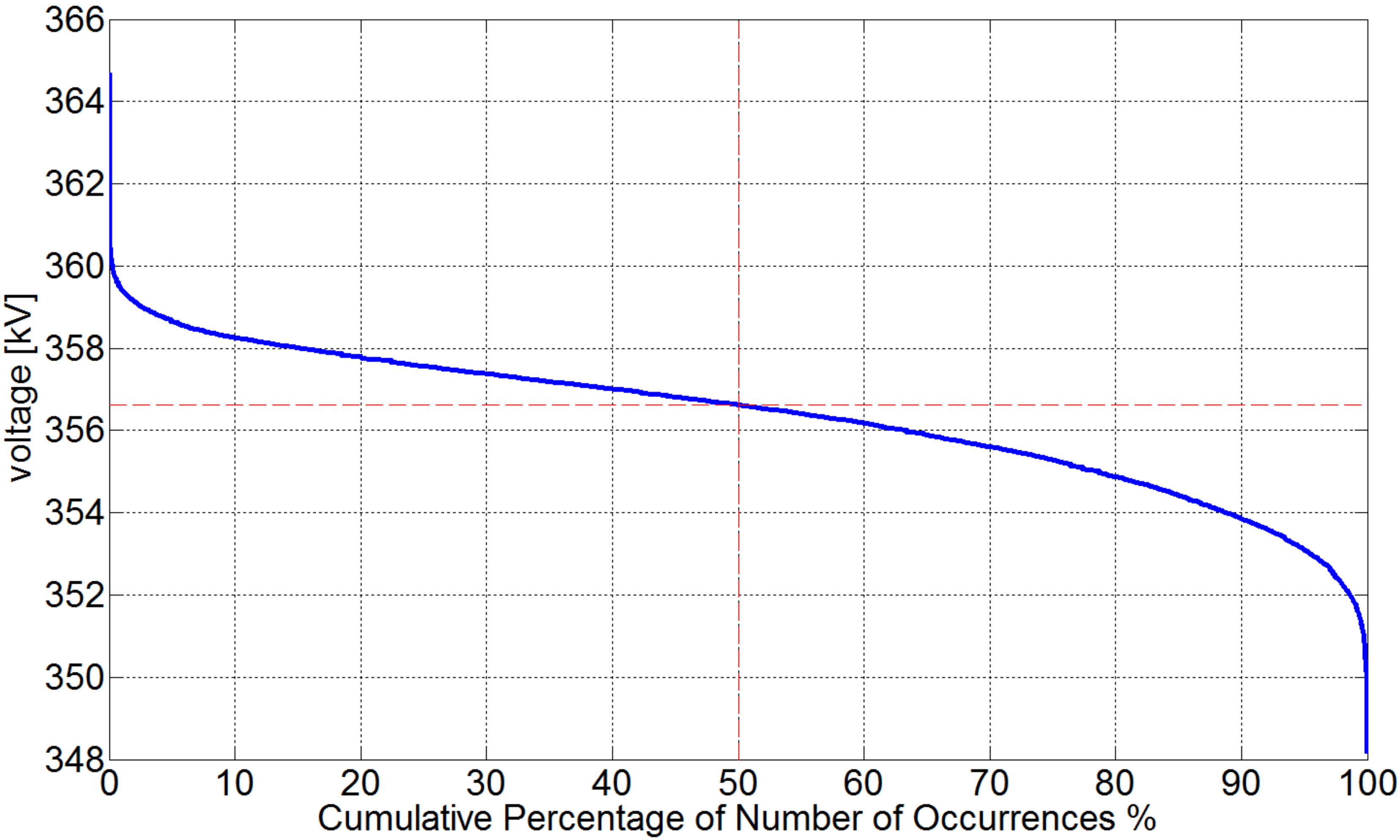
364
362
360
358
356
354
352
350
348
346
344
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

West 2*

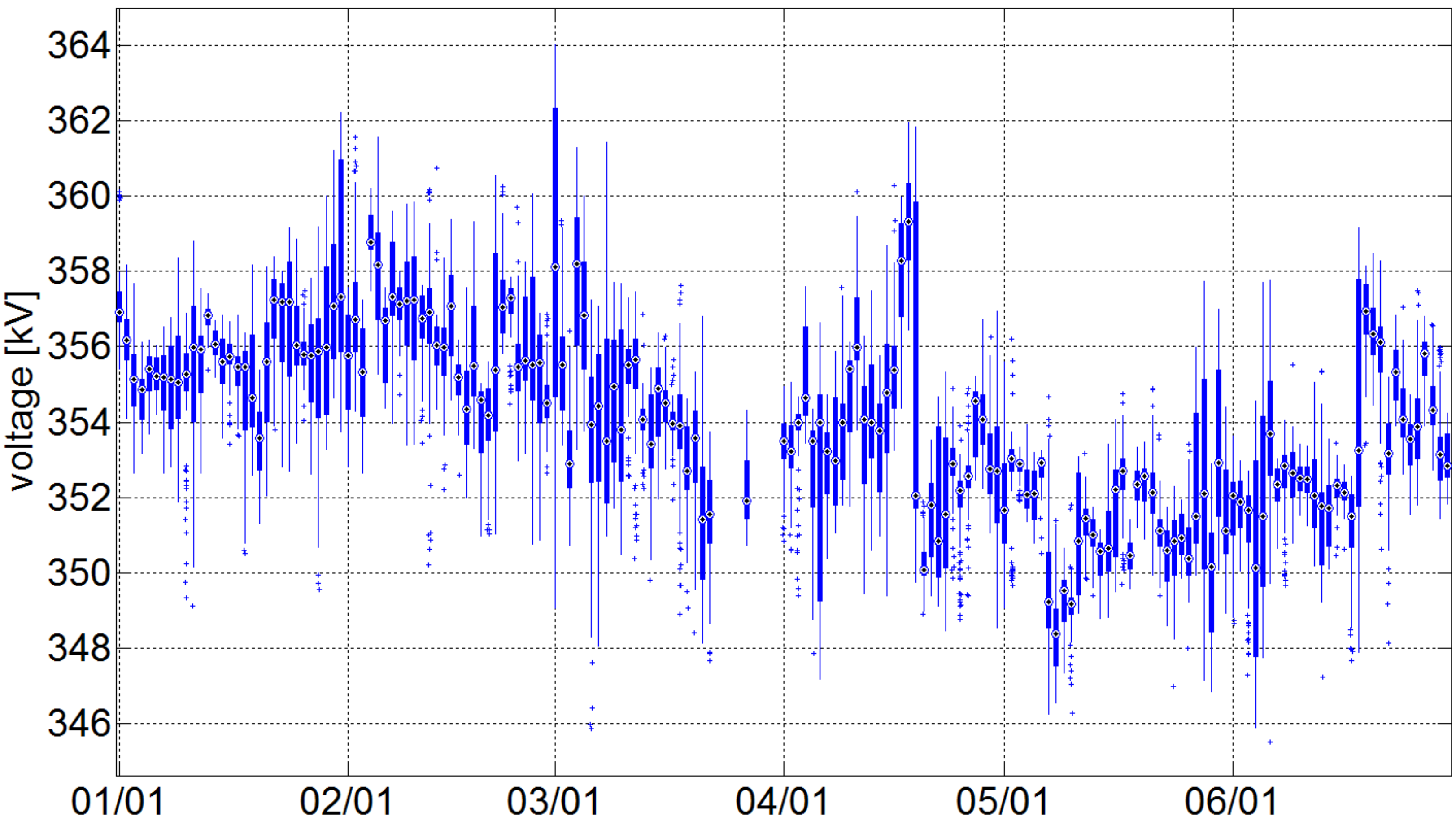


voltage [kV]
364
362
360
358
356
354
352
350
348
01/01
02/01
03/01
04/01
05/01
06/01

West 2*

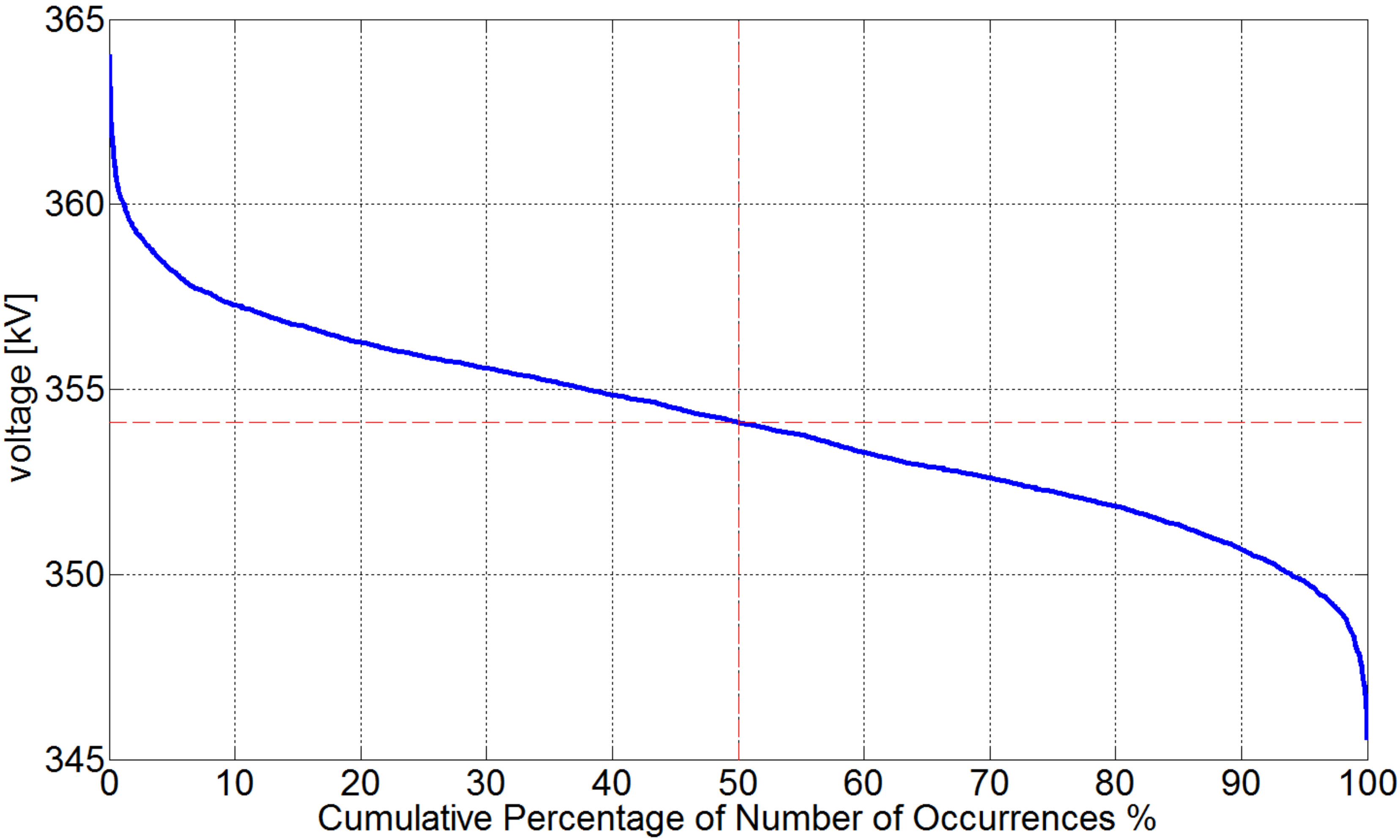

366
364
362
360
358
356
354
352
350
348
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

West 9*



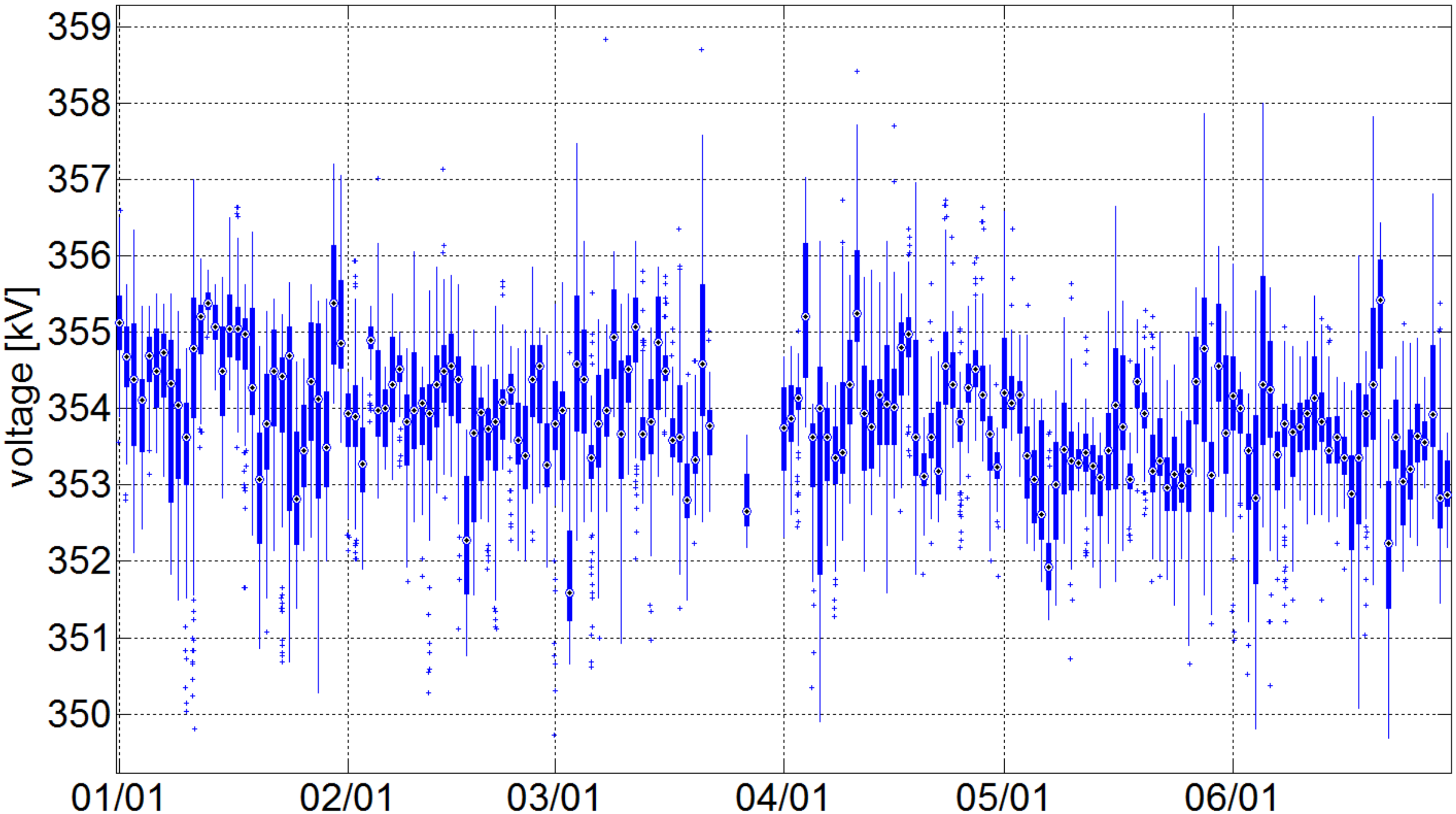
voltage [kV]
364
362
360
358
356
354
352
350
348
346
01/01
02/01
03/01
04/01
05/01
06/01

West 9*



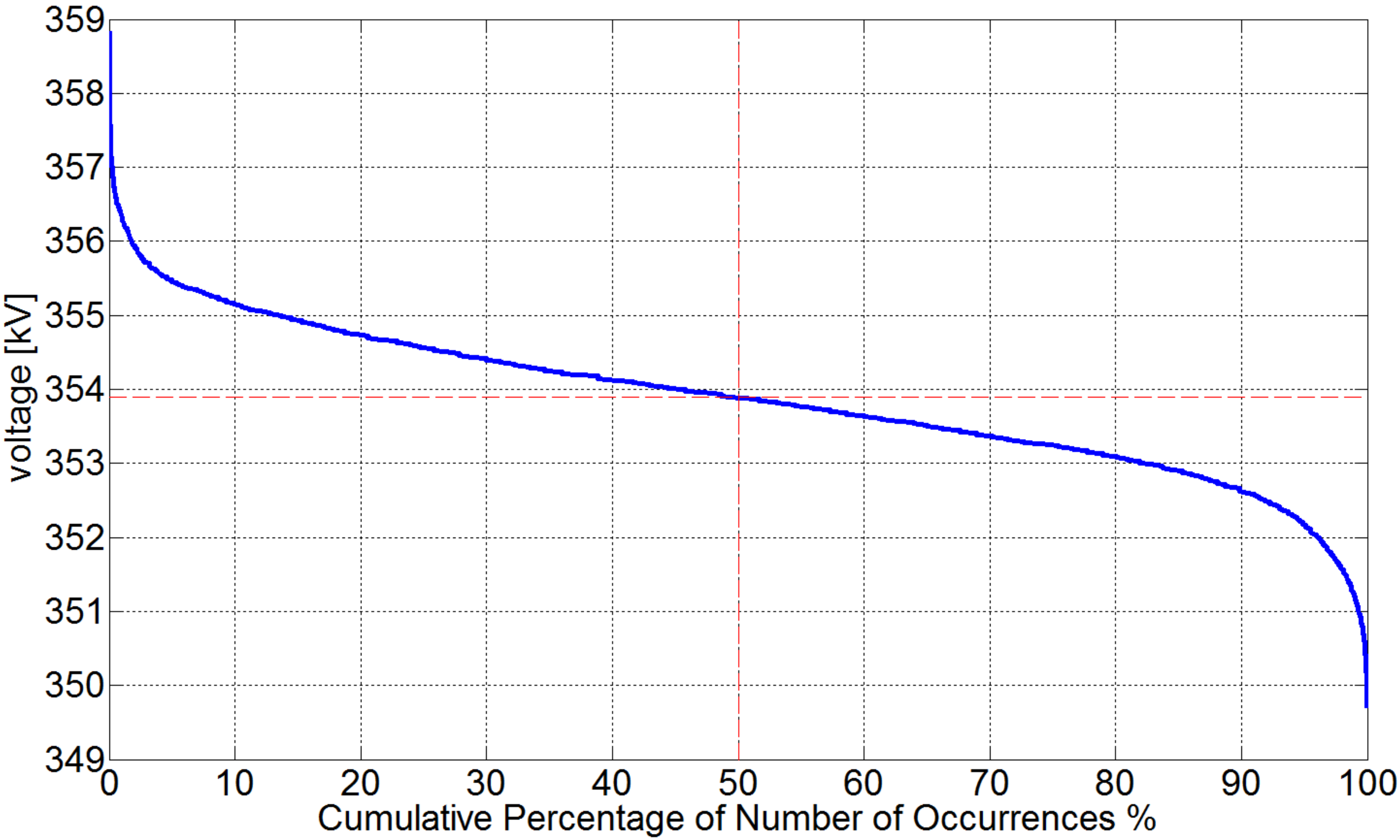
365
360
355
350
345
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

West 11



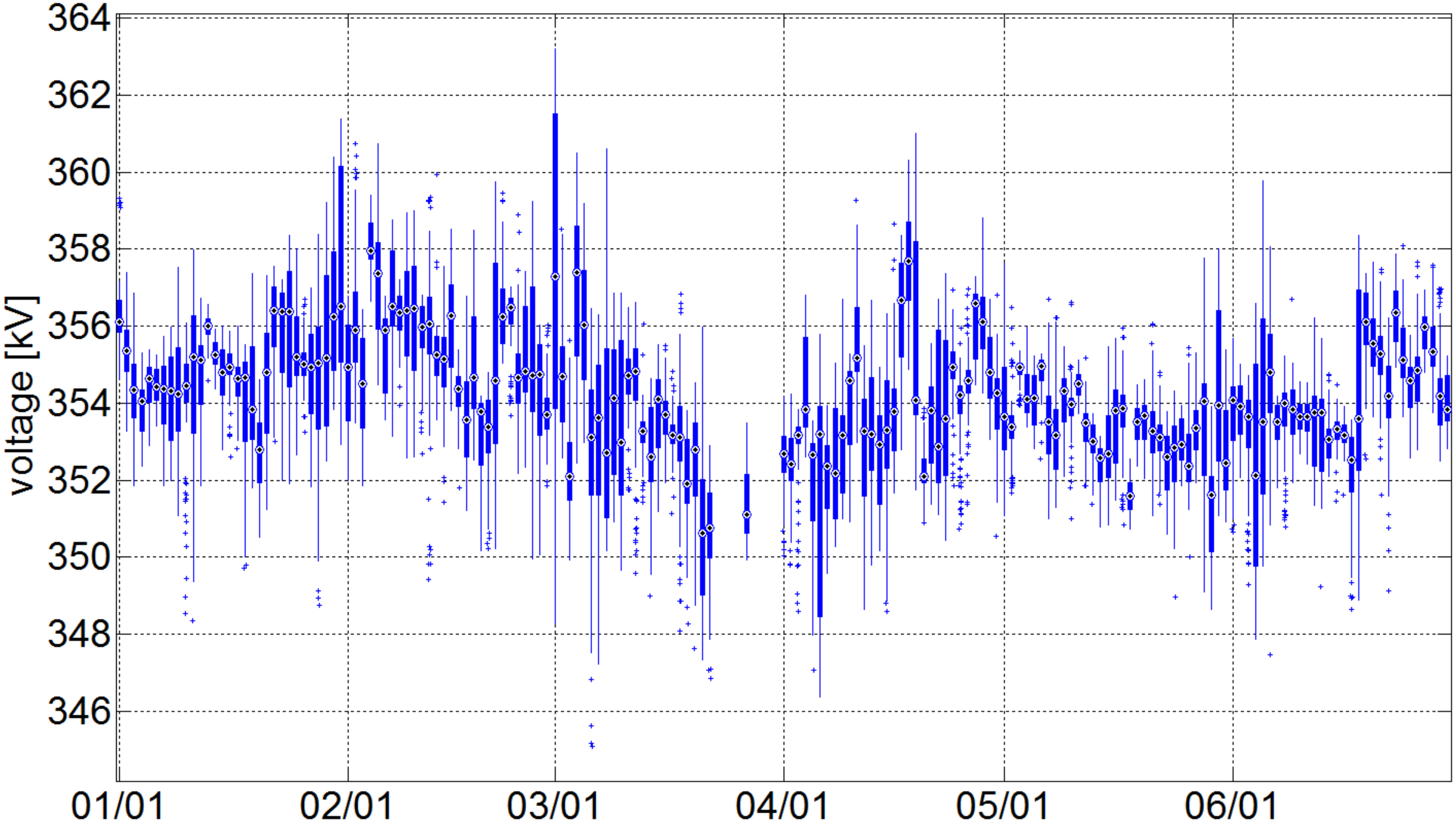
359
358
357
356
355
354
353
352
351
350
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01

West 11



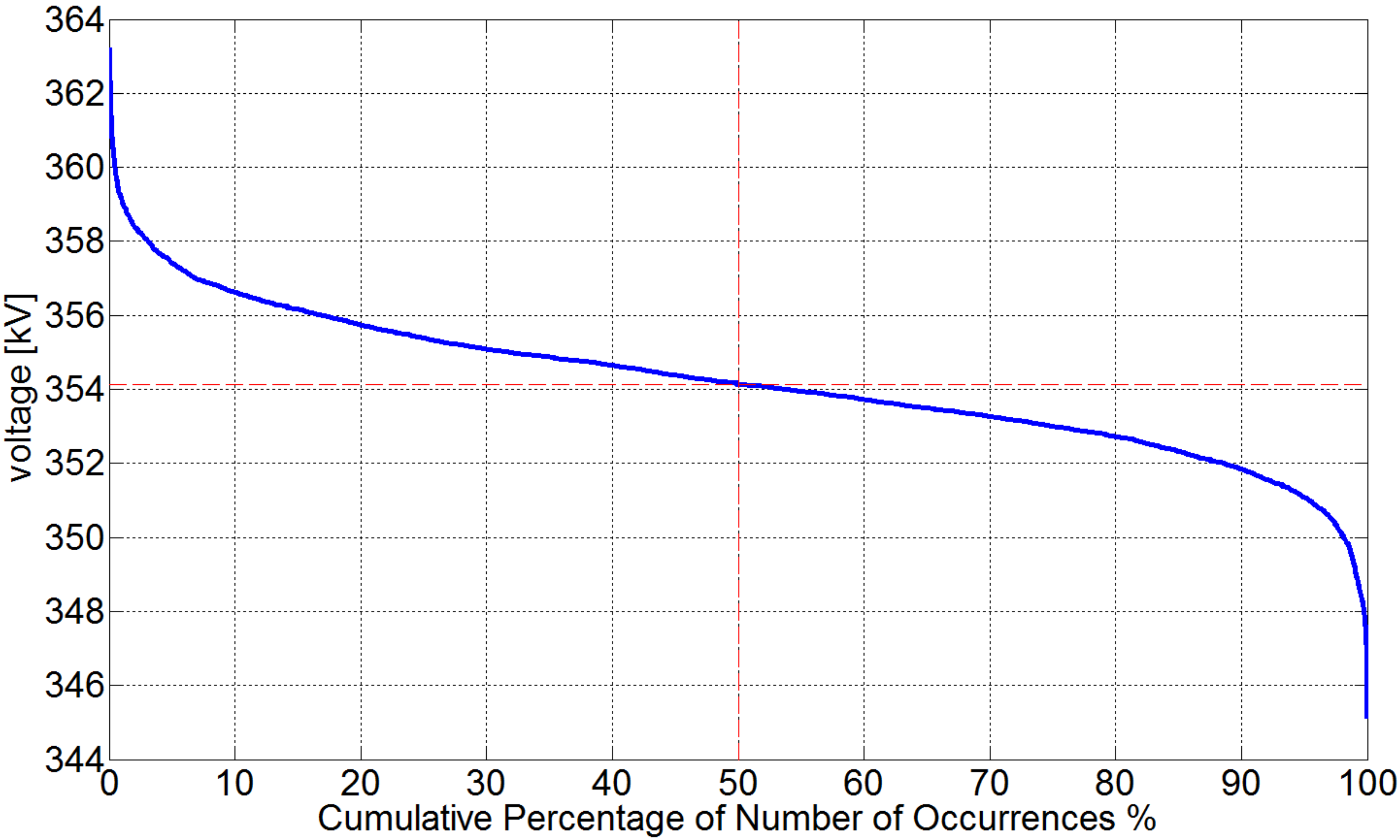
voltage [kV]
359
358
357
356
355
354
353
352
351
350
349
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

West 12*



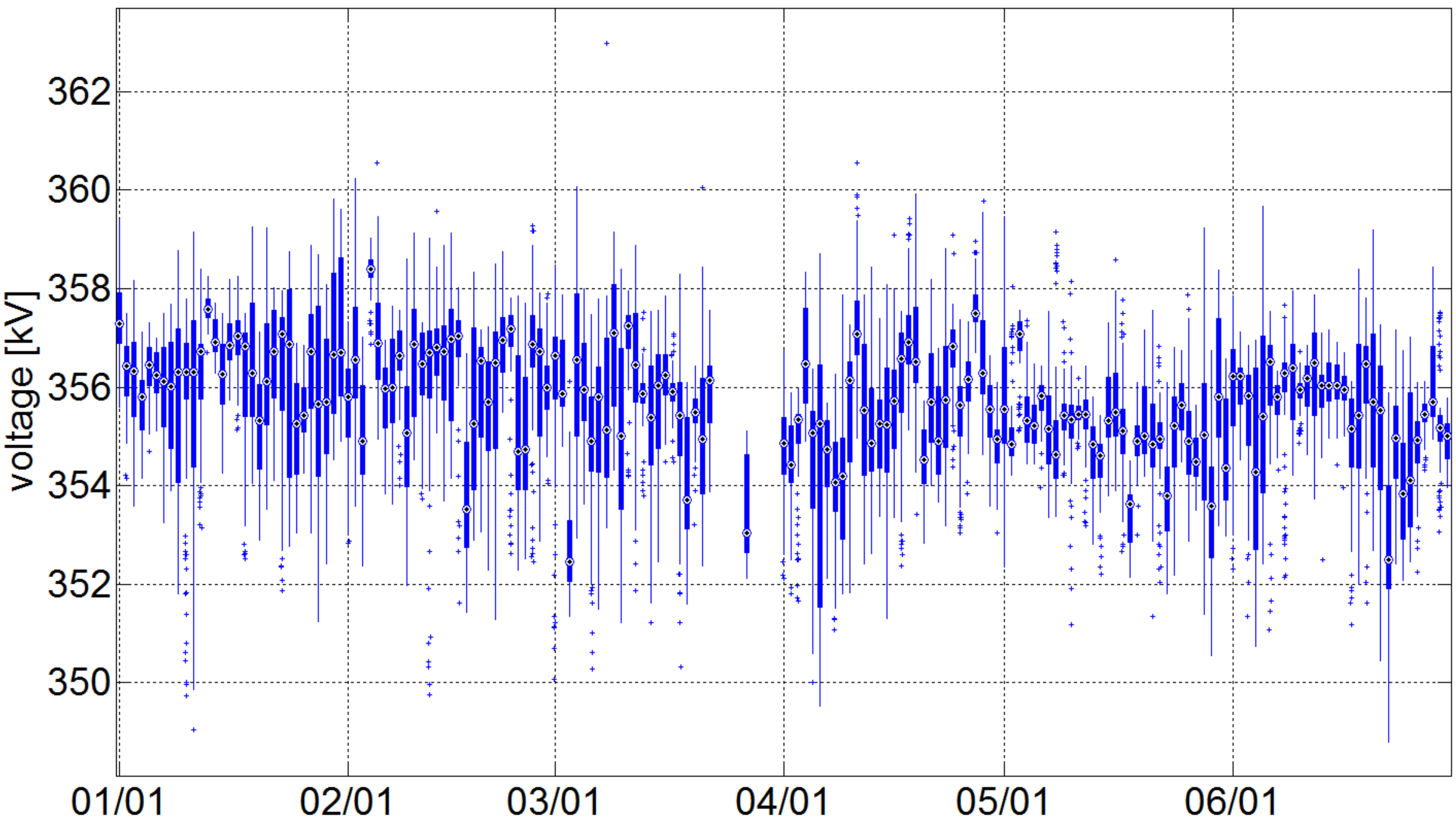
voltage [kV]
364
362
360
358
356
354
352
350
348
346
01/01
02/01
03/01
04/01
05/01
06/01

West 12*



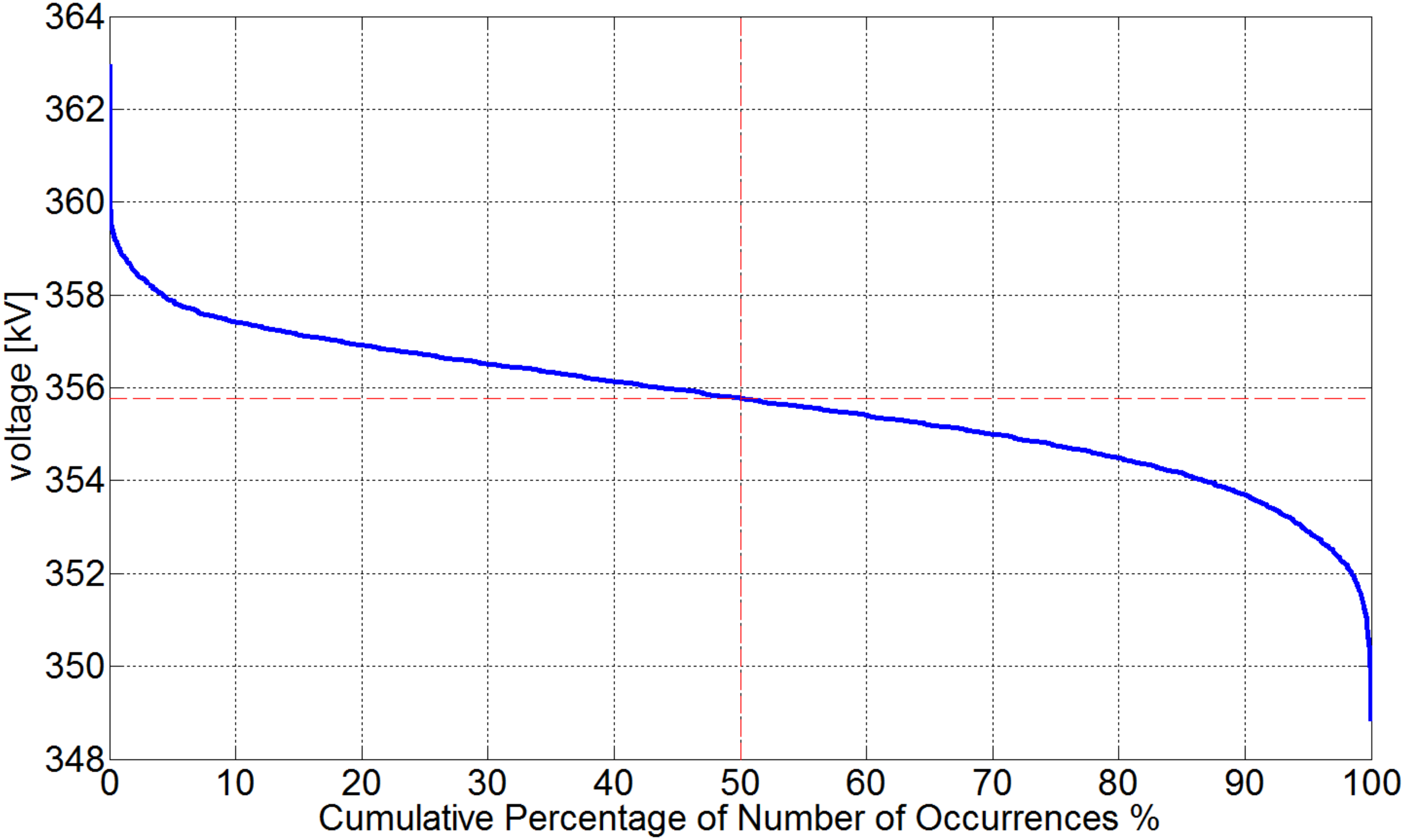
364
362
360
358
356
354
352
350
348
346
344
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

West 5*



362
360
358
356
354
352
350
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01

West 5*


364
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348
voltage [kV]
0
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20
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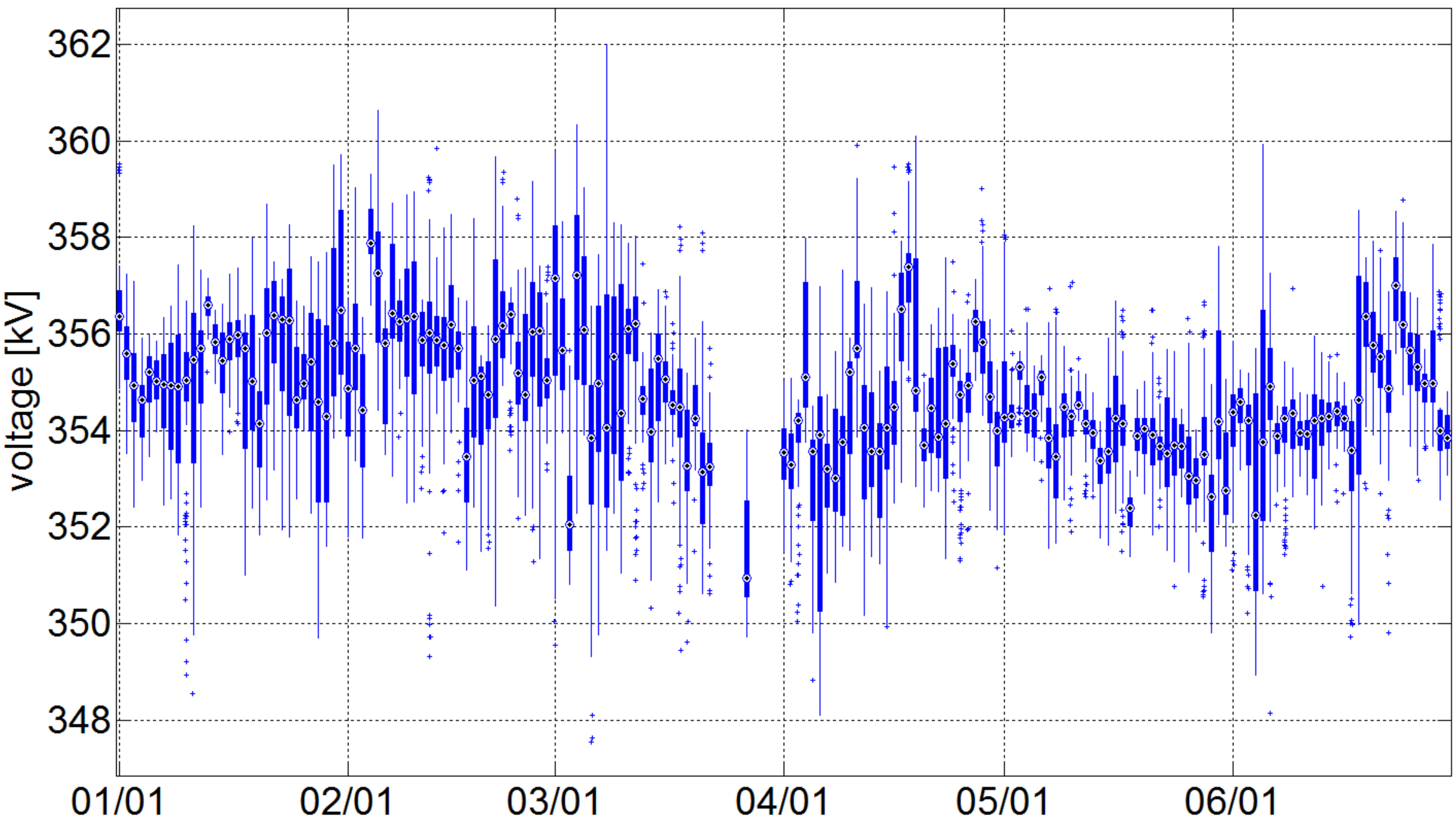
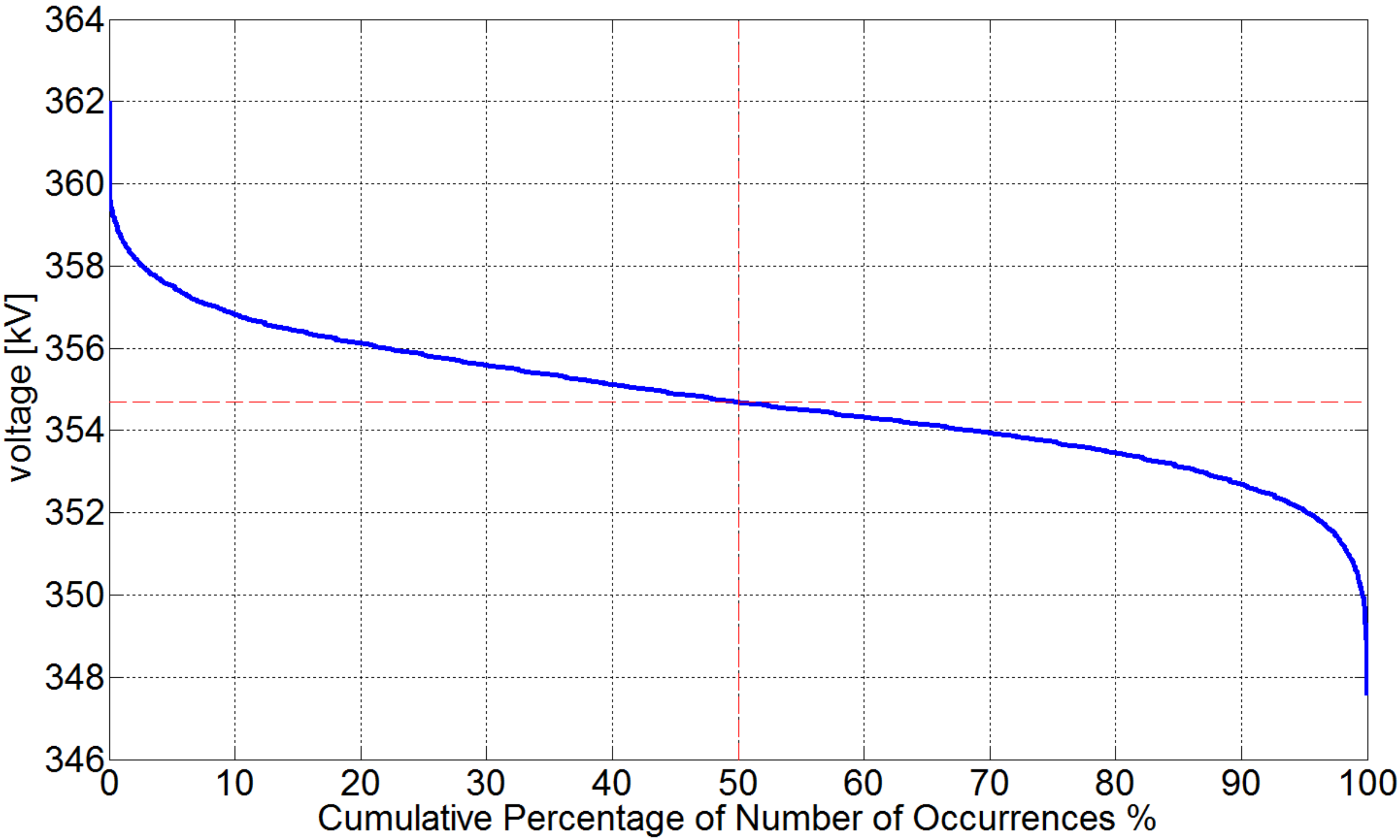
90
100
Cumulative Percentage of Number of Occurrences %

West 6



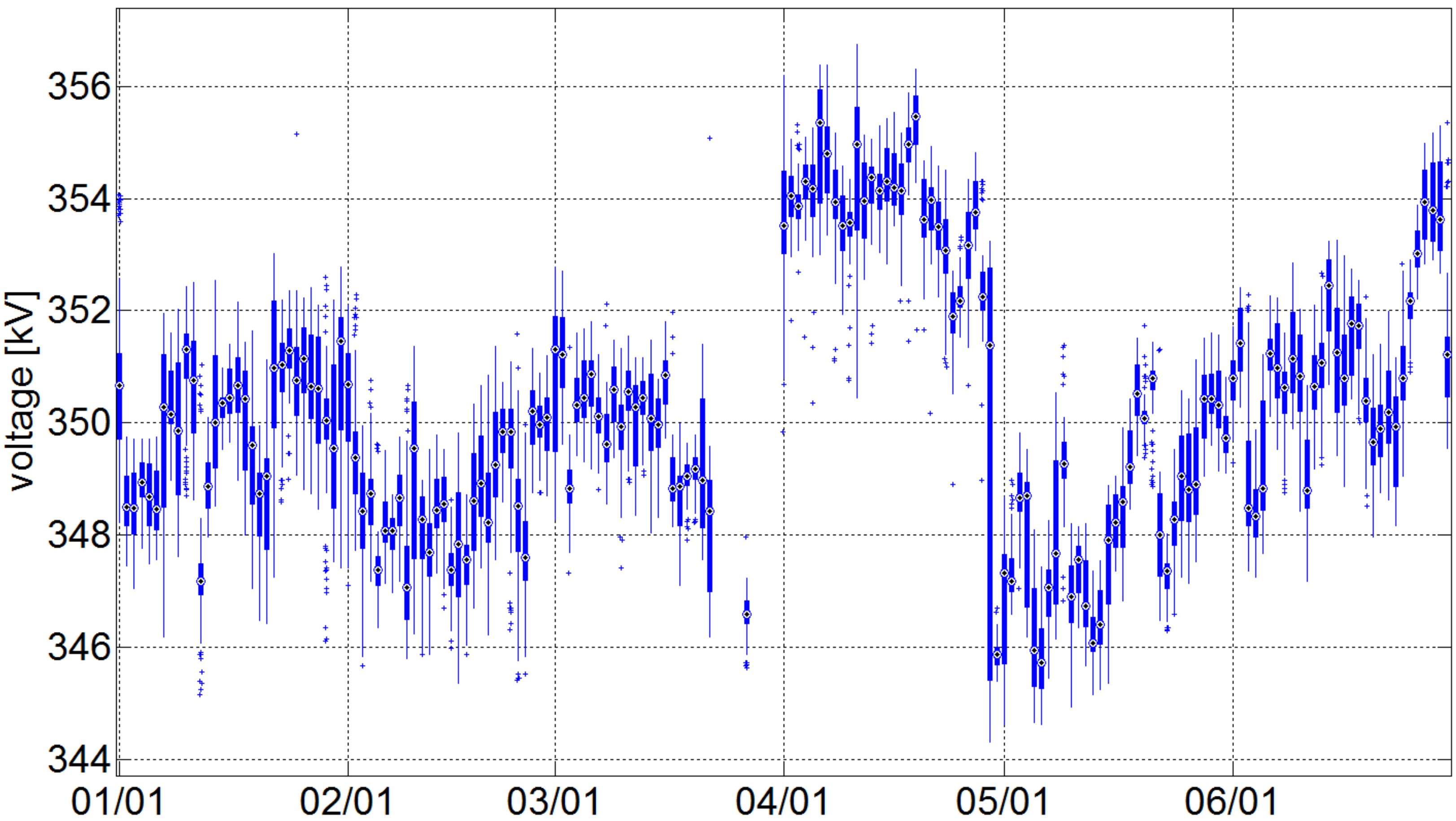
voltage [kV]
362
360
358
356
354
352
350
348
01/01
02/01
03/01
04/01
05/01
06/01

West 6



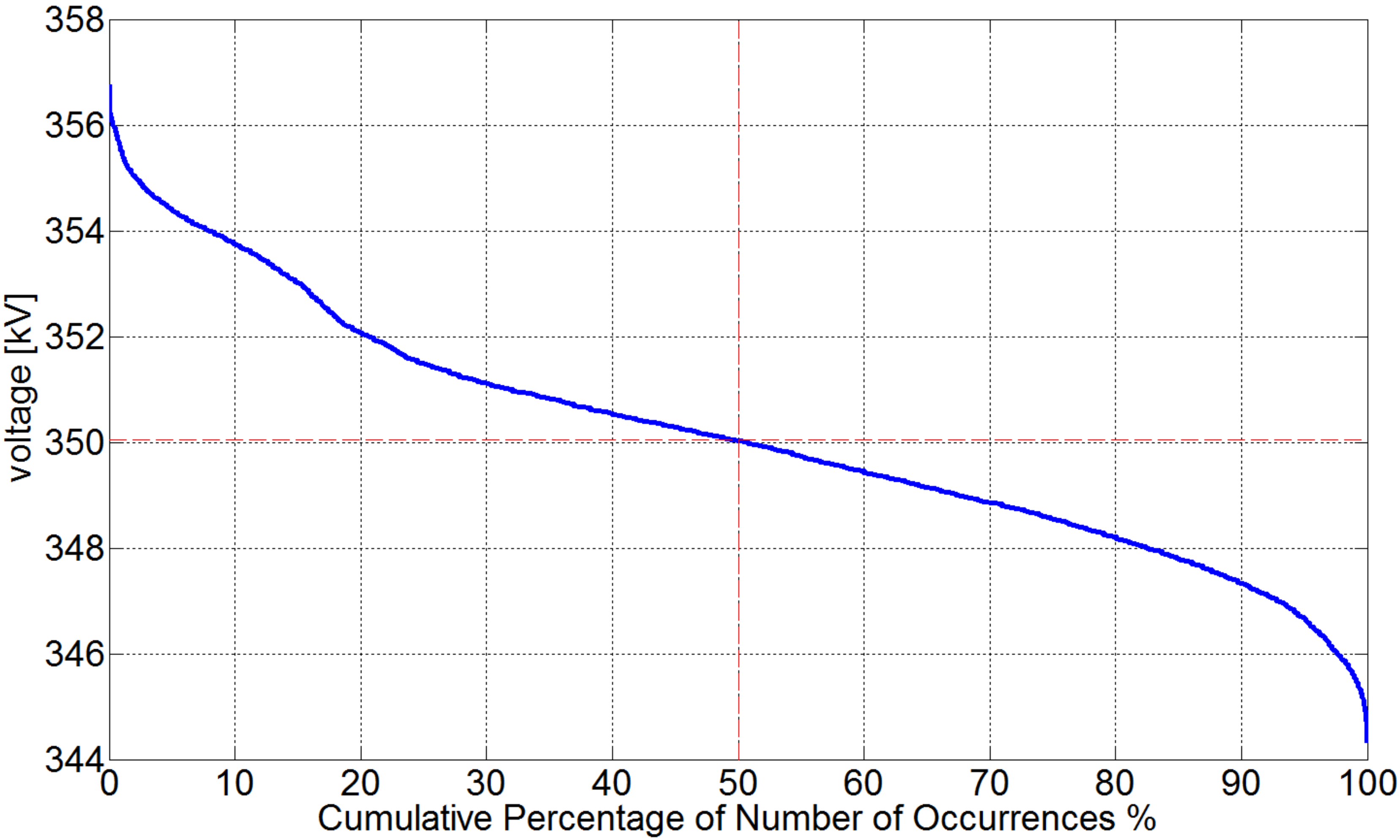
364
362
360
358
356
354
352
350
348
346
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

North 1

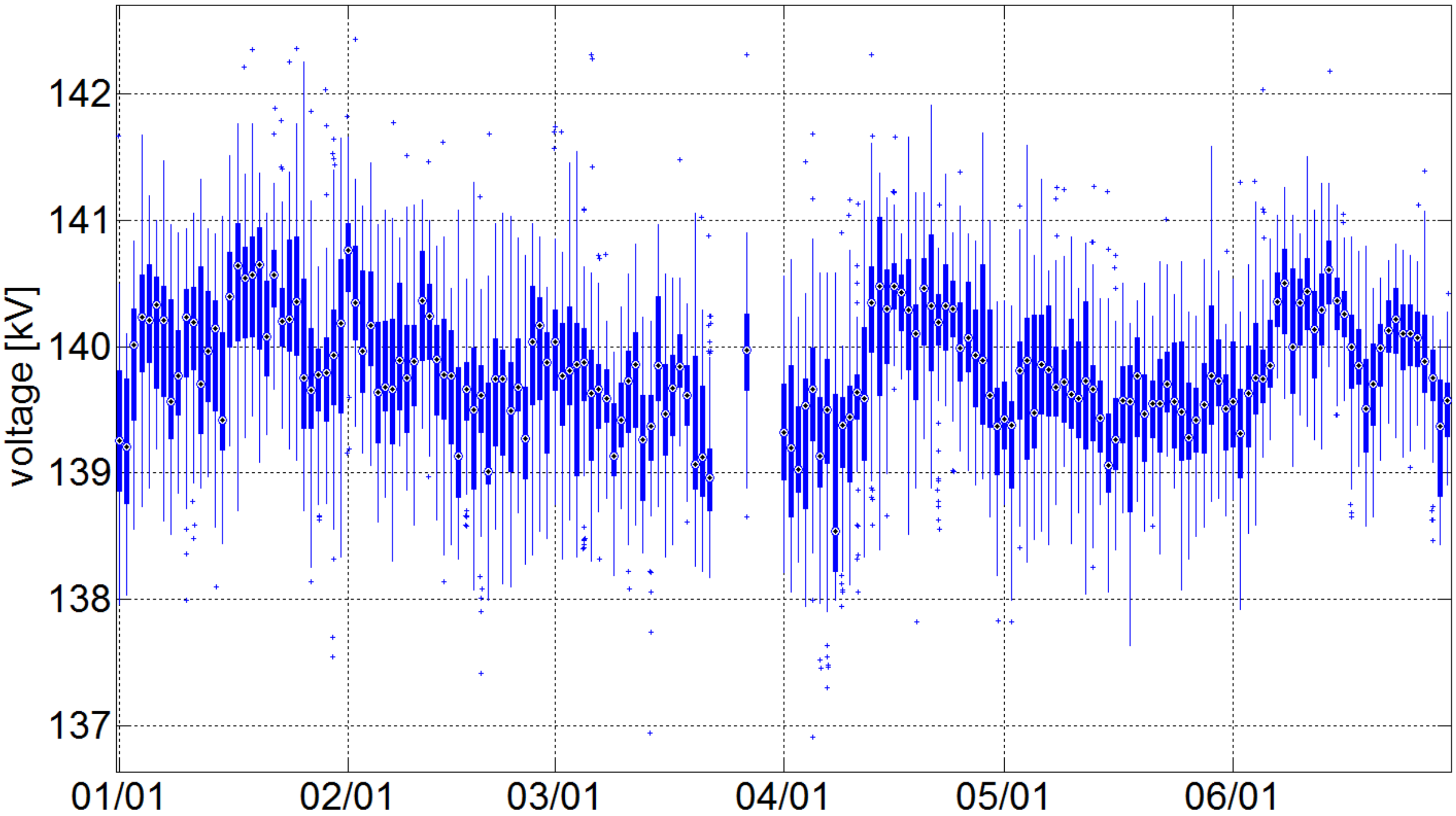


voltage [kV]
356
354
352
350
348
346
344
01/01
02/01
03/01
04/01
05/01
06/01

North 1

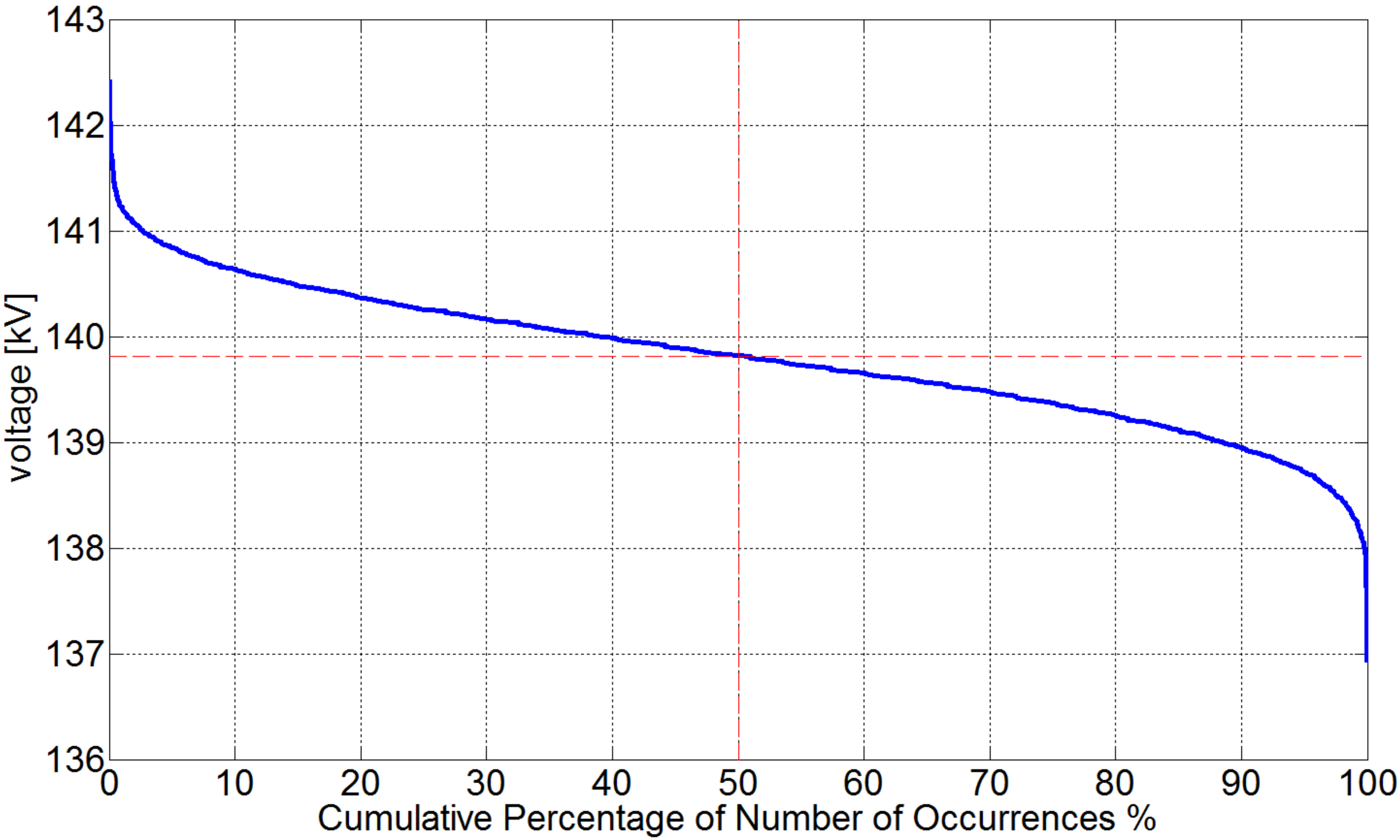

358
356
354
352
350
348
346
344
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

North 2



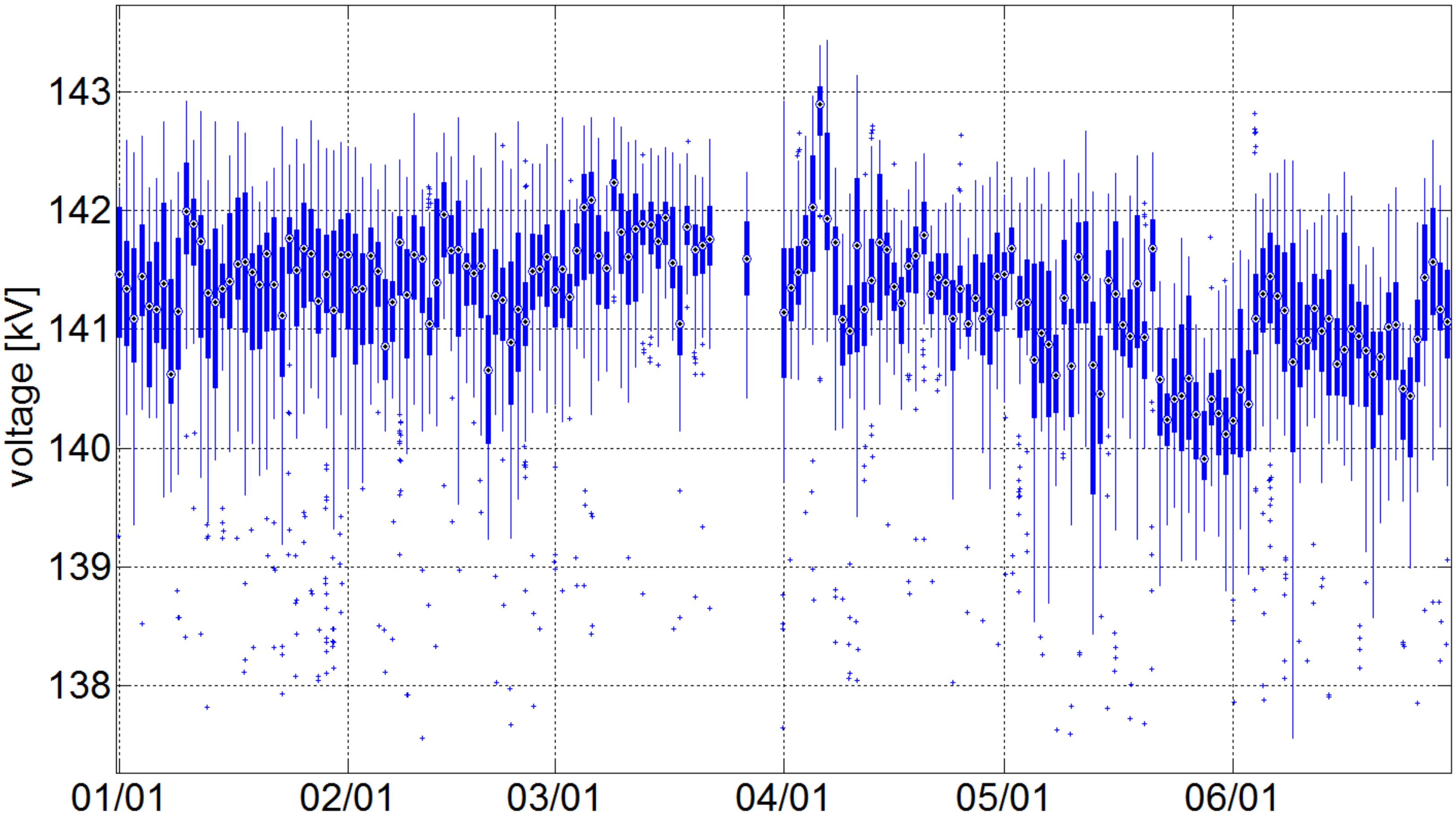
voltage [kV]
142
141
140
139
138
137
01/01
02/01
03/01
04/01
05/01
06/01

North 2



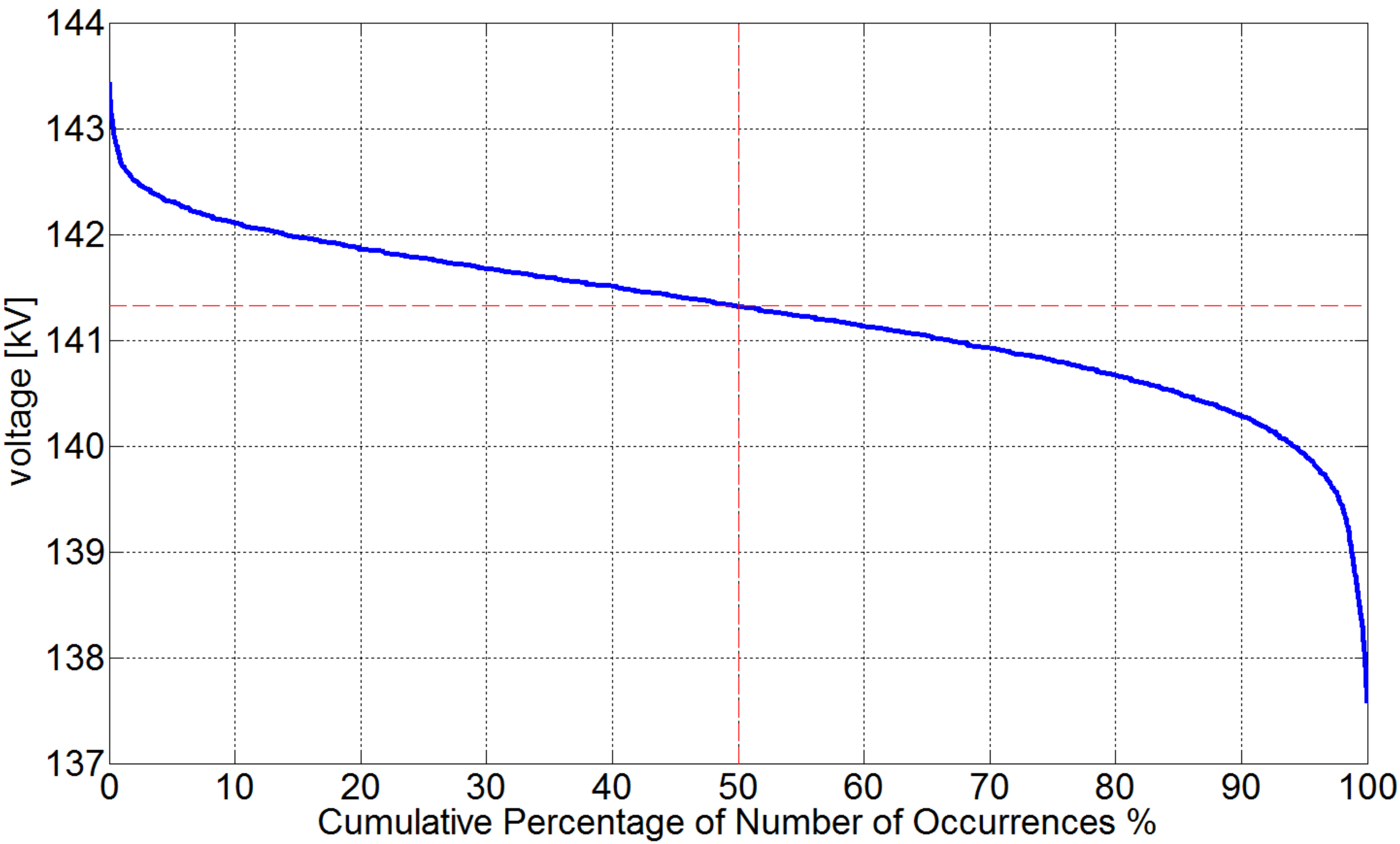
143
142
141
140
139
138
137
136
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

North 4



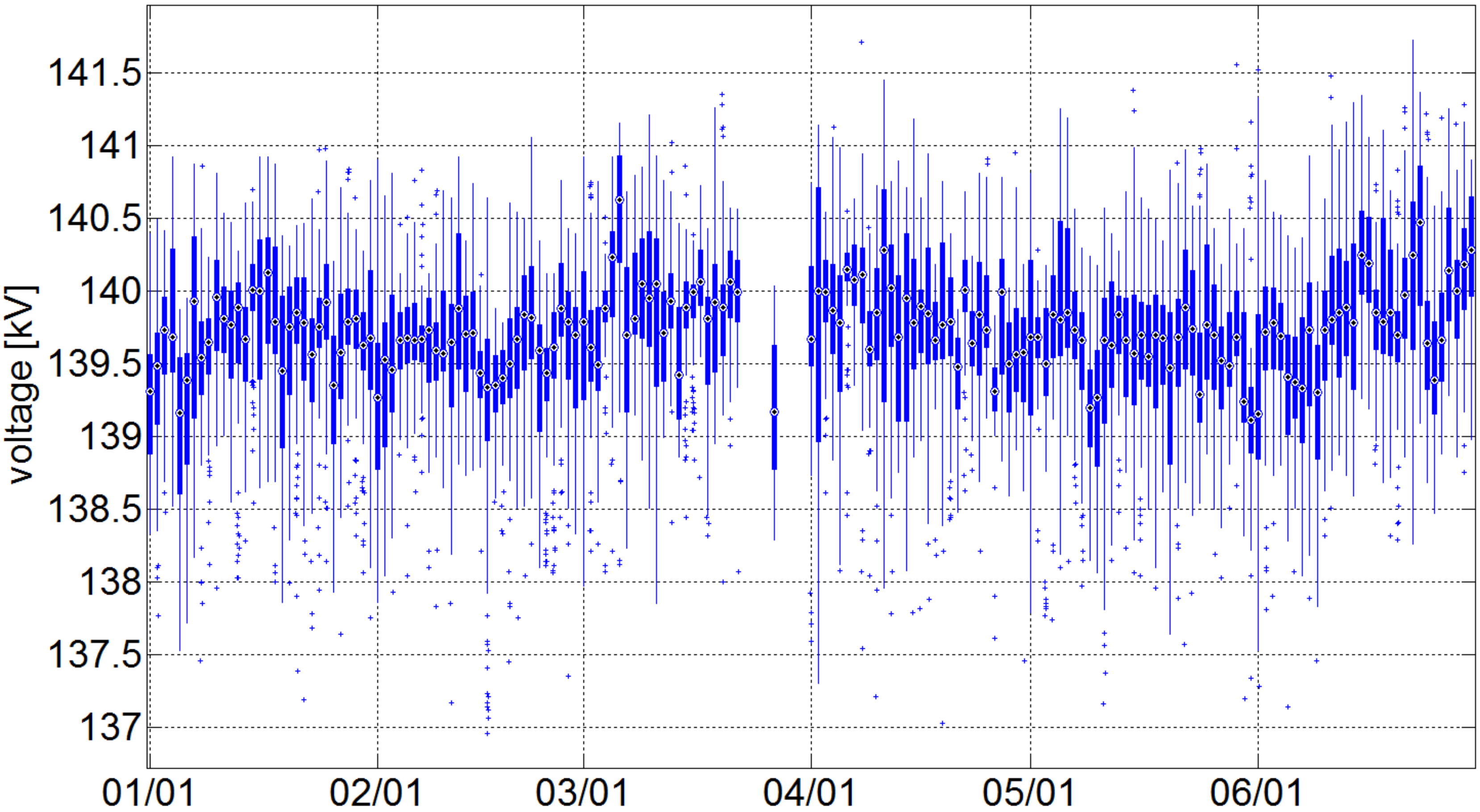
143
142
141
140
139
138
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01

North 4



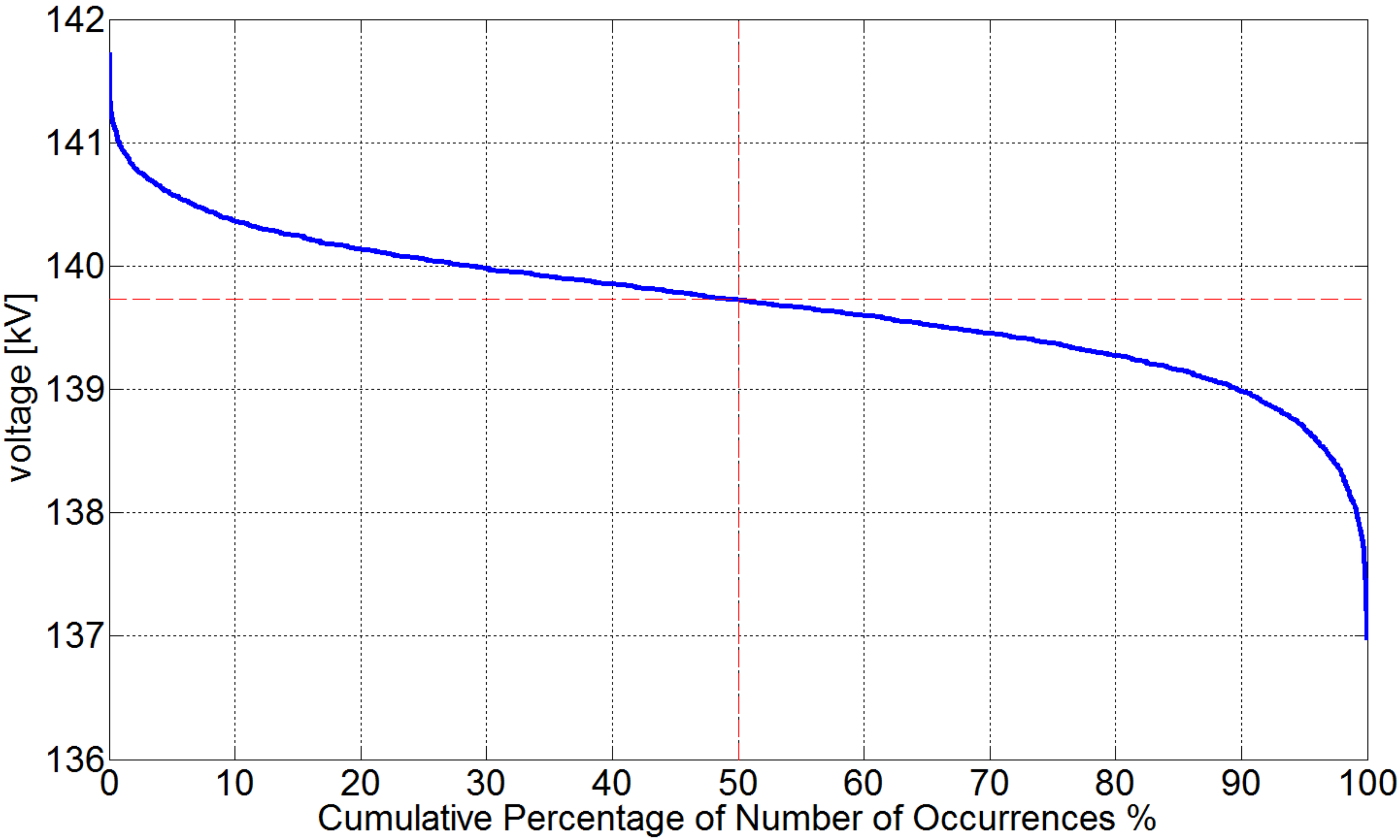
144
143
142
141
140
139
138
137
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

North 5



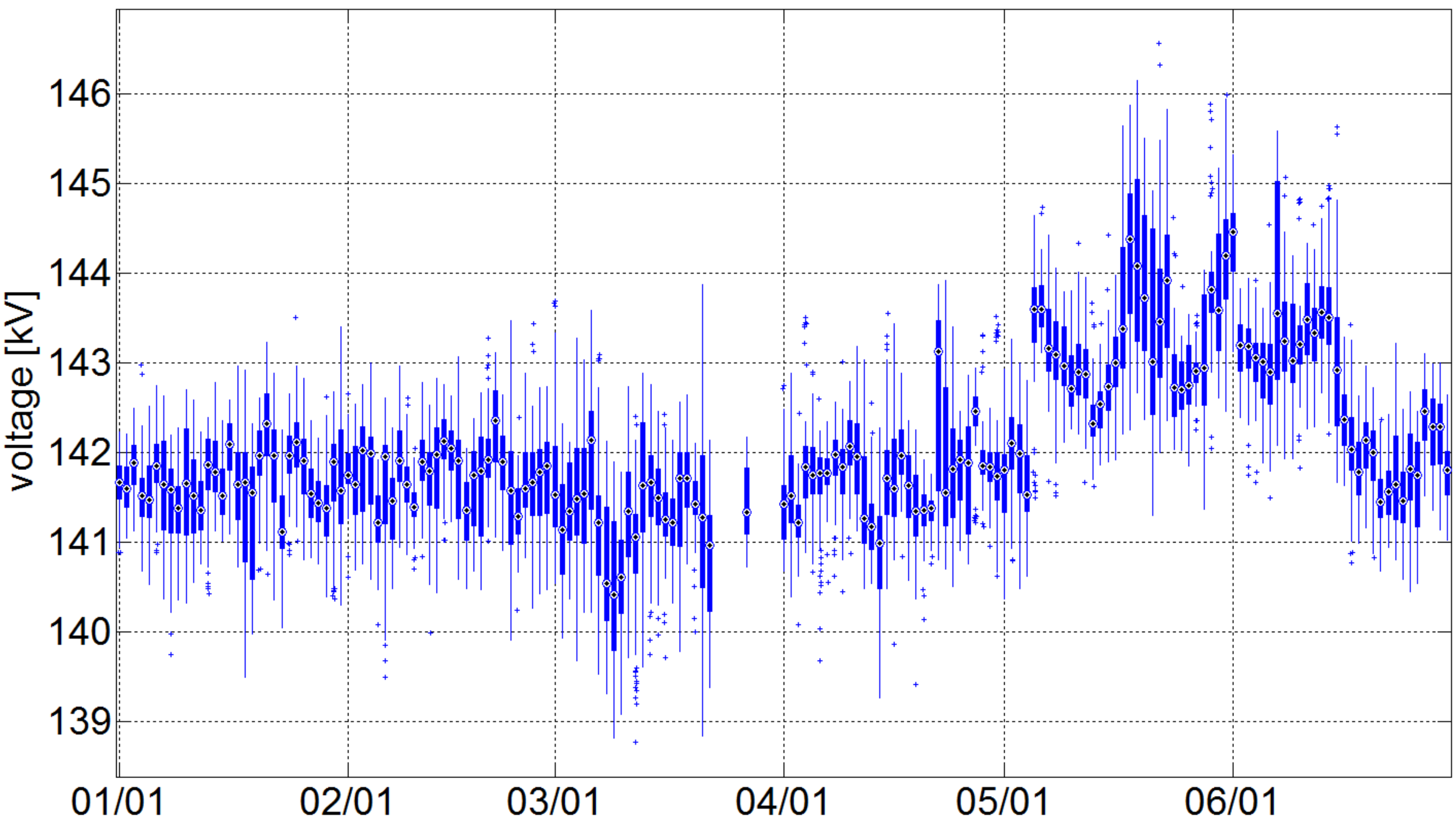
voltage [kV]
141.5
141
140.5
140
139.5
139
138.5
138
137.5
137
01/01
02/01
03/01
04/01
05/01
06/01

North 5



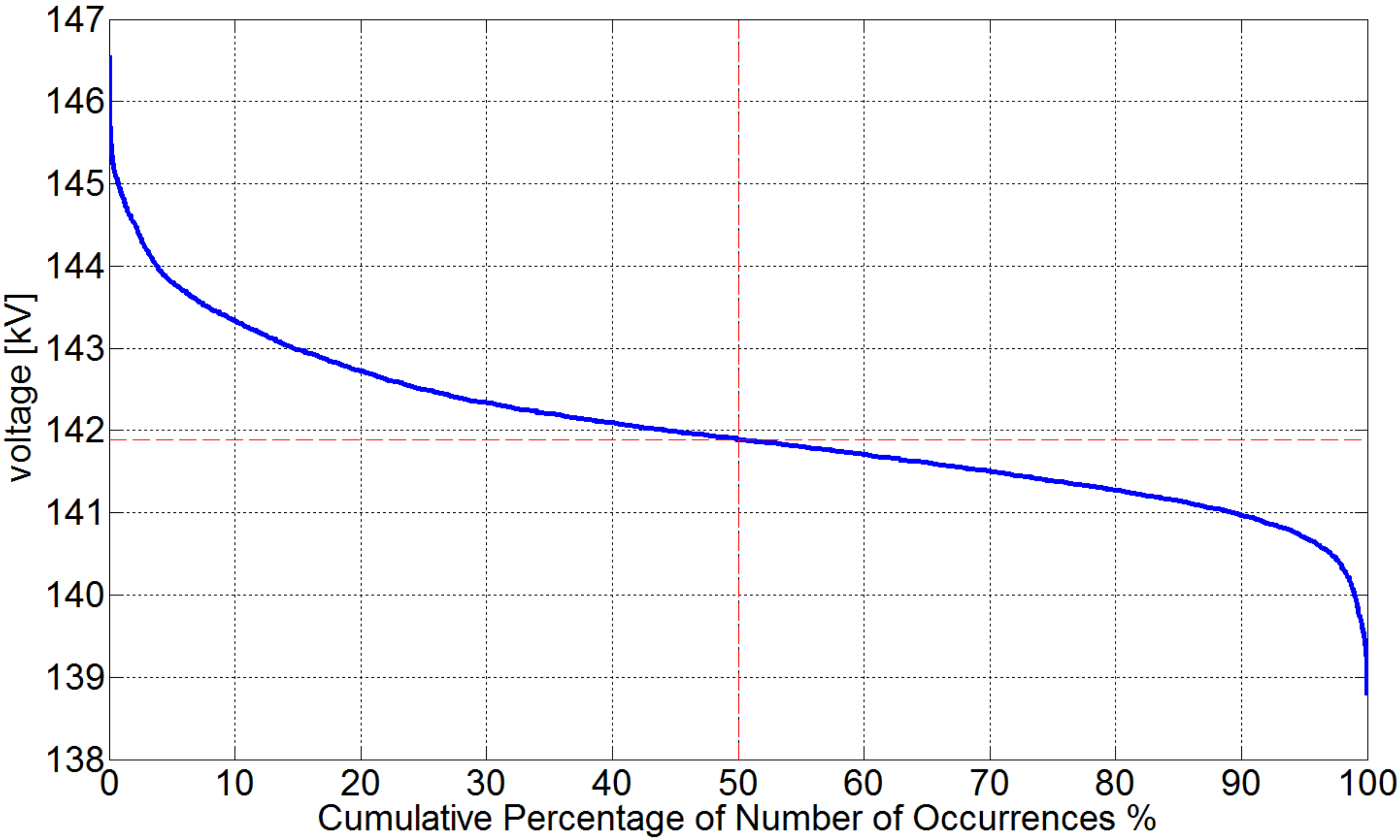
142
141
140
139
138
137
136
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

North 6



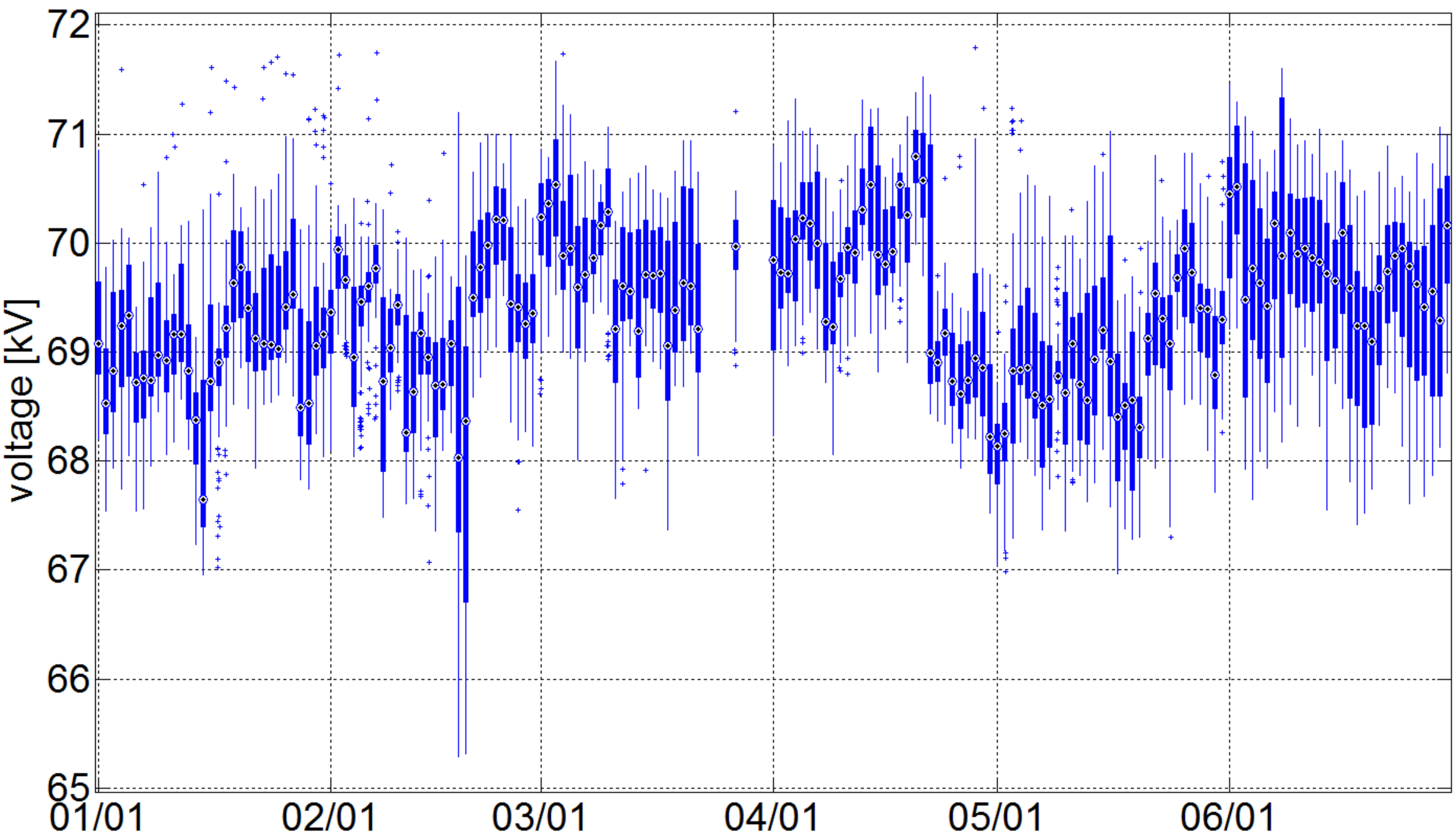
voltage [kV]
146
145
144
143
142
141
140
139
01/01
02/01
03/01
04/01
05/01
06/01

North 6

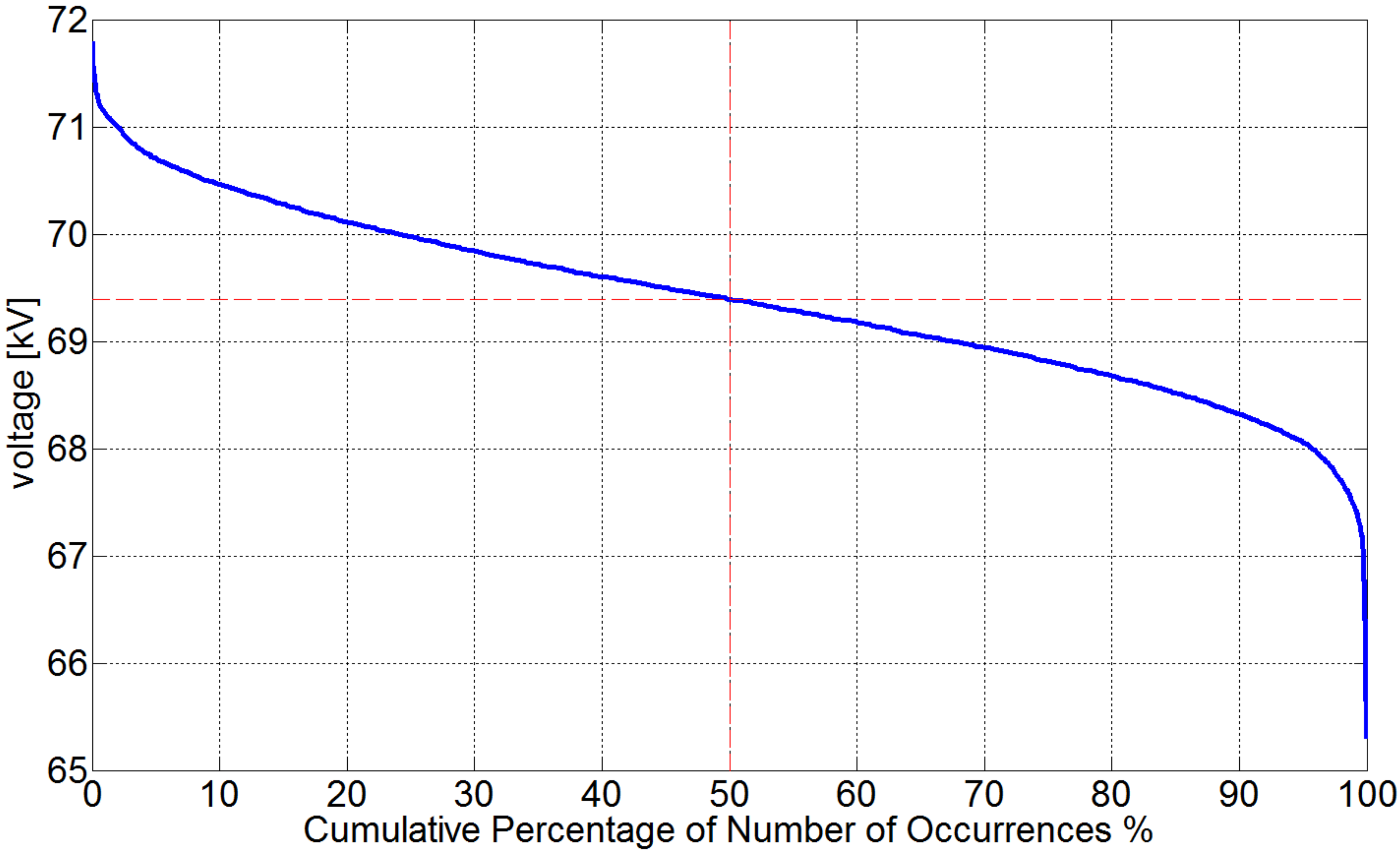


147
146
145
144
143
142
141
140
139
138
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

FarWest 2*

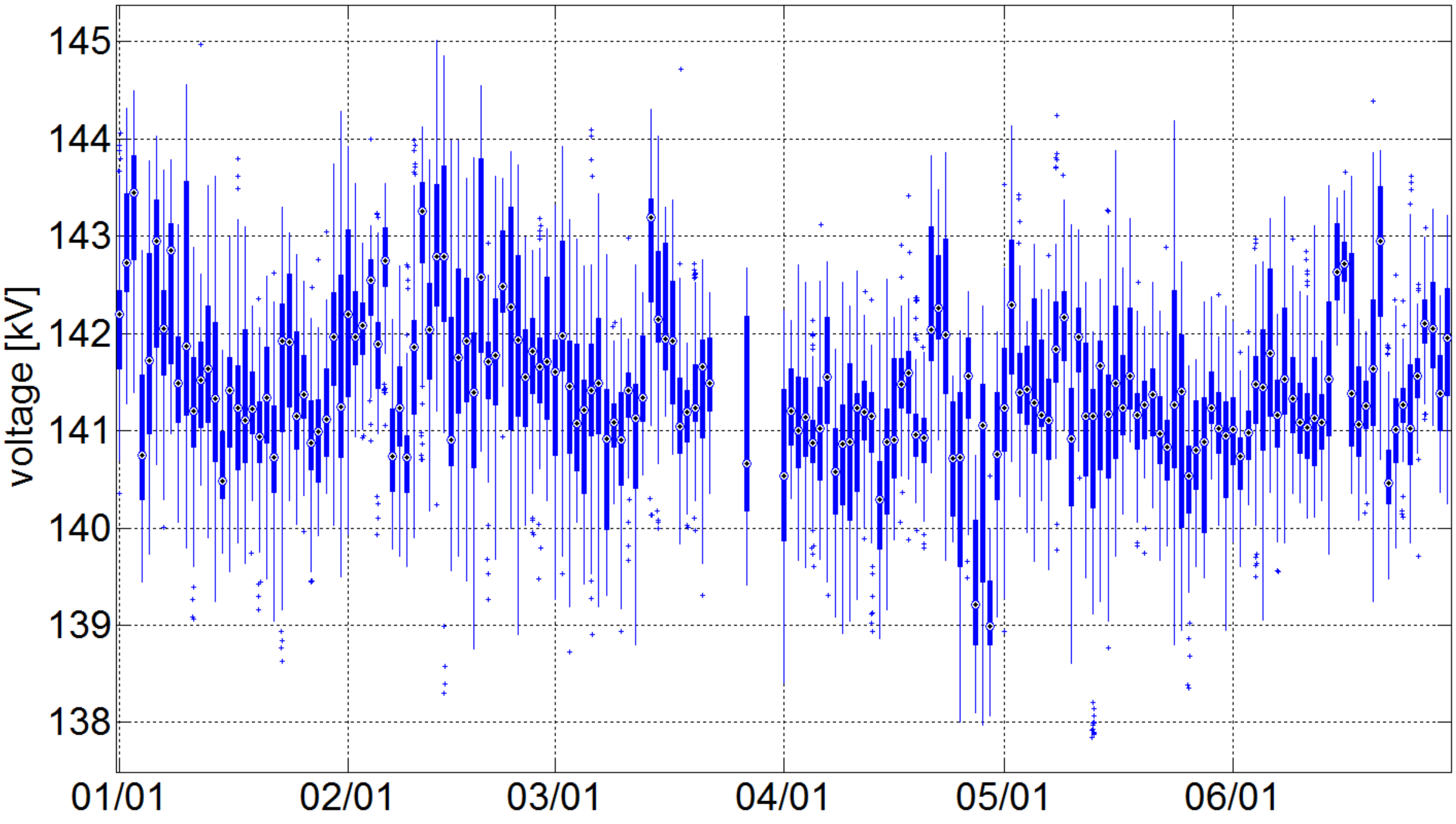


FarWest 2*



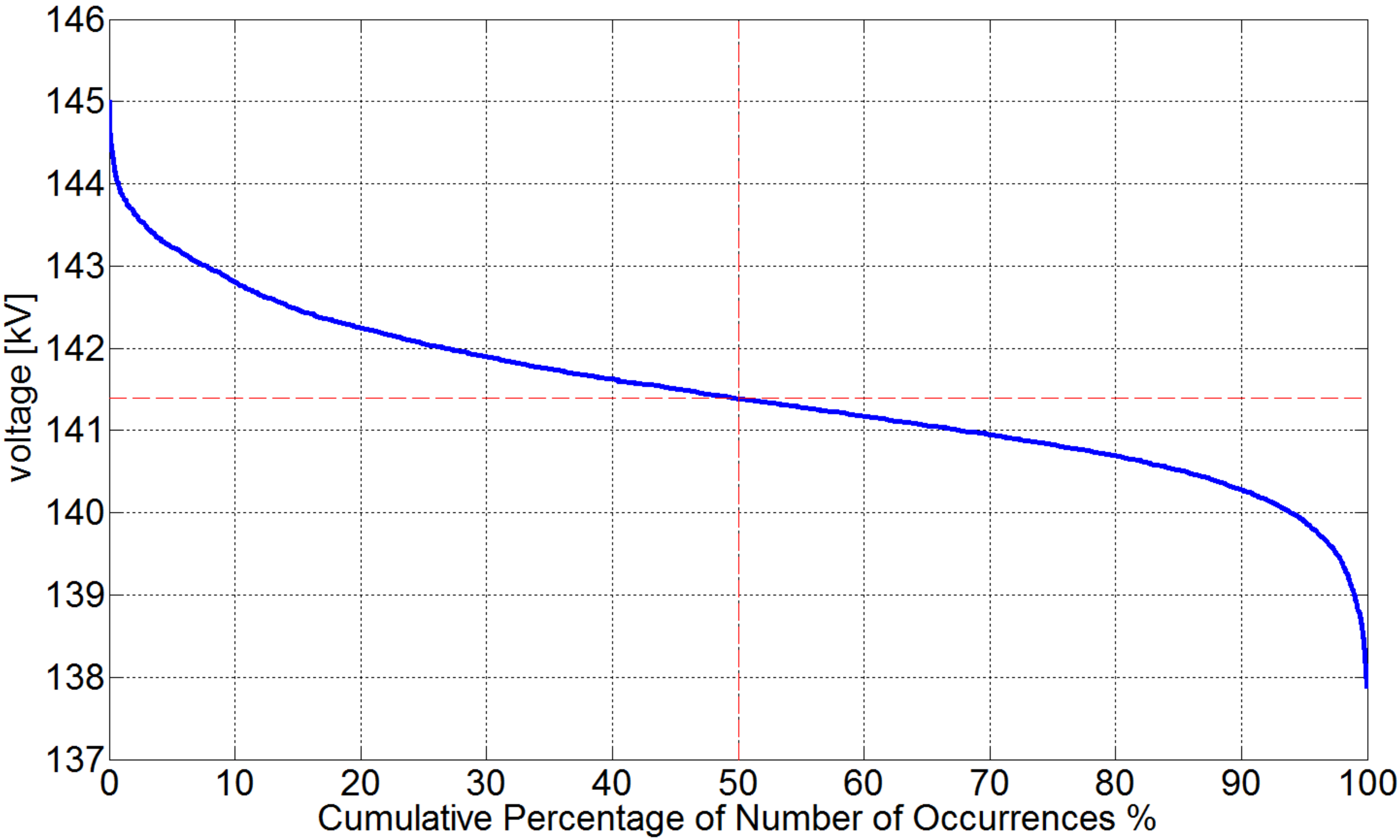
72
71
70
69
68
67
66
65
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

North 7



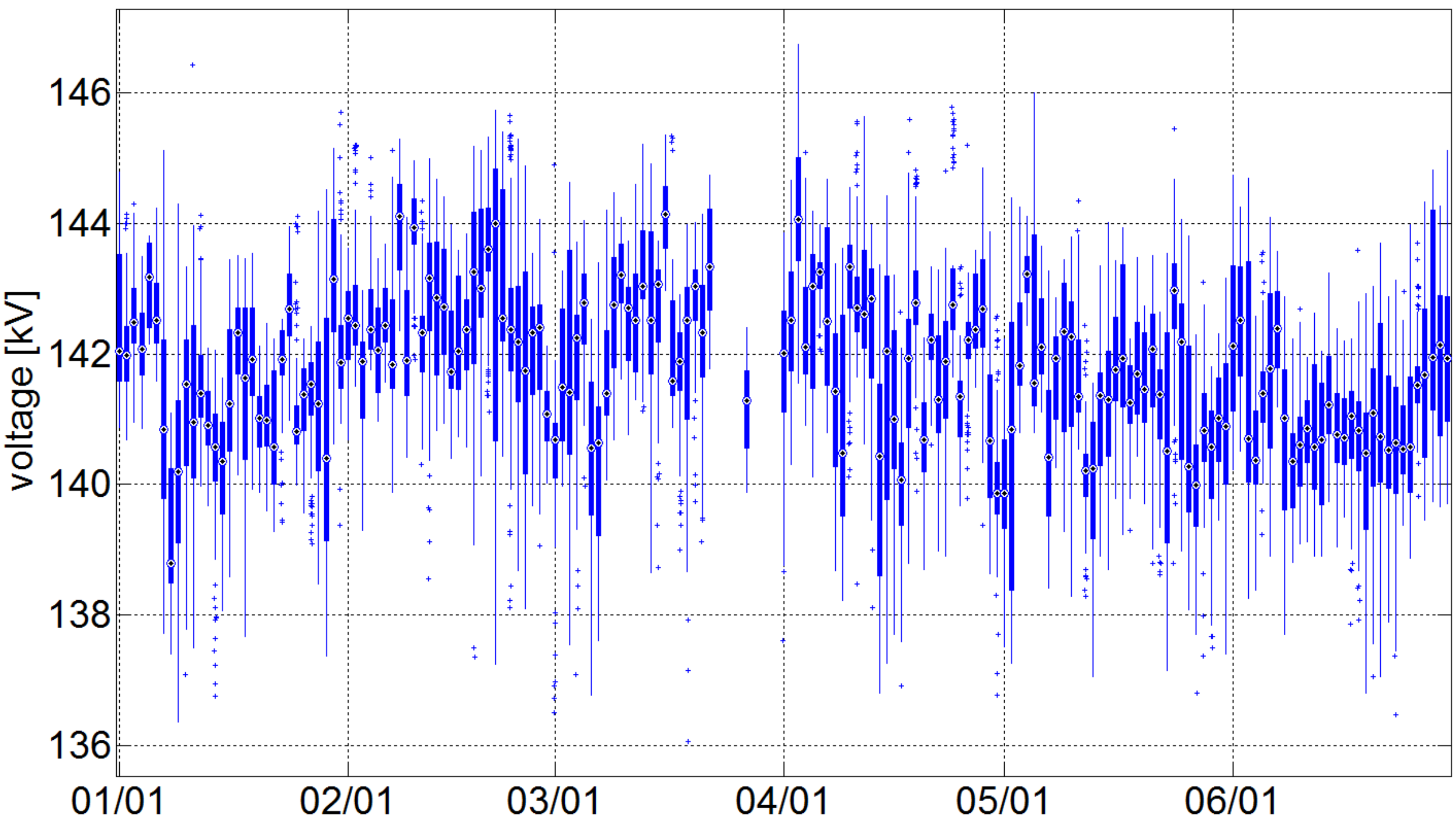
voltage [kV]
145
144
143
142
141
140
139
138
01/01
02/01
03/01
04/01
05/01
06/01

North 7



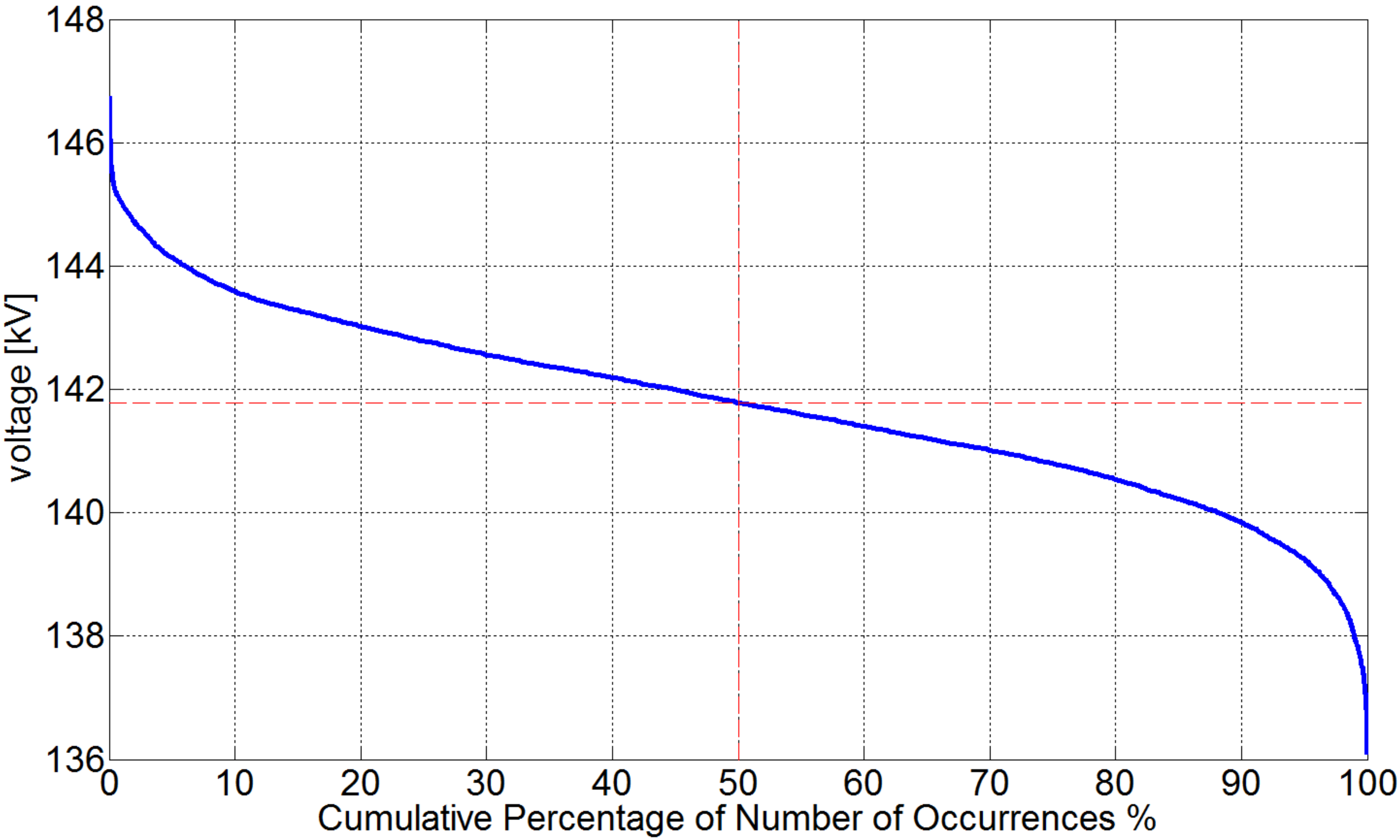
146
145
144
143
142
141
140
139
138
137
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

West 4



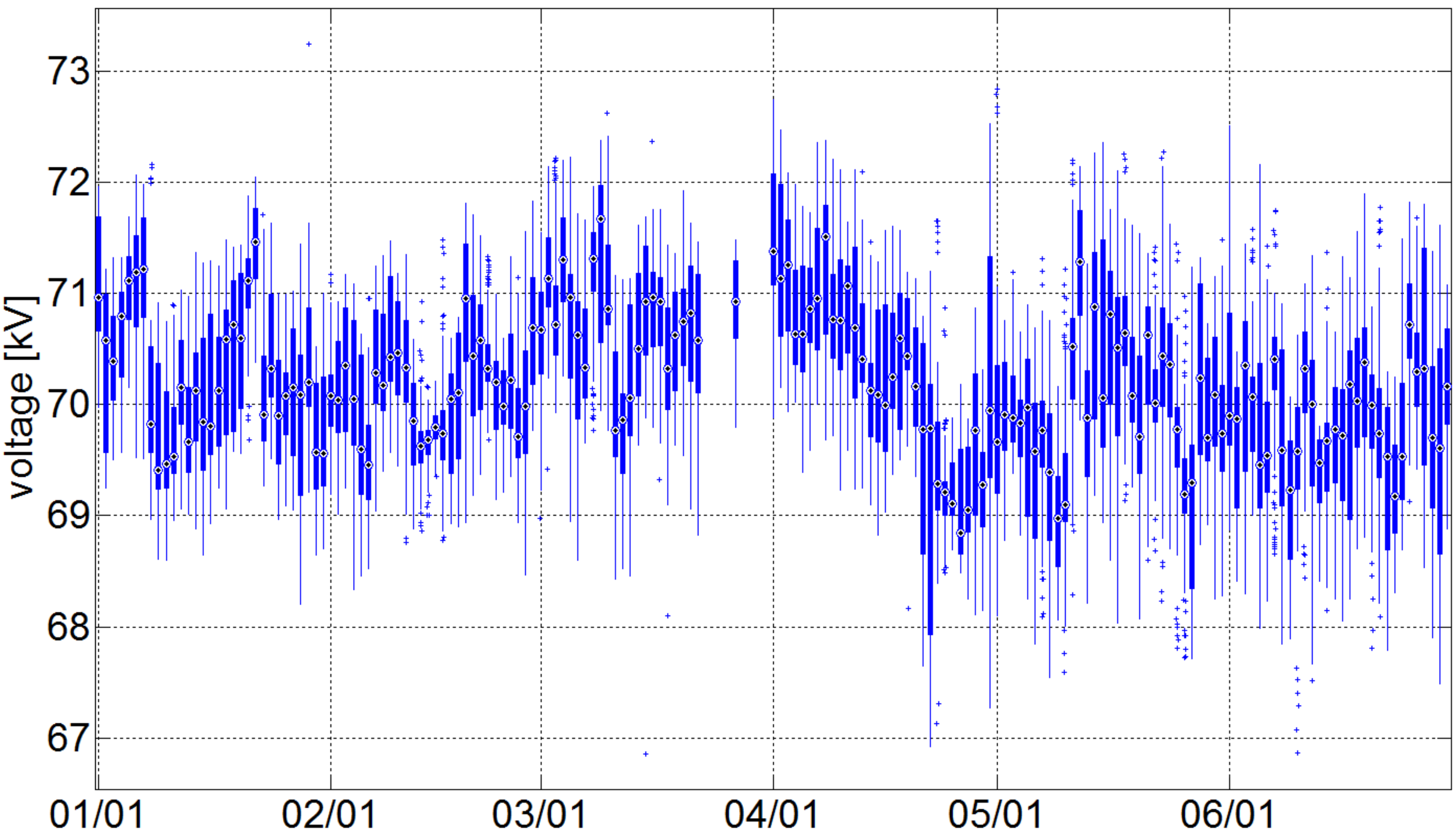
146
144
142
140
138
136
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01

West 4

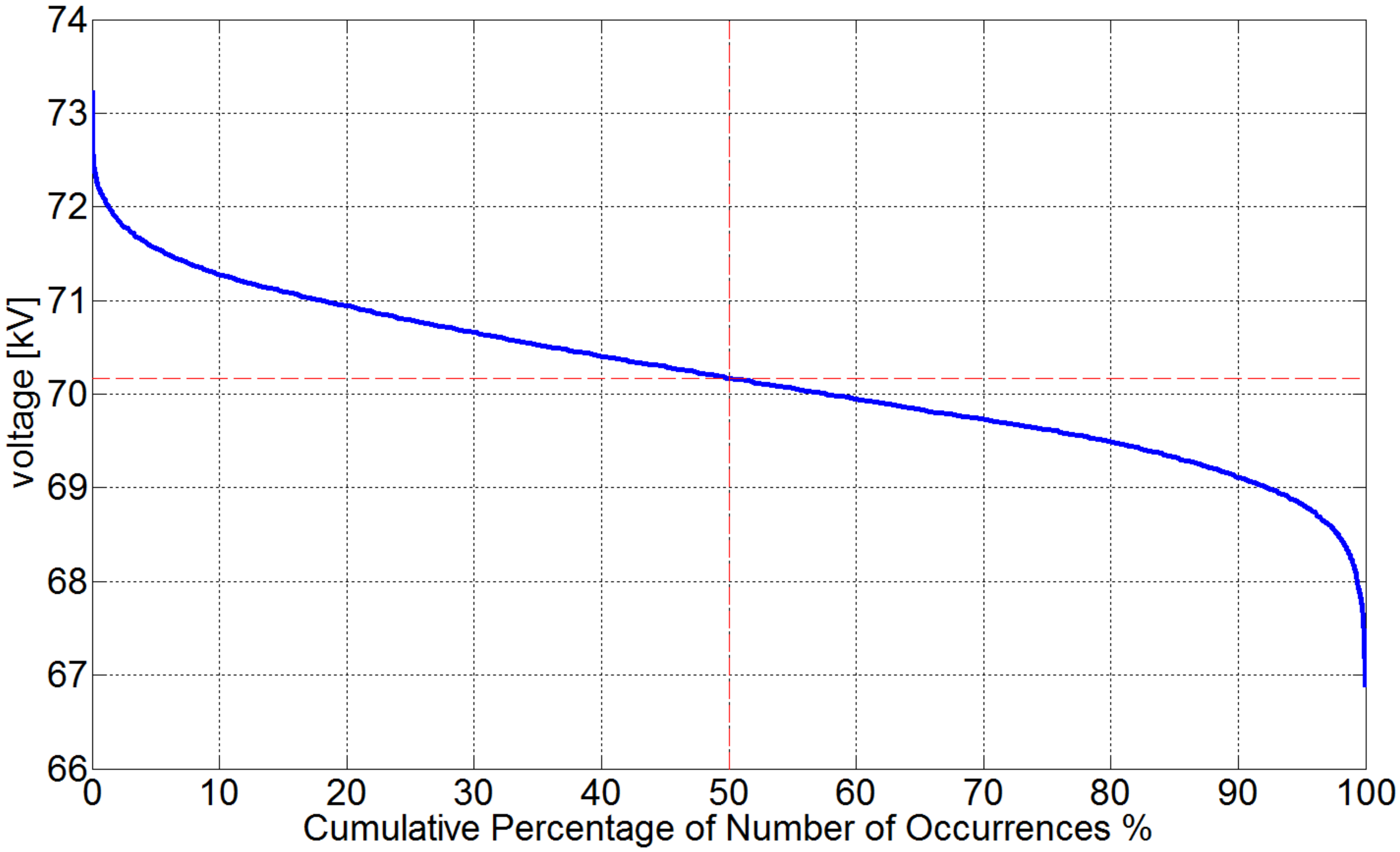


148
146
144
142
140
138
136
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

Coast 2*

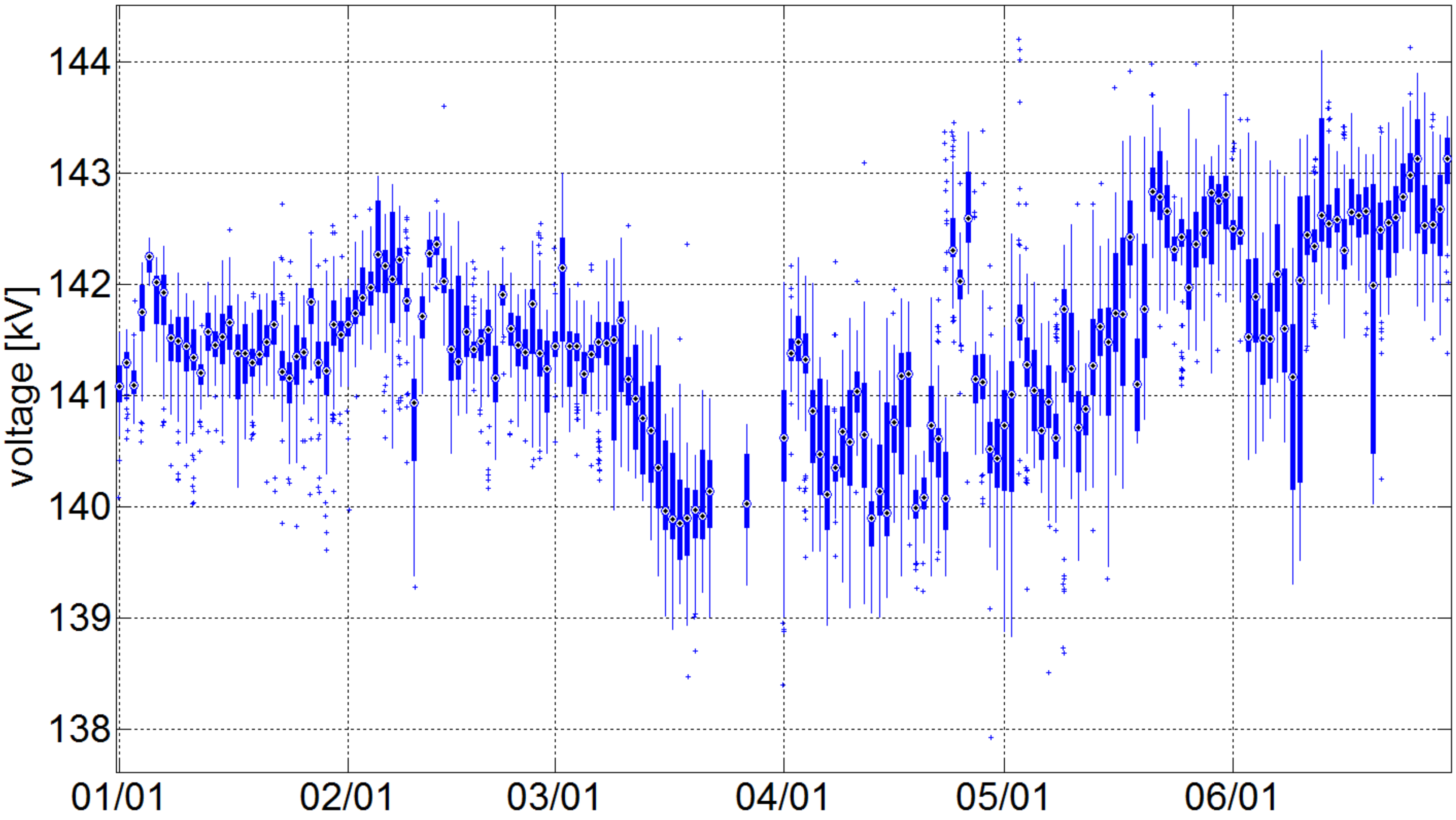


Coast 2*



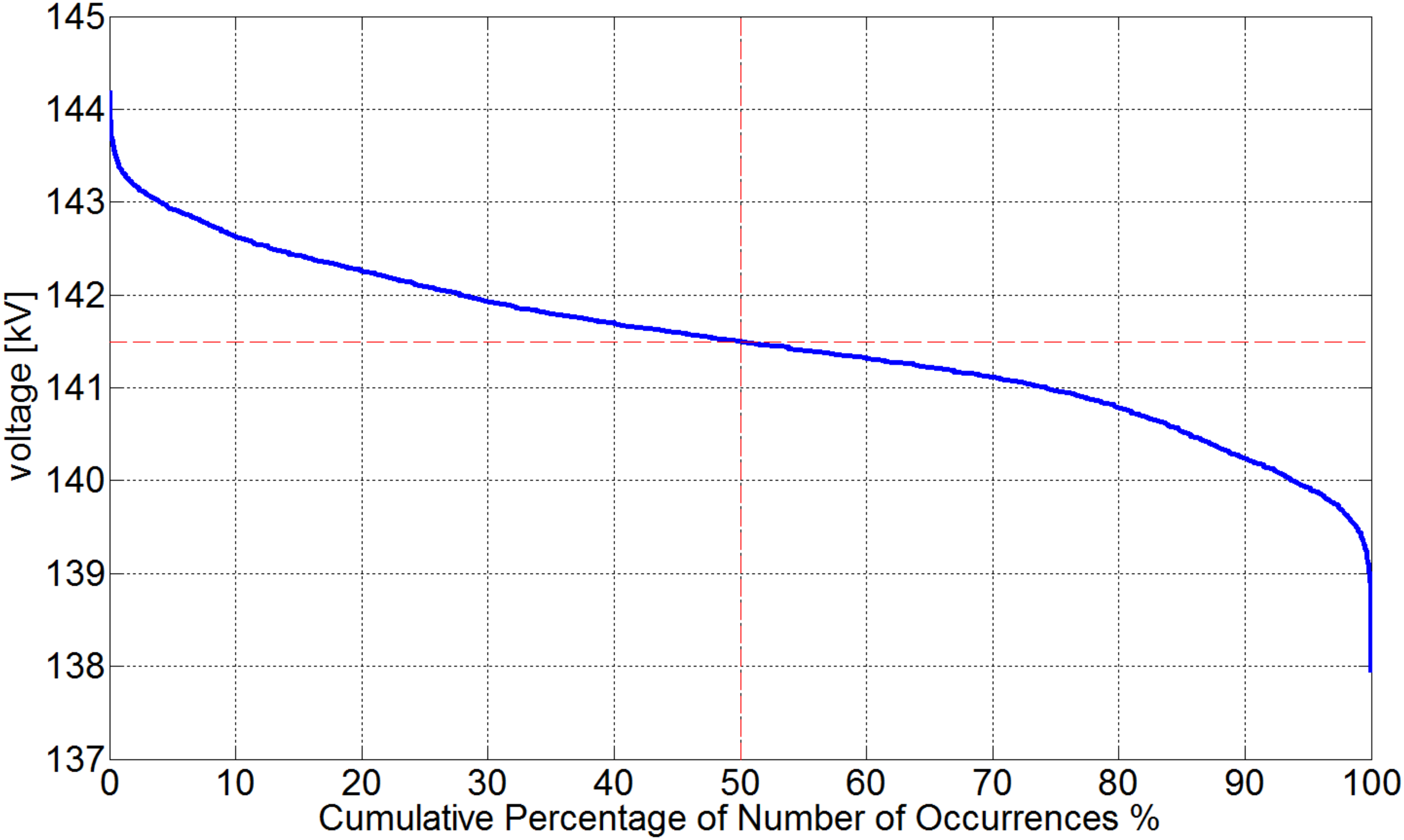
74
73
72
71
70
69
68
67
66
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

Coast 1



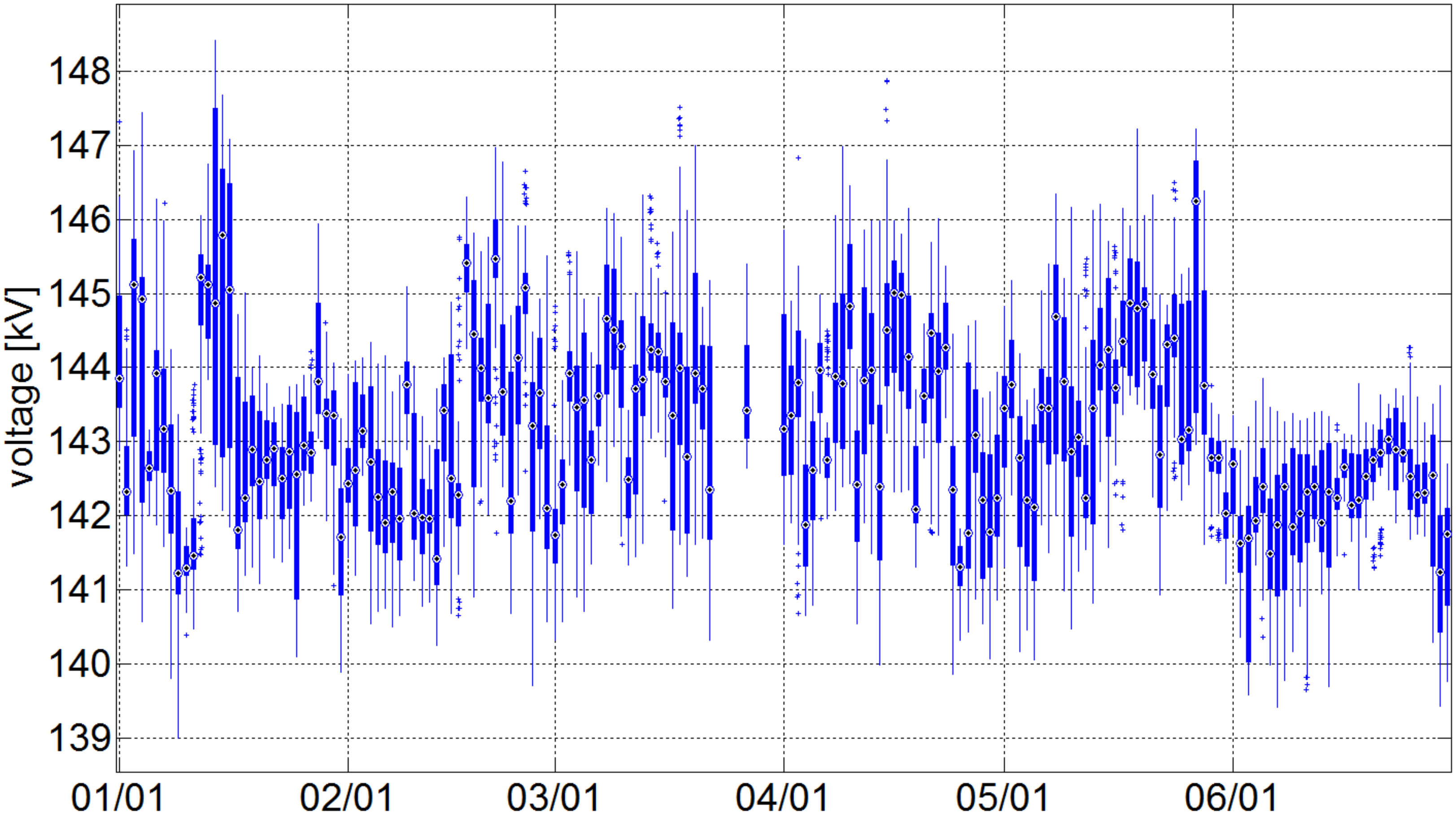
144
143
142
141
140
139
138
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01

Coast 1



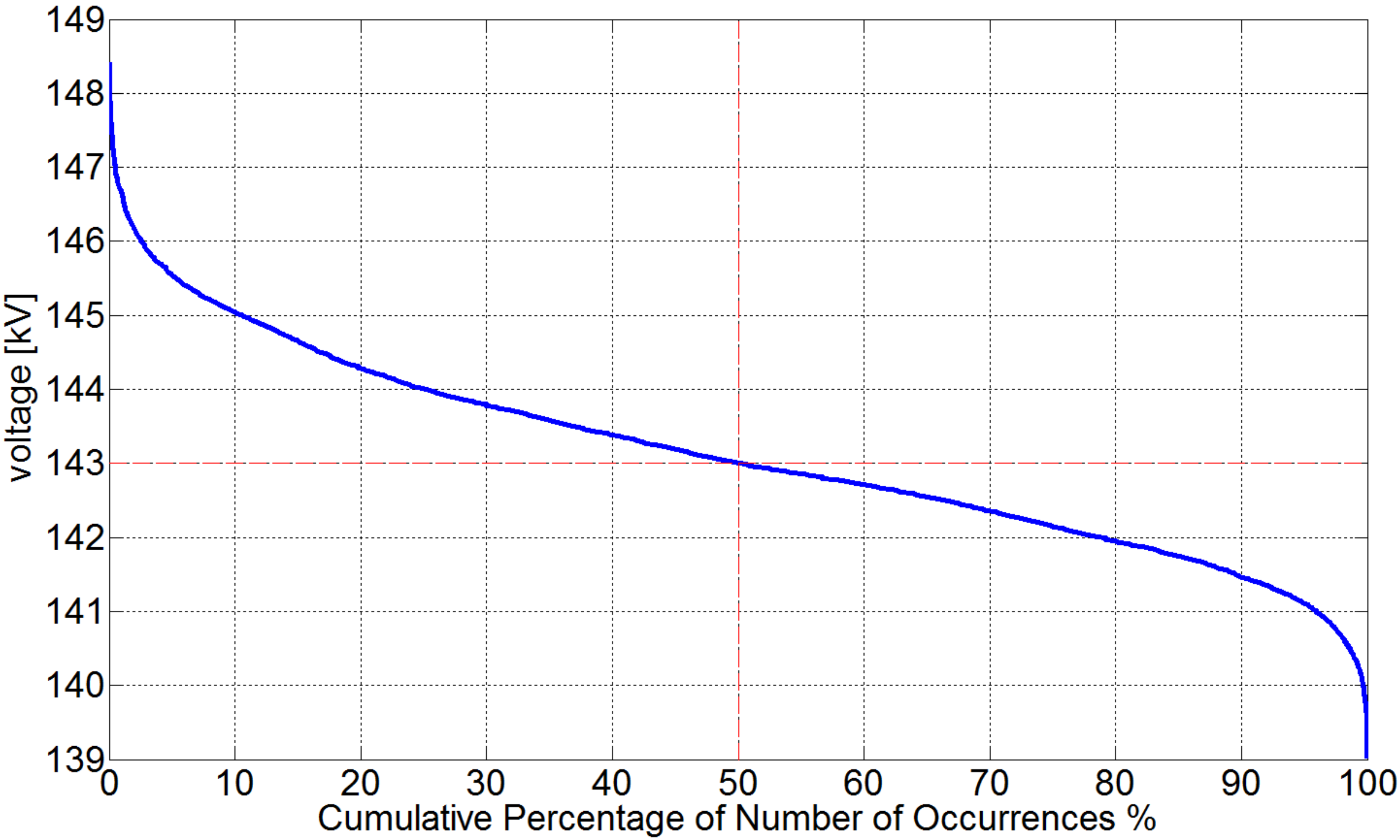
145
144
143
142
141
140
139
138
137
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 3*



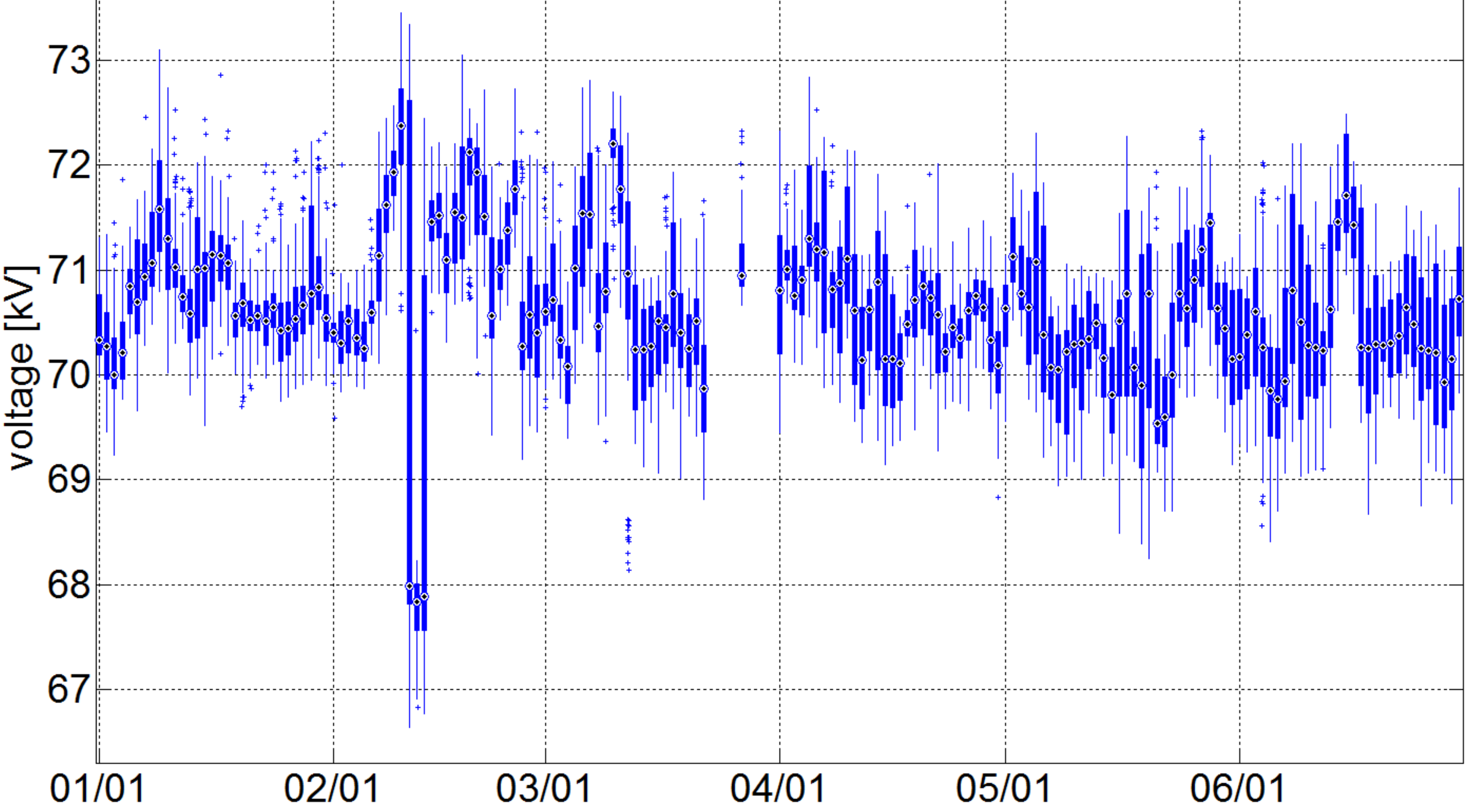
voltage [kV]
148
147
146
145
144
143
142
141
140
139
01/01
02/01
03/01
04/01
05/01
06/01

South 3*

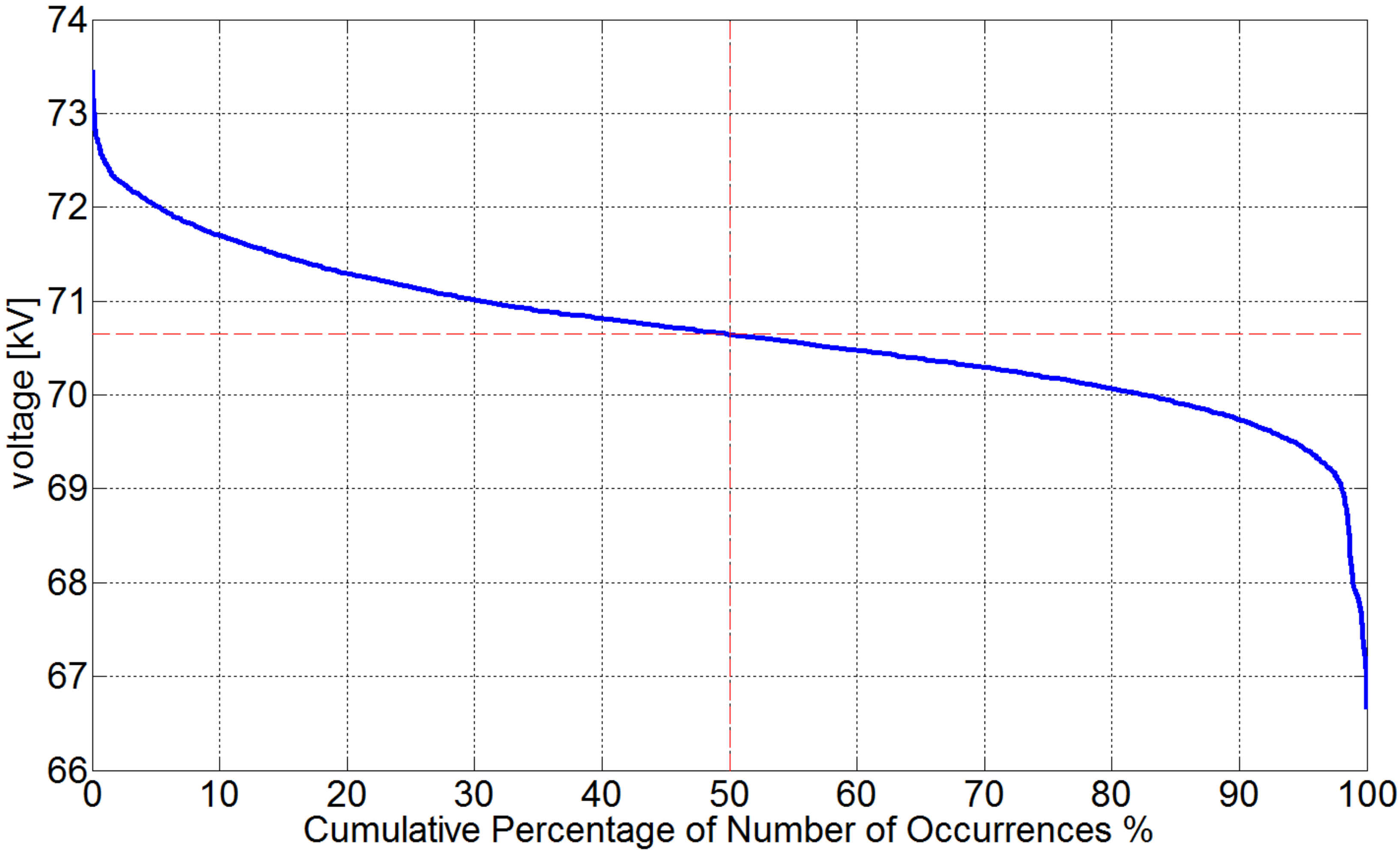


149
148
147
146
145
144
143
142
141
140
139
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 5*

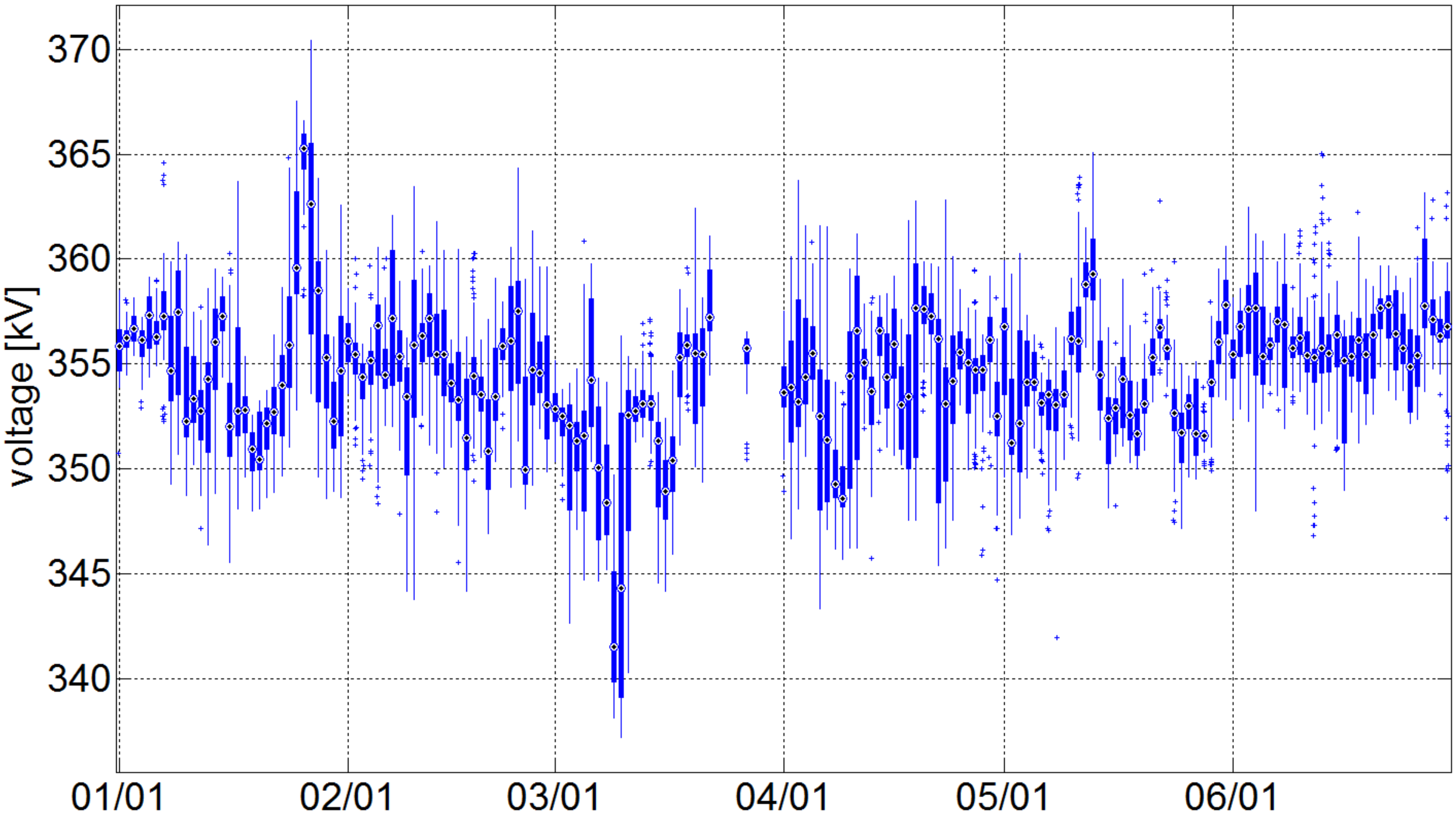


South 5*



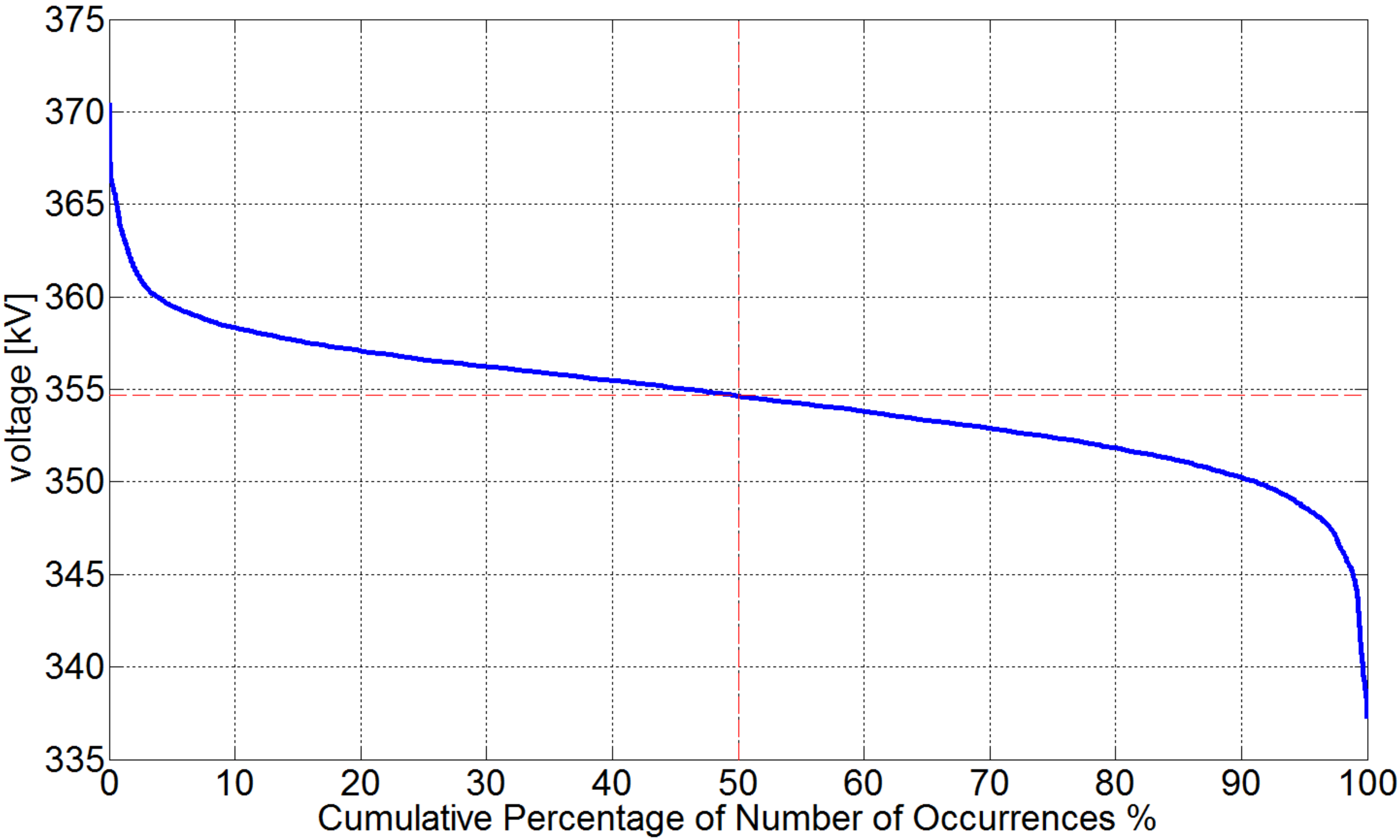
74
73
72
71
70
69
68
67
66
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

Coast 4



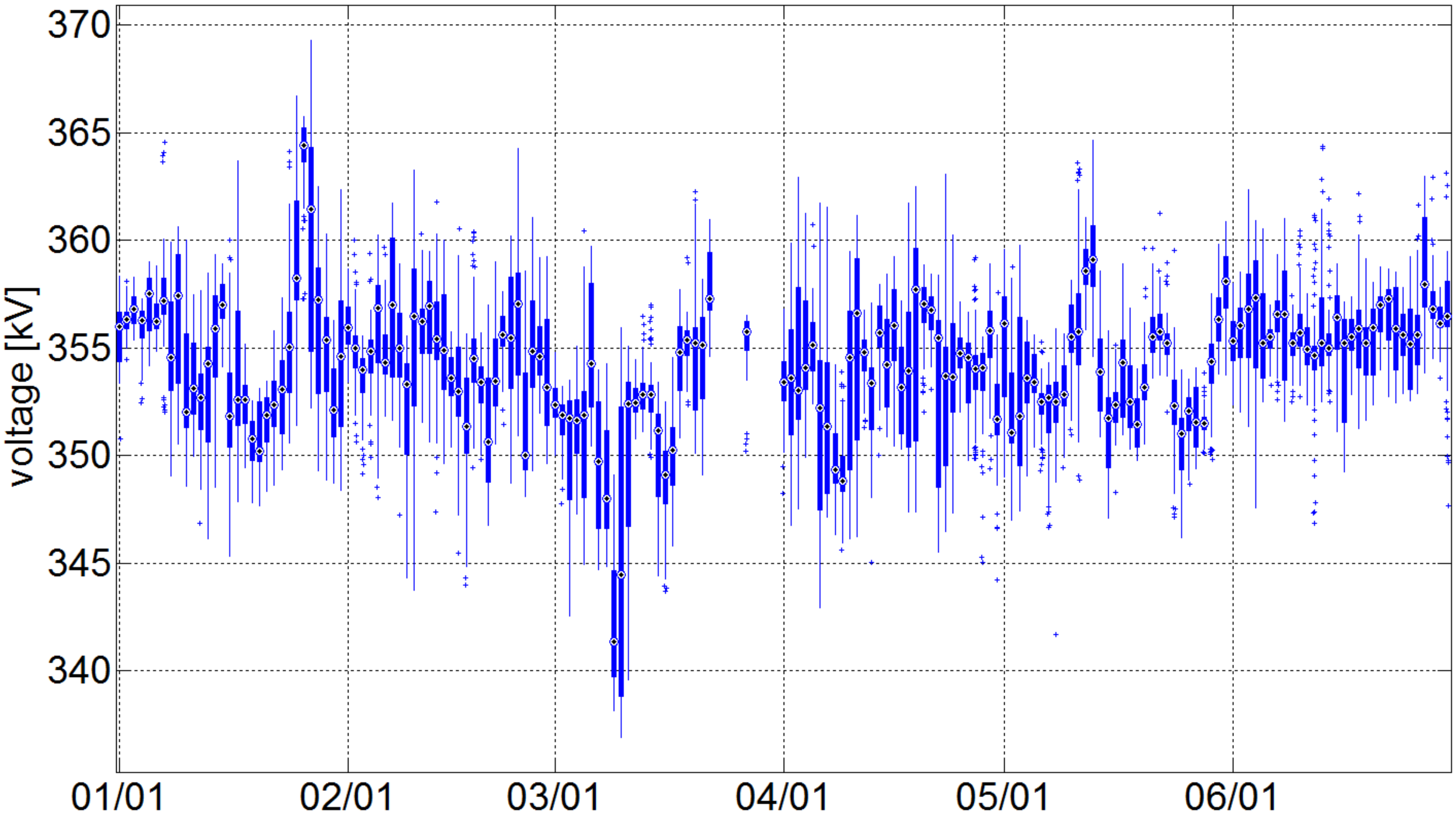
voltage [kV]
370
365
360
355
350
345
340
01/01
02/01
03/01
04/01
05/01
06/01

Coast 4



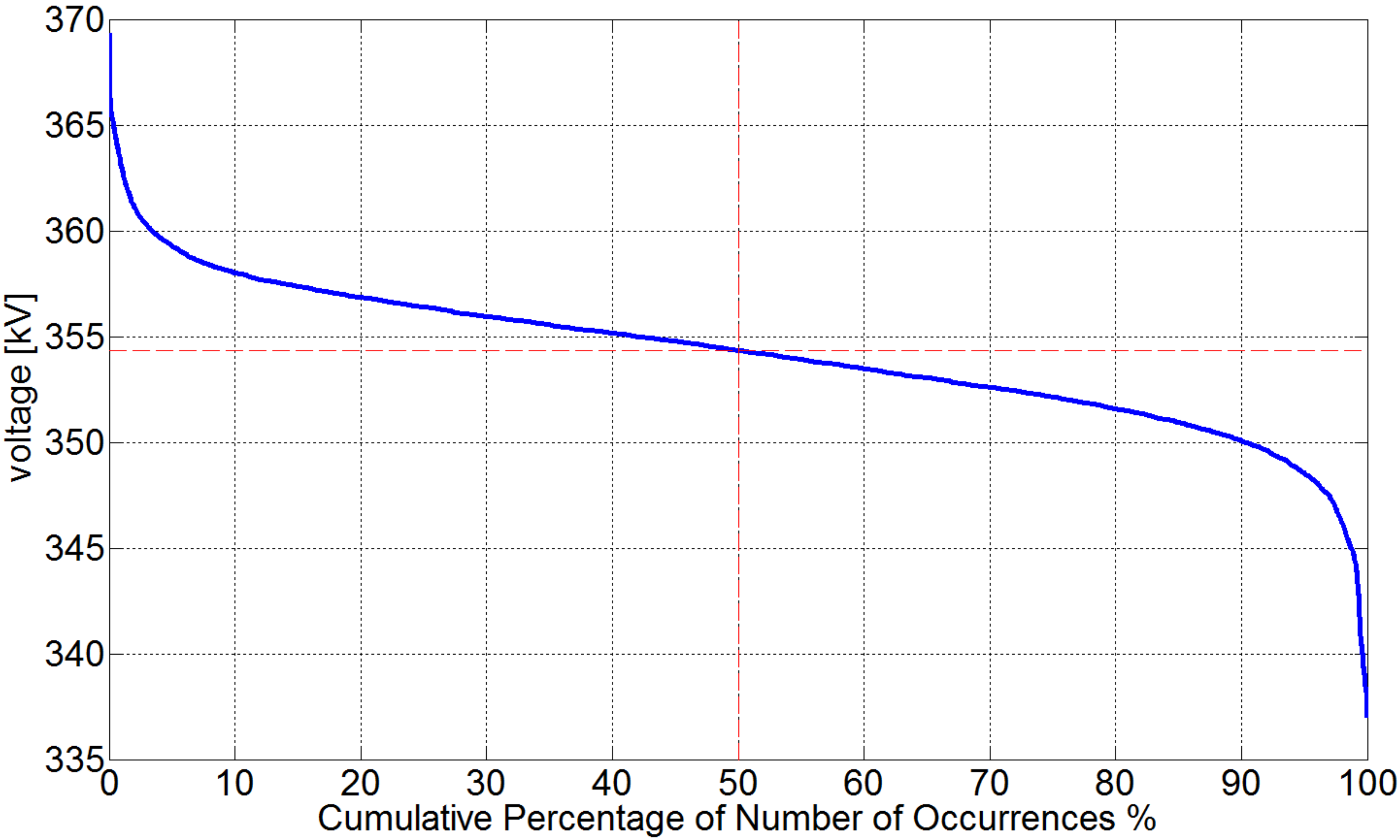
375
370
365
360
355
350
345
340
335
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

Coast 3



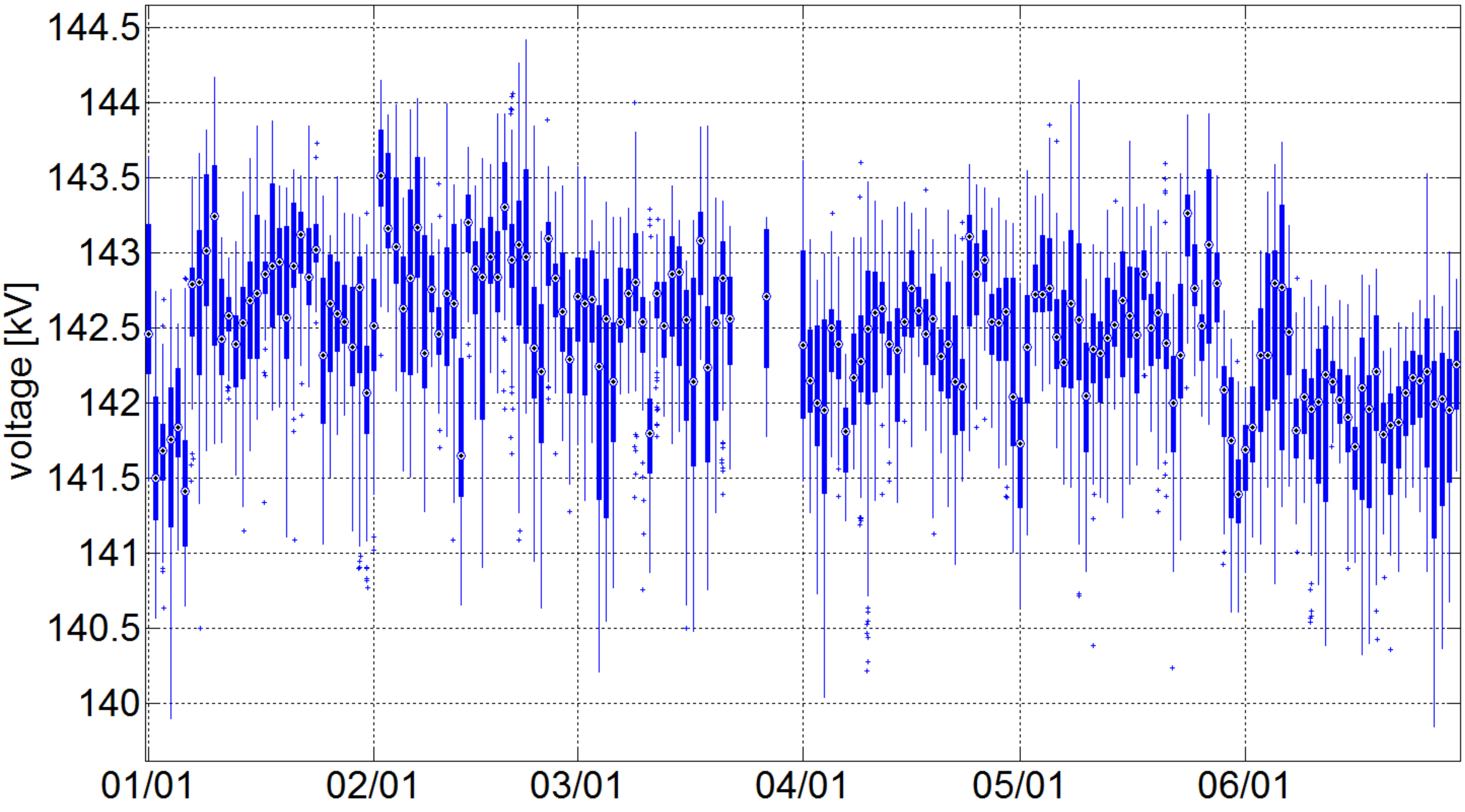
voltage [kV]
370
365
360
355
350
345
340
01/01
02/01
03/01
04/01
05/01
06/01

Coast 3



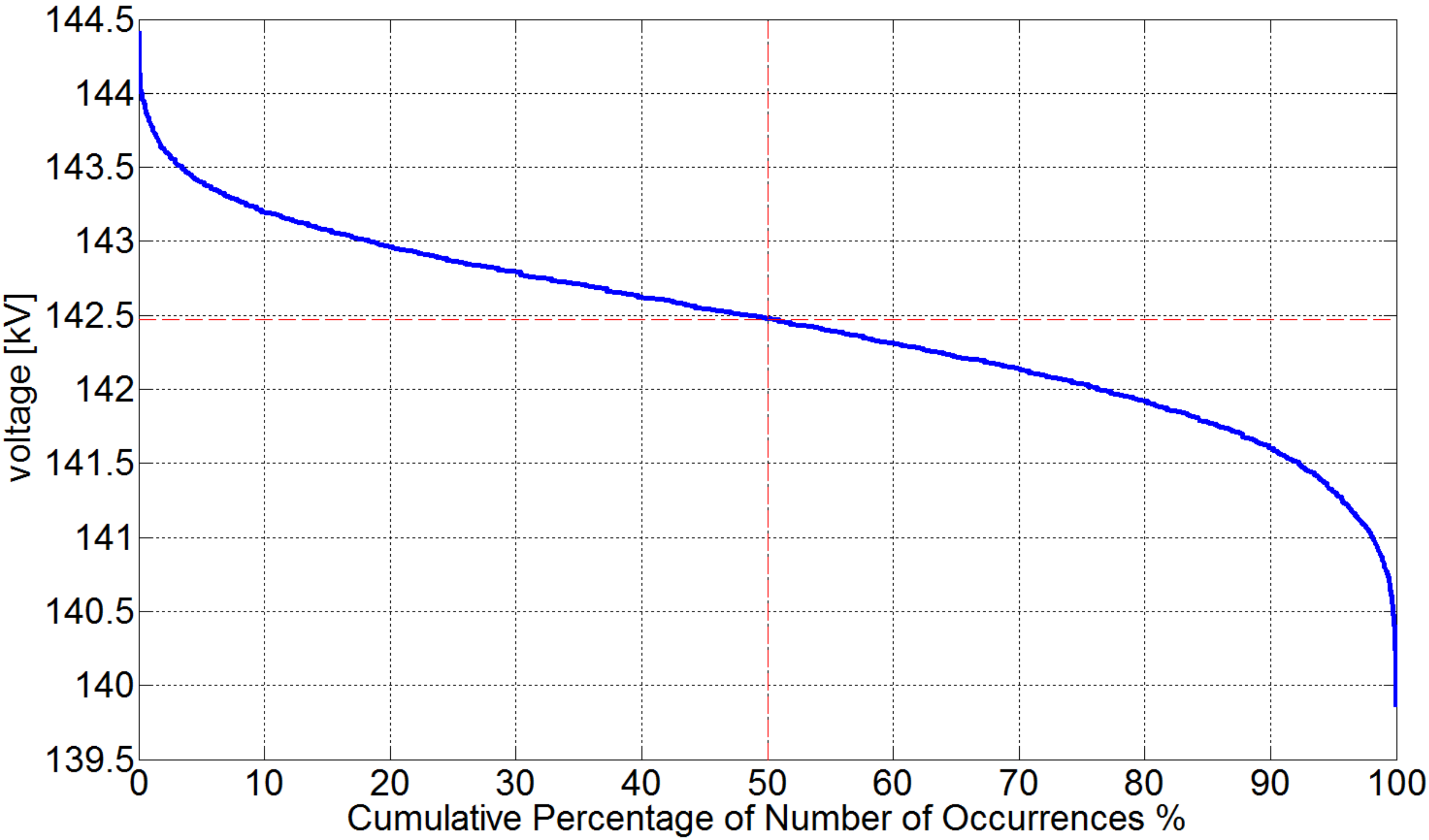
370
365
360
355
350
345
340
335
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 6*



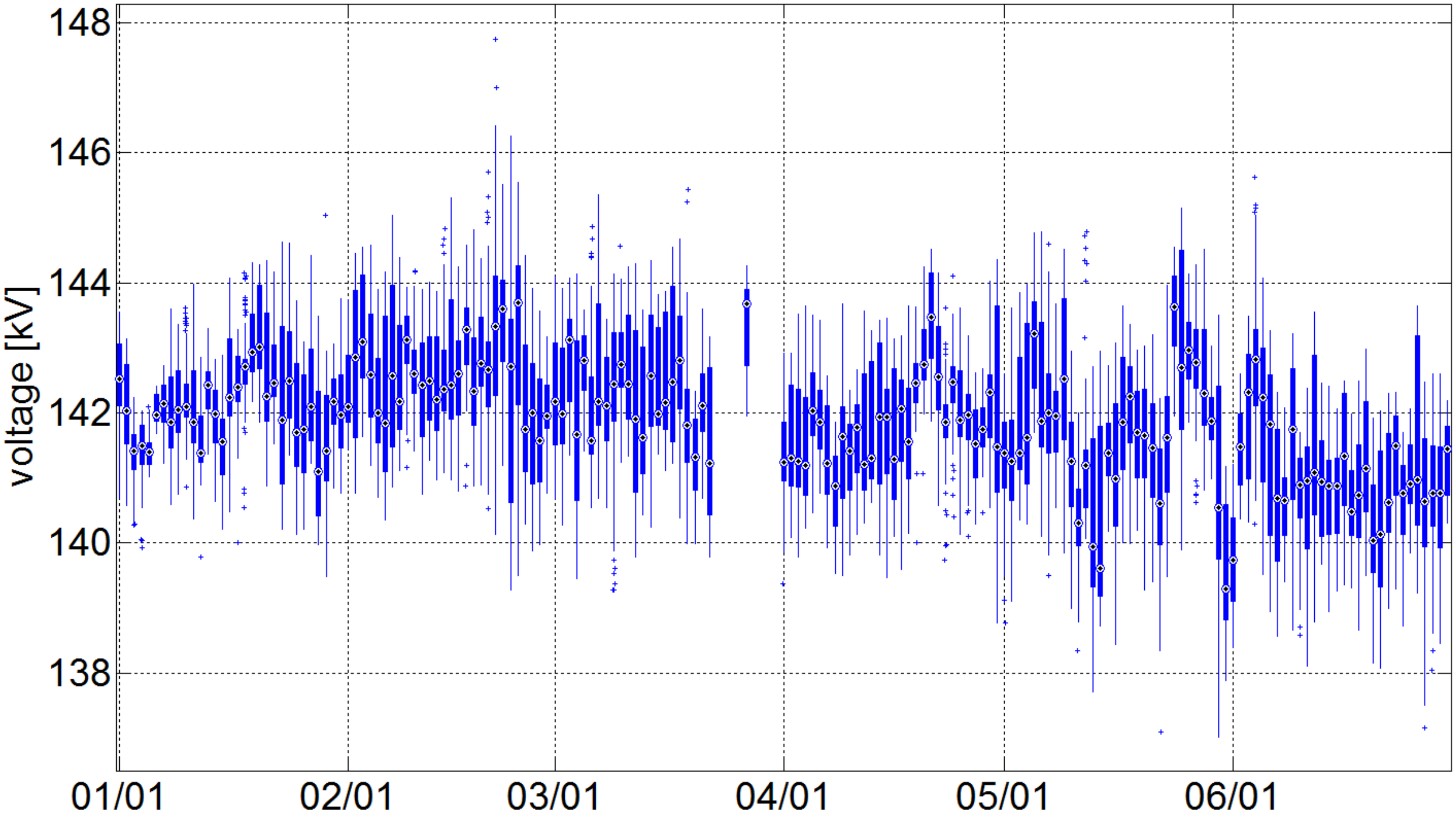
voltage [kV]
144.5
144
143.5
143
142.5
142
141.5
141
140.5
140
01/01
02/01
03/01
04/01
05/01
06/01

South 6*



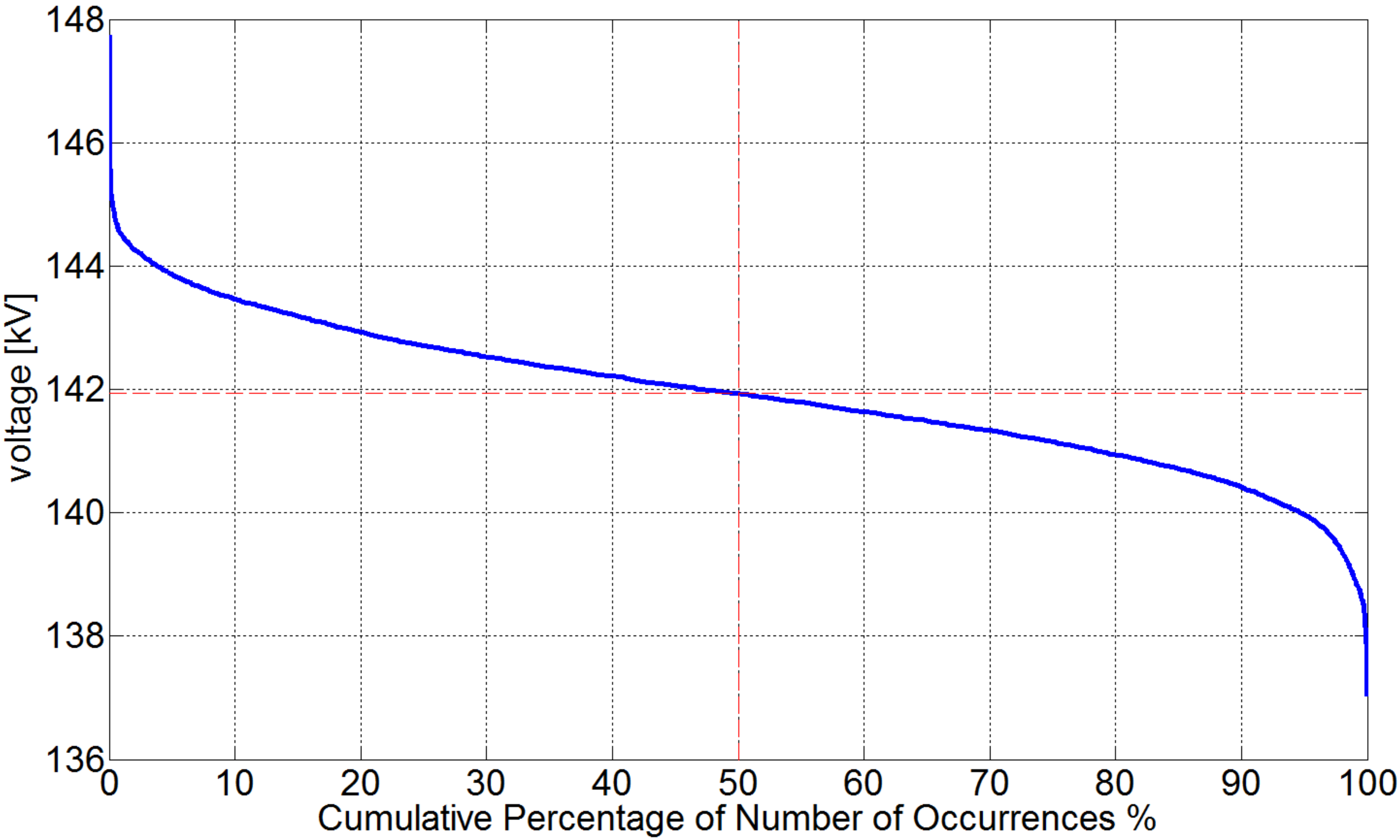
144.5
144
143.5
143
142.5
142
141.5
141
140.5
140
139.5
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 13



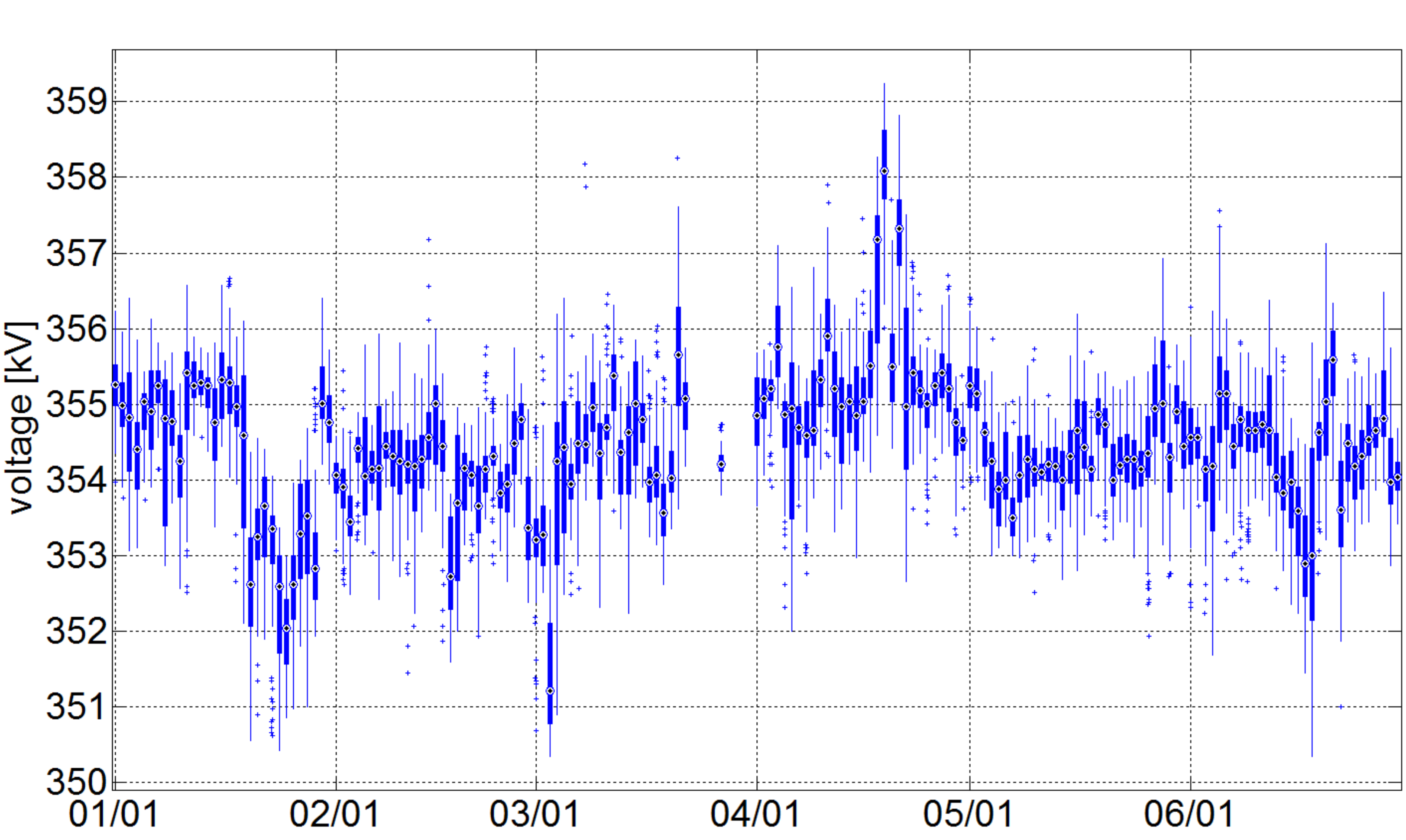
148
146
144
142
140
138
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01

South 13



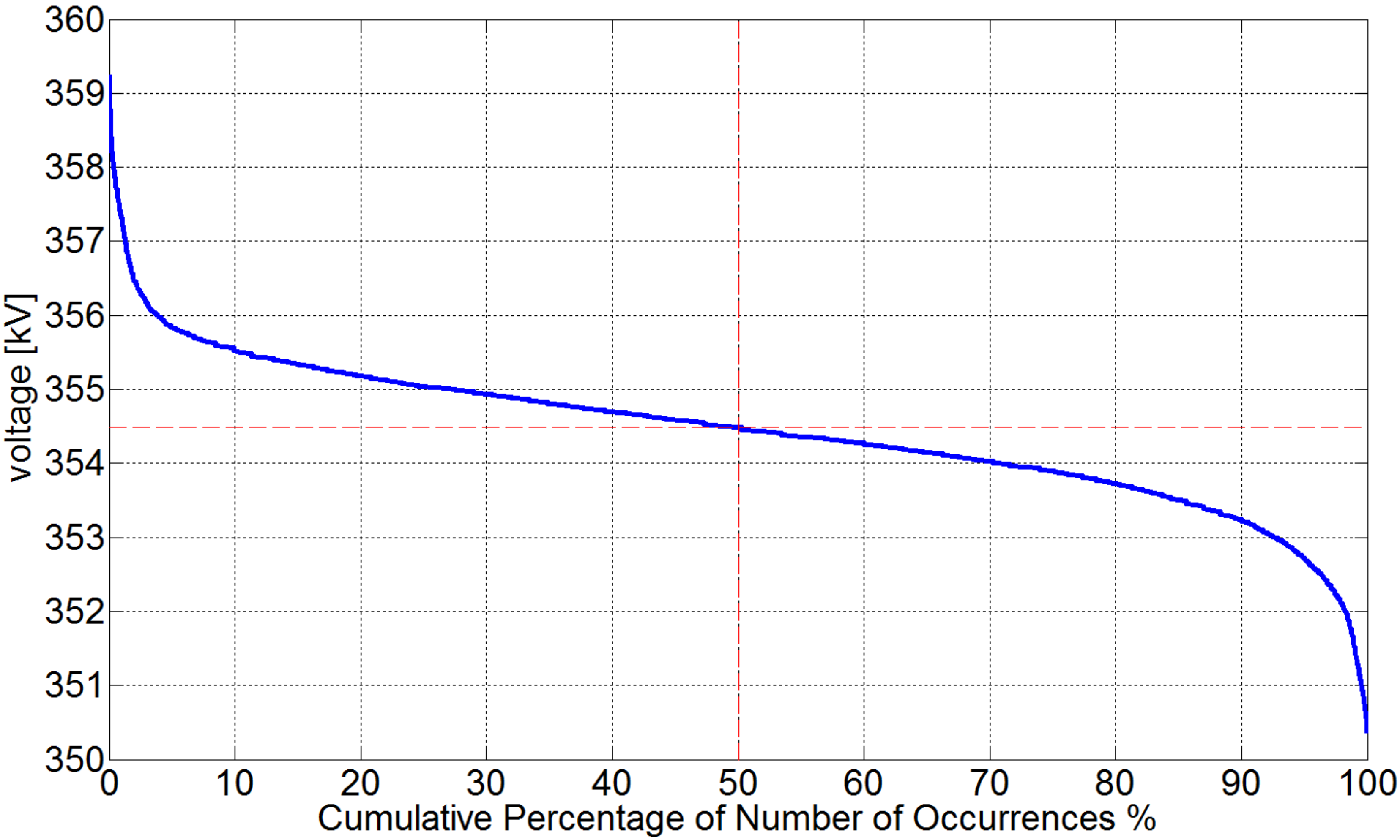
148
146
144
142
140
138
136
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

FarWest 4



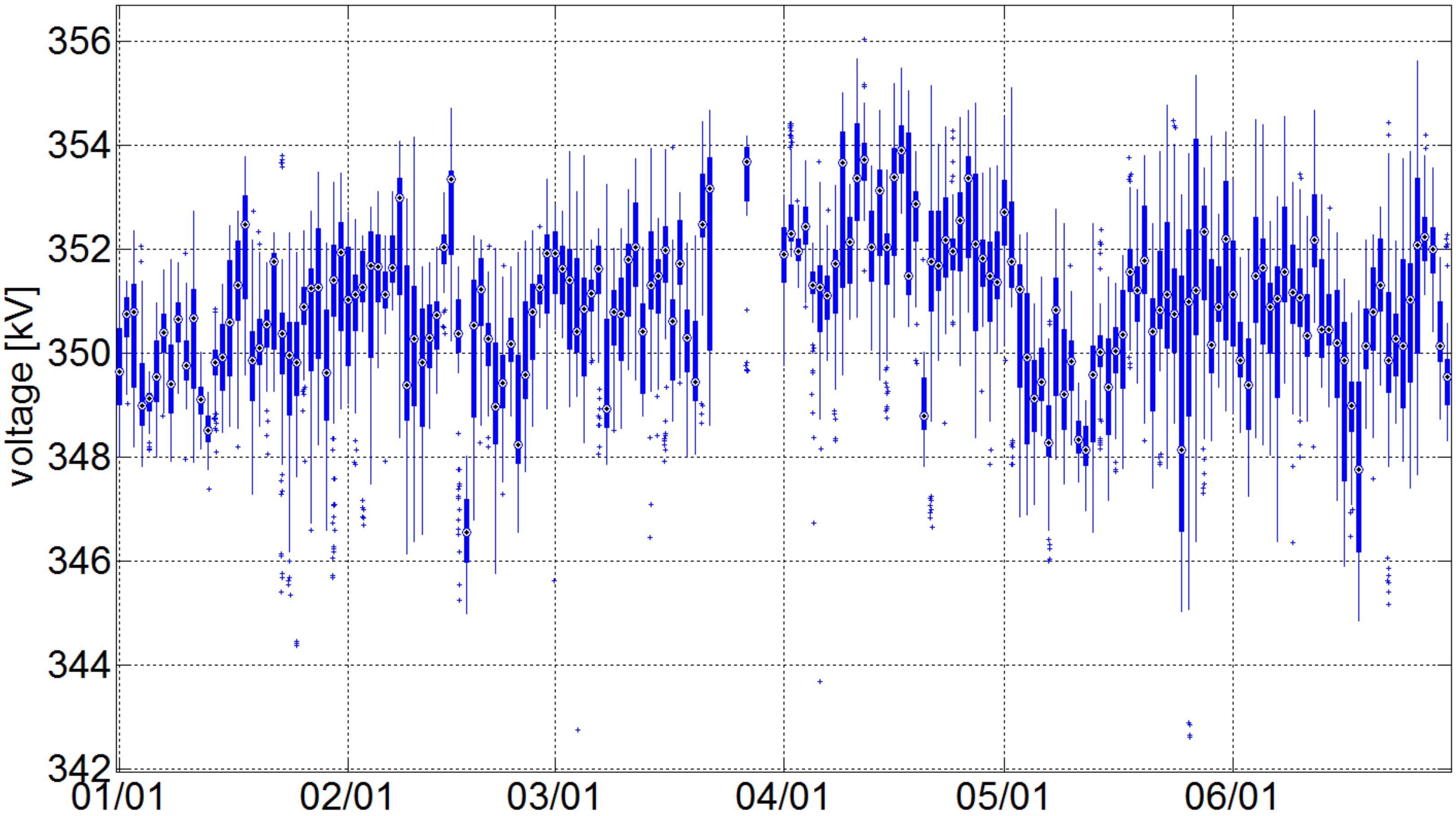
voltage [kV]
359
358
357
356
355
354
353
352
351
350
01/01
02/01
03/01
04/01
05/01
06/01

FarWest 4



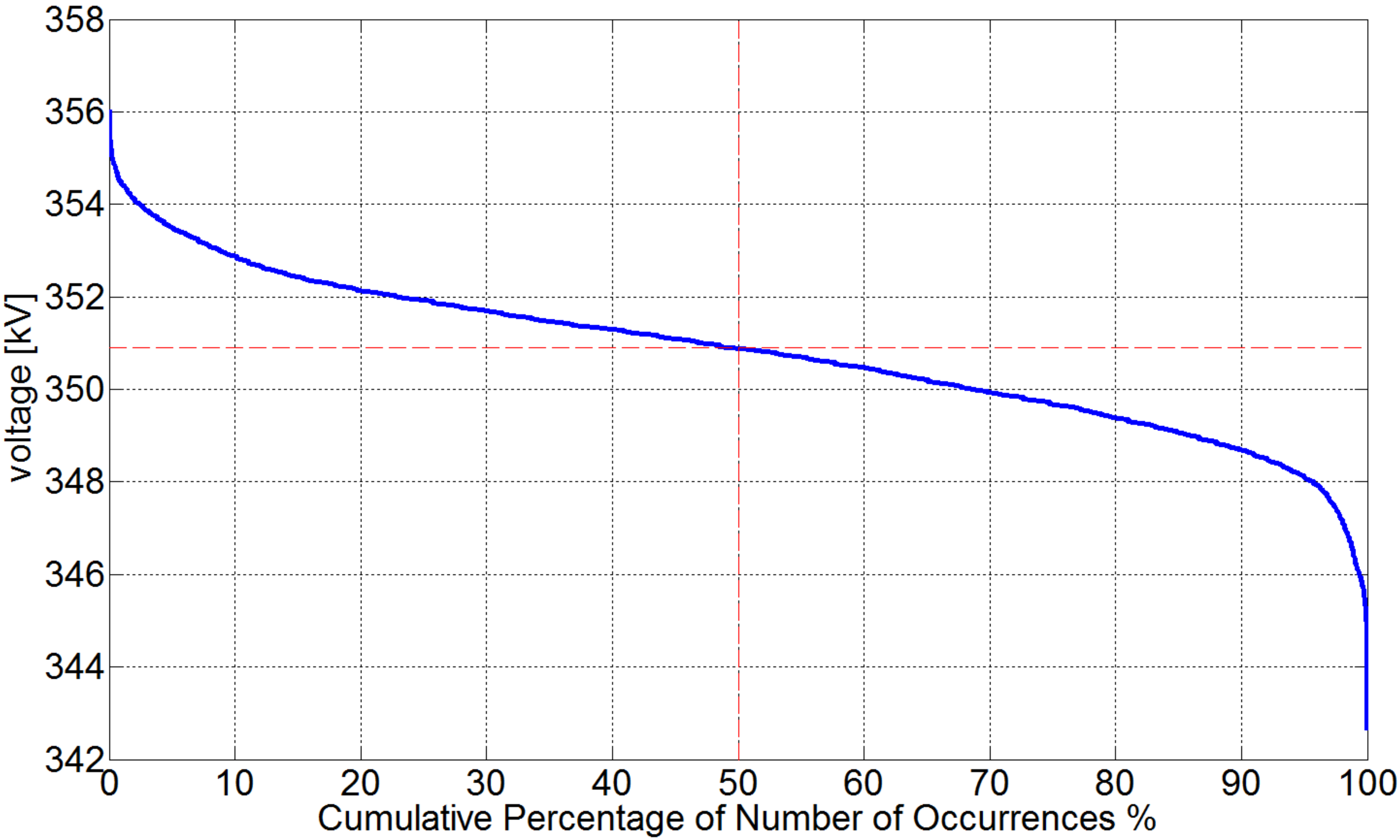
360
359
358
357
356
355
354
353
352
351
350
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

FarWest 7



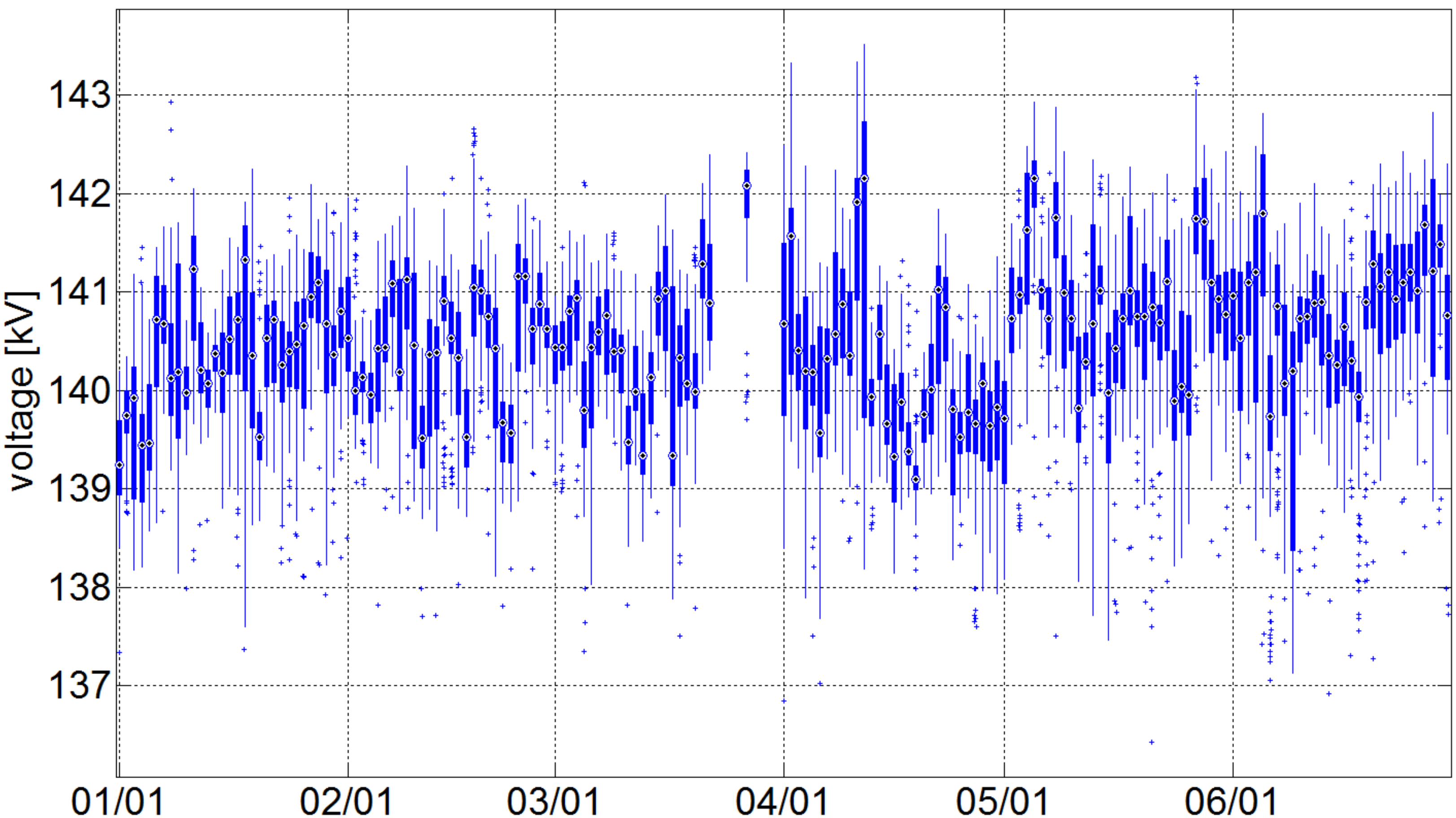
voltage [kV]
356
354
352
350
348
346
344
342
01/01
02/01
03/01
04/01
05/01
06/01

FarWest 7



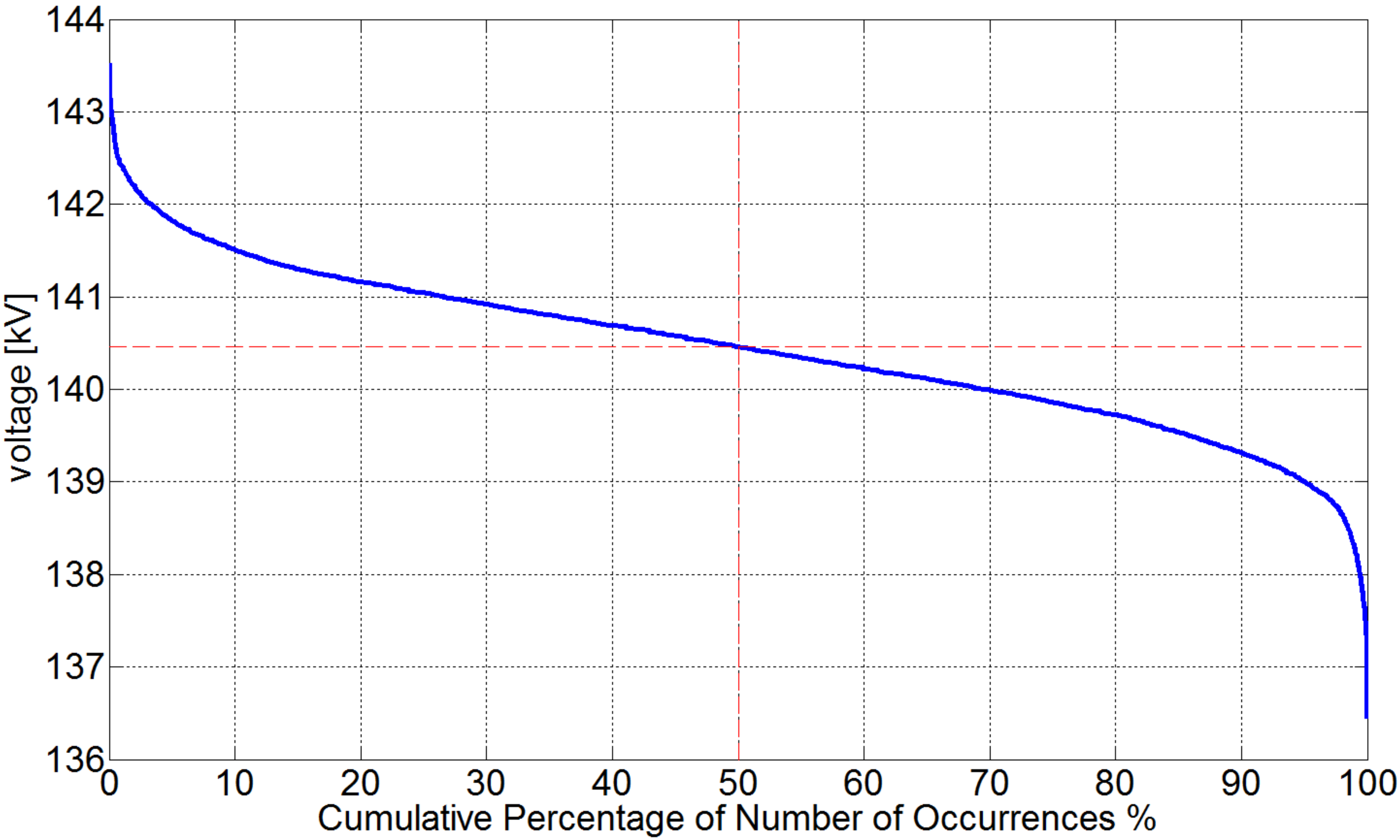
358
356
354
352
350
348
346
344
342
0
10
20
30
40
50
60
70
80
90
100
voltage [kV]
Cumulative Percentage of Number of Occurrences %

FarWest 8



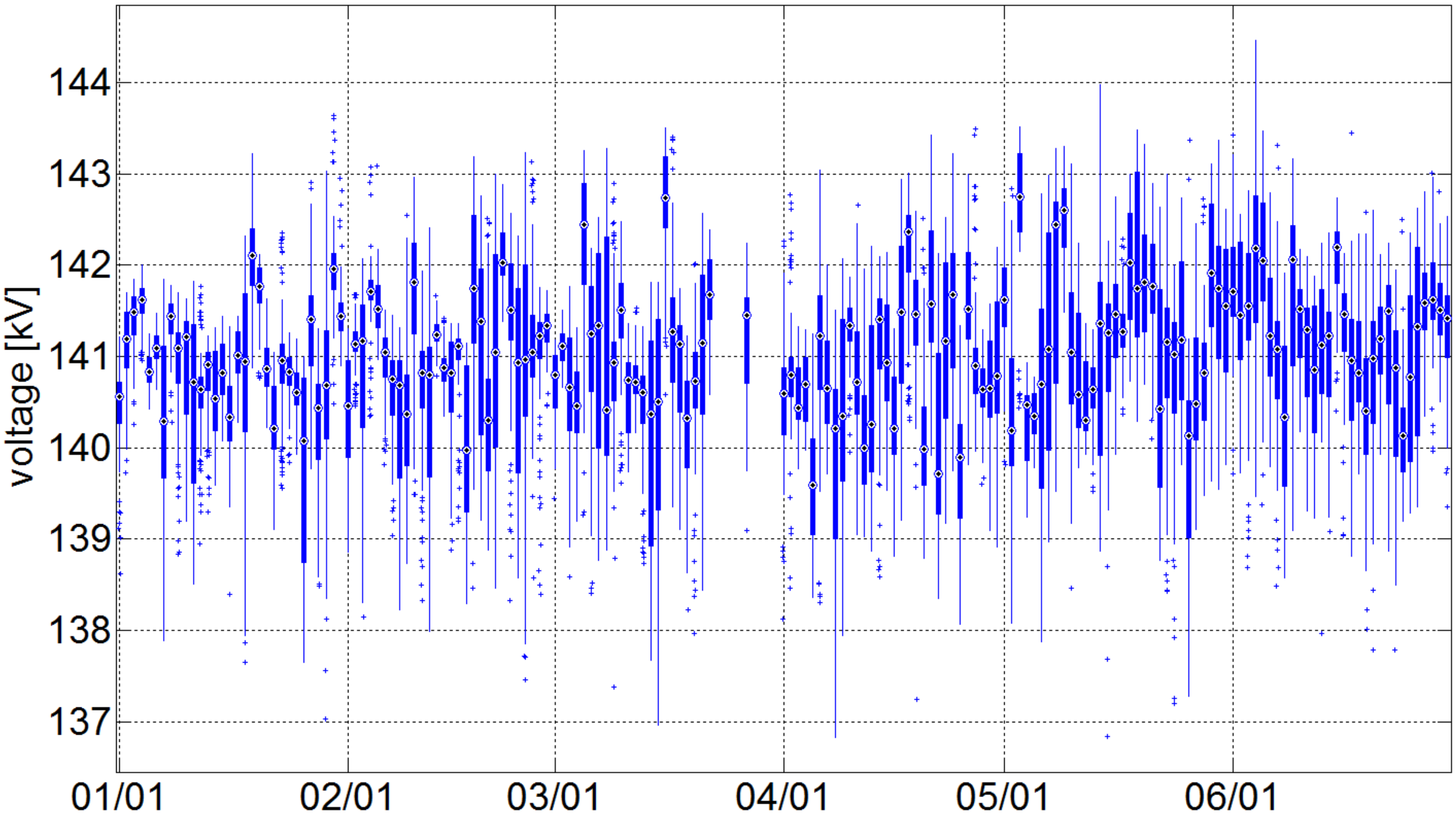
143
142
141
140
139
138
137
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01

FarWest 8



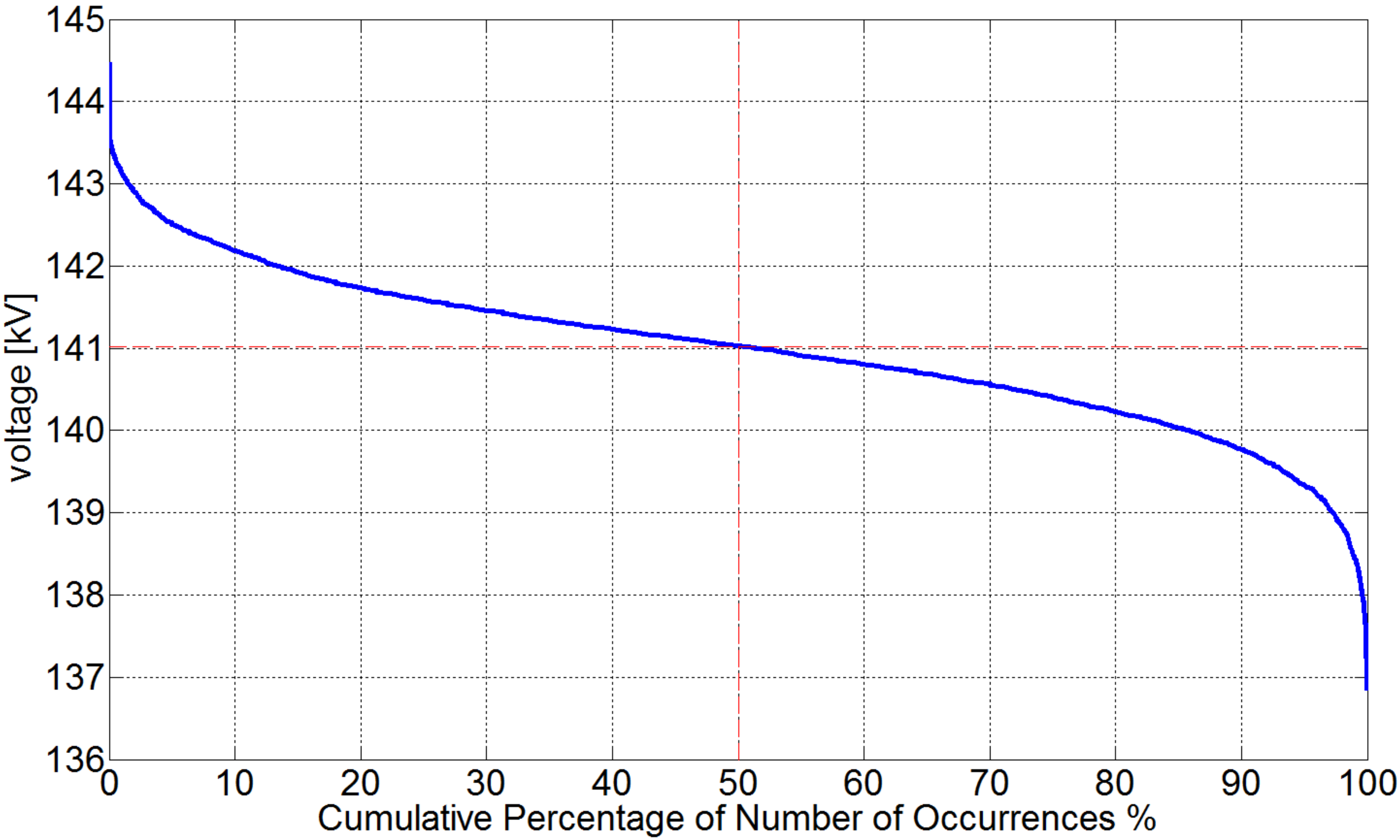
144
143
142
141
140
139
138
137
136
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

FarWest 9



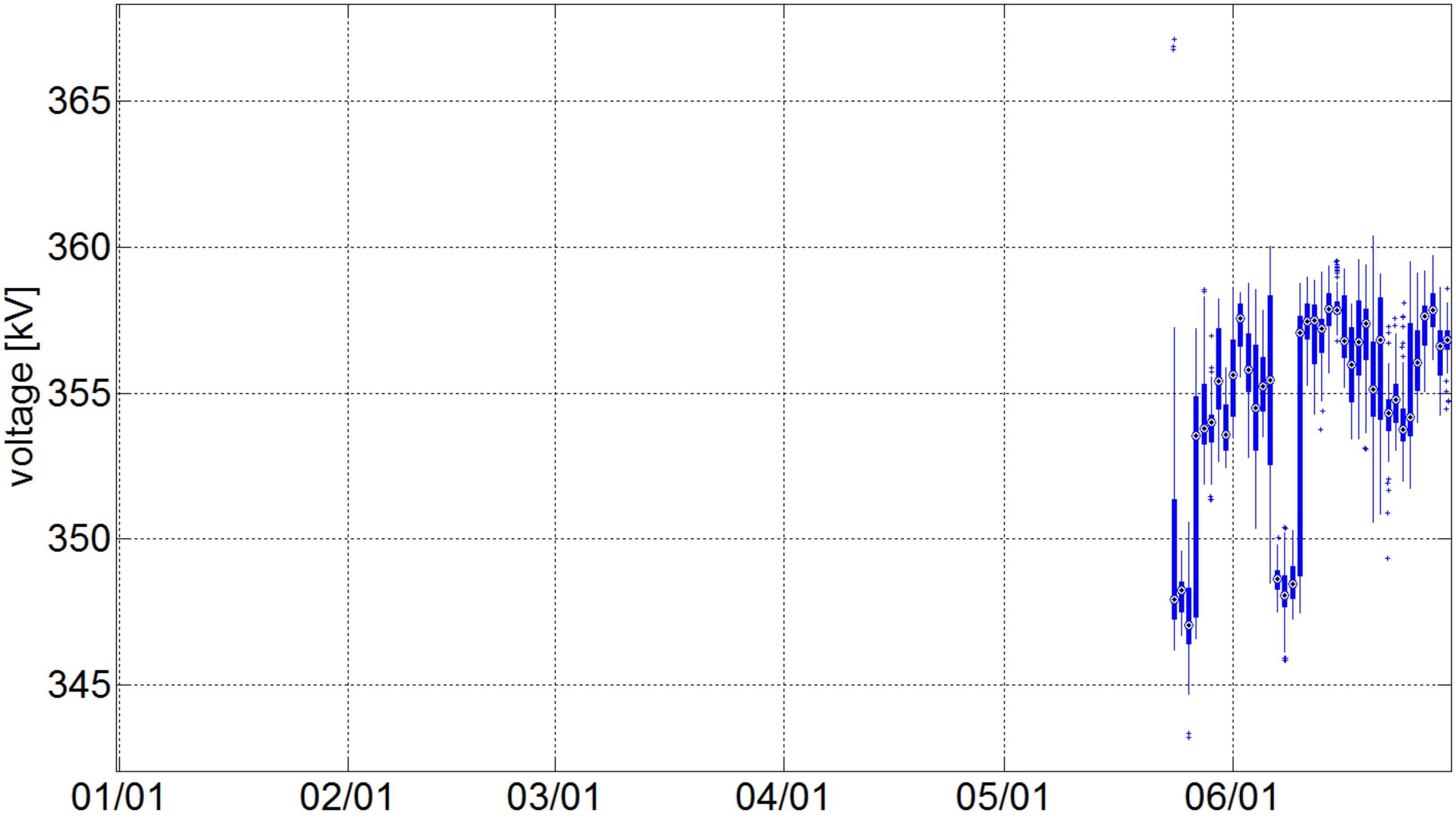
voltage [kV]
144
143
142
141
140
139
138
137
01/01
02/01
03/01
04/01
05/01
06/01

FarWest 9

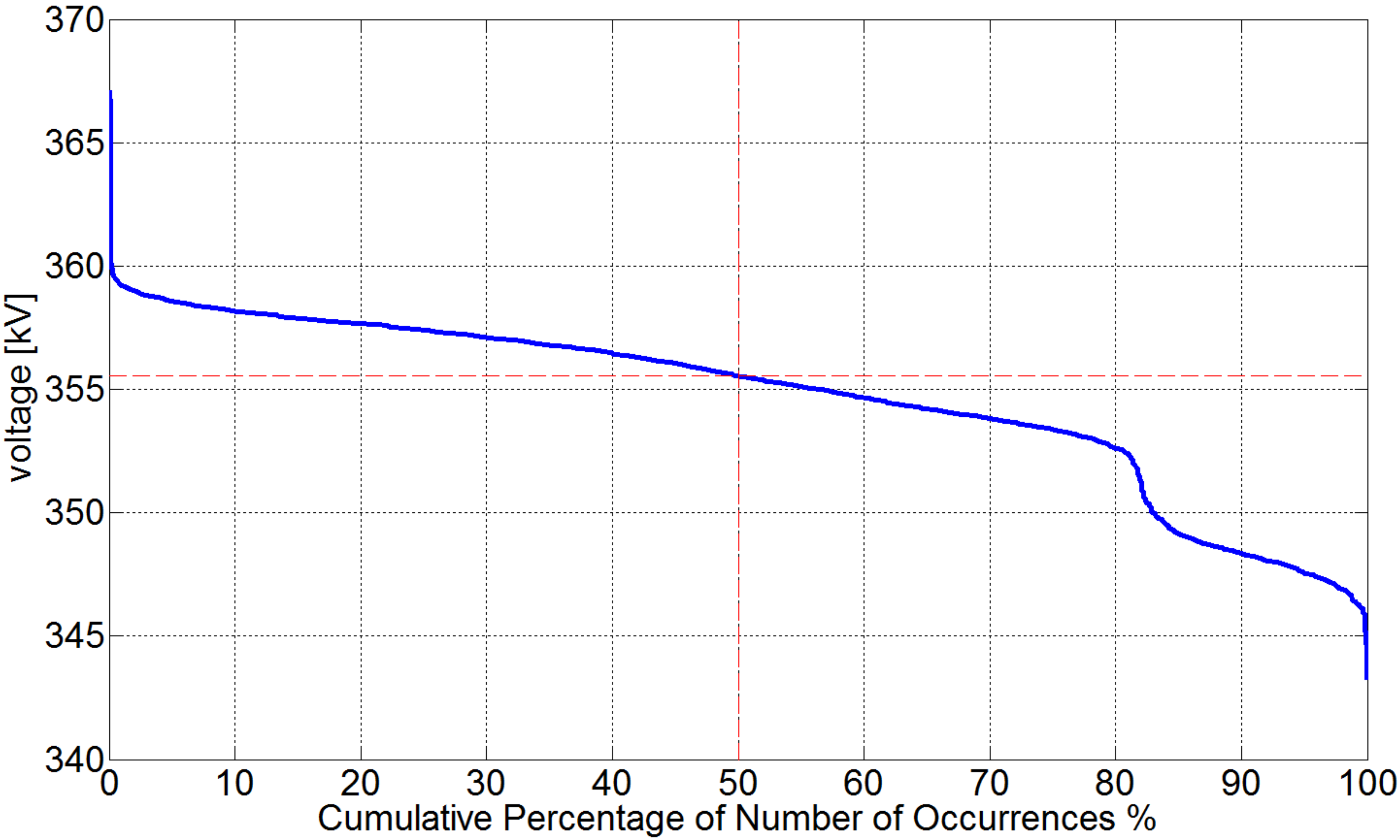


145
144
143
142
141
140
139
138
137
136
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

West 8*

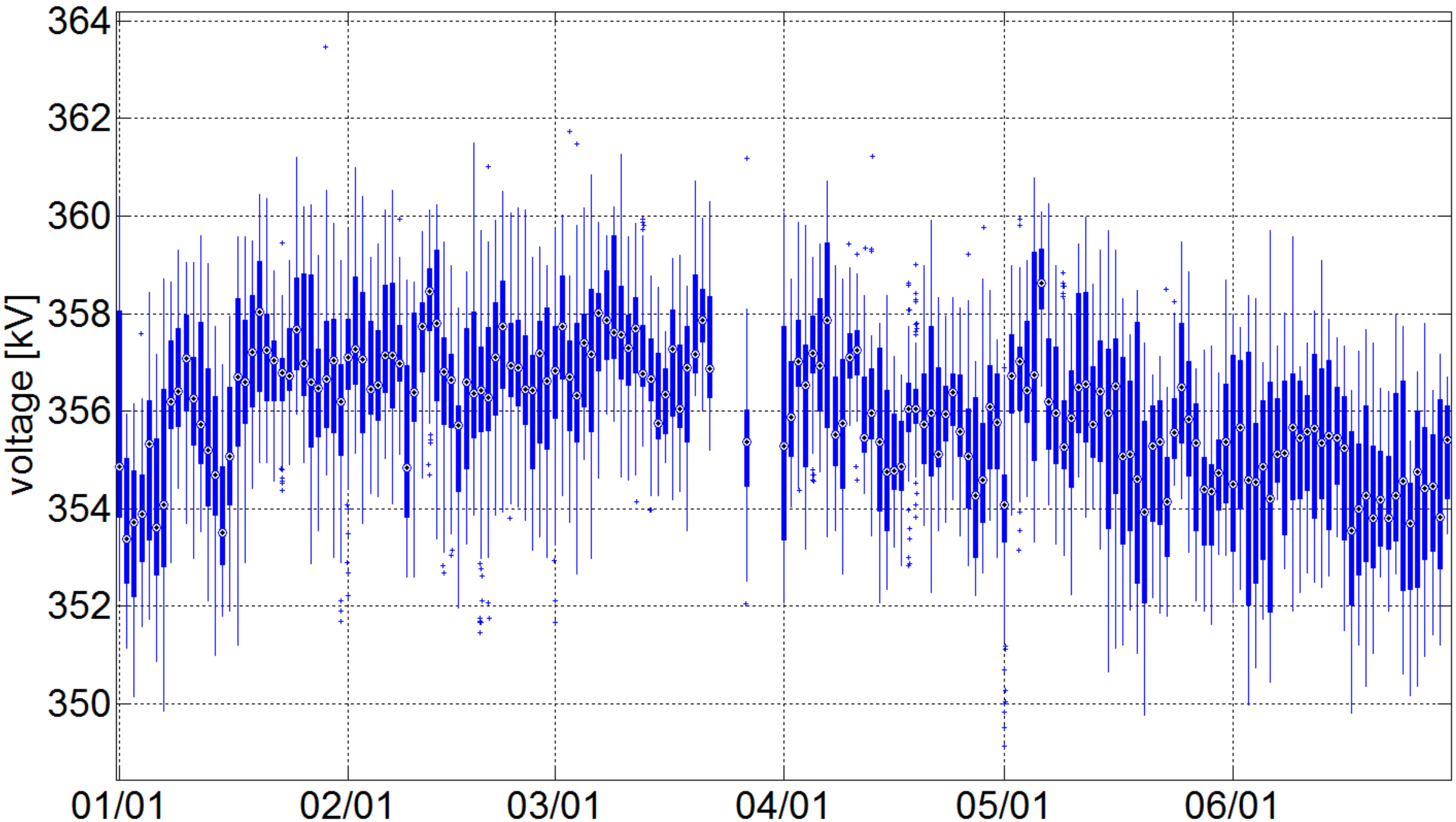


West 8*



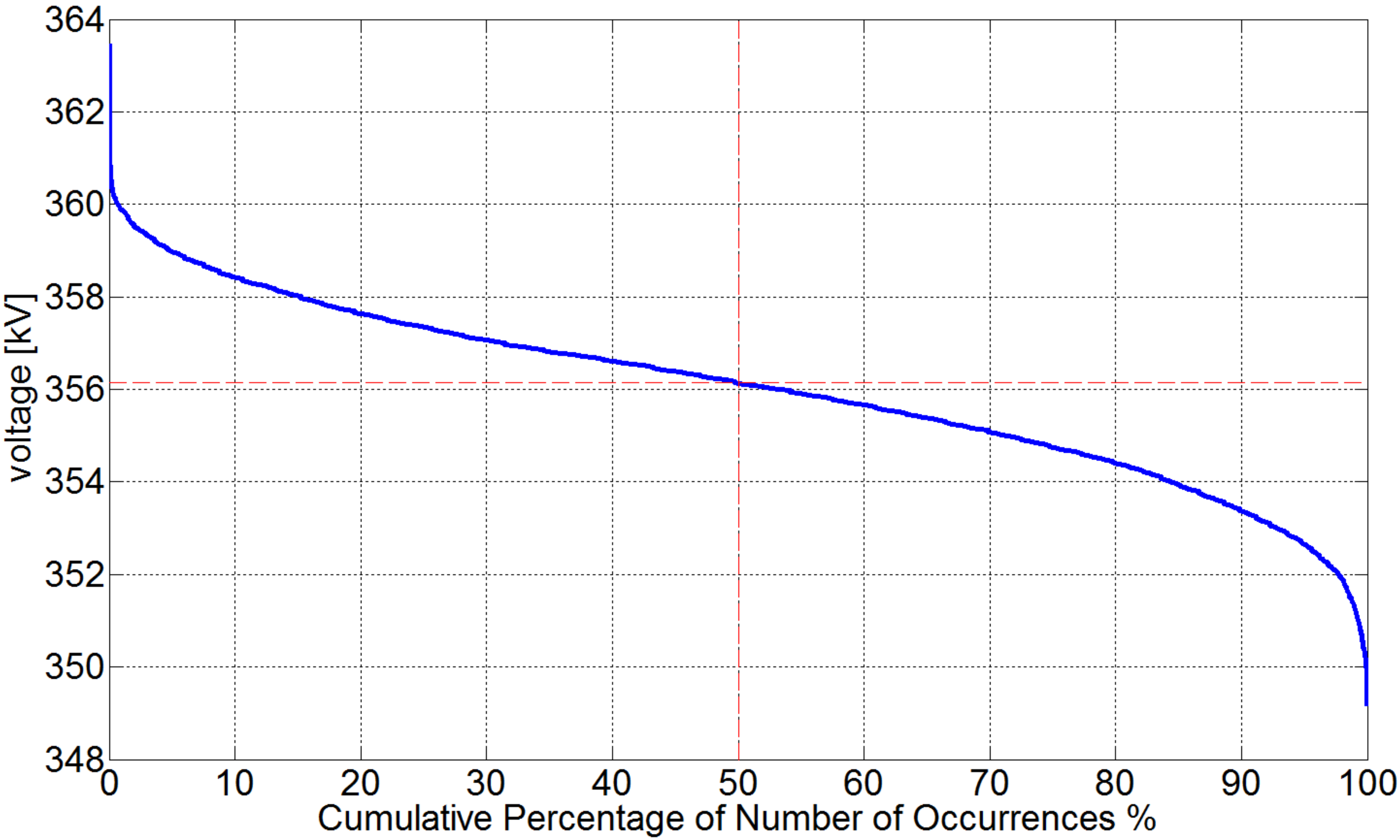
370
365
360
355
350
345
340
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 15*



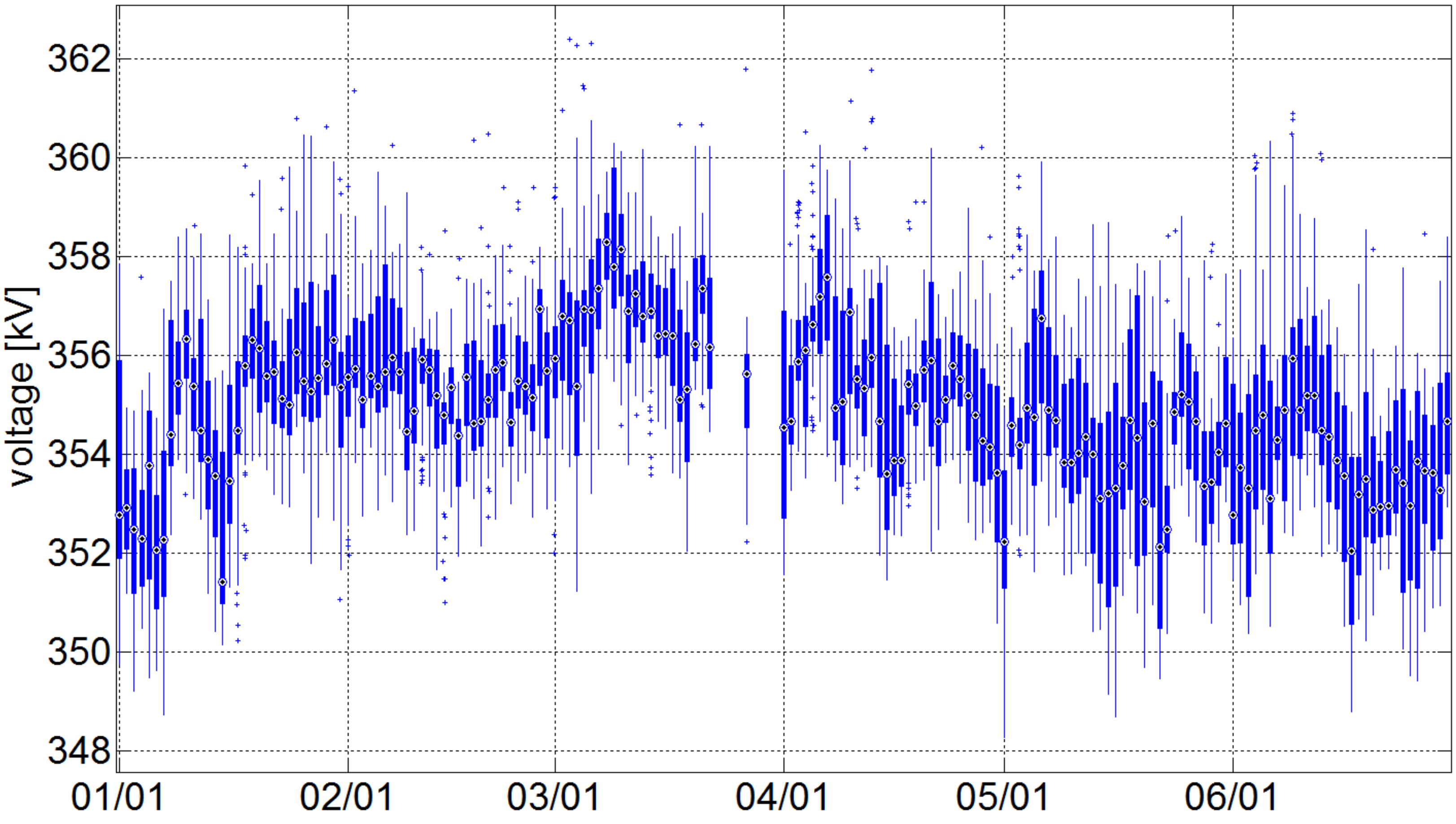
364
362
360
358
356
354
352
350
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01

South 15*



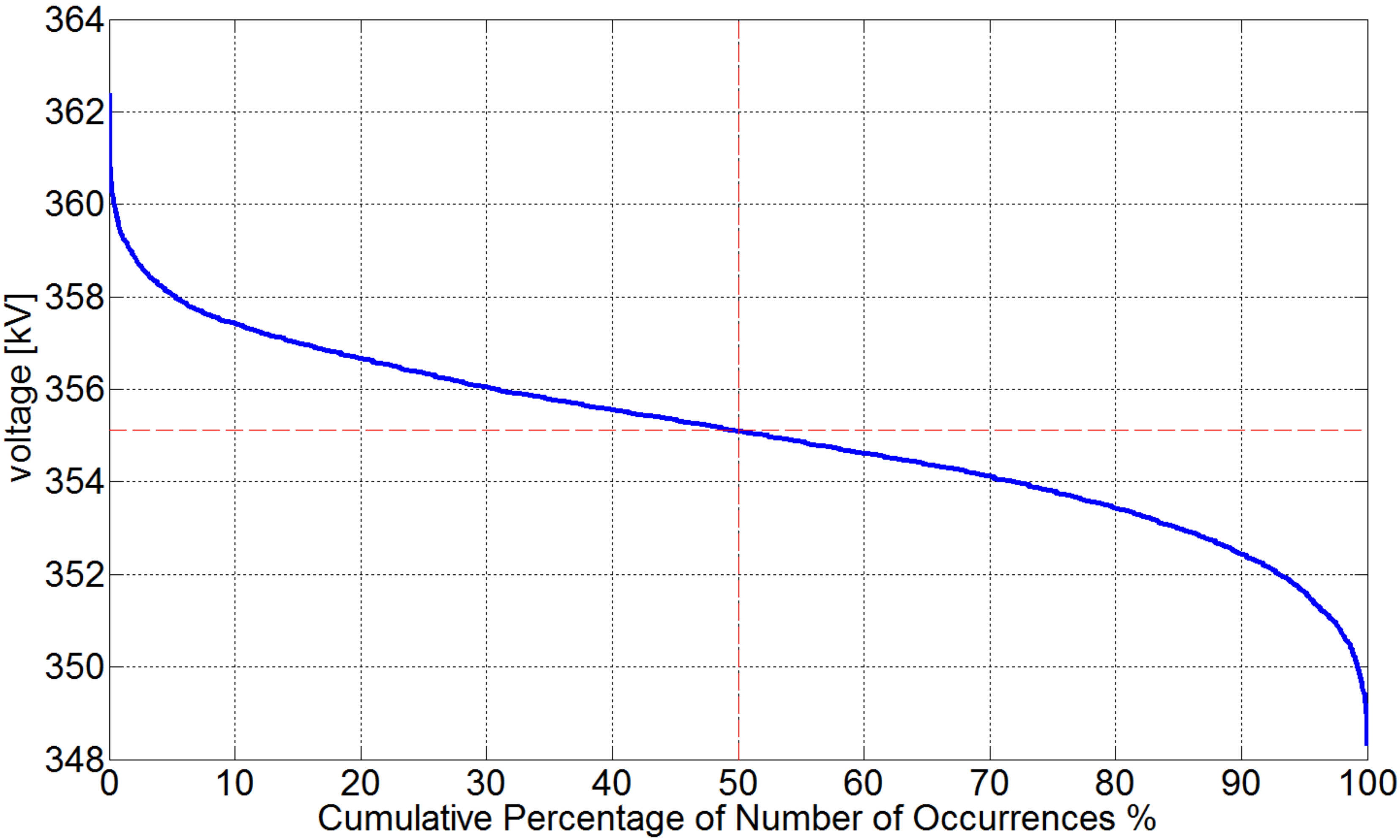
364
362
360
358
356
354
352
350
348
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 2*



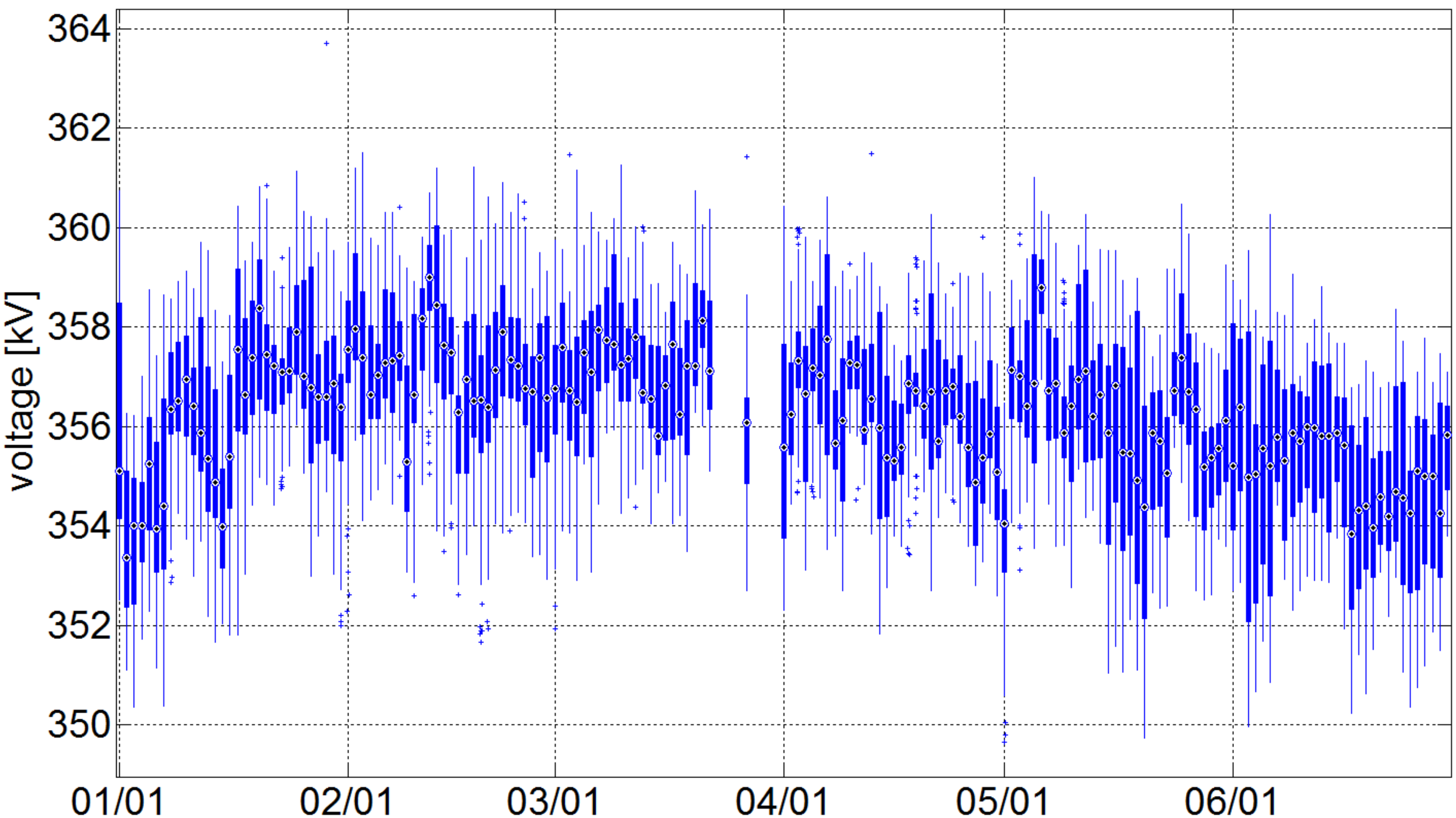
voltage [kV]
362
360
358
356
354
352
350
348
01/01
02/01
03/01
04/01
05/01
06/01

South 2*



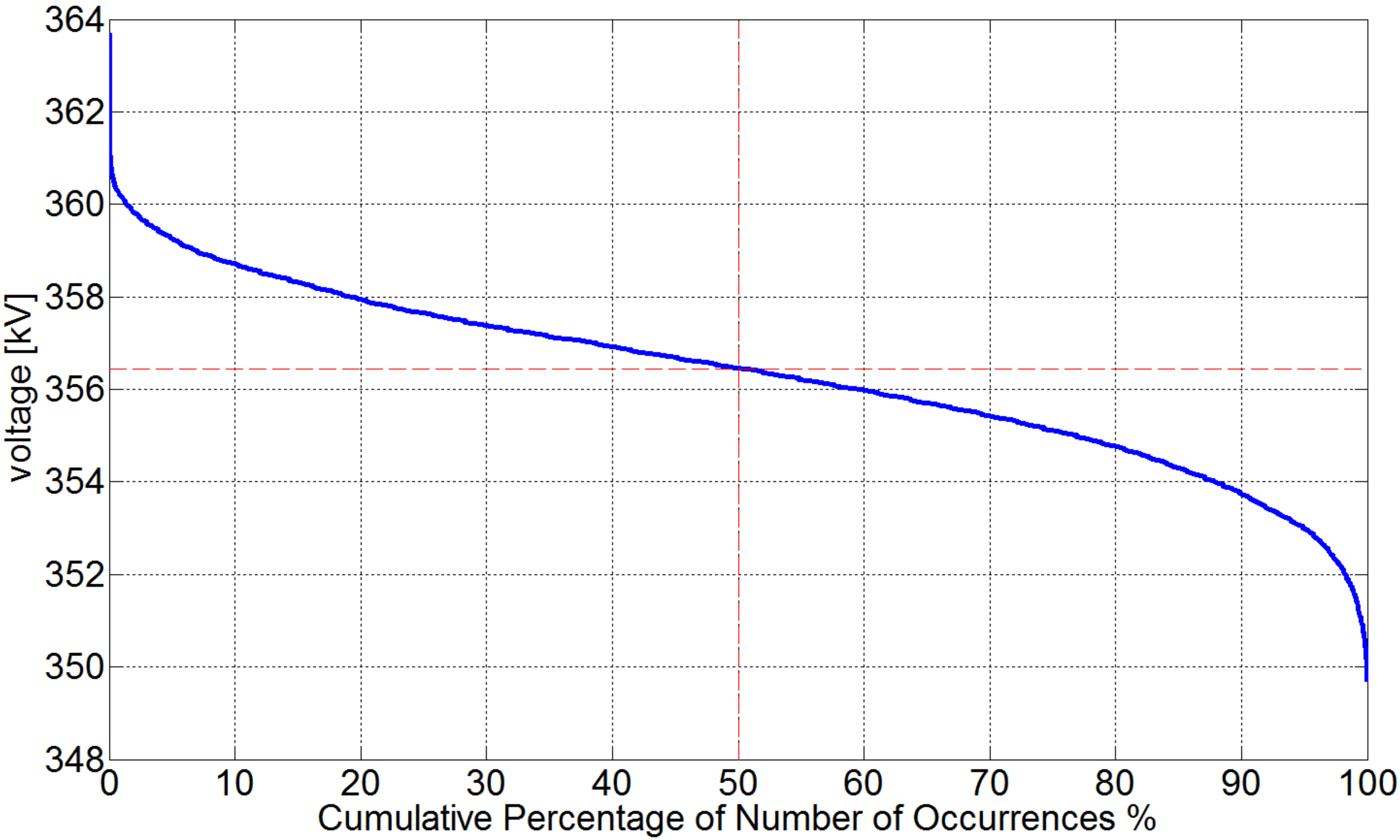
364
362
360
358
356
354
352
350
348
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 4*



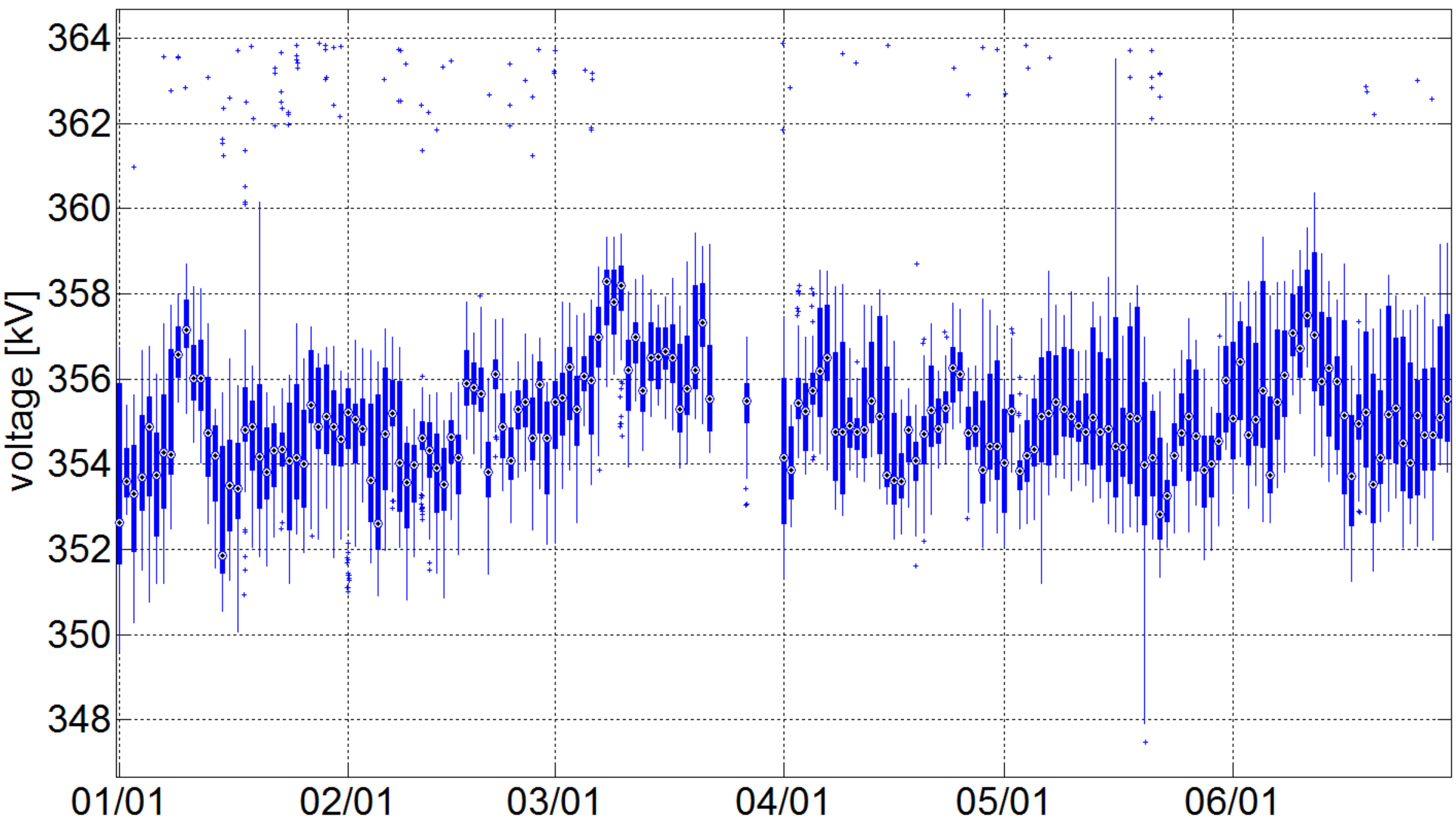
voltage [kV]
364
362
360
358
356
354
352
350
01/01
02/01
03/01
04/01
05/01
06/01

South 4*



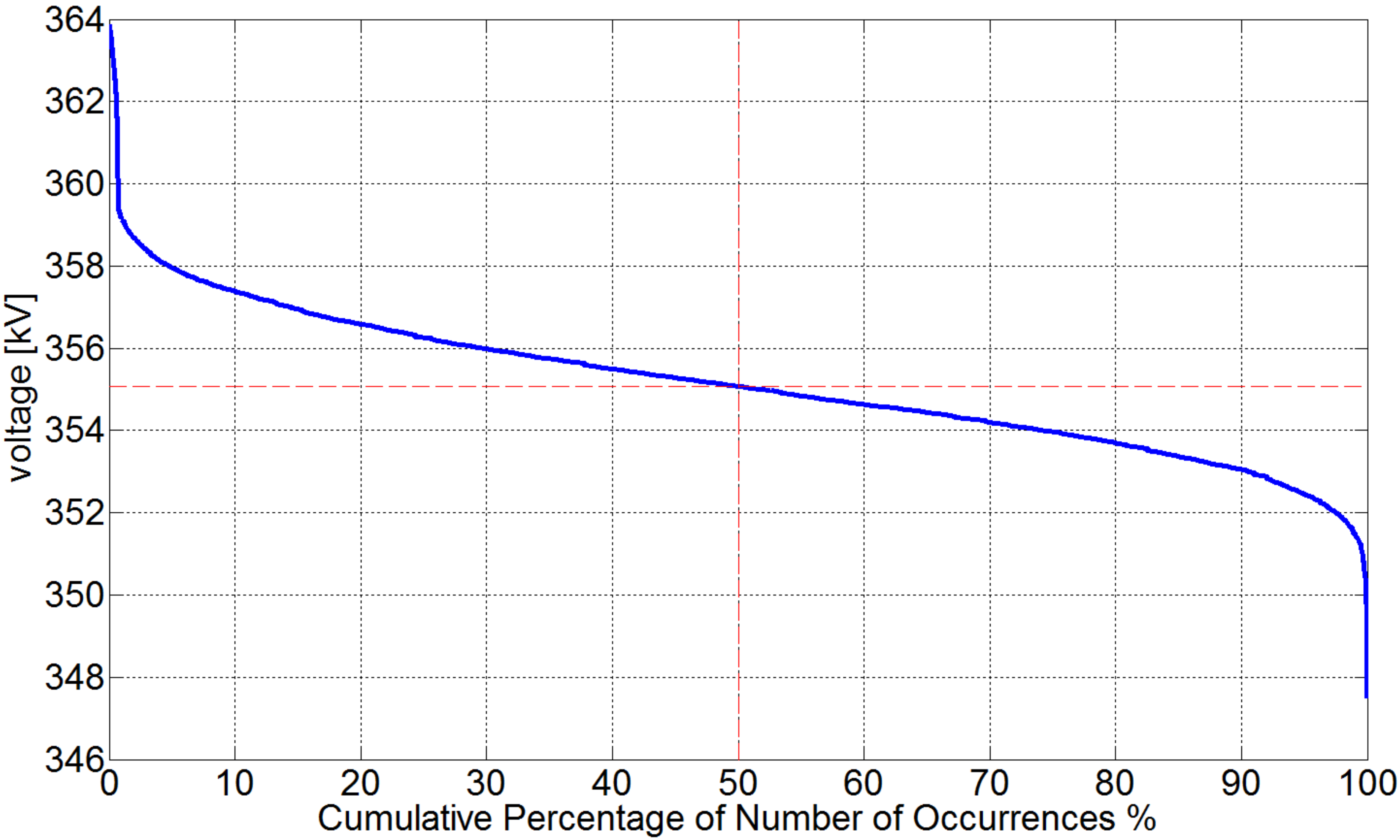
364
362
360
358
356
354
352
350
348
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 7*



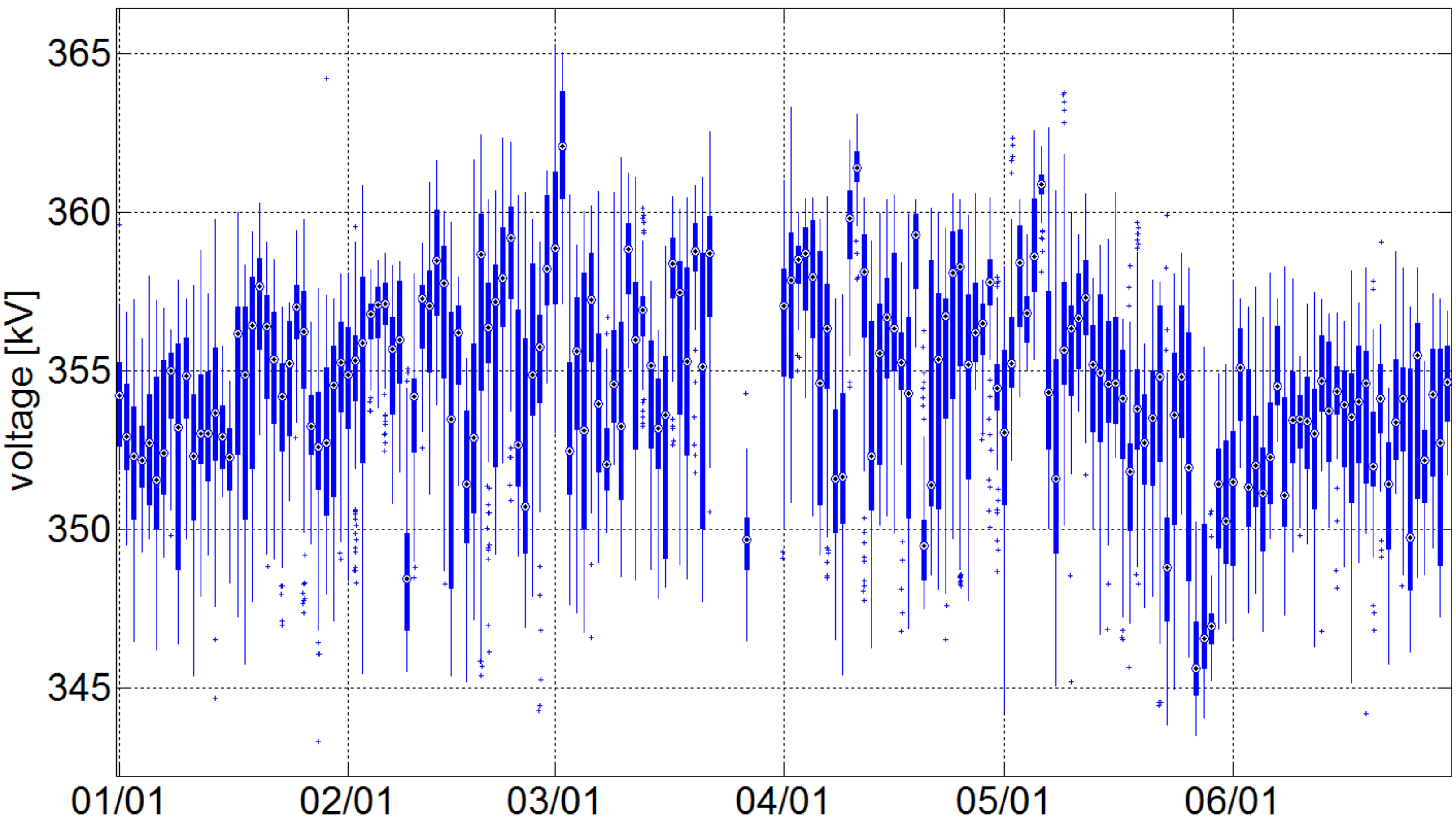
voltage [kV]
364
362
360
358
356
354
352
350
348
01/01
02/01
03/01
04/01
05/01
06/01

South 7*

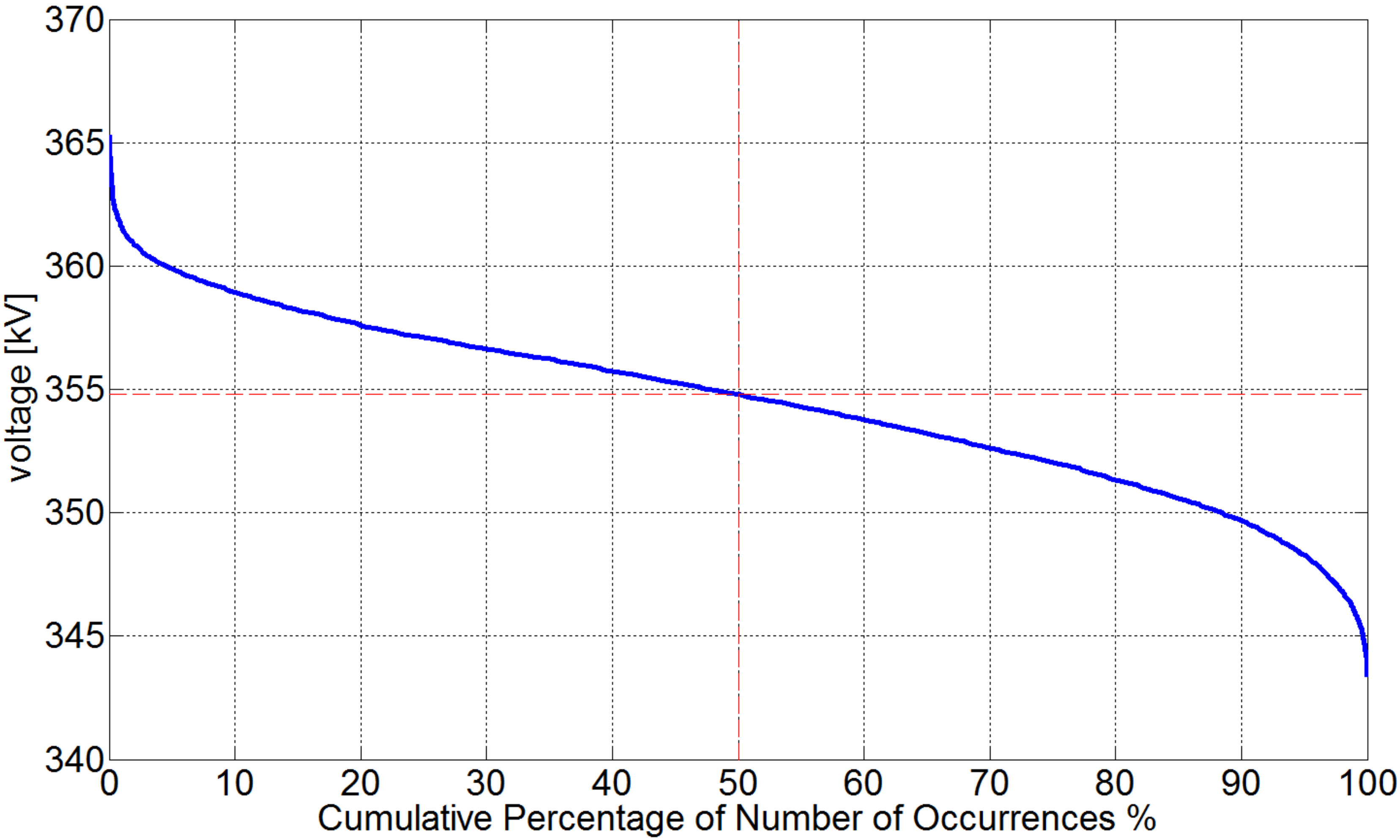


voltage [kV]
364
362
360
358
356
354
352
350
348
346
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 9*

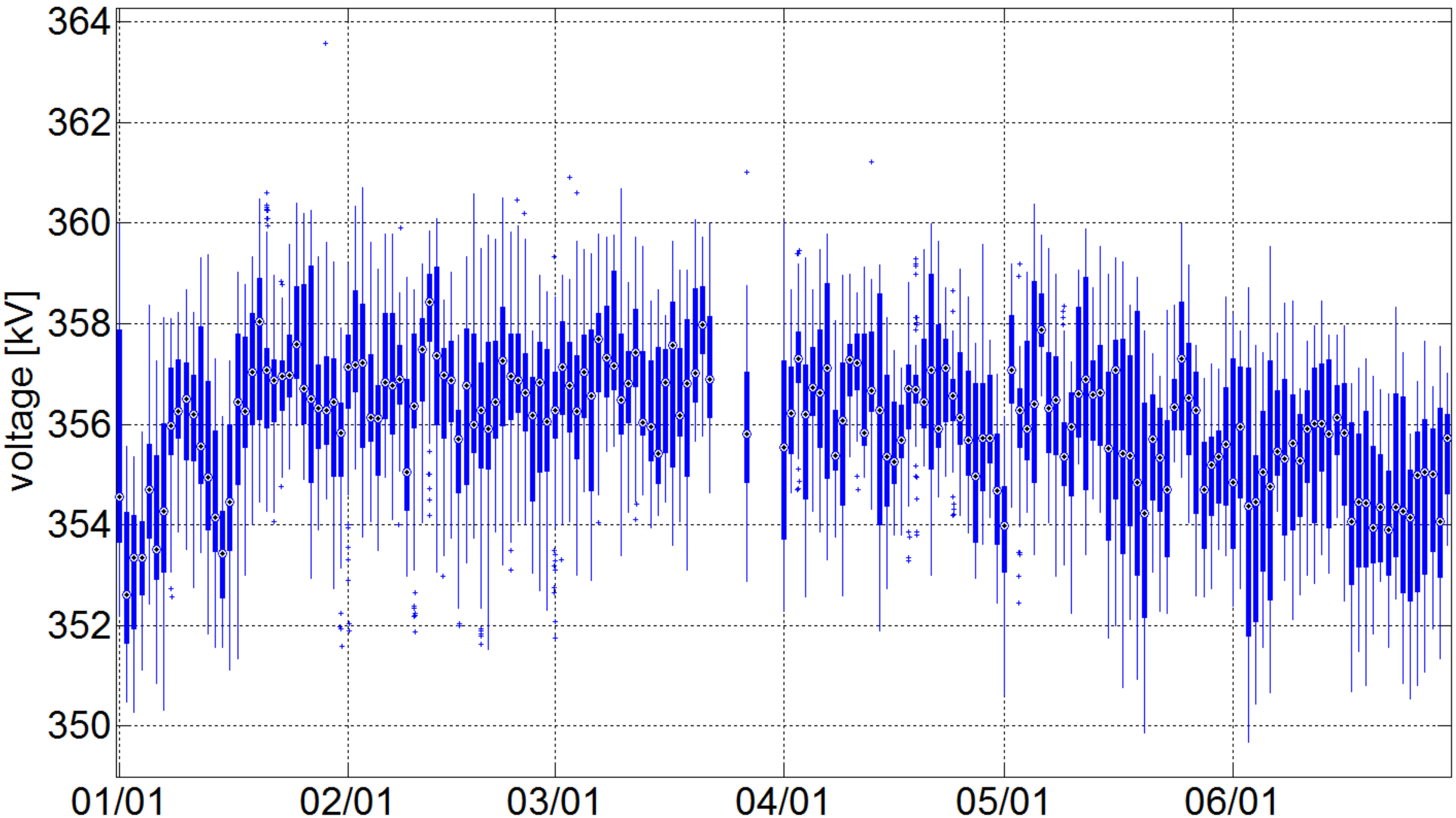


South 9*

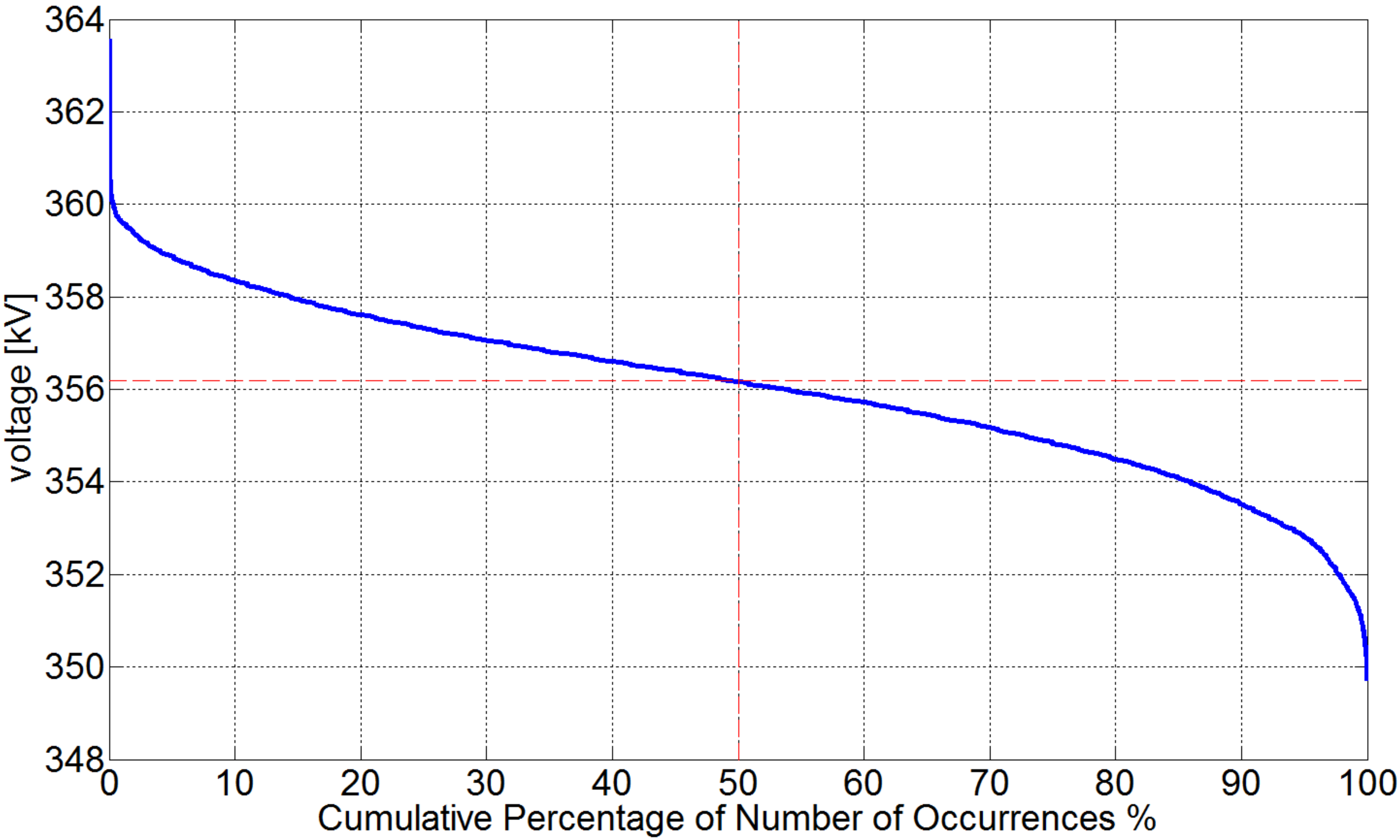


370
365
360
355
350
345
340
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 11*

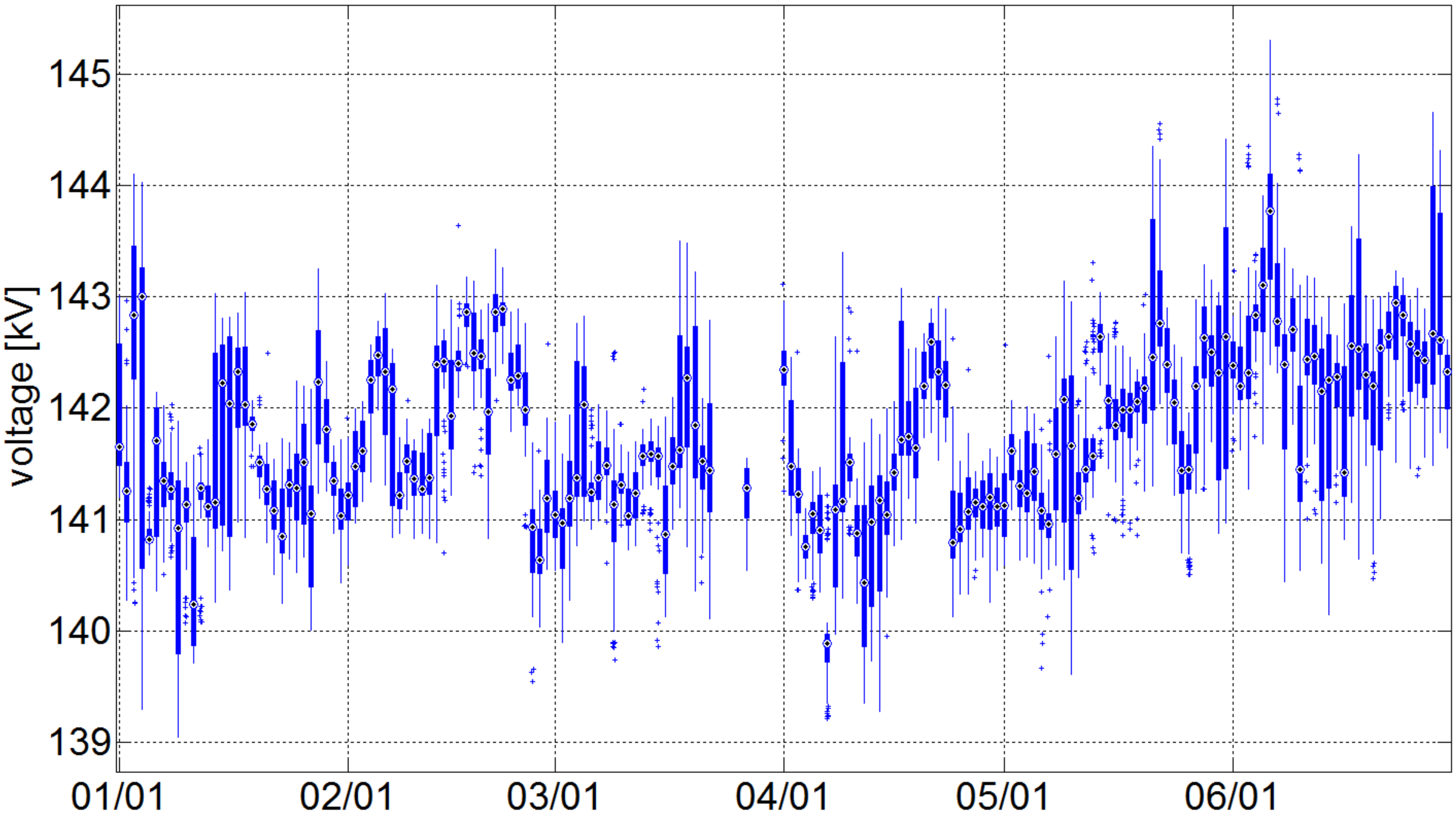

364
362
360
358
356
354
352
350
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01

South 11*



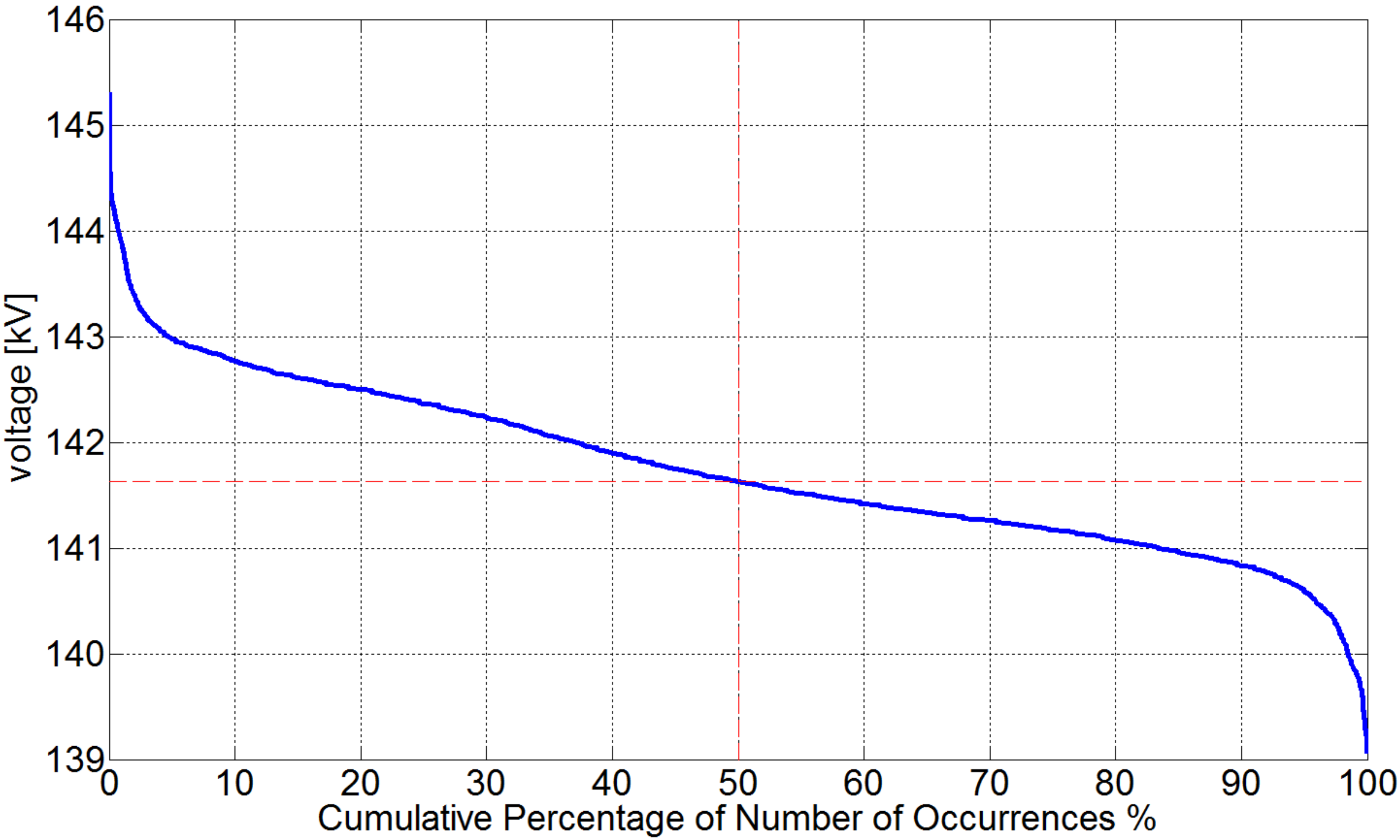
364
362
360
358
356
354
352
350
348
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 10*



voltage [kV]
145
144
143
142
141
140
139
01/01
02/01
03/01
04/01
05/01
06/01

South 10*



146
145
144
143
142
141
140
139
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

Appendix A – Part 2

CCET Discovery Across Texas project

Baseline Analysis Update - Voltage Magnitudes

Phasor Data: January to June 2013

Box-Whisker Plots and Time Duration Curves

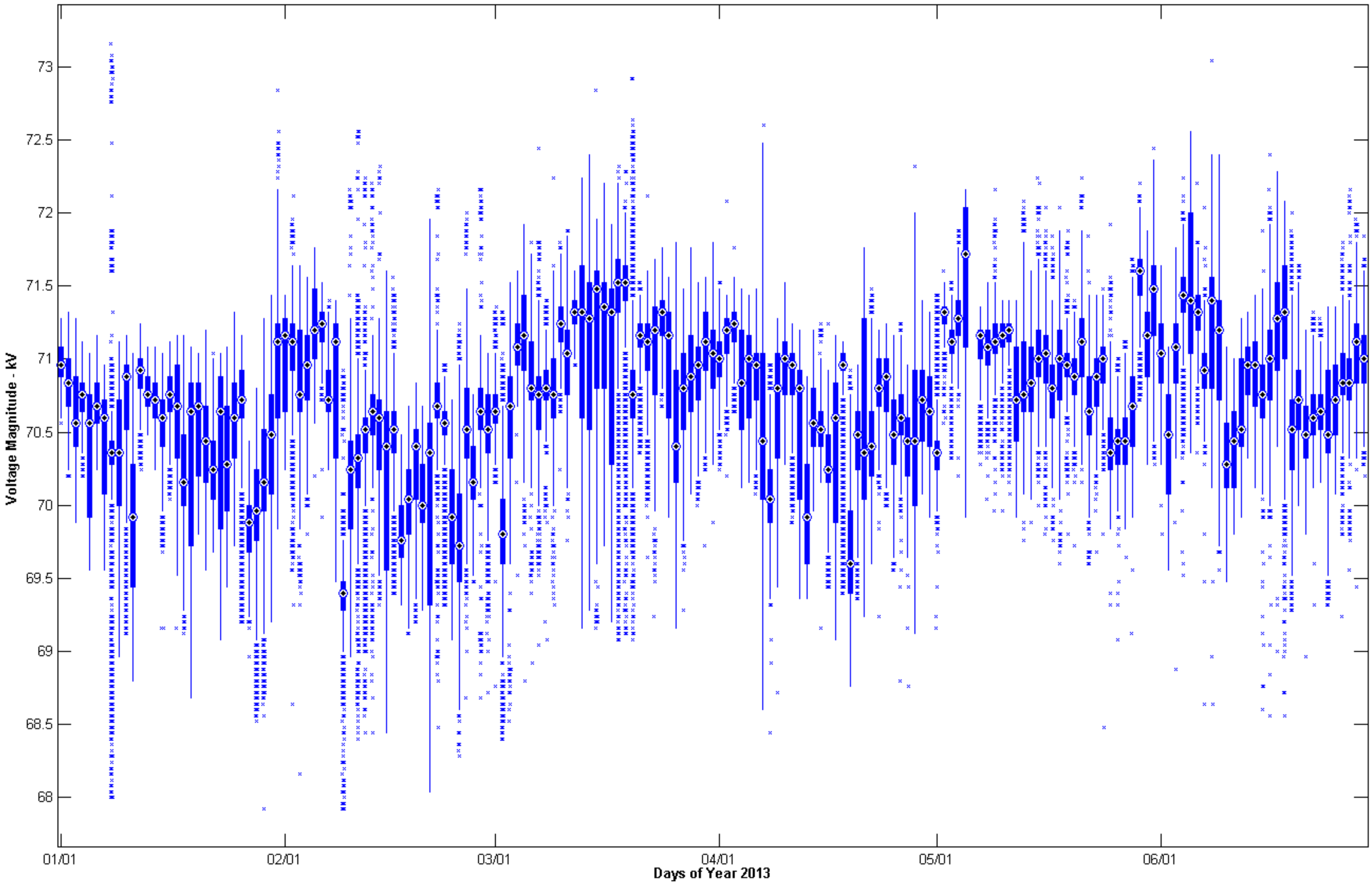
External Version

Electric Power Group

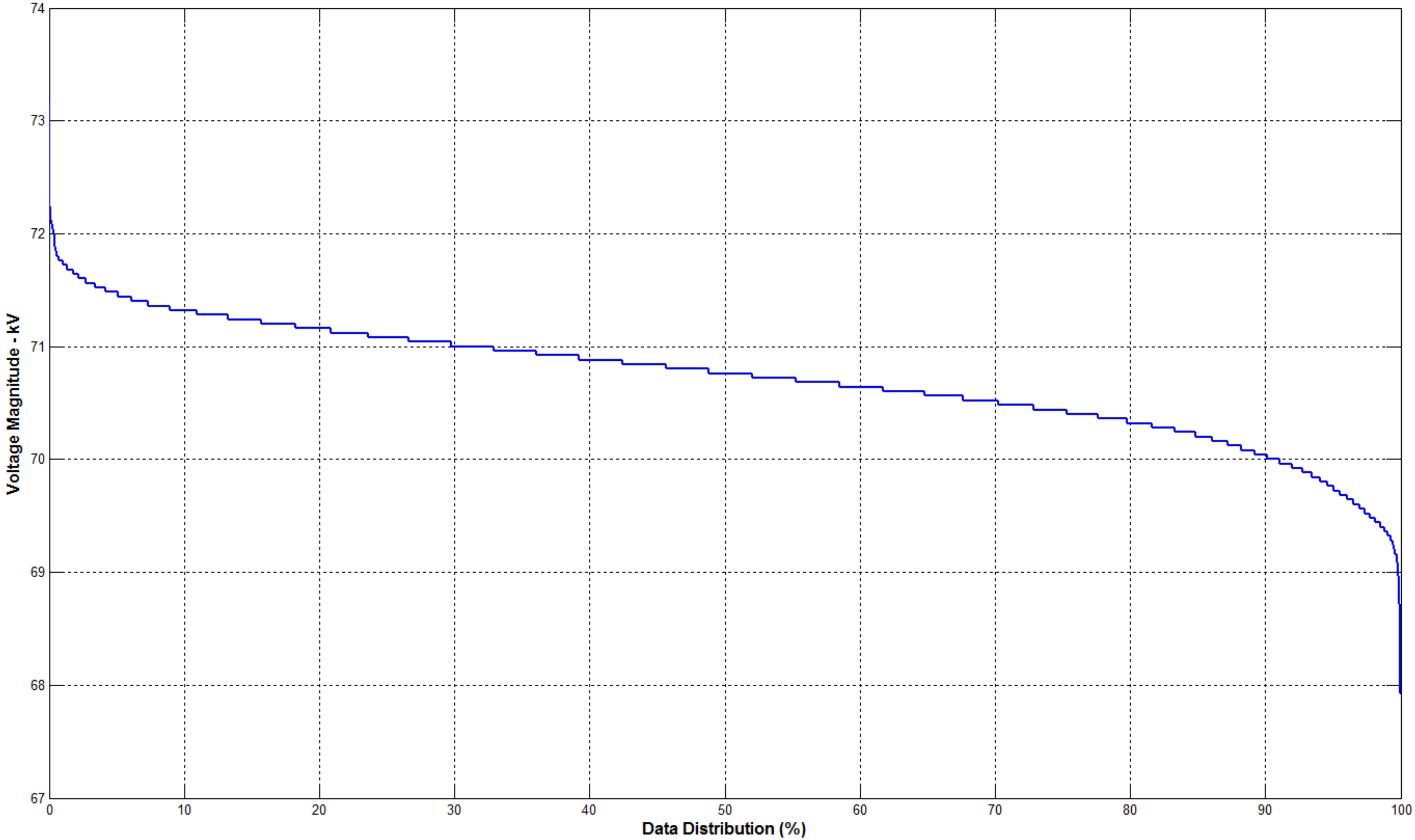
CCET

ERCOT

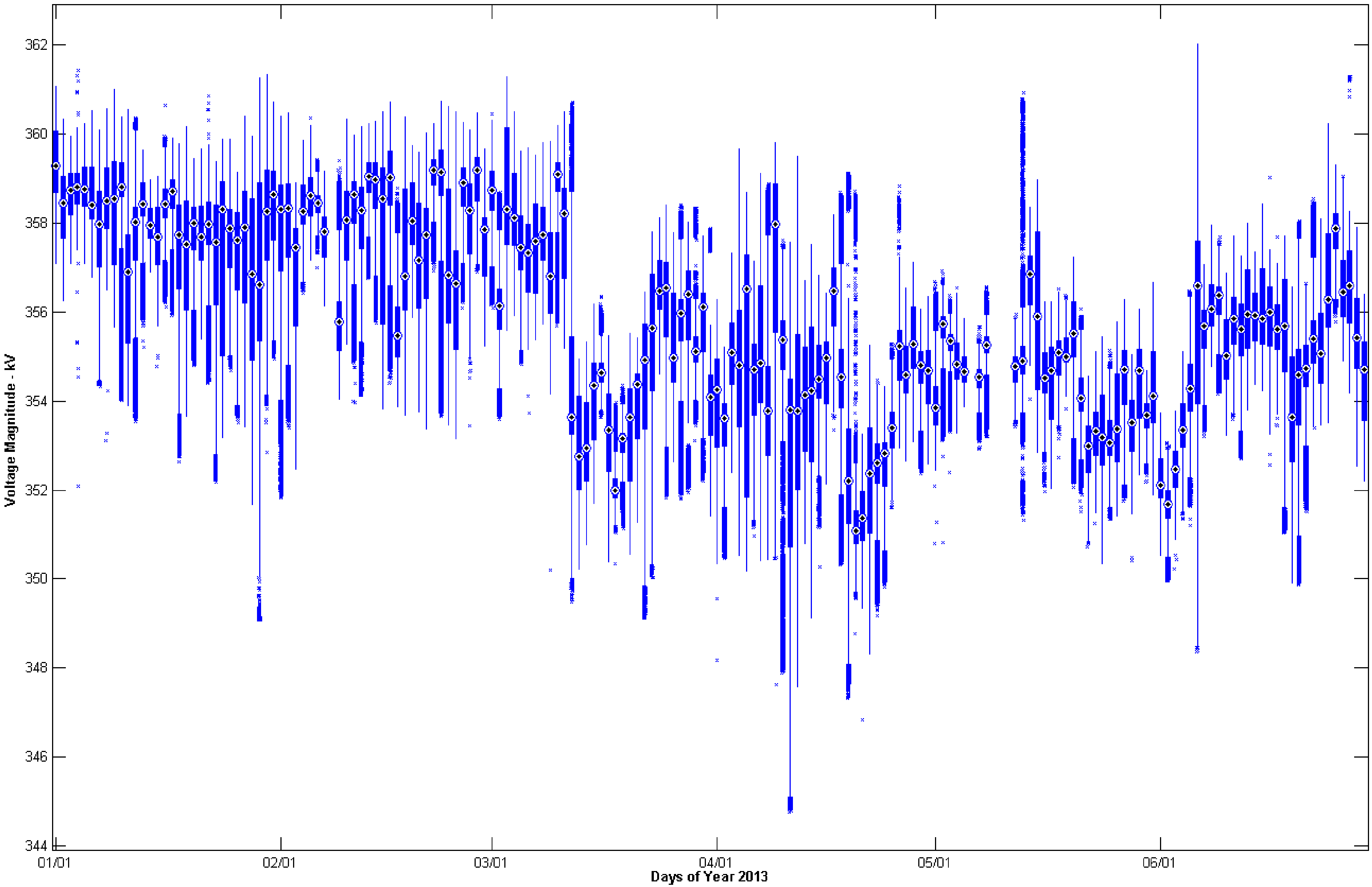
West 10 – Voltage Magnitude



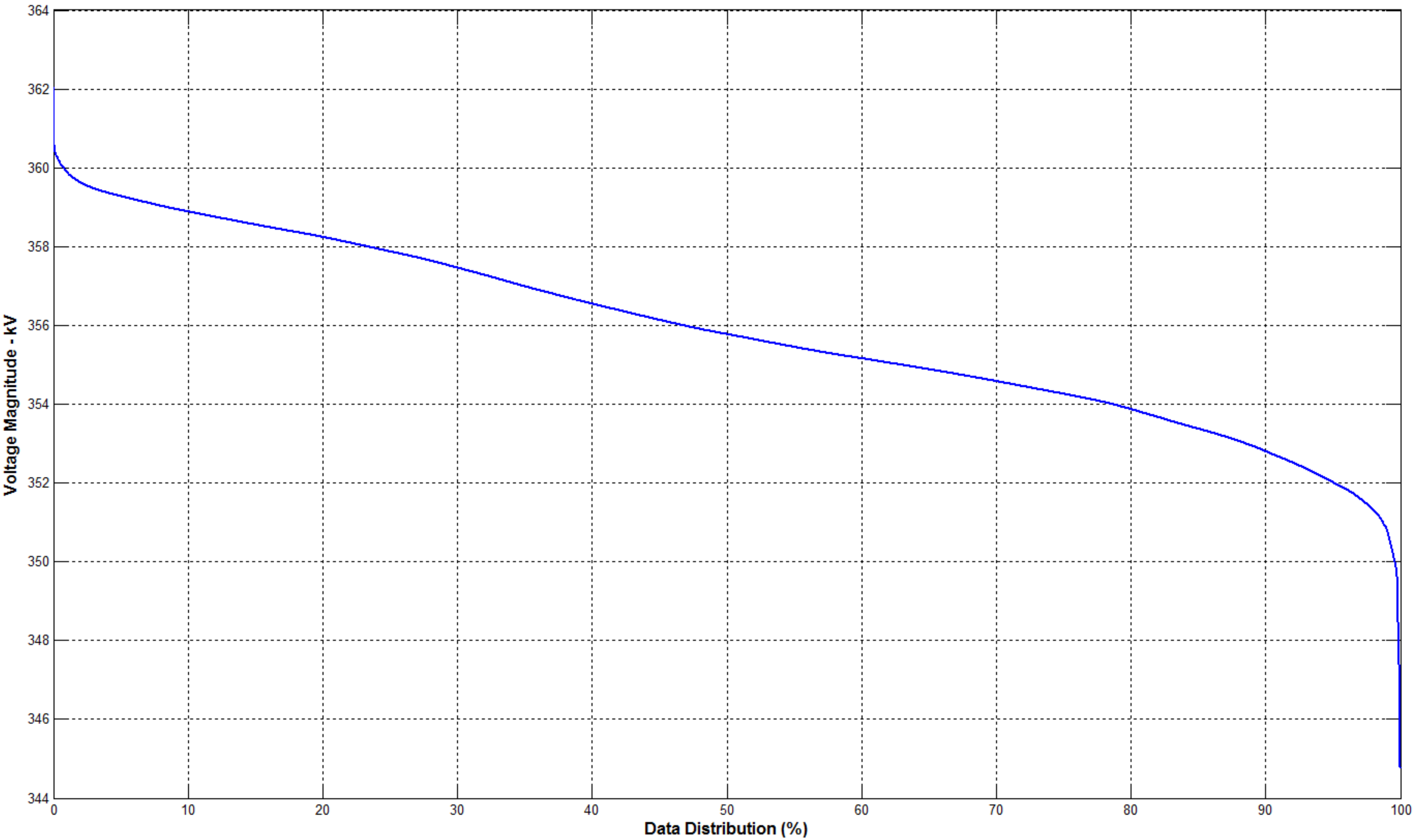
West 10 – Voltage Magnitude



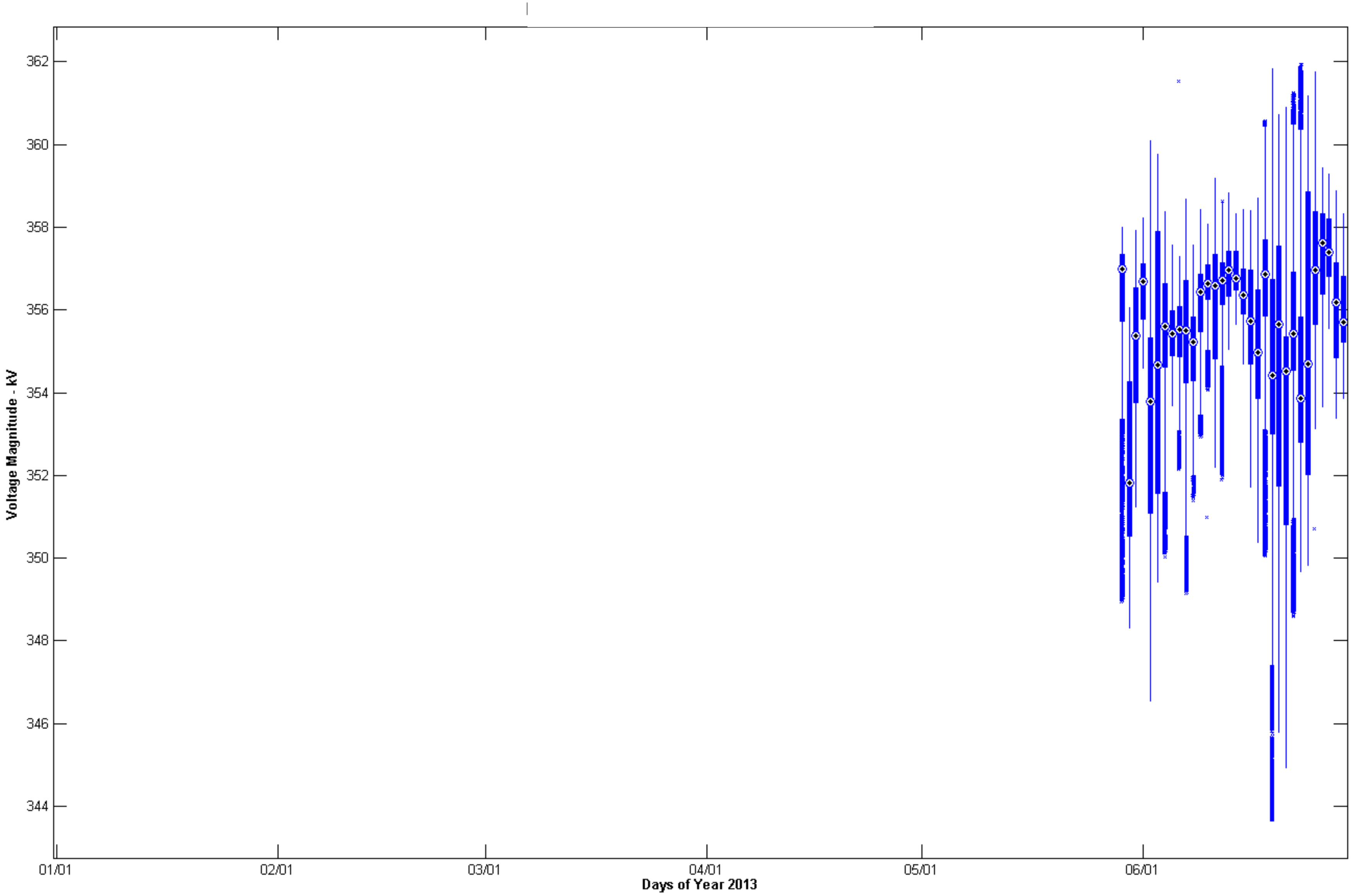
West 14 – Voltage Magnitude



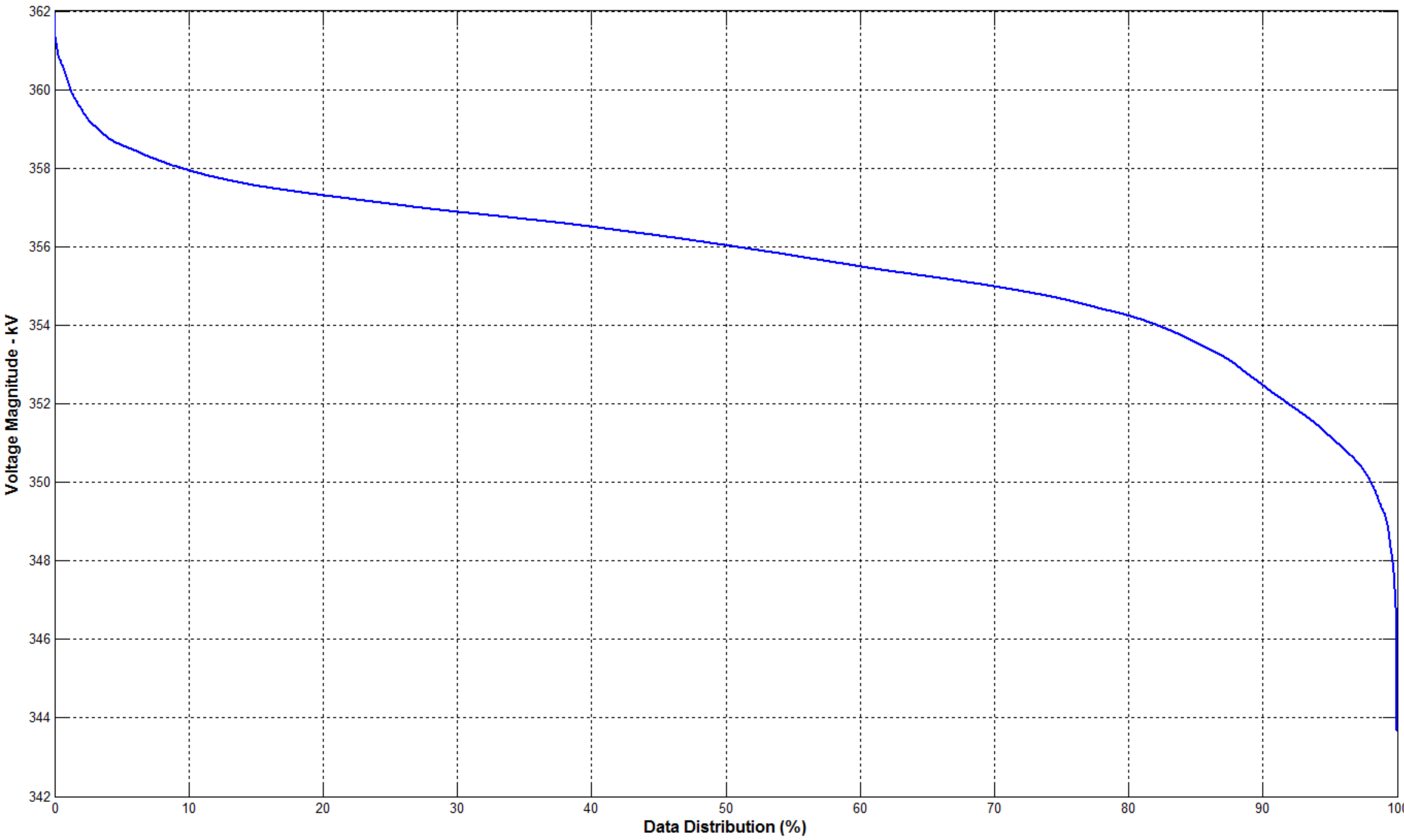
West 14 – Voltage Magnitude



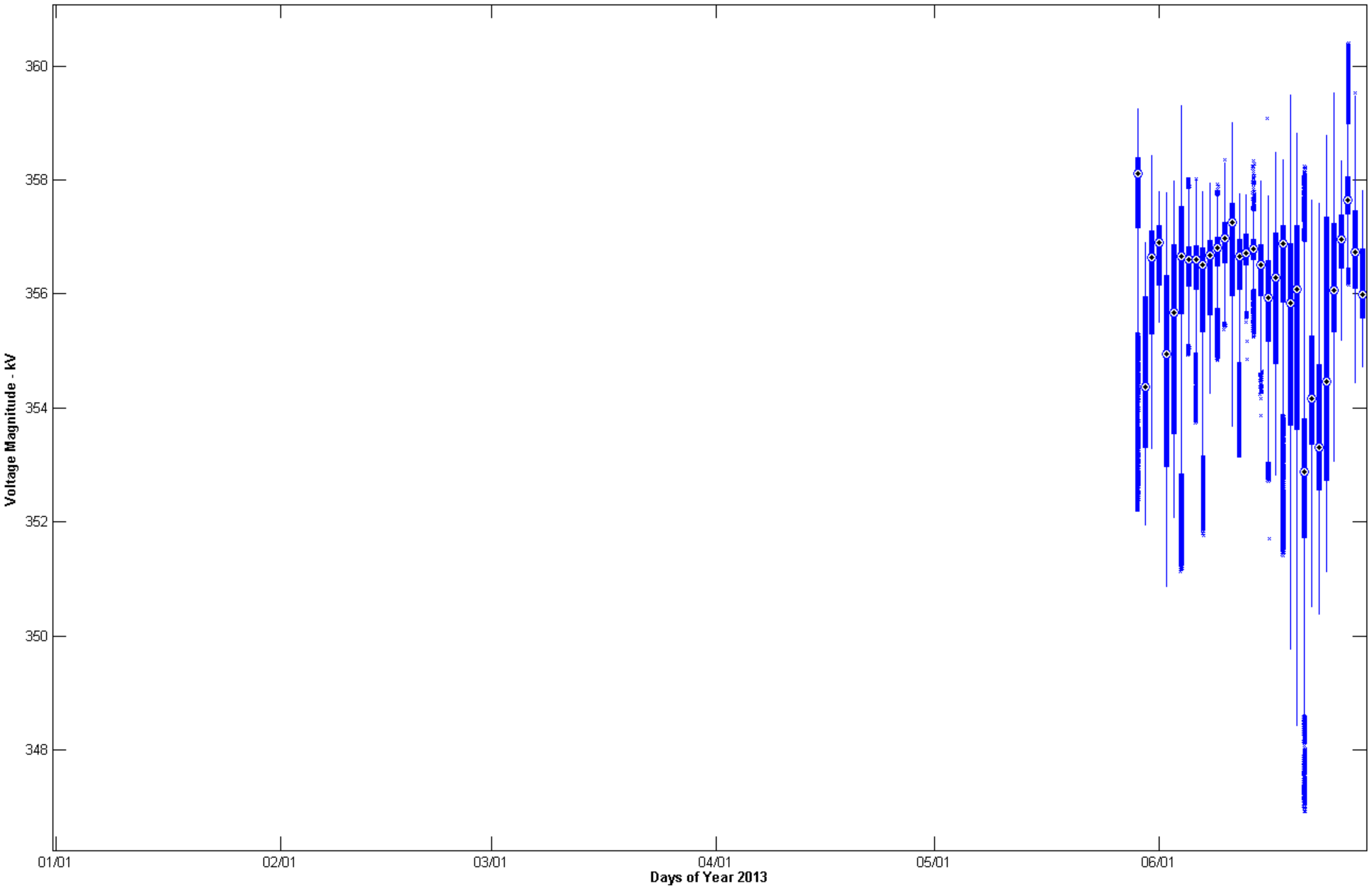
West 1 – Voltage Magnitude



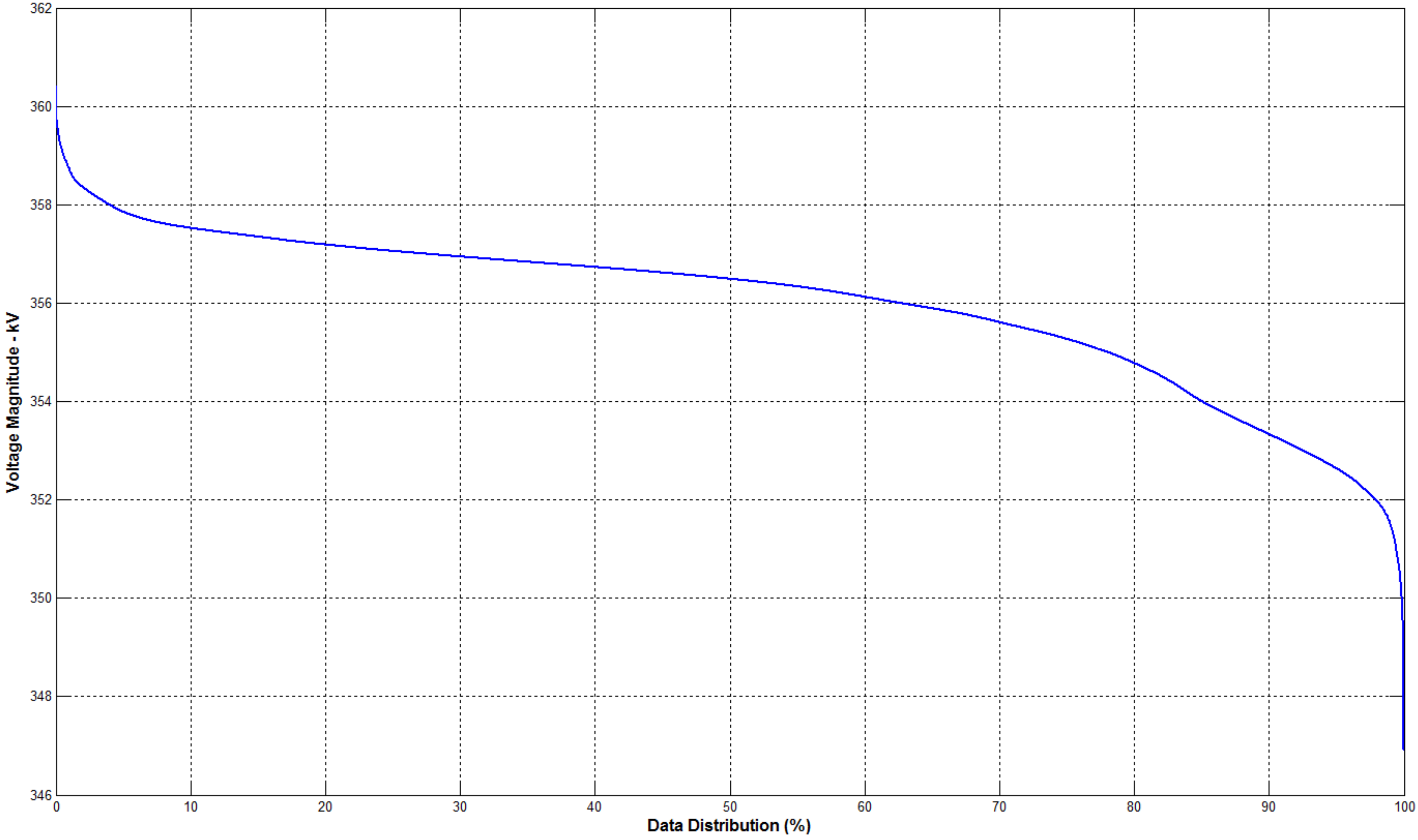
West 1 – Voltage Magnitude



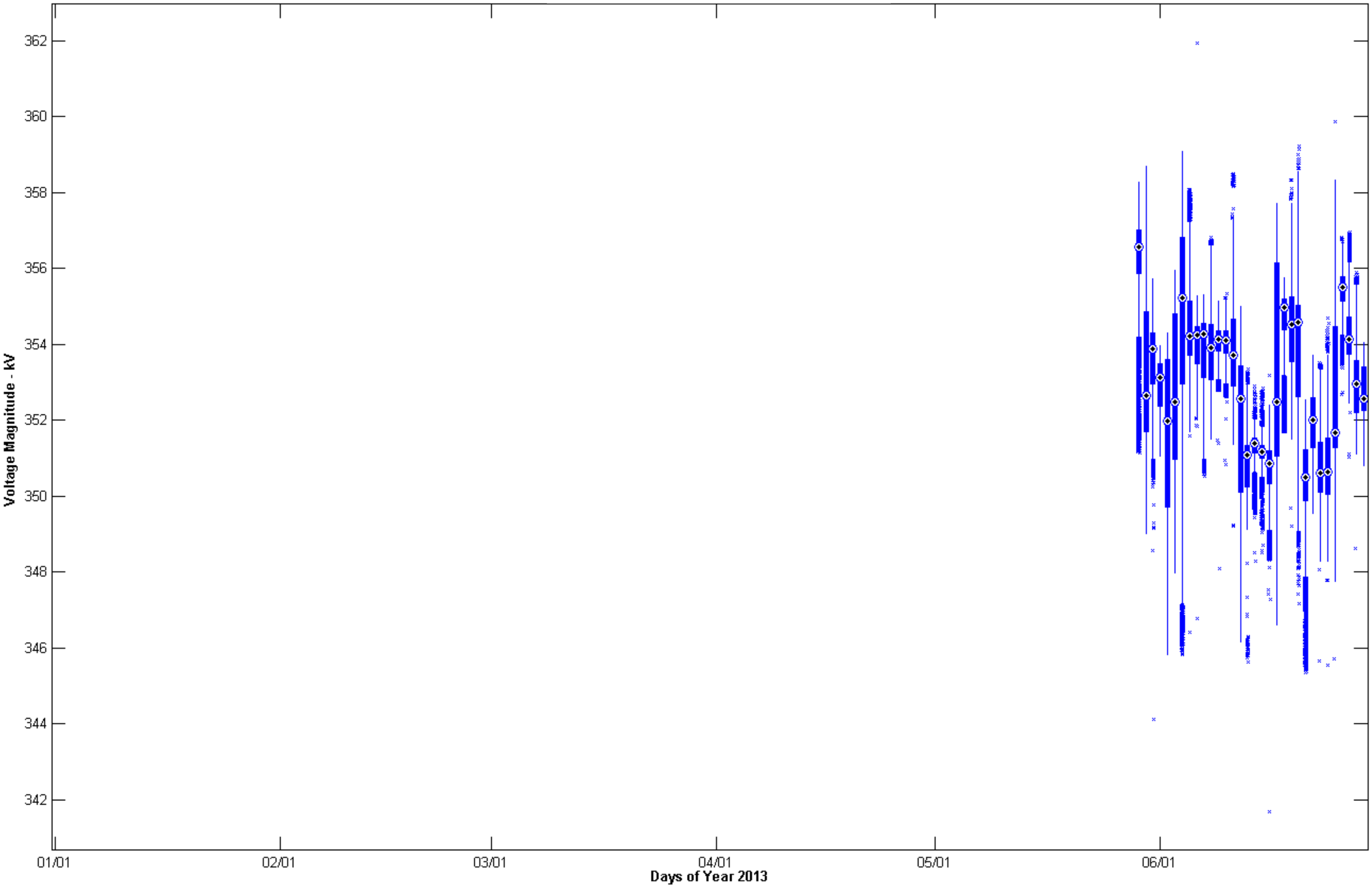
West 2 – Voltage Magnitude



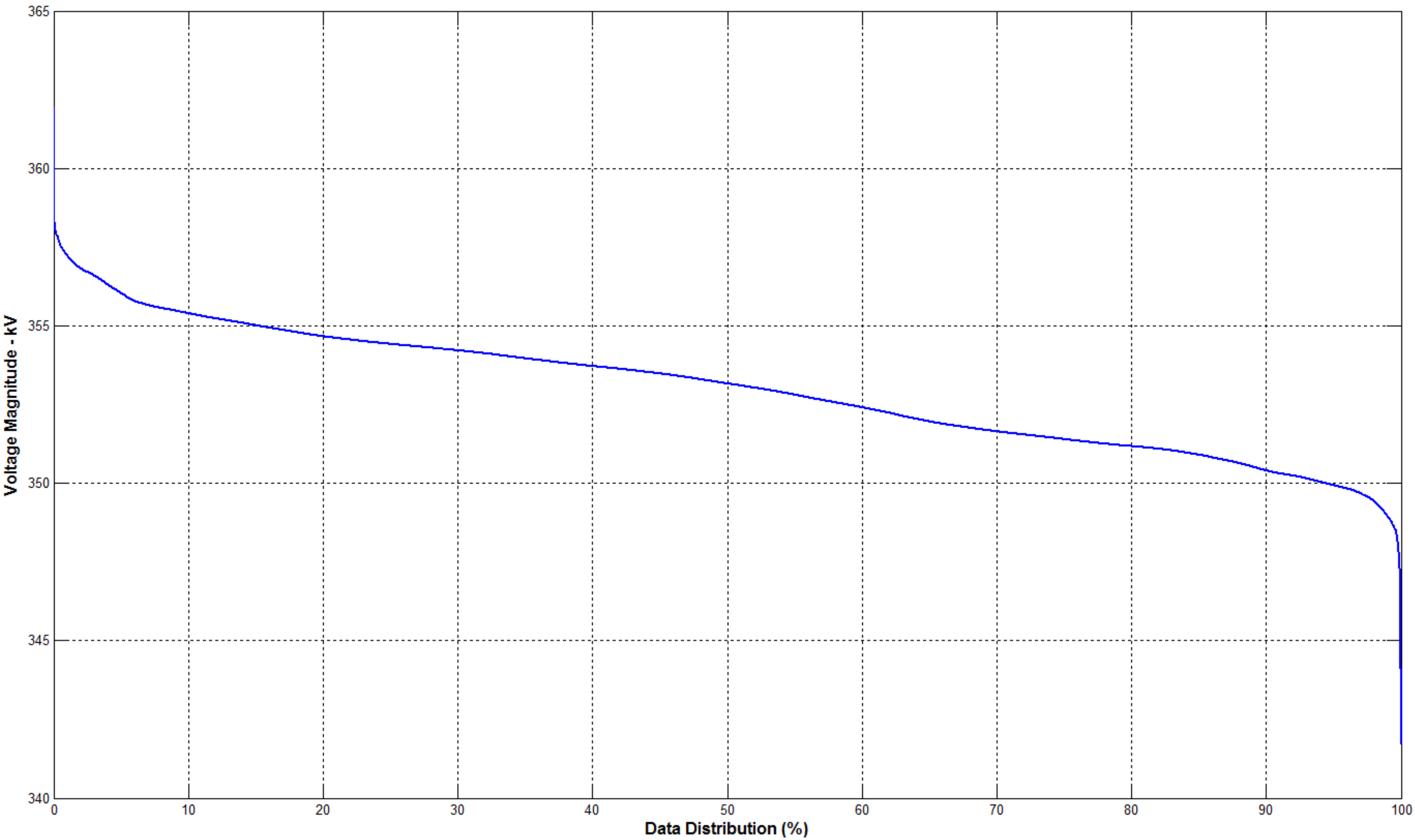
West 2 – Voltage Magnitude



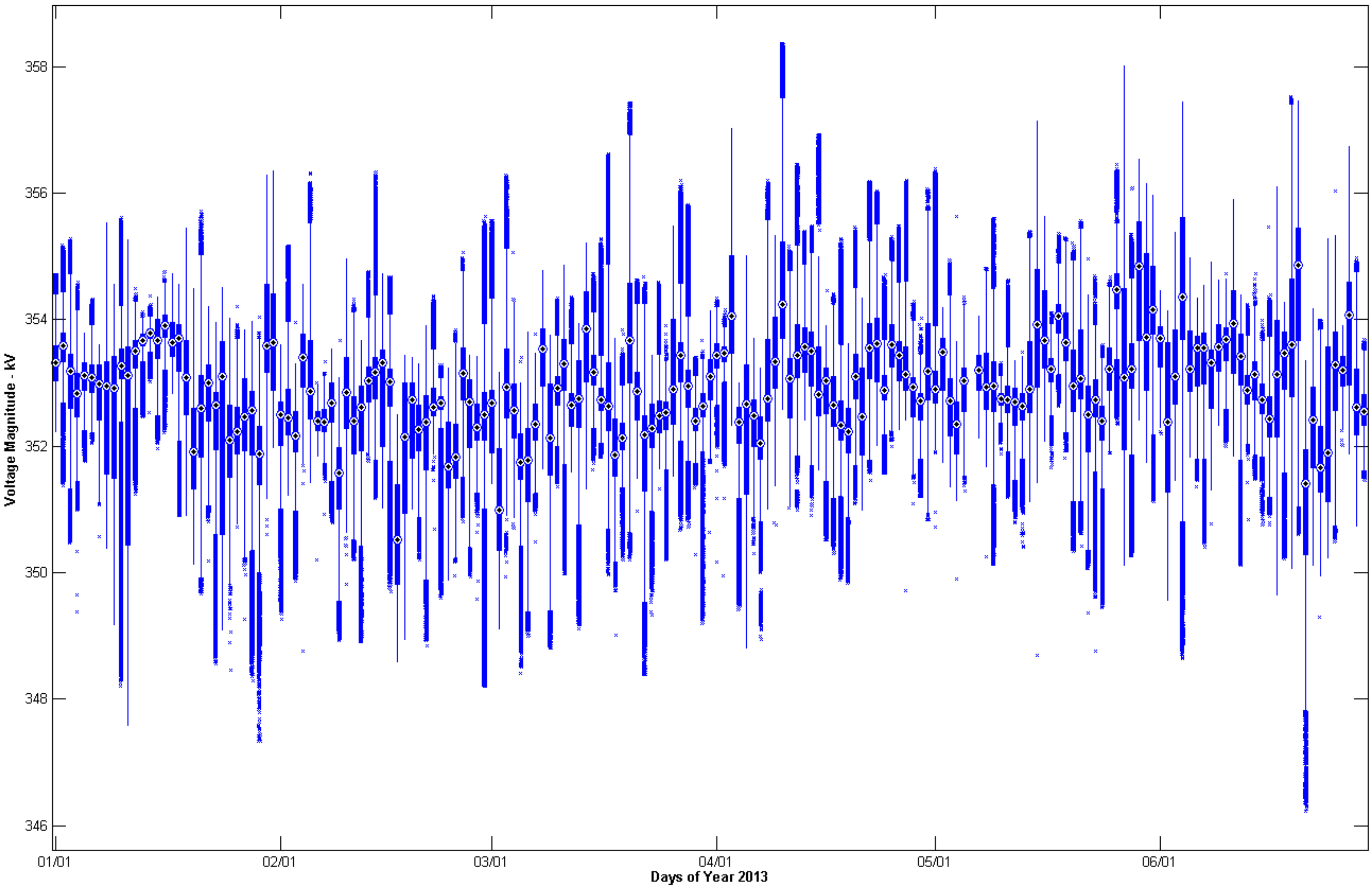
West 9 – Voltage Magnitude



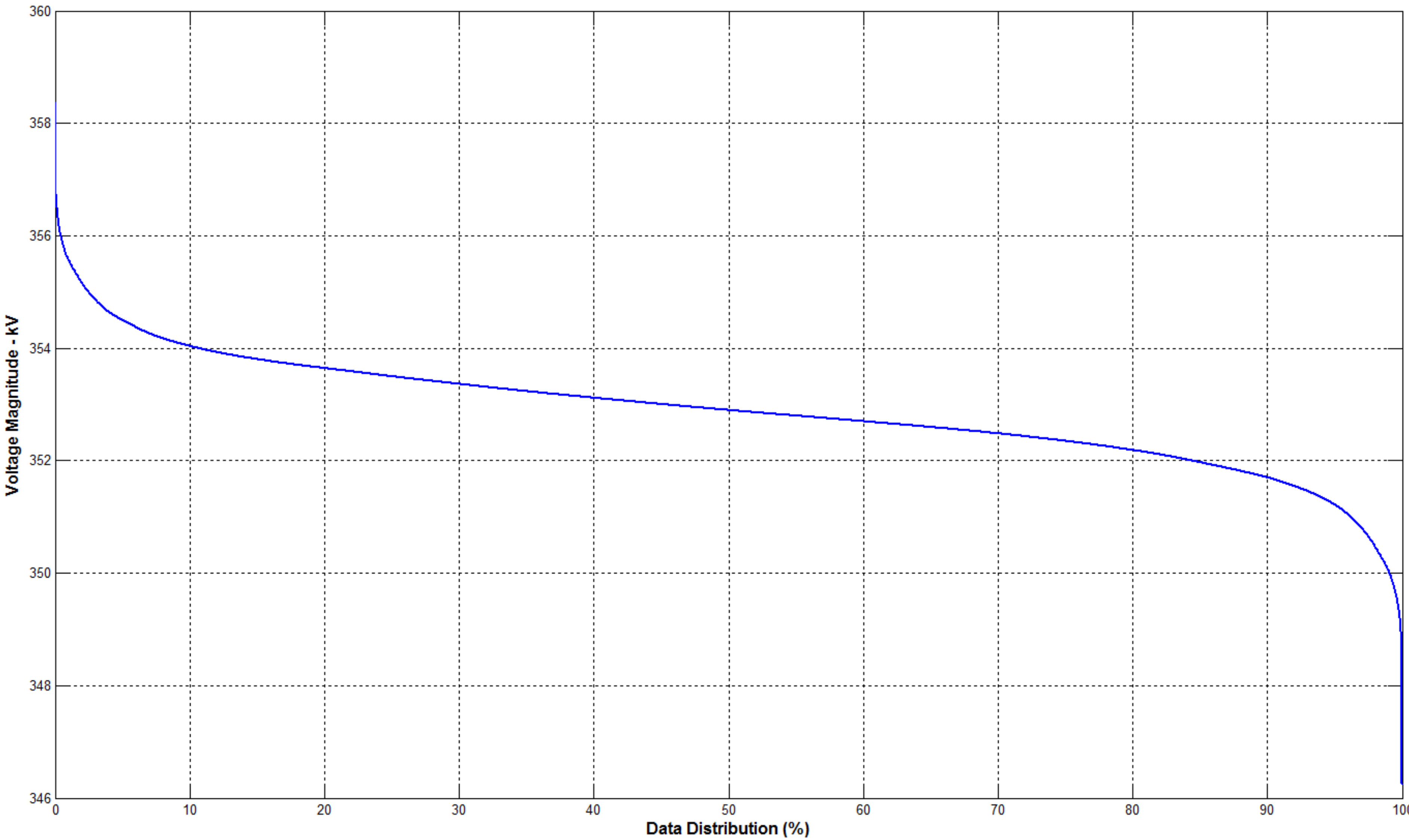
West 9 – Voltage Magnitude



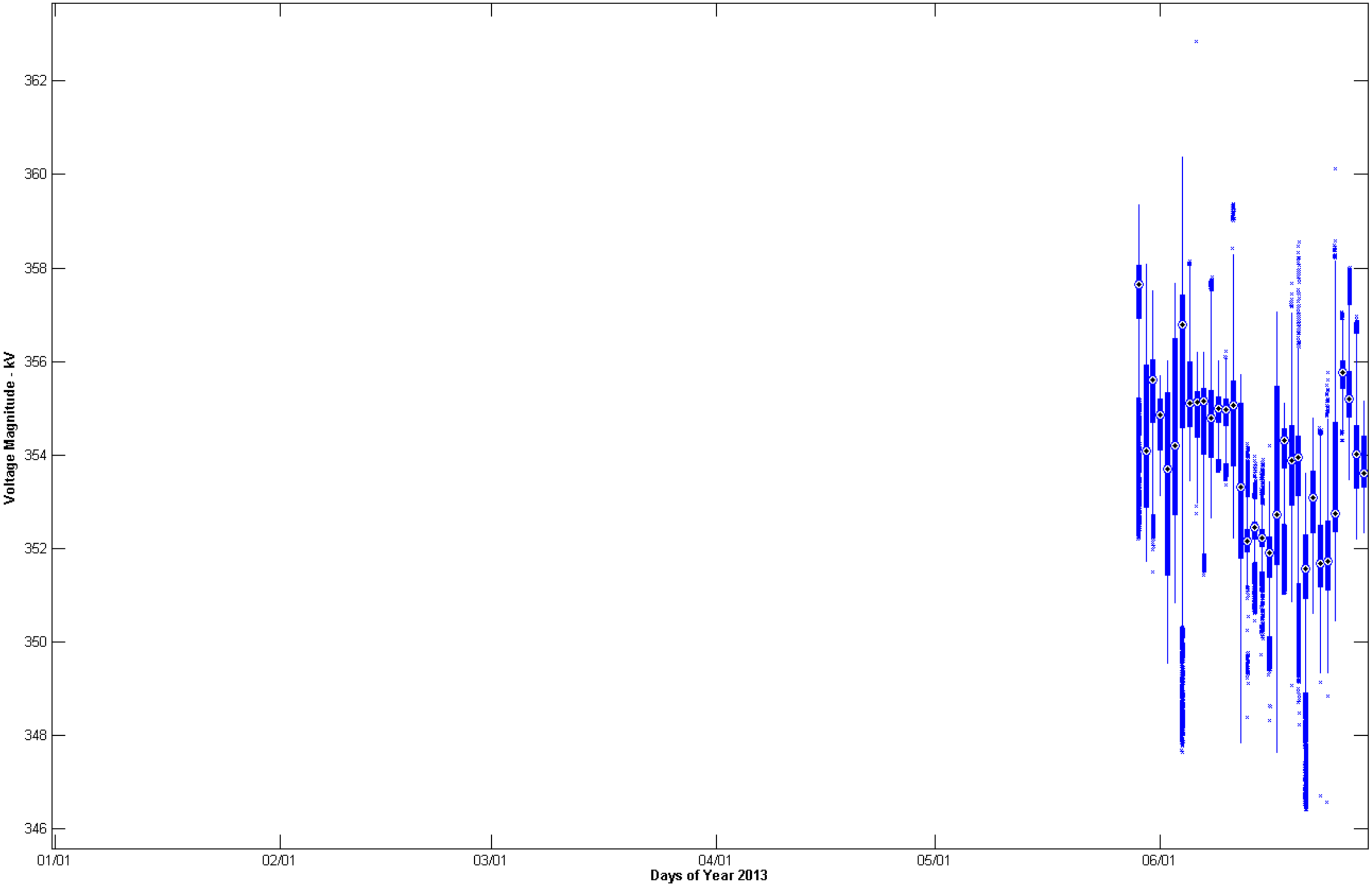
West 11– Voltage Magnitude



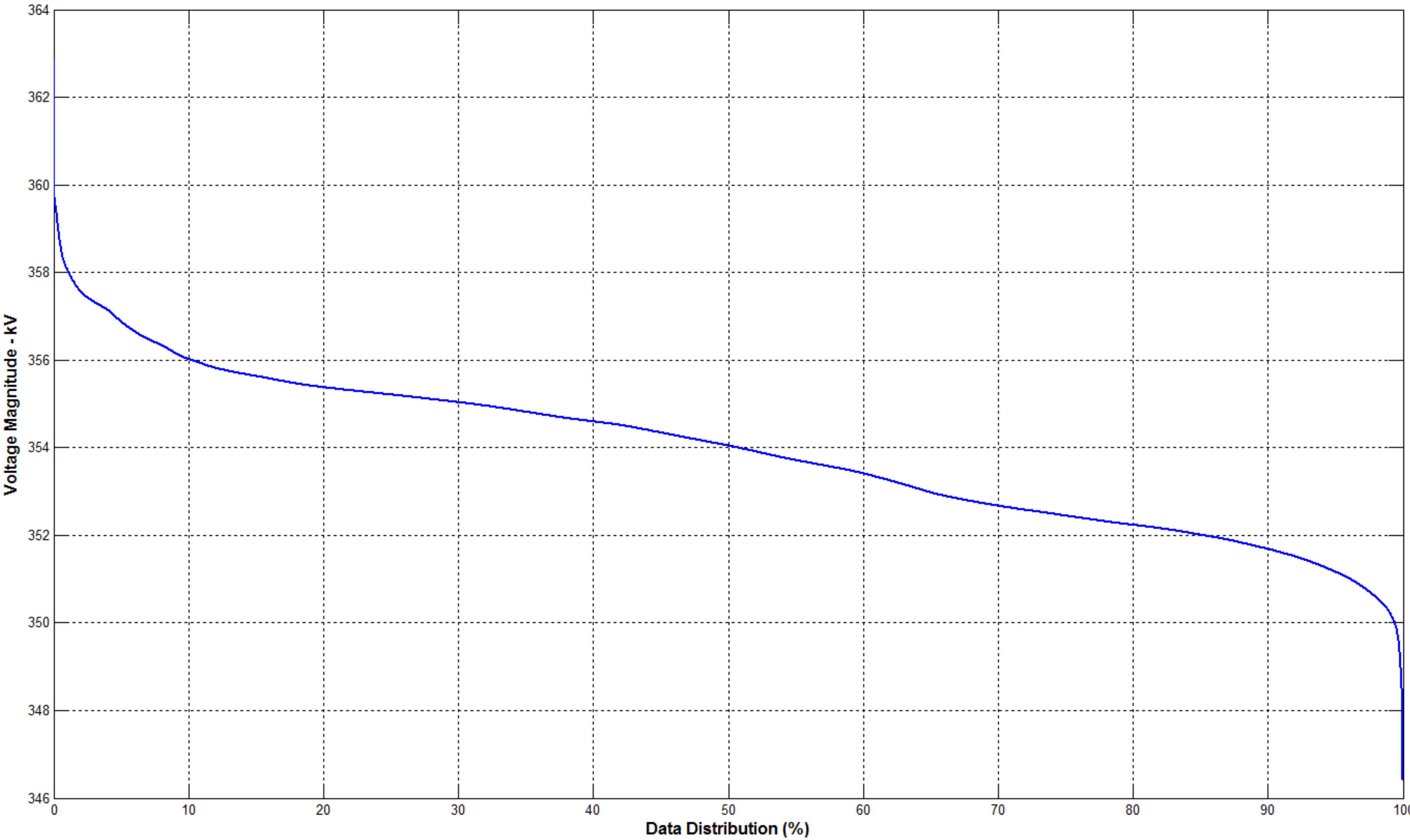
West 11– Voltage Magnitude



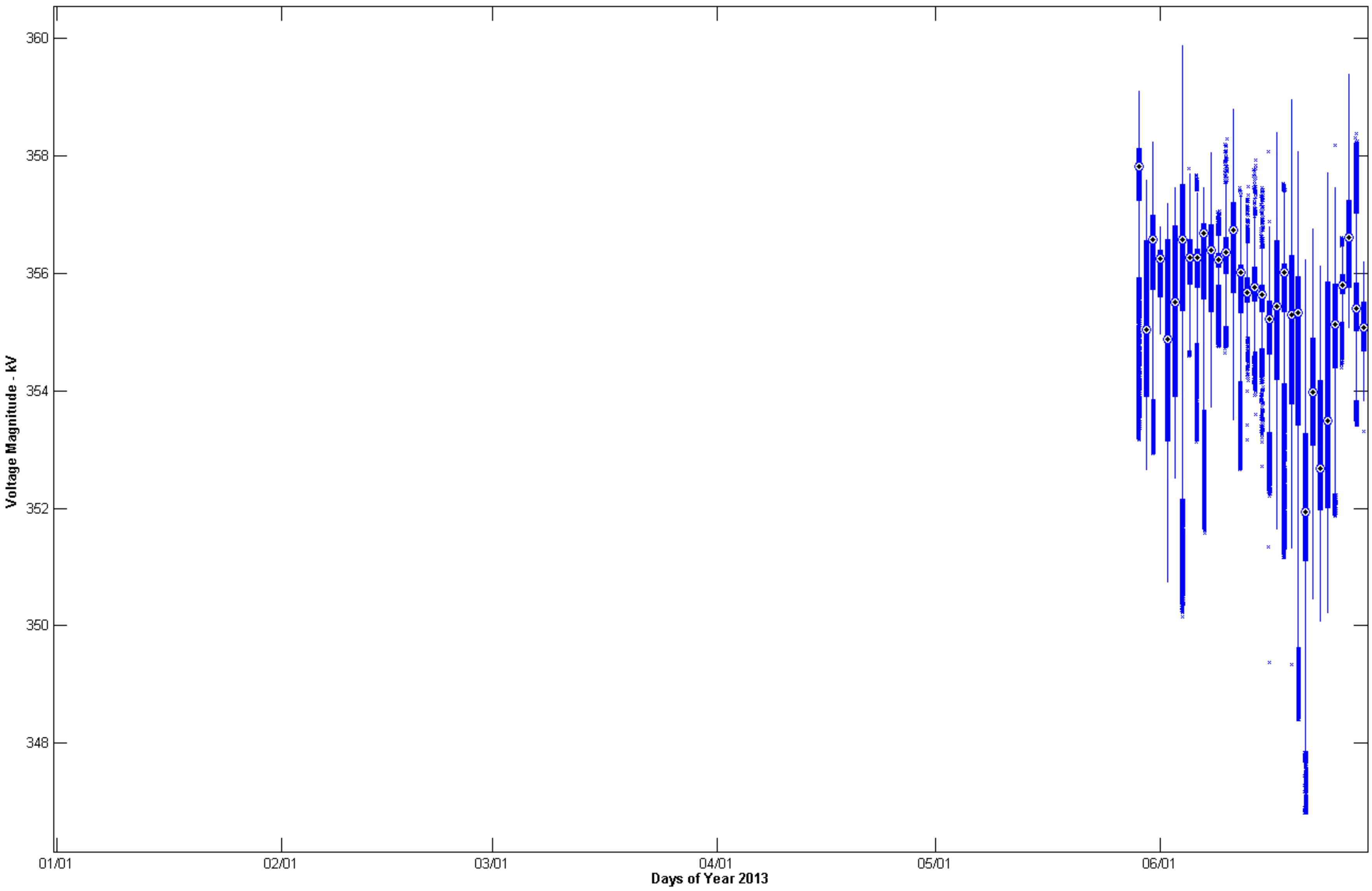
West 12– Voltage Magnitude



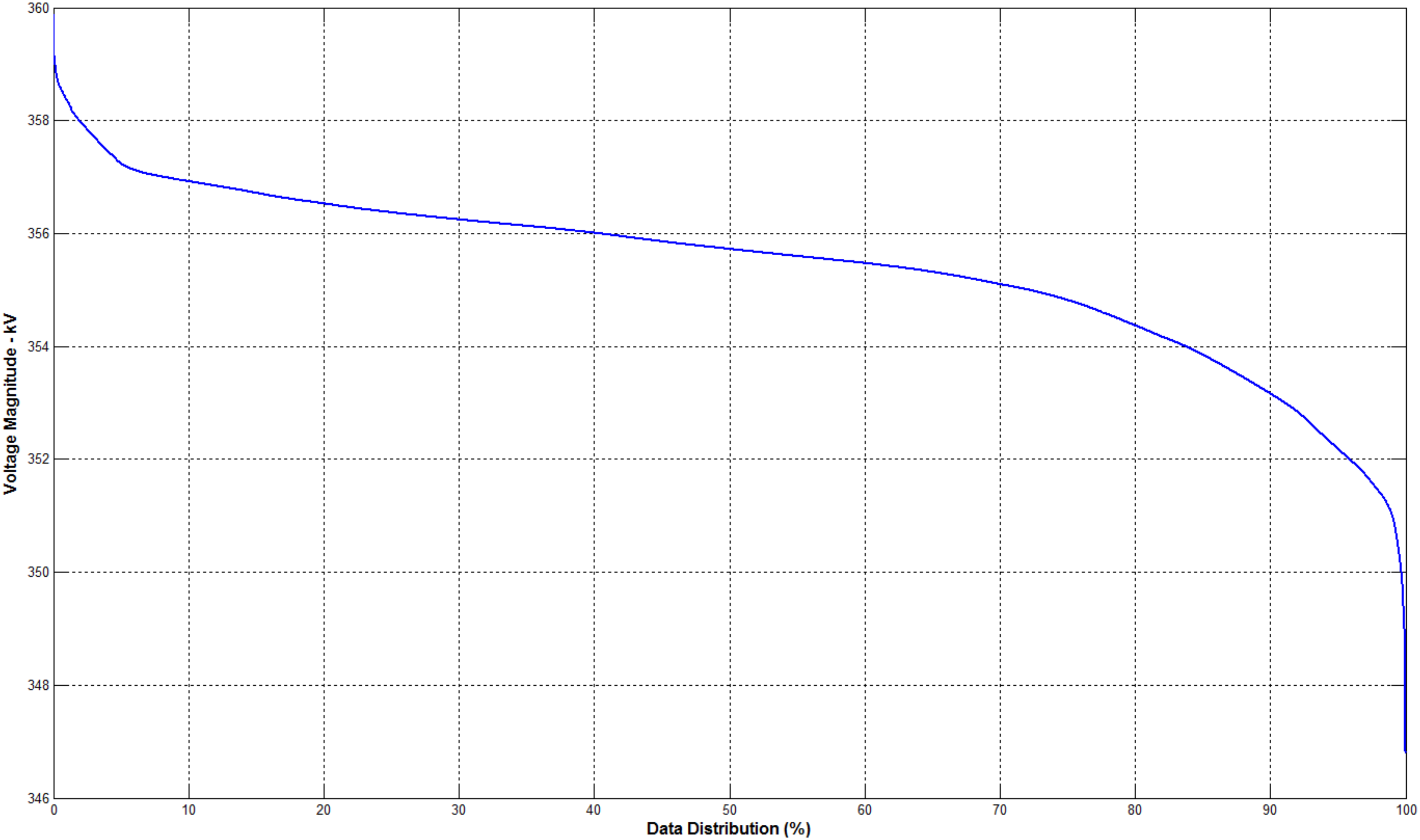
West 12– Voltage Magnitude



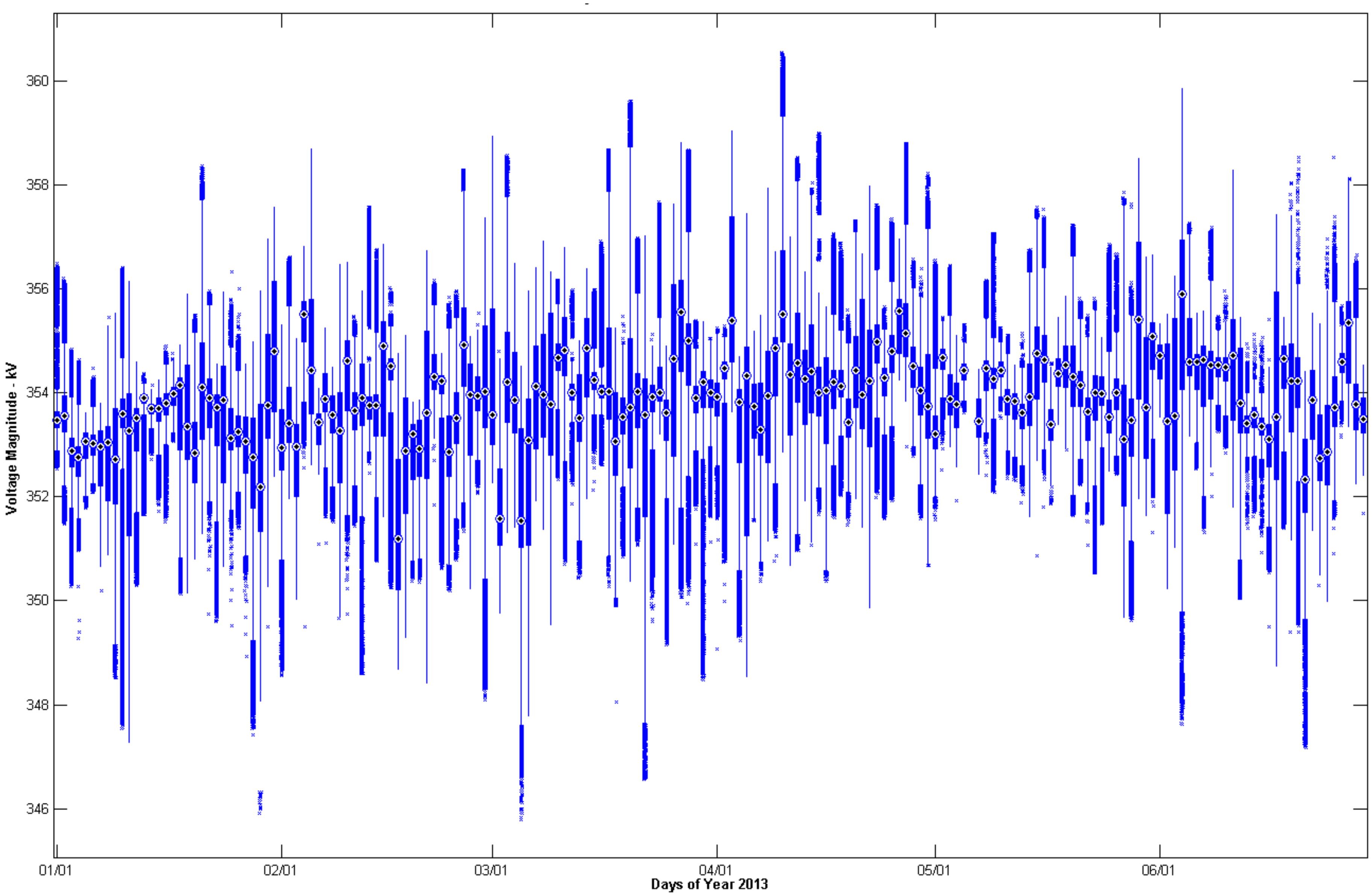
West 5 – Voltage Magnitude



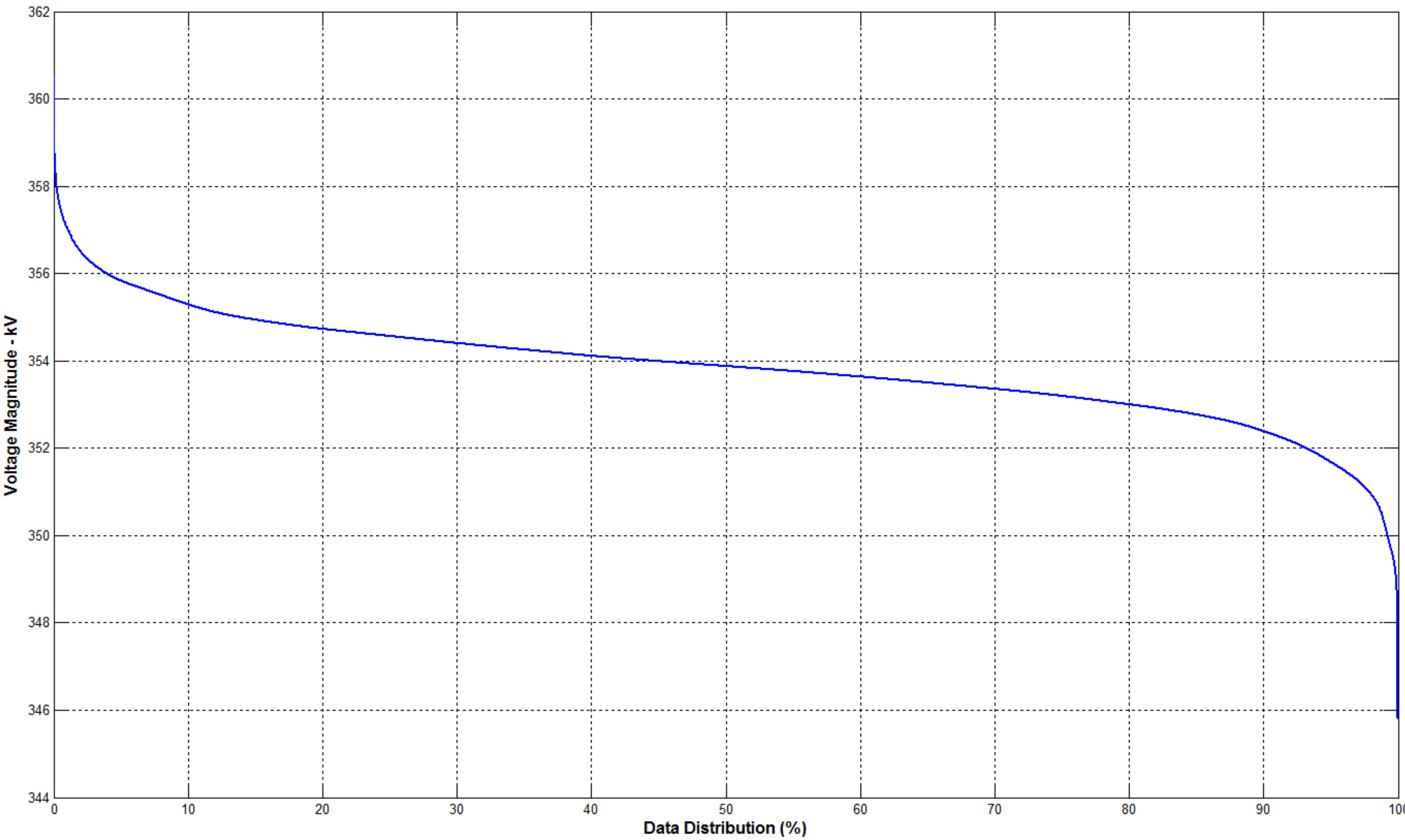
West 5 – Voltage Magnitude



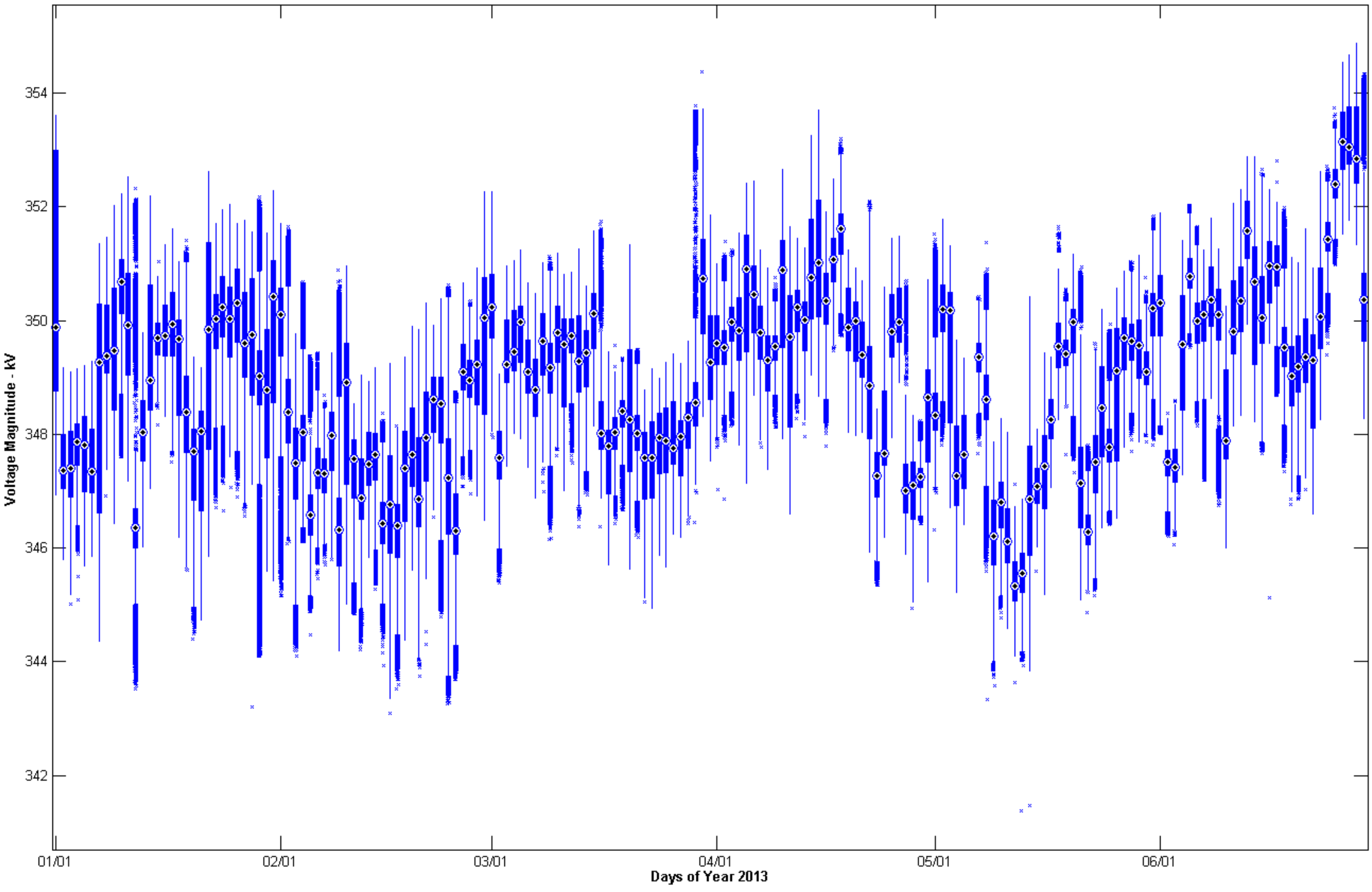
West 6 – Voltage Magnitude



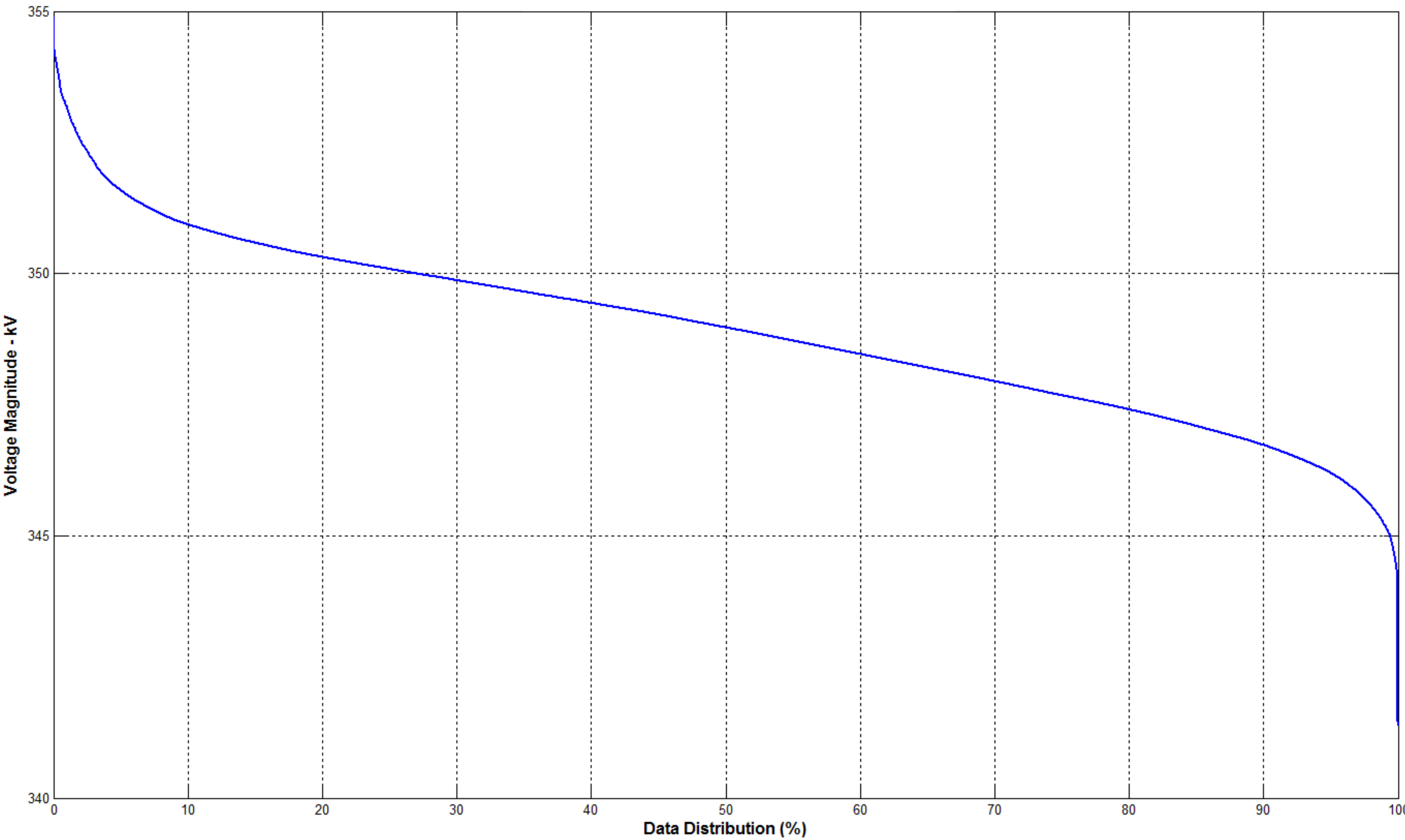
West 6 – Voltage Magnitude



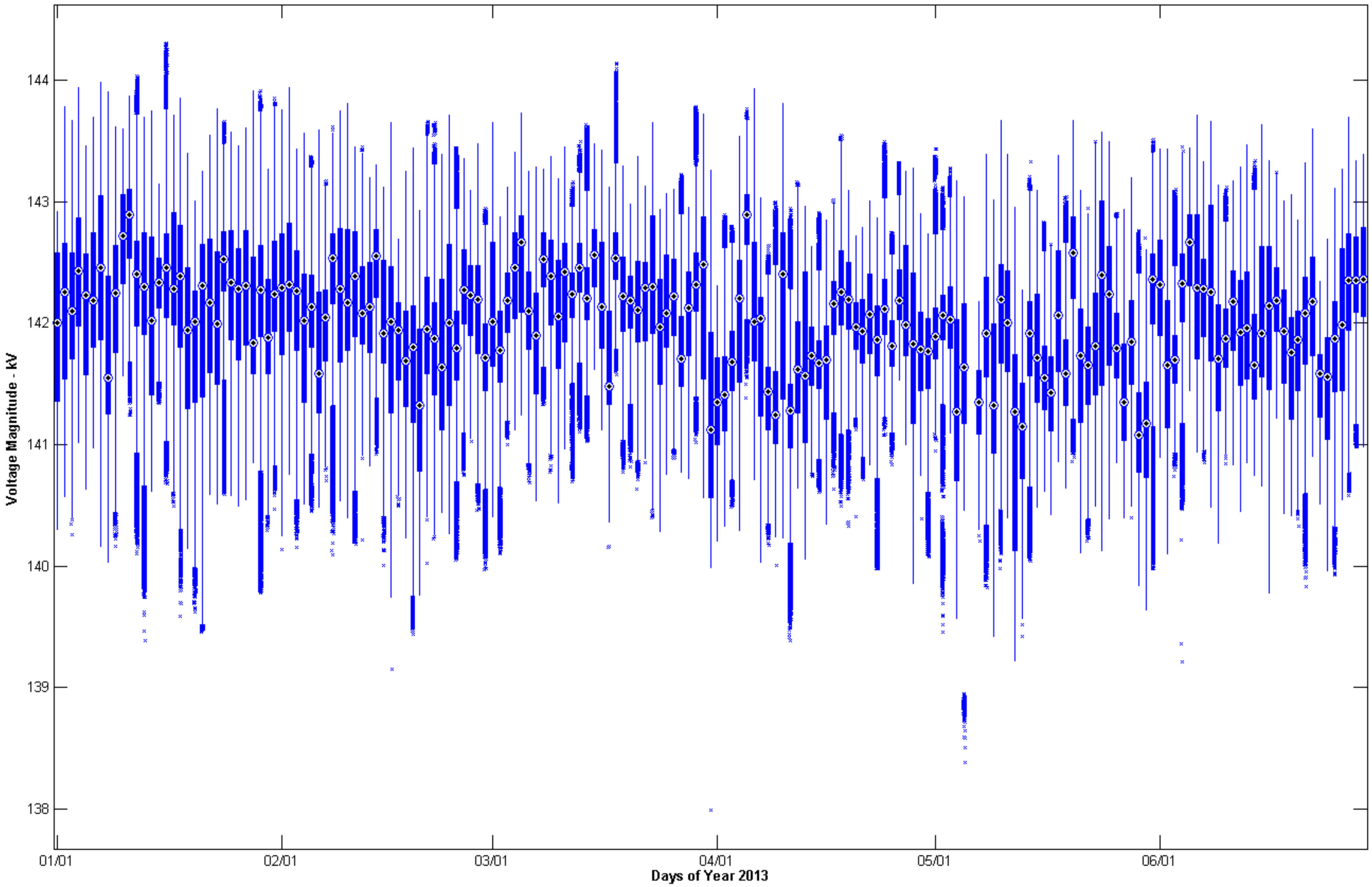
North 1 – Voltage Magnitude



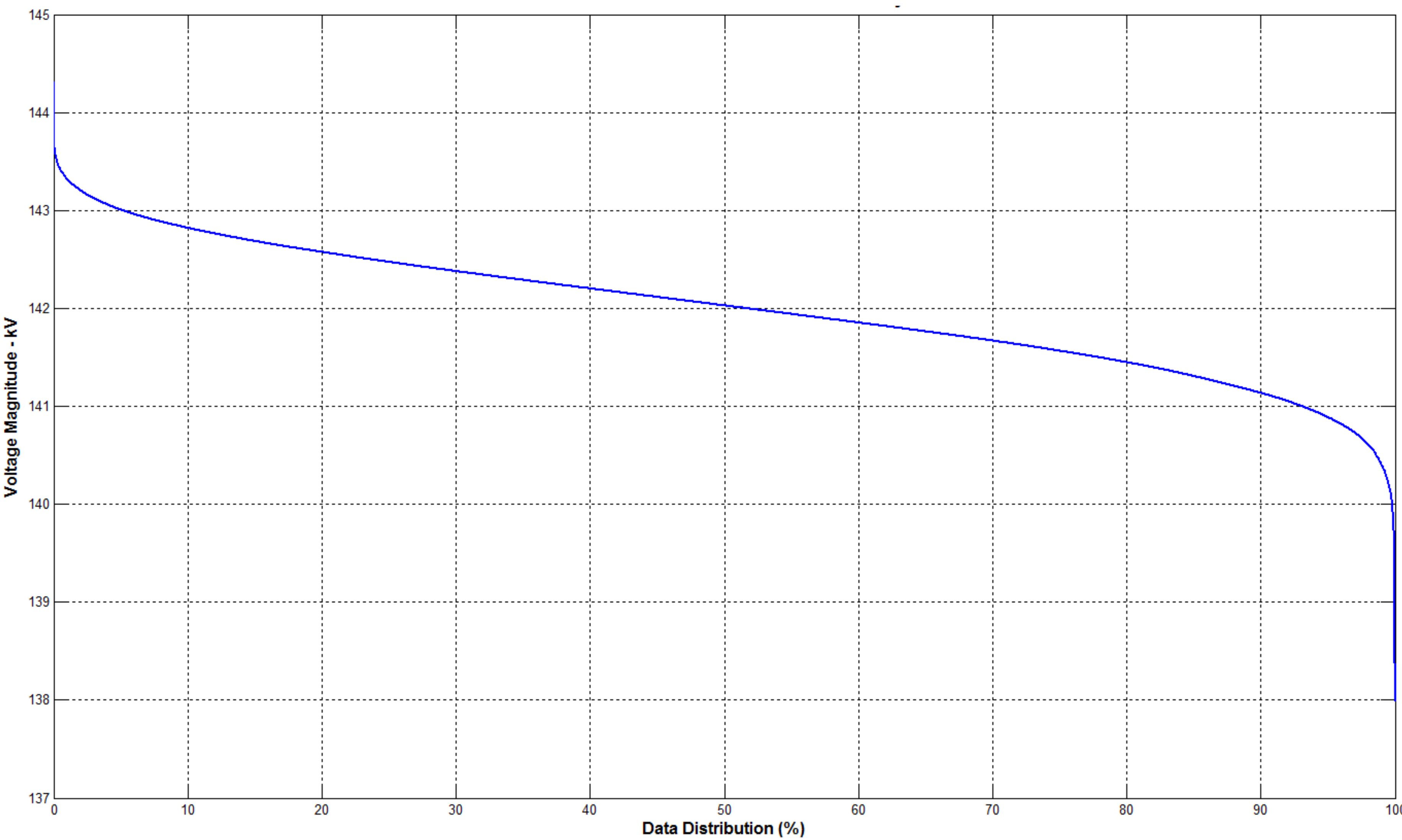
North 1 – Voltage Magnitude



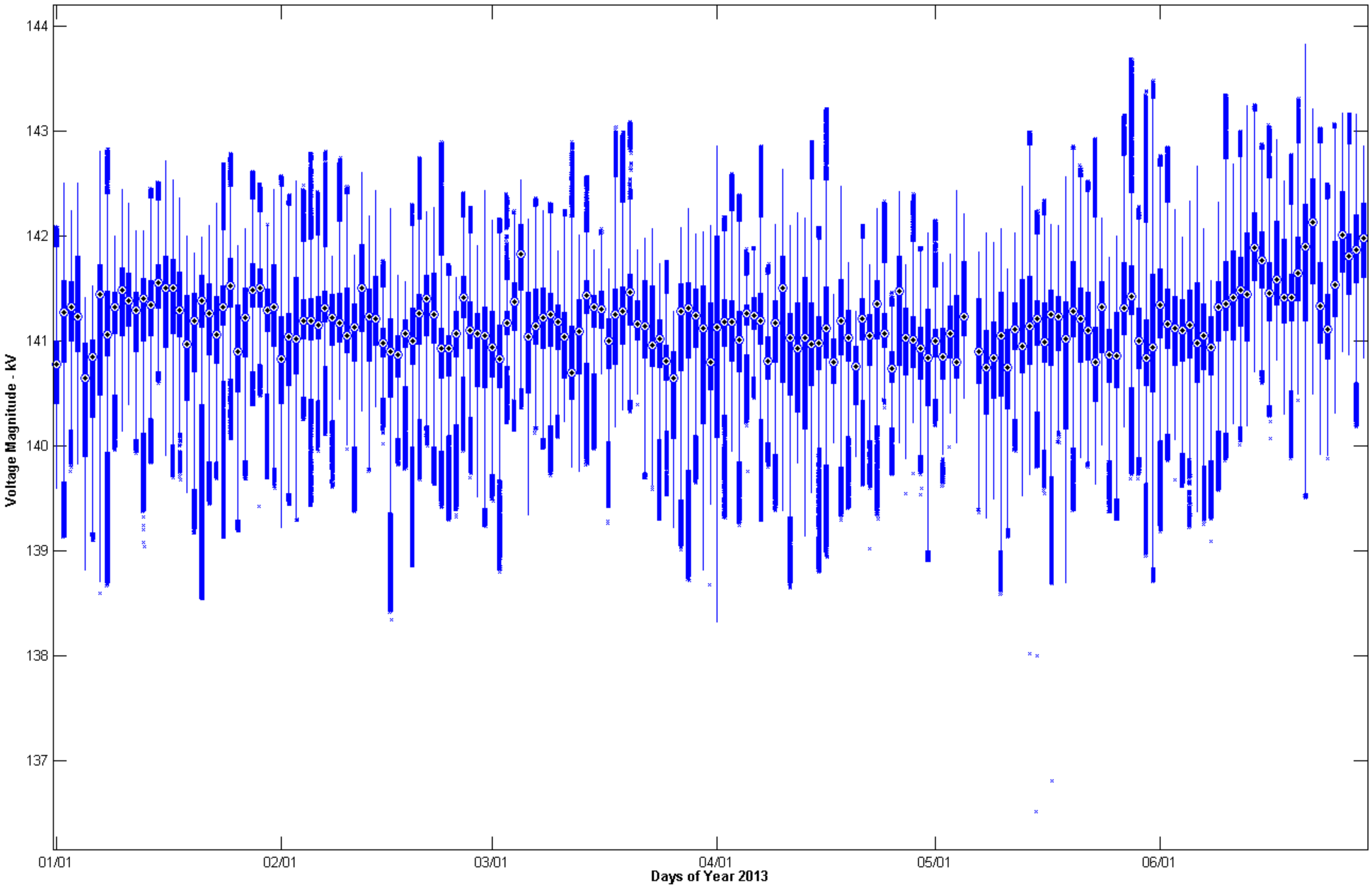
North 4 – Voltage Magnitude



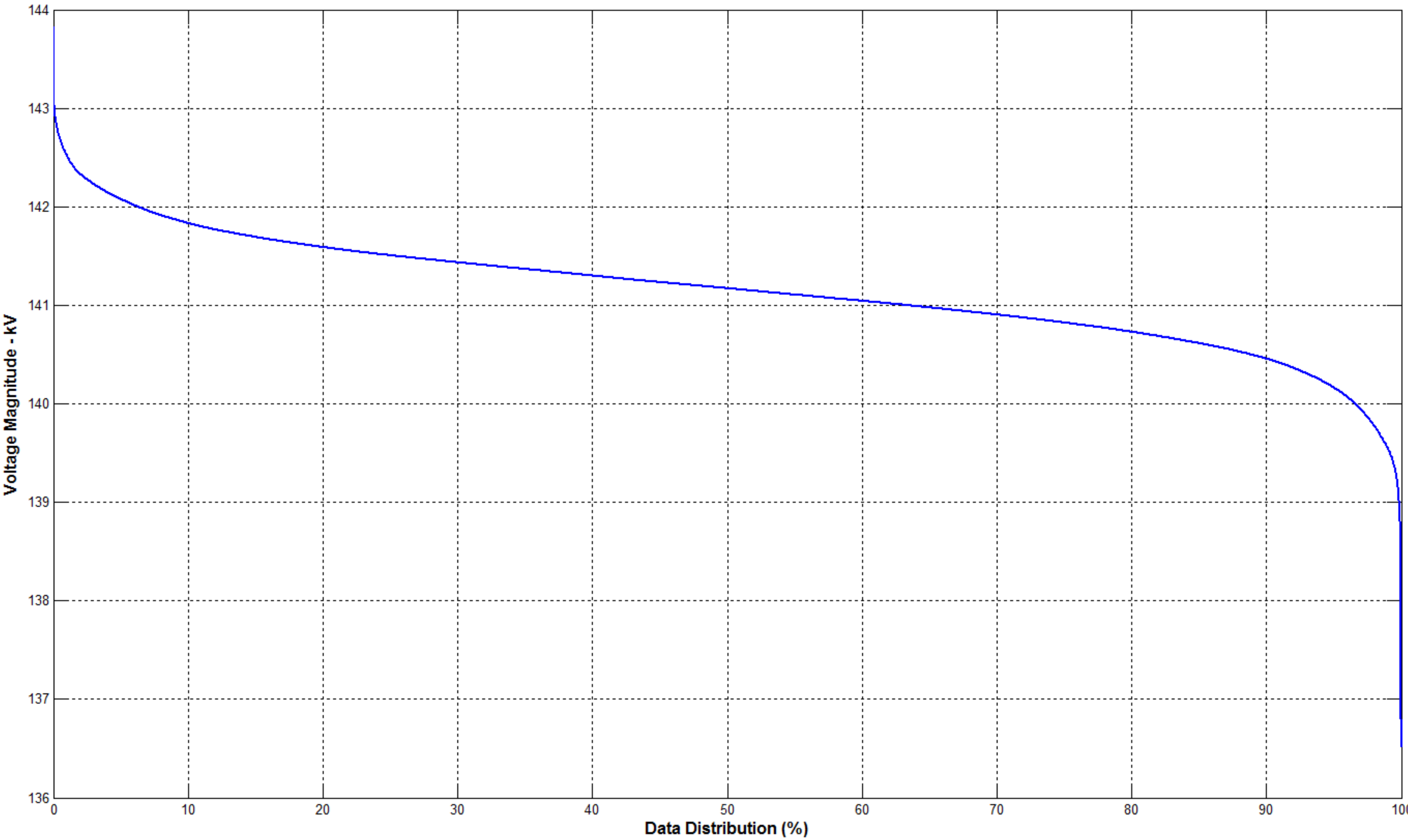
North 4 – Voltage Magnitude



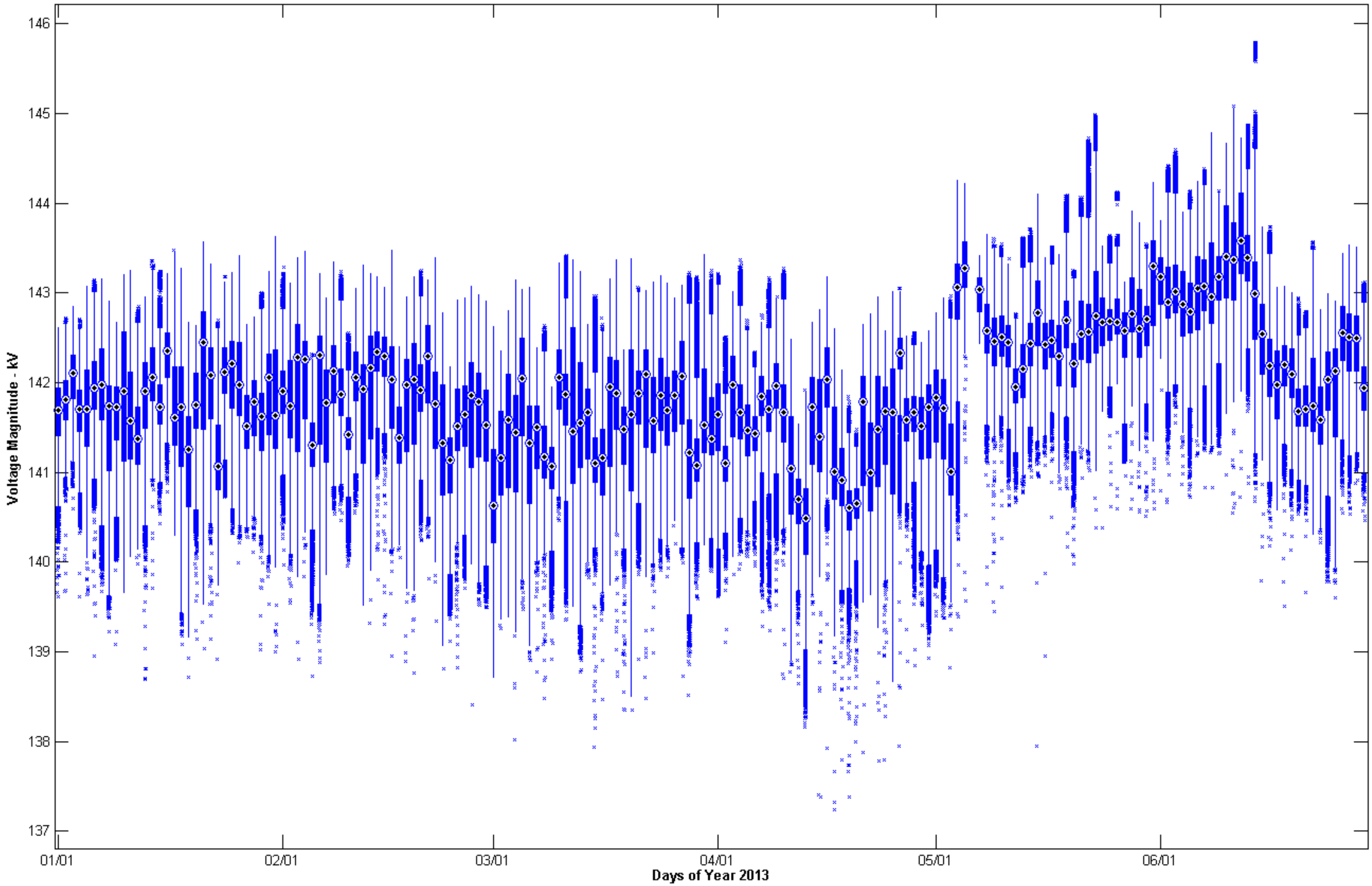
North 5 – Voltage Magnitude



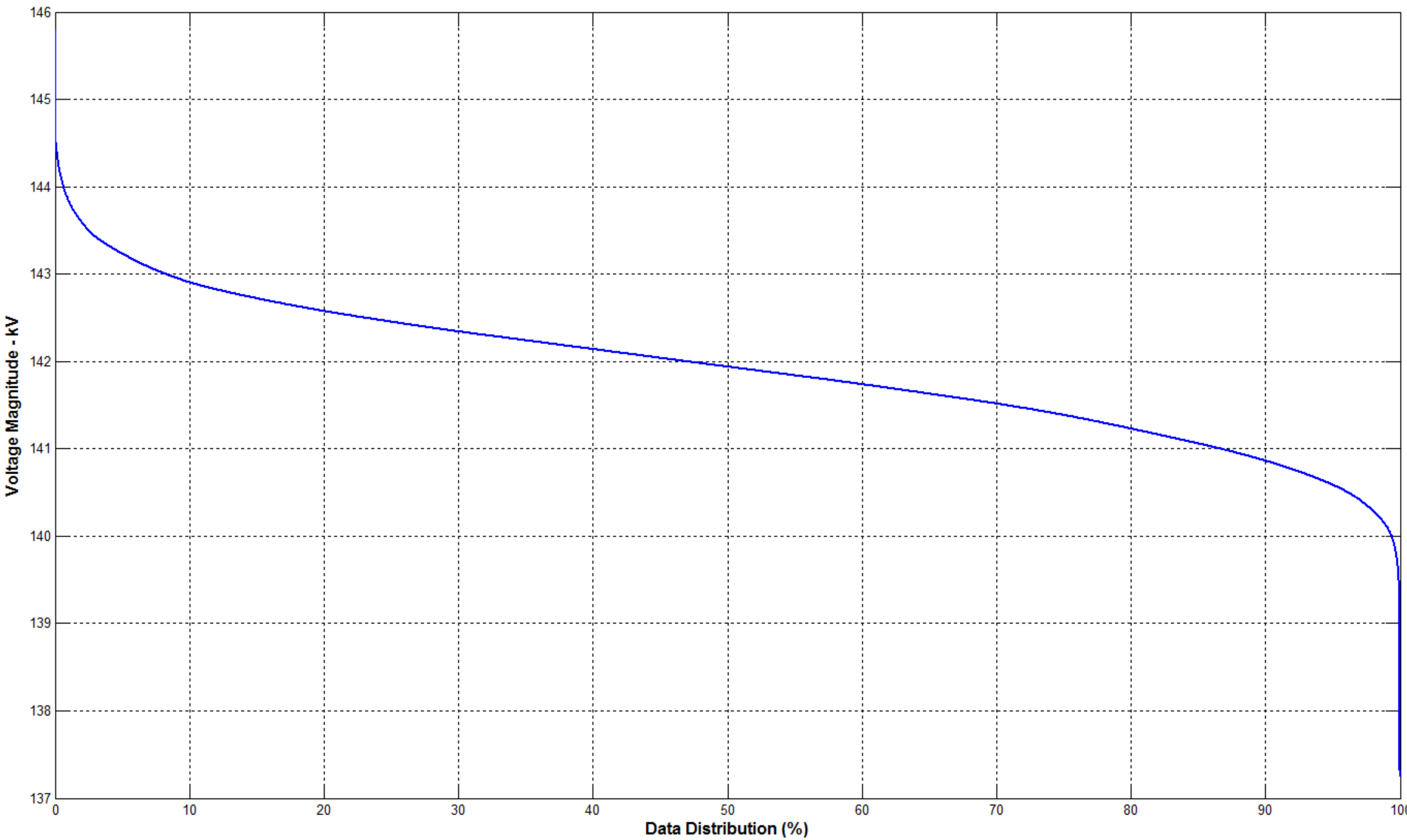
North 5 – Voltage Magnitude



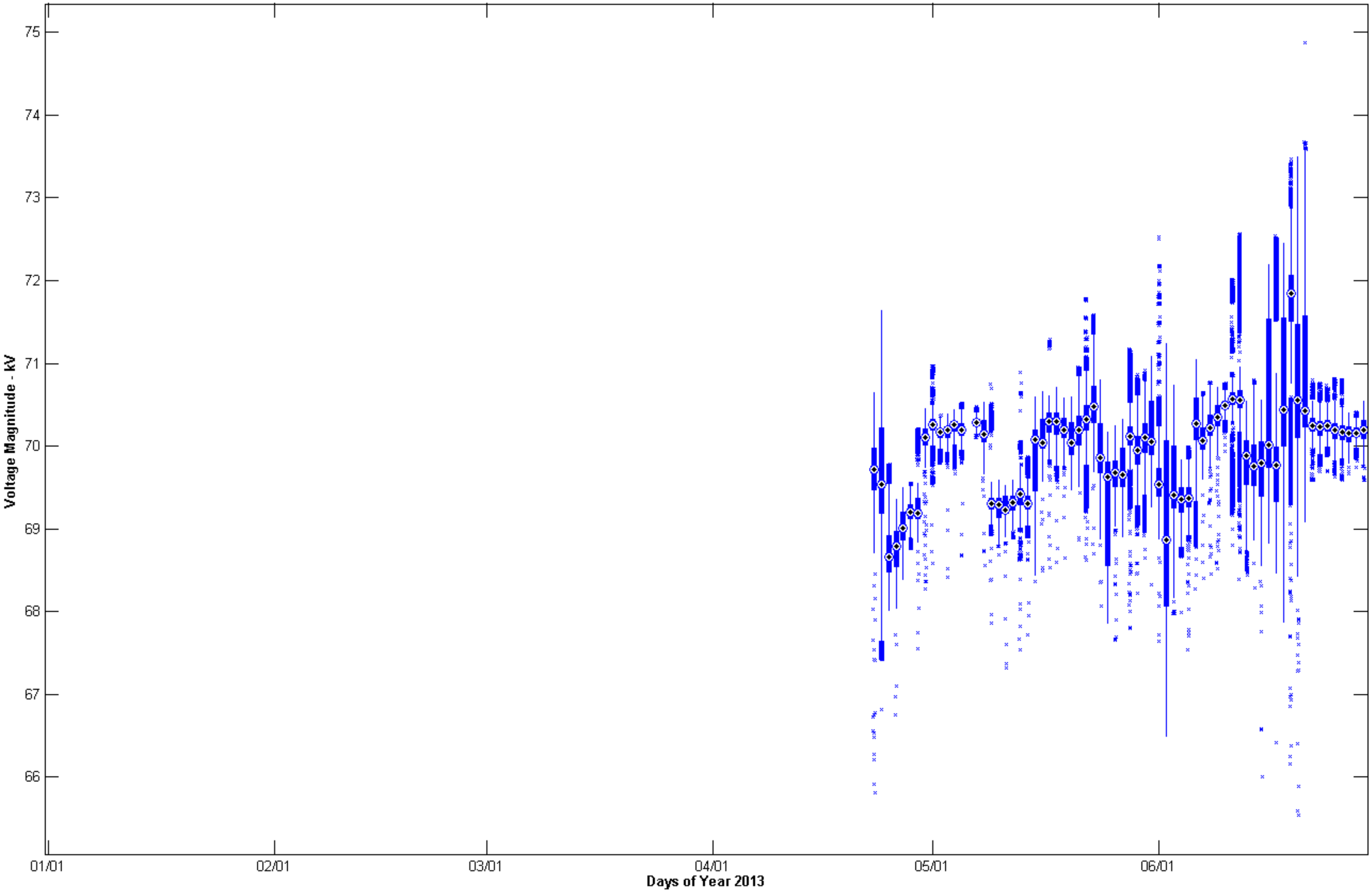
North 6 – Voltage Magnitude



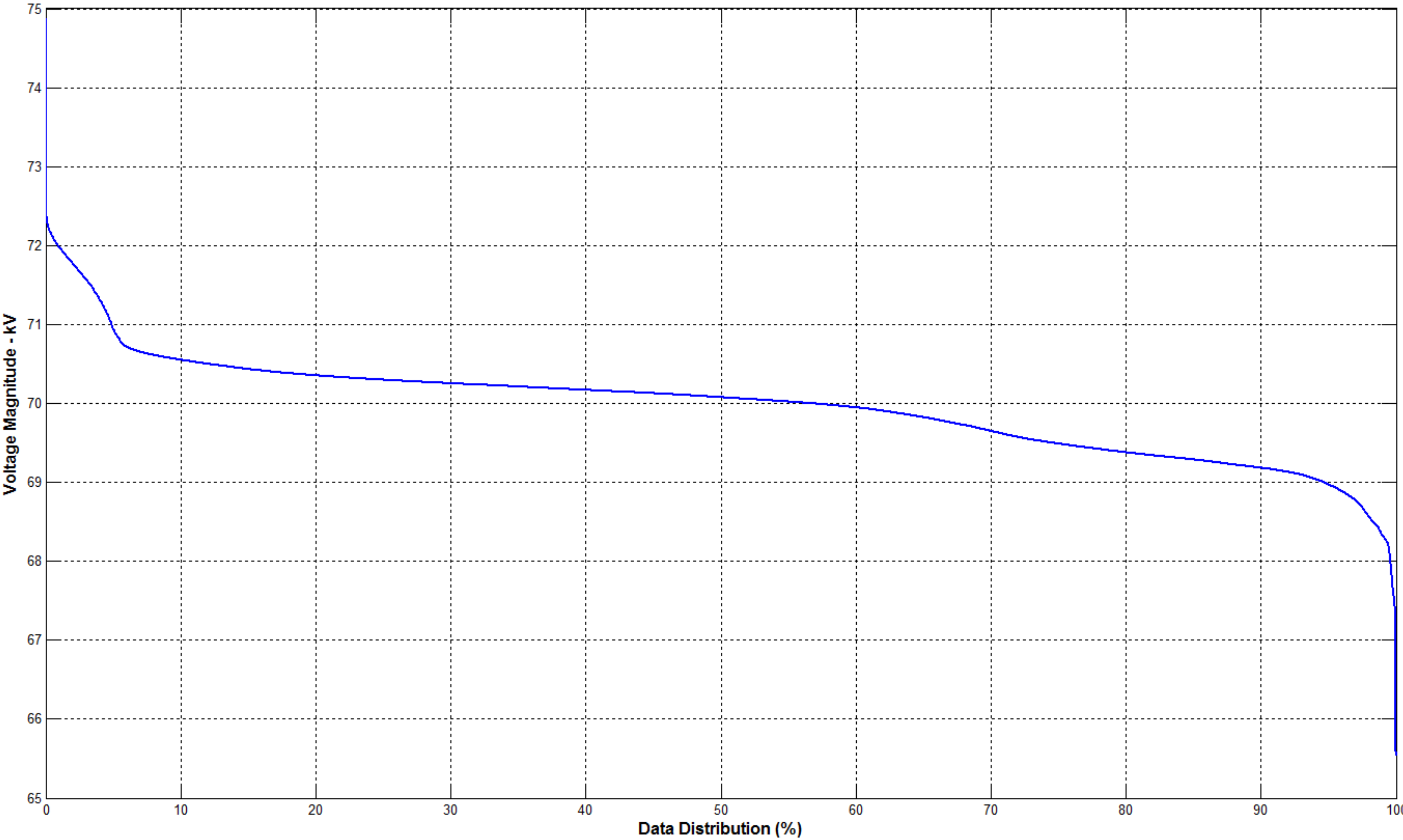
North 6 – Voltage Magnitude



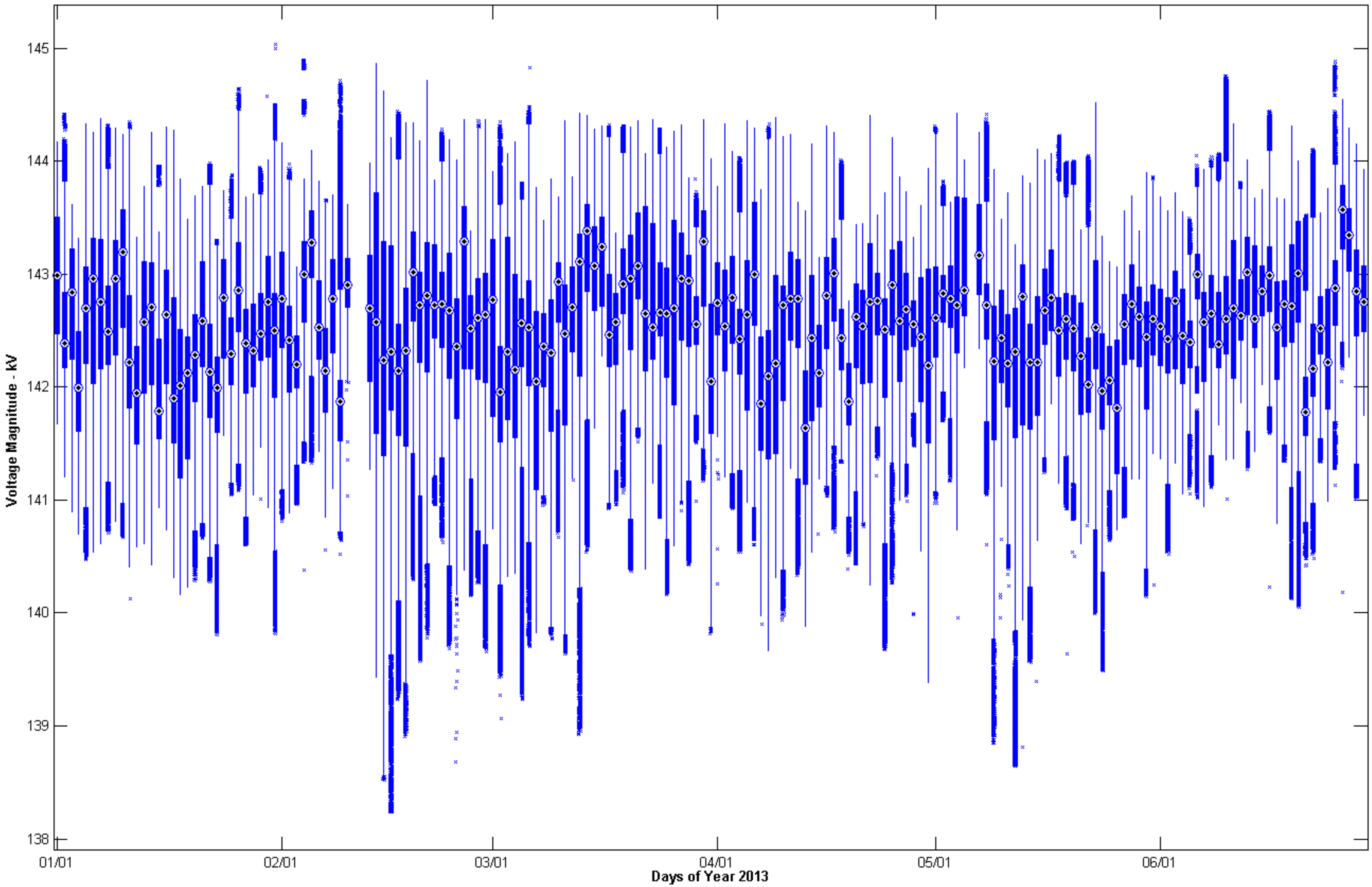
FarWest 2 – Voltage Magnitude



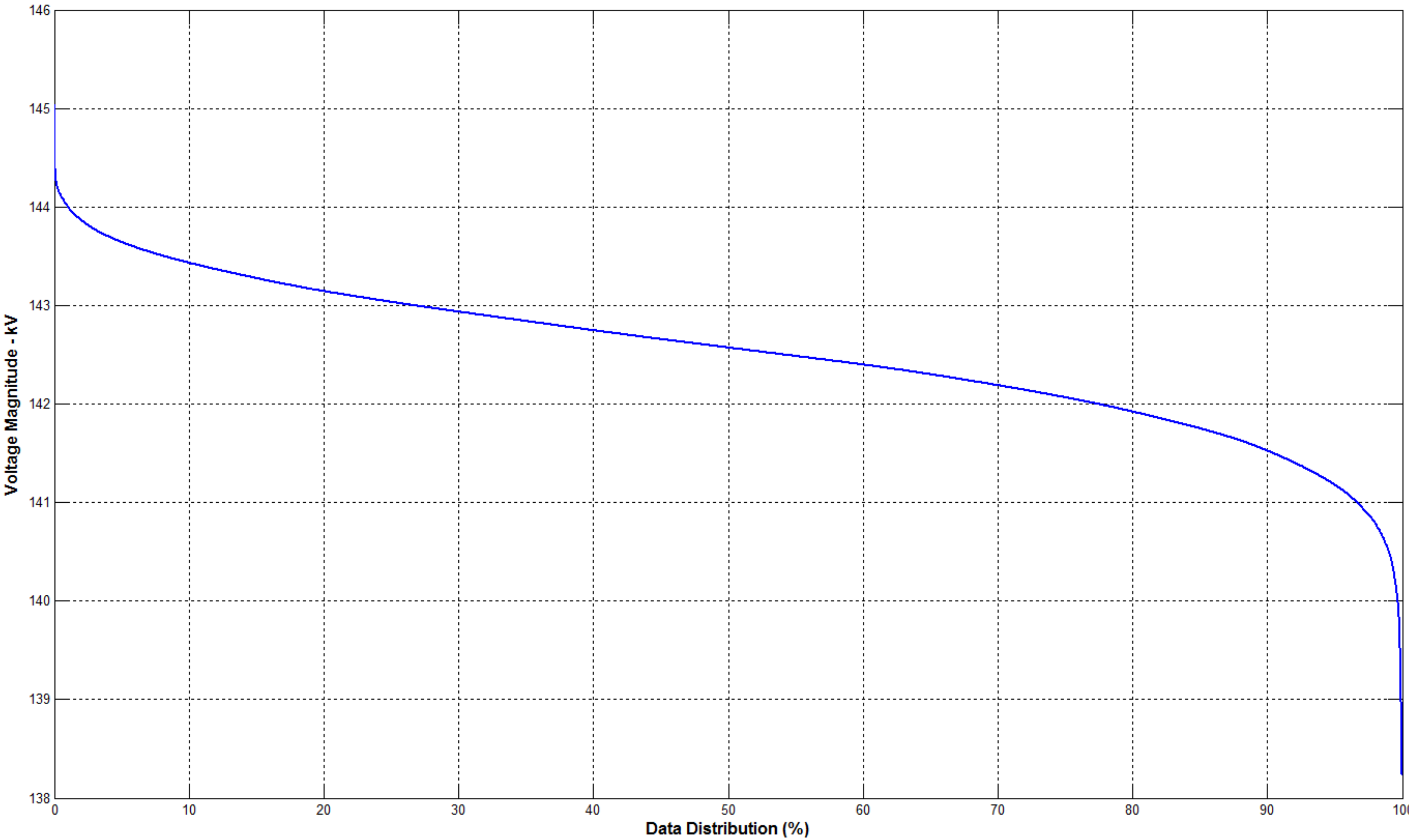
FarWest 2 – Voltage Magnitude



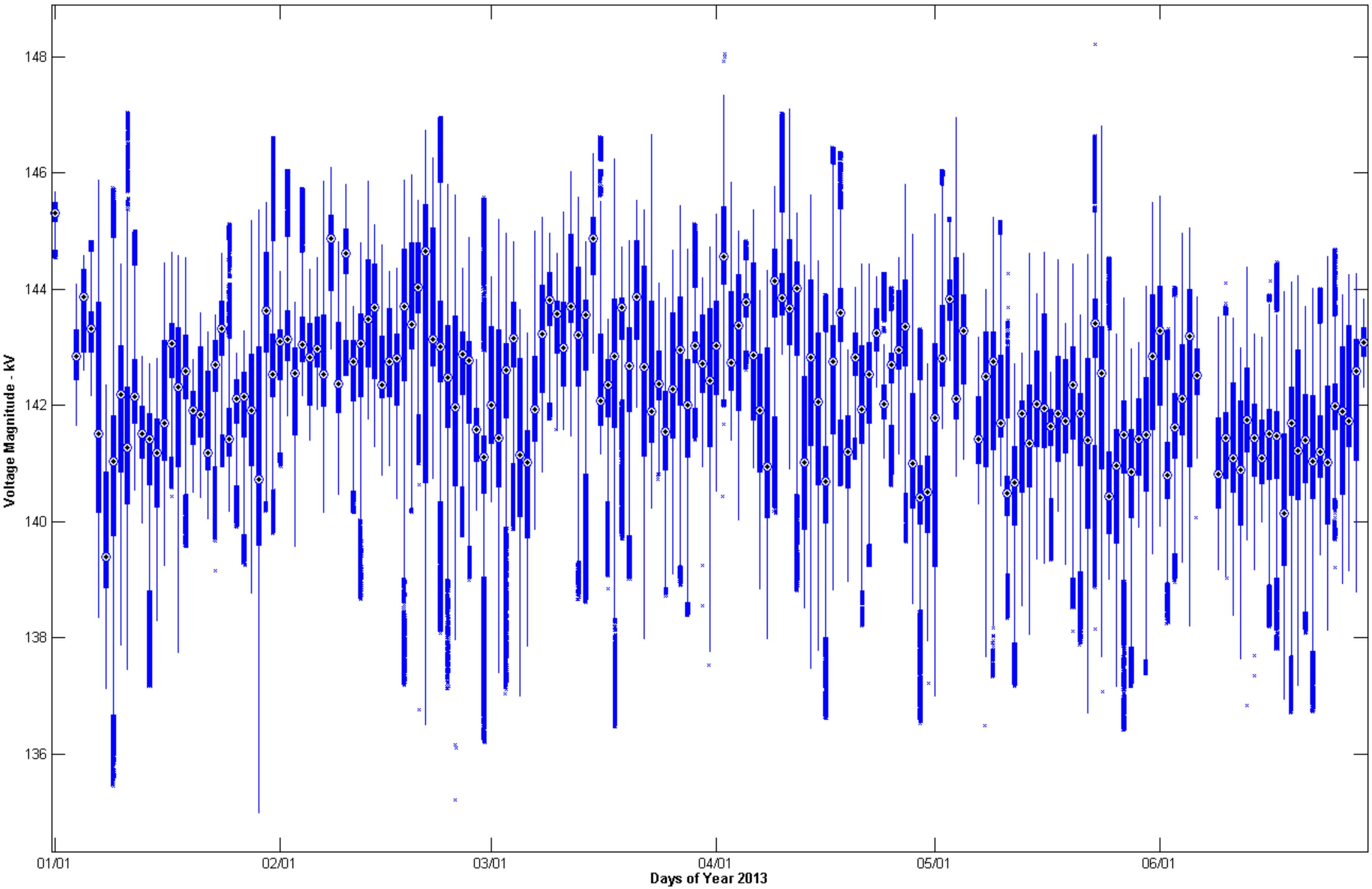
North 7 – Voltage Magnitude



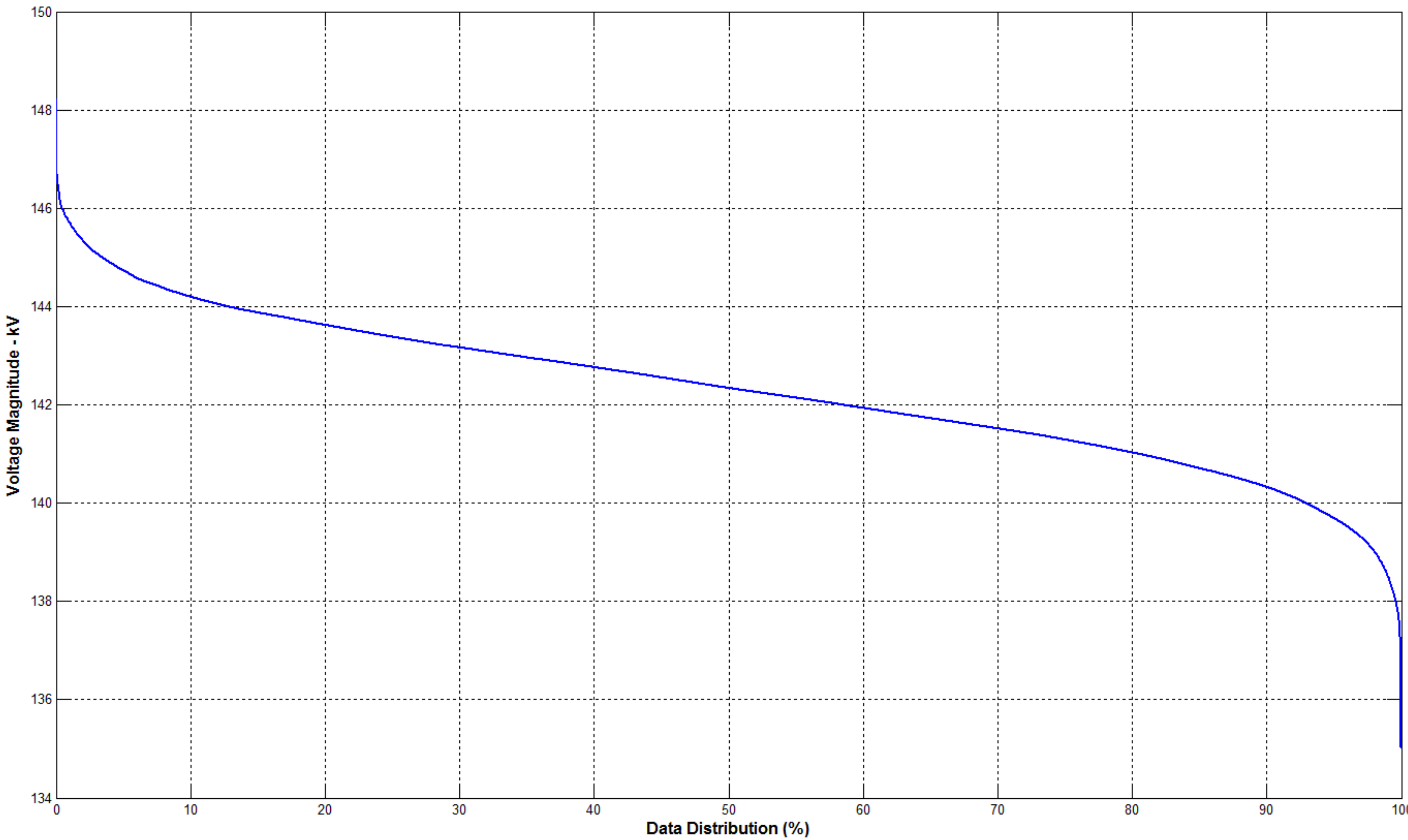
North 7 – Voltage Magnitude



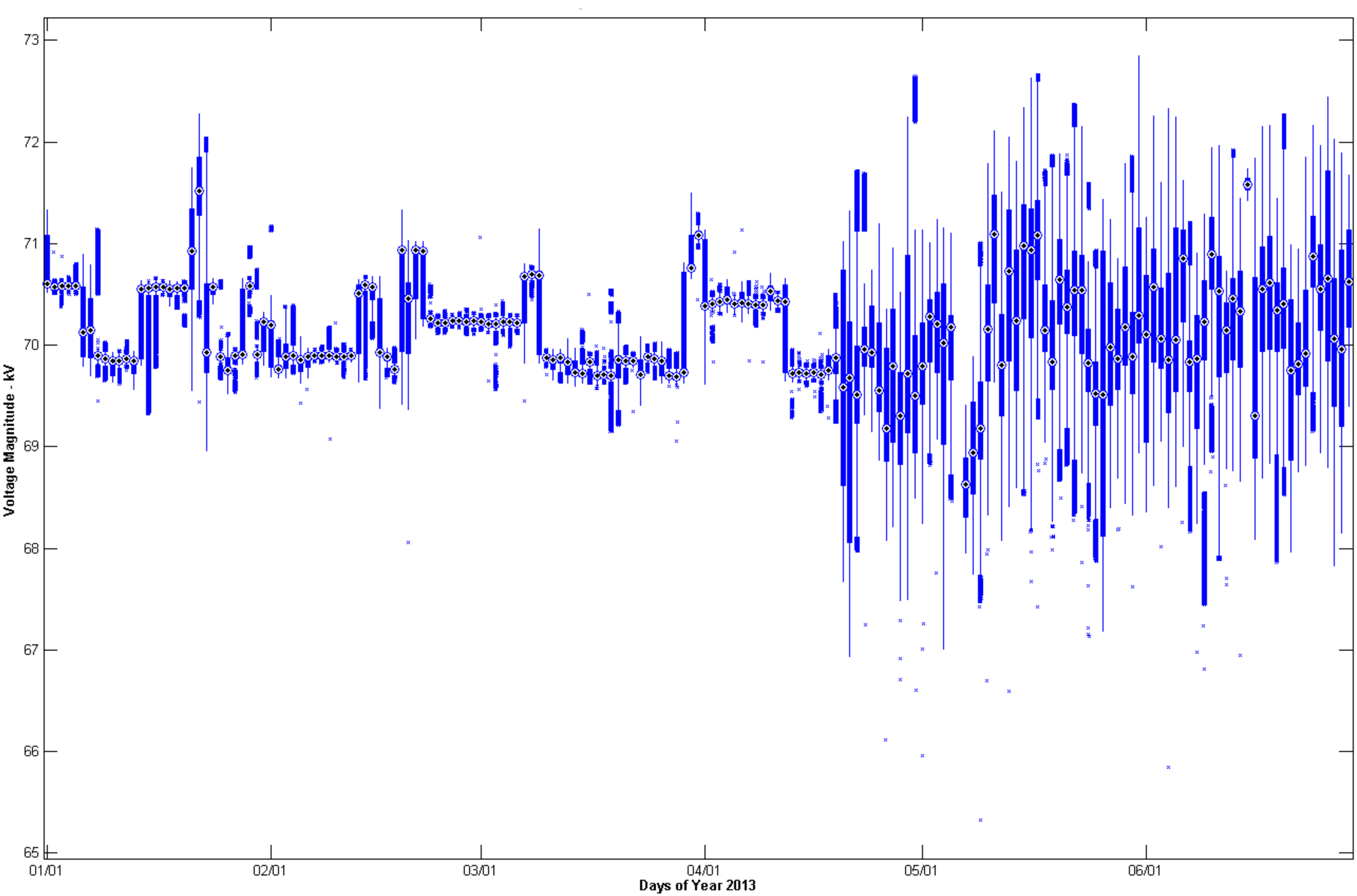
West 4 – Voltage Magnitude



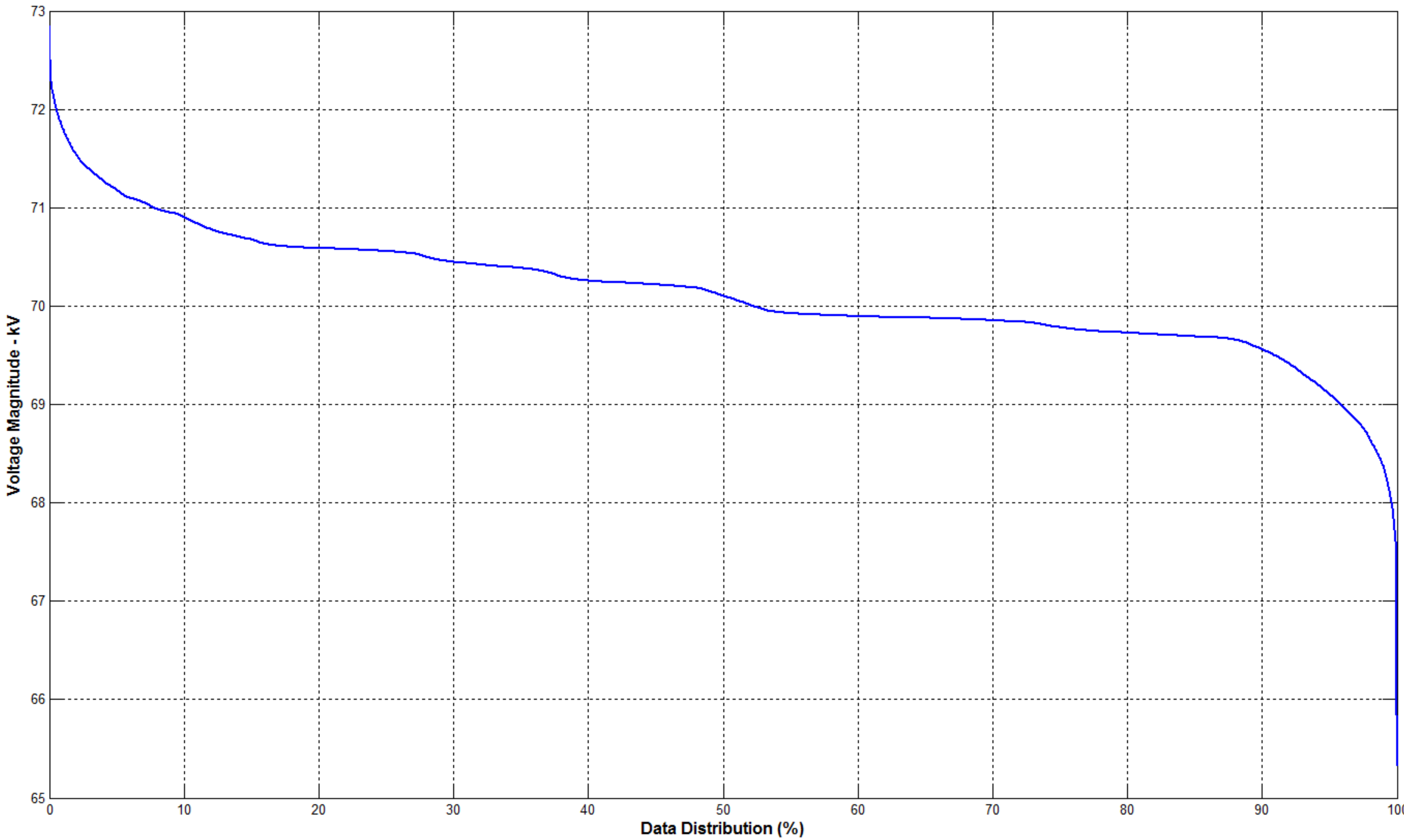
West 4 – Voltage Magnitude



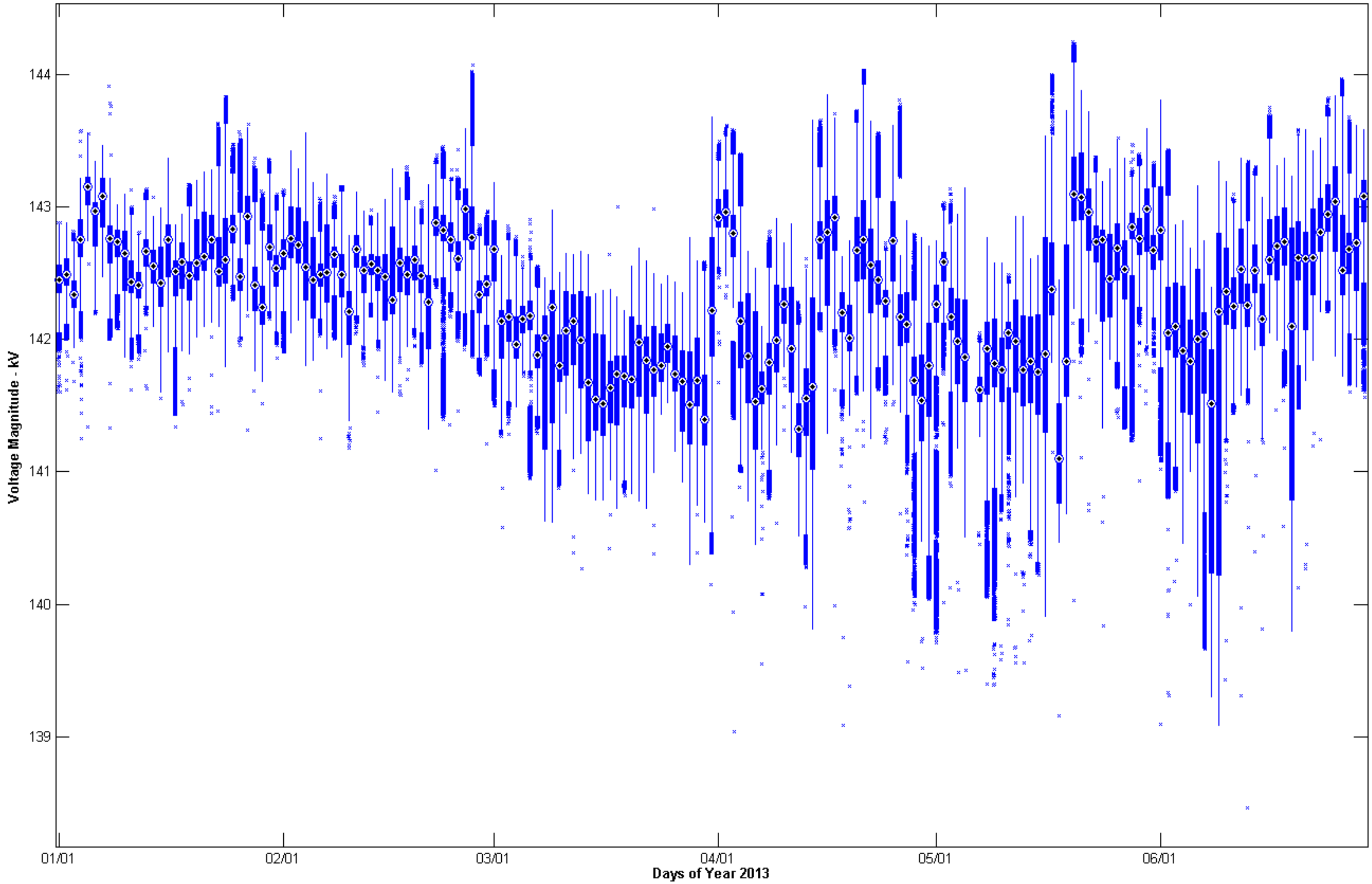
Coast 2 – Voltage Magnitude



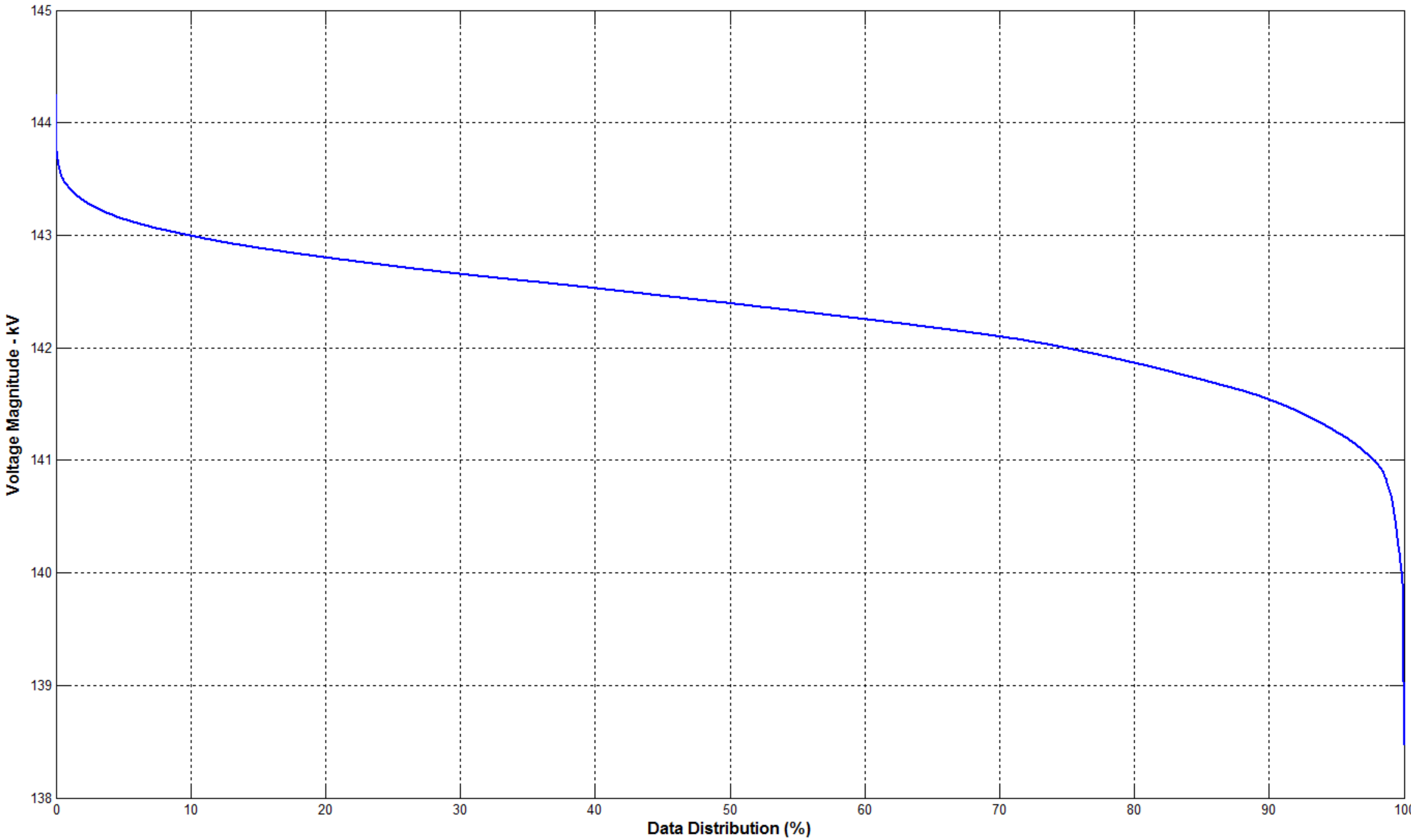
Coast 2 – Voltage Magnitude



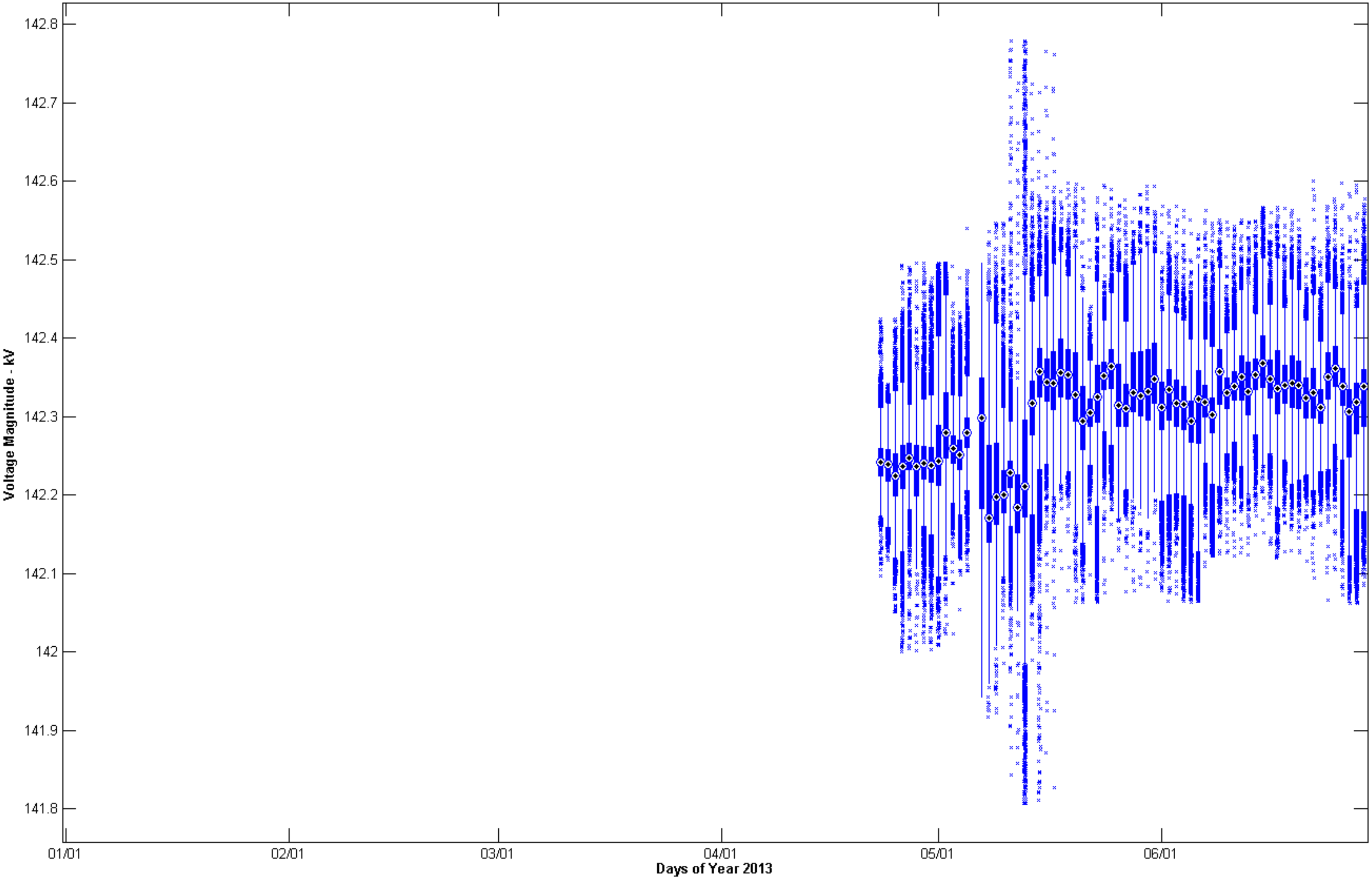
Coast 1 – Voltage Magnitude



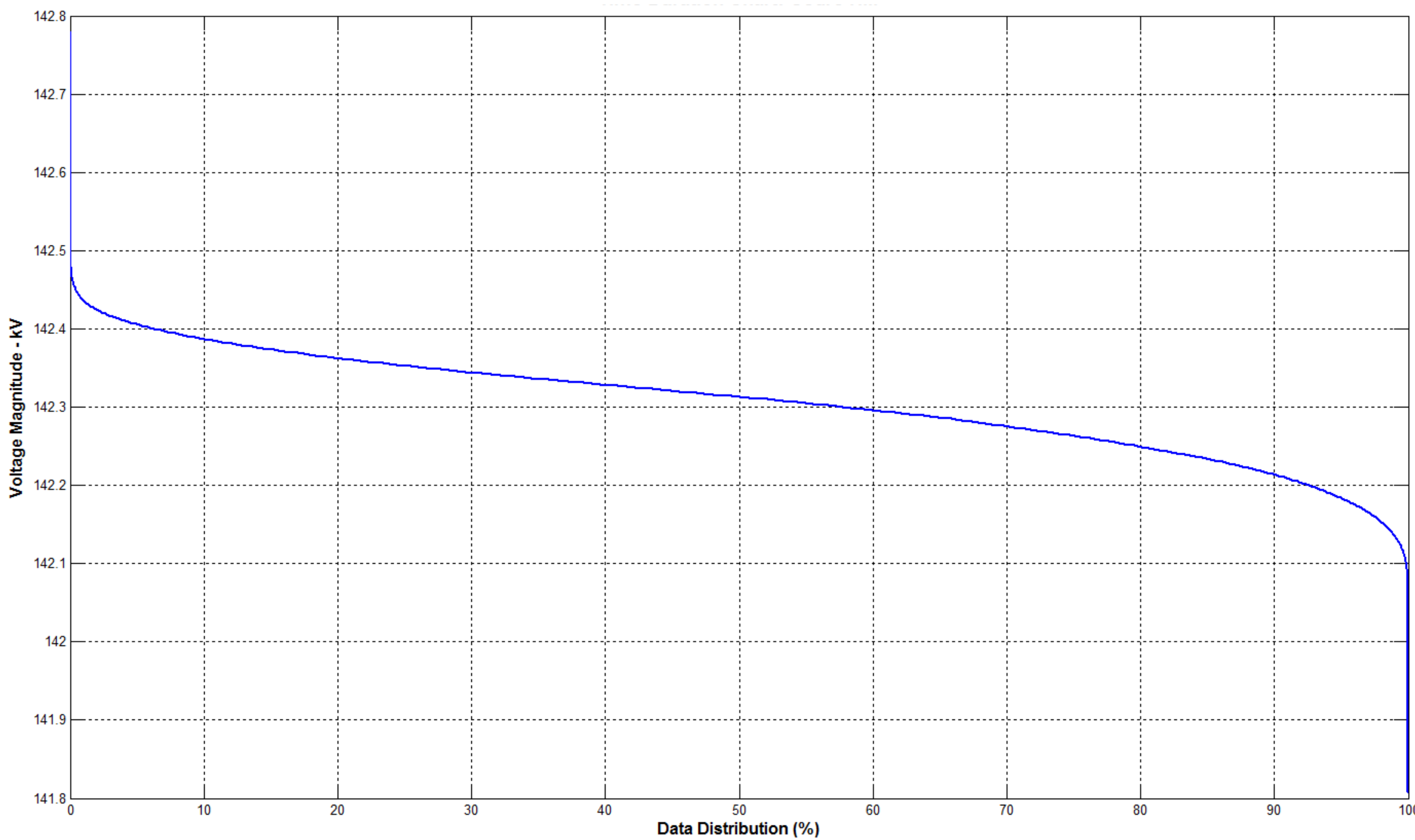
Coast 1 – Voltage Magnitude



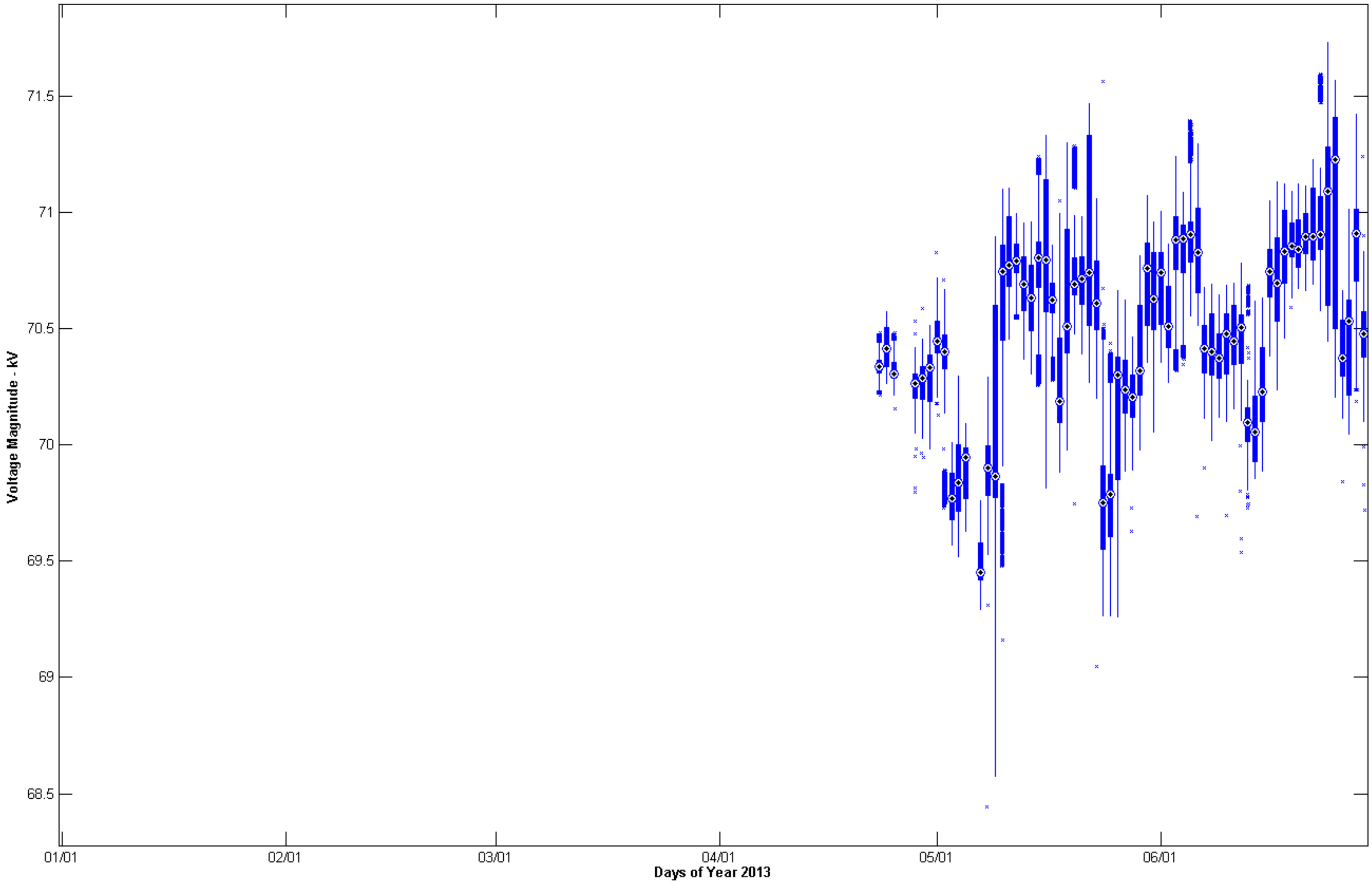
South 3 – Voltage Magnitude



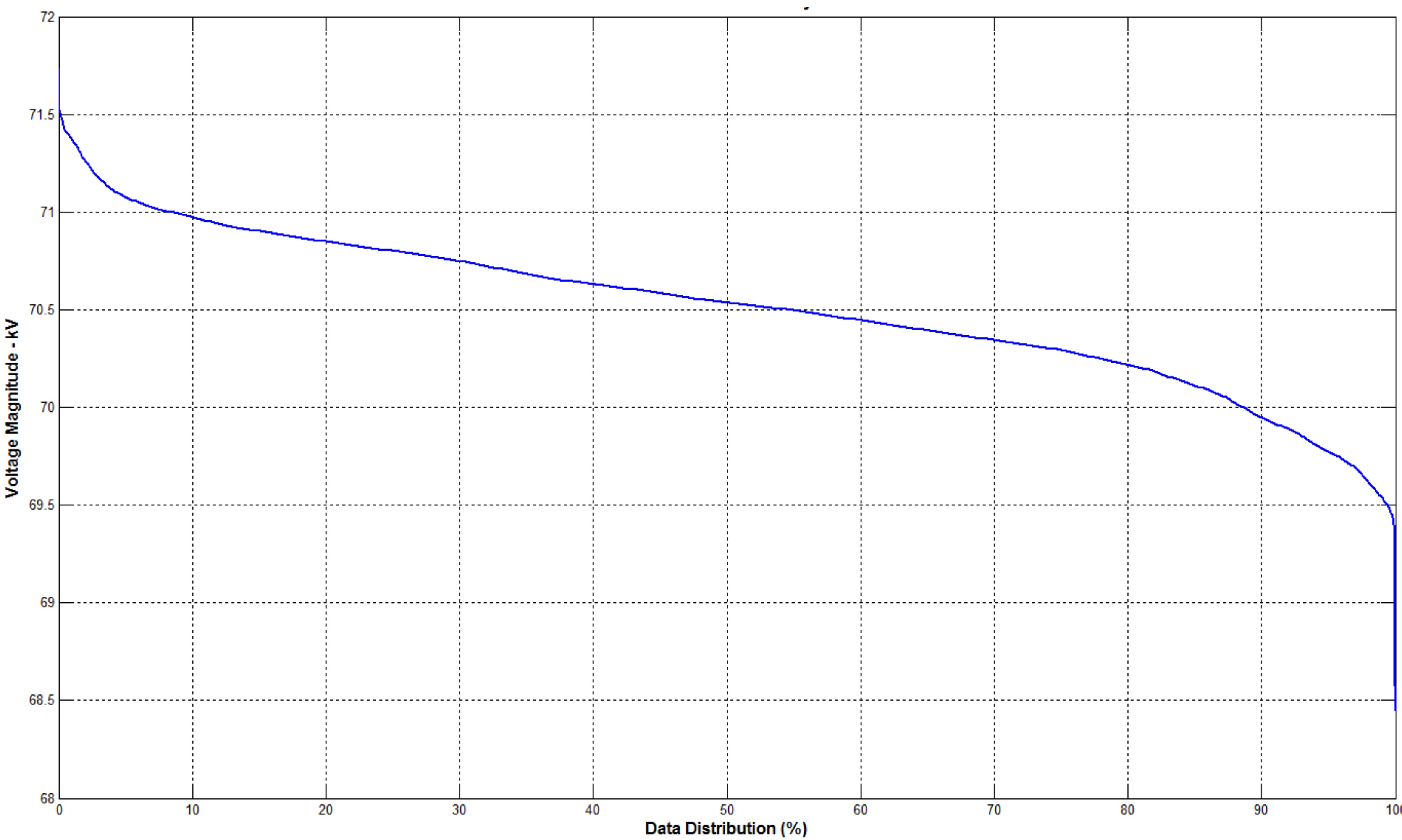
South 3 – Voltage Magnitude



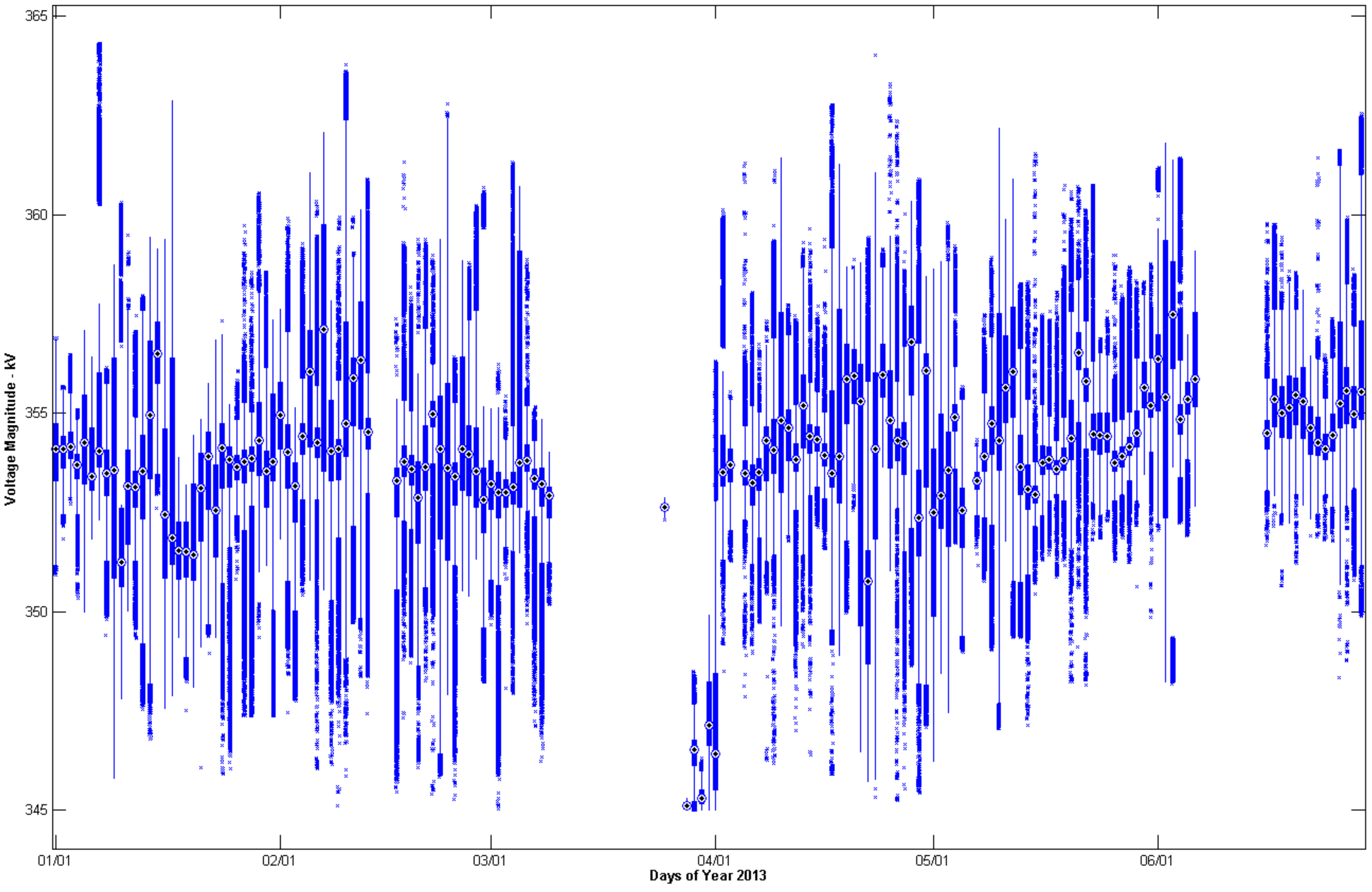
South 5 – Voltage Magnitude



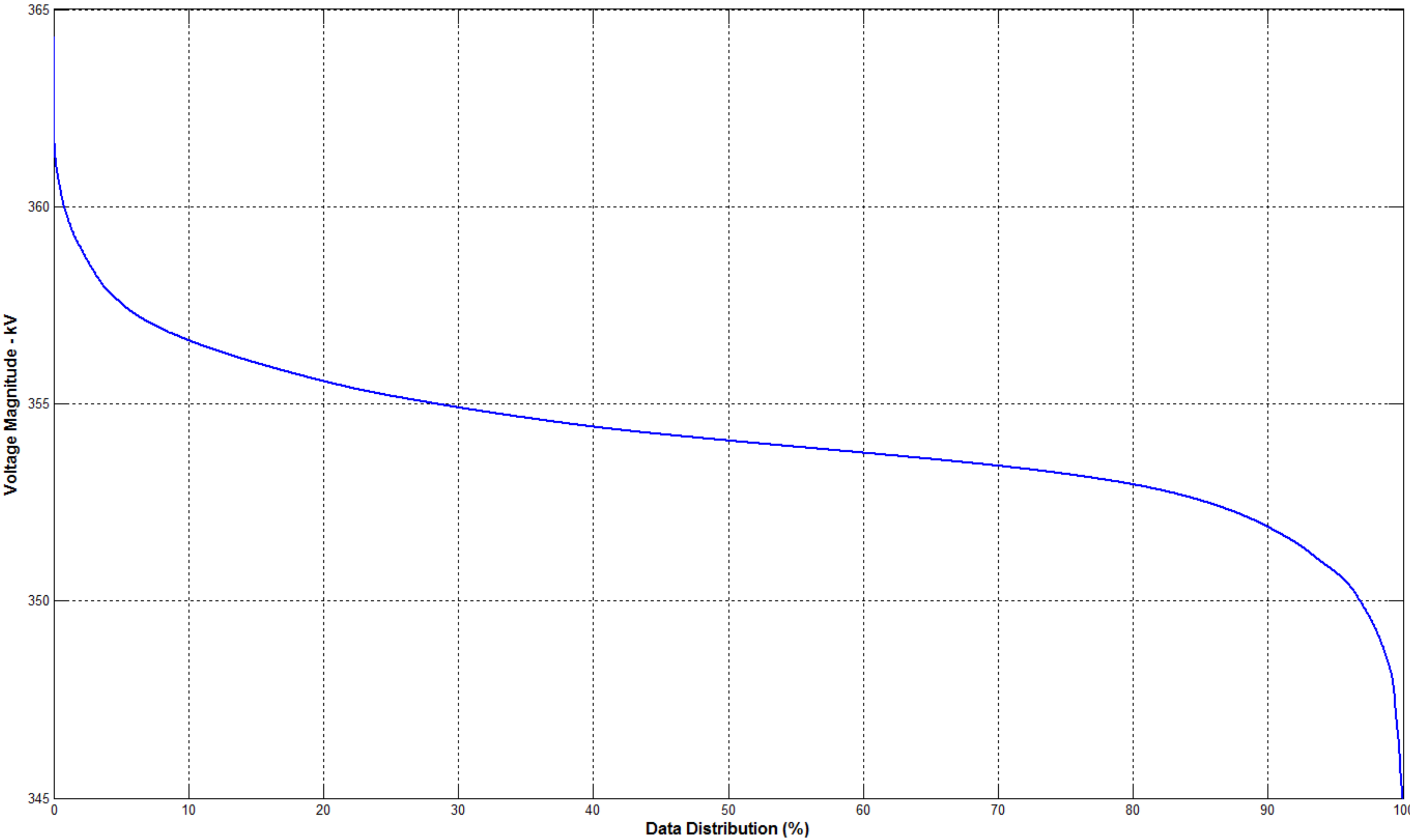
South 5 – Voltage Magnitude



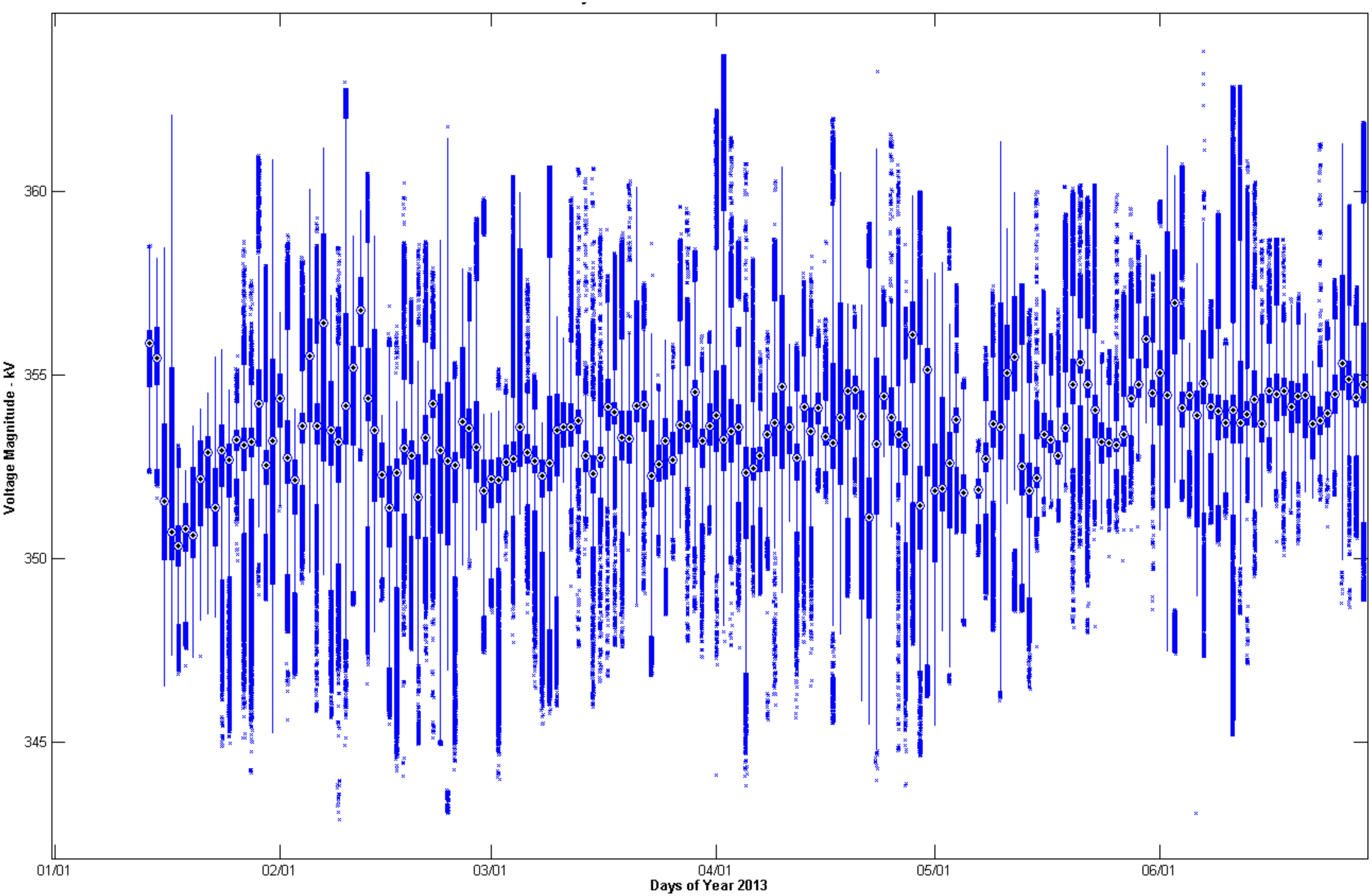
Coast 4 – Voltage Magnitude



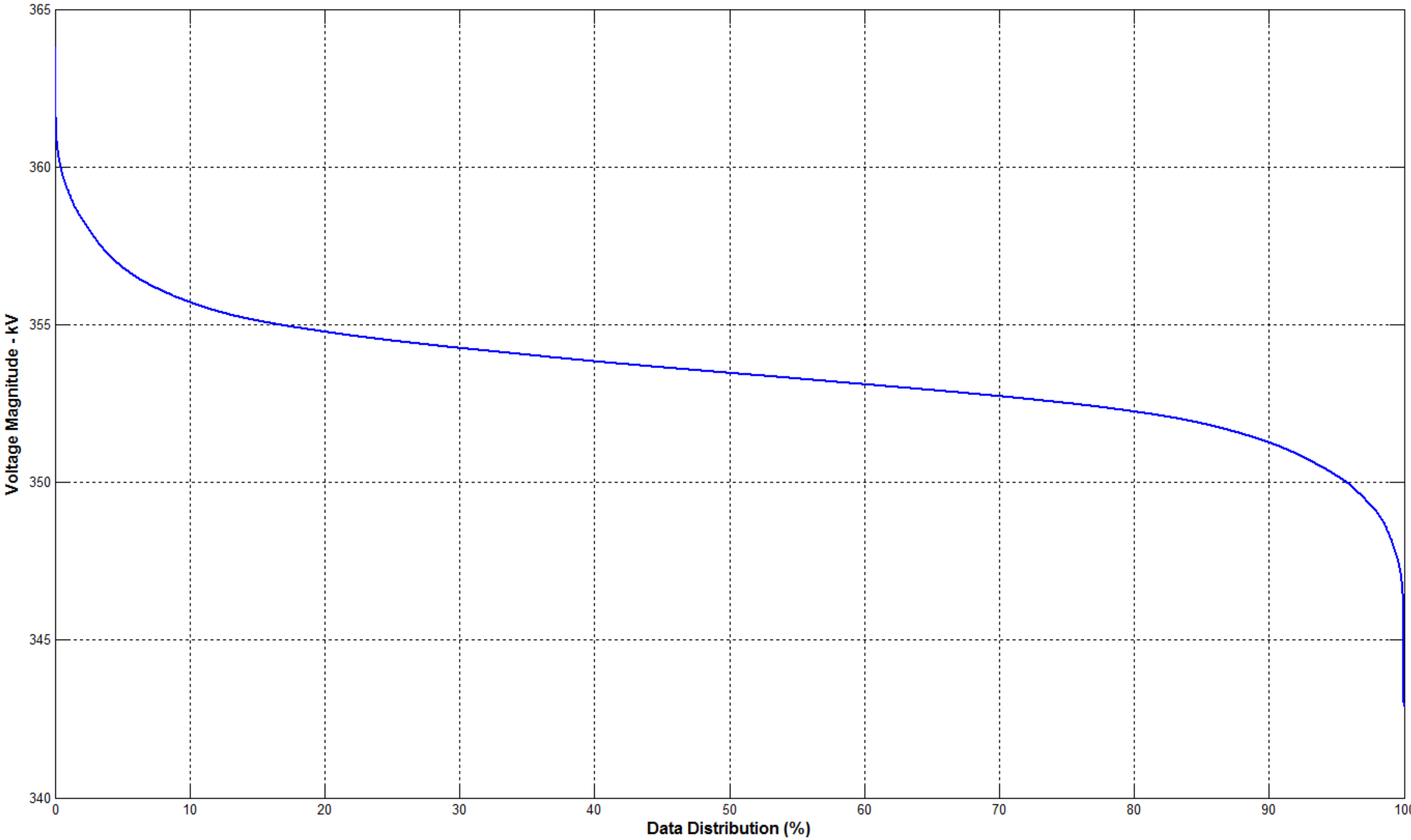
Coast 4 – Voltage Magnitude



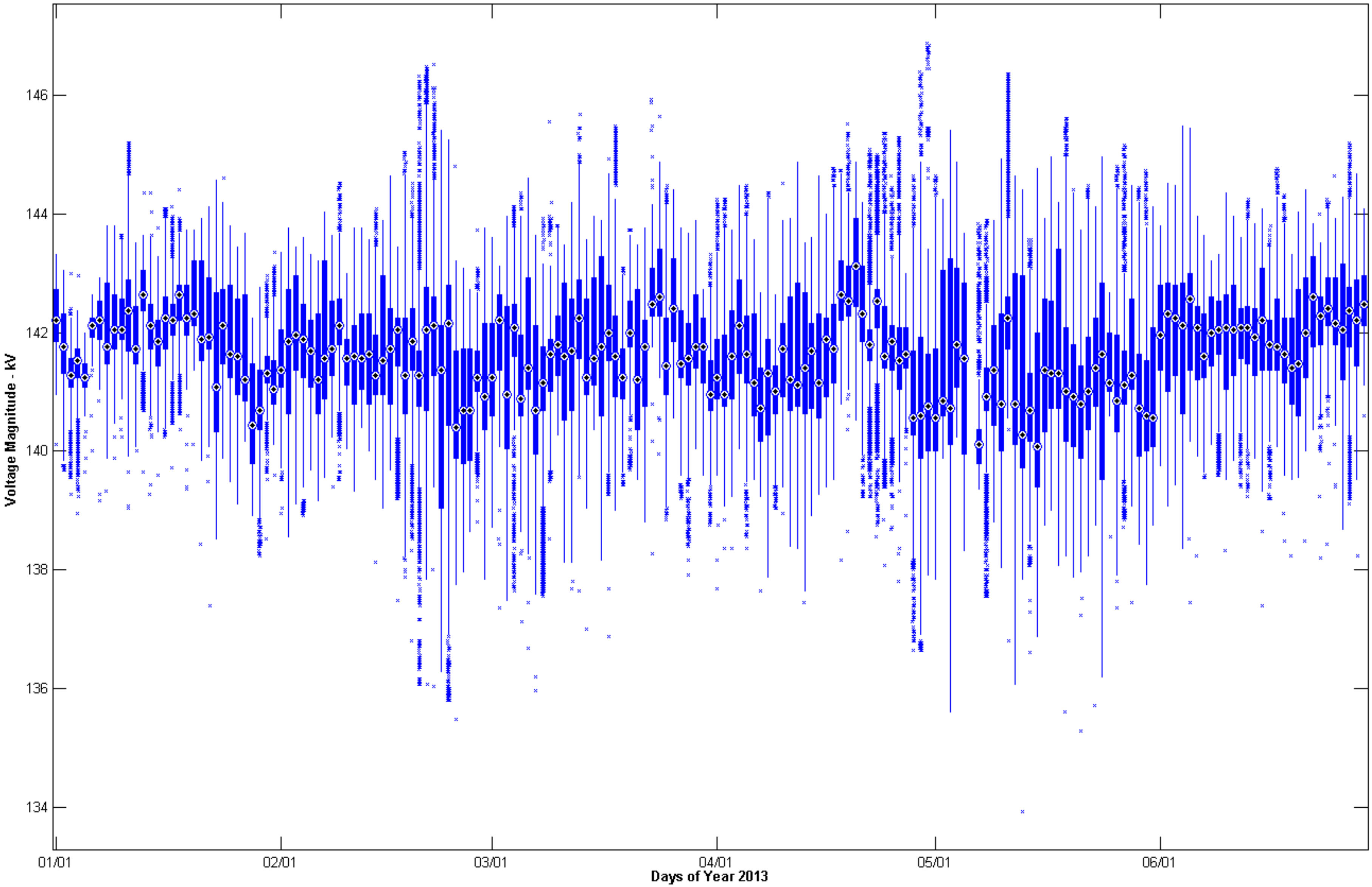
Coast 3 – Voltage Magnitude



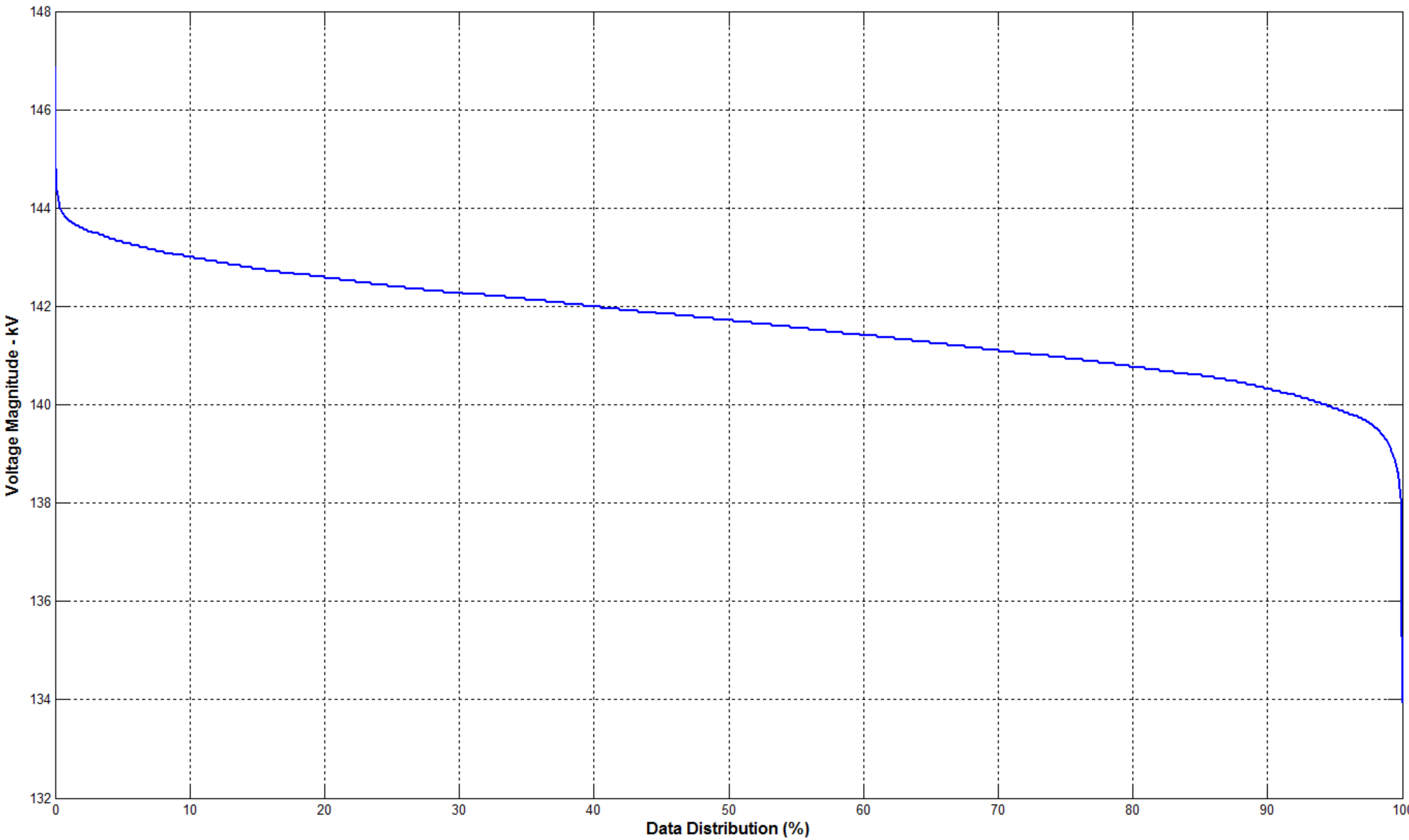
Coast 3 – Voltage Magnitude



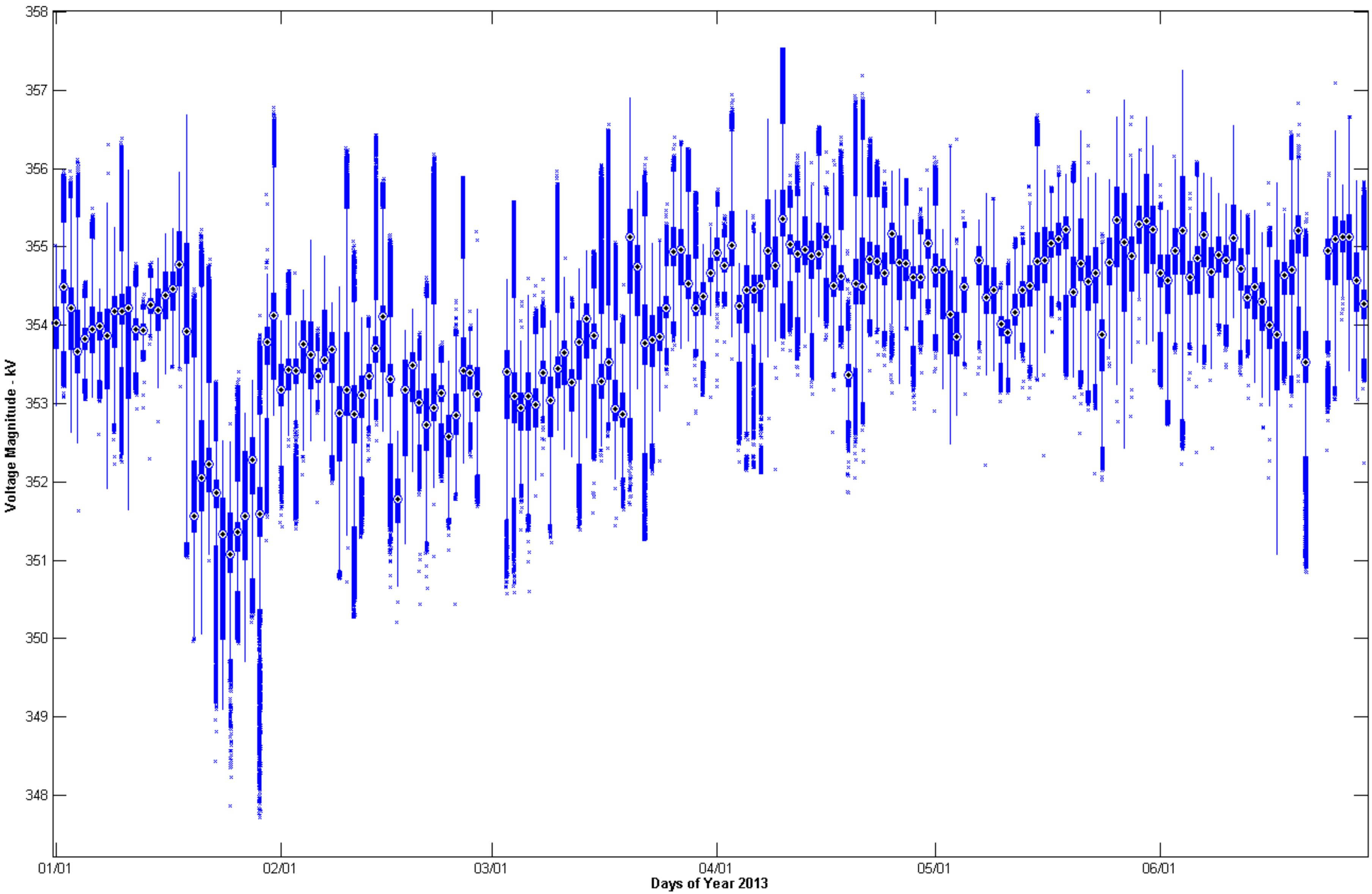
South 13 – Voltage Magnitude



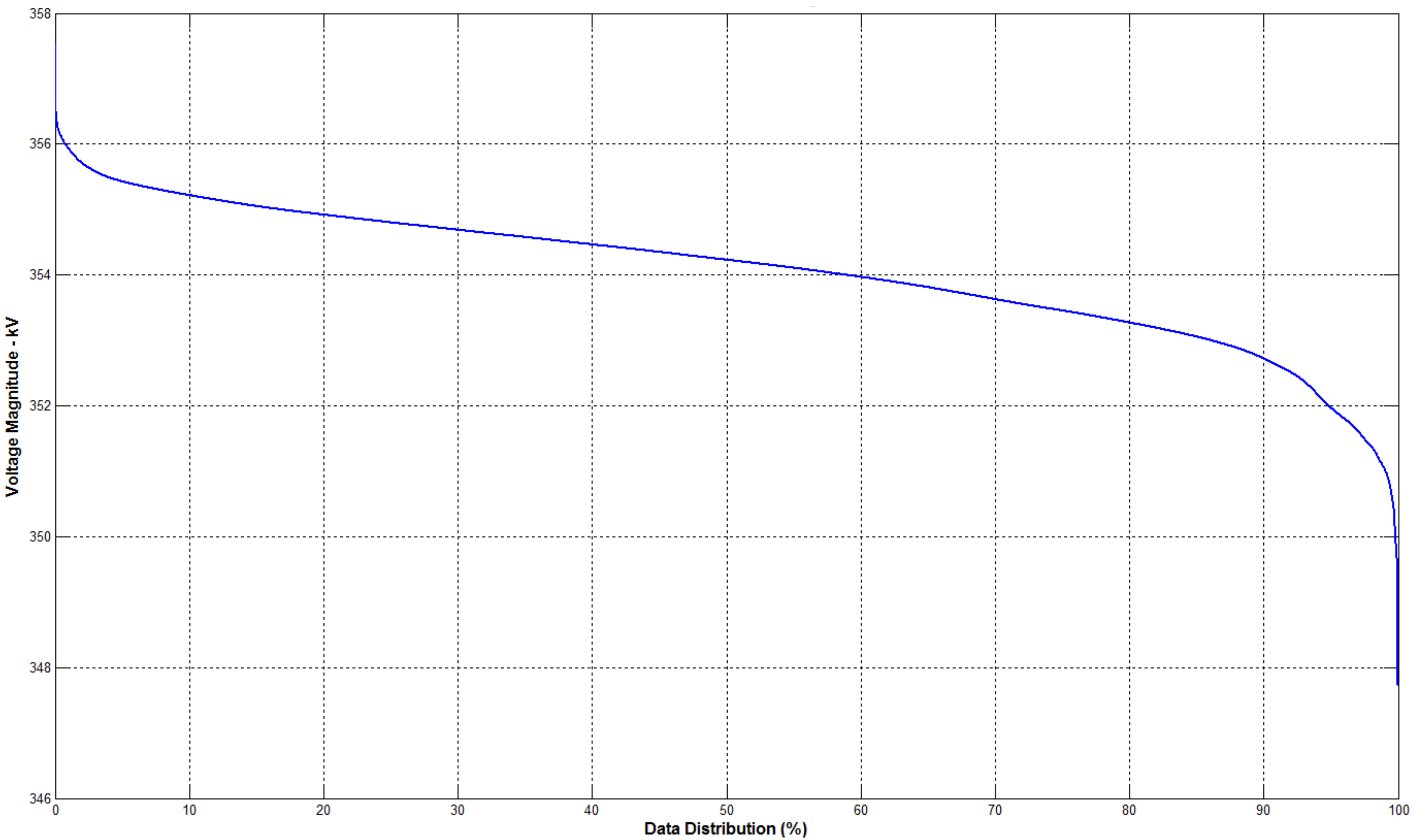
South 13 – Voltage Magnitude



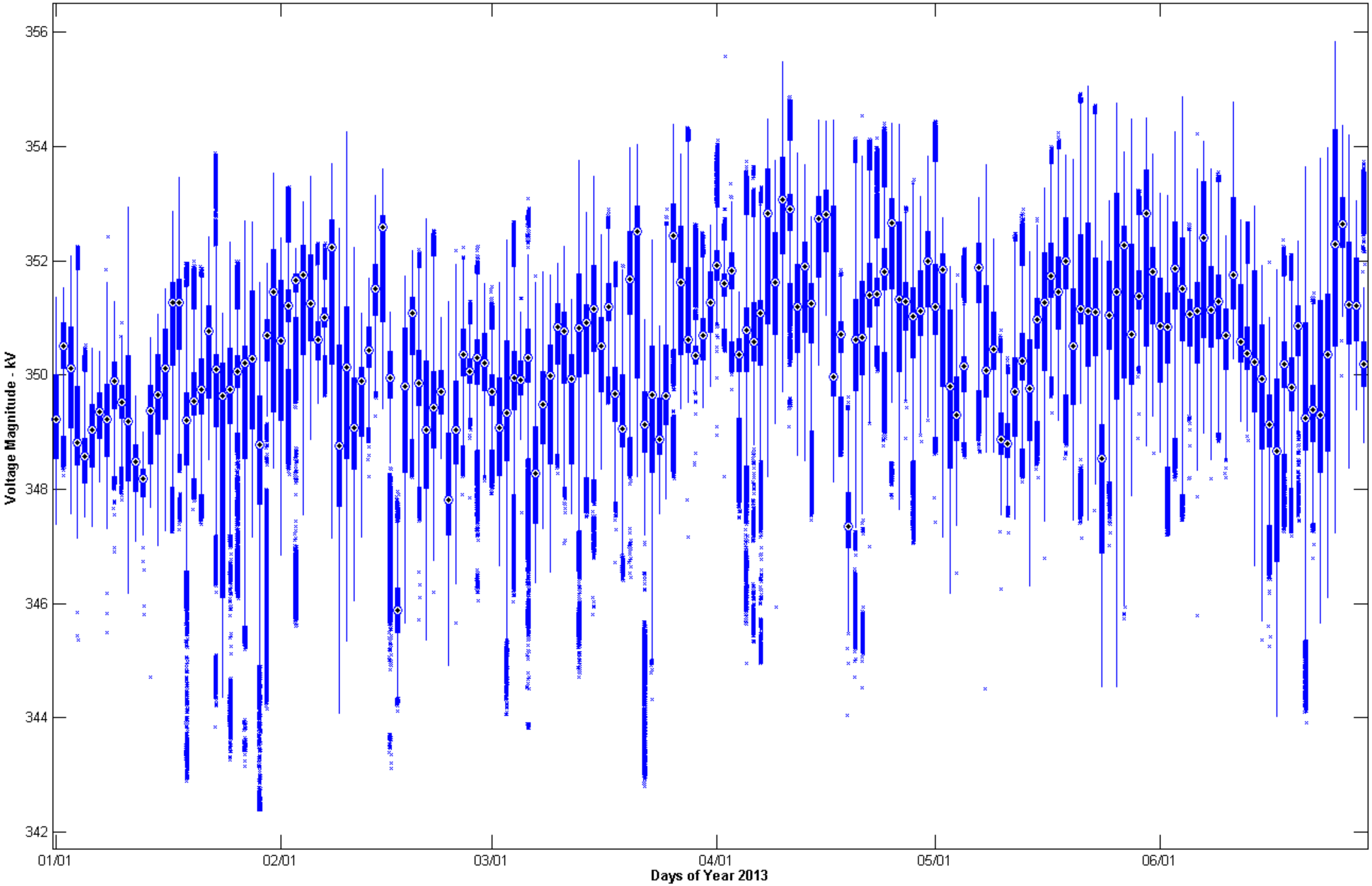
FarWest 4 – Voltage Magnitude



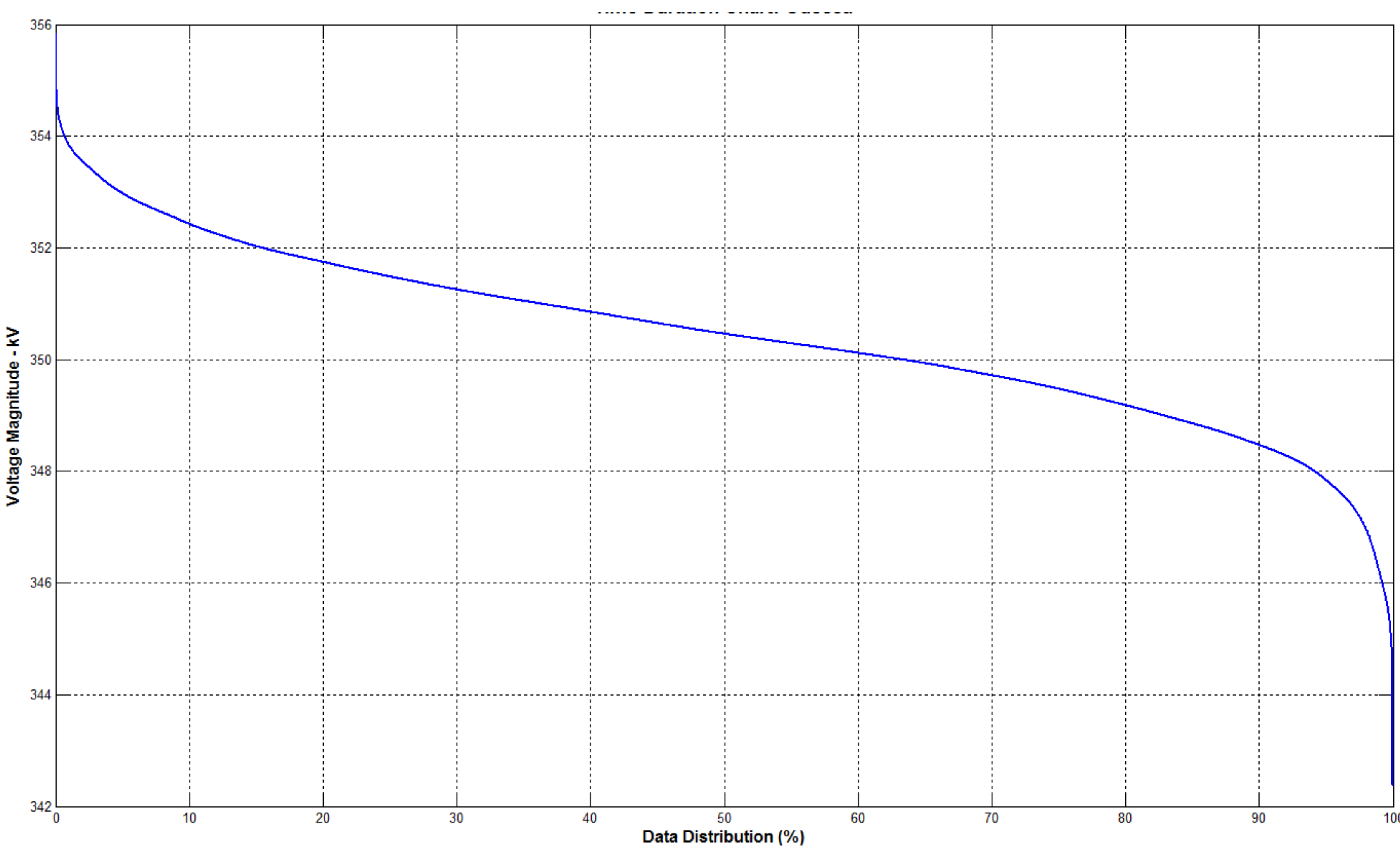
FarWest 4 – Voltage Magnitude



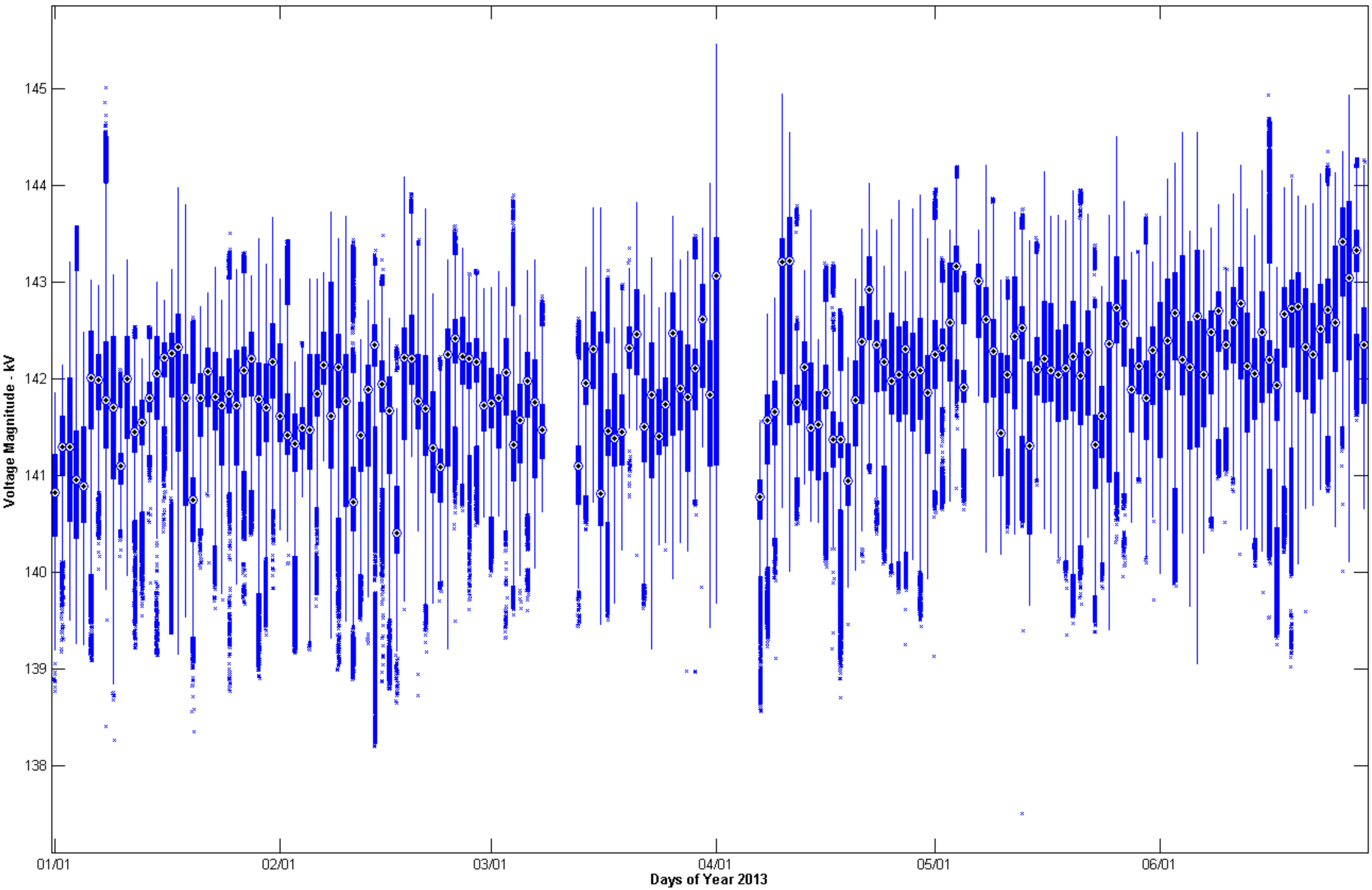
FarWest 7 – Voltage Magnitude



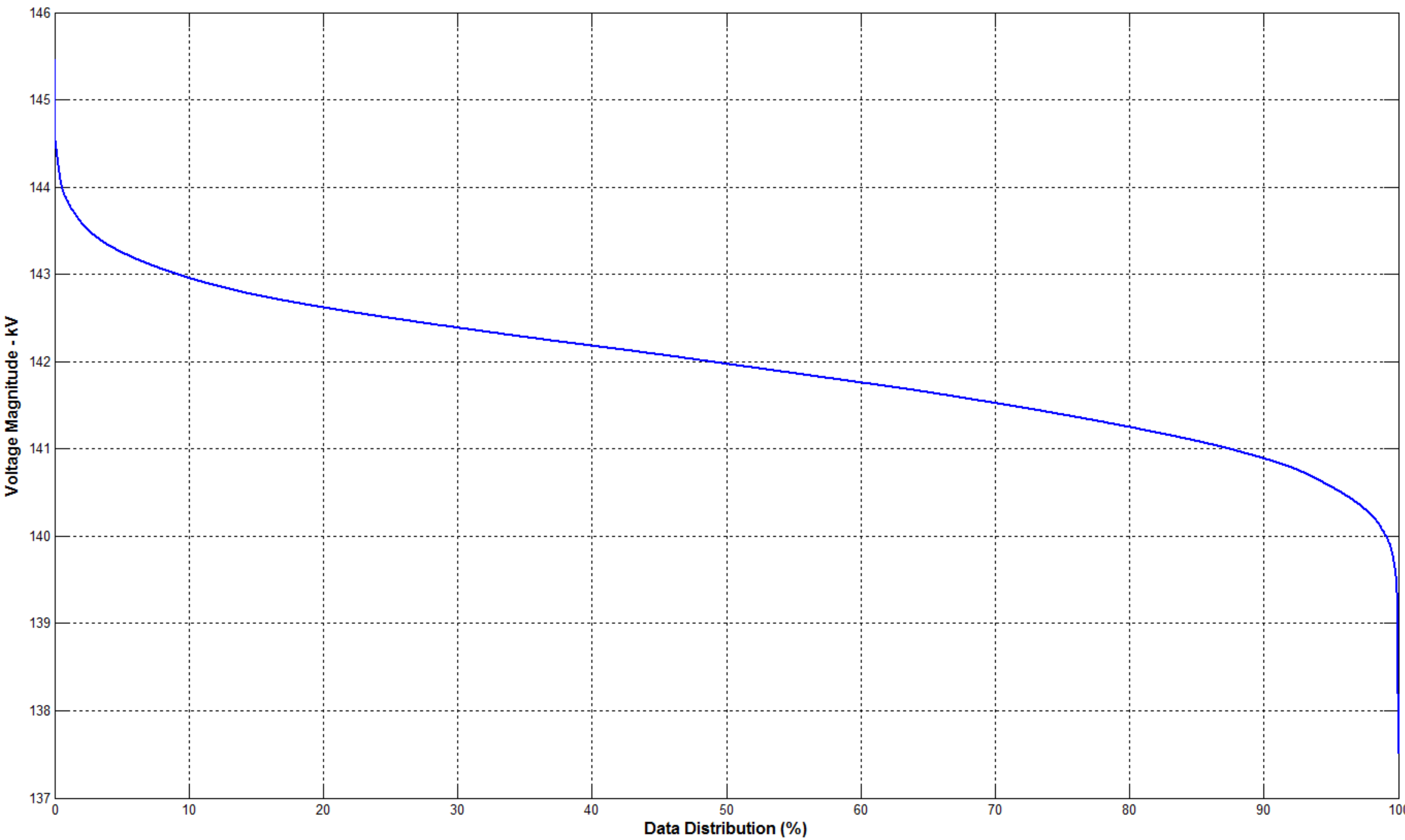
FarWest 7 – Voltage Magnitude



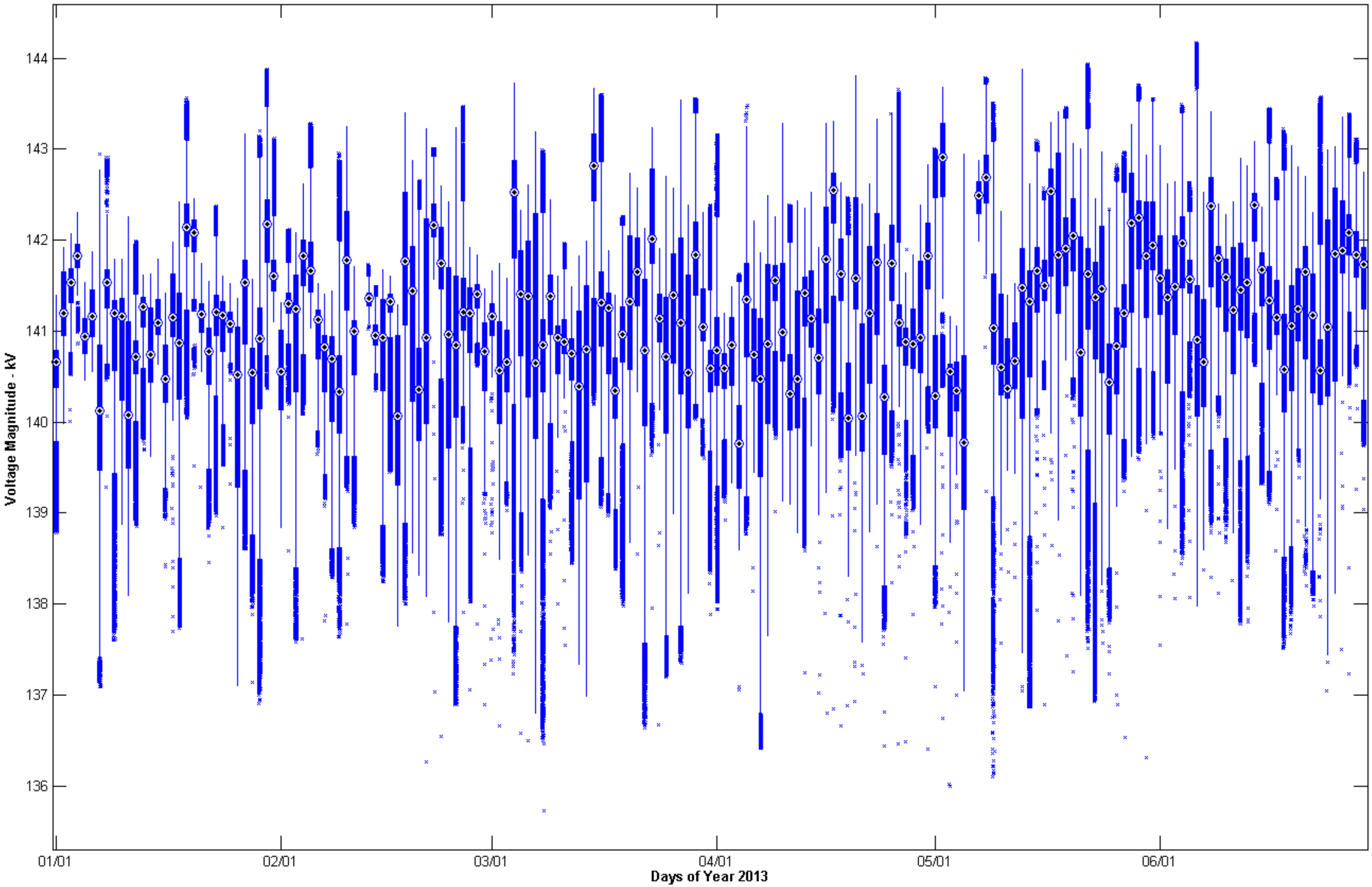
FarWest 8 – Voltage Magnitude



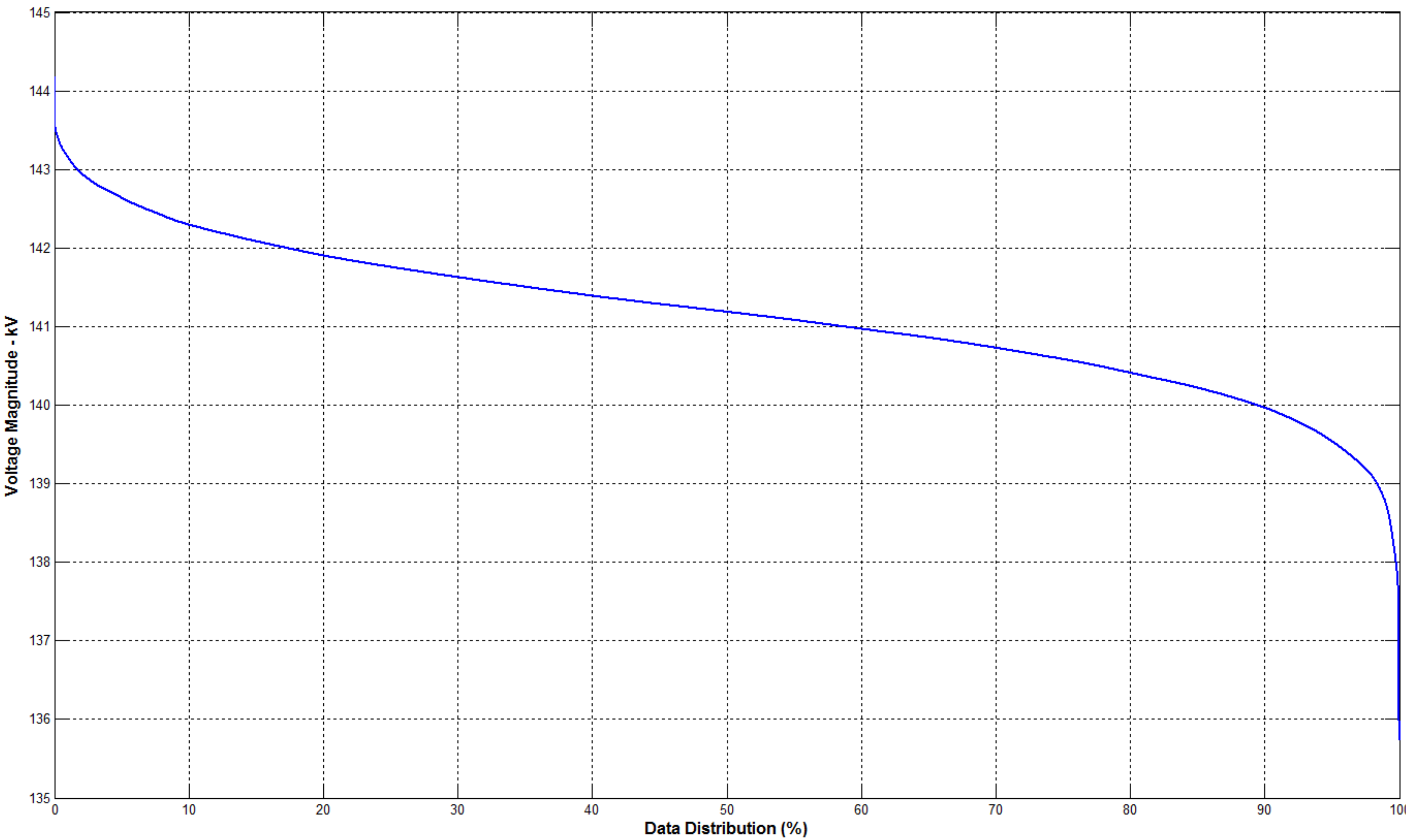
FarWest 8 – Voltage Magnitude



FarWest 9 – Voltage Magnitude



FarWest 9 – Voltage Magnitude



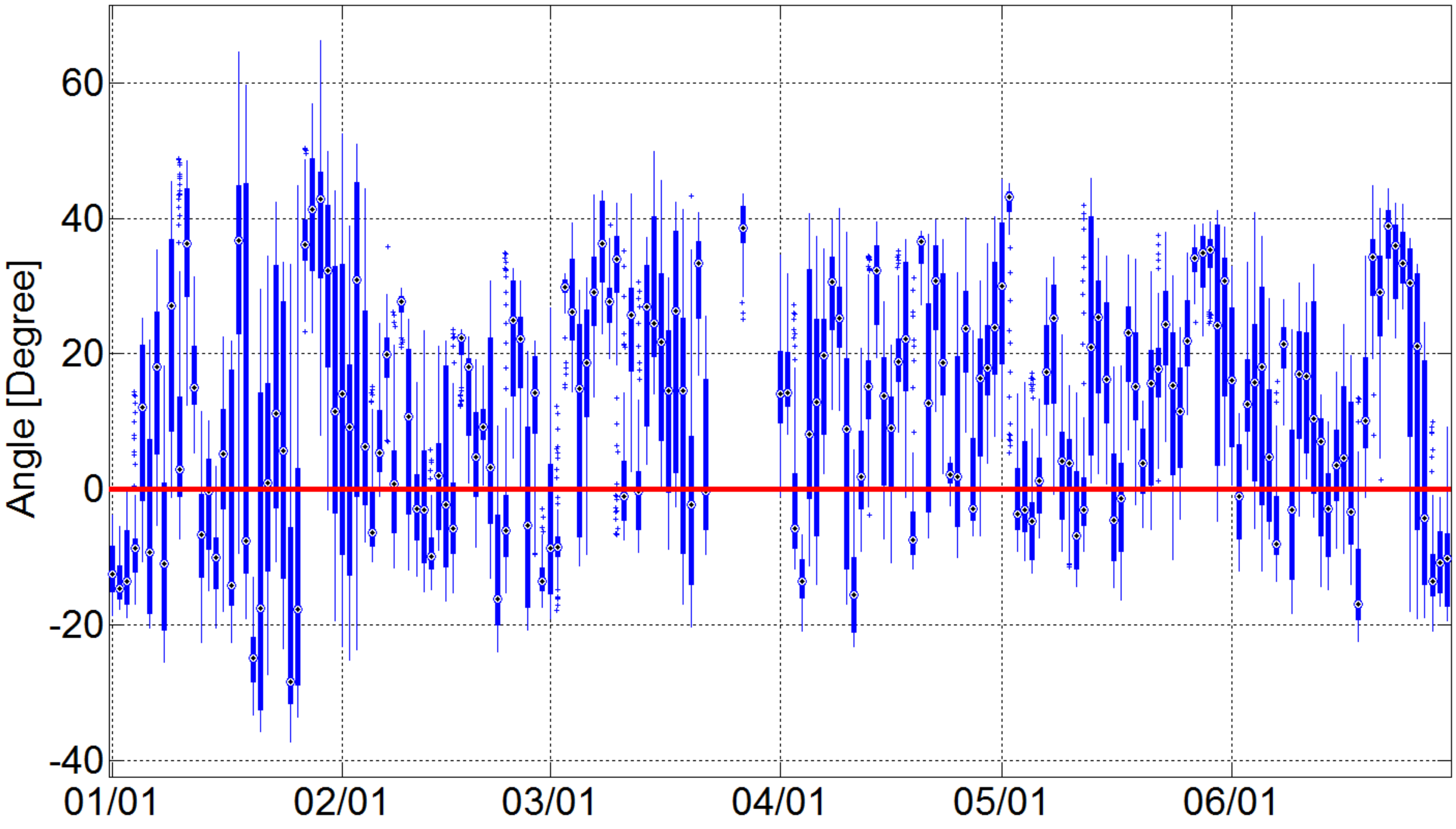
Appendix B – Part 1
CCET Discovery Across Texas project

Baseline Analysis Update - Voltage Angles (Ref.: North 7)

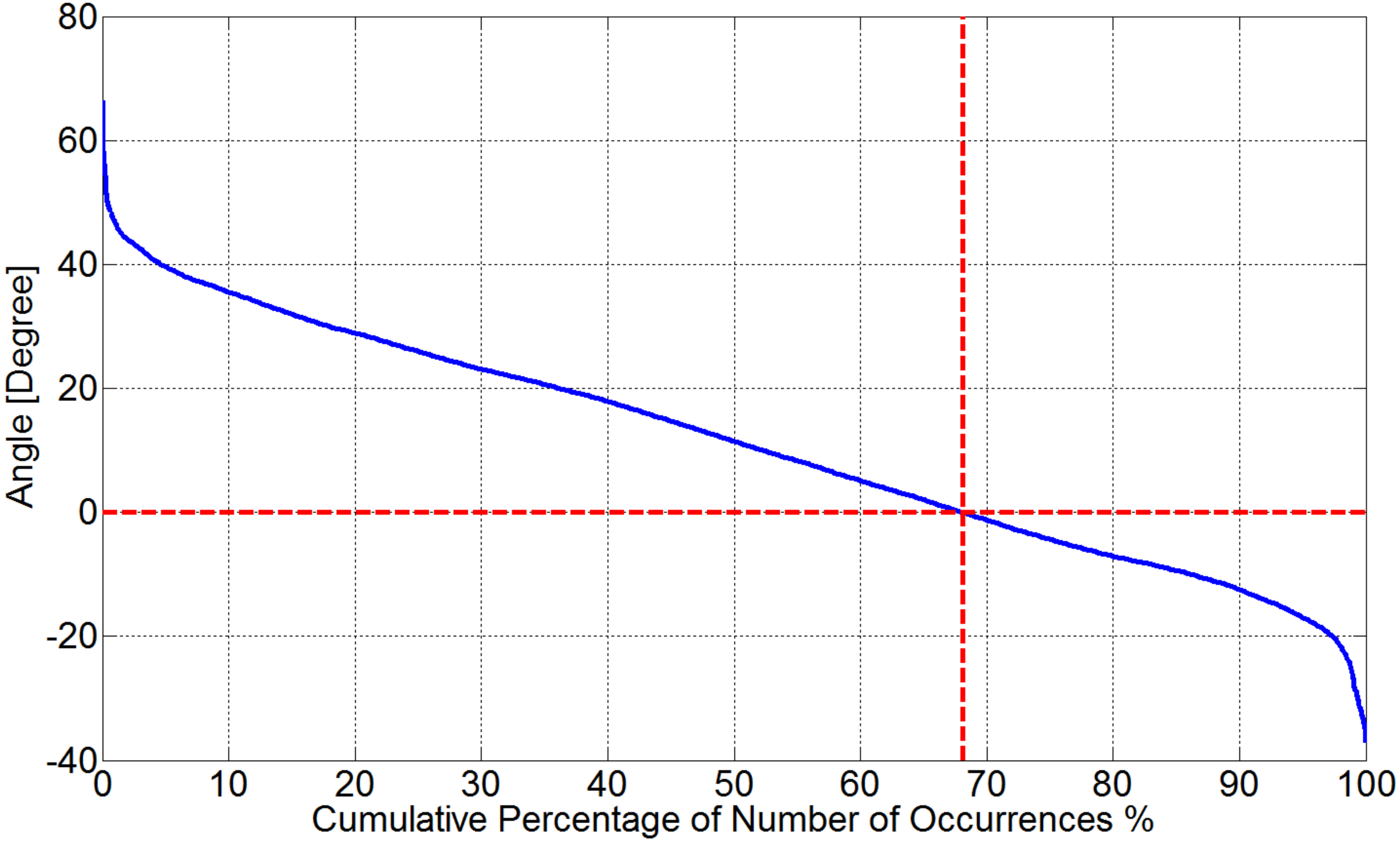
State Estimator Data: January to June 2013
Box-Whisker Plots and Time Duration Curves

External Version

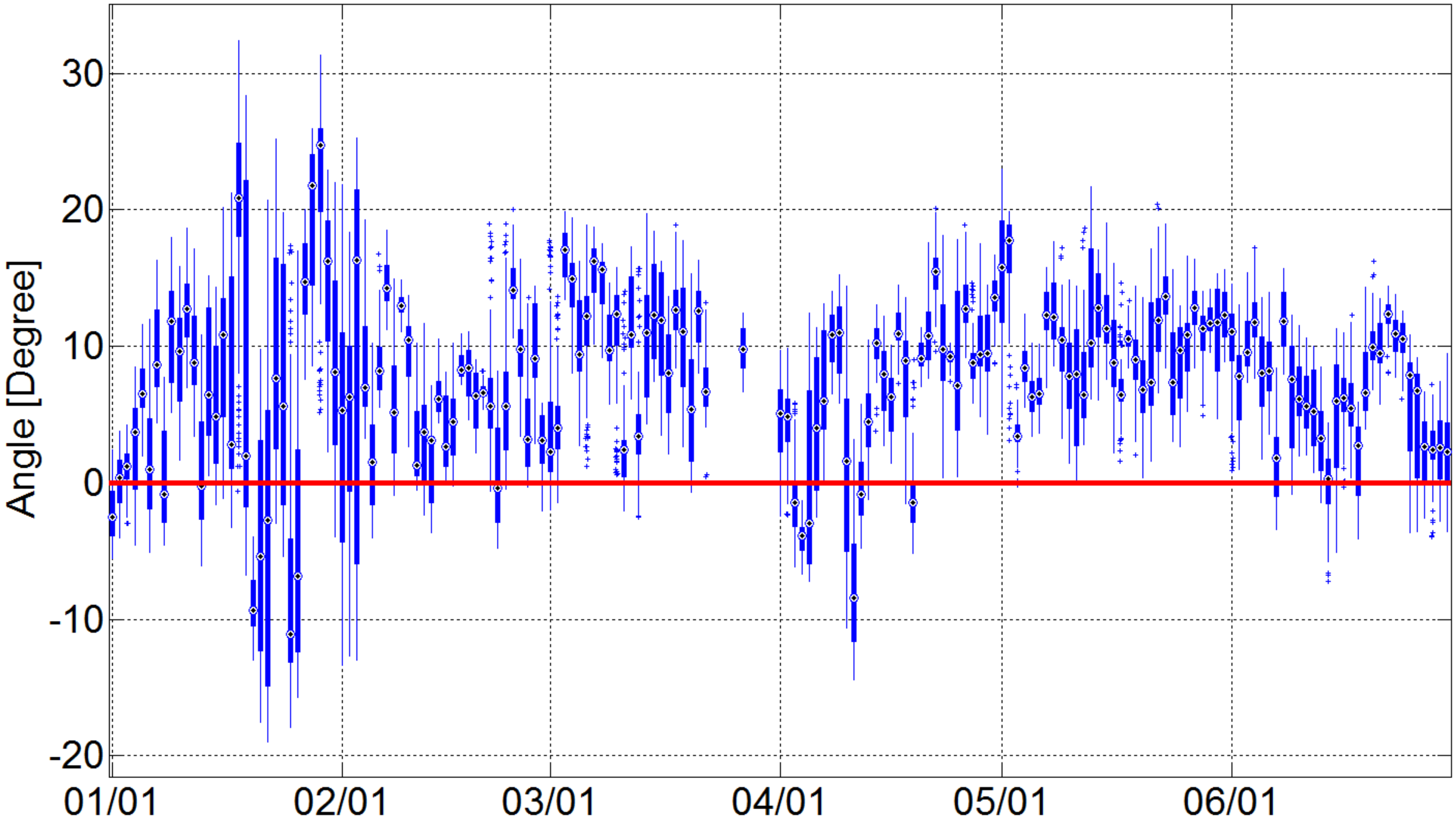
West 10-North 7



West 10-North 7



West 14-North 7



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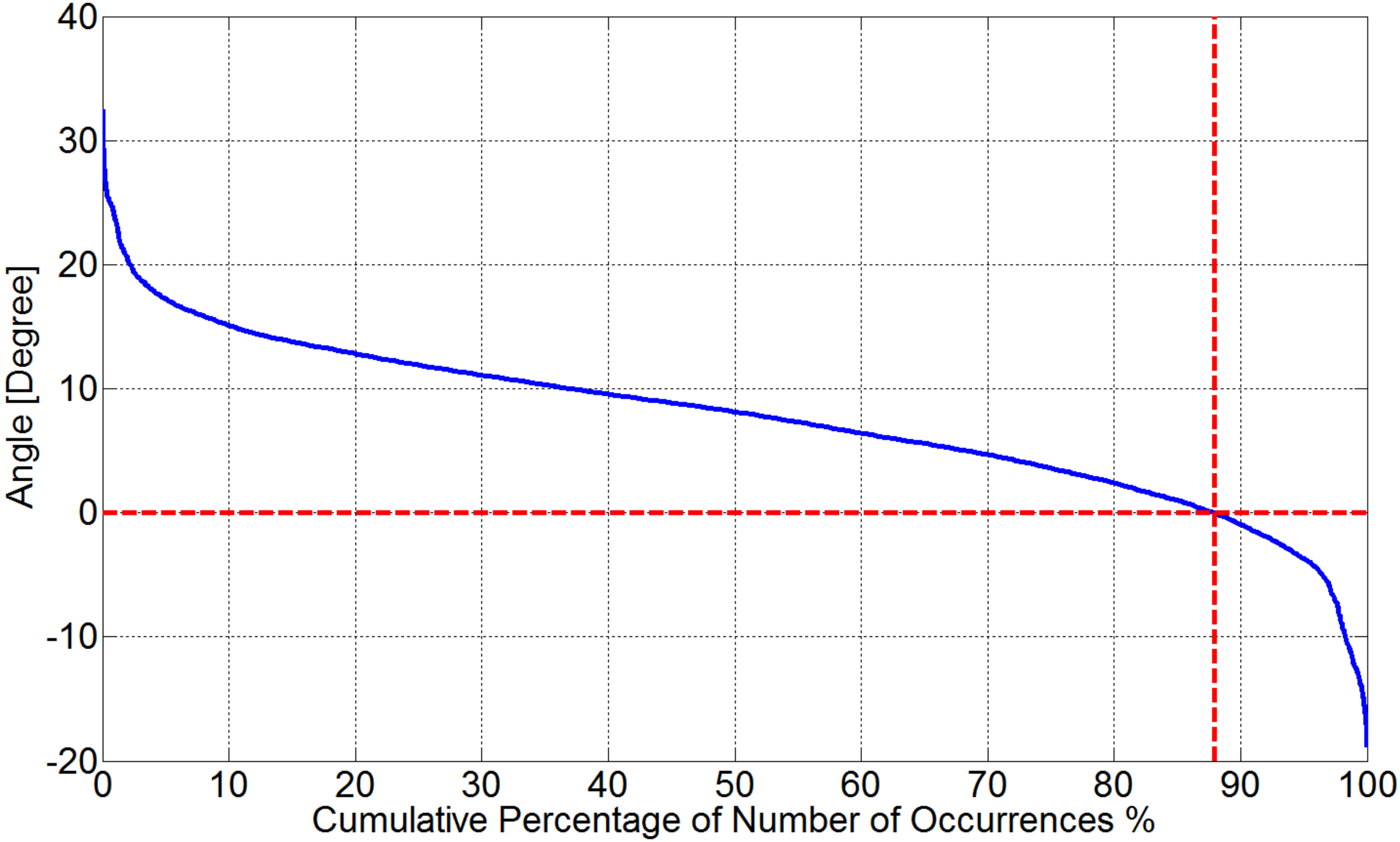

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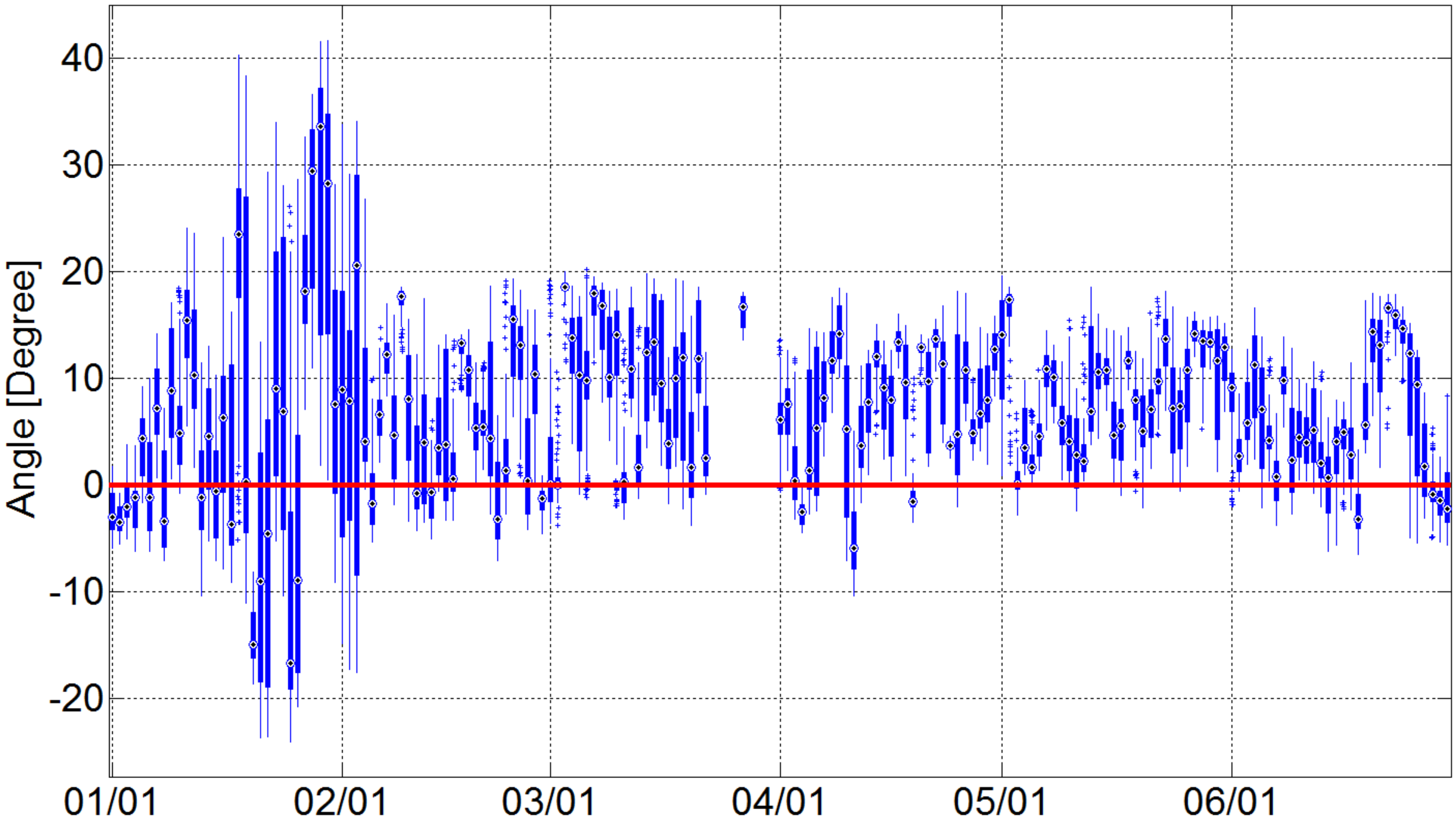

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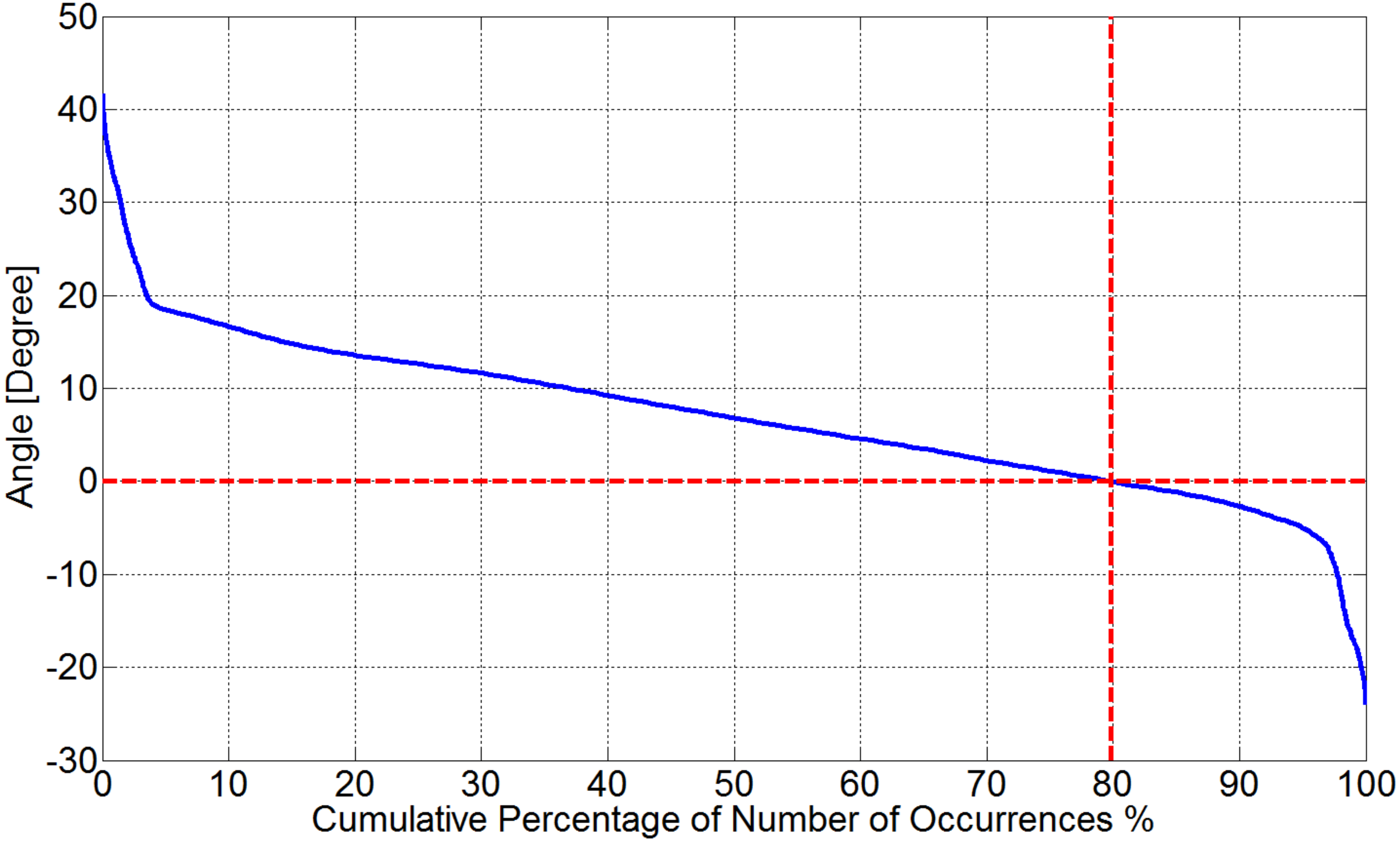

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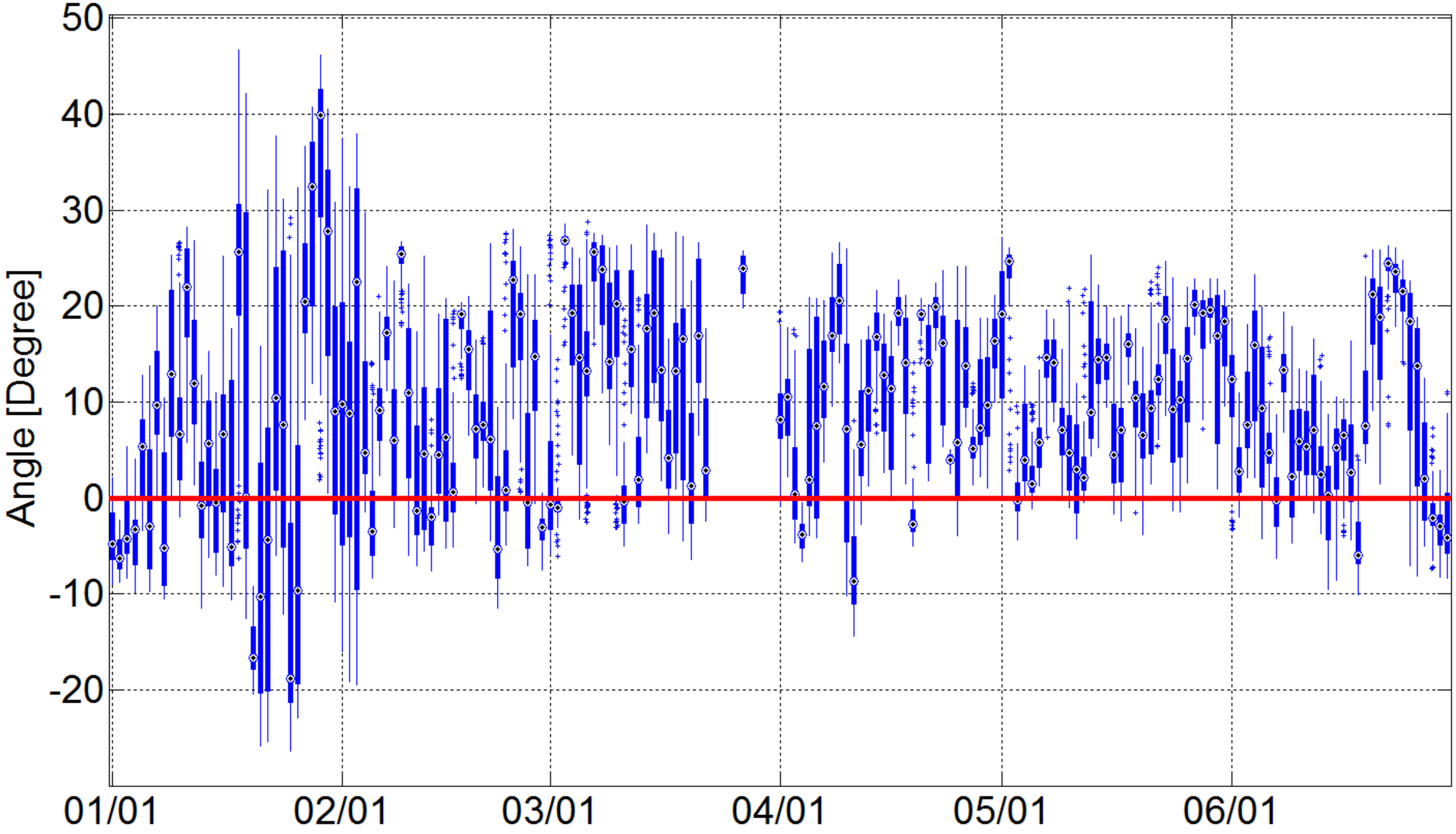

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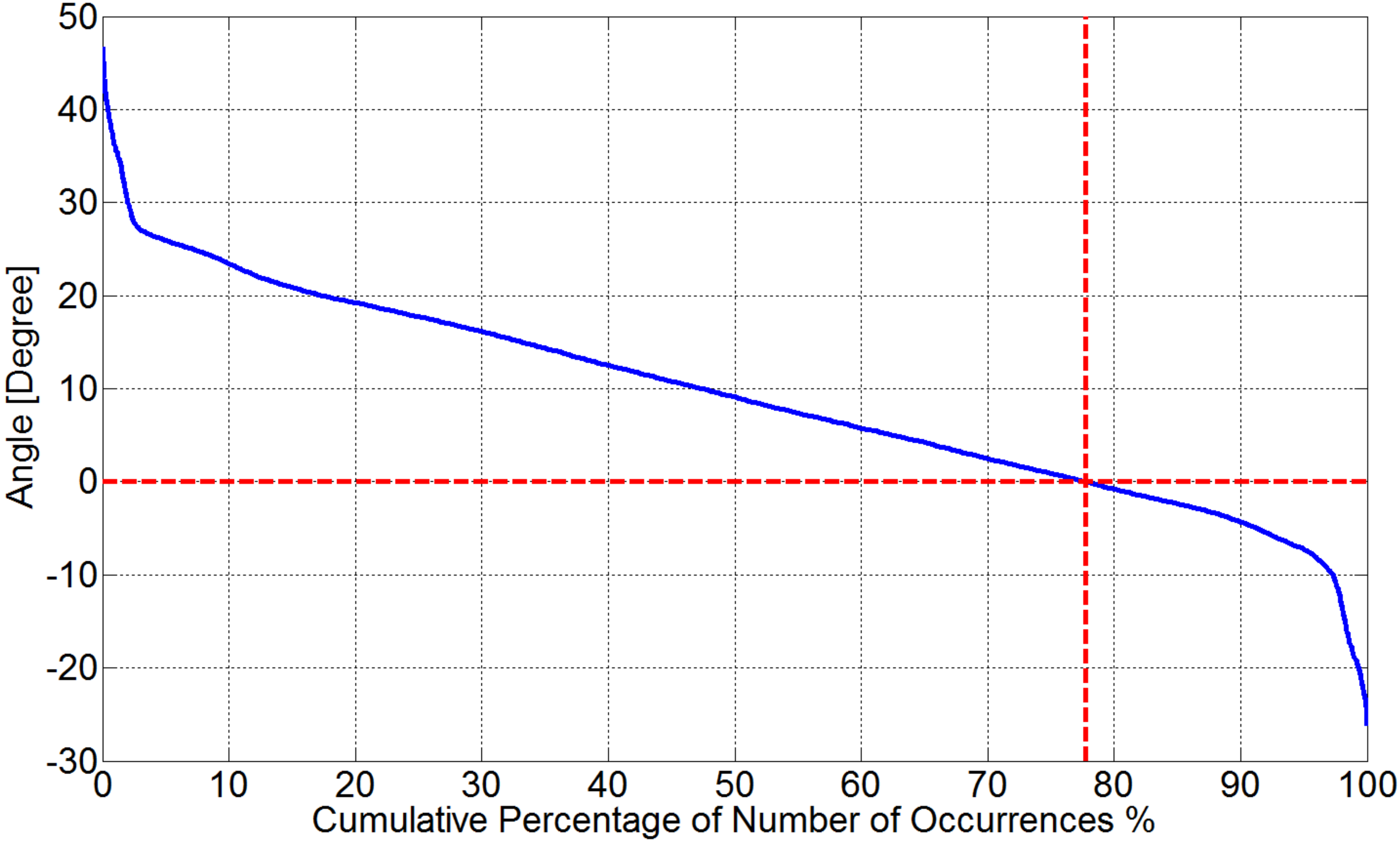

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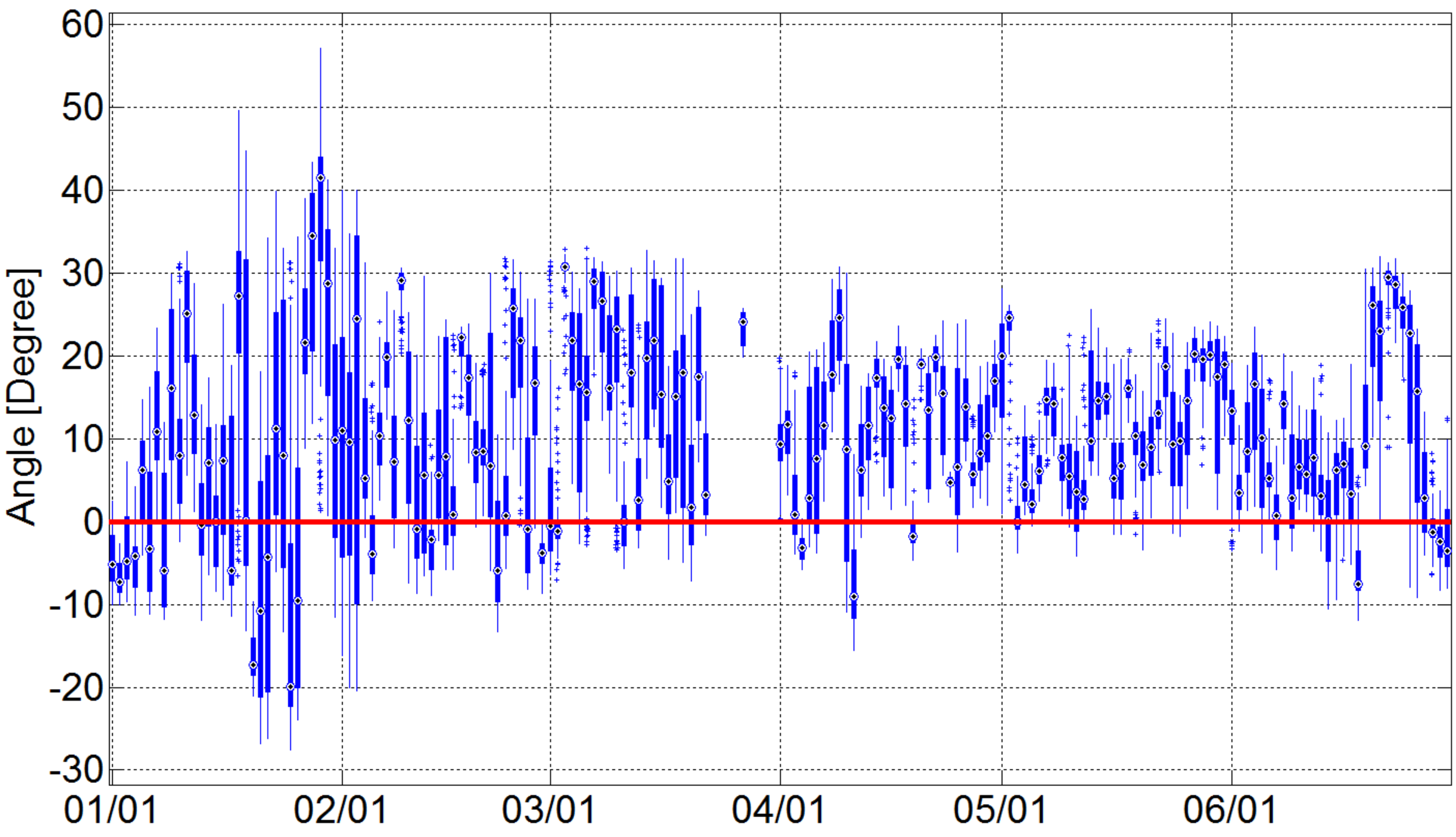

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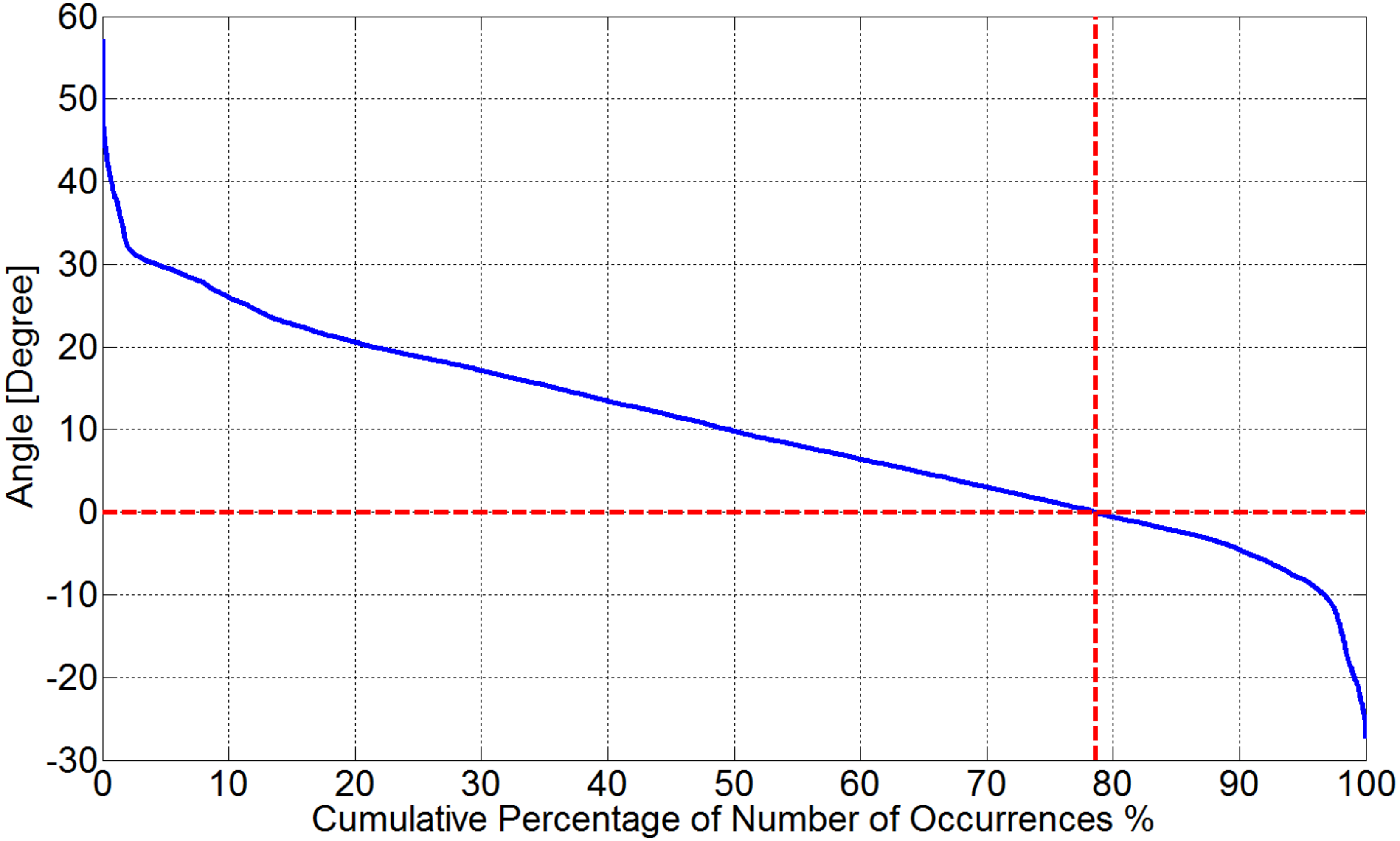
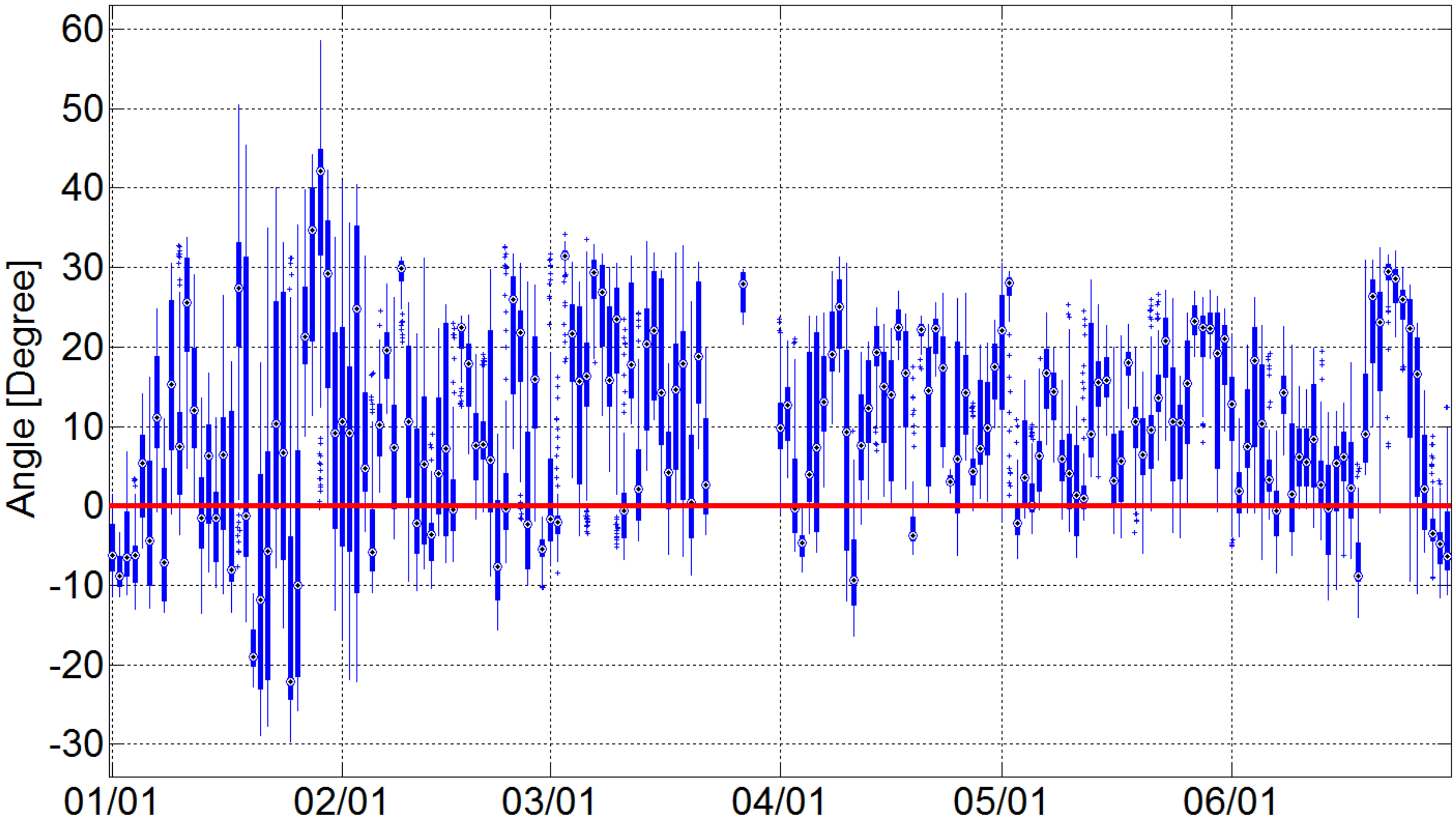


West 11-North 7



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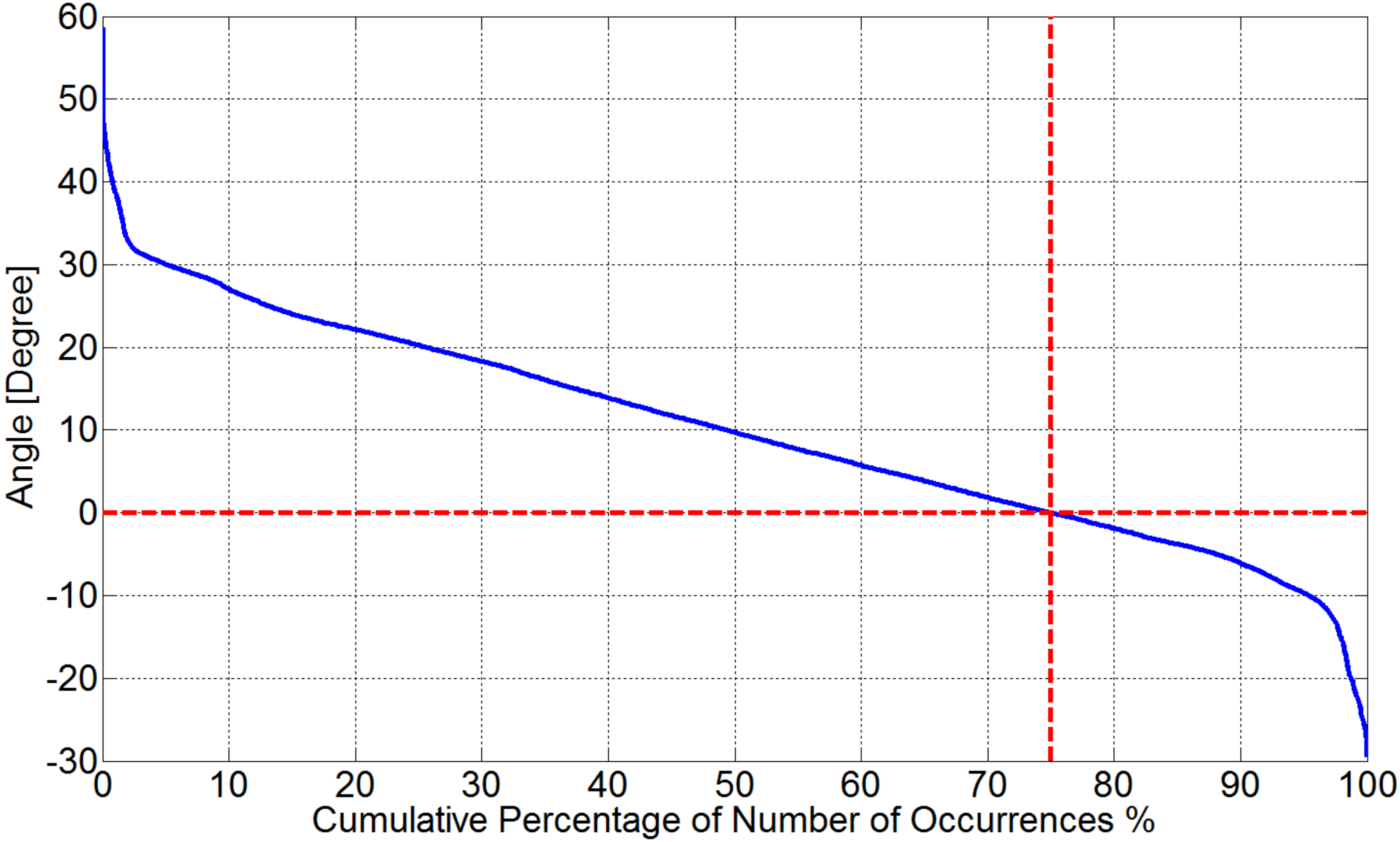

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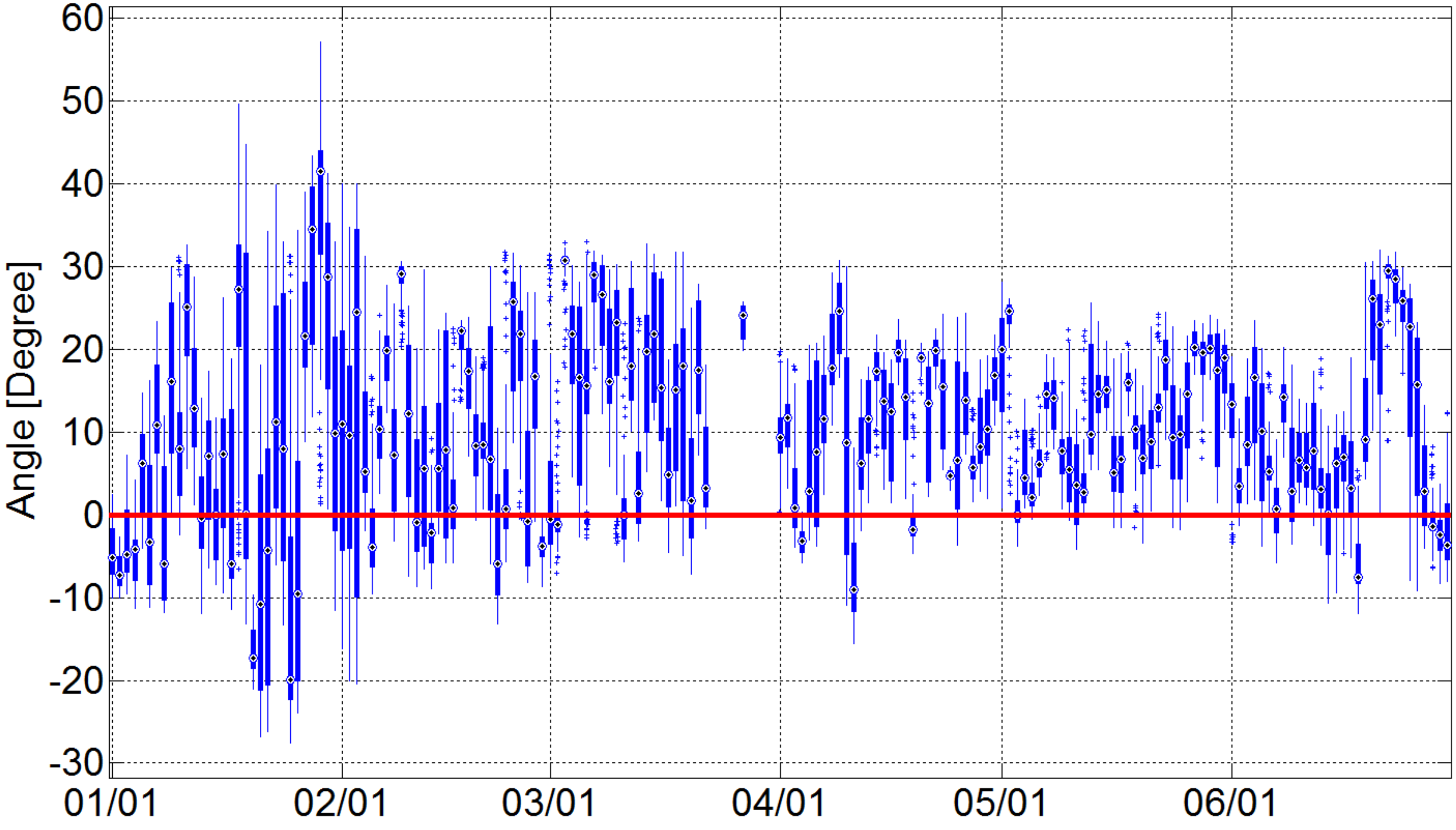

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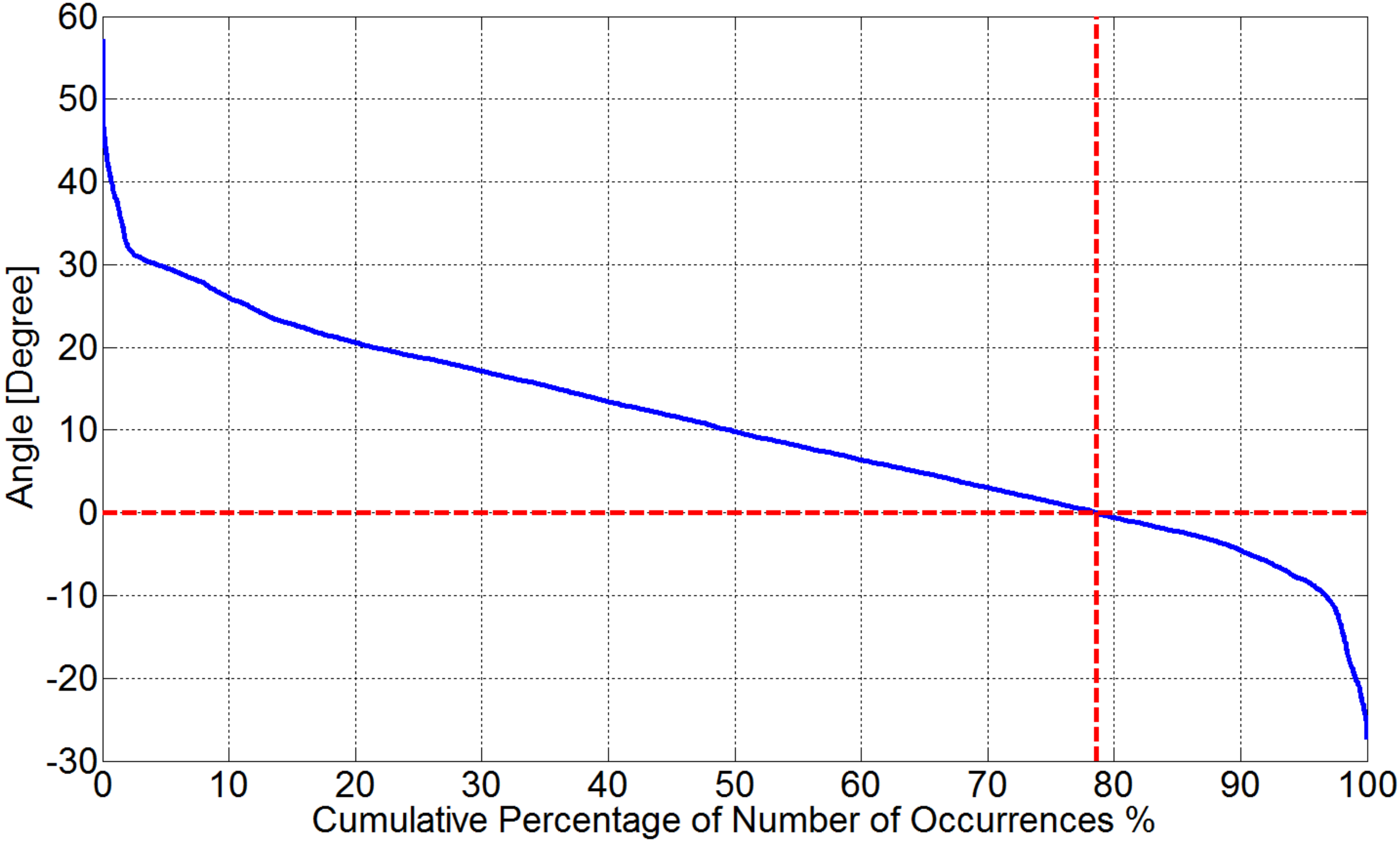

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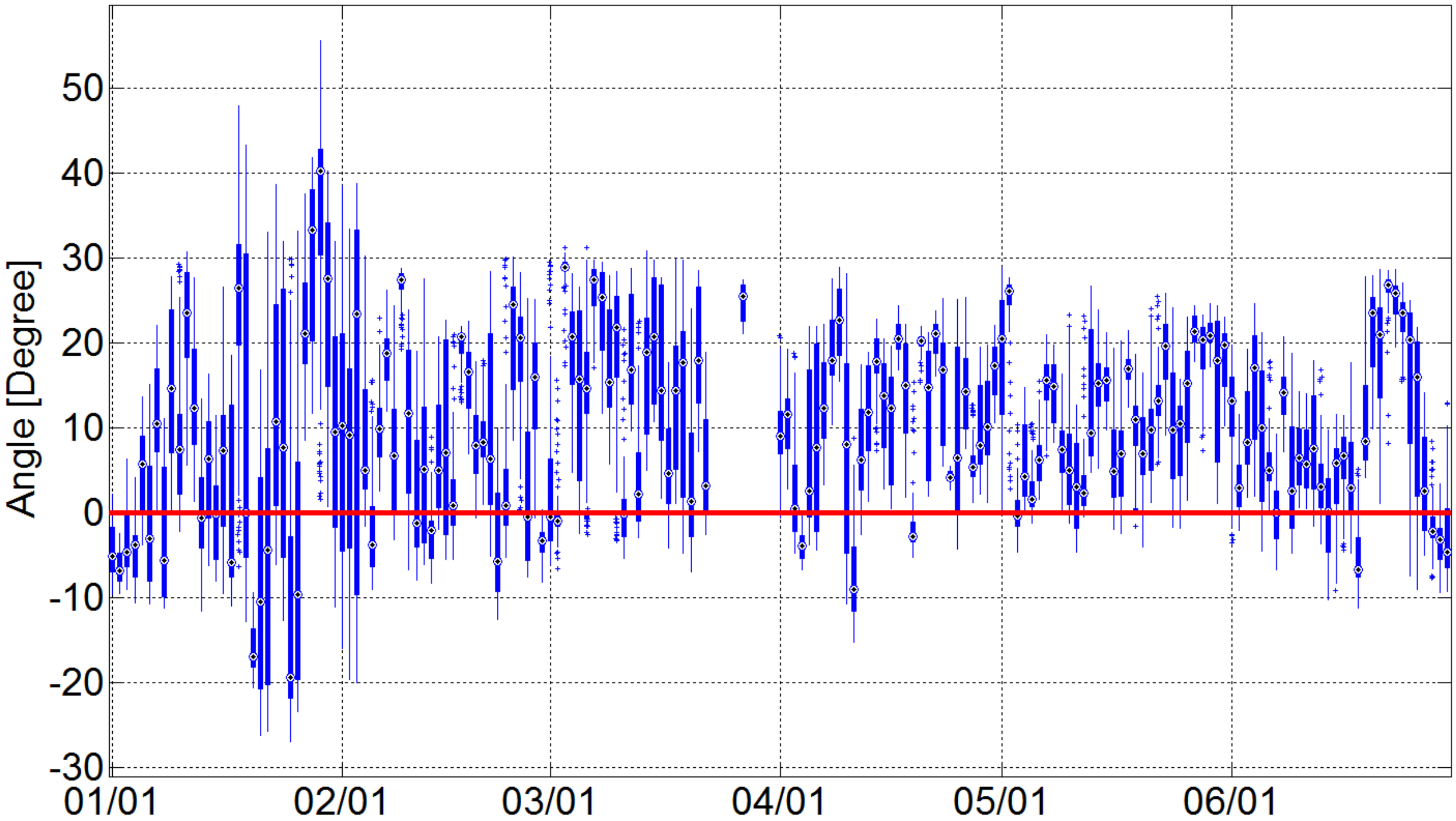

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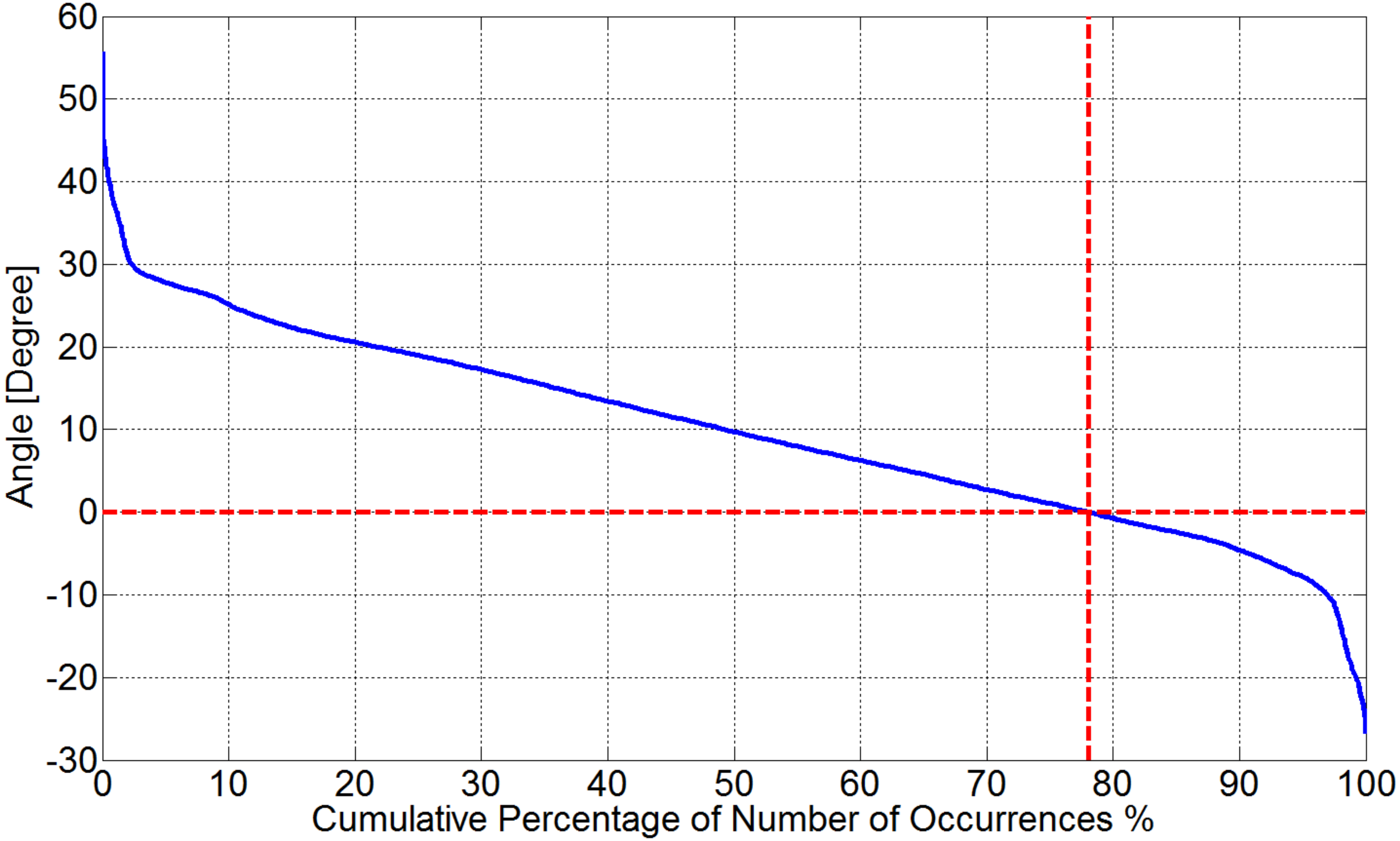

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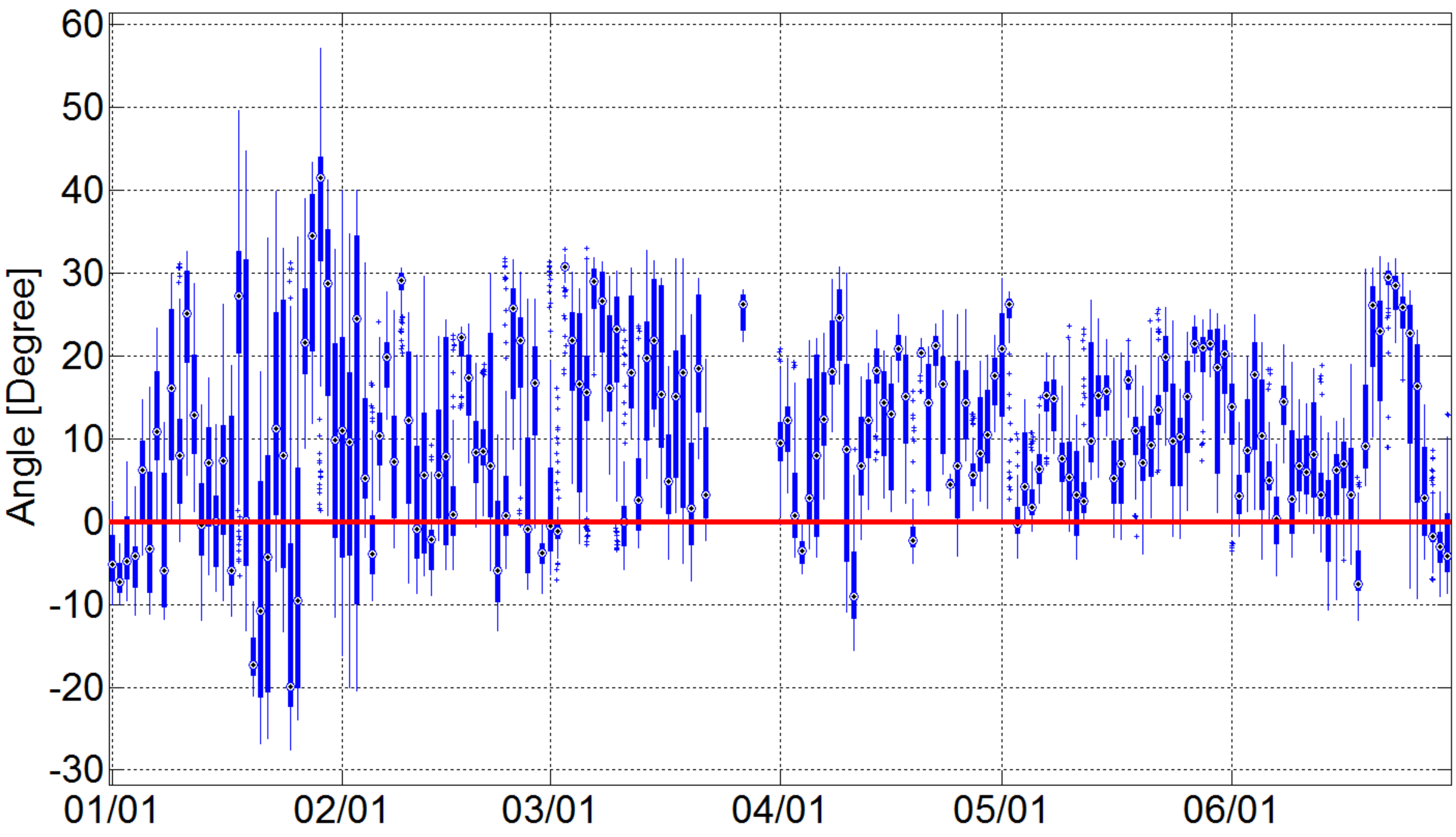

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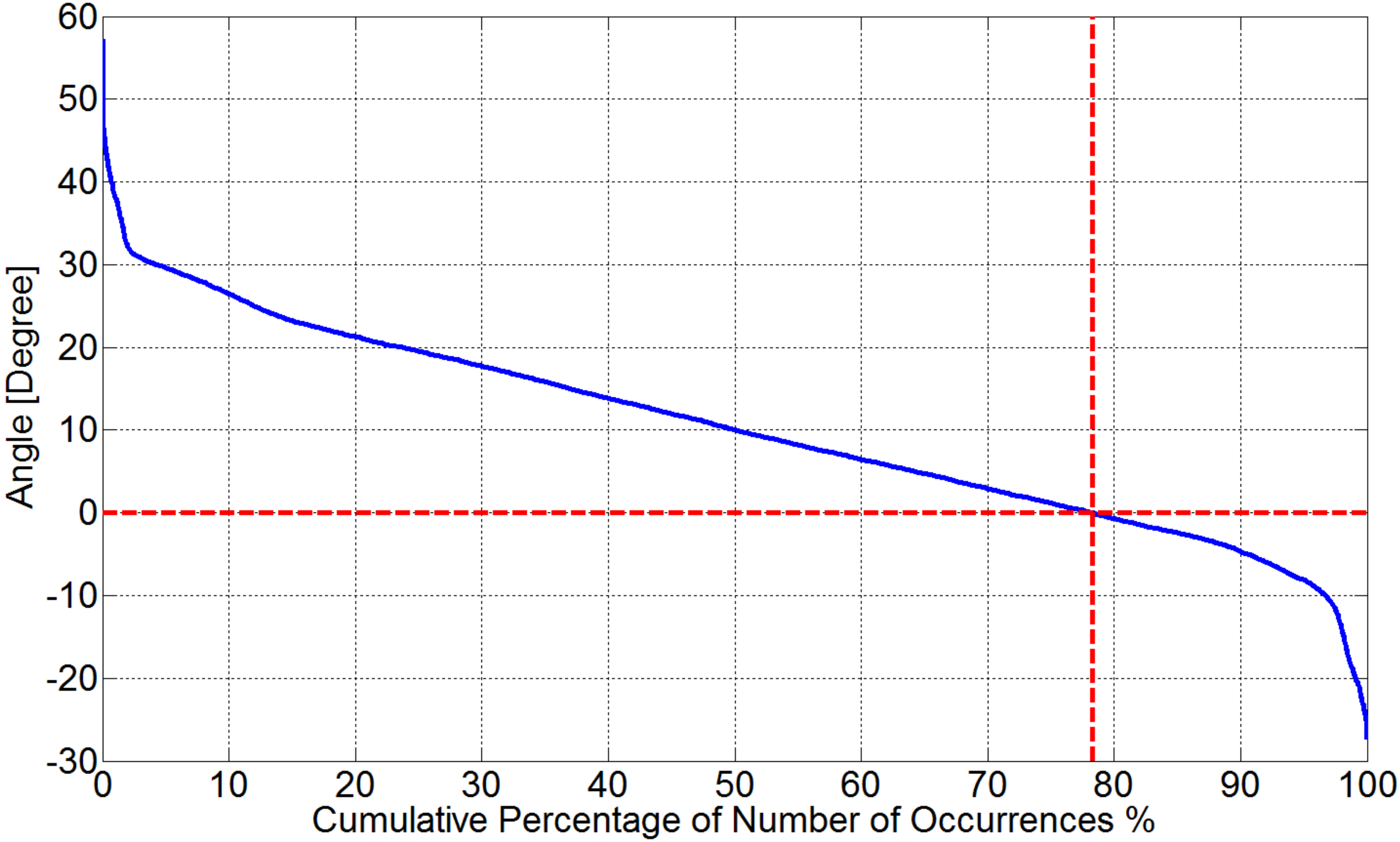

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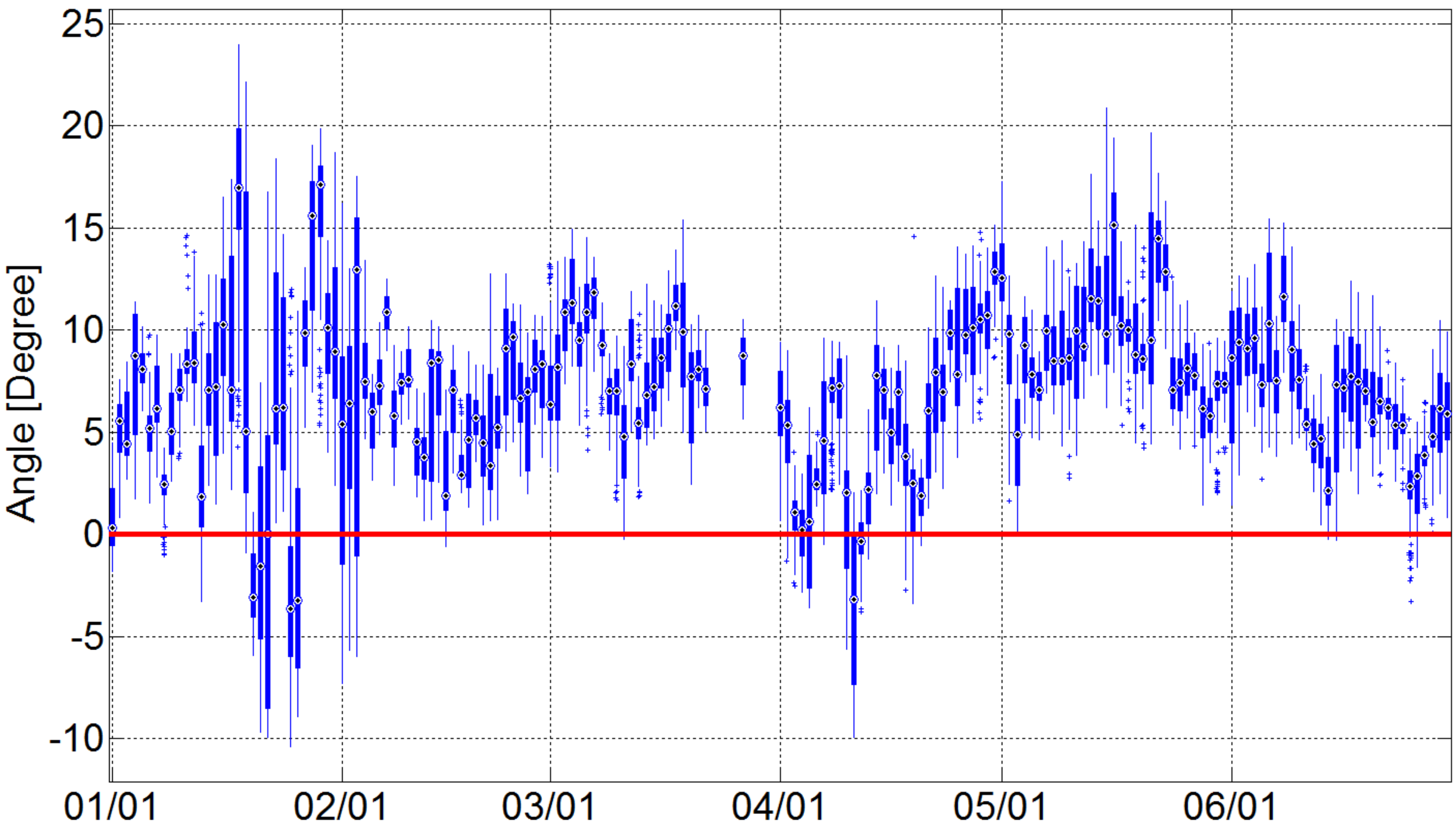

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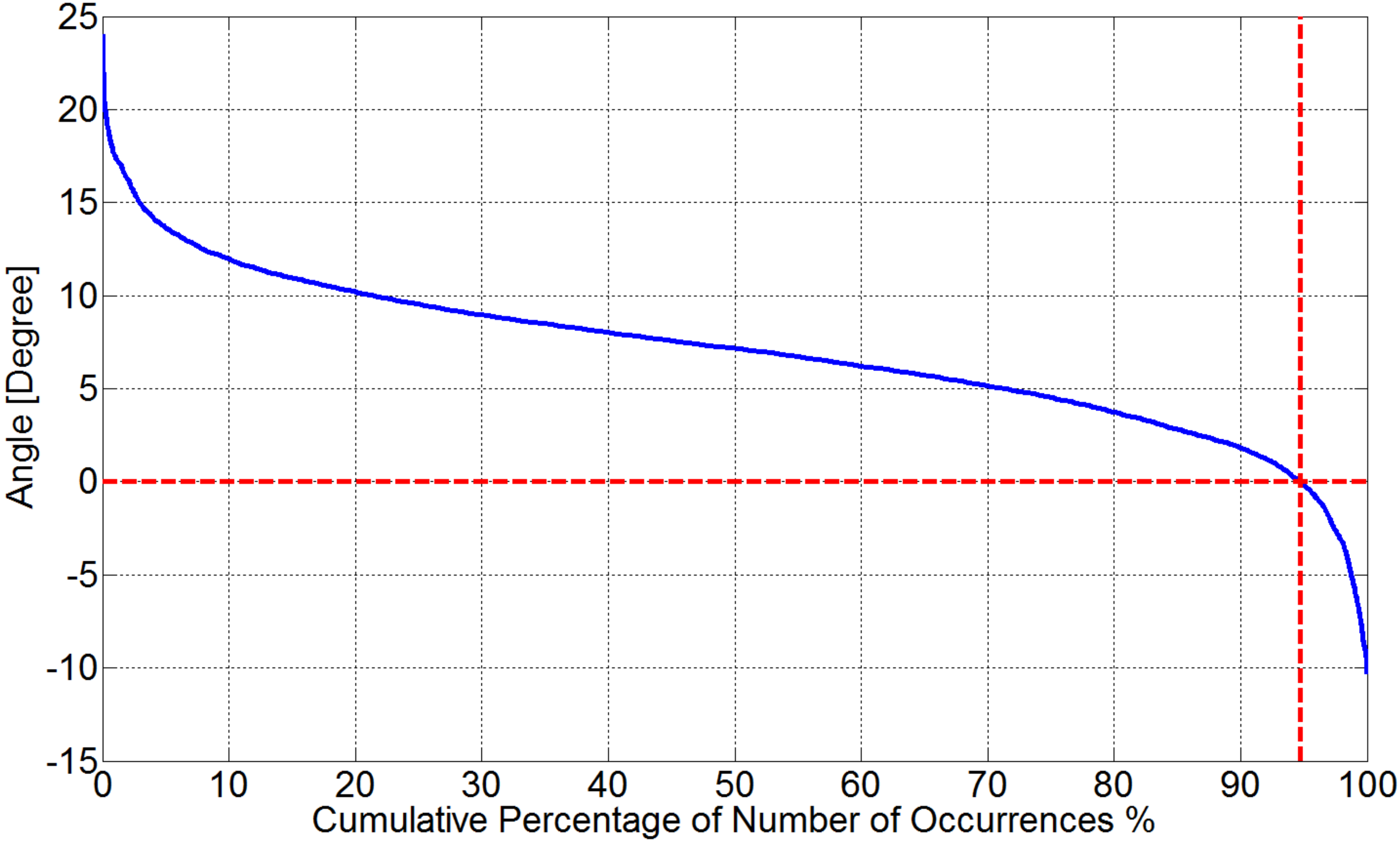

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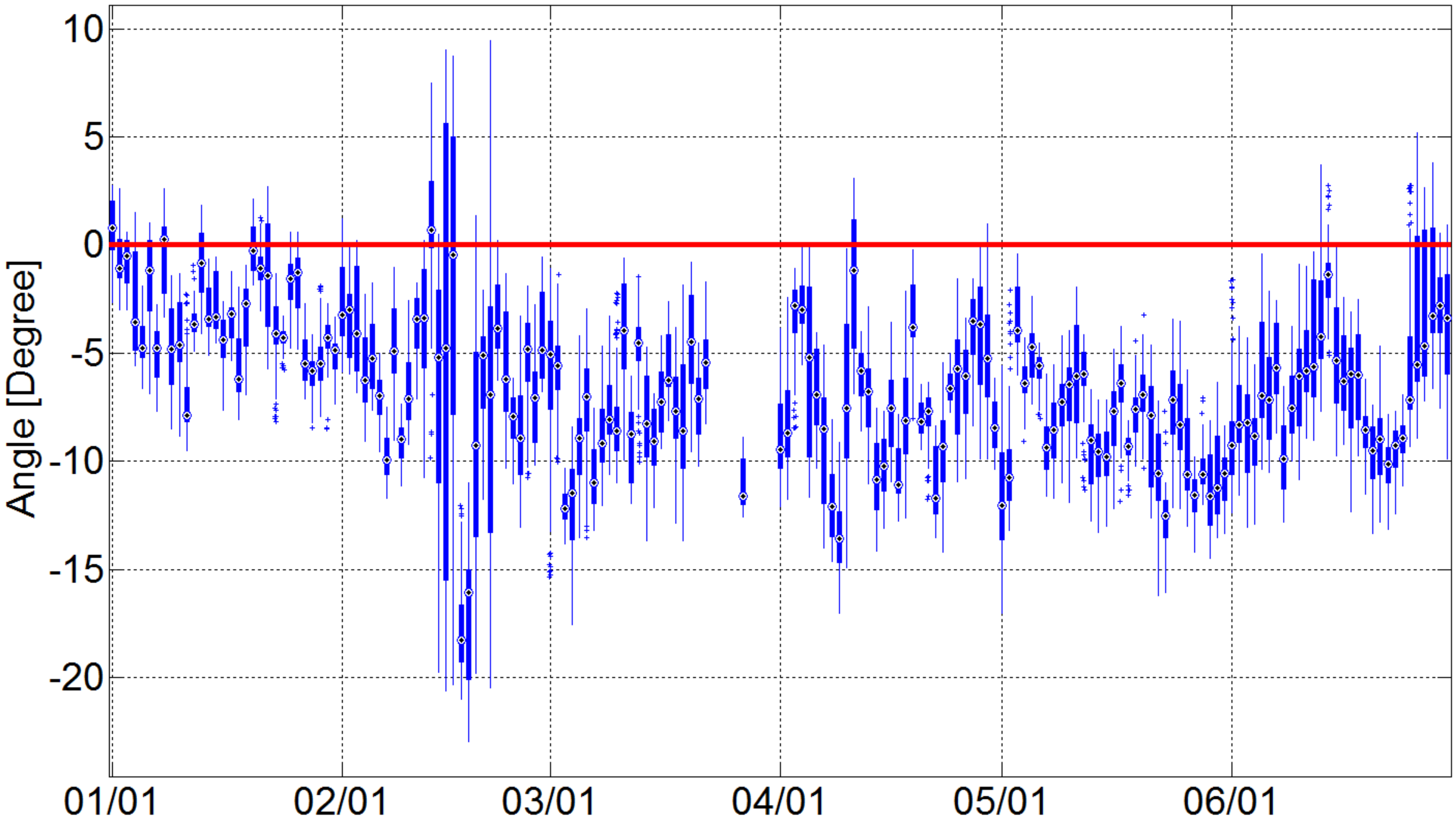

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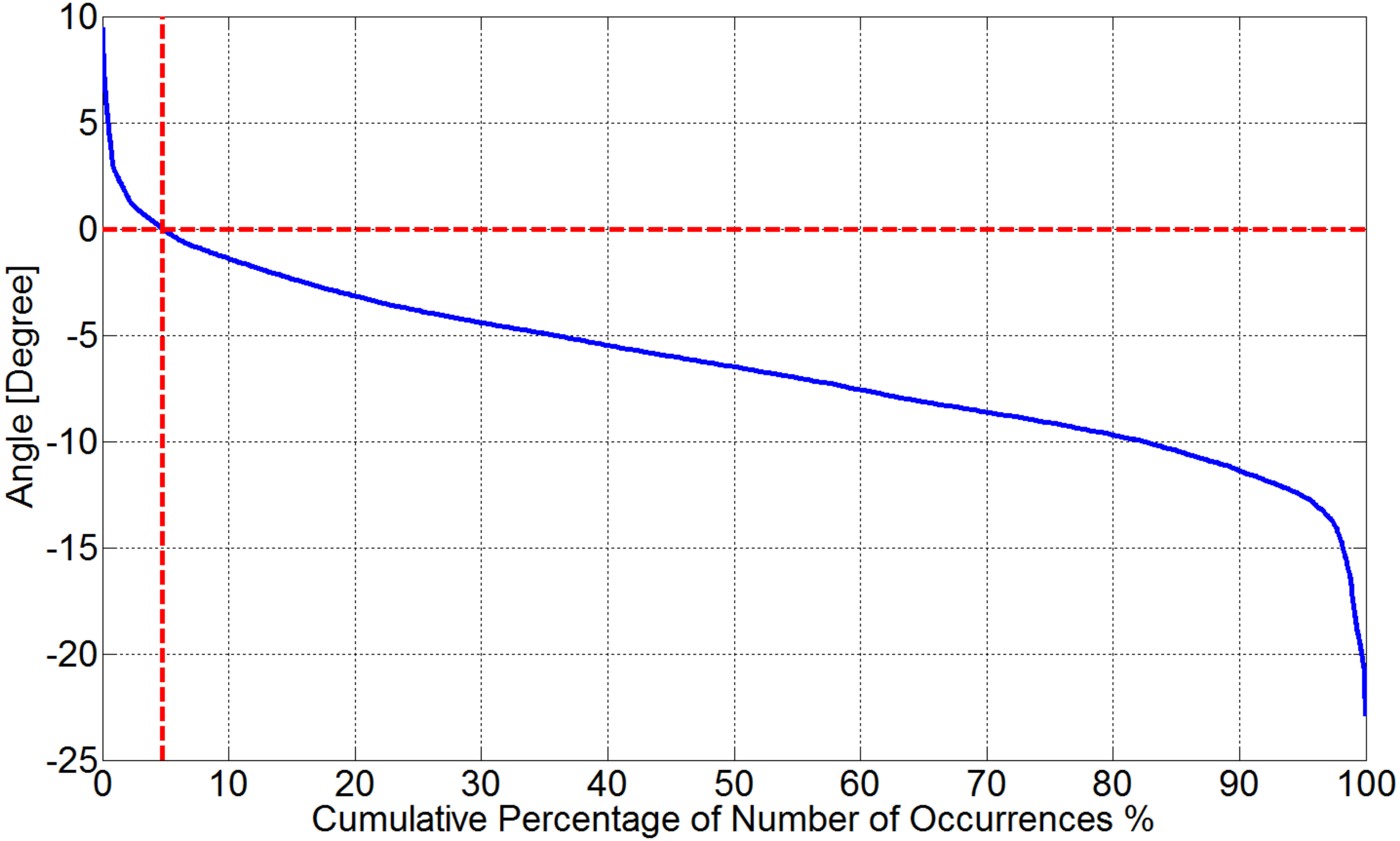

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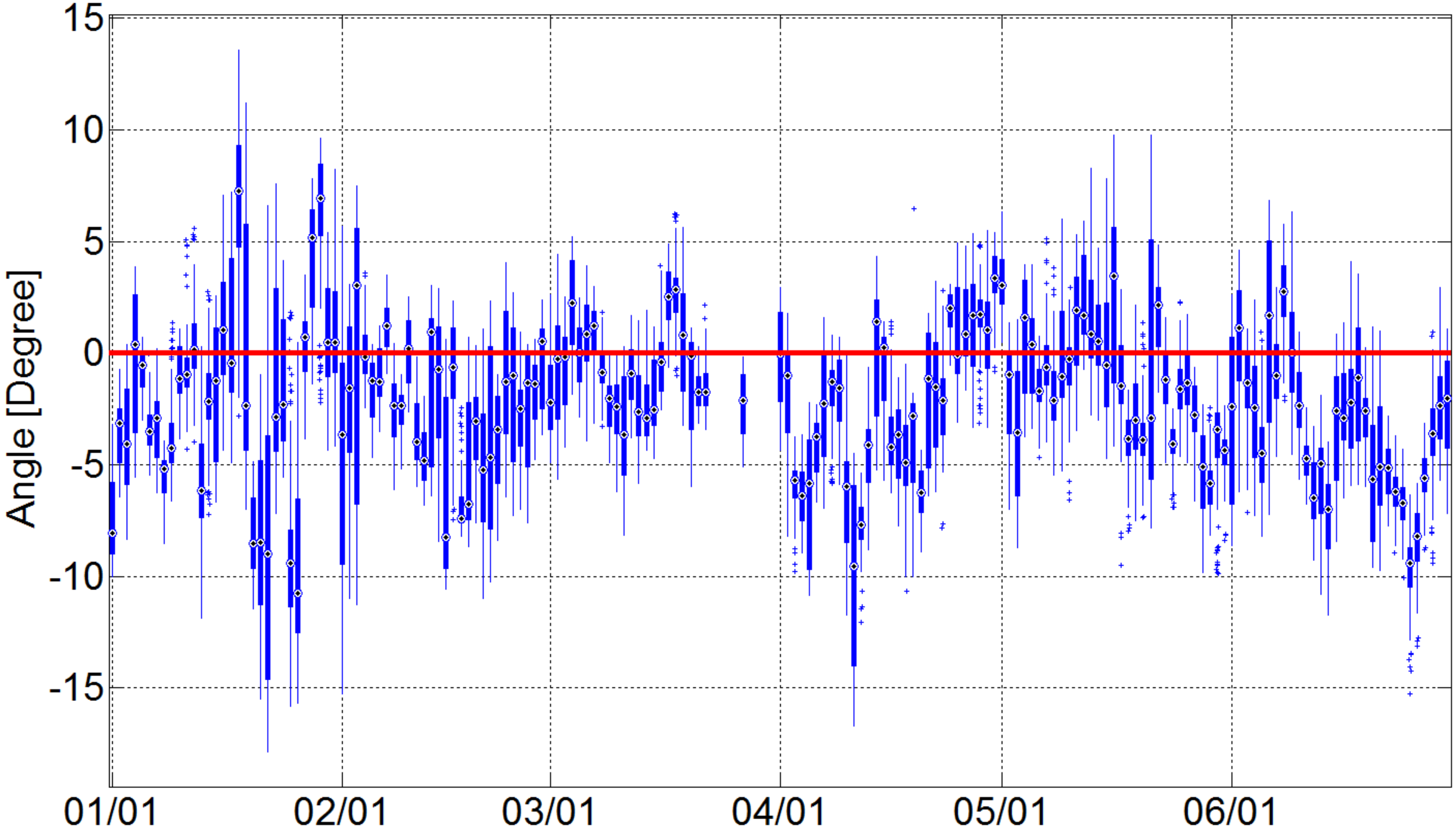

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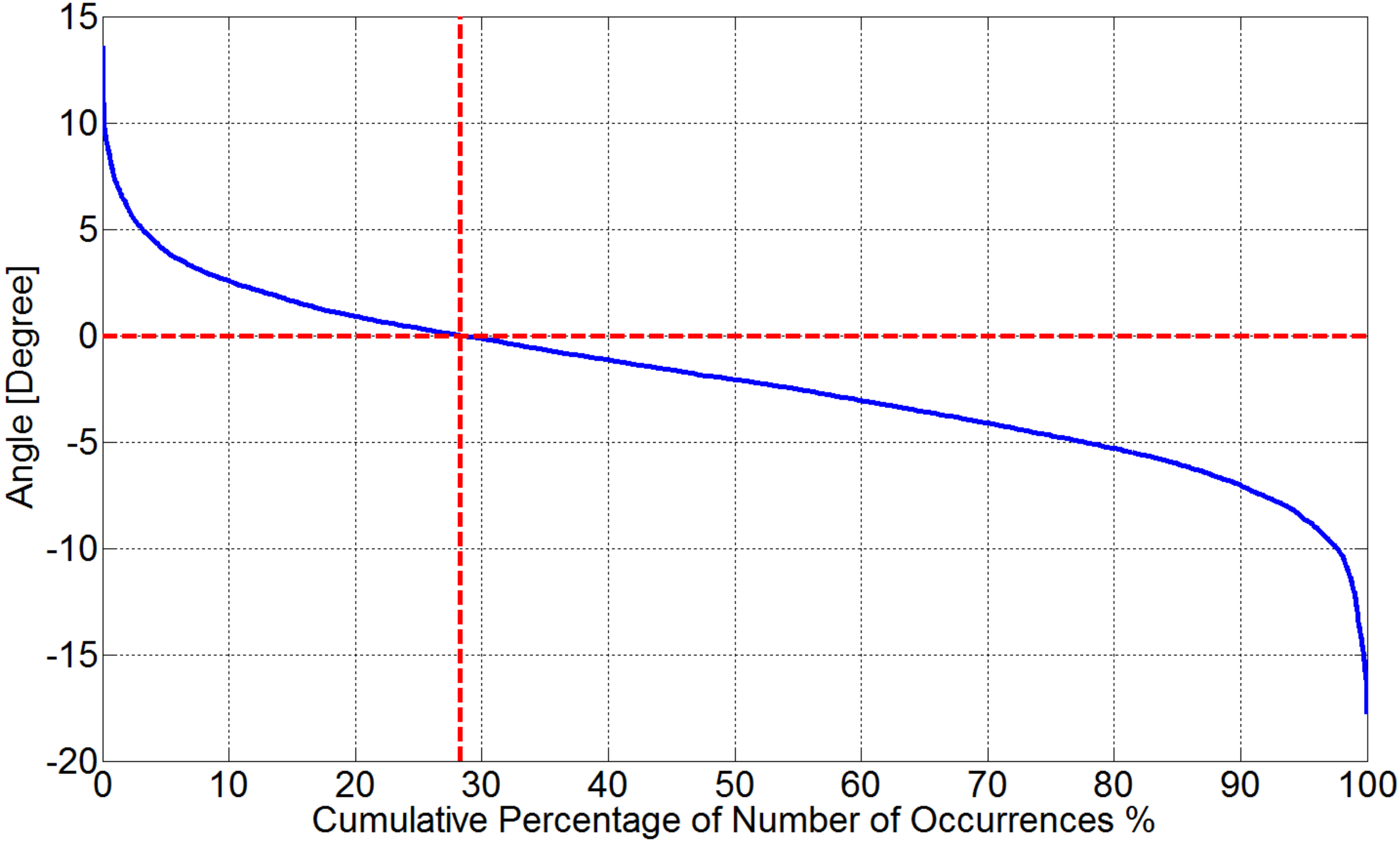

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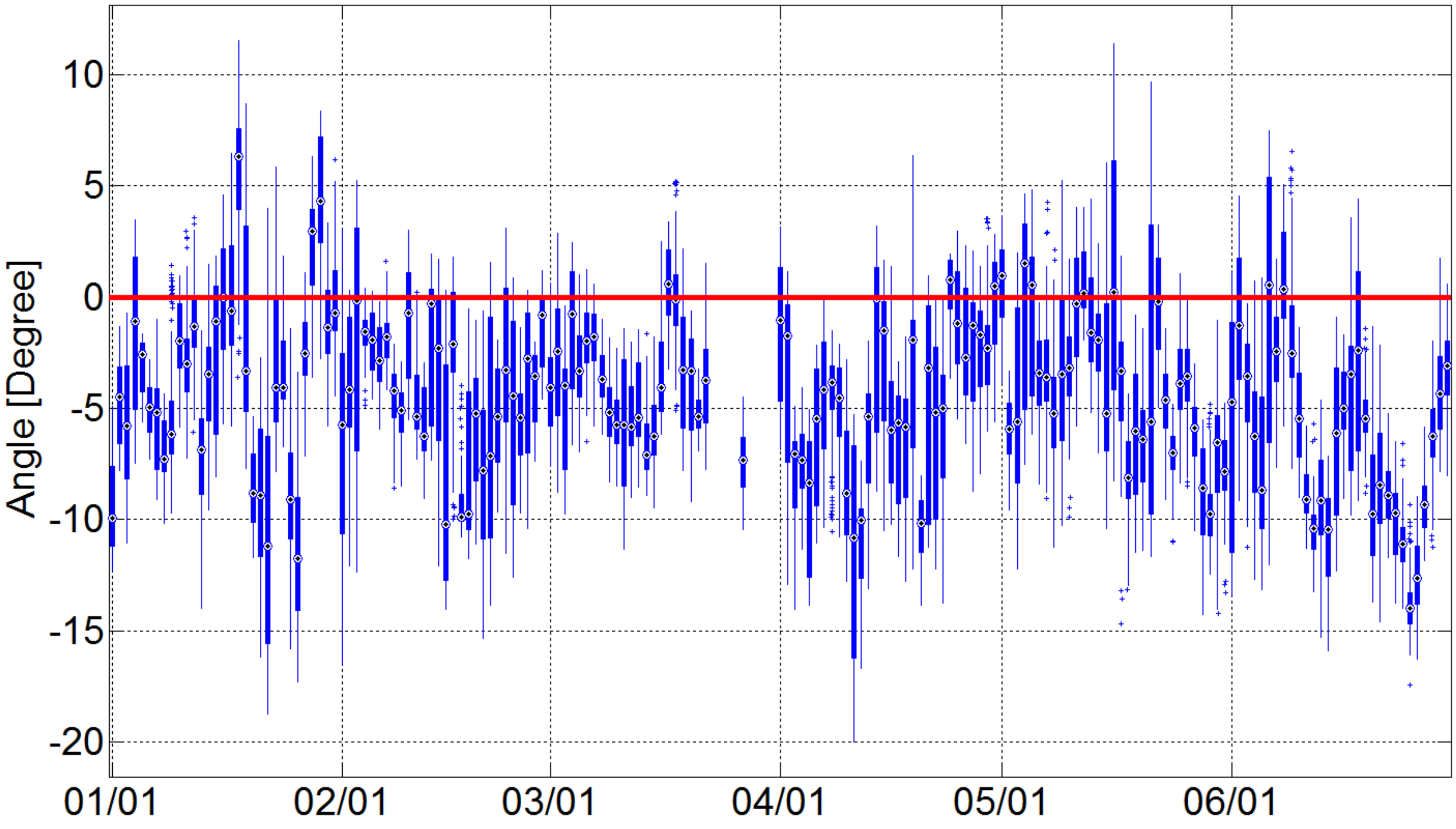

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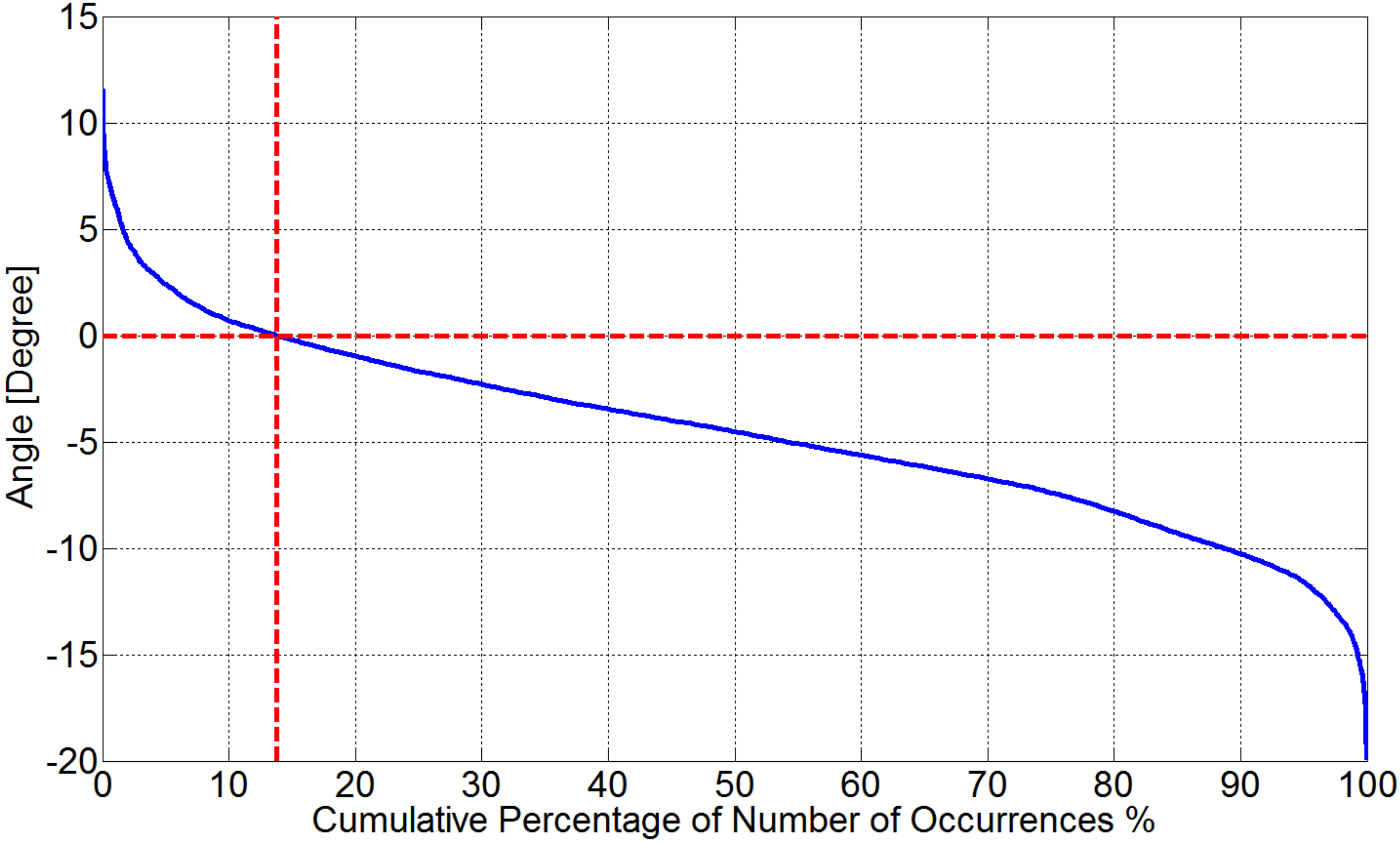

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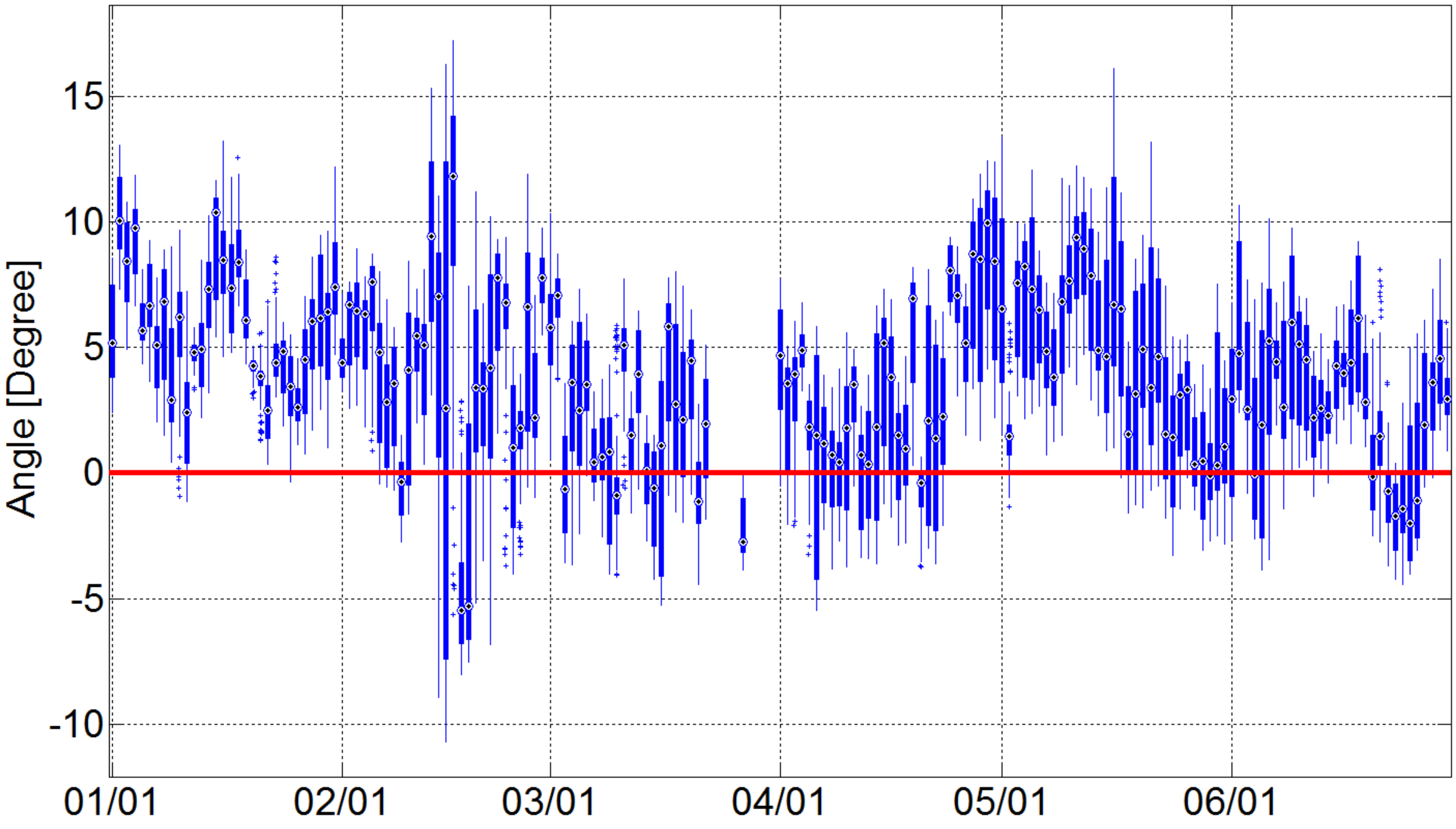

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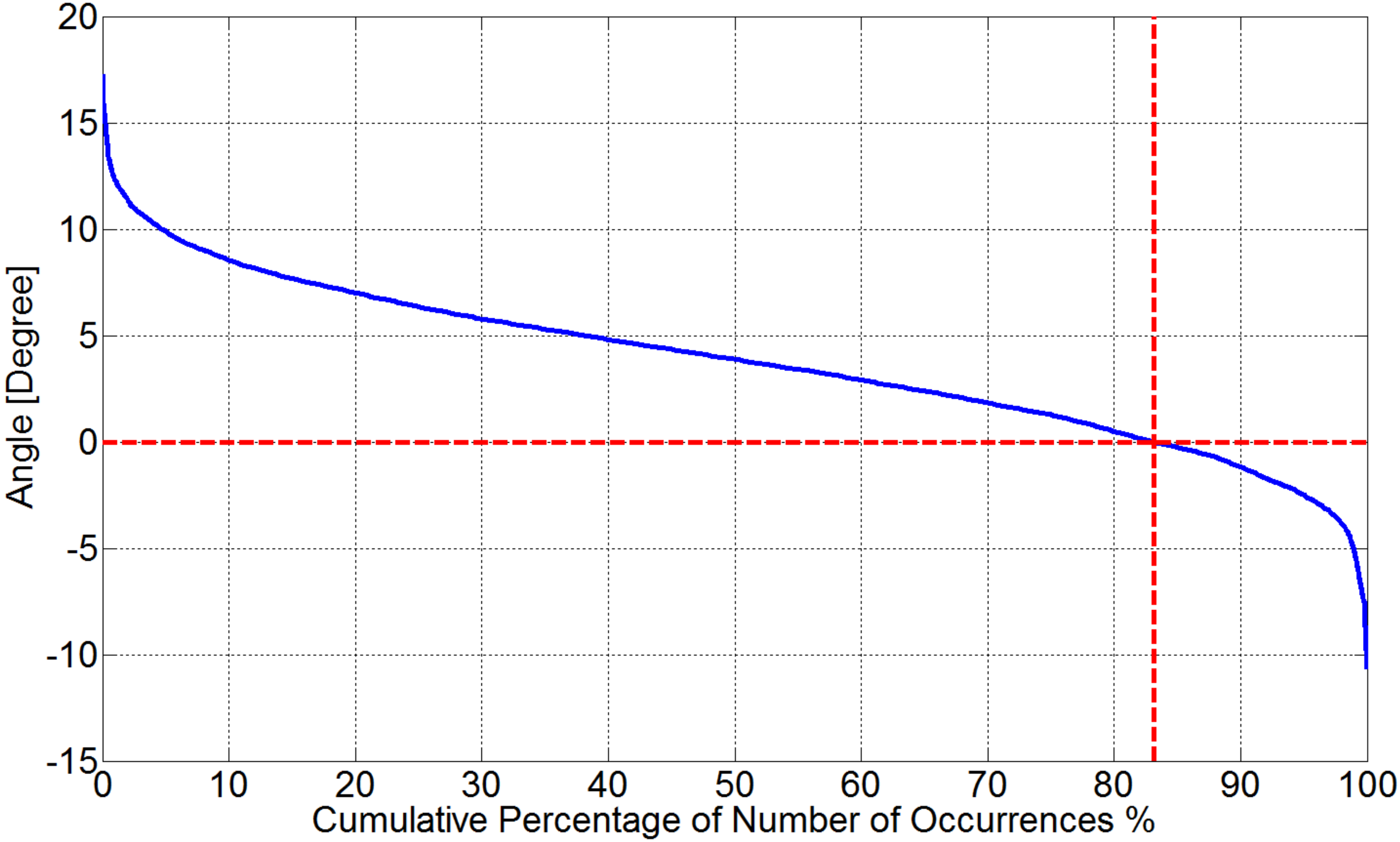

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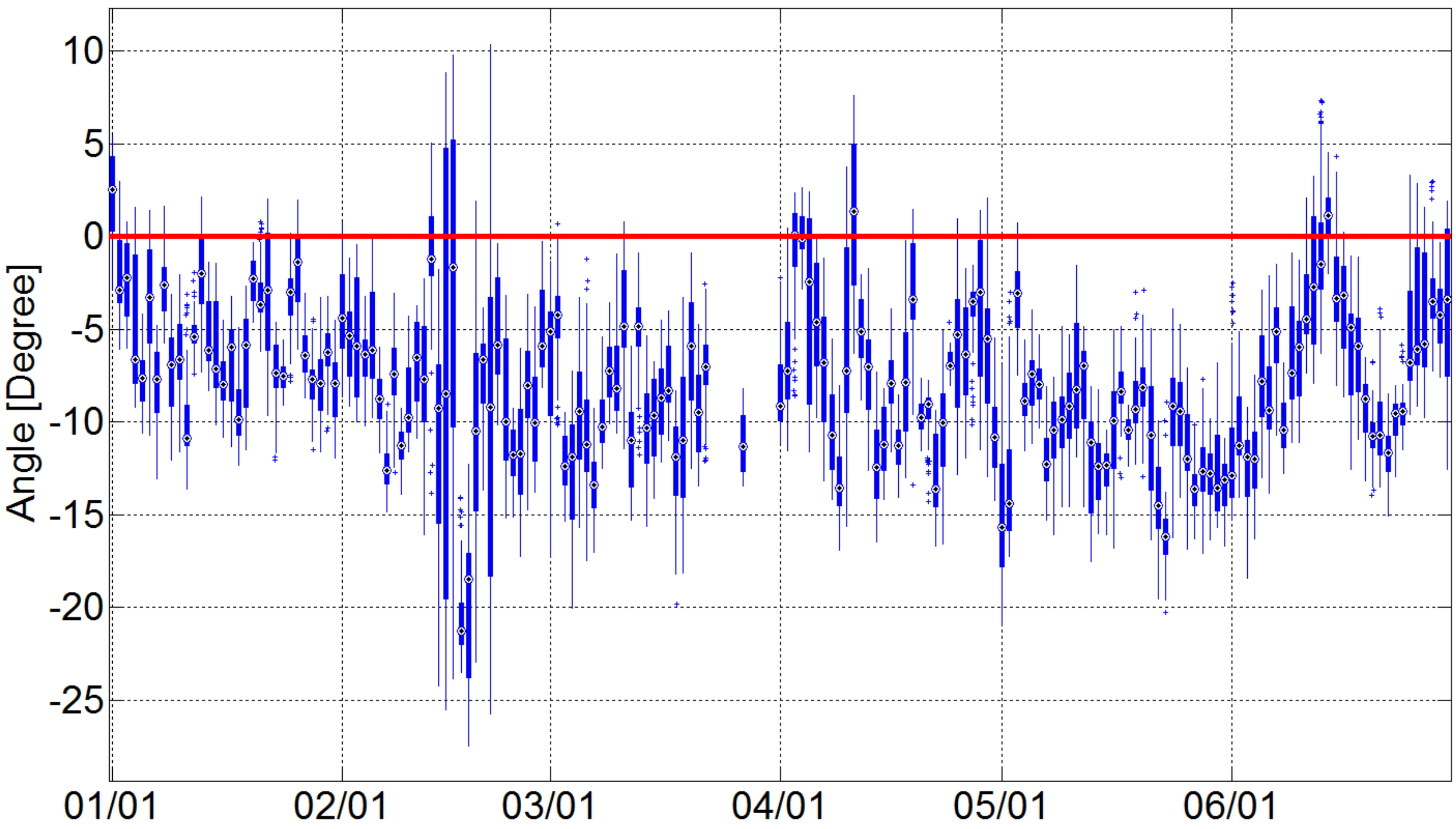

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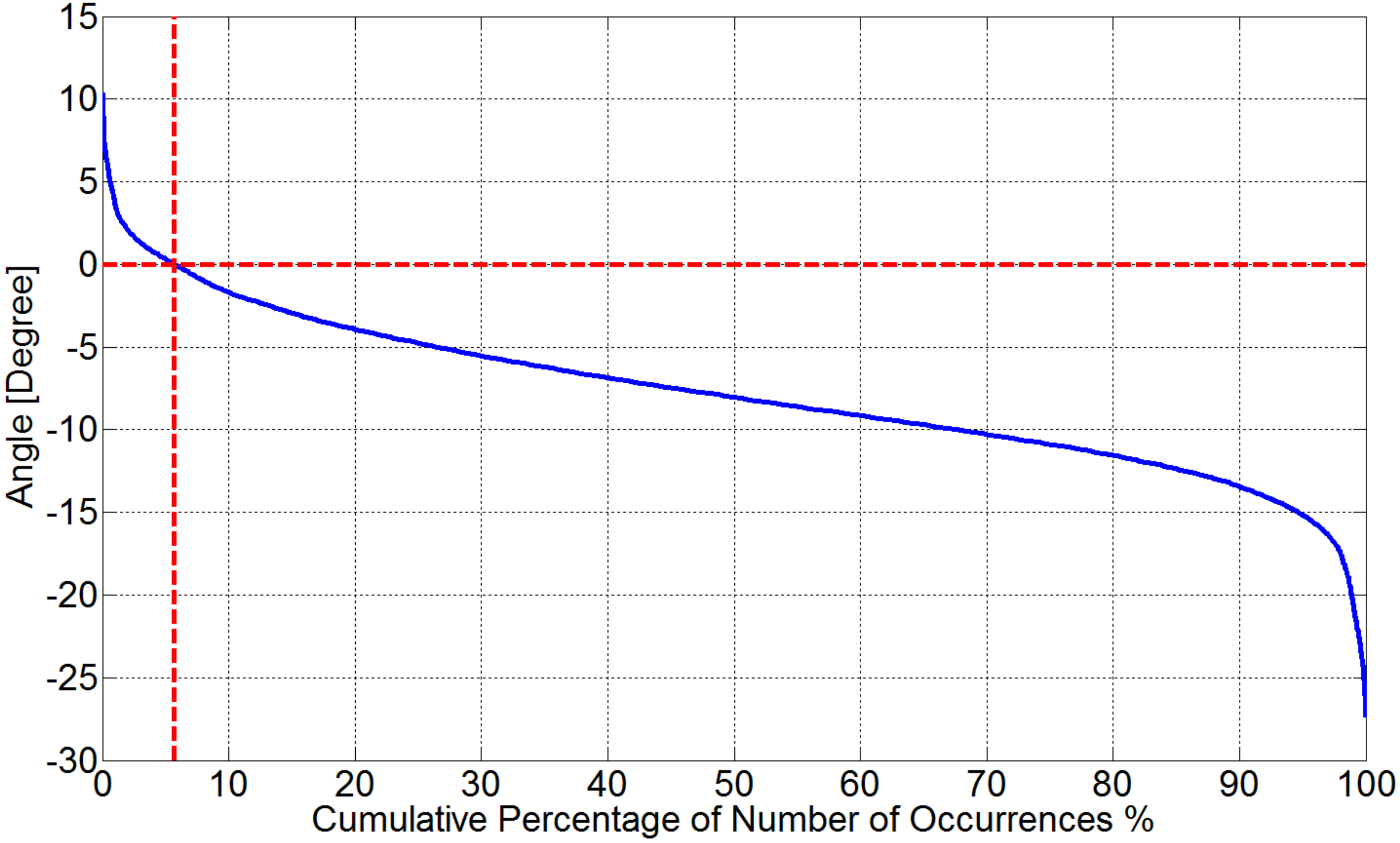

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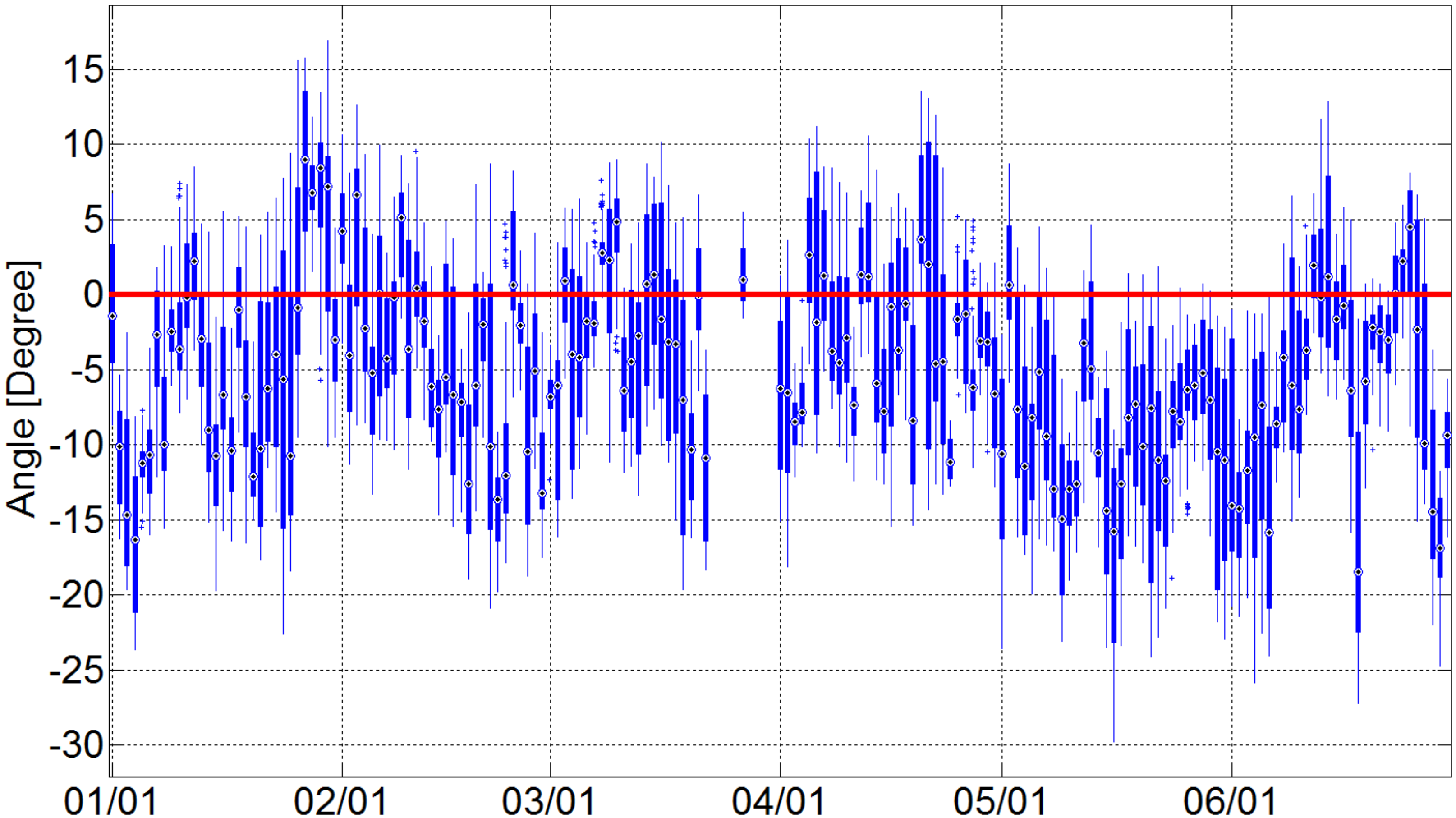

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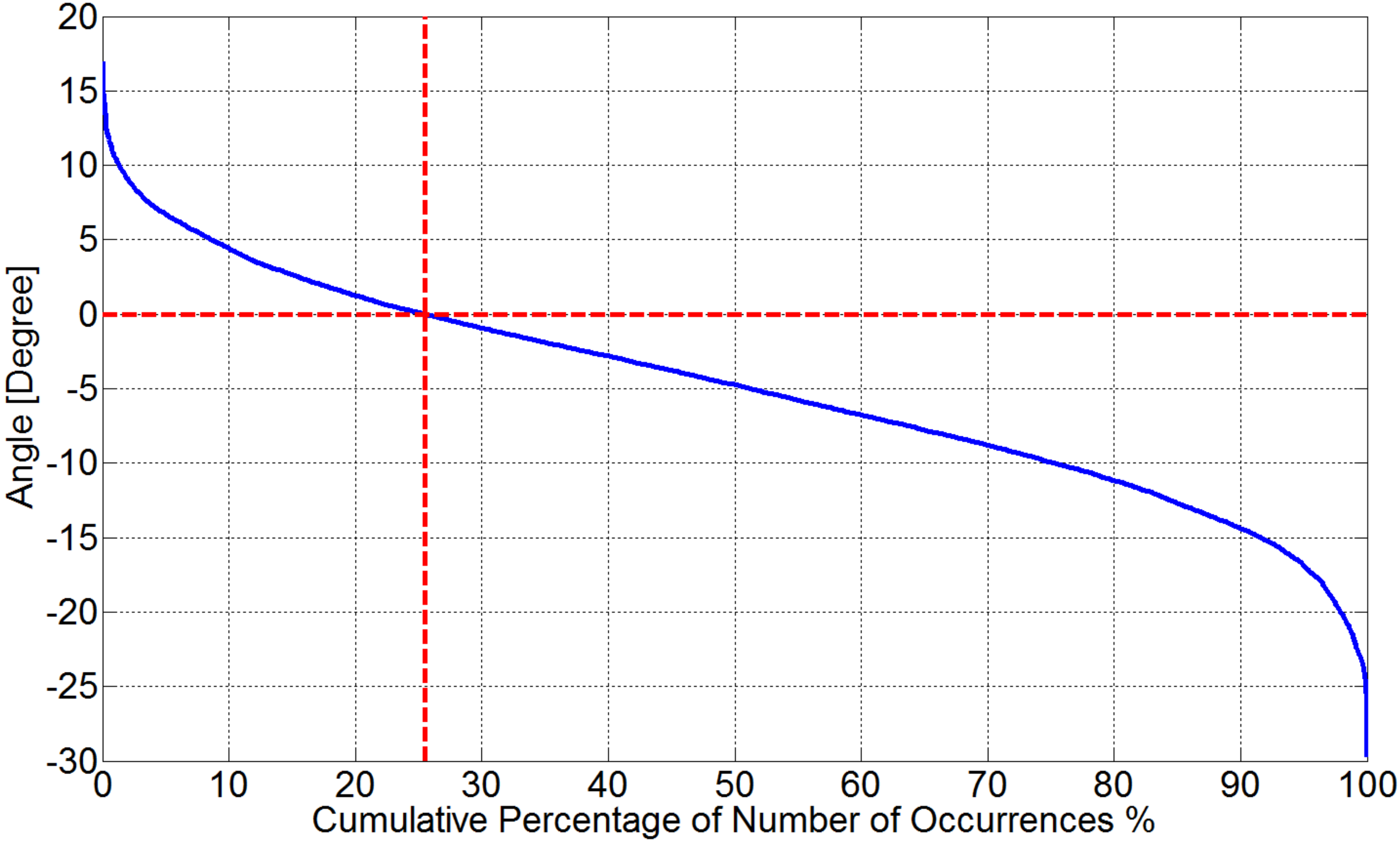

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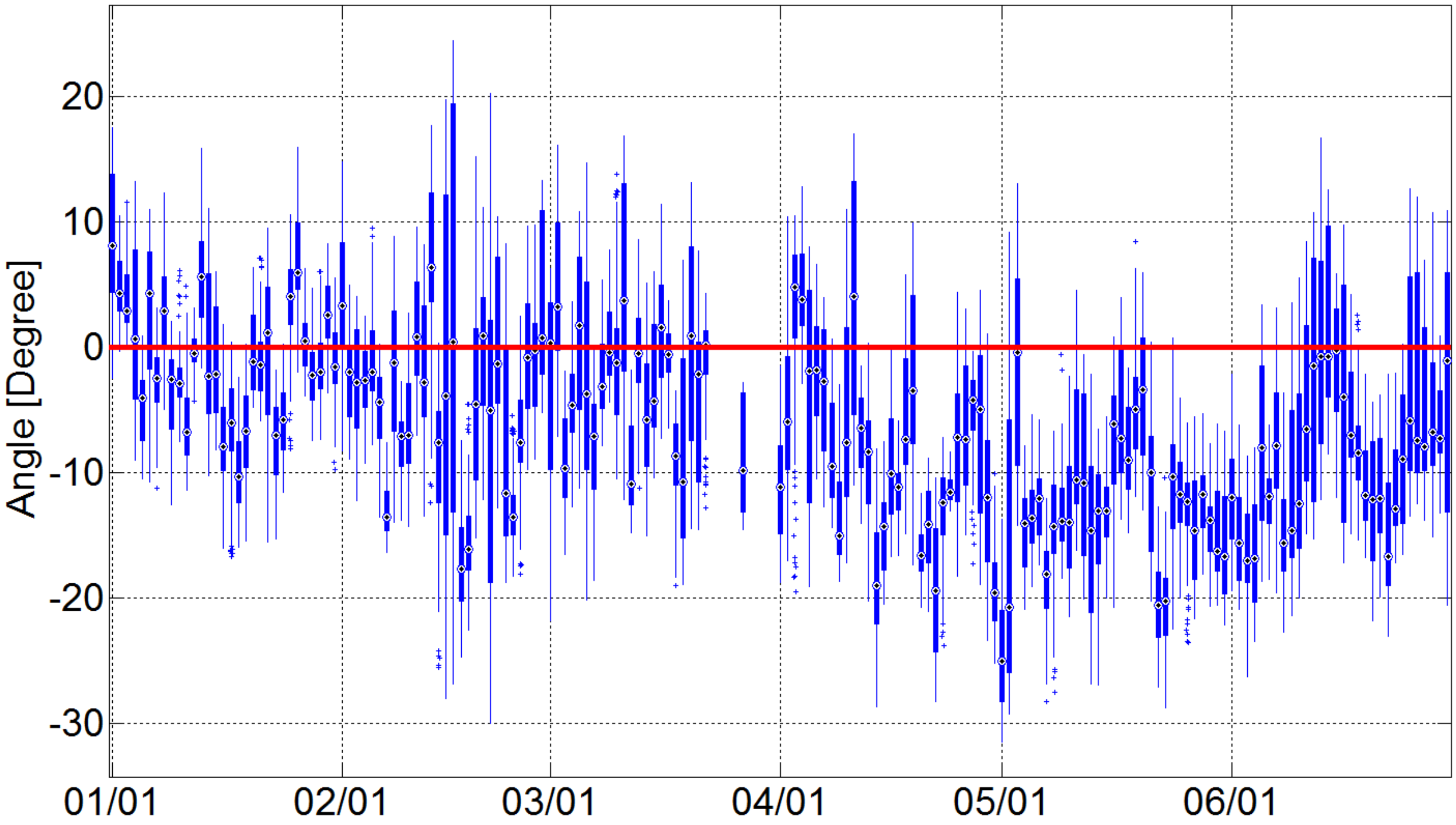

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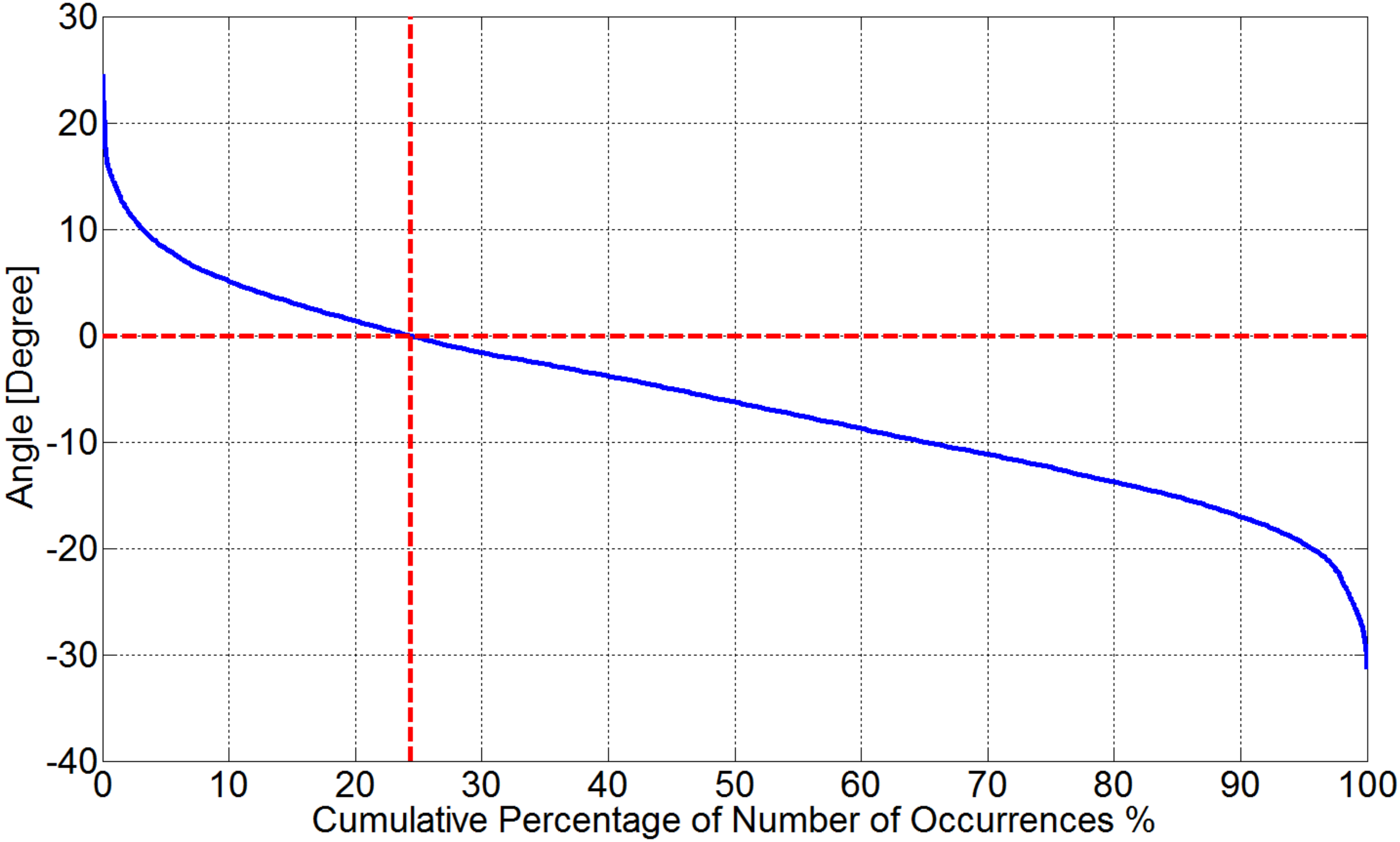

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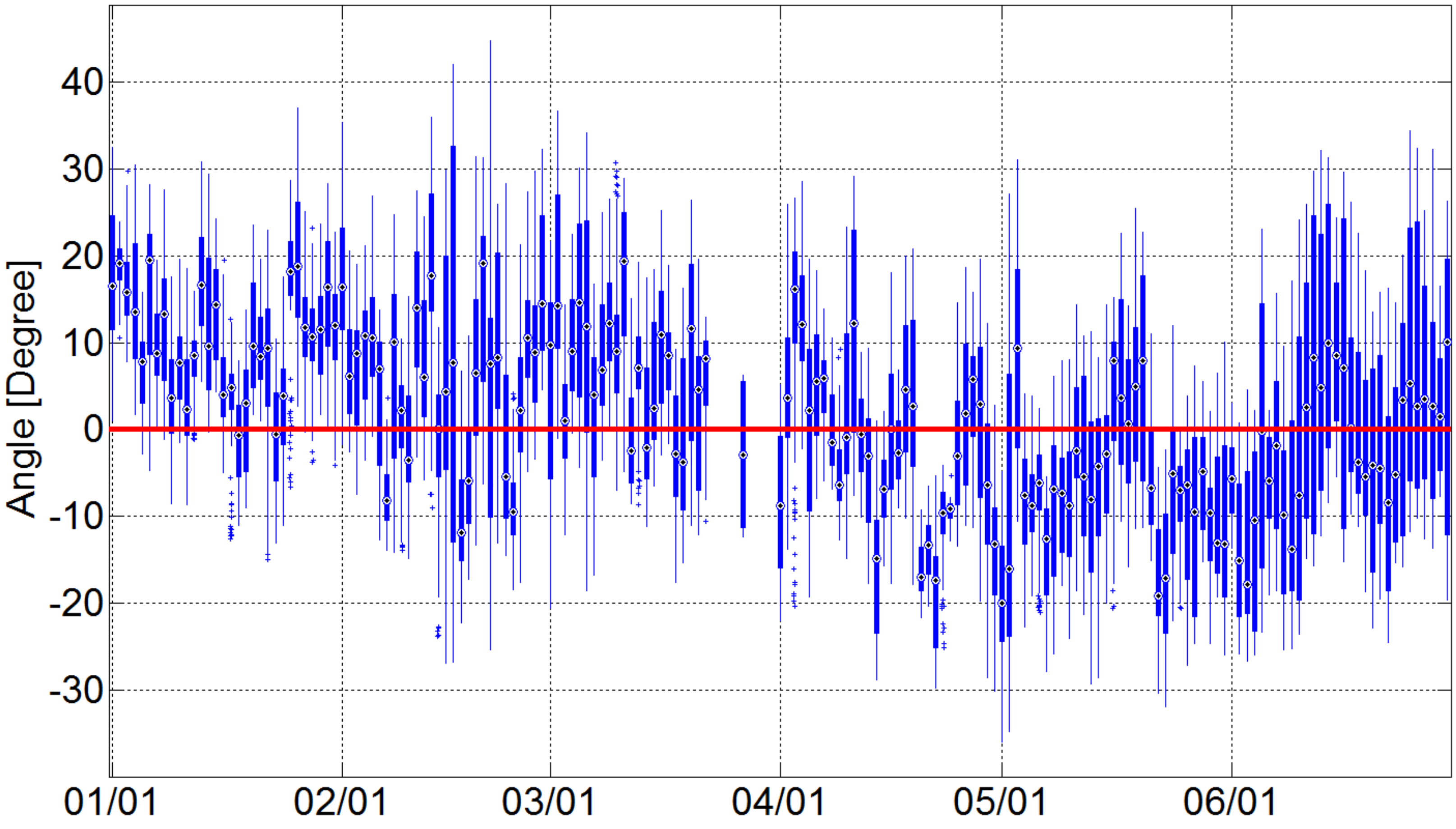

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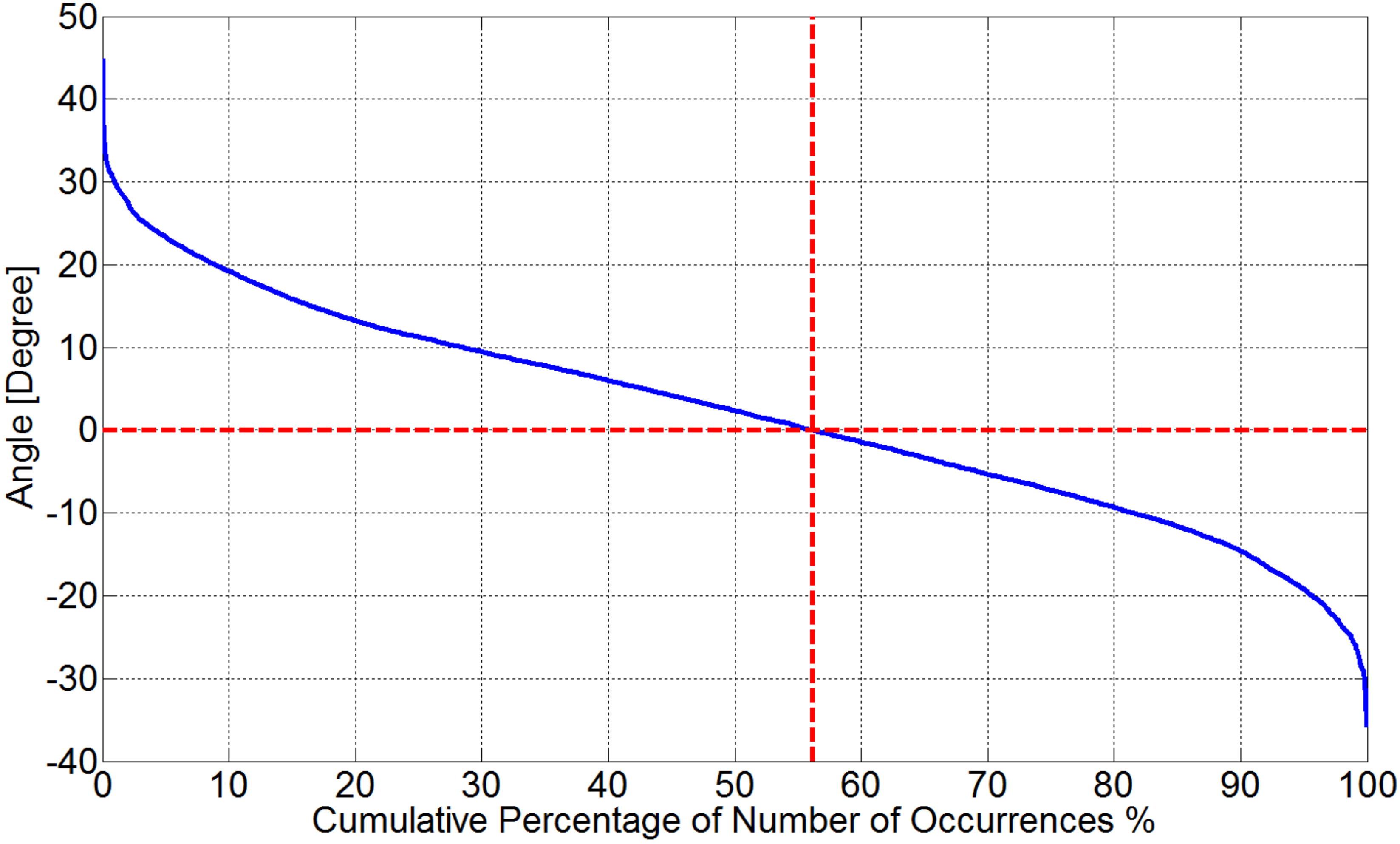

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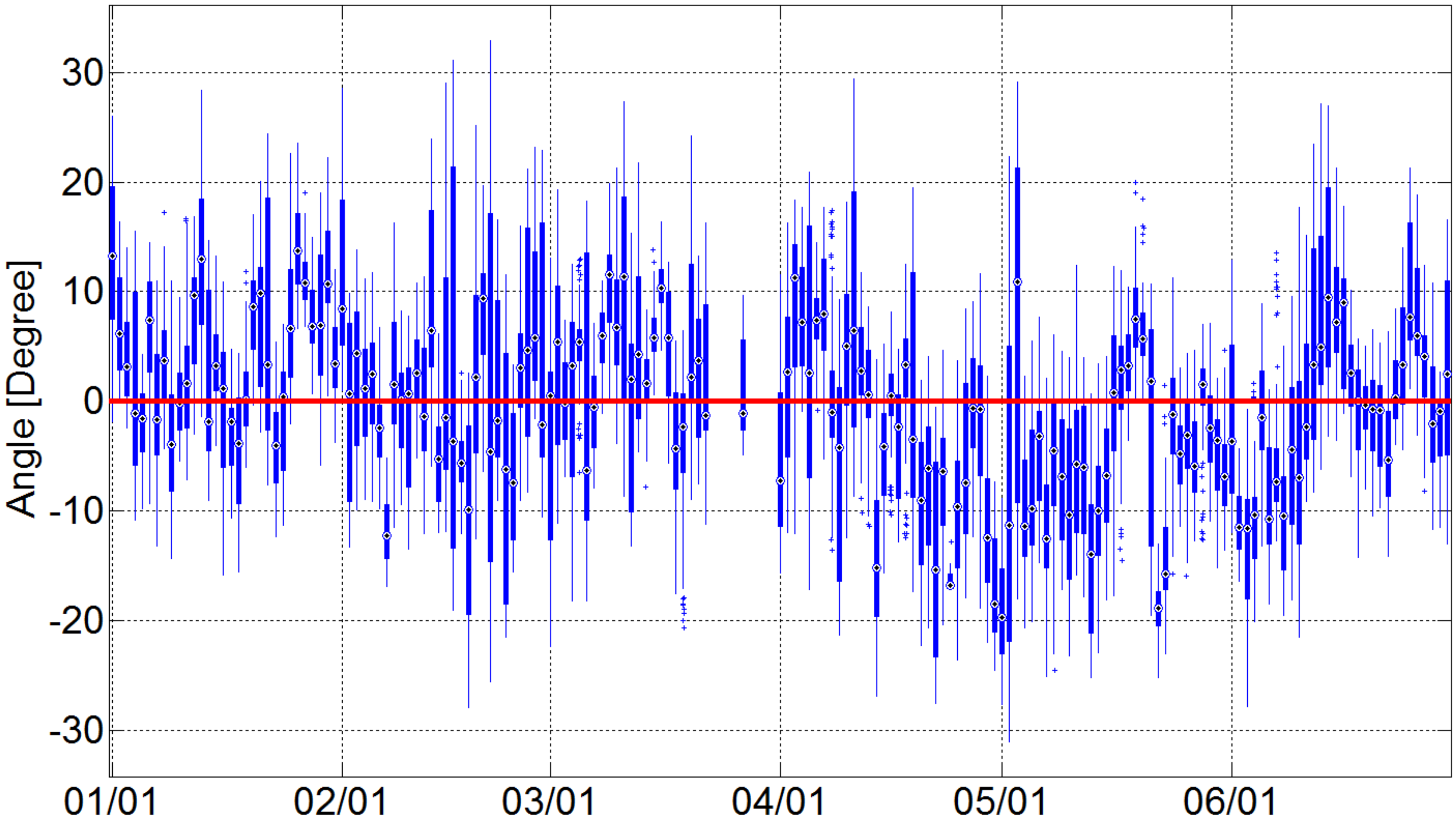

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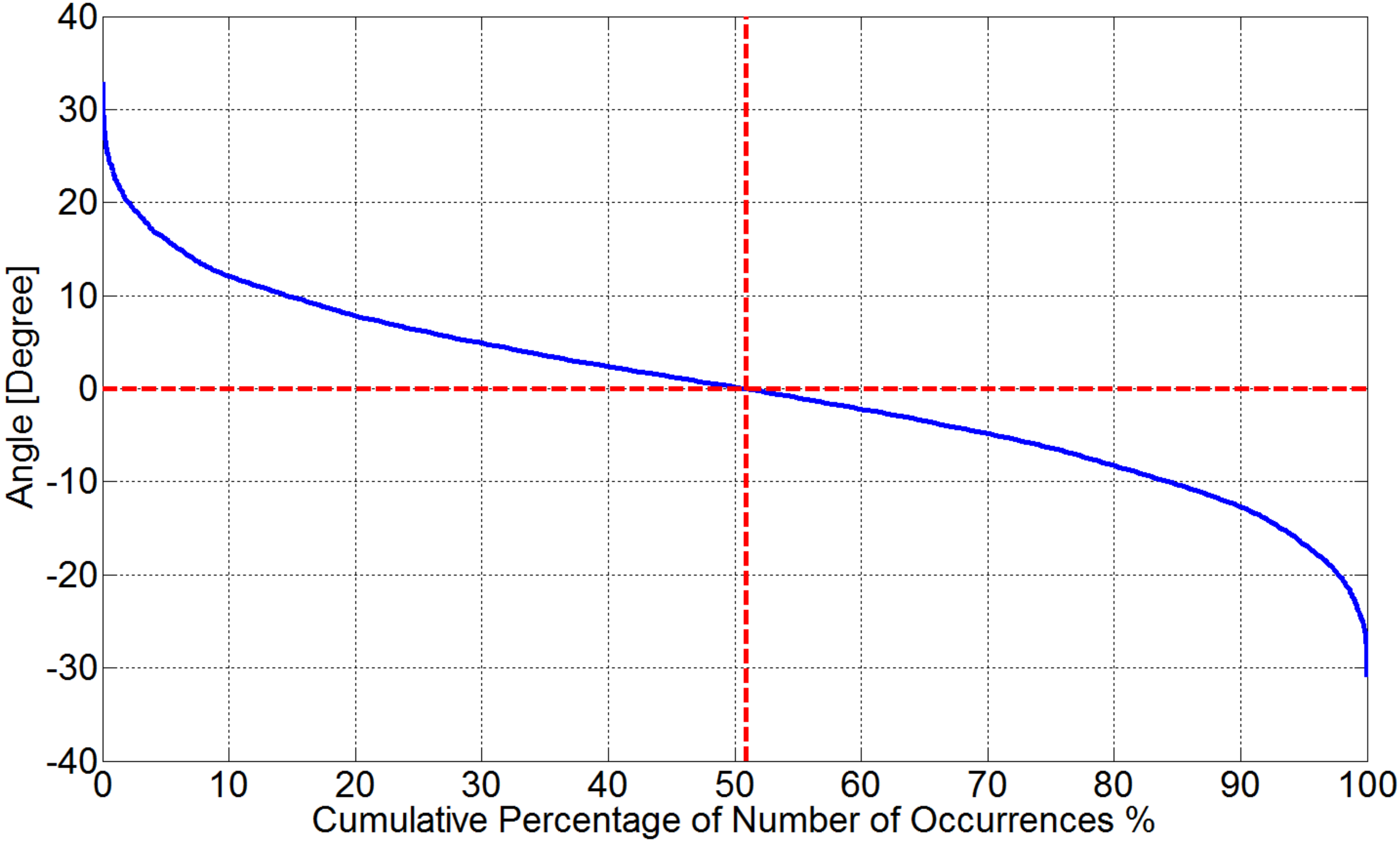

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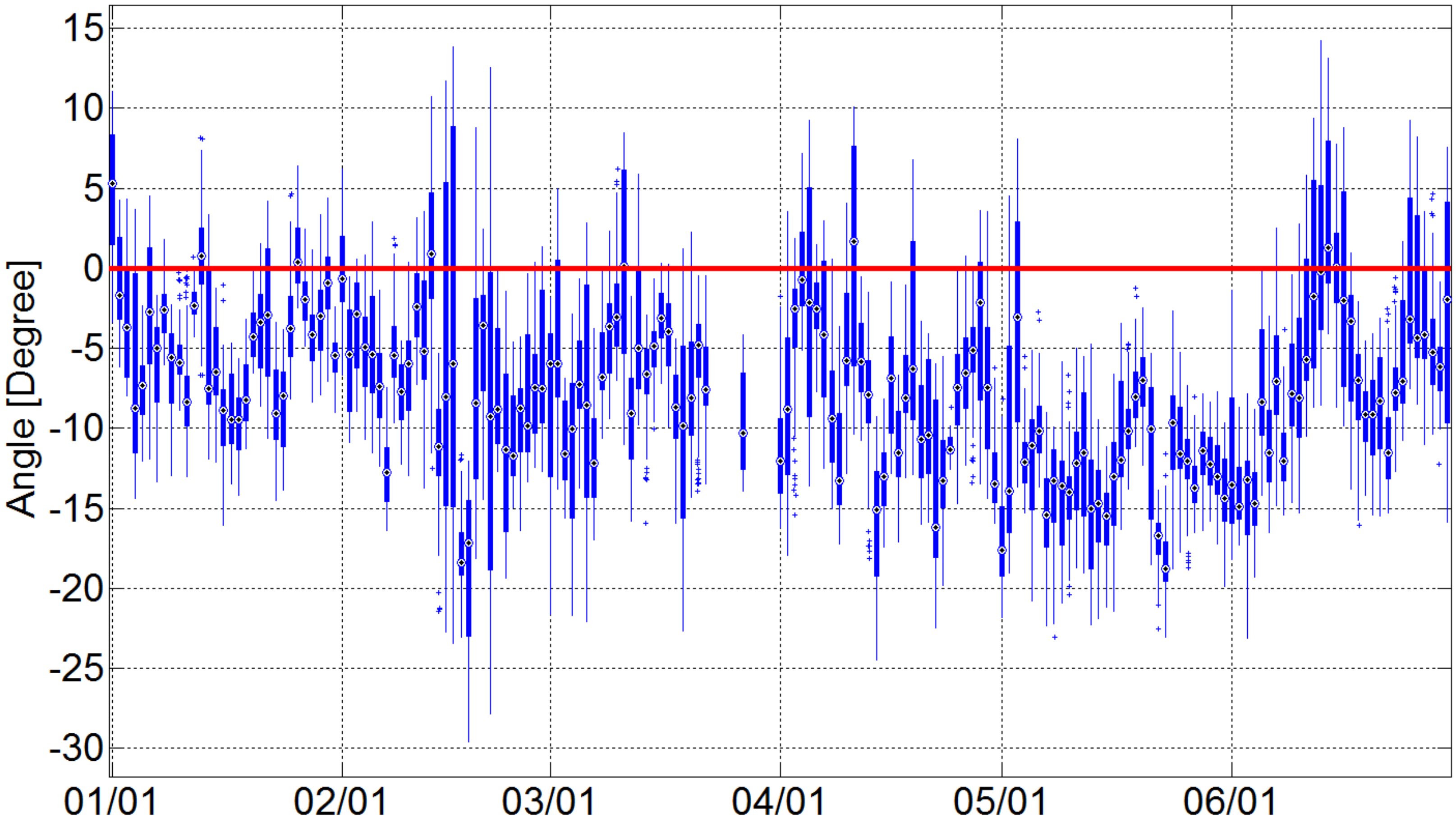

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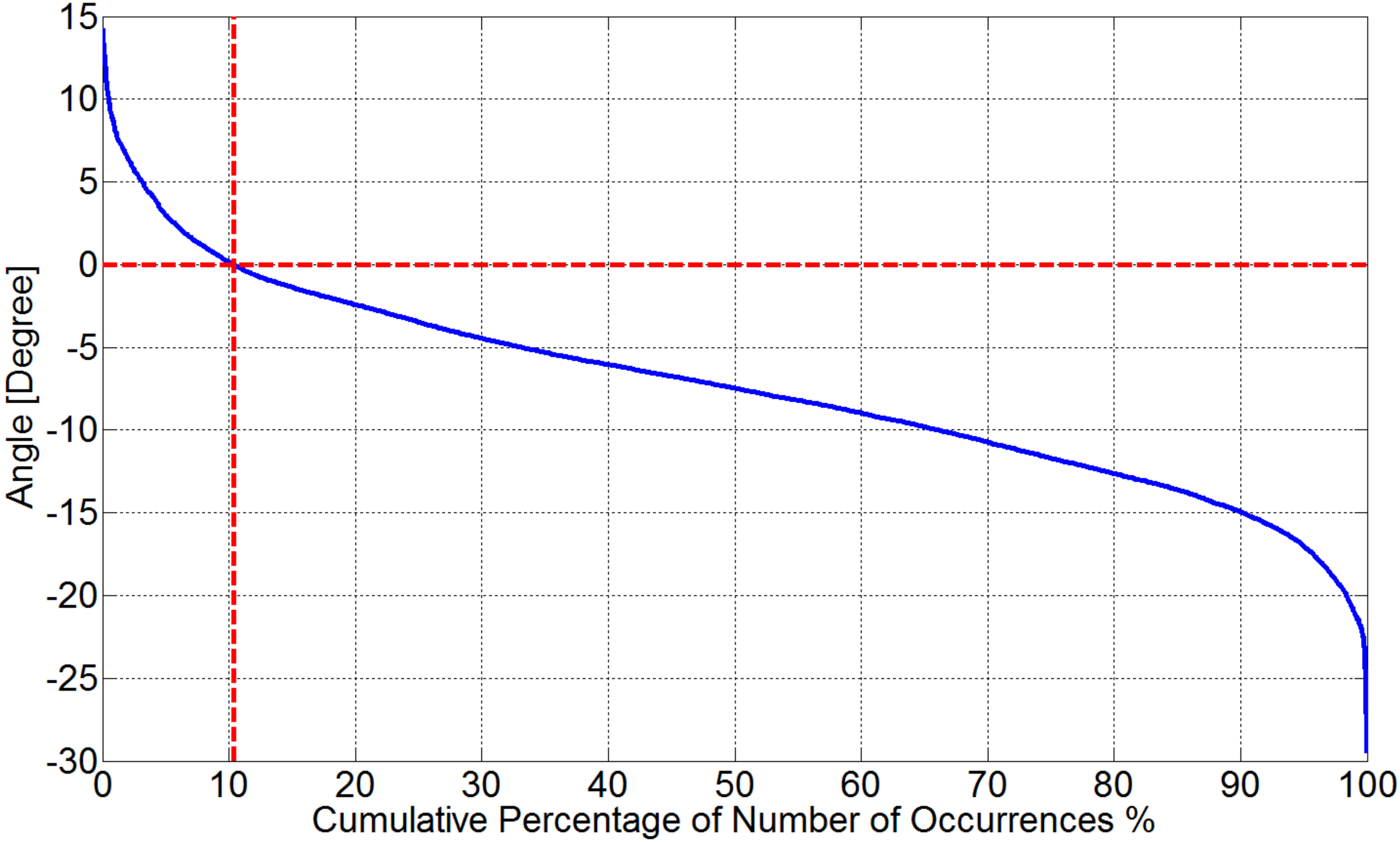

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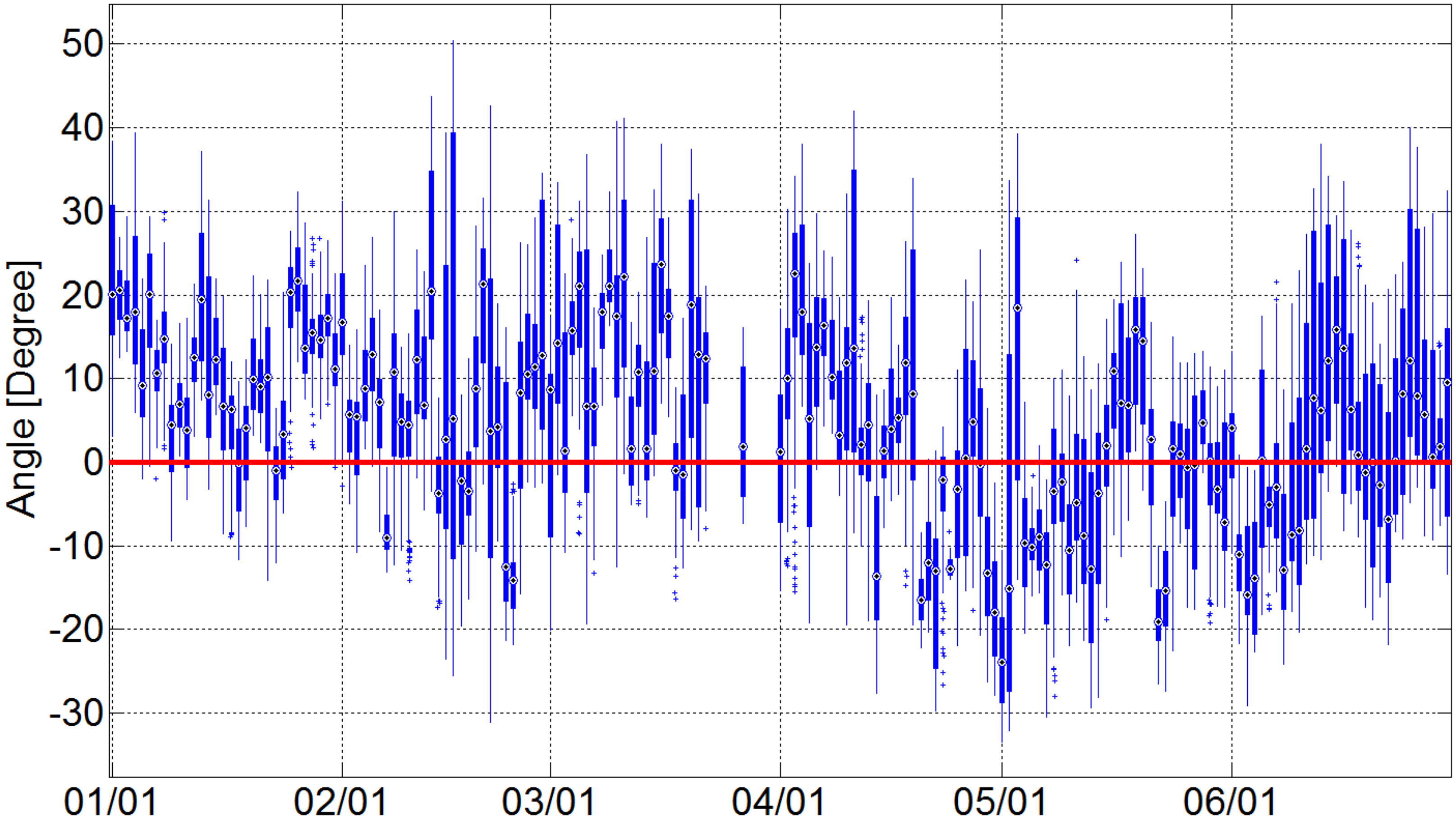

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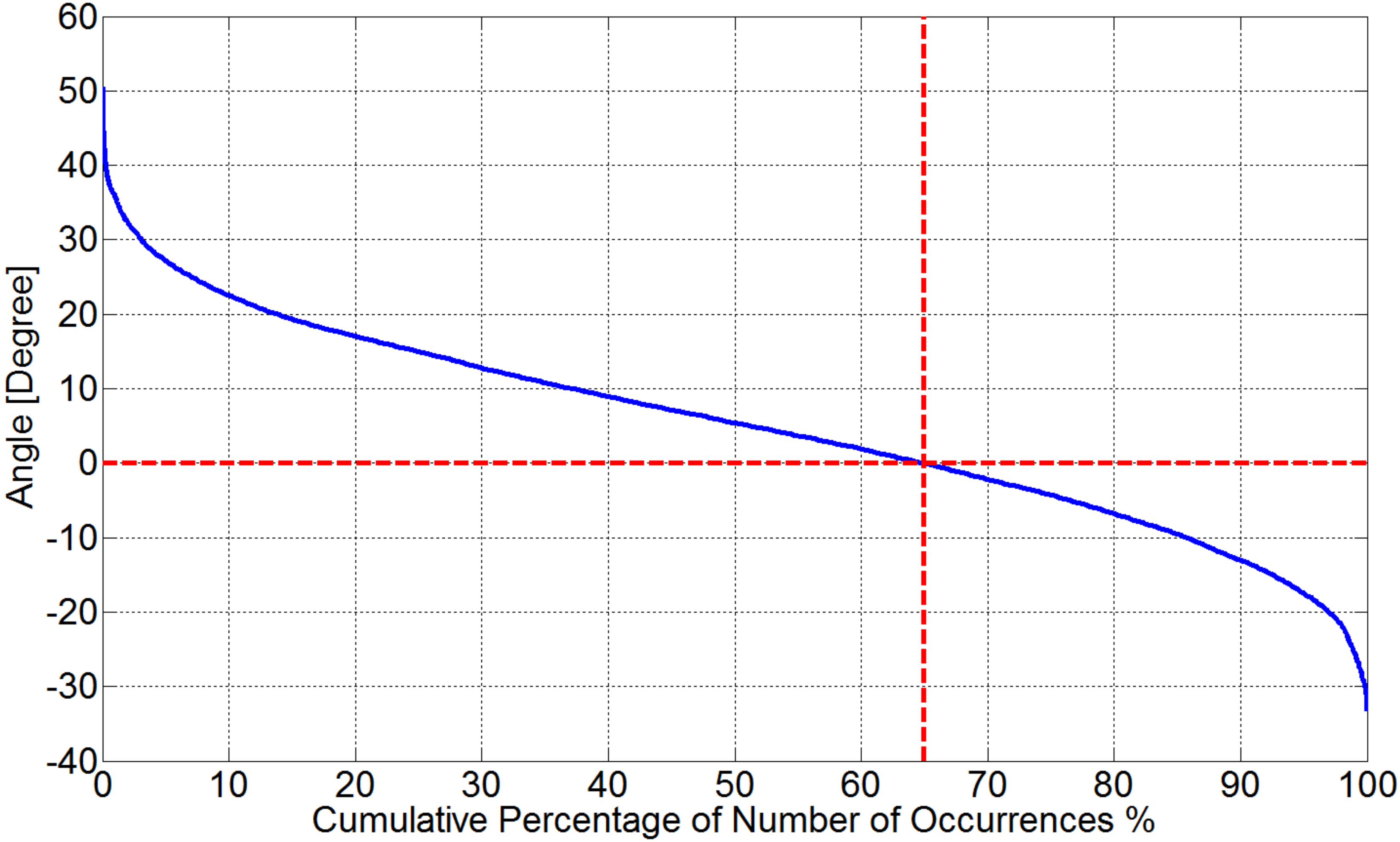

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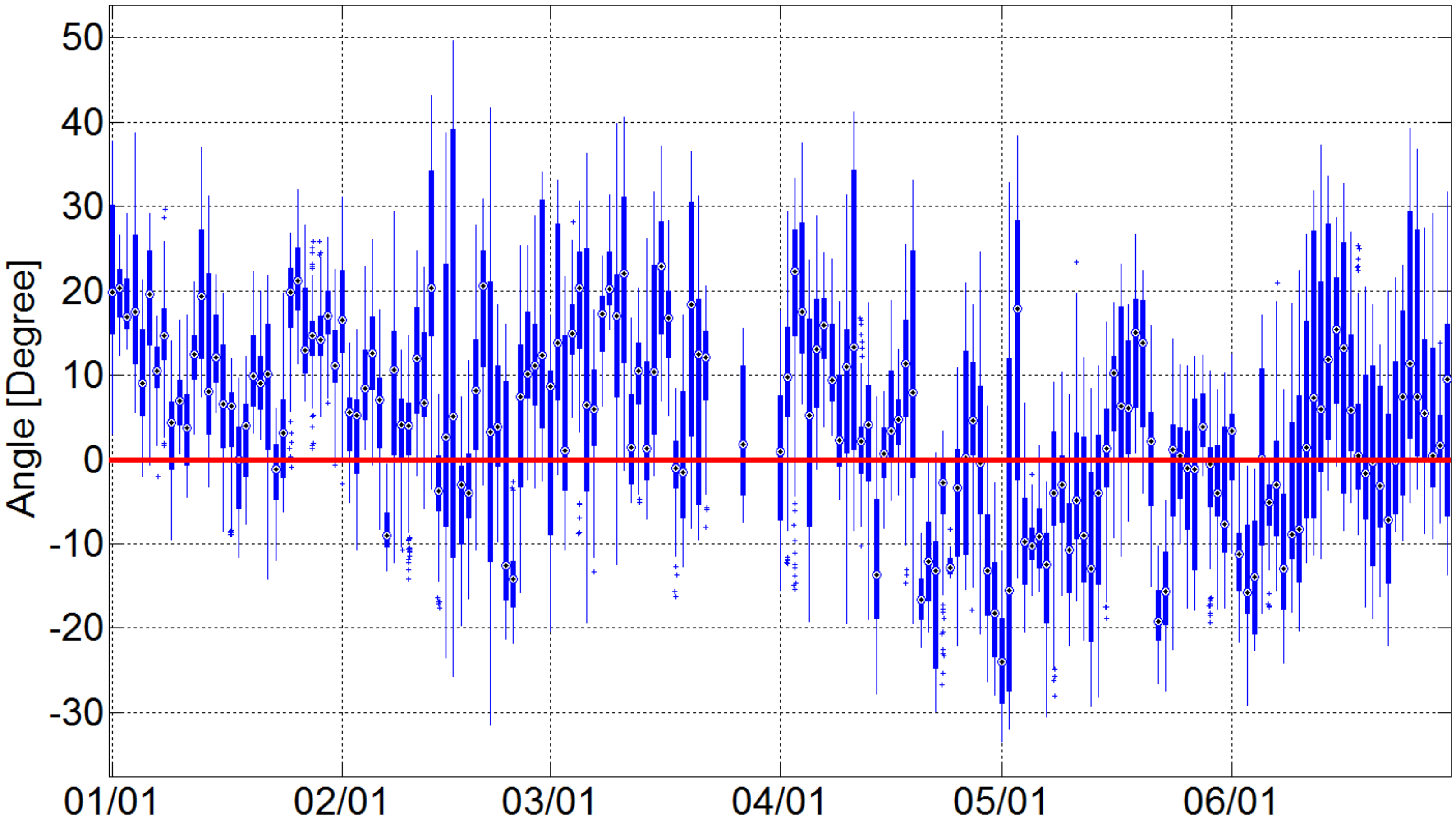

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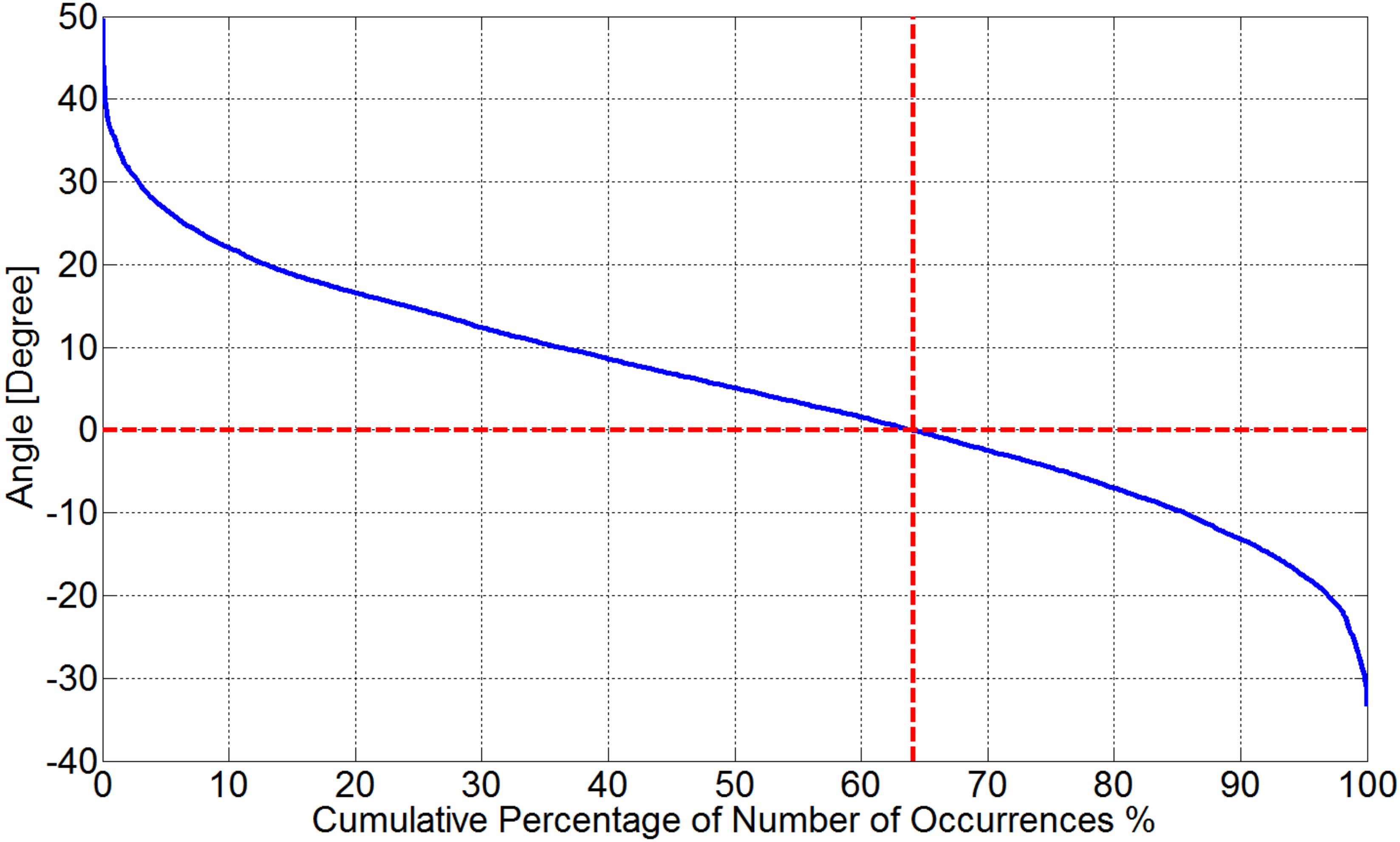

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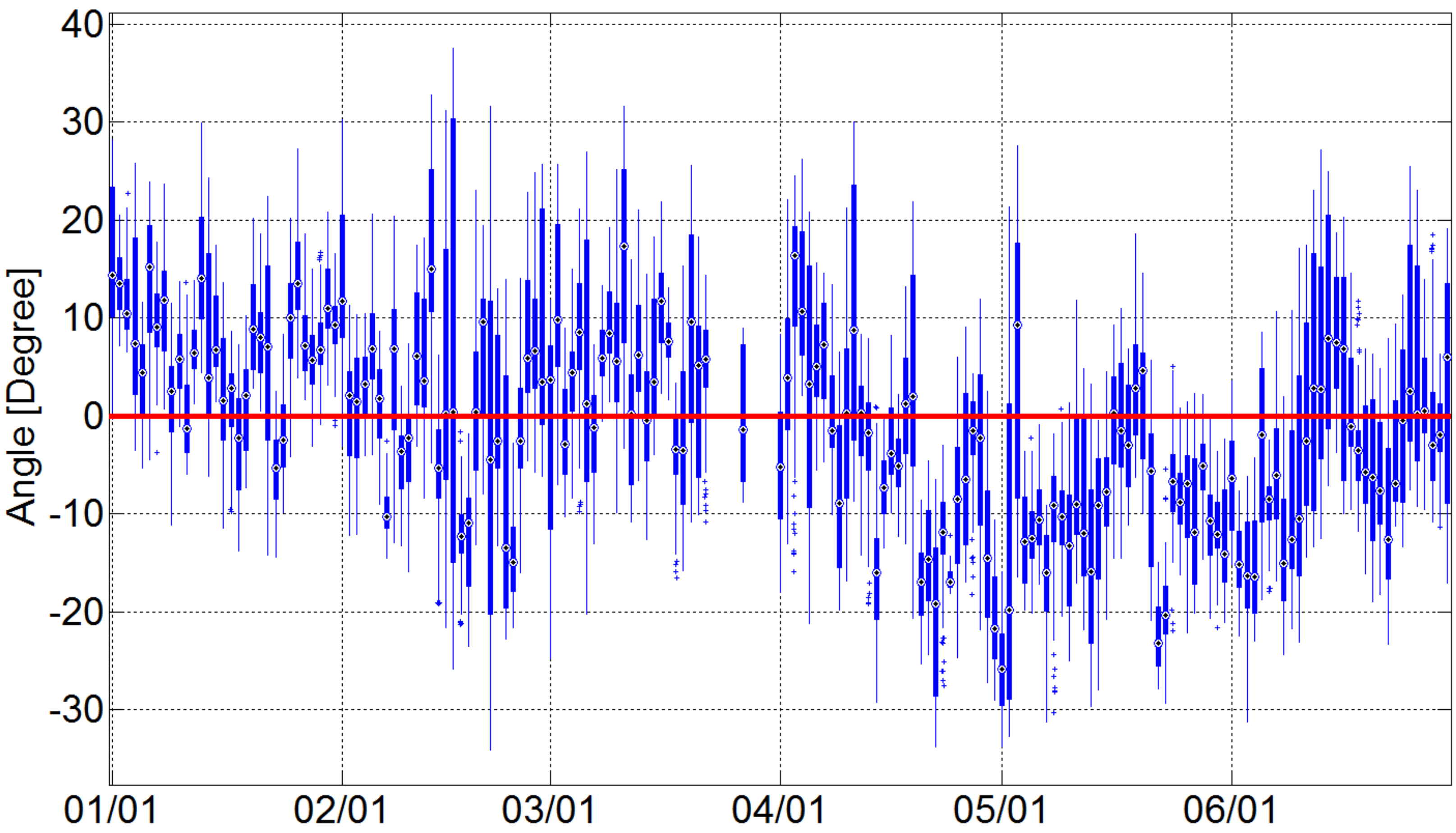

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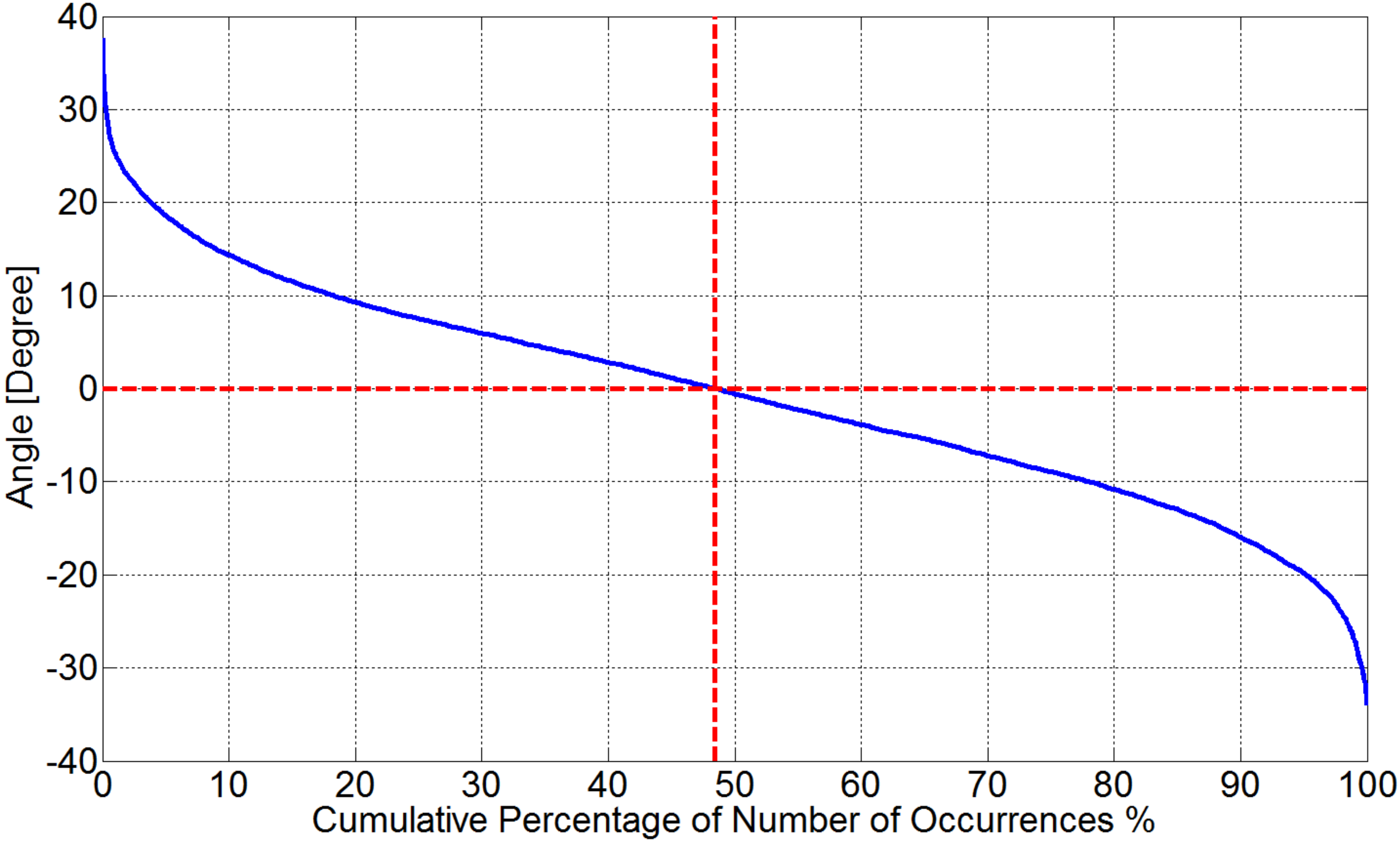

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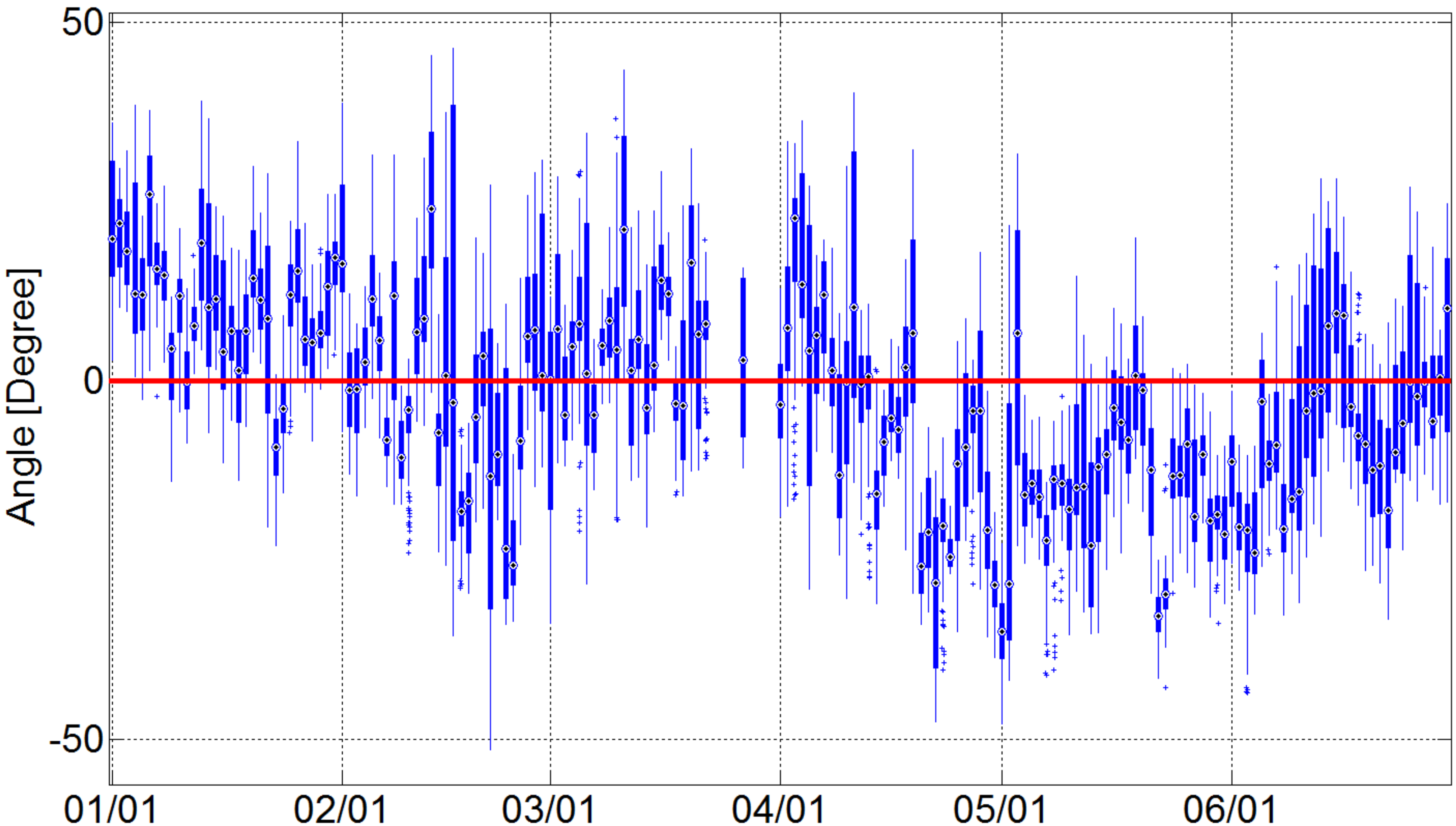

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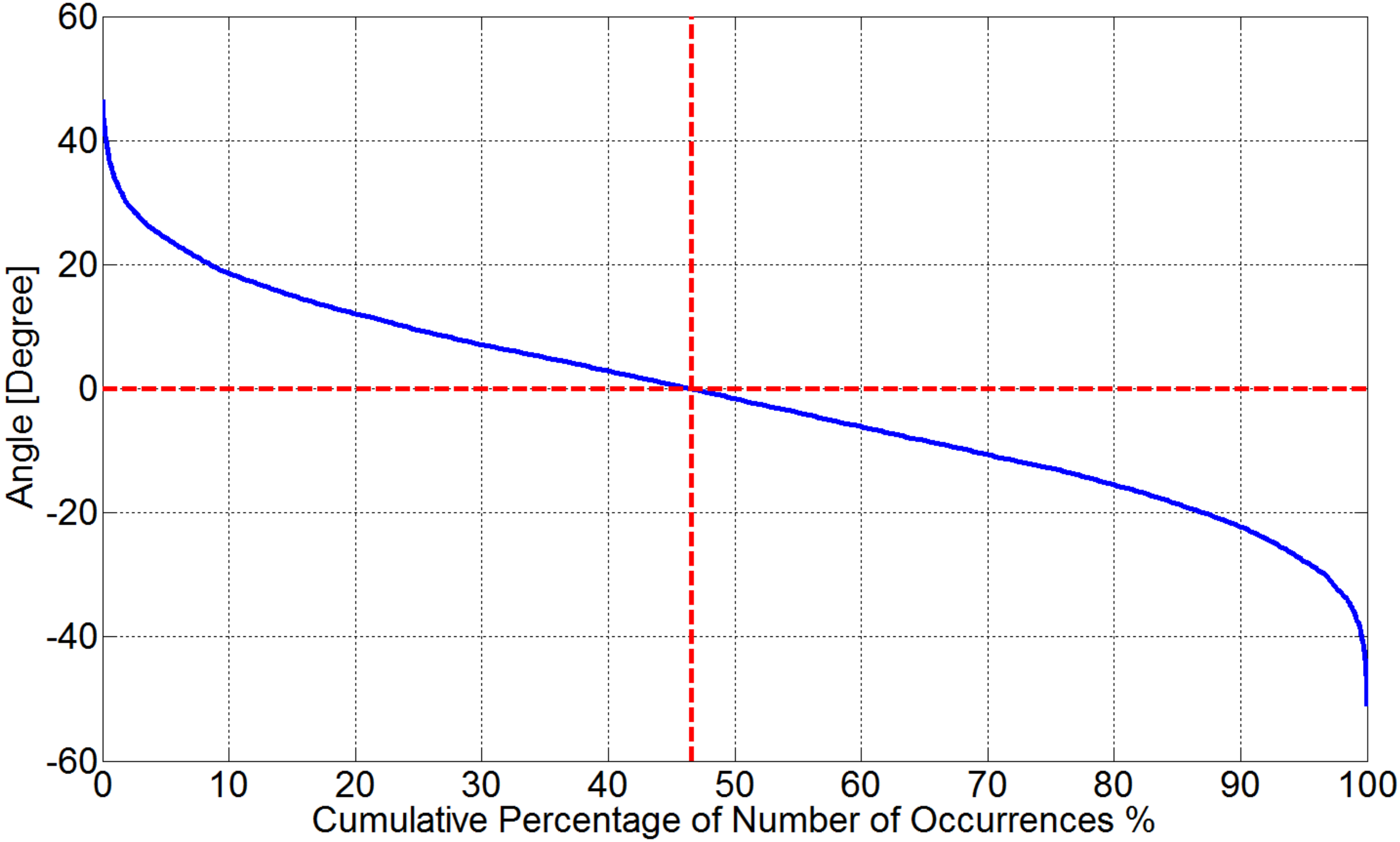

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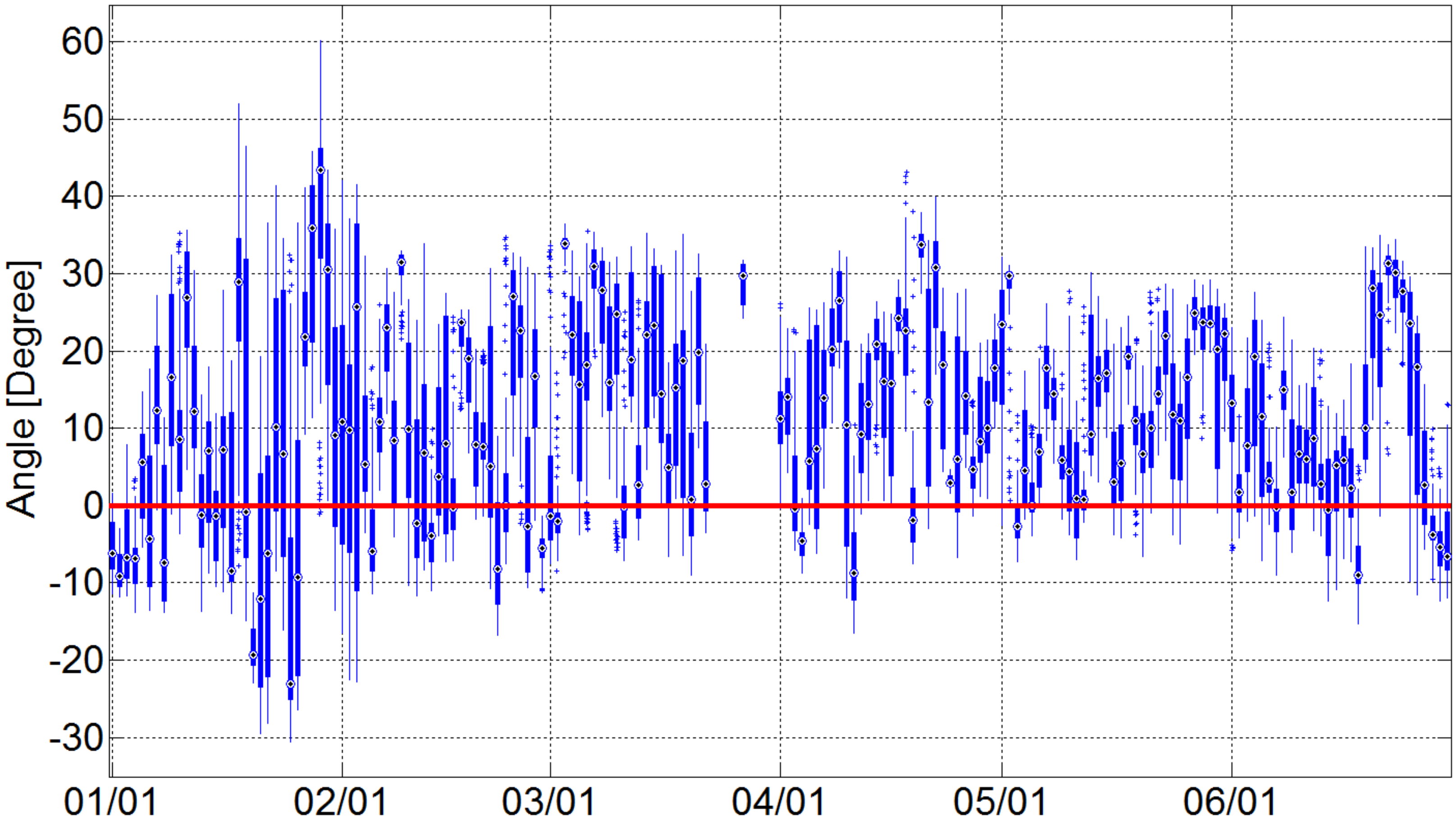

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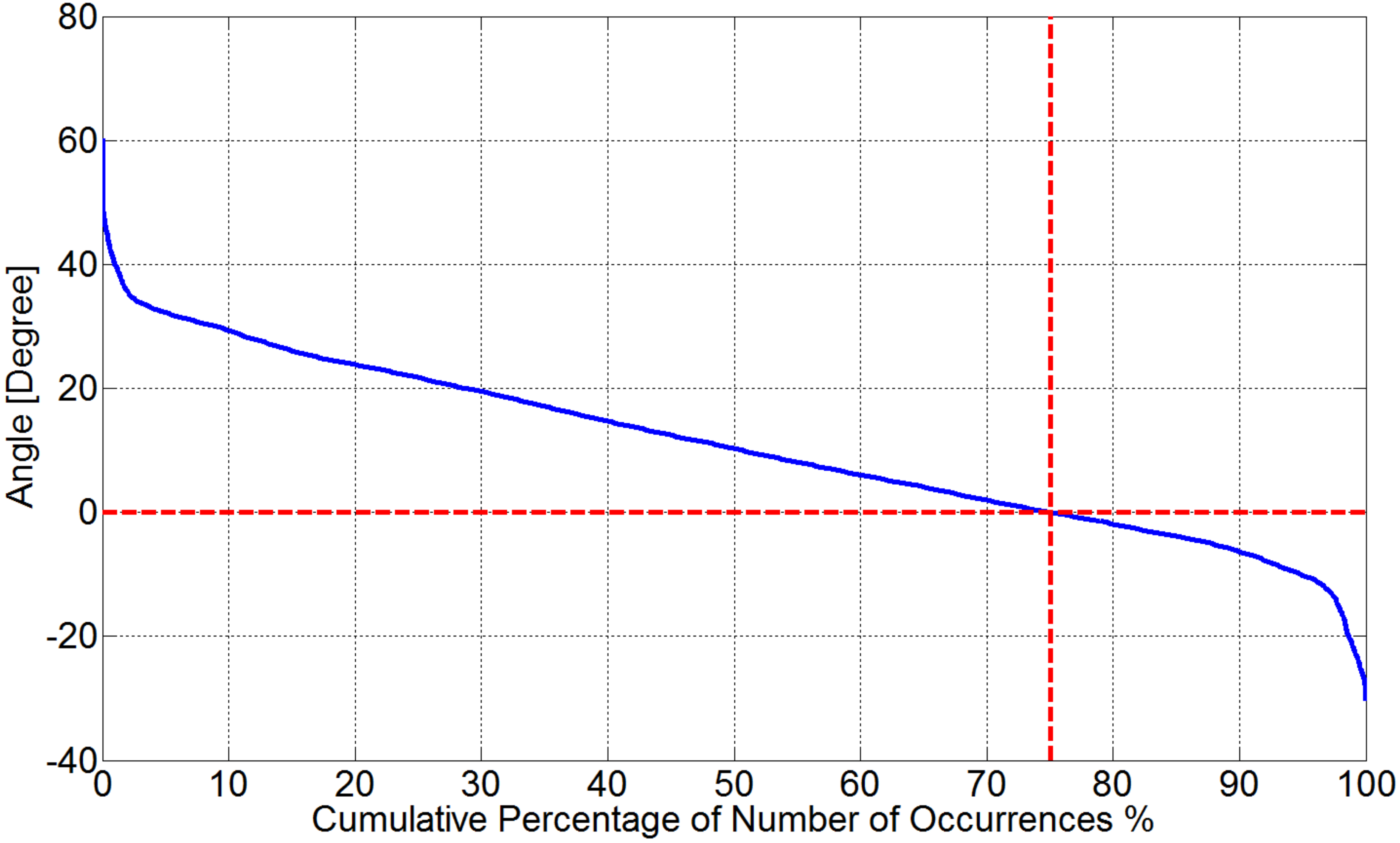

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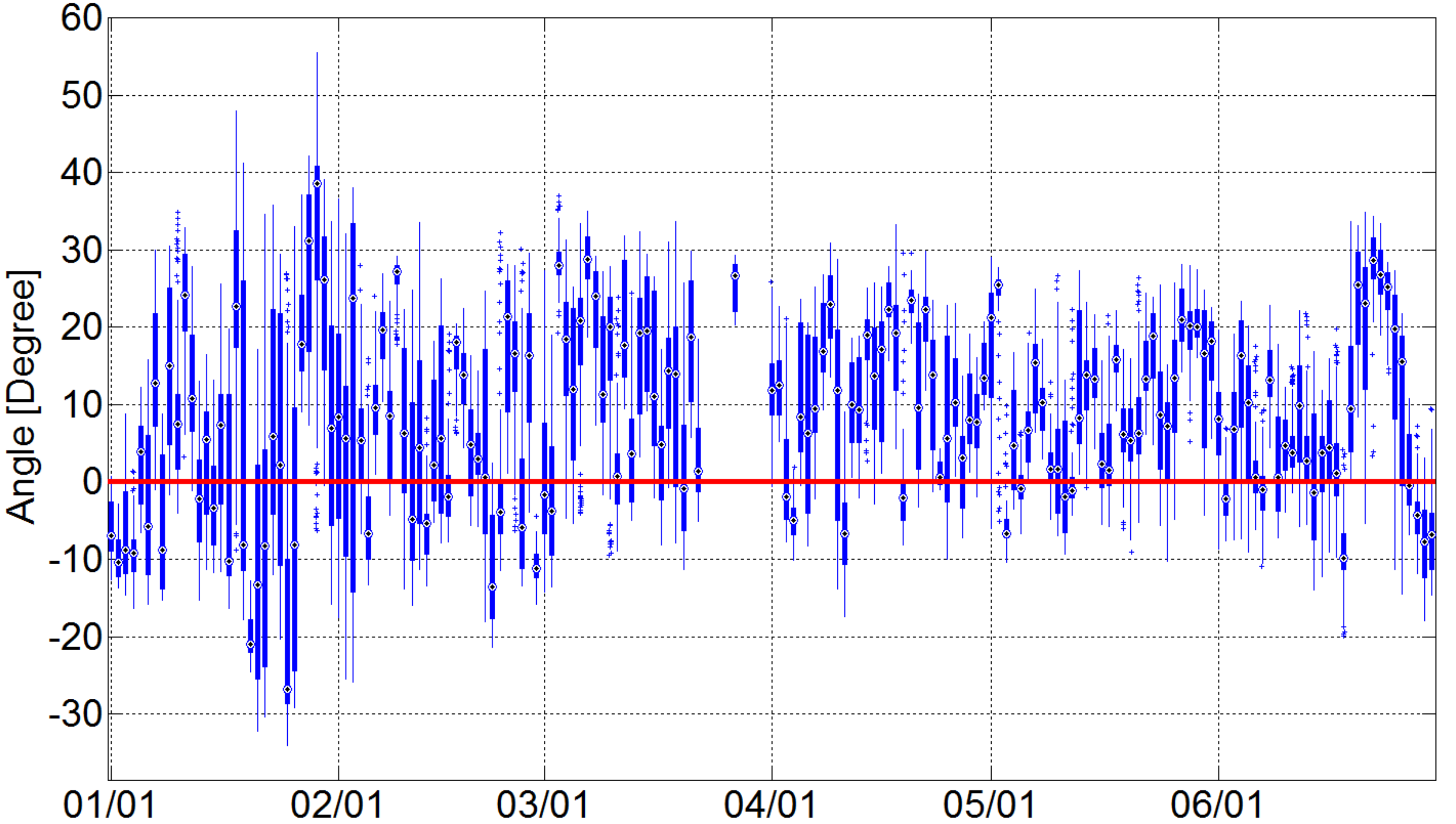

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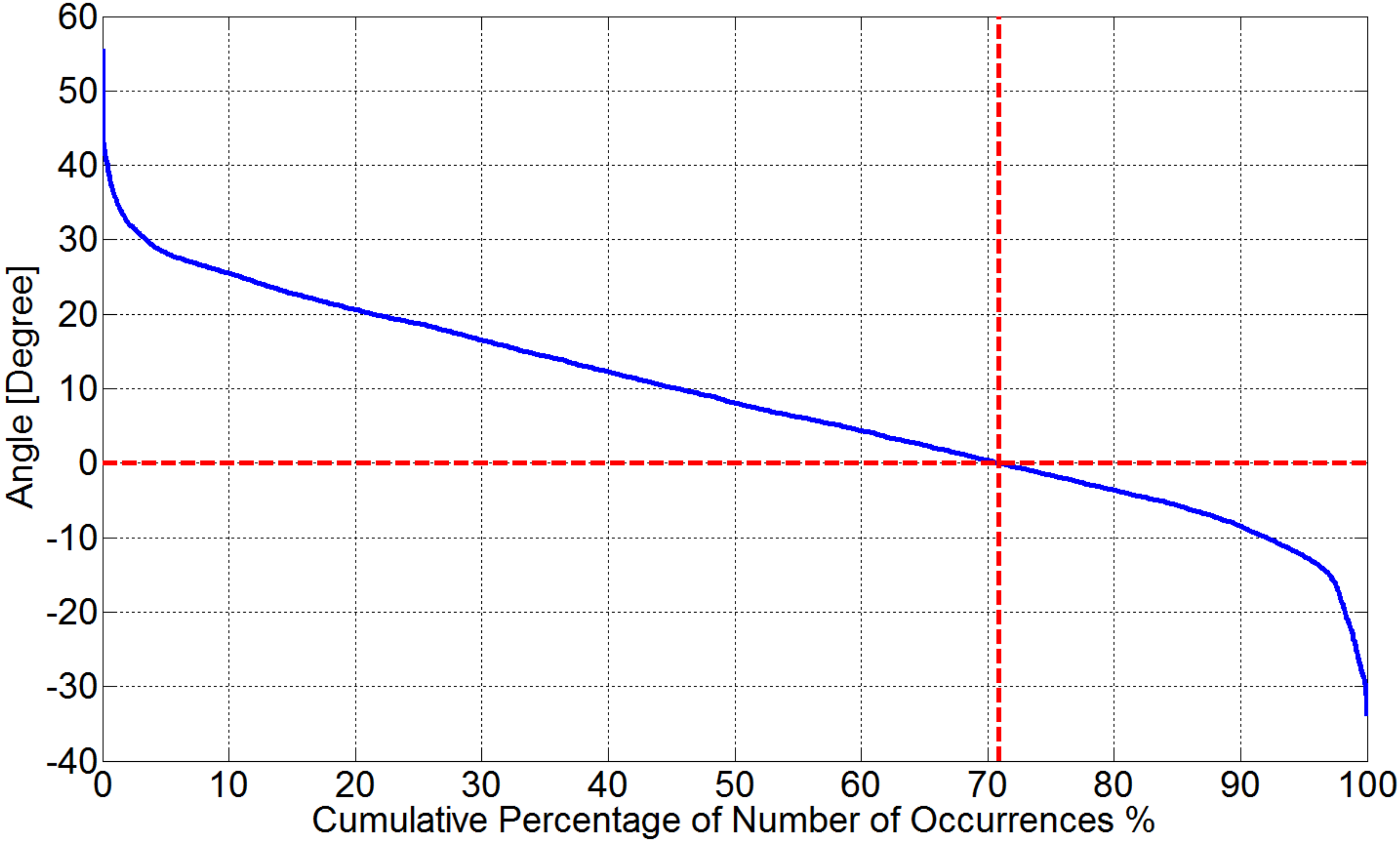

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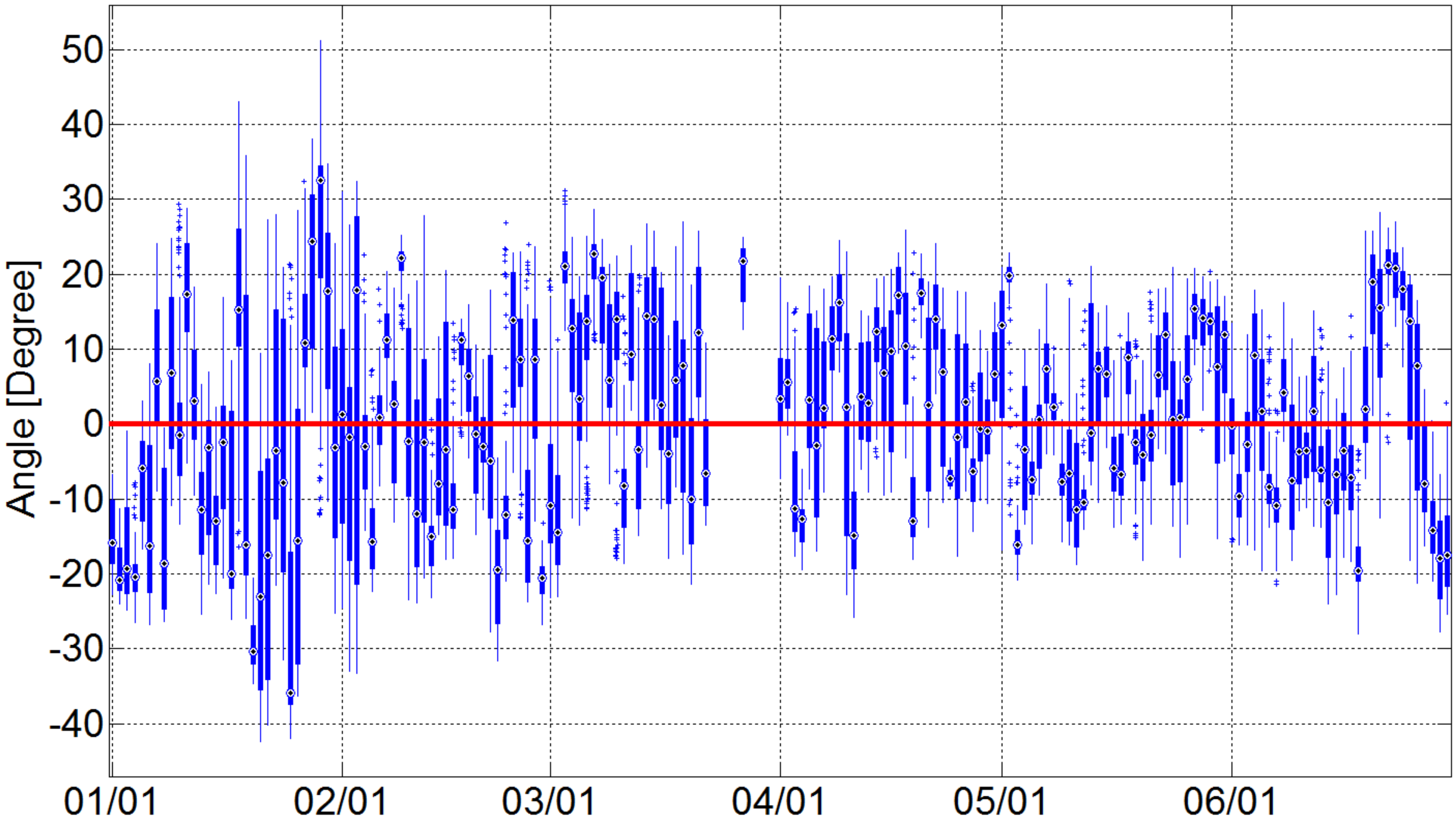

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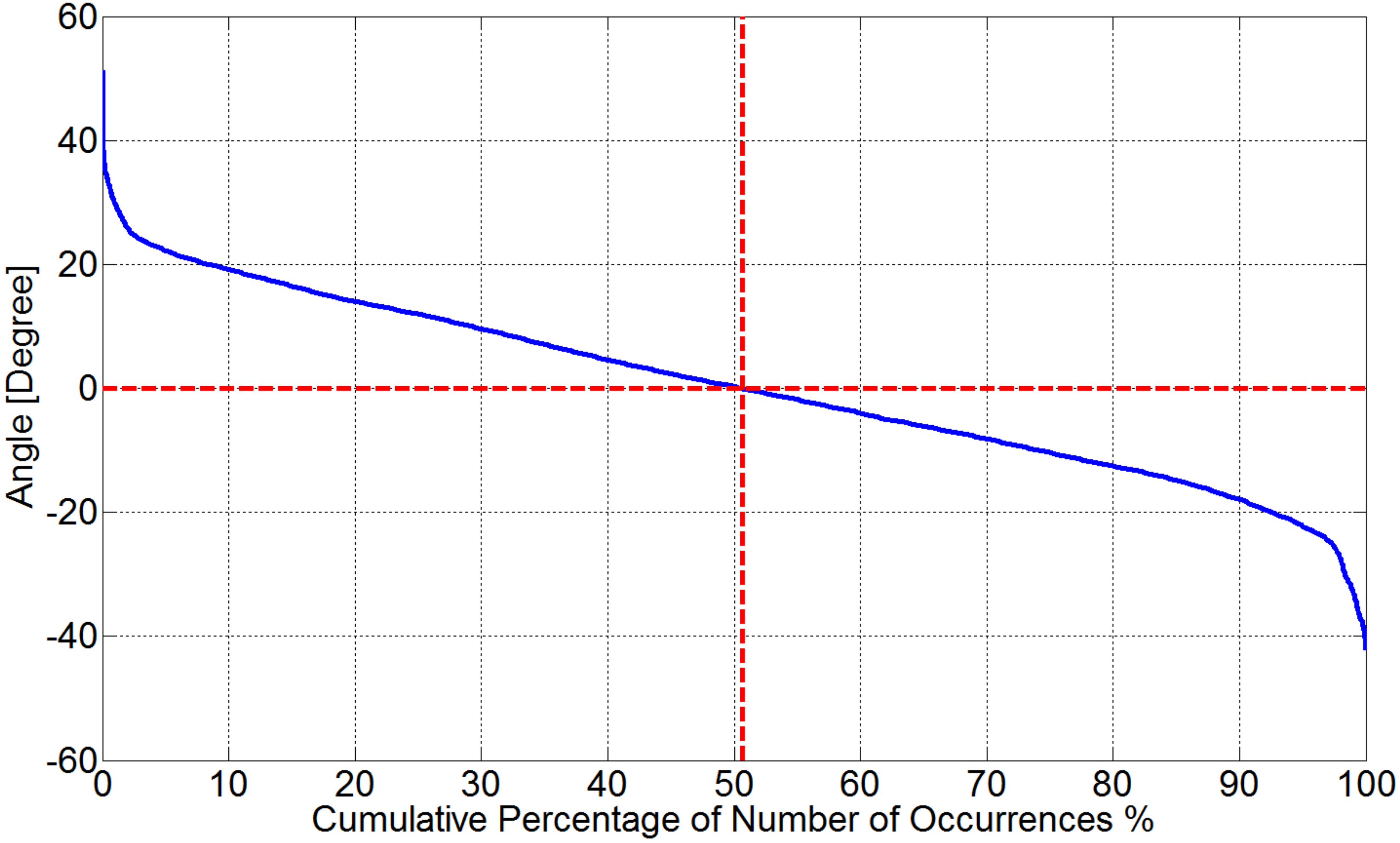

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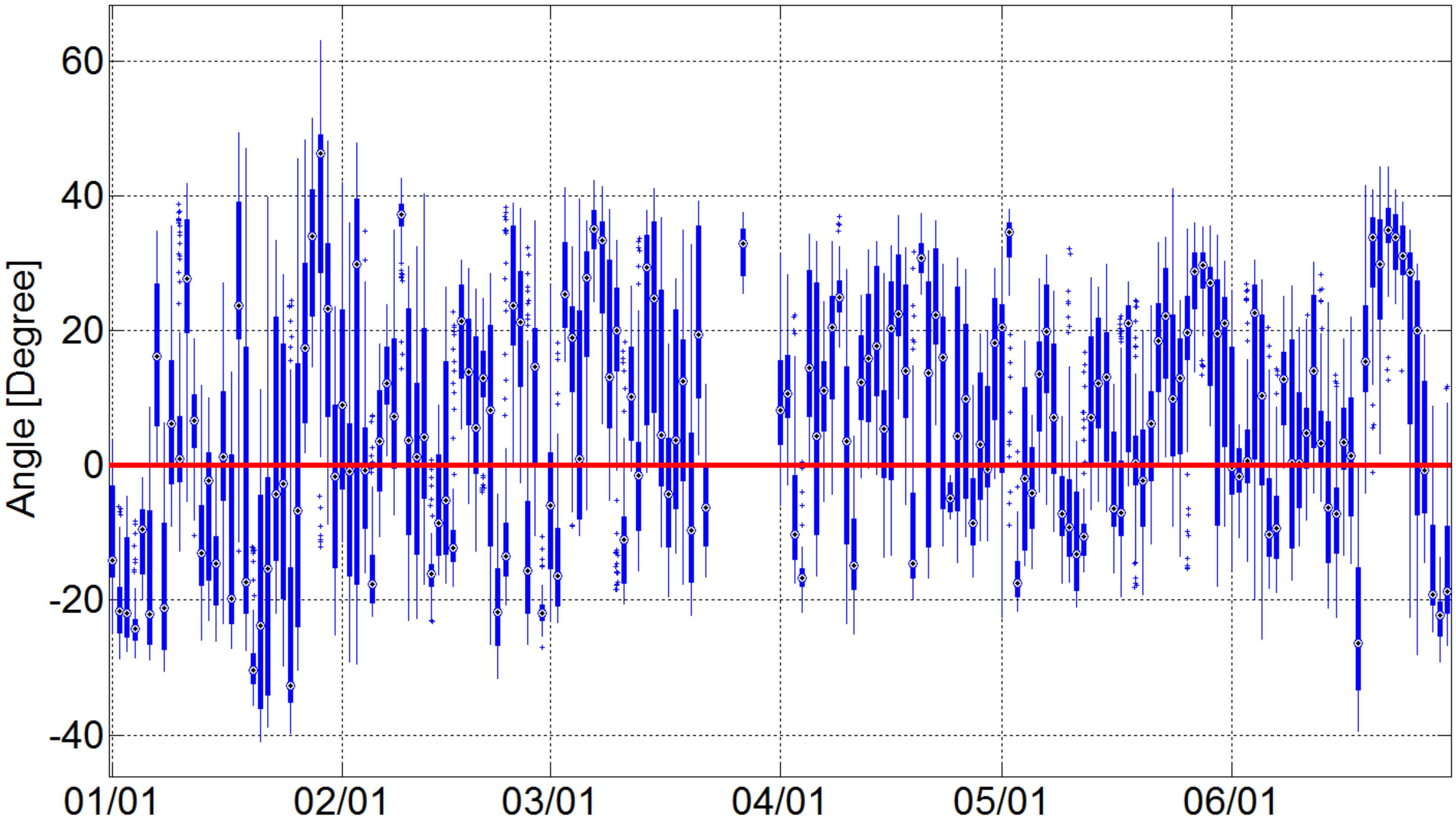

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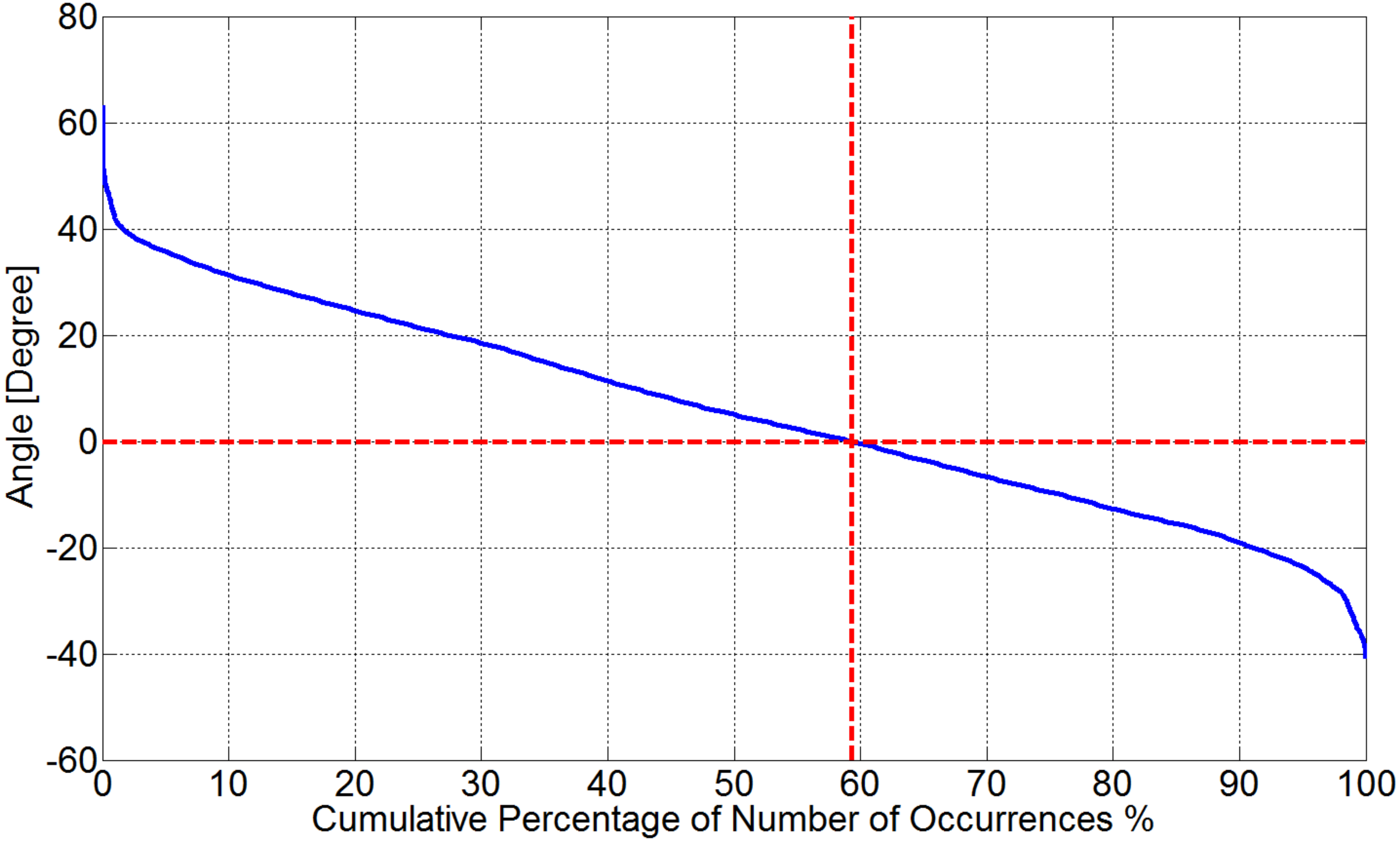

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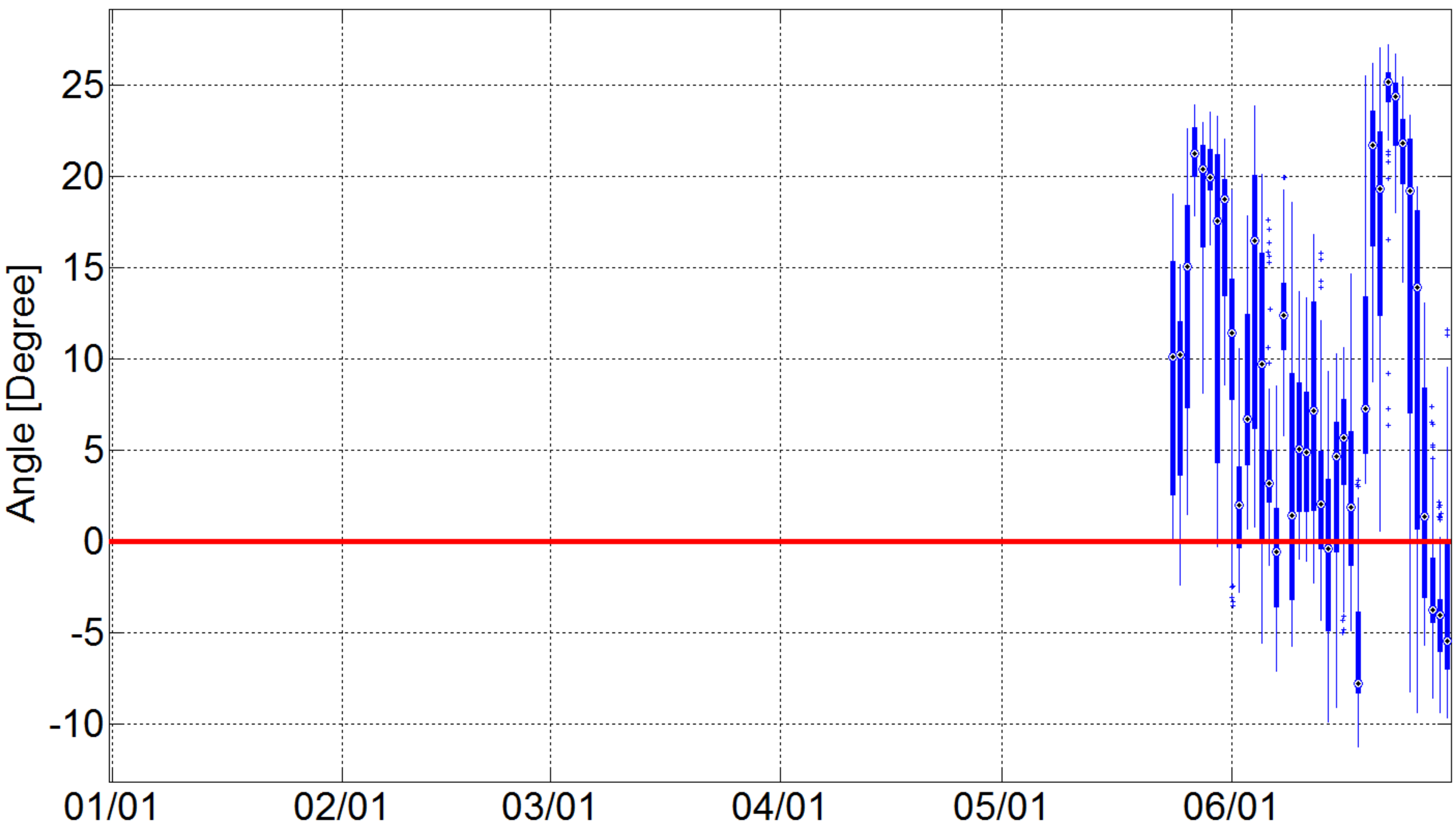

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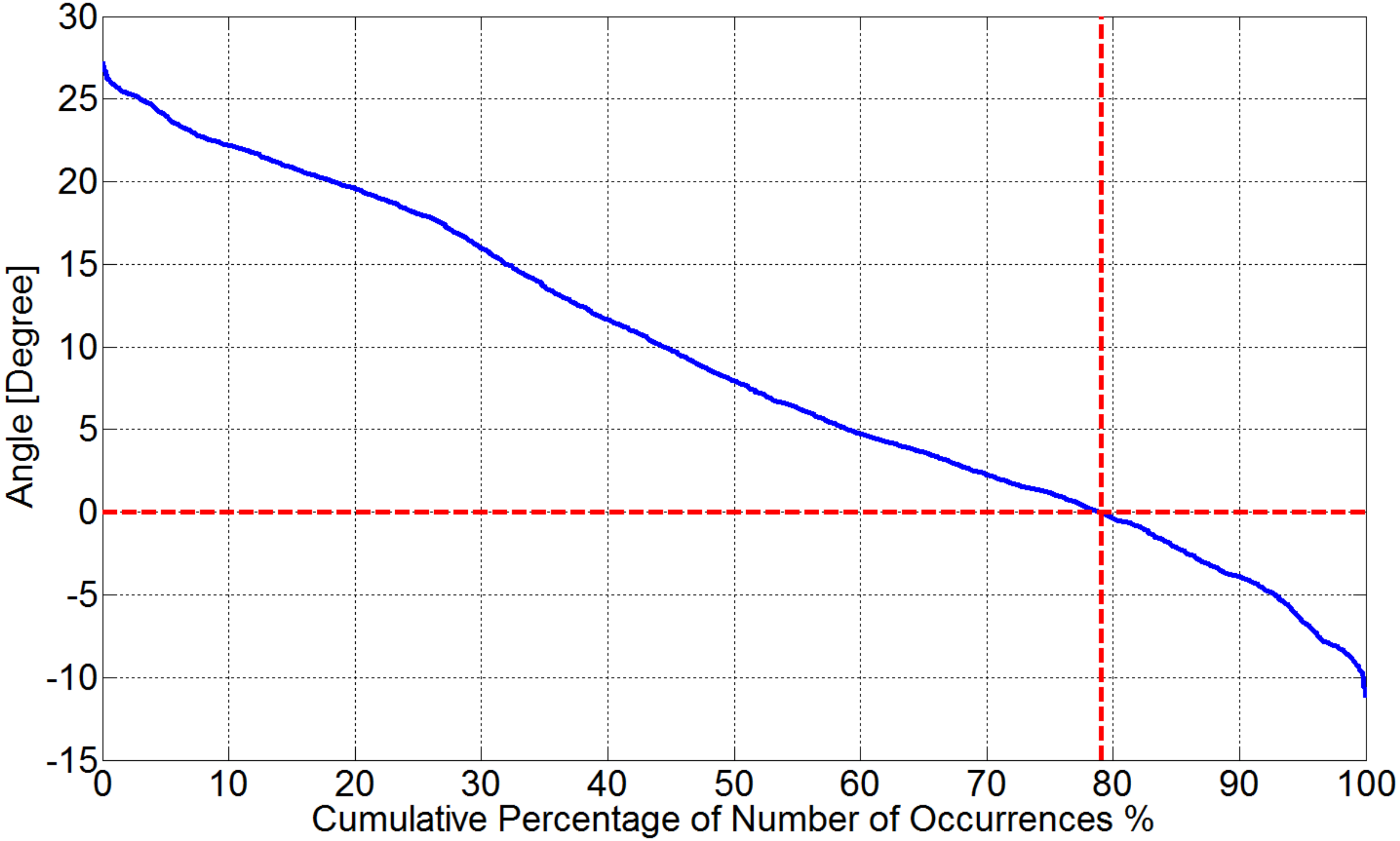

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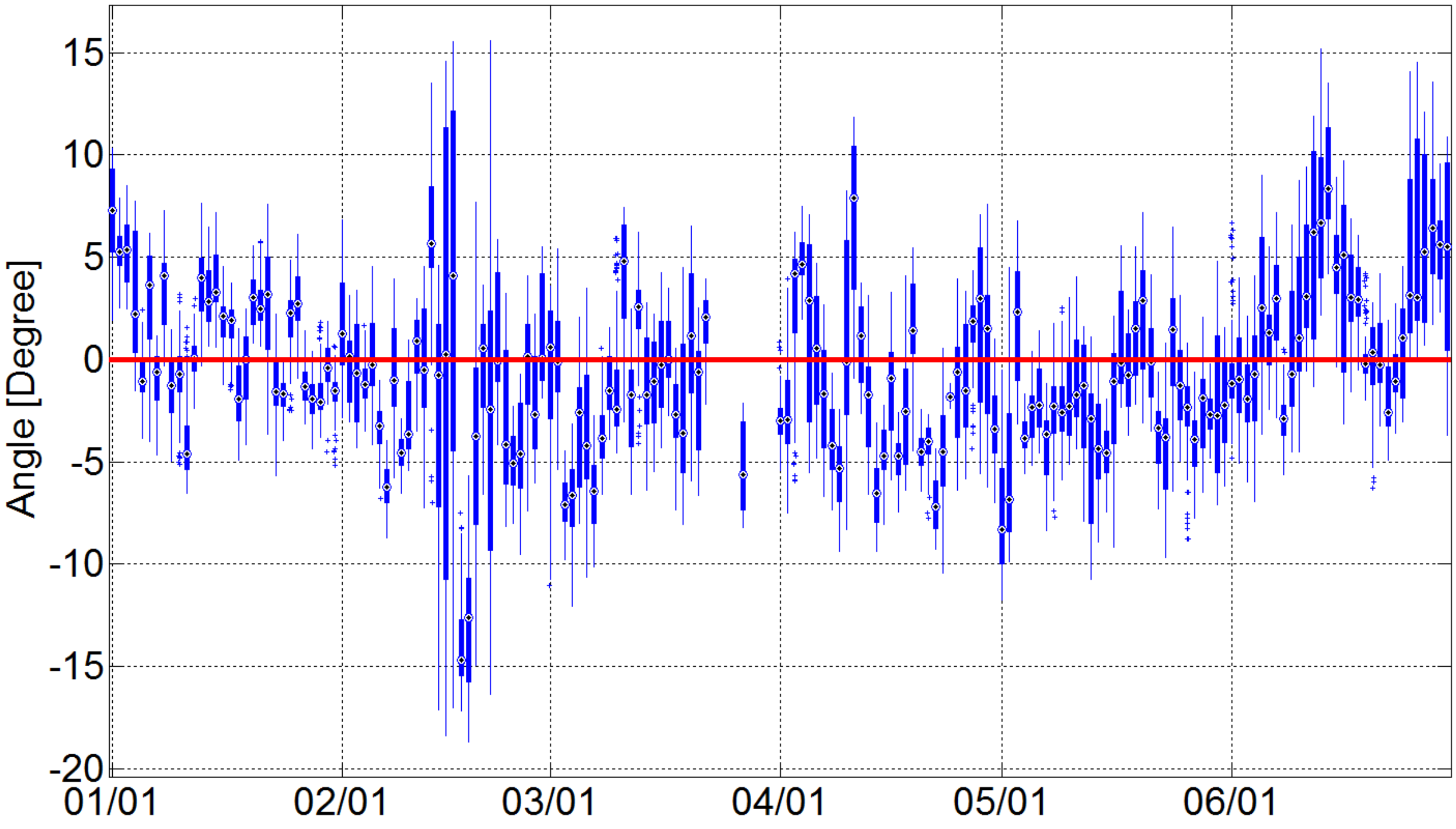

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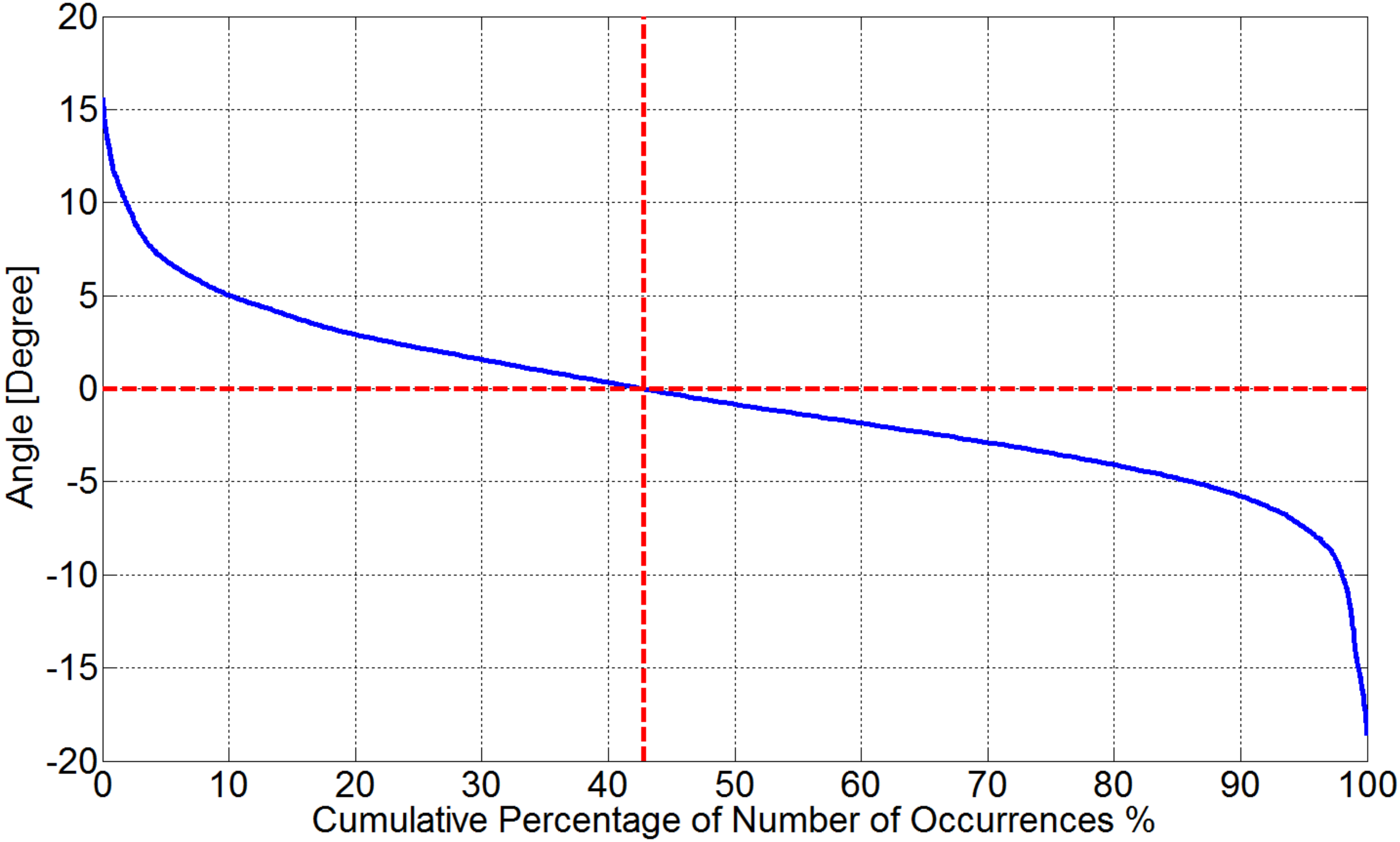

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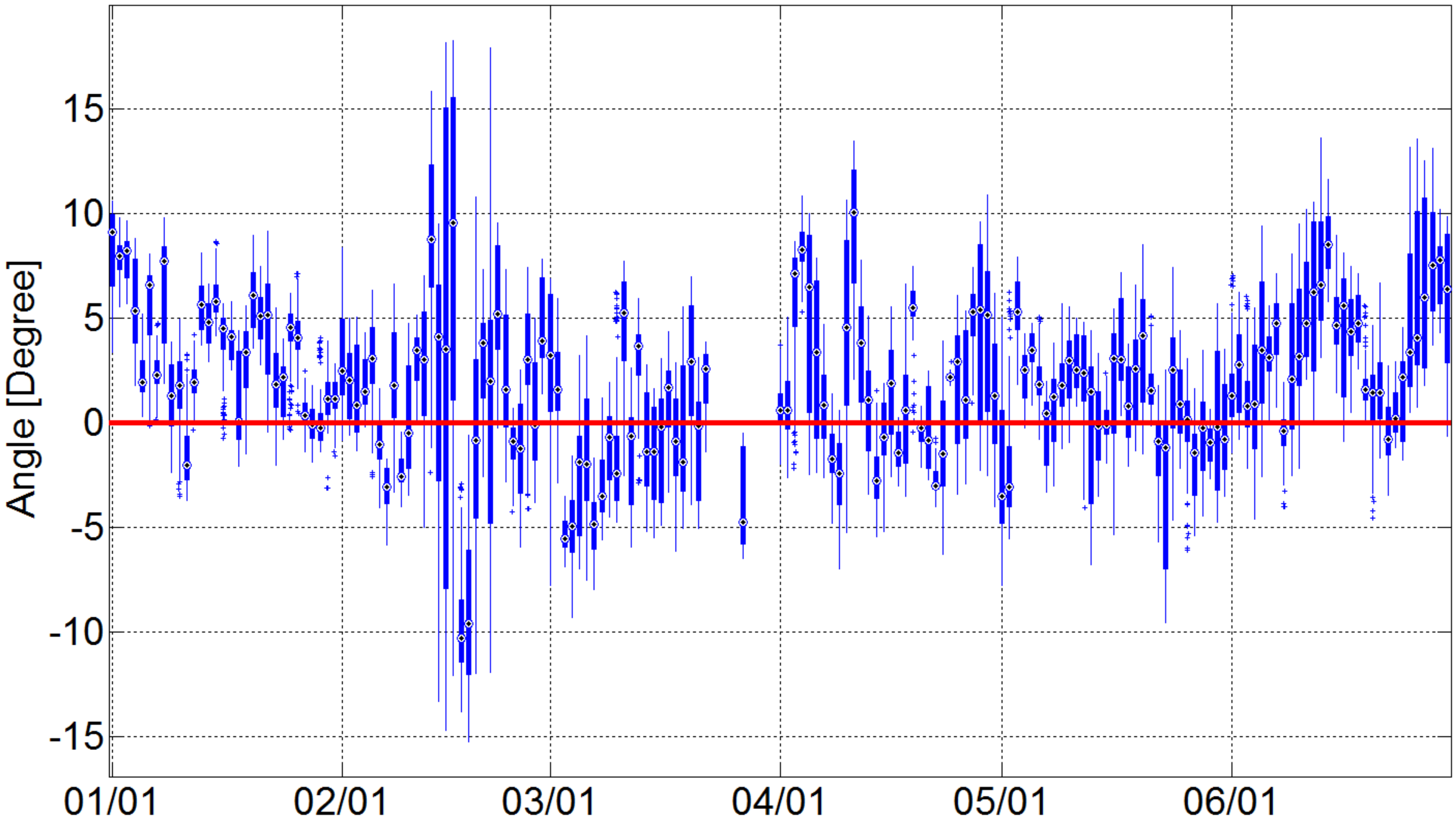

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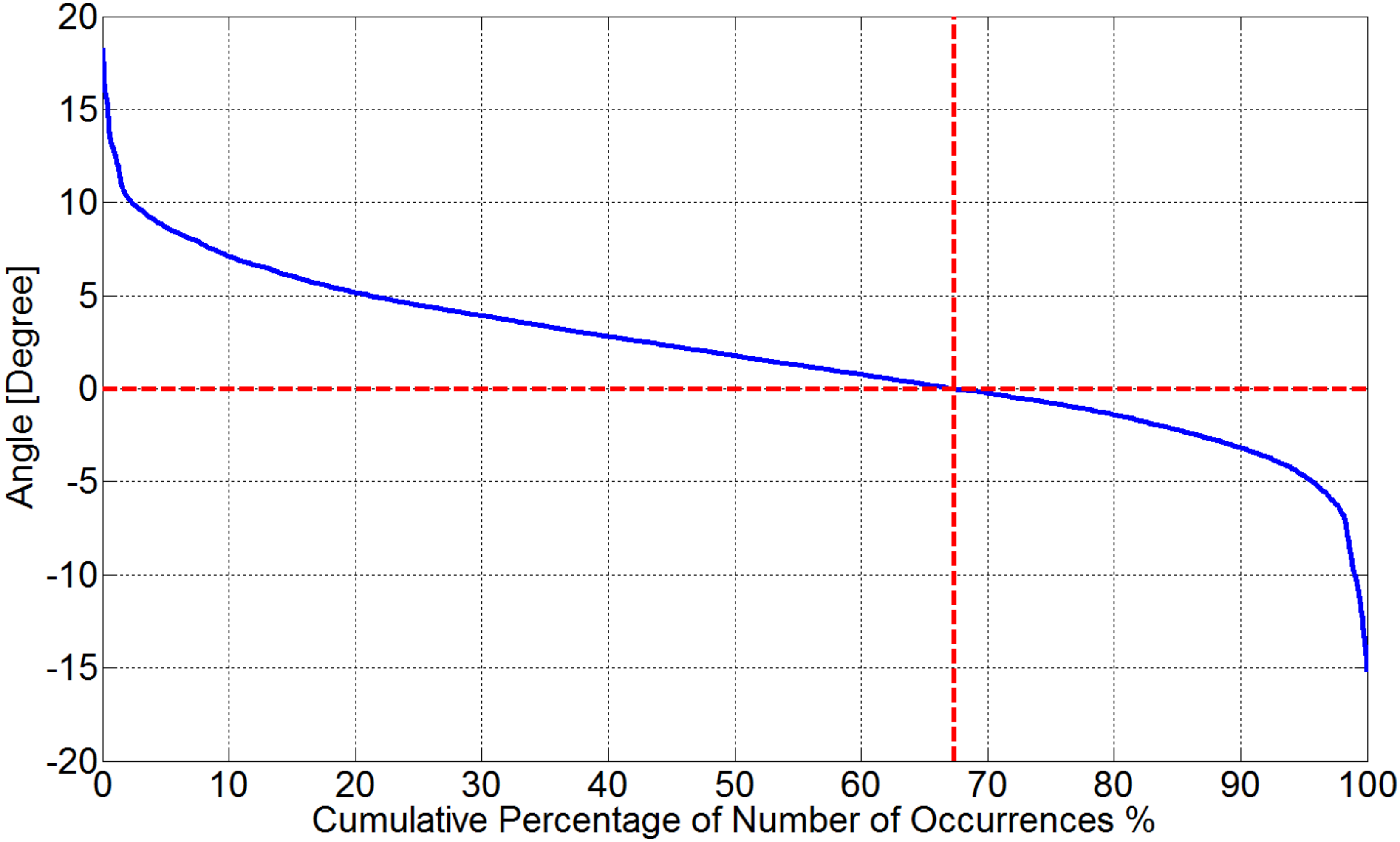

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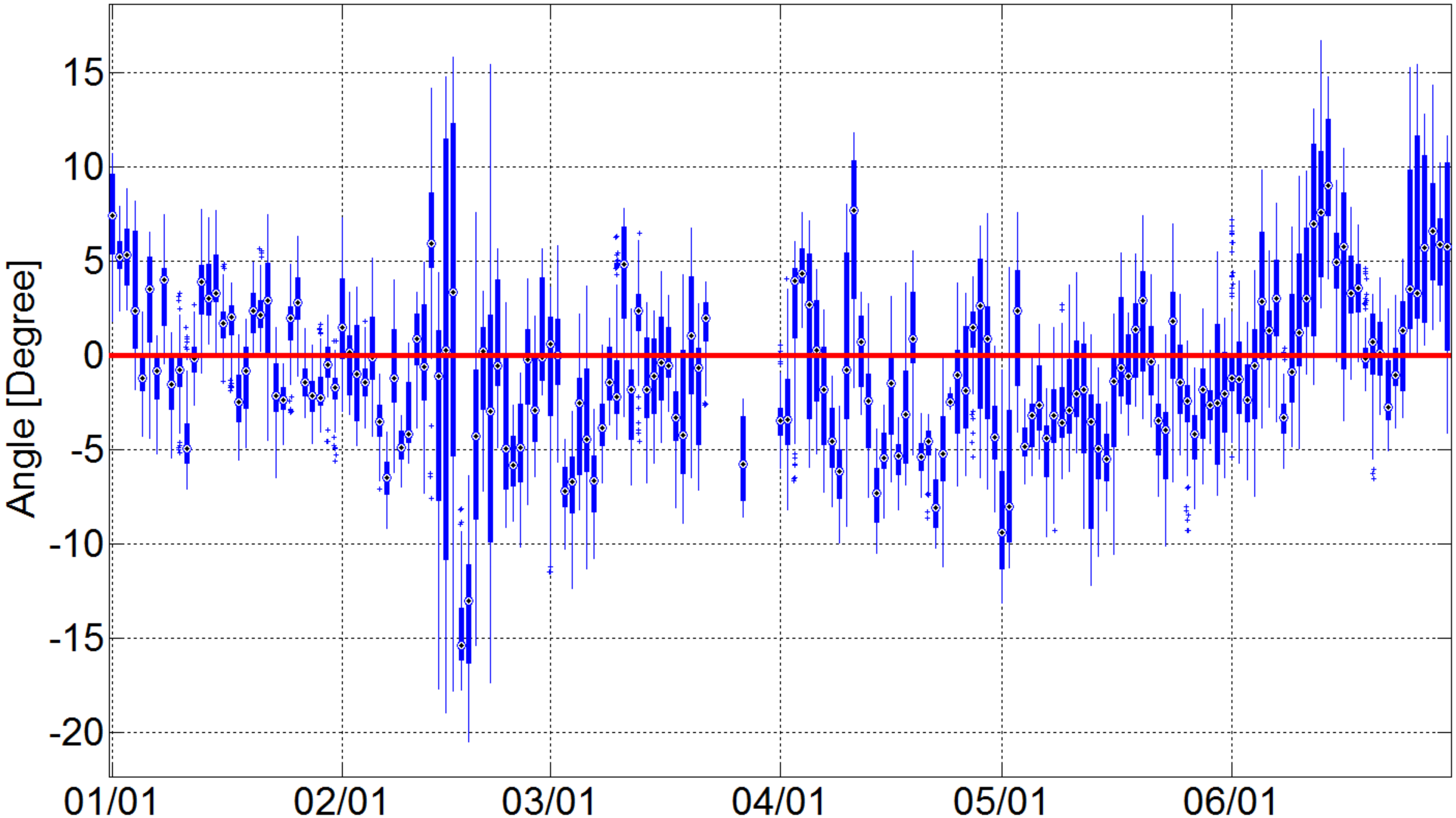

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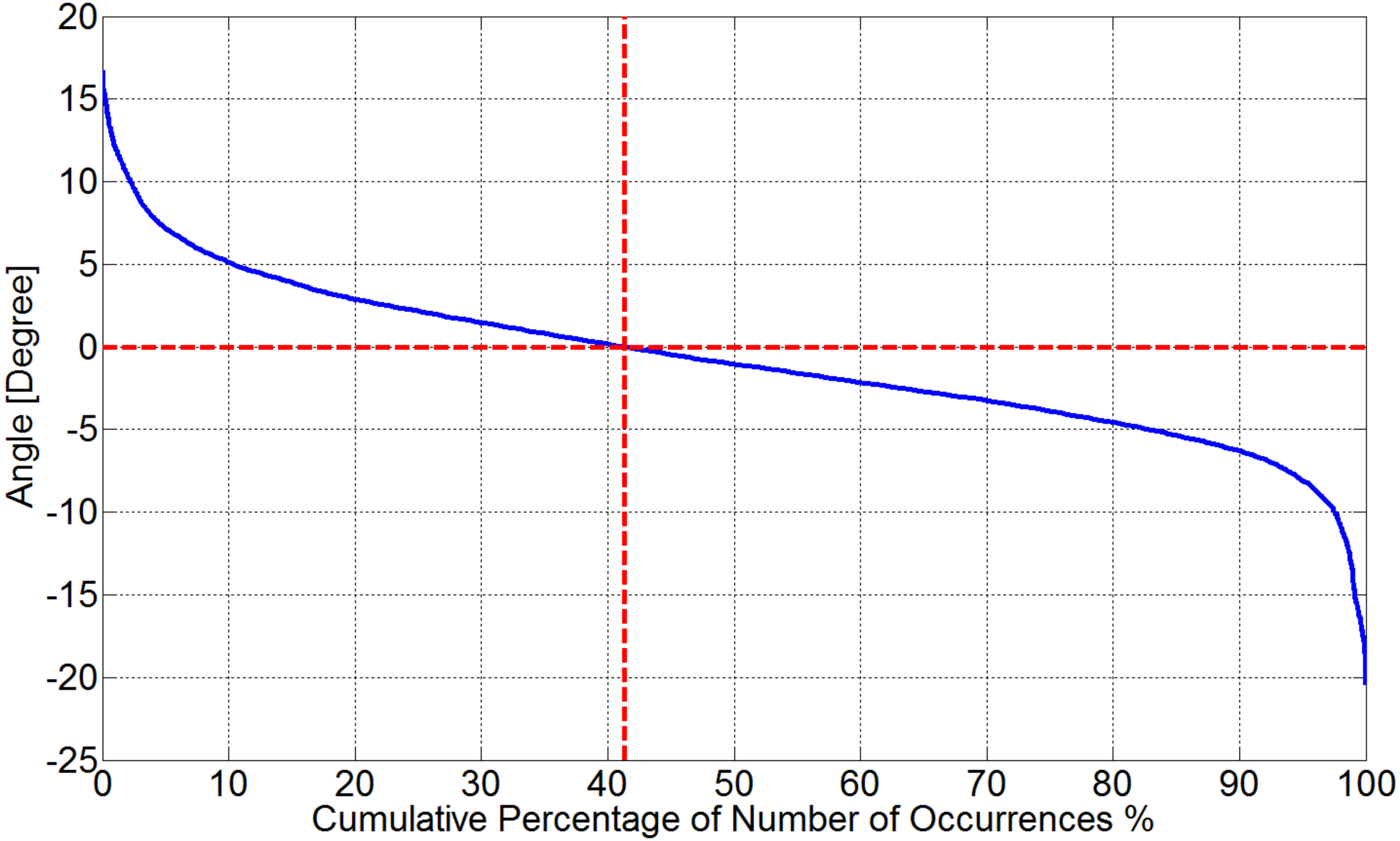

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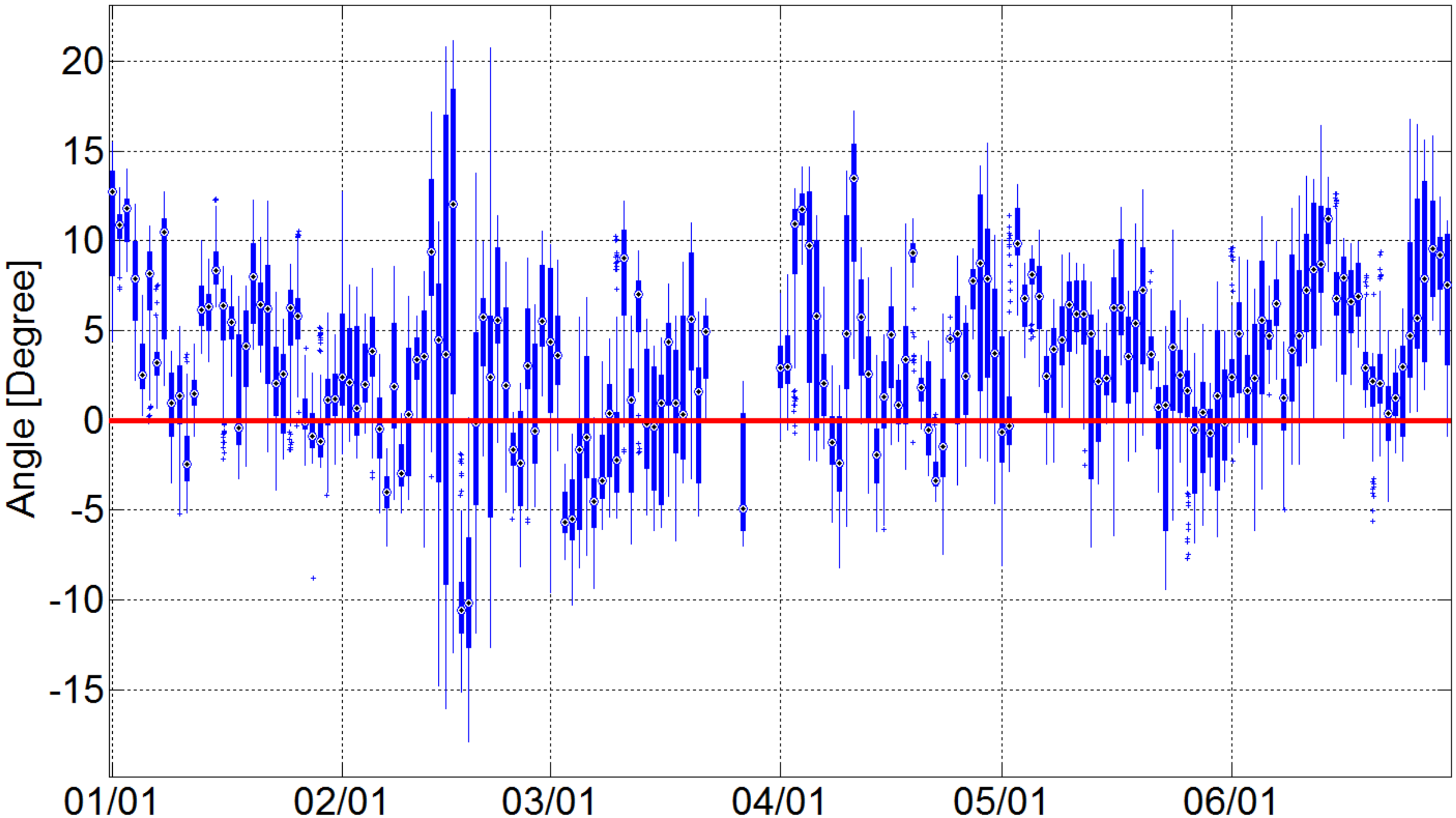

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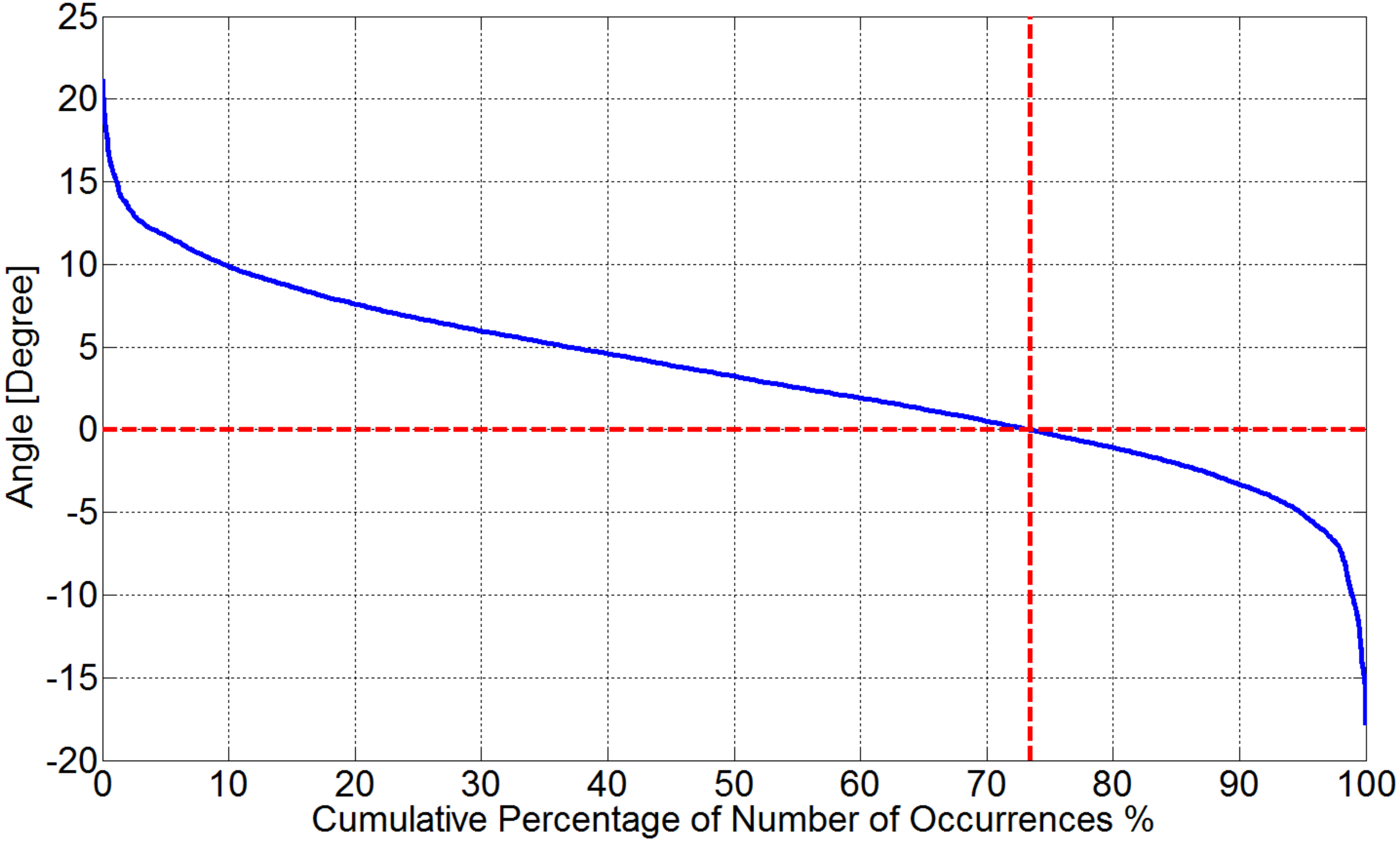

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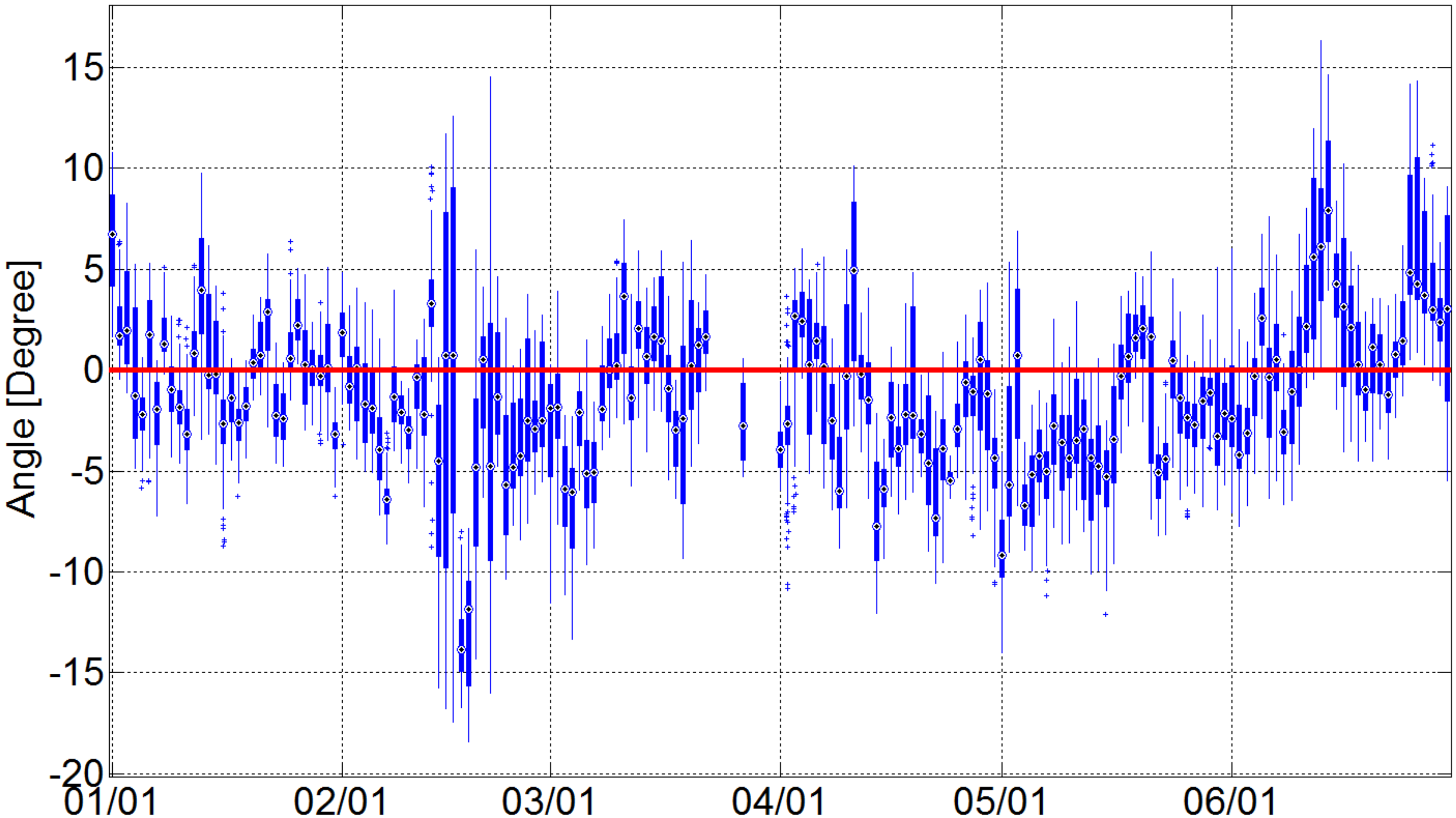

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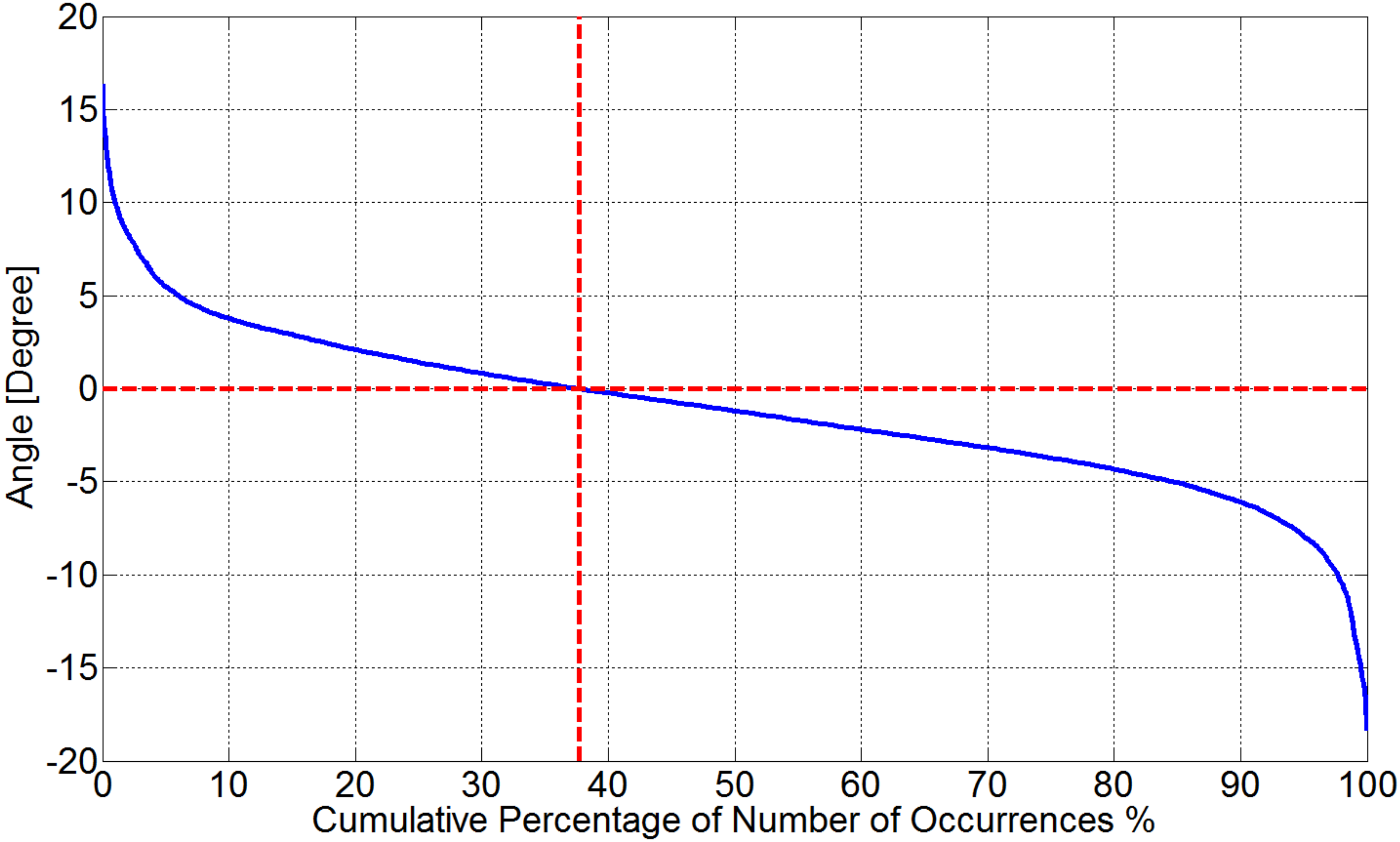

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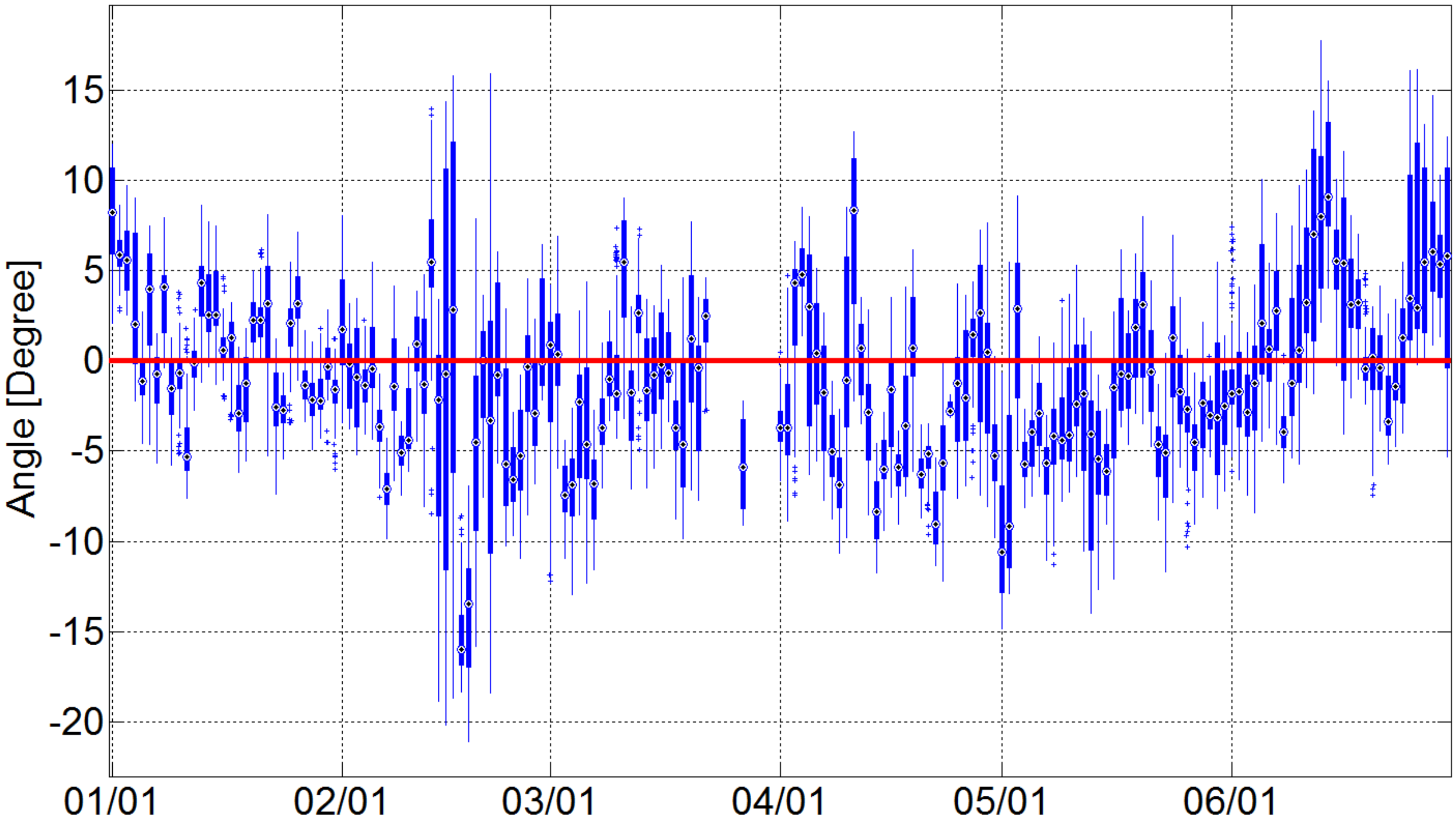

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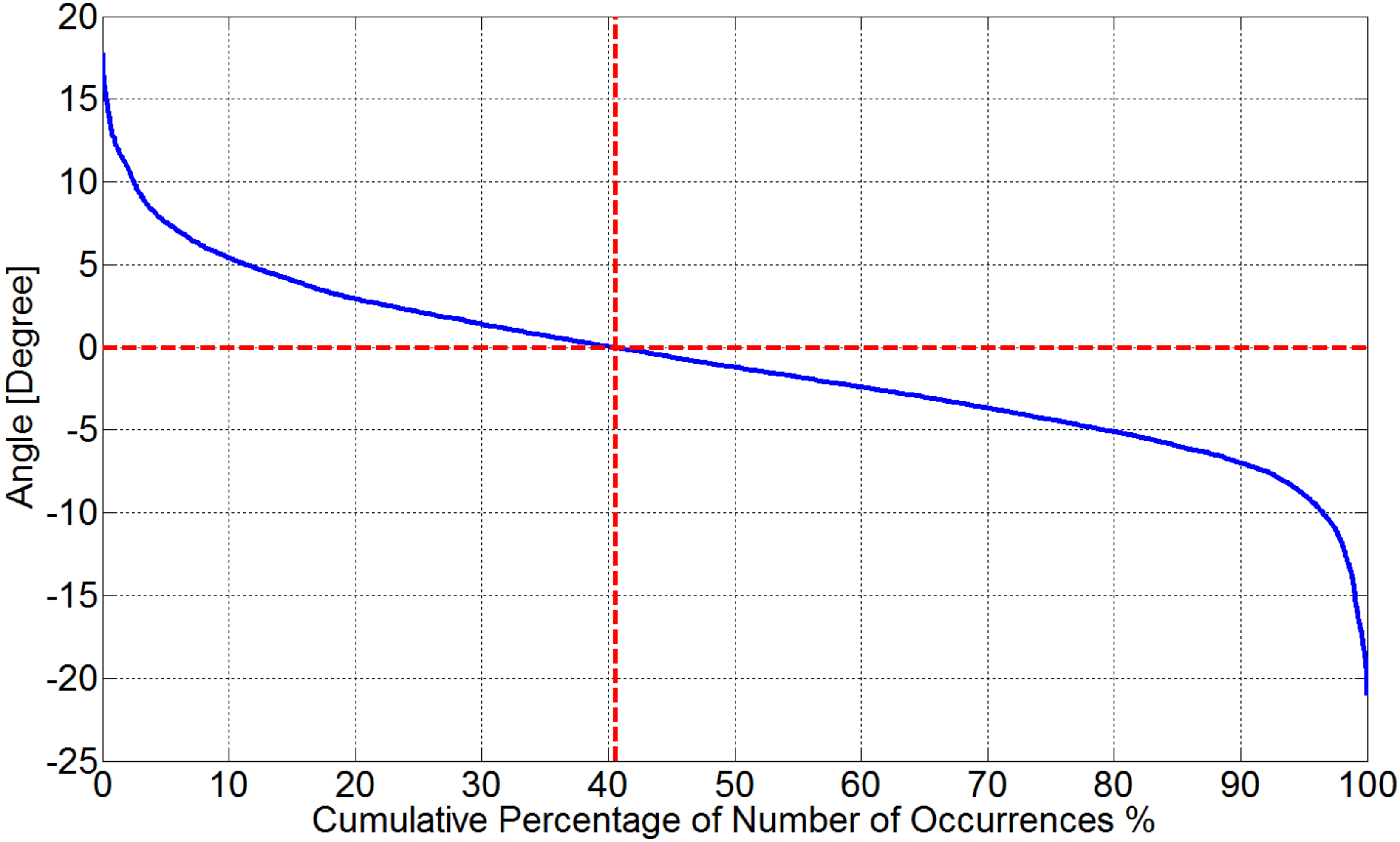

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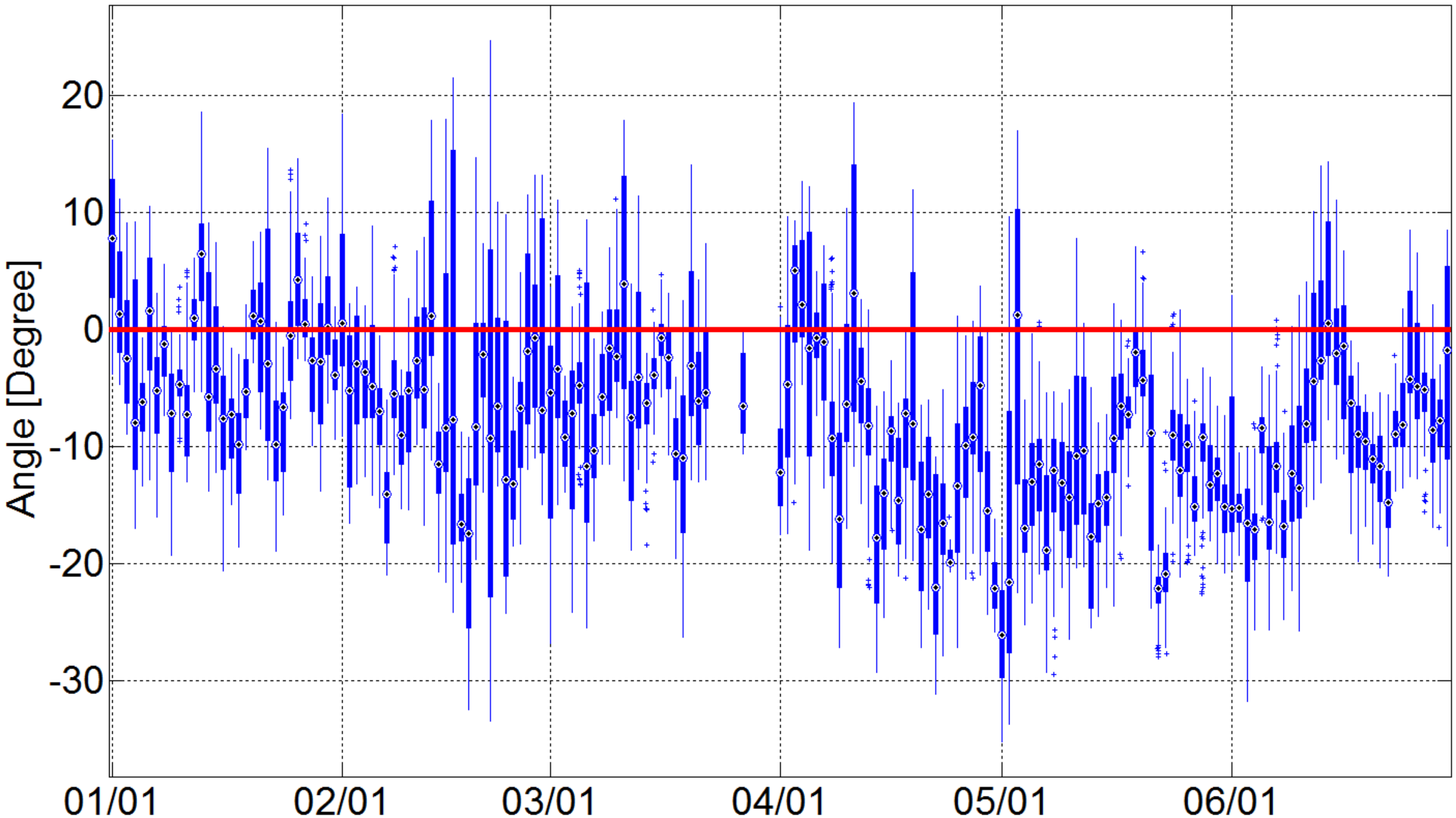

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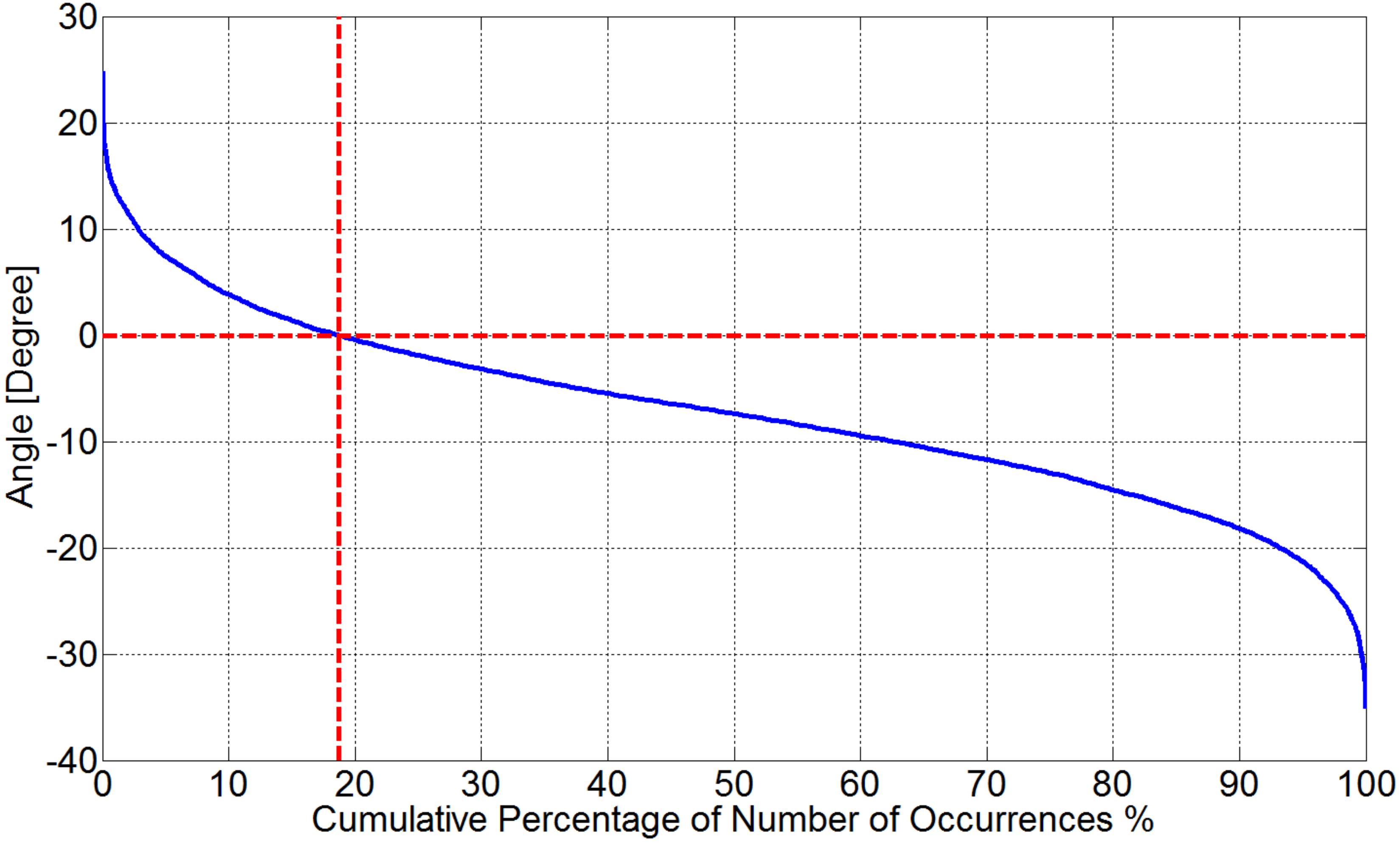


Appendix B – Part 2

CCET Discovery Across Texas project

Baseline Analysis Update - Voltage Angles (Ref.: North 7)

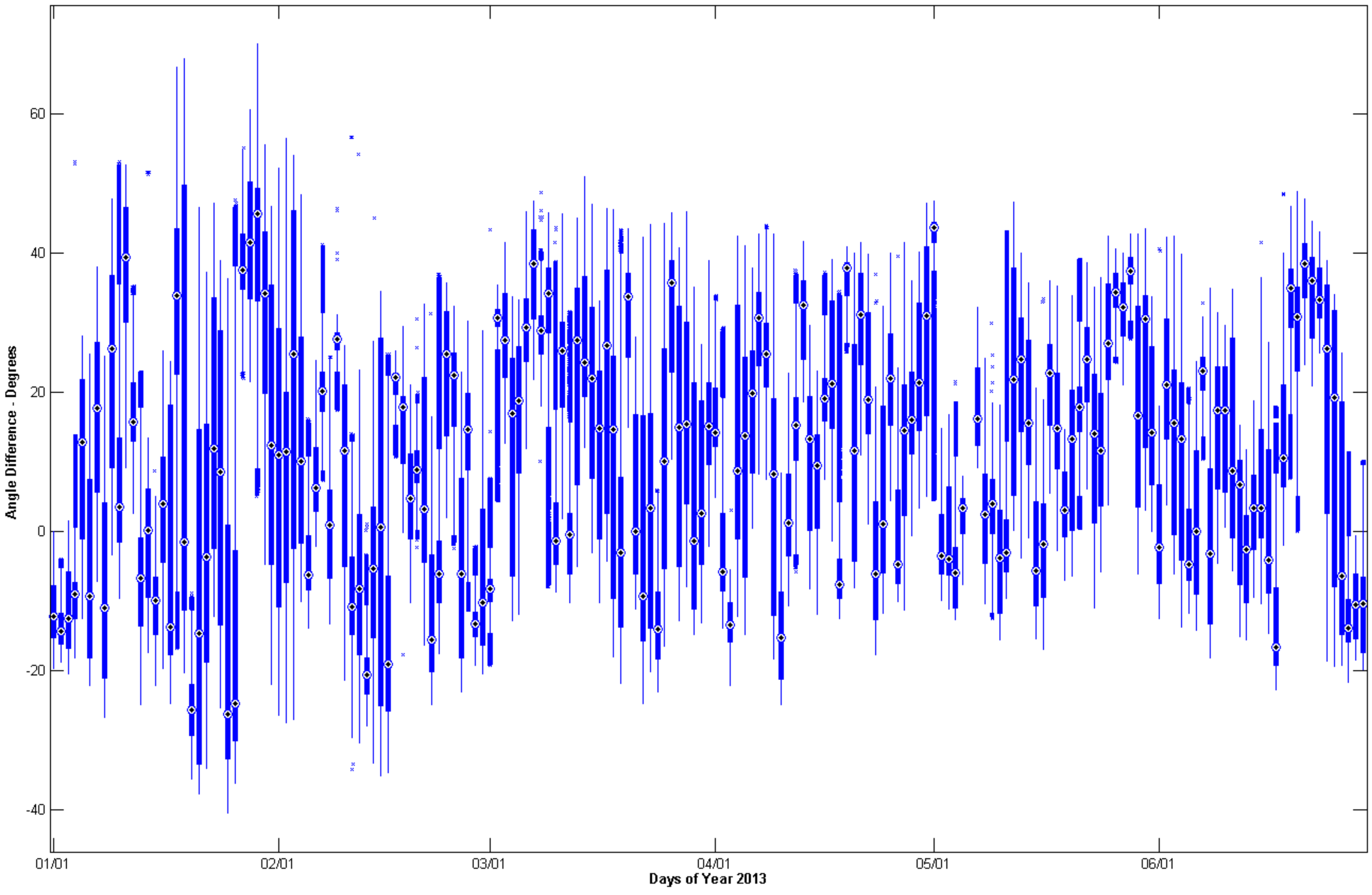
<u>Phasor Data</u>: January to June 2013

Box-Whisker Plots and Time Duration Curves

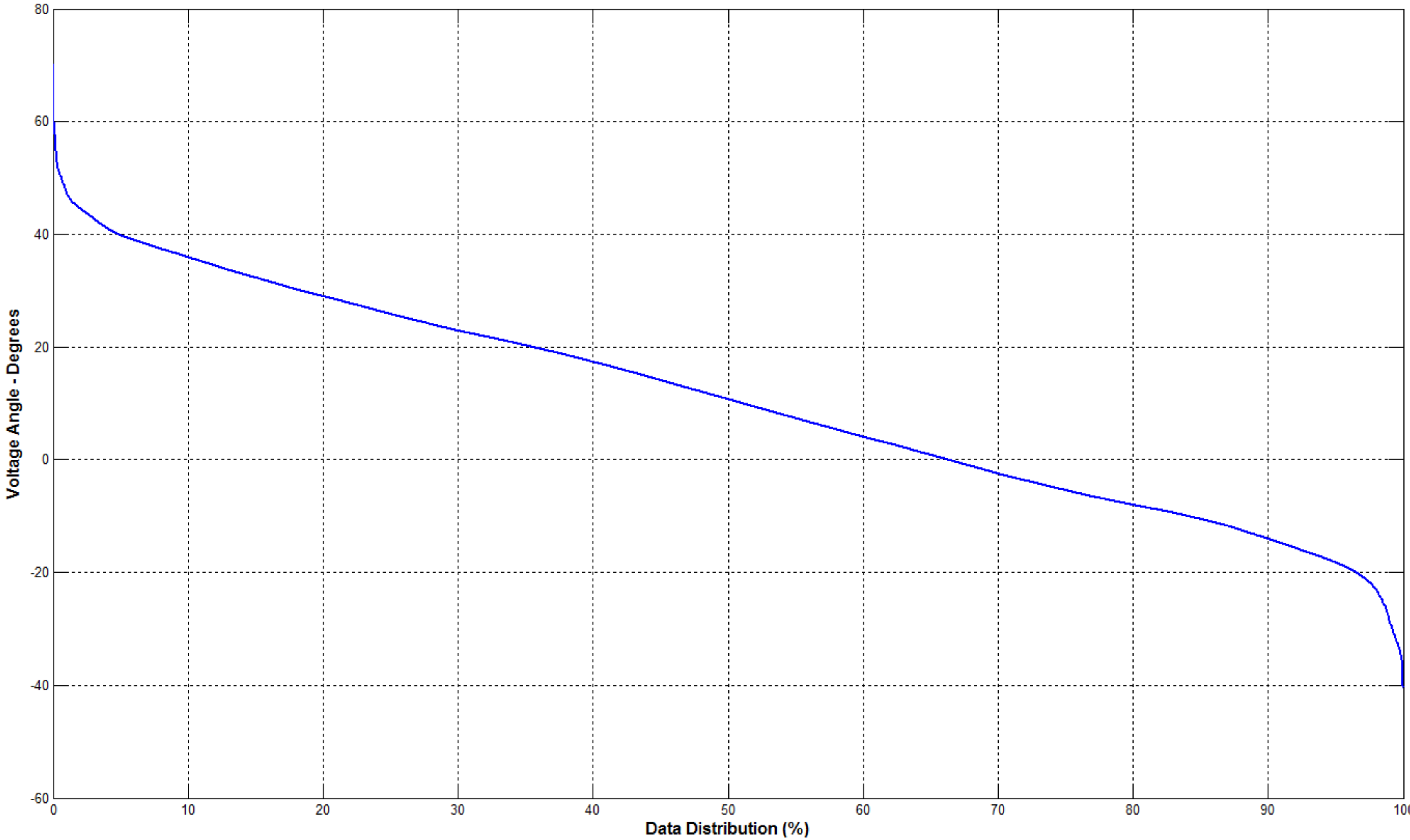
External Version

Electric Power Group · CCET · ERCOT

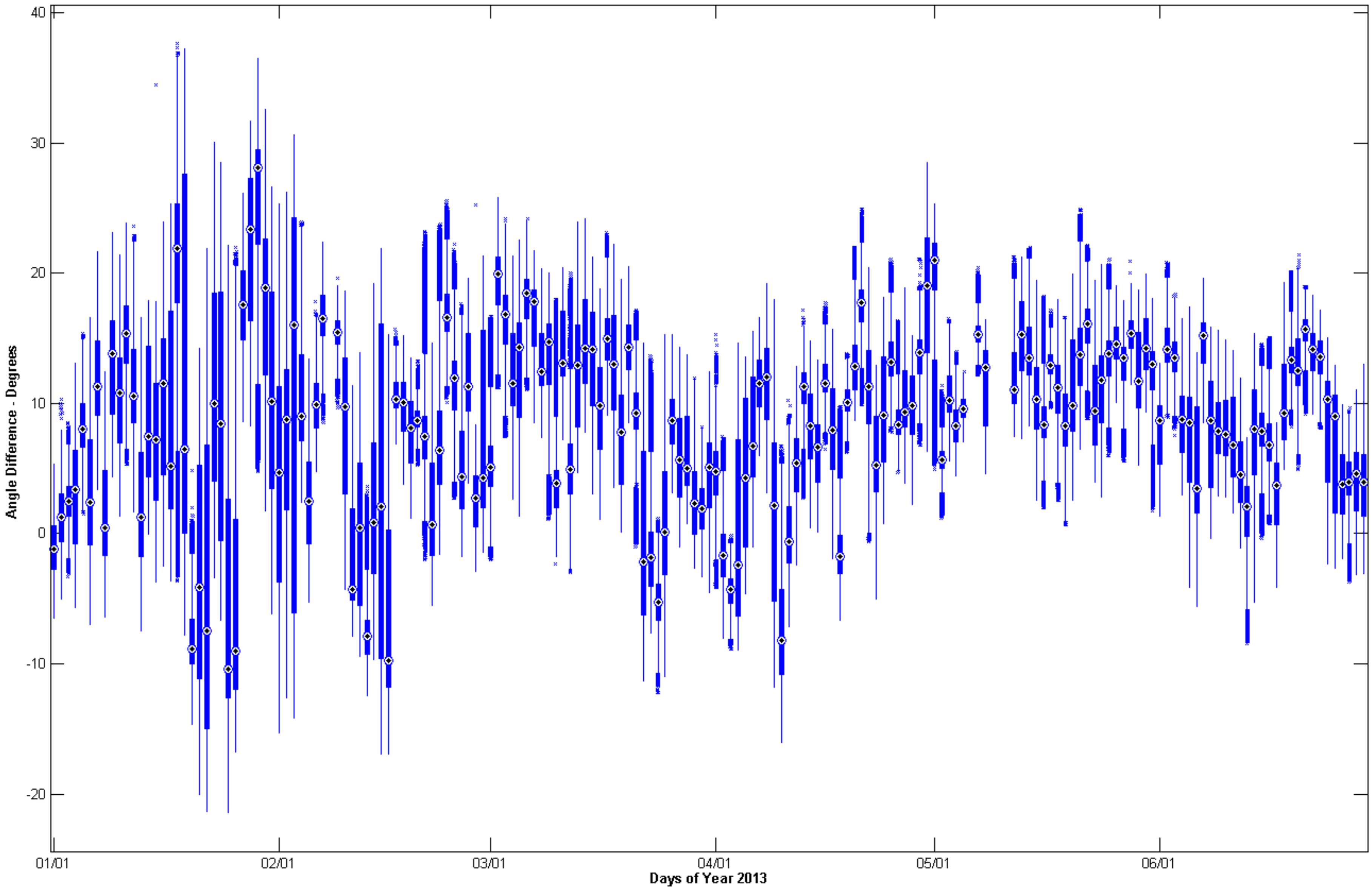
West 10 – Voltage Angle



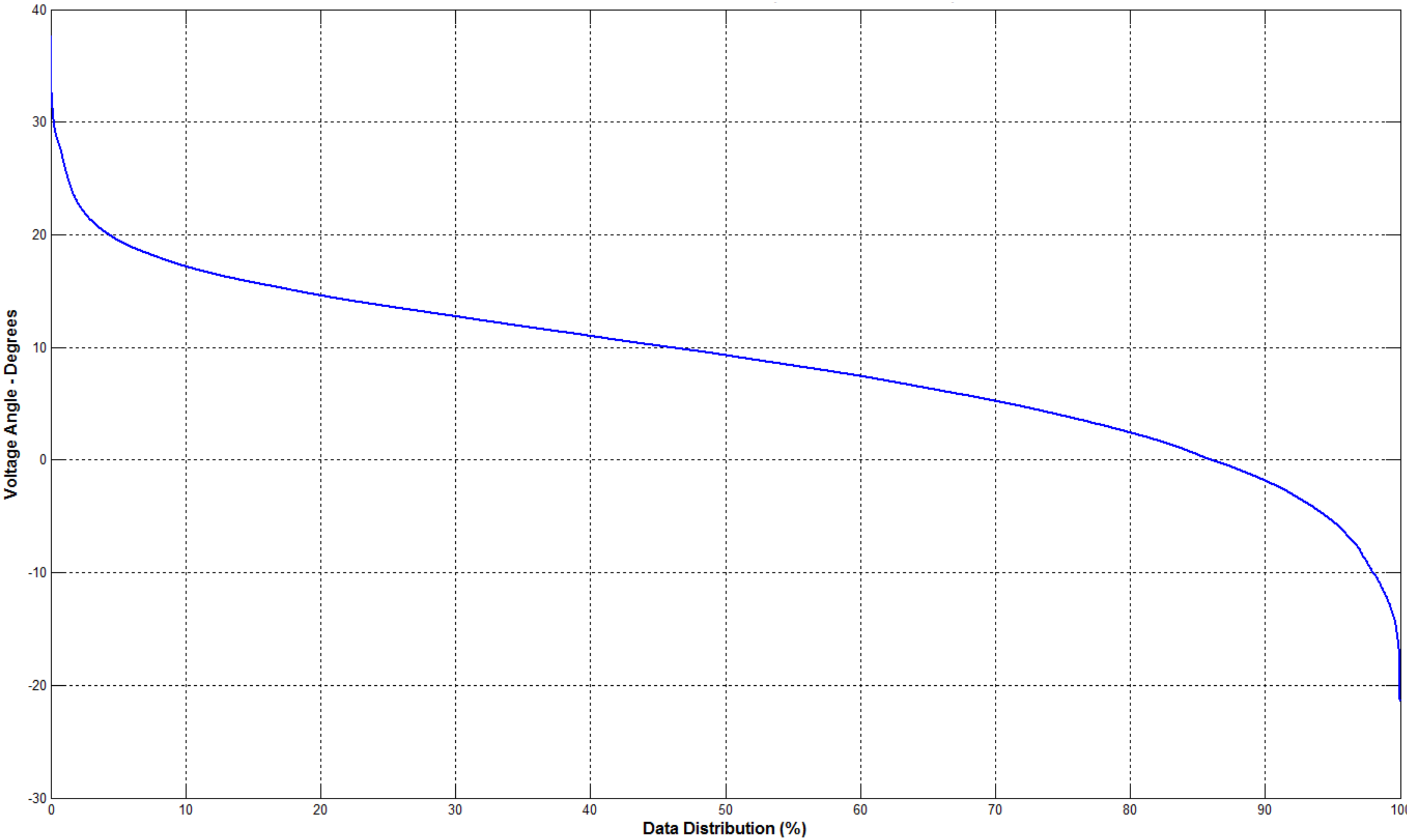
West 10 – Voltage Angle



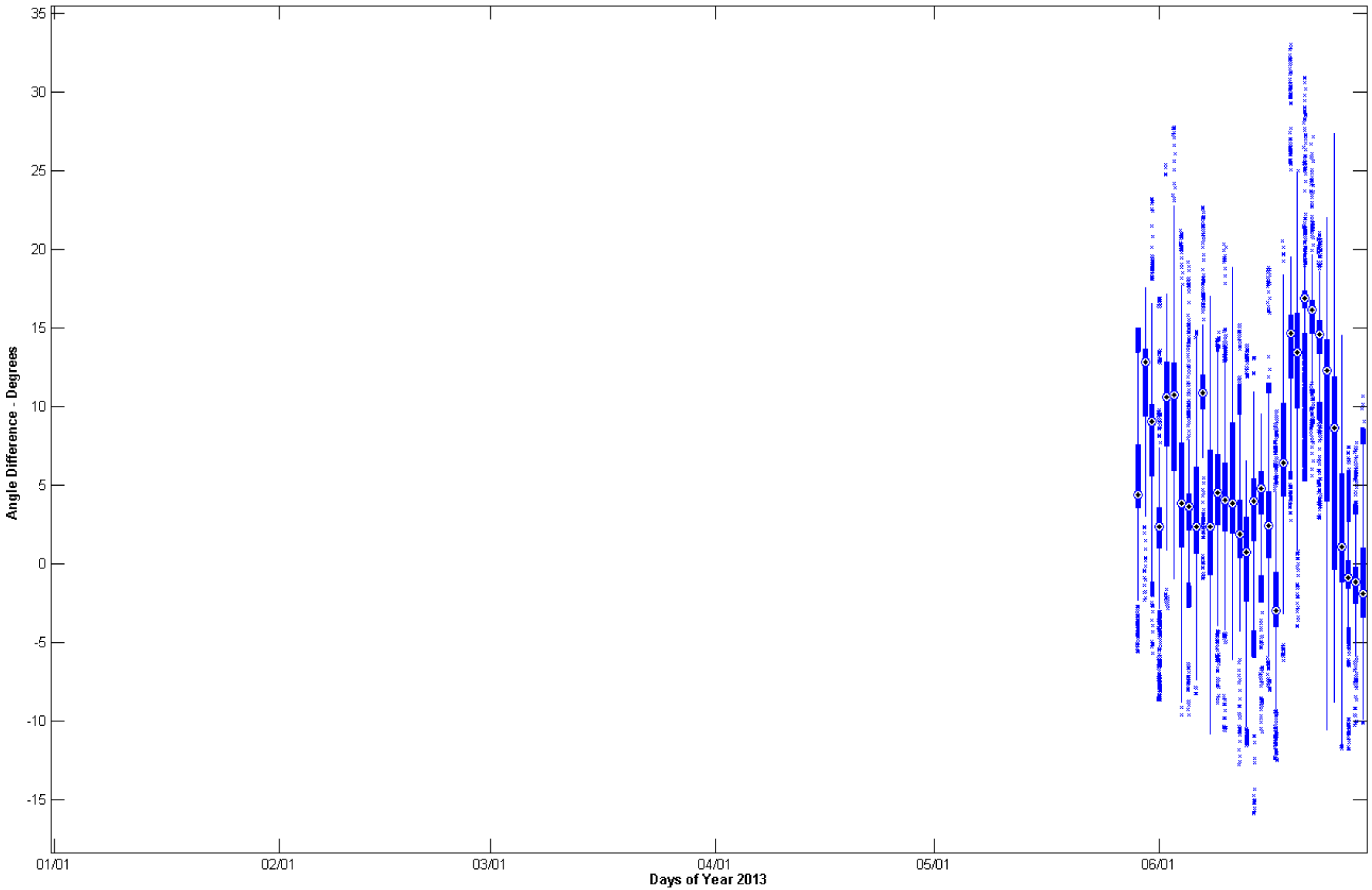
West 14 – Voltage Angle



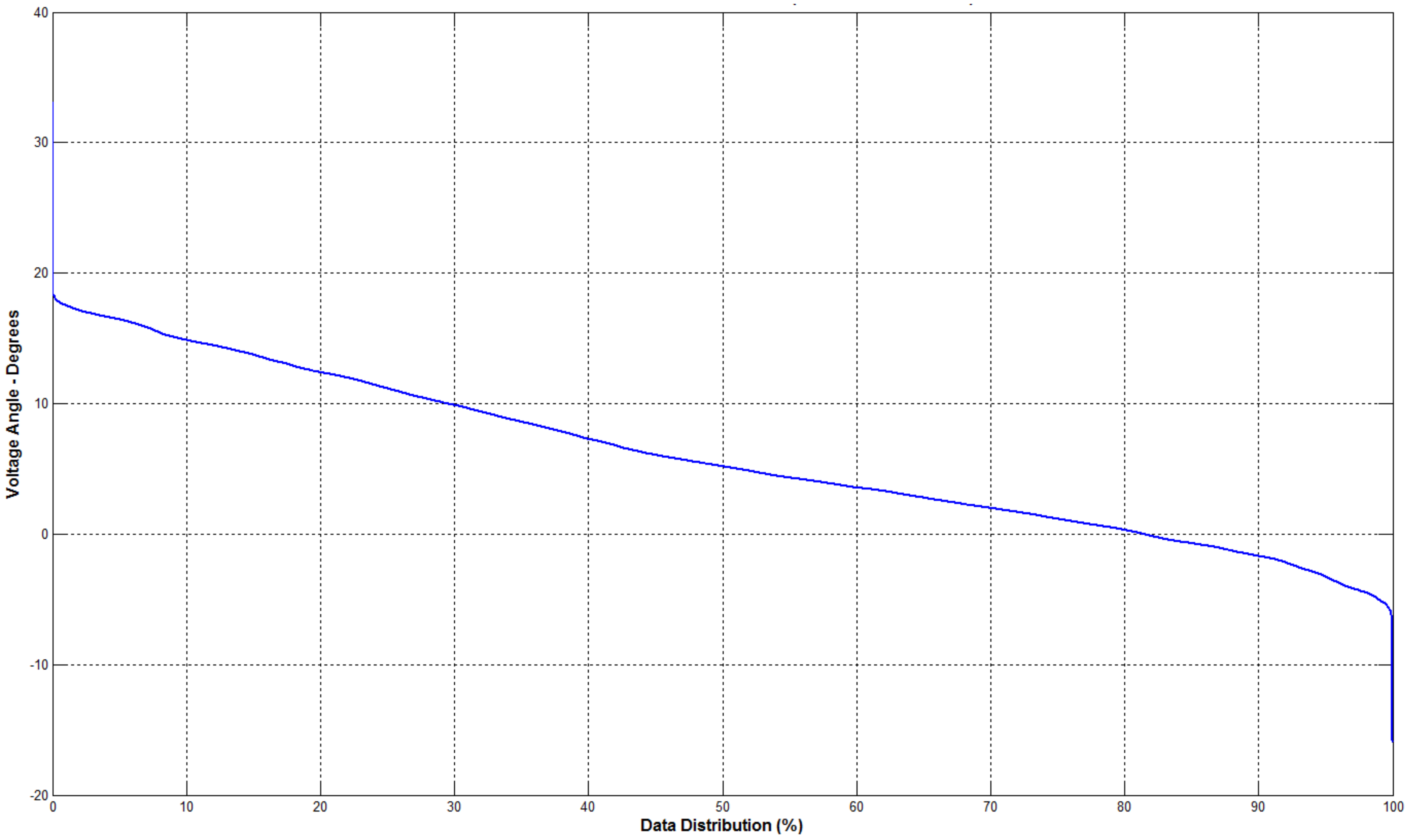
West 14 – Voltage Angle



West 1 – Voltage Angle



West 1 – Voltage Angle



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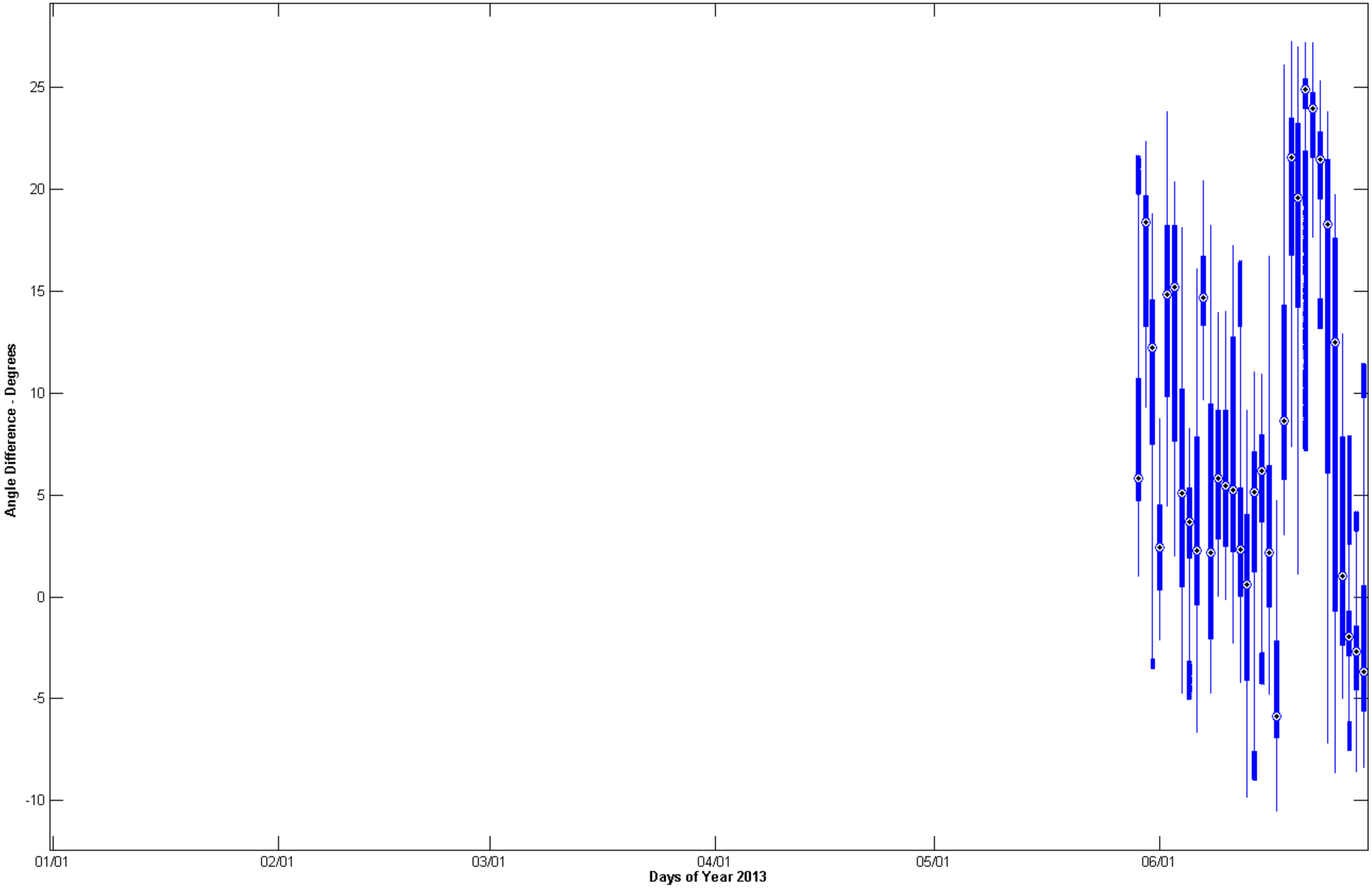

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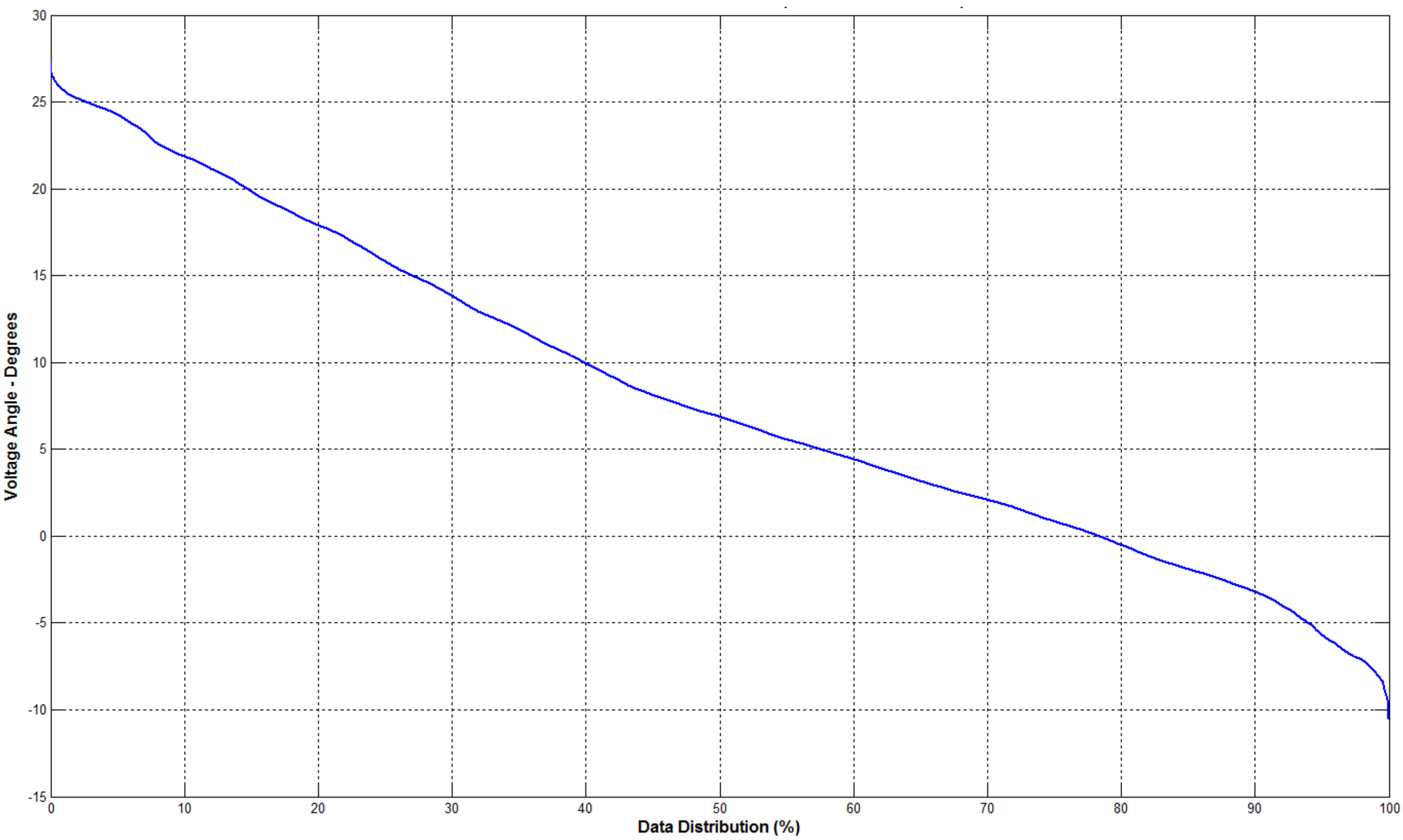
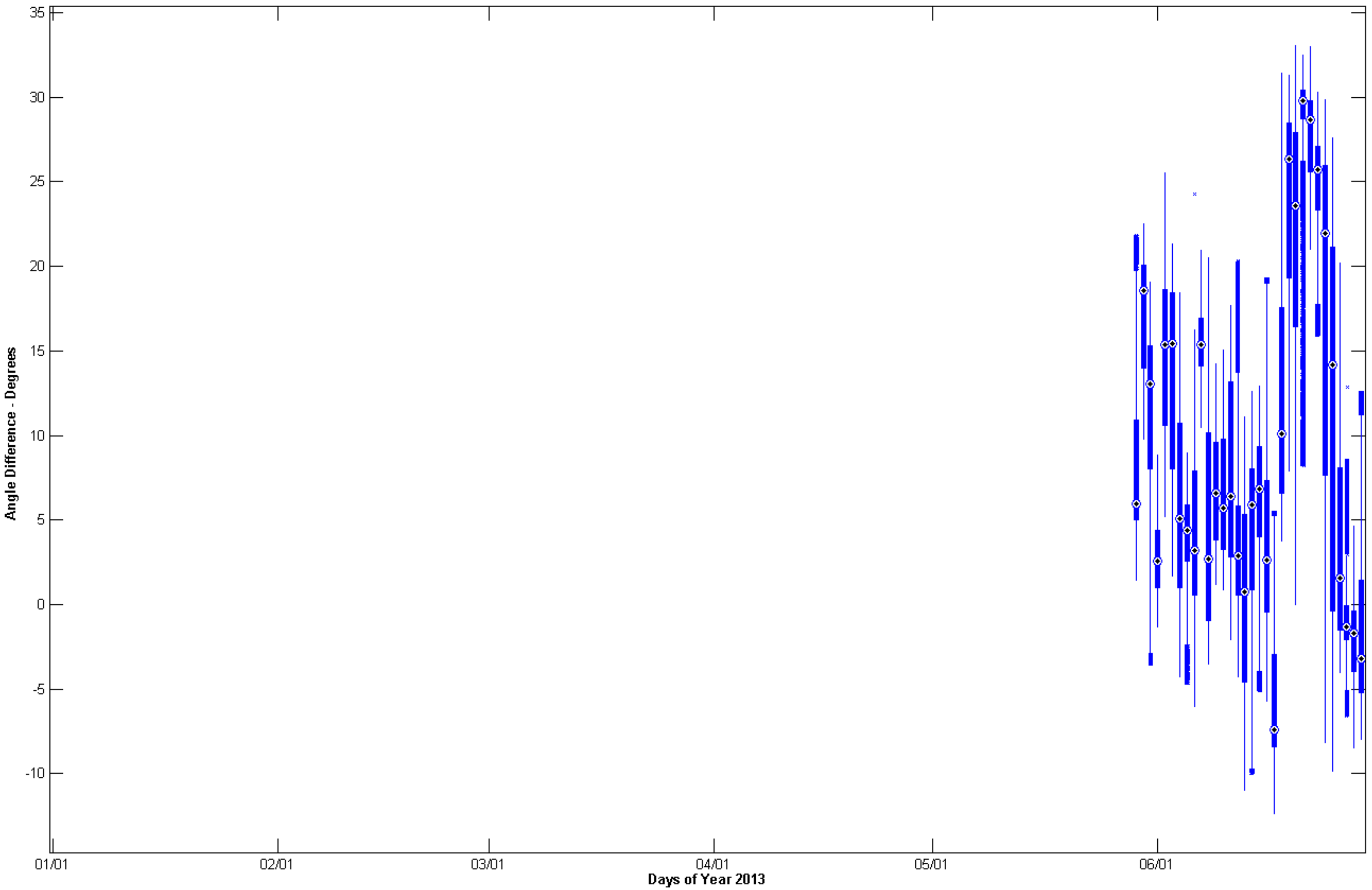
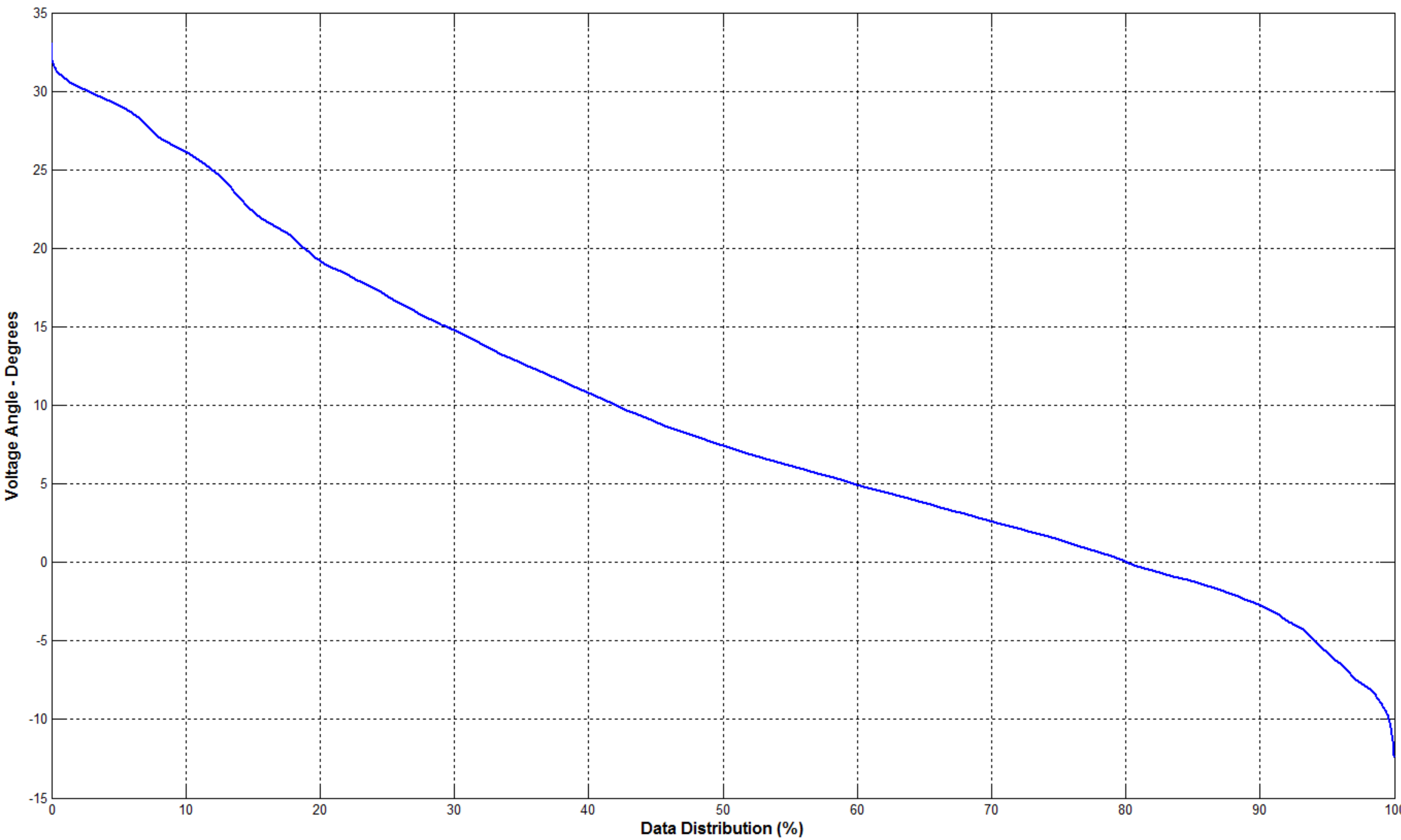


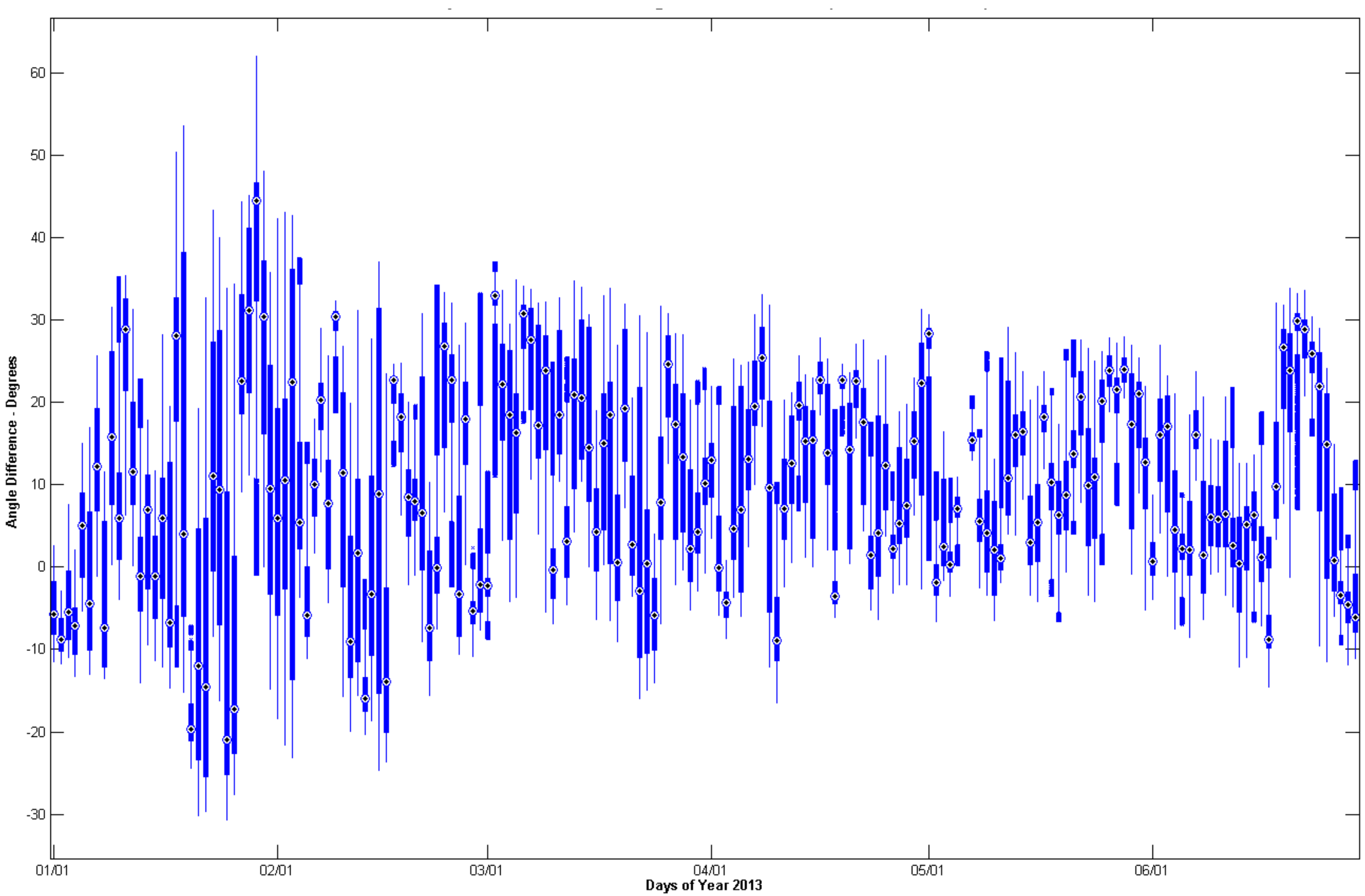
West 9 – Voltage Angle



West 9 – Voltage Angle



West 11– Voltage Angle



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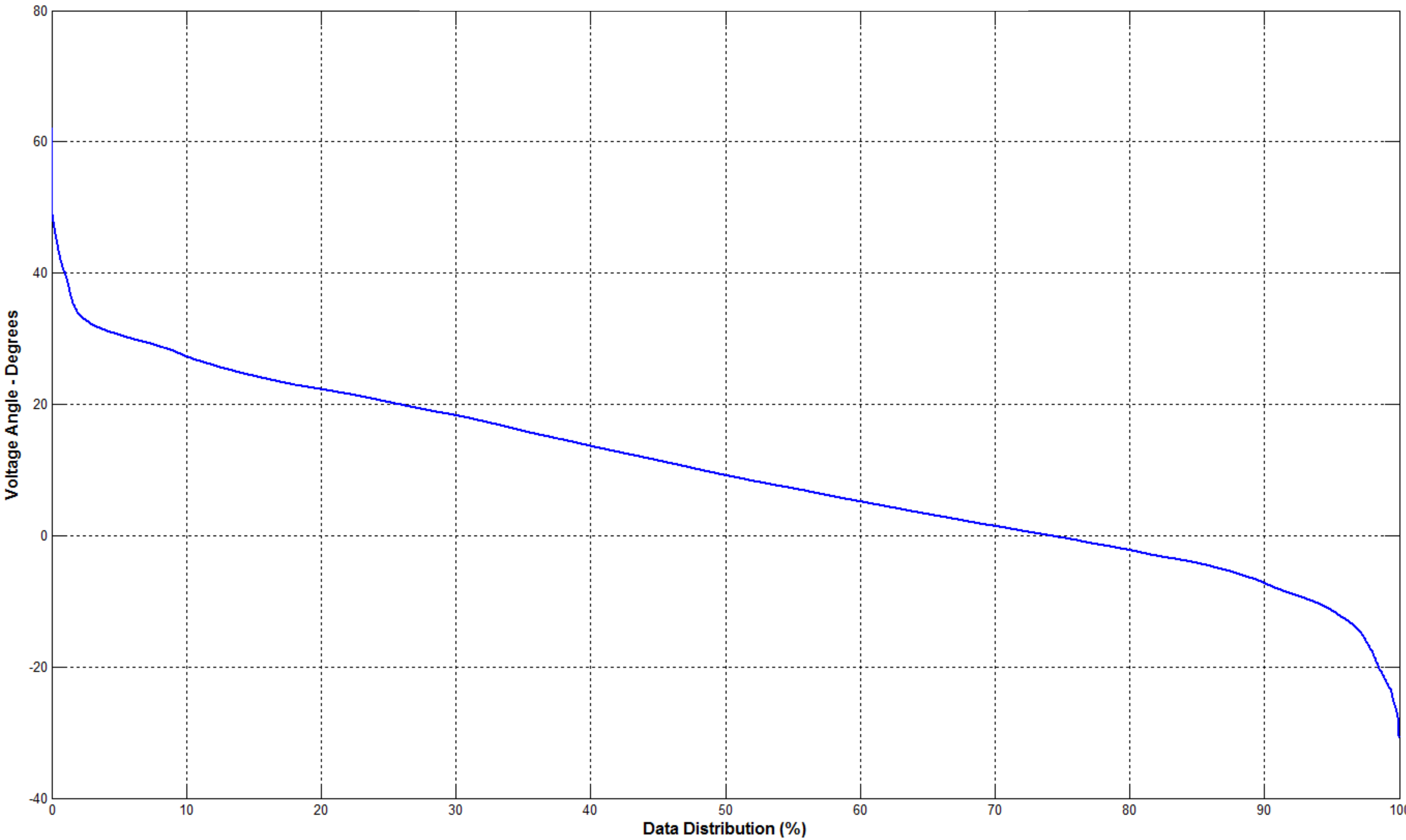

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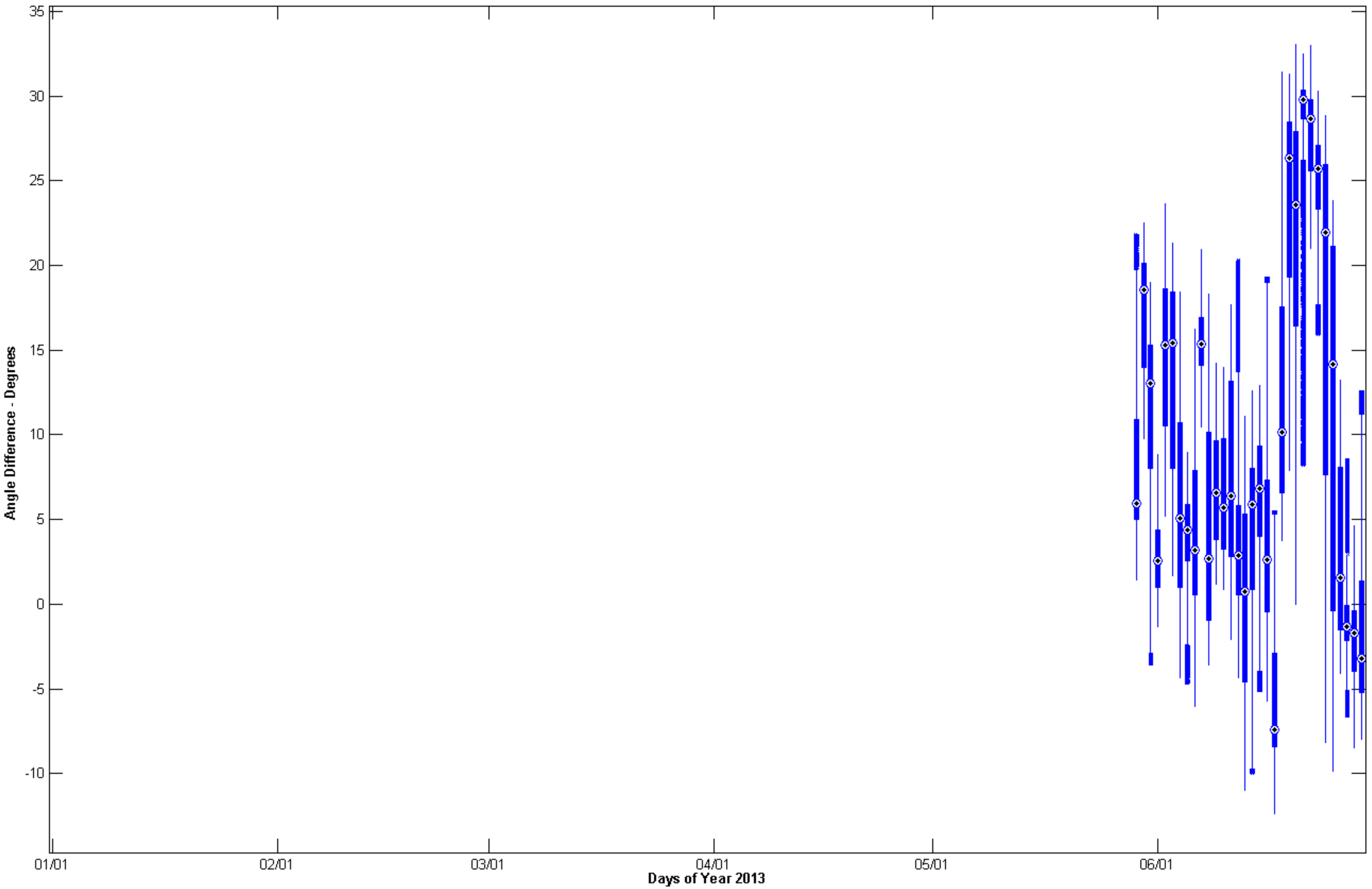

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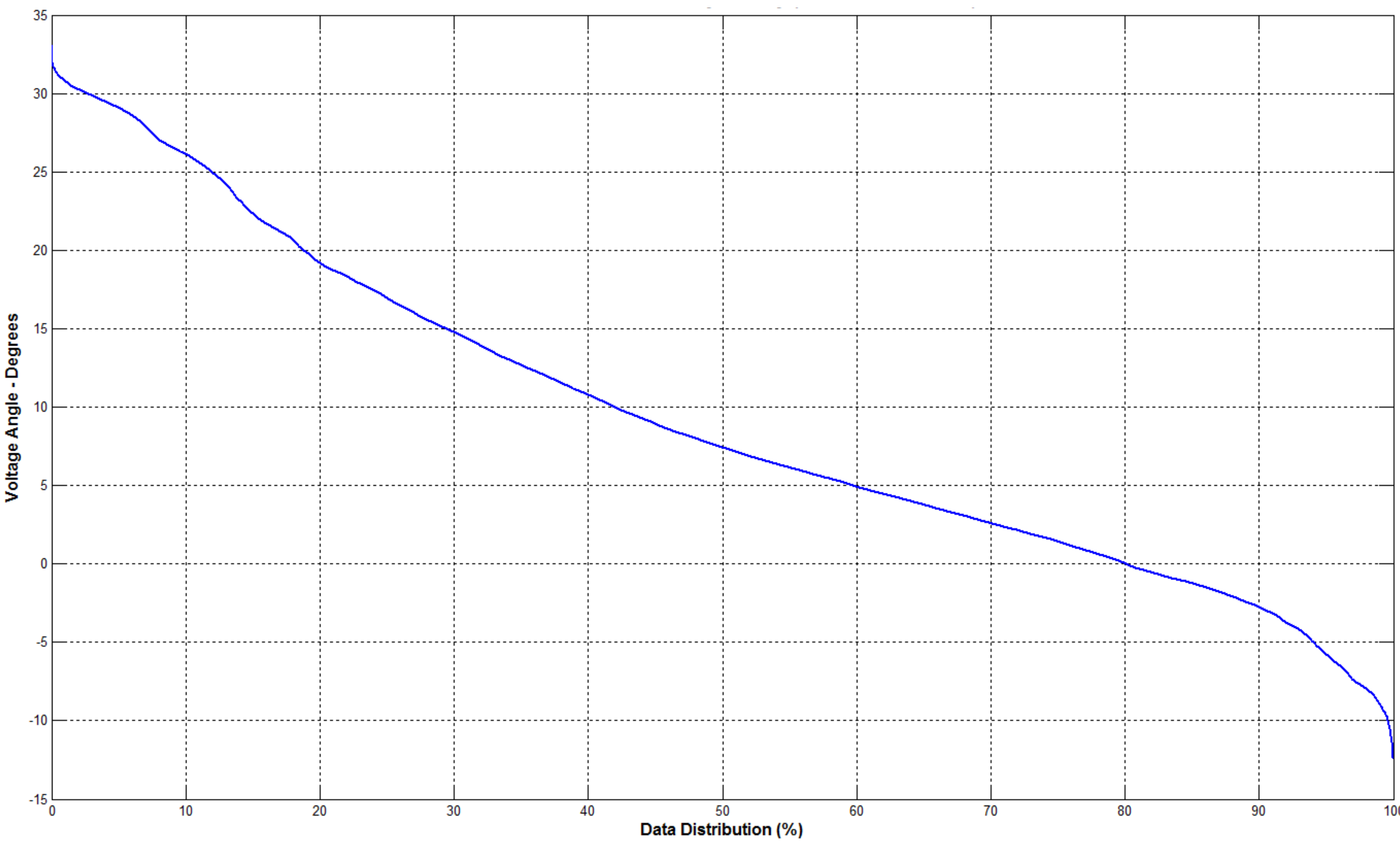
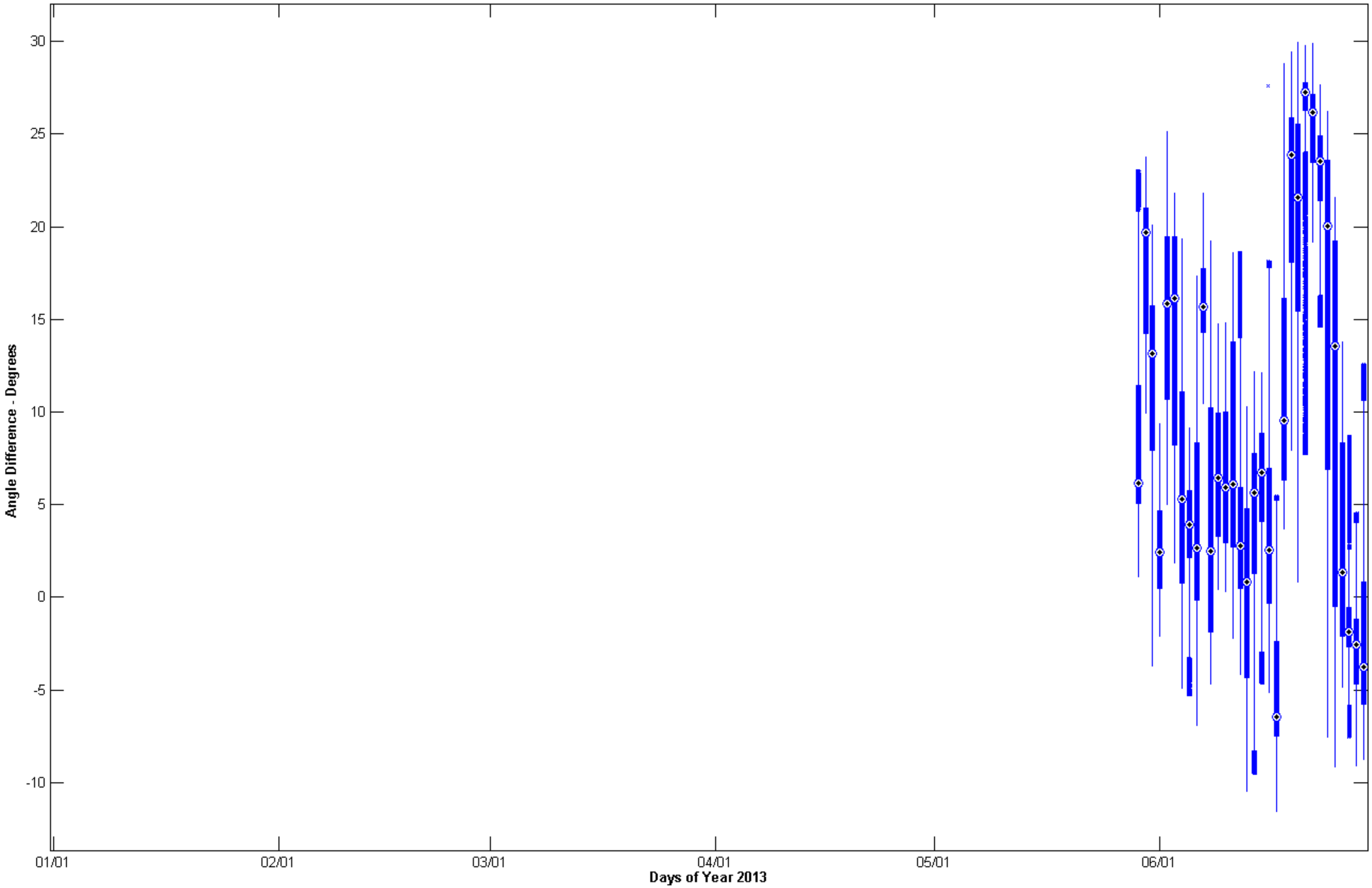
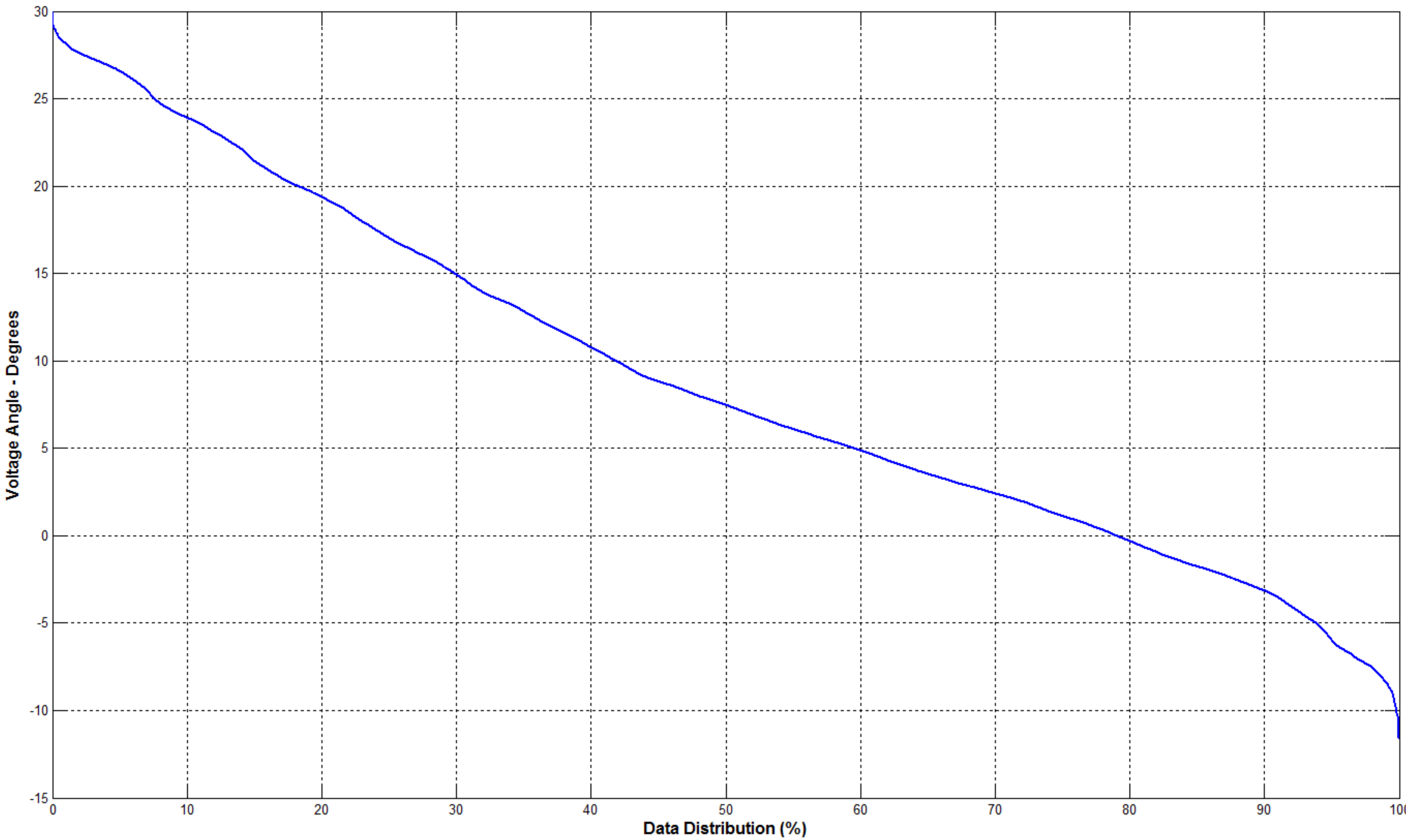


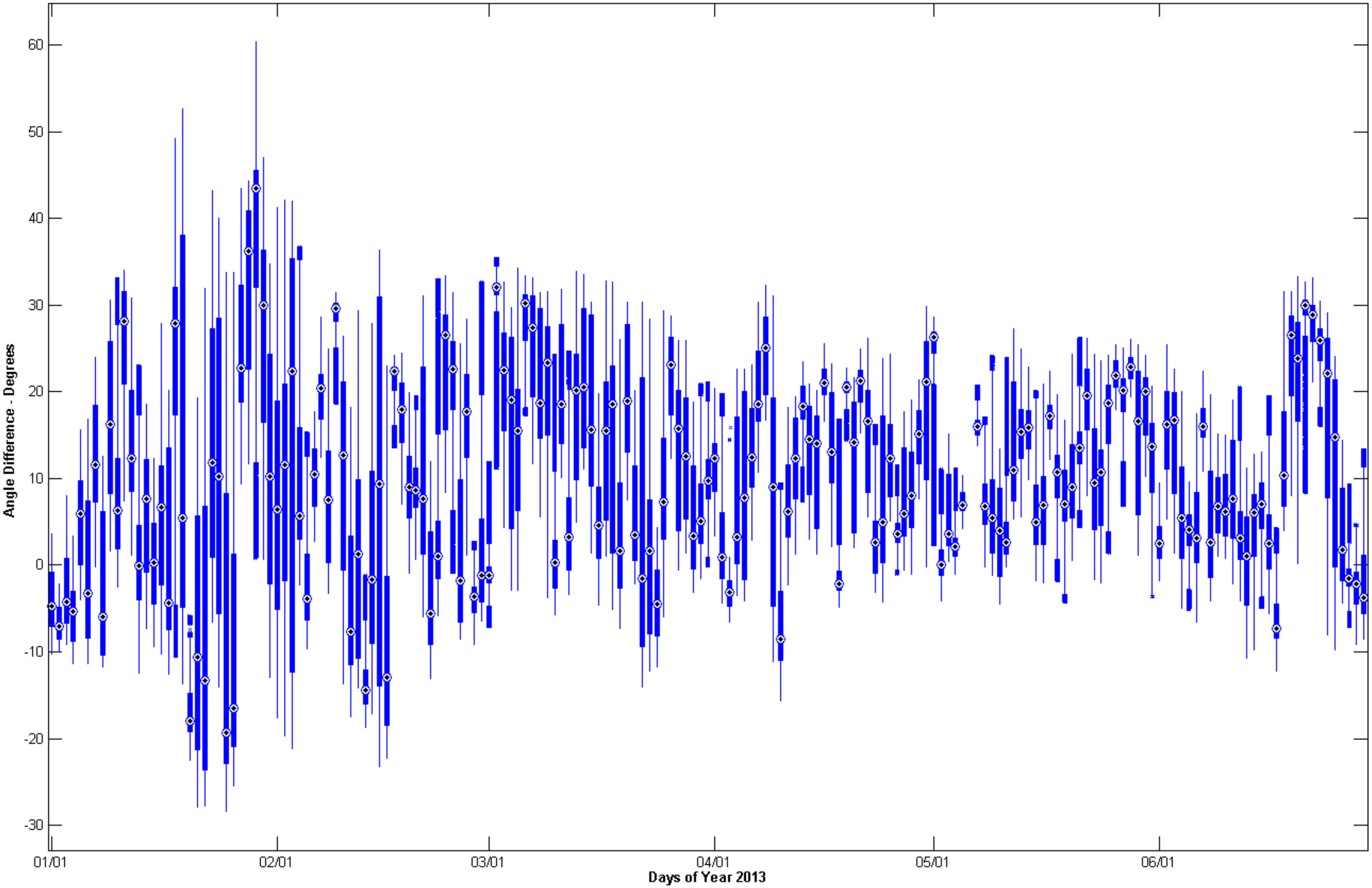
West 5 – Voltage Angle



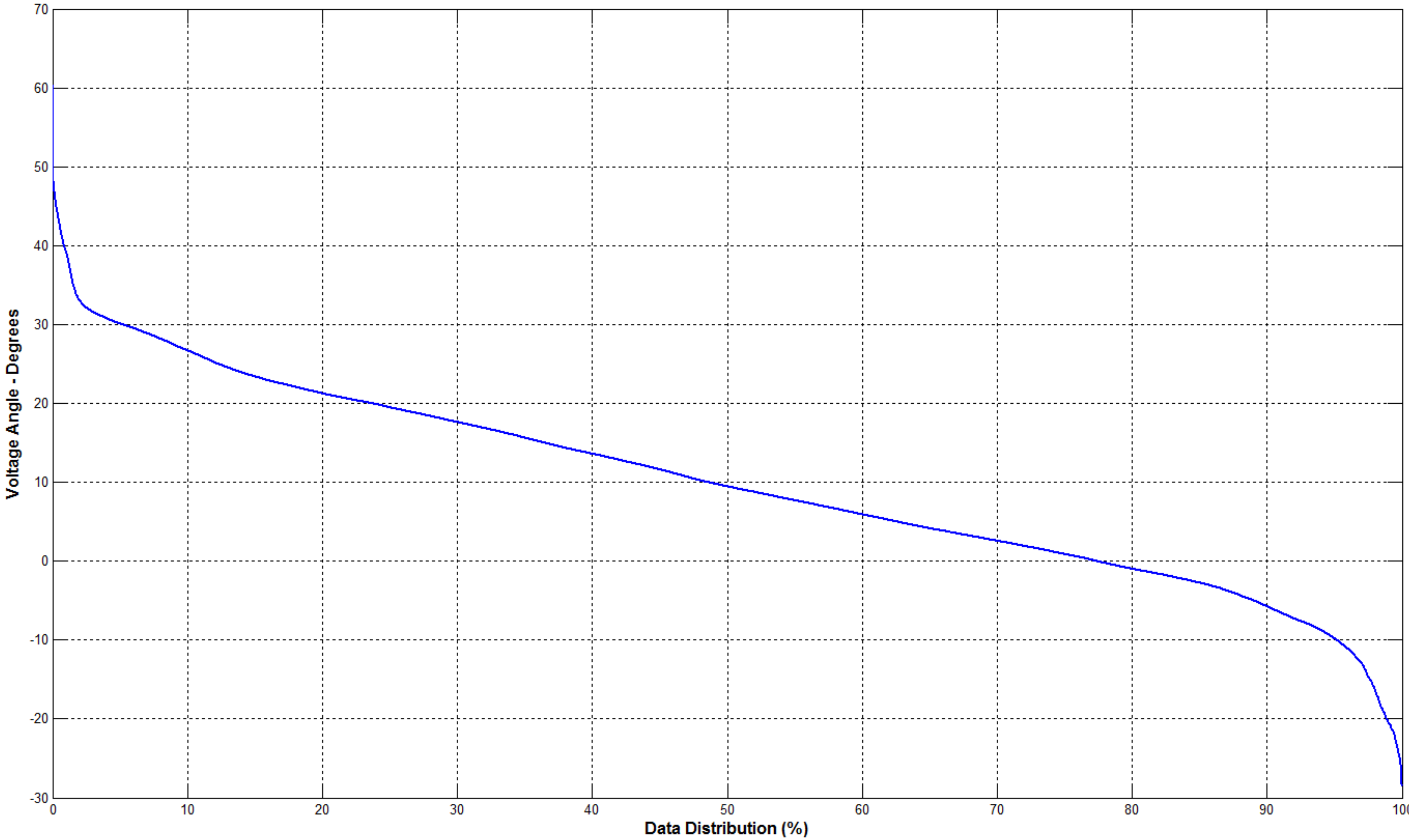
West 5 – Voltage Angle



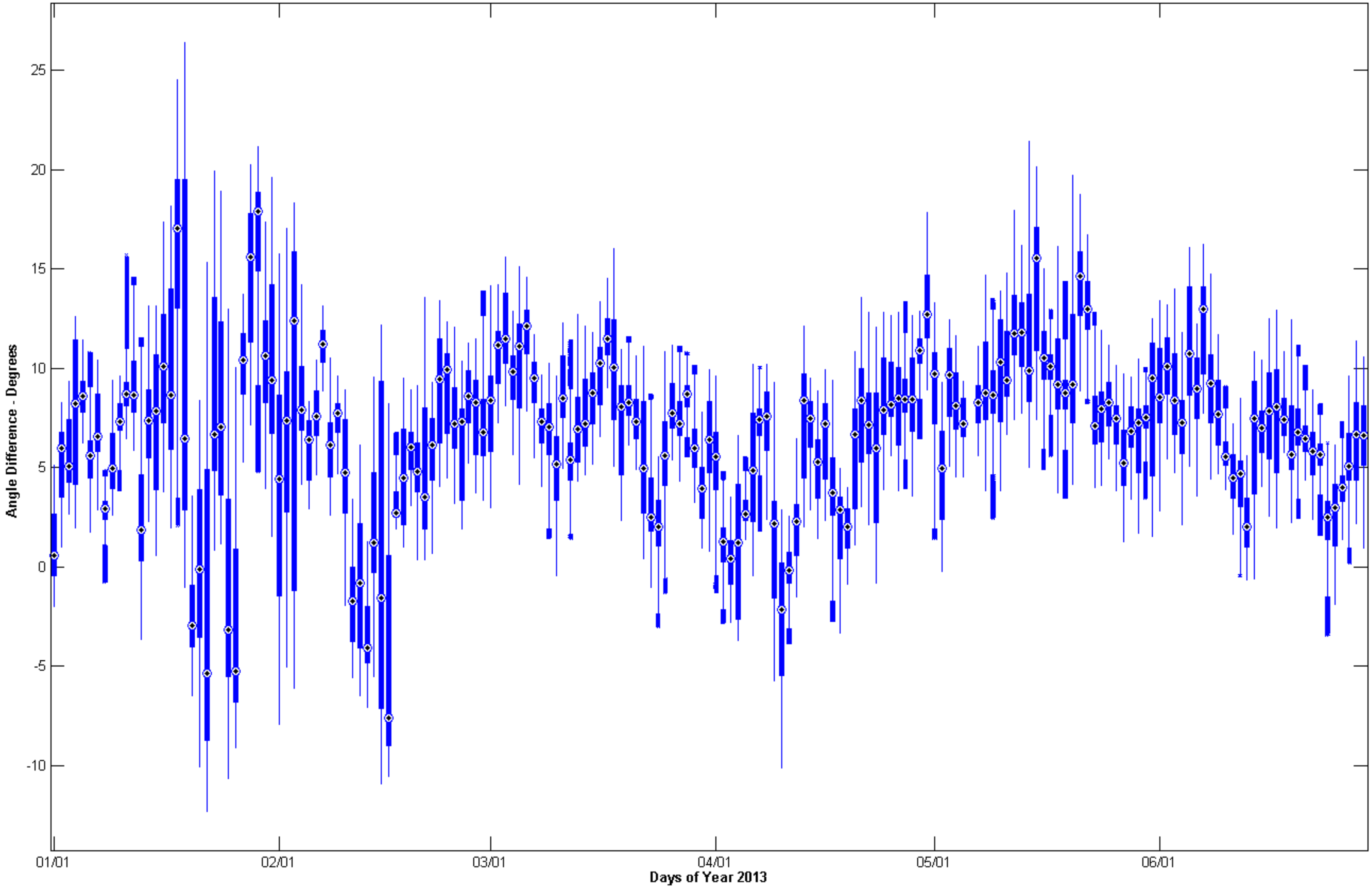
West 6 – Voltage Angle



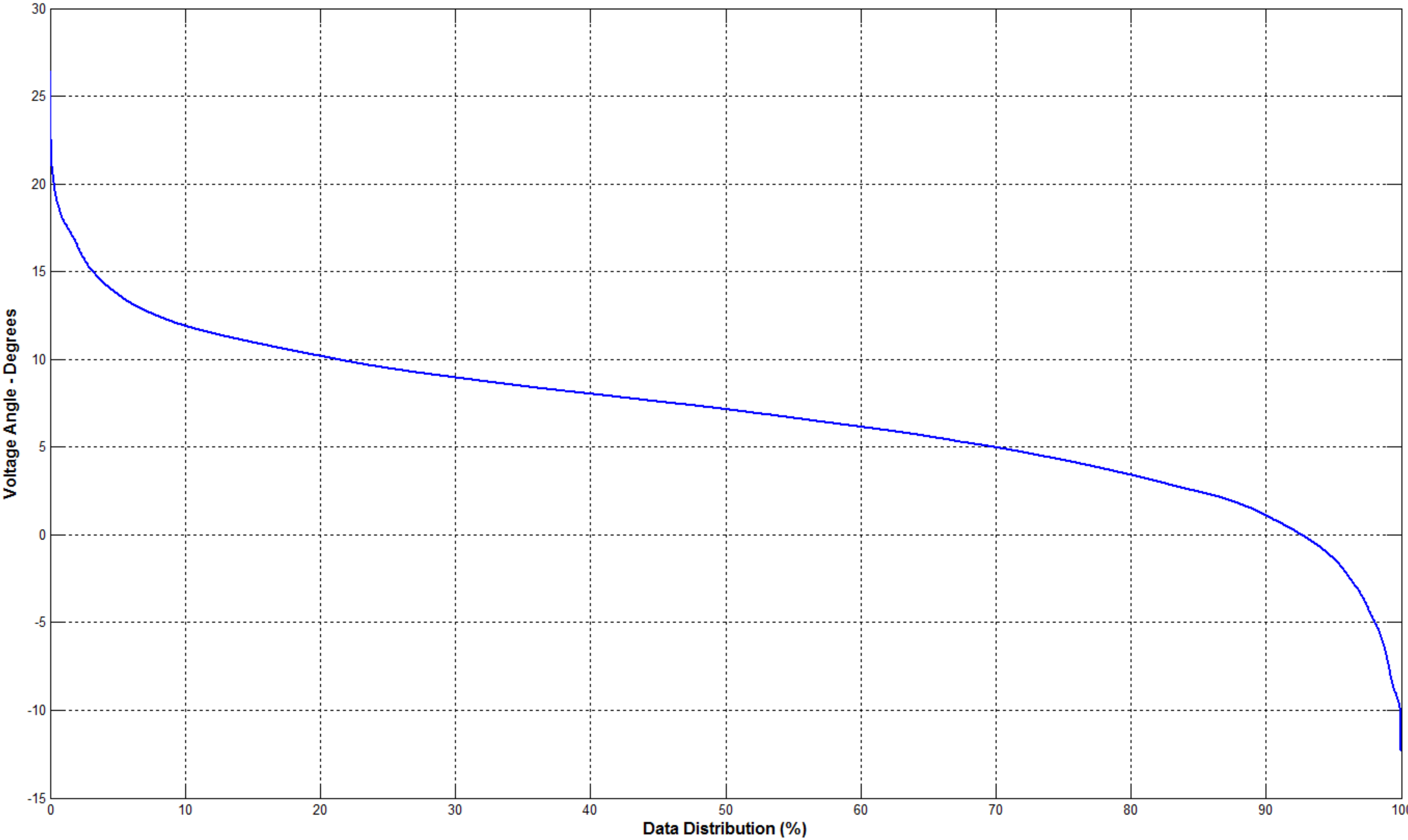
West 6 – Voltage Angle



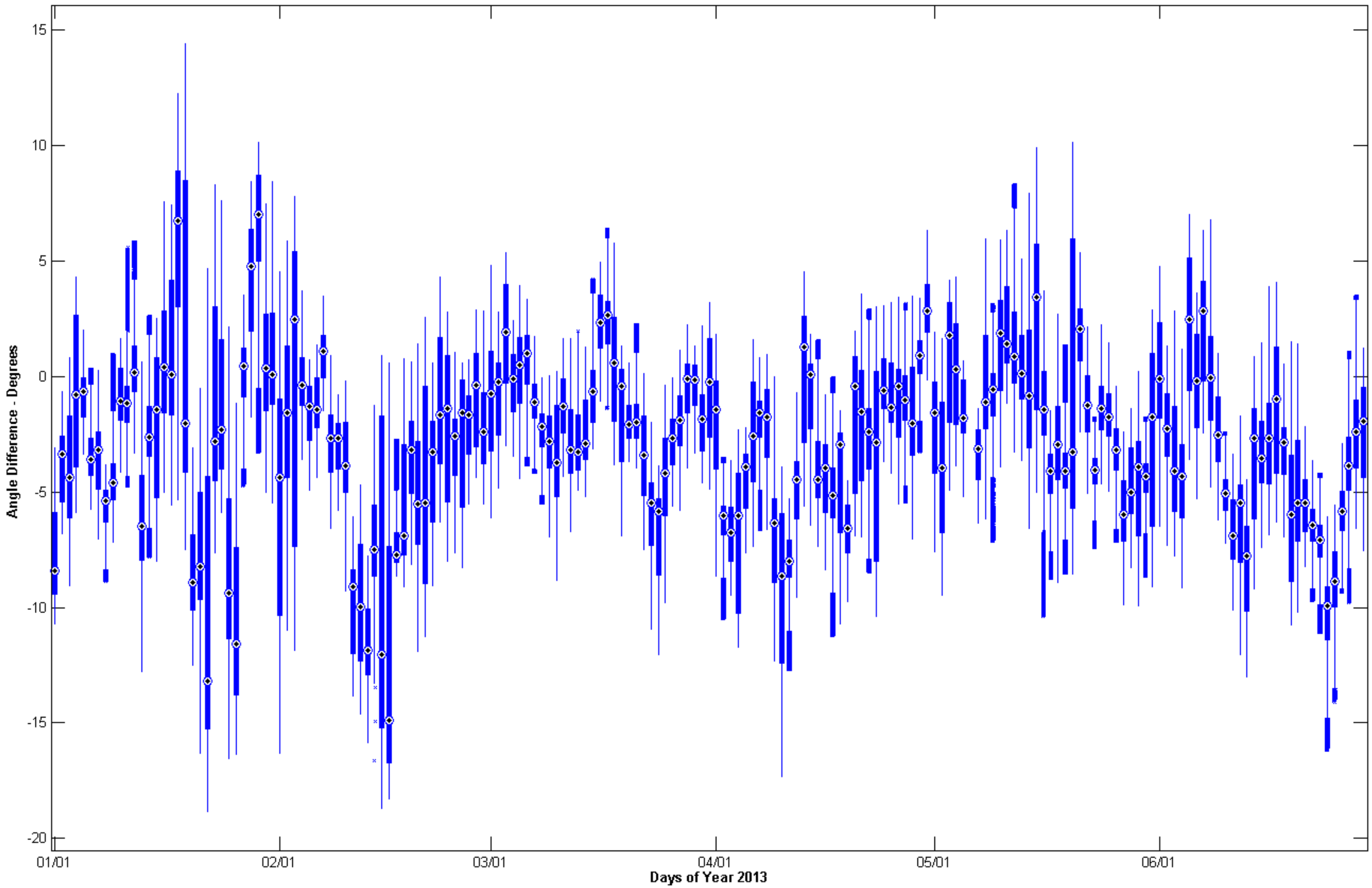
North 1 – Voltage Angle



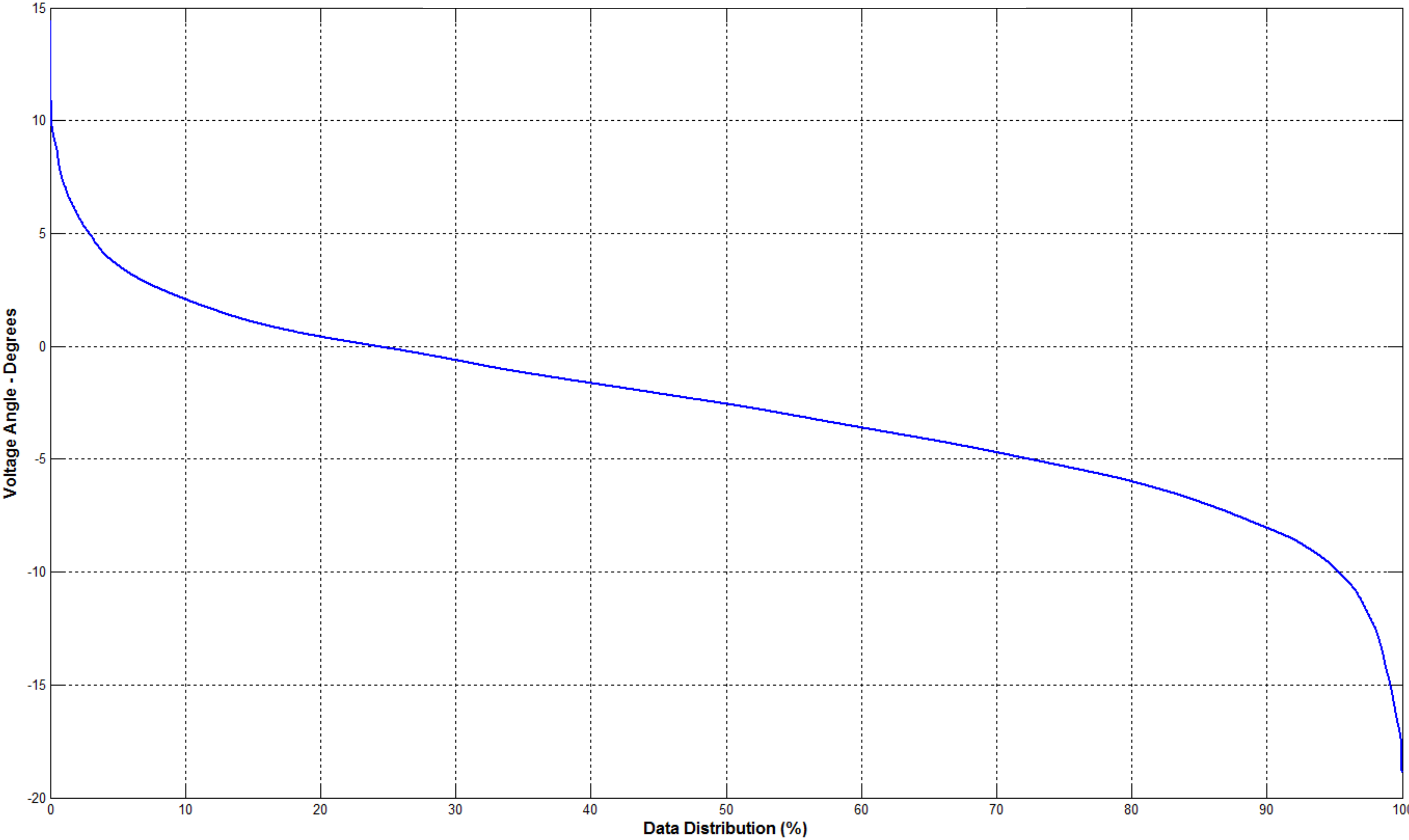
North 1 – Voltage Angle



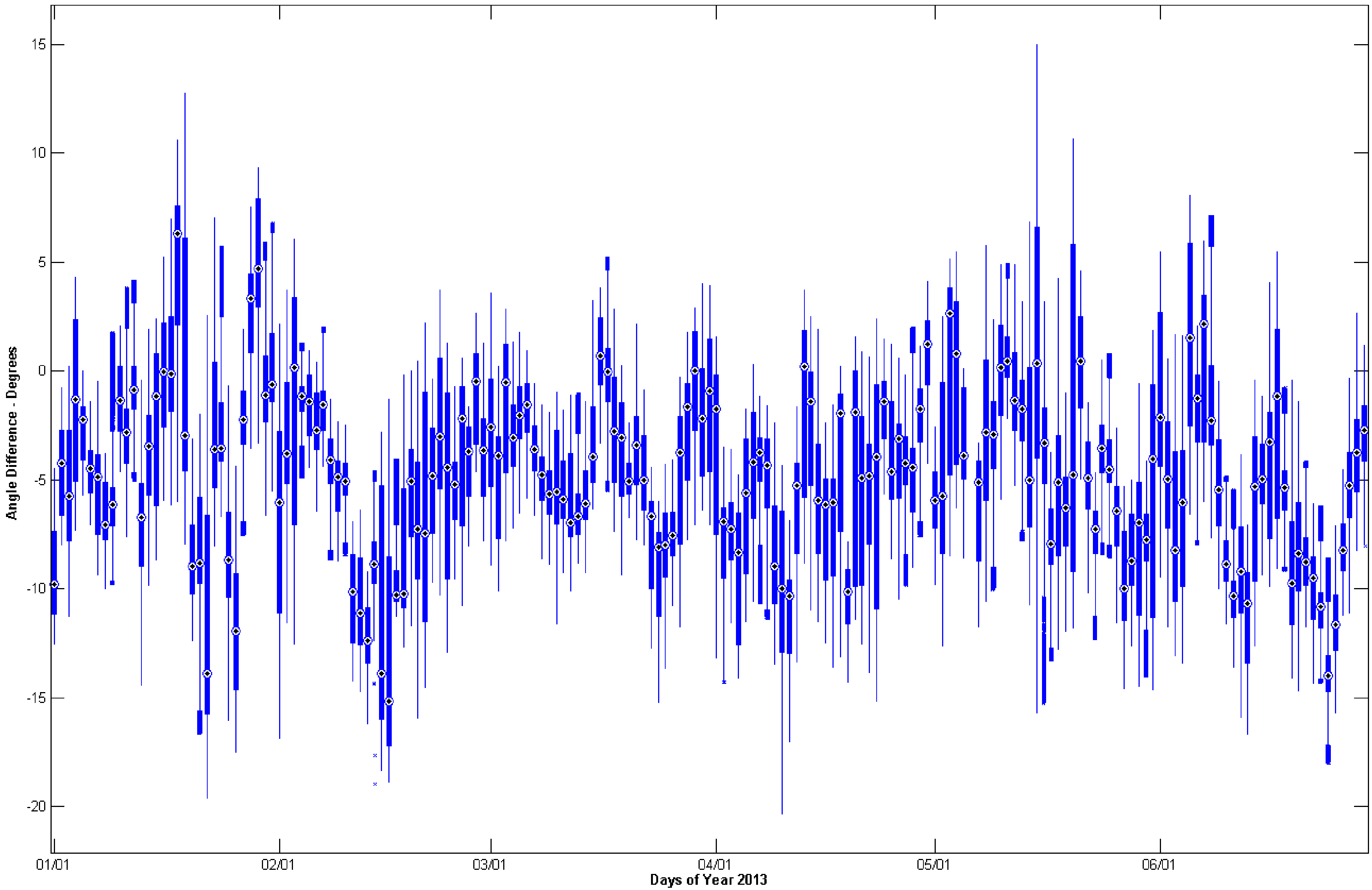
North 4 – Voltage Angle



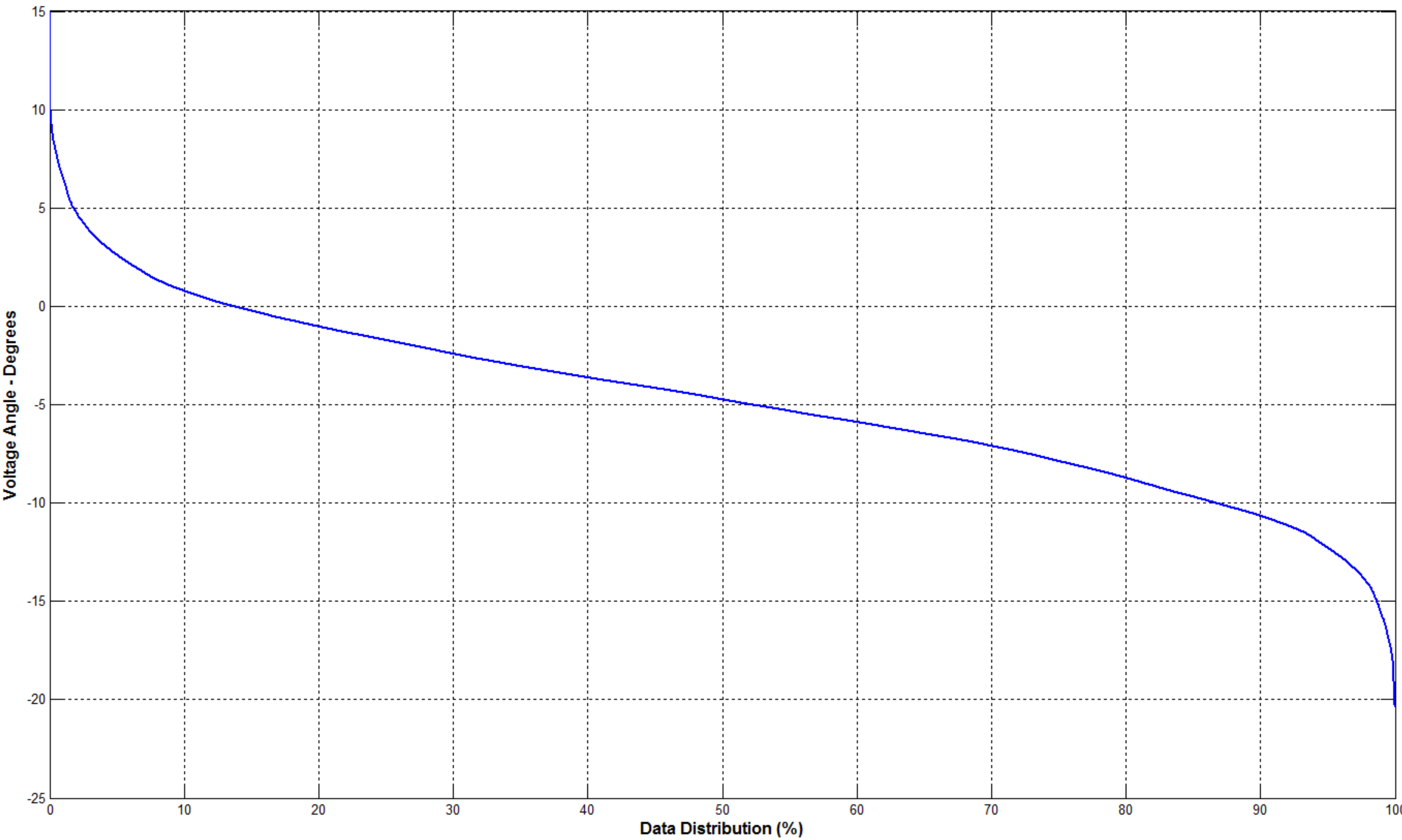
North 4 – Voltage Angle



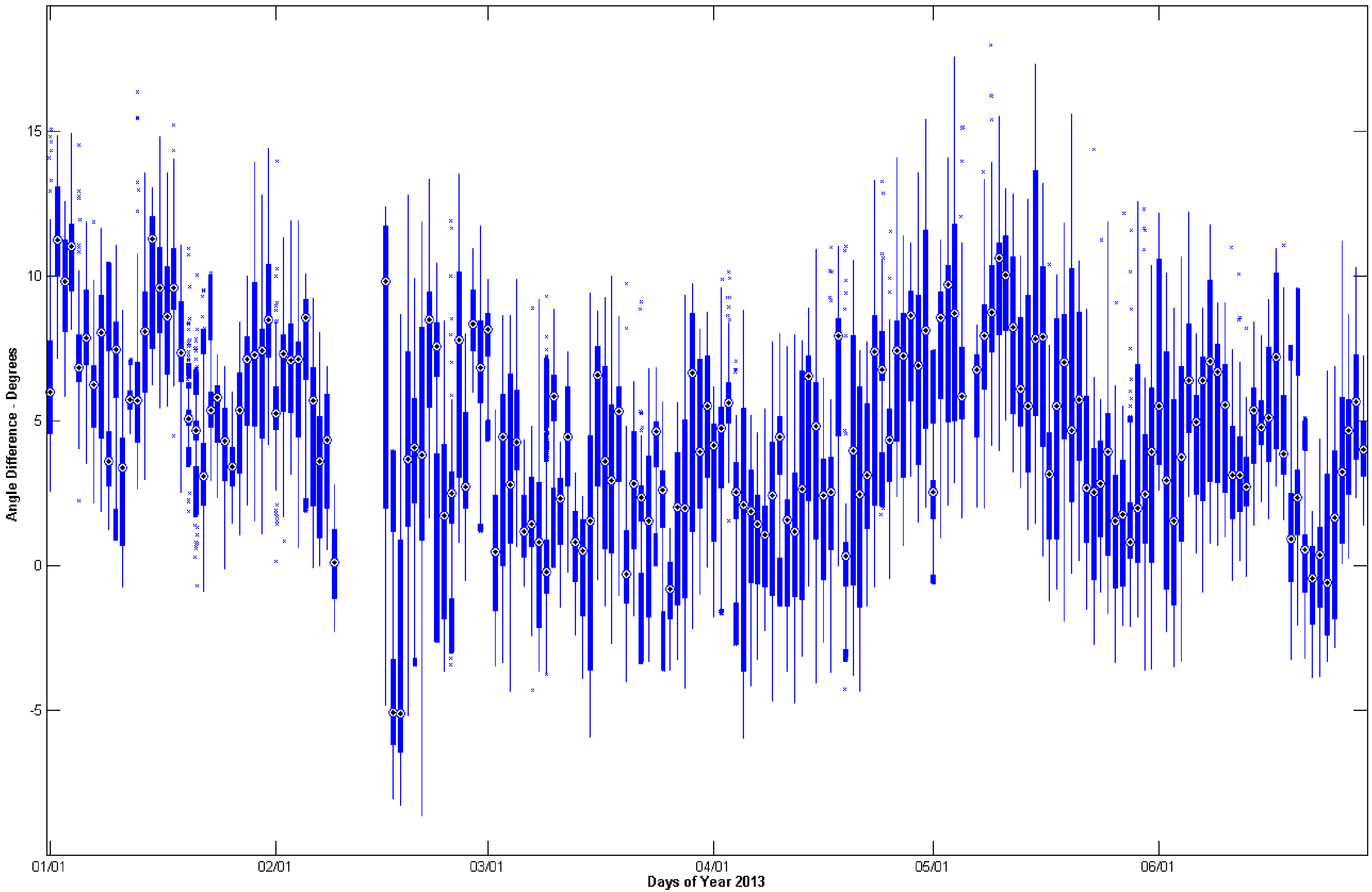
North 5 – Voltage Angle



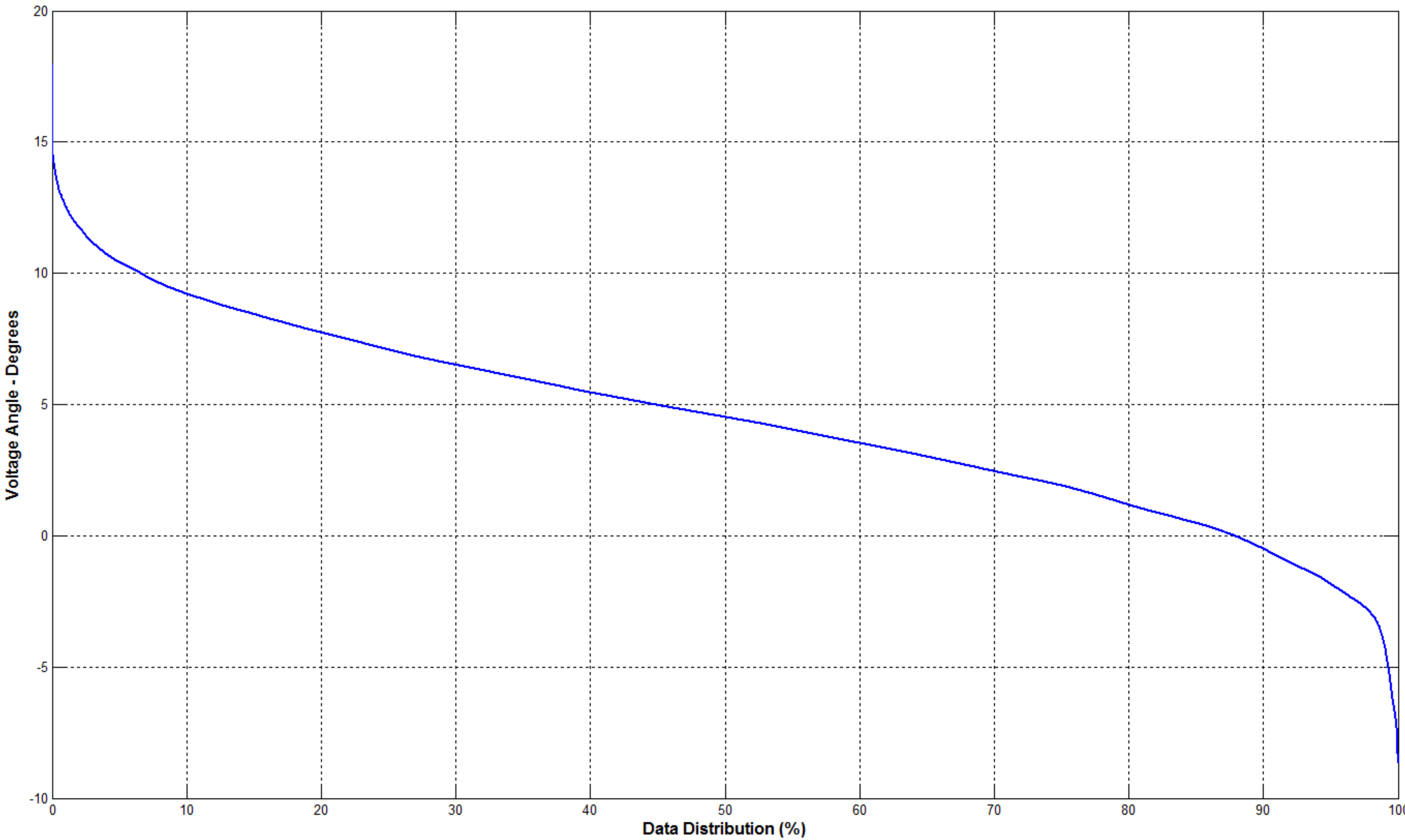
North 5 – Voltage Angle



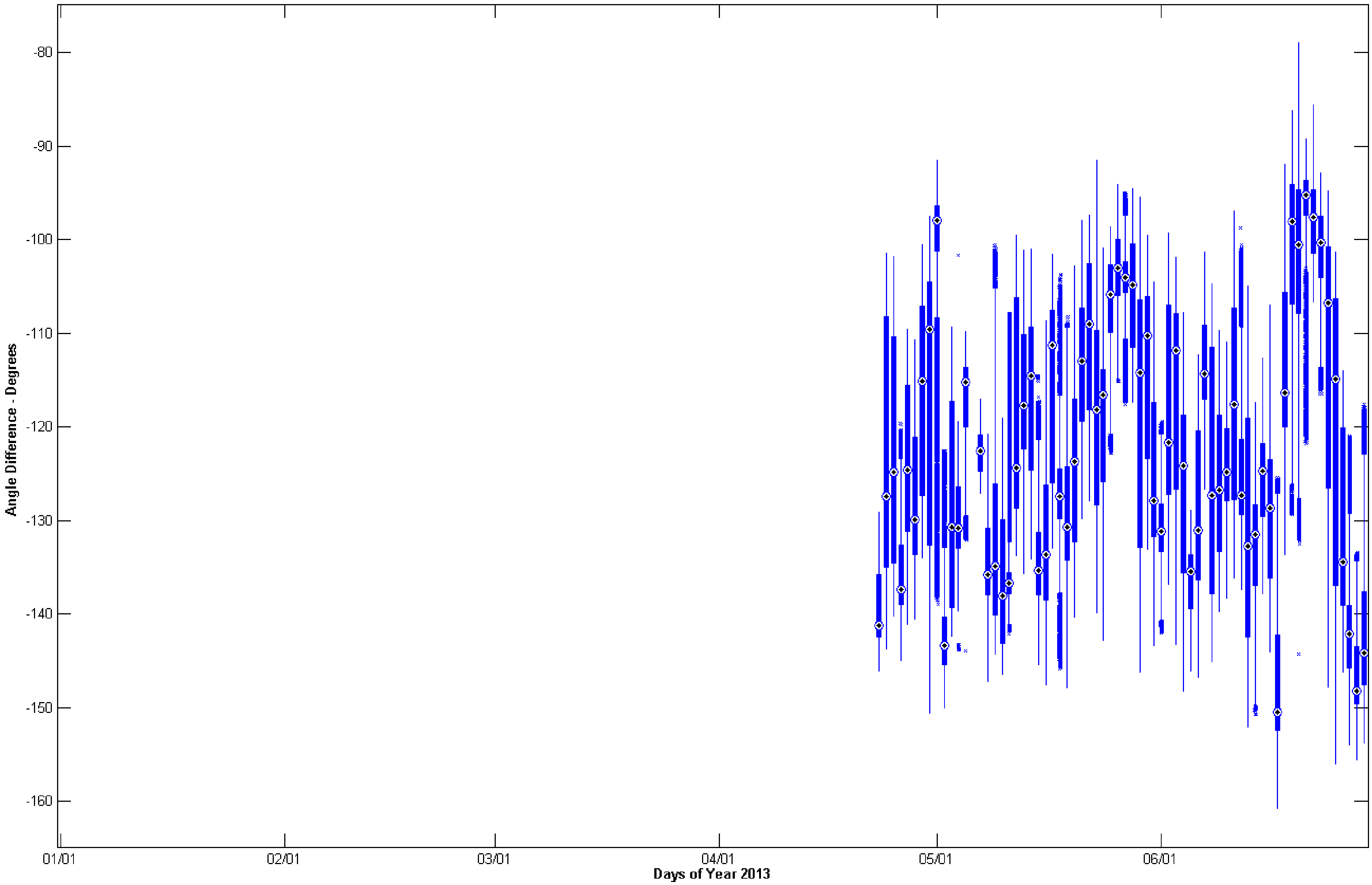
North 6 – Voltage Angle



North 6 – Voltage Angle



FarWest 2 – Voltage Angle



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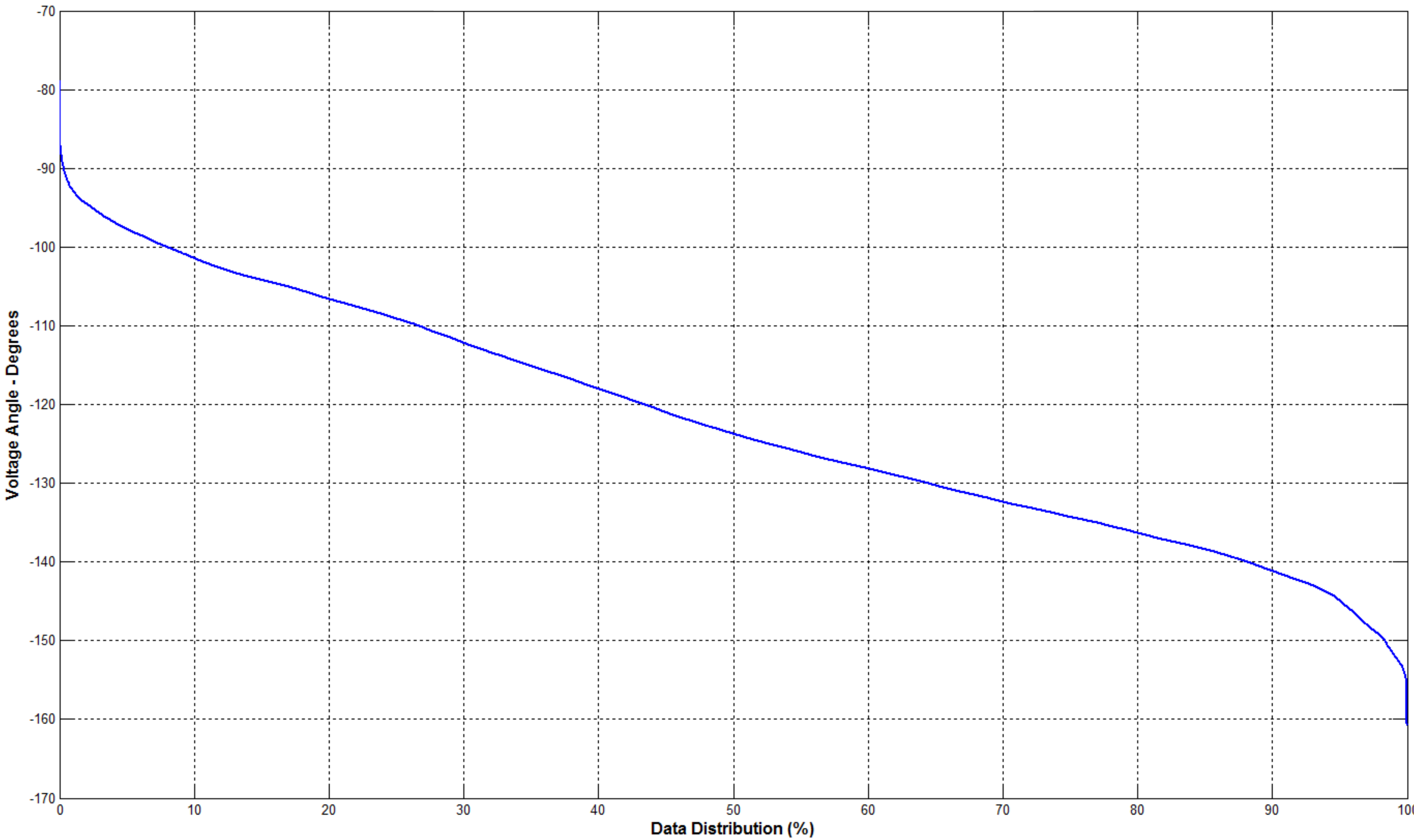
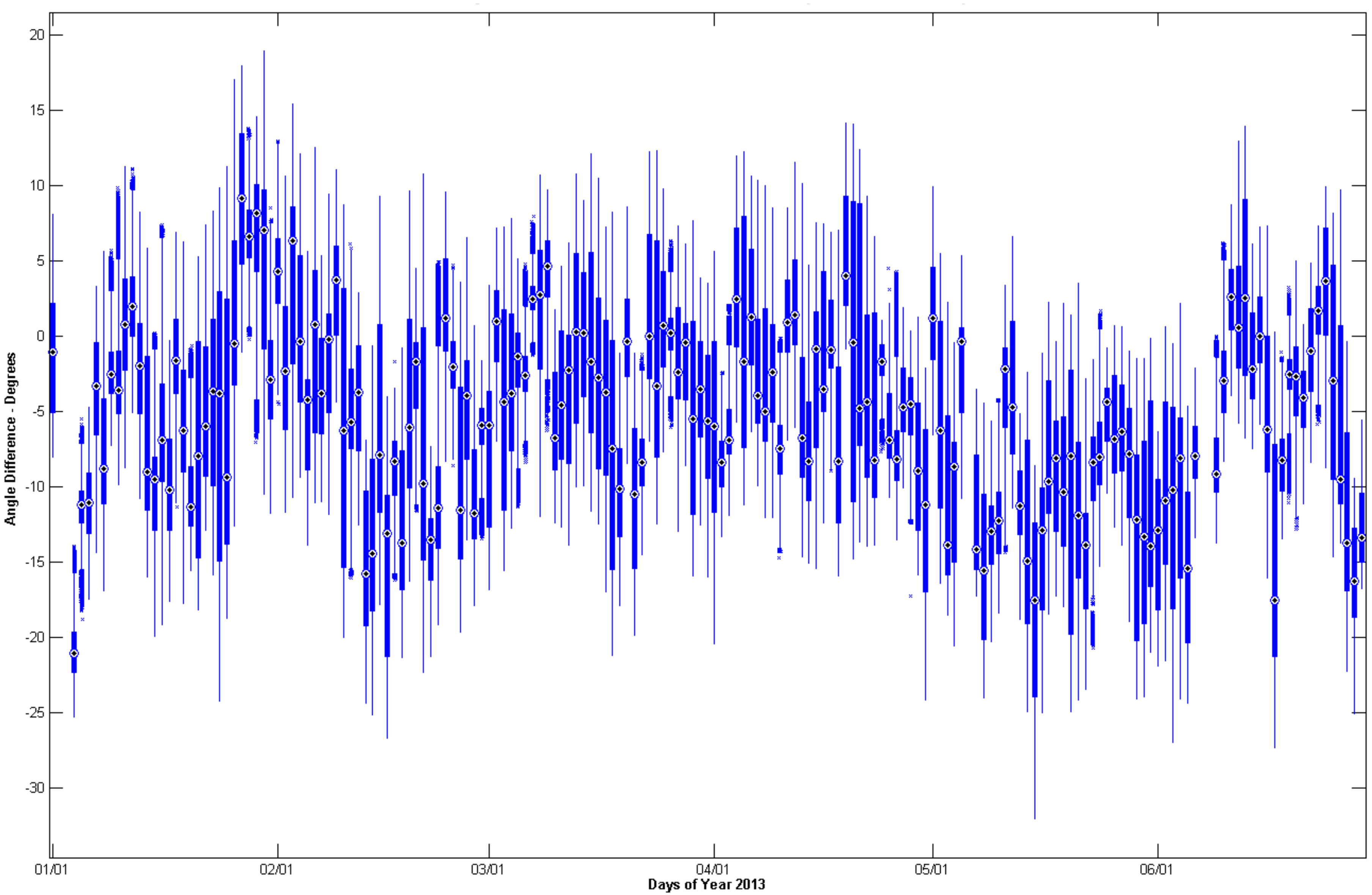


West 4 – Voltage Angle



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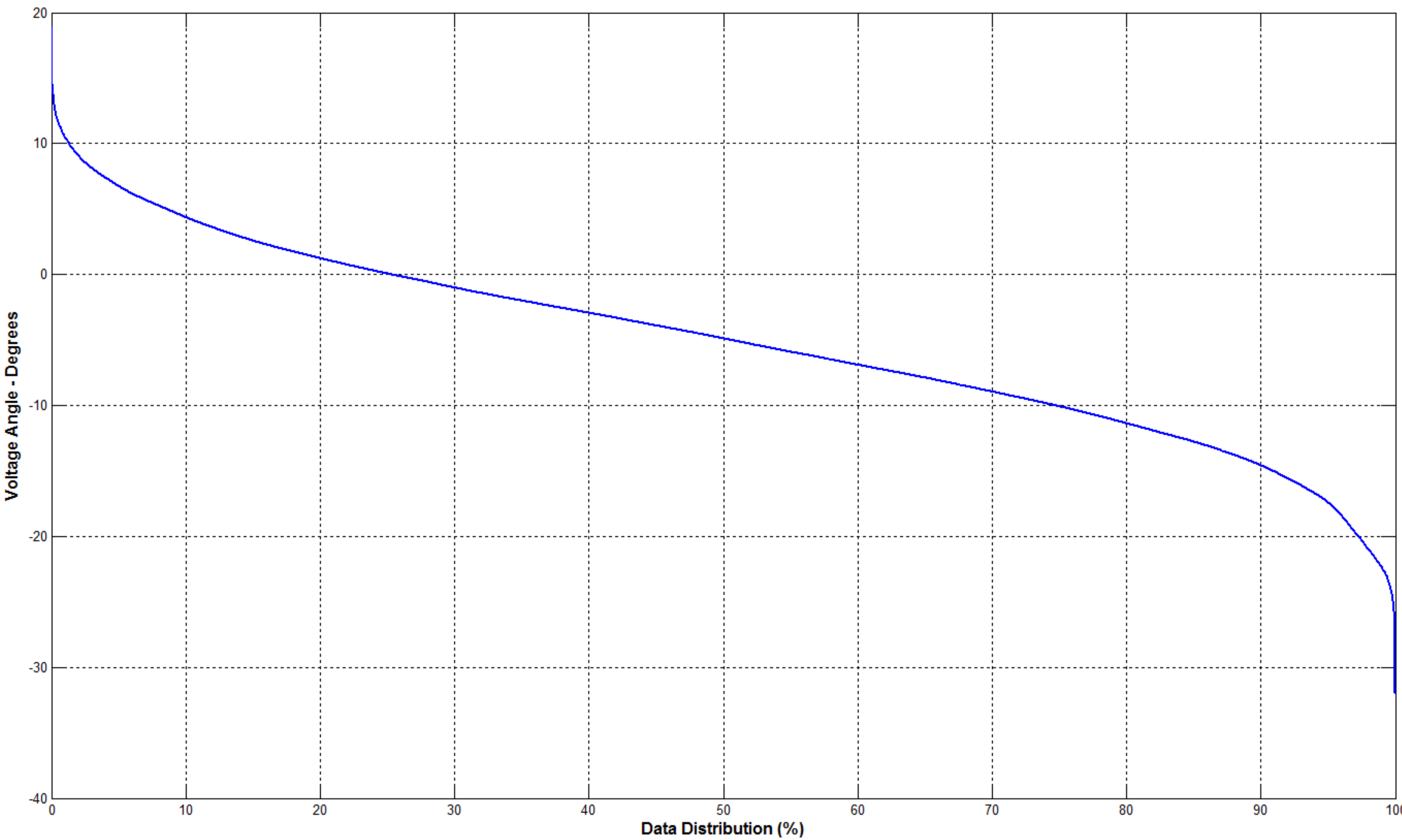
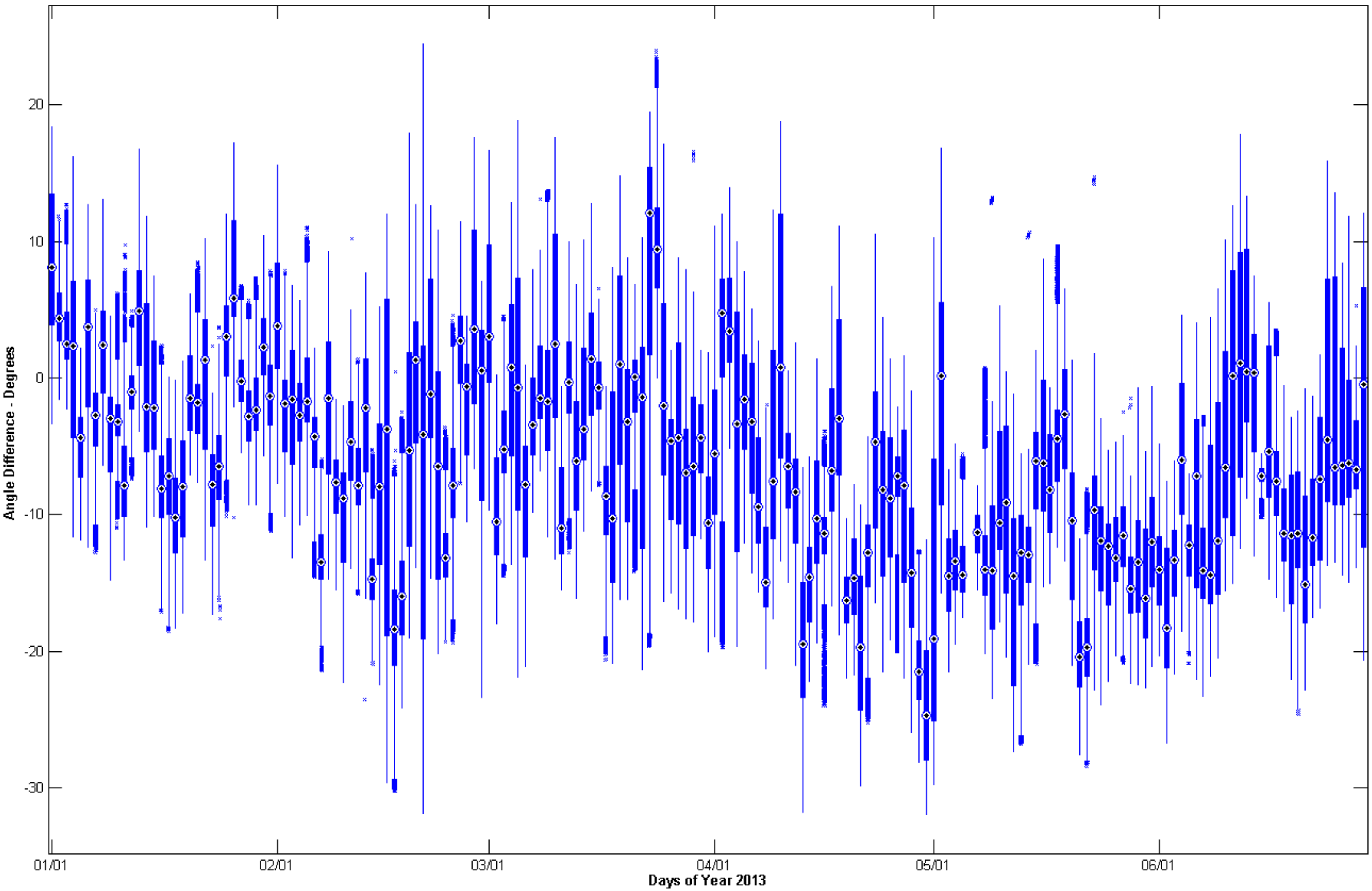
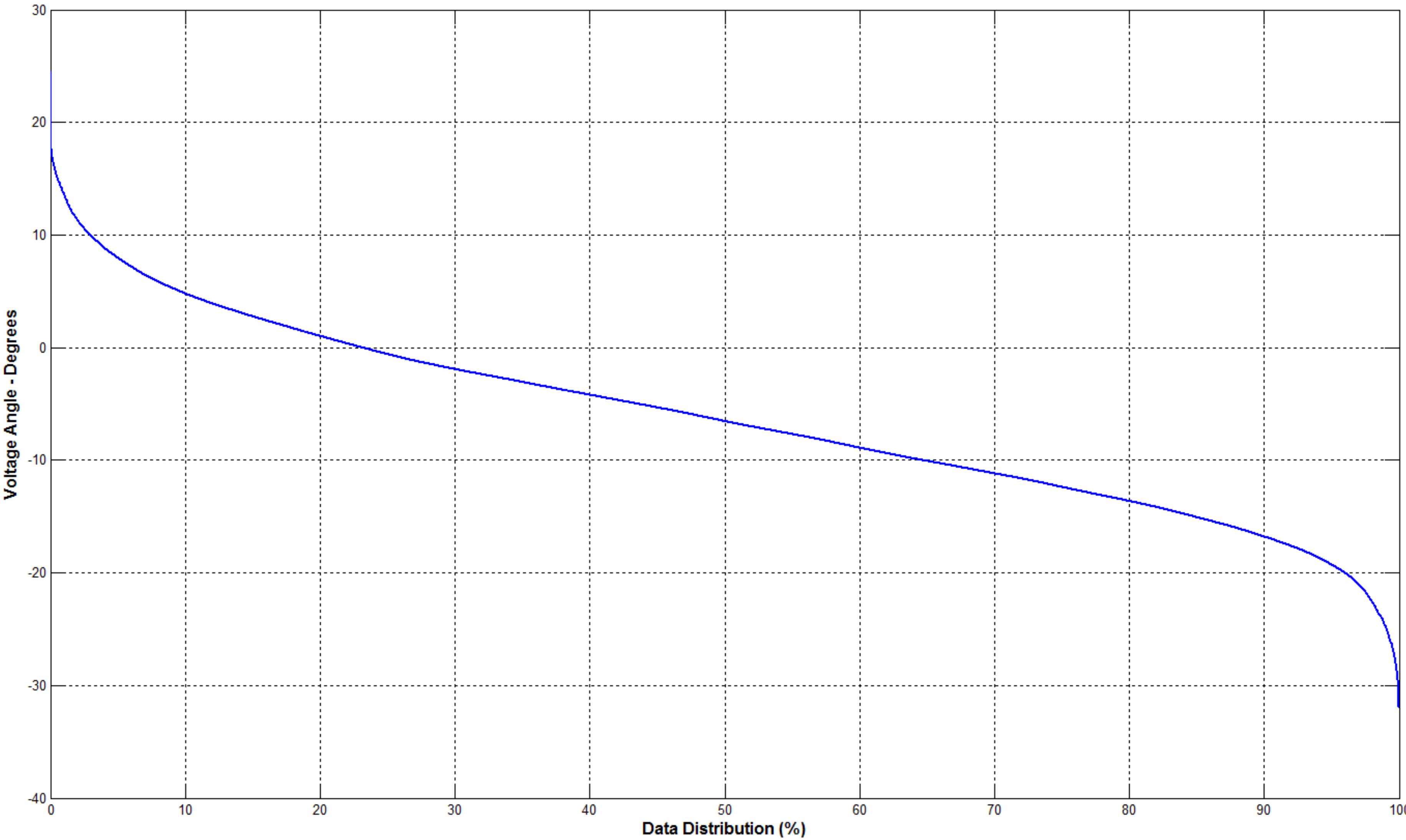


Coast 2 – Voltage Angle



Coast 2 – Voltage Angle



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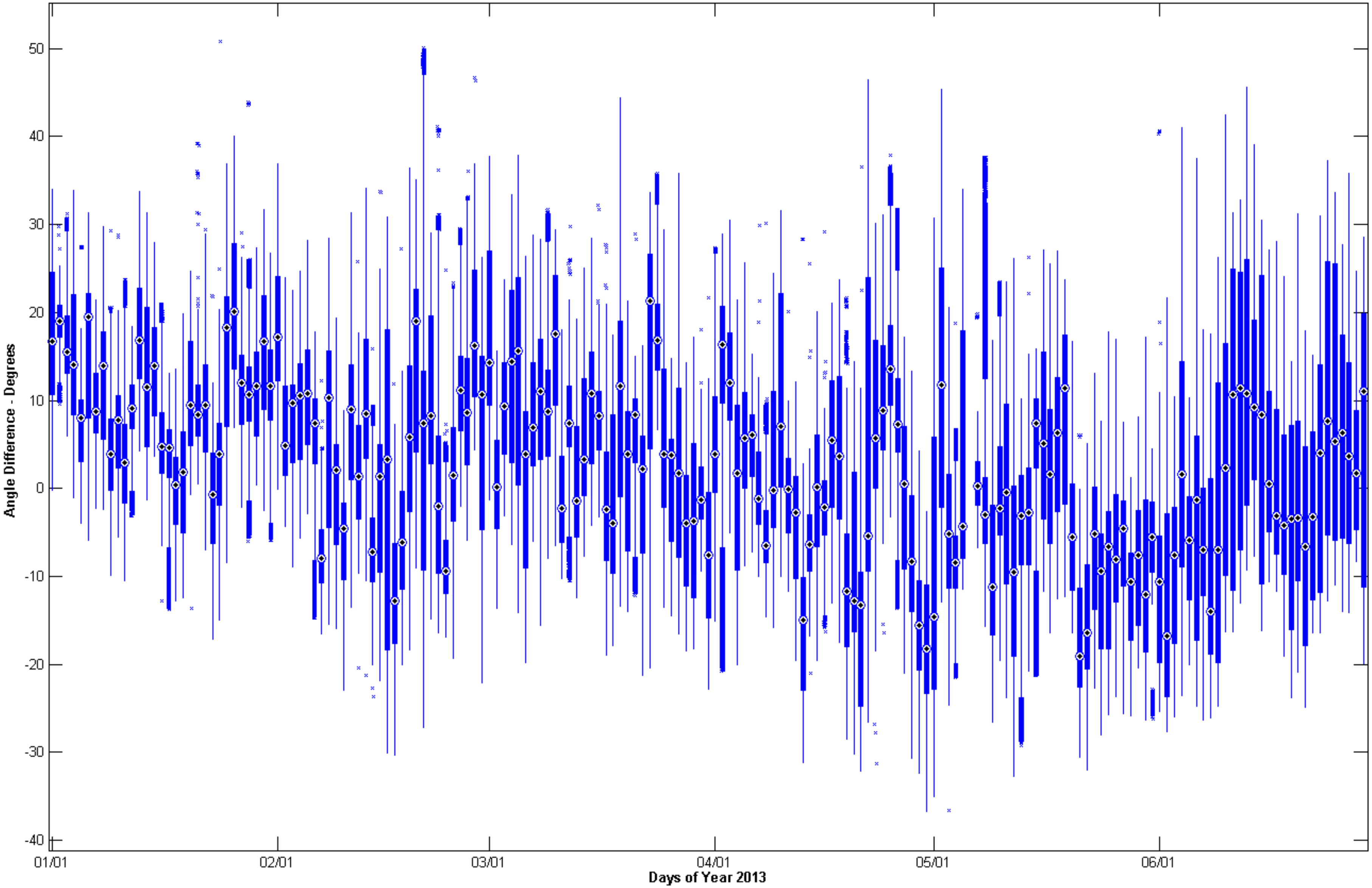

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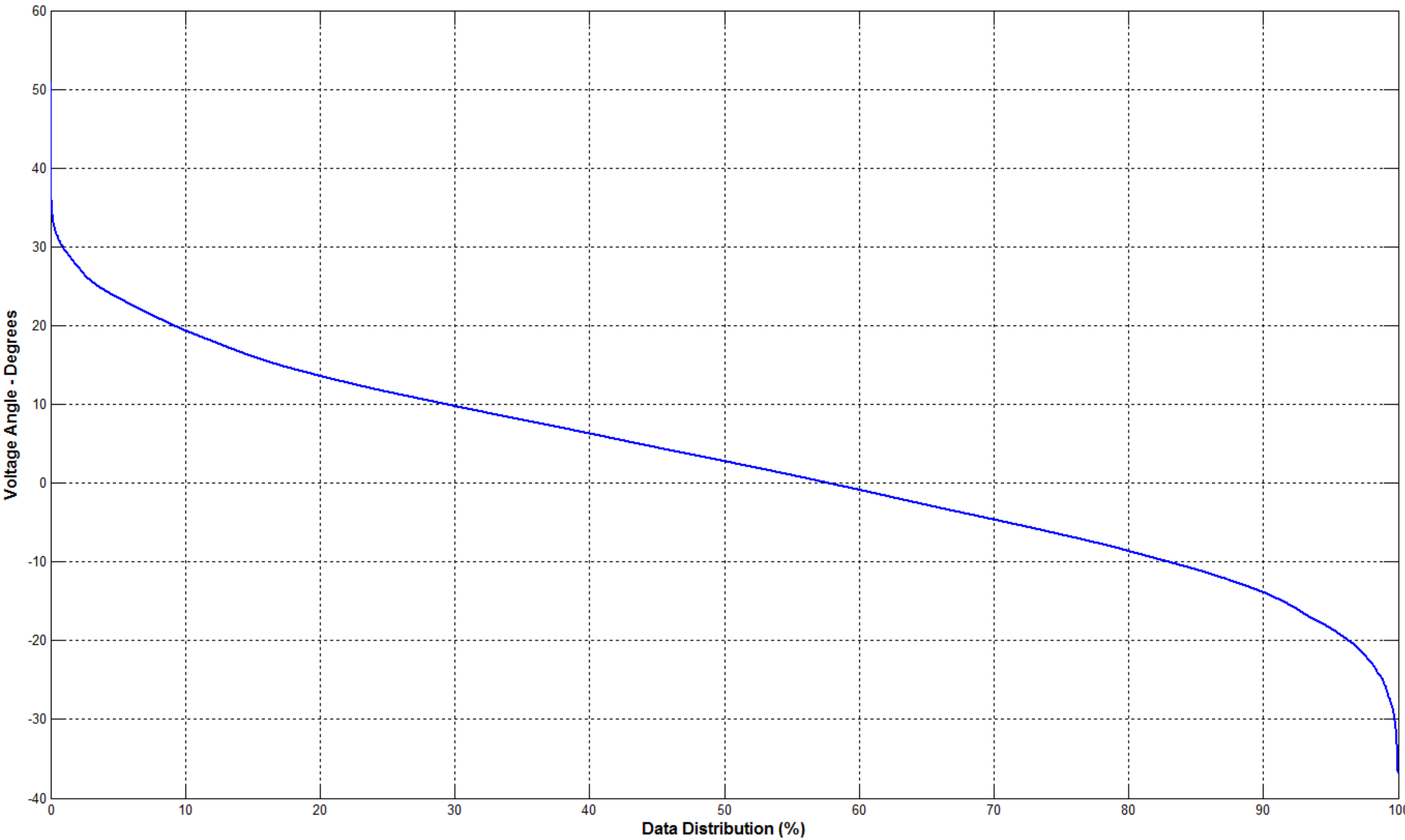
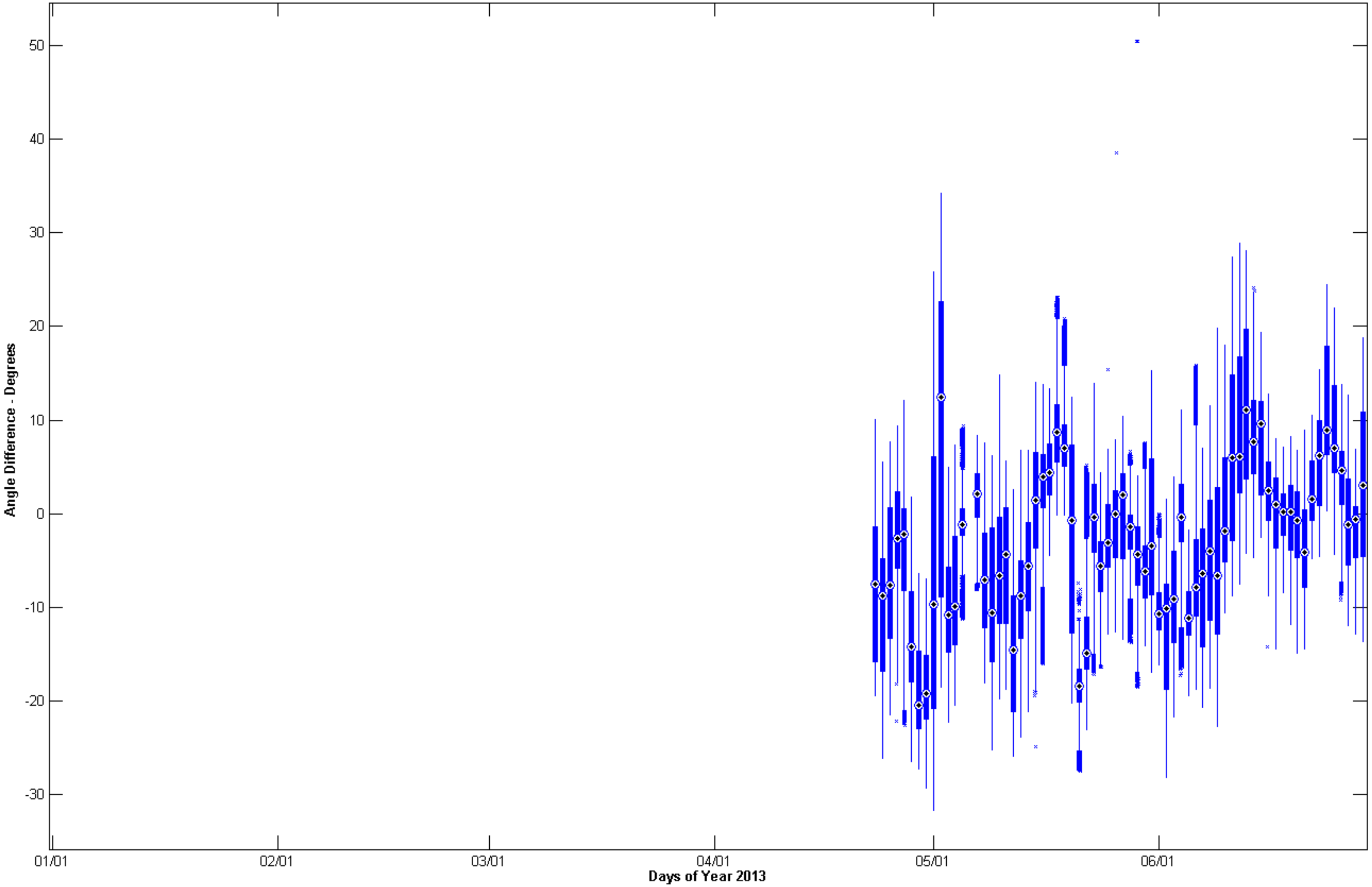
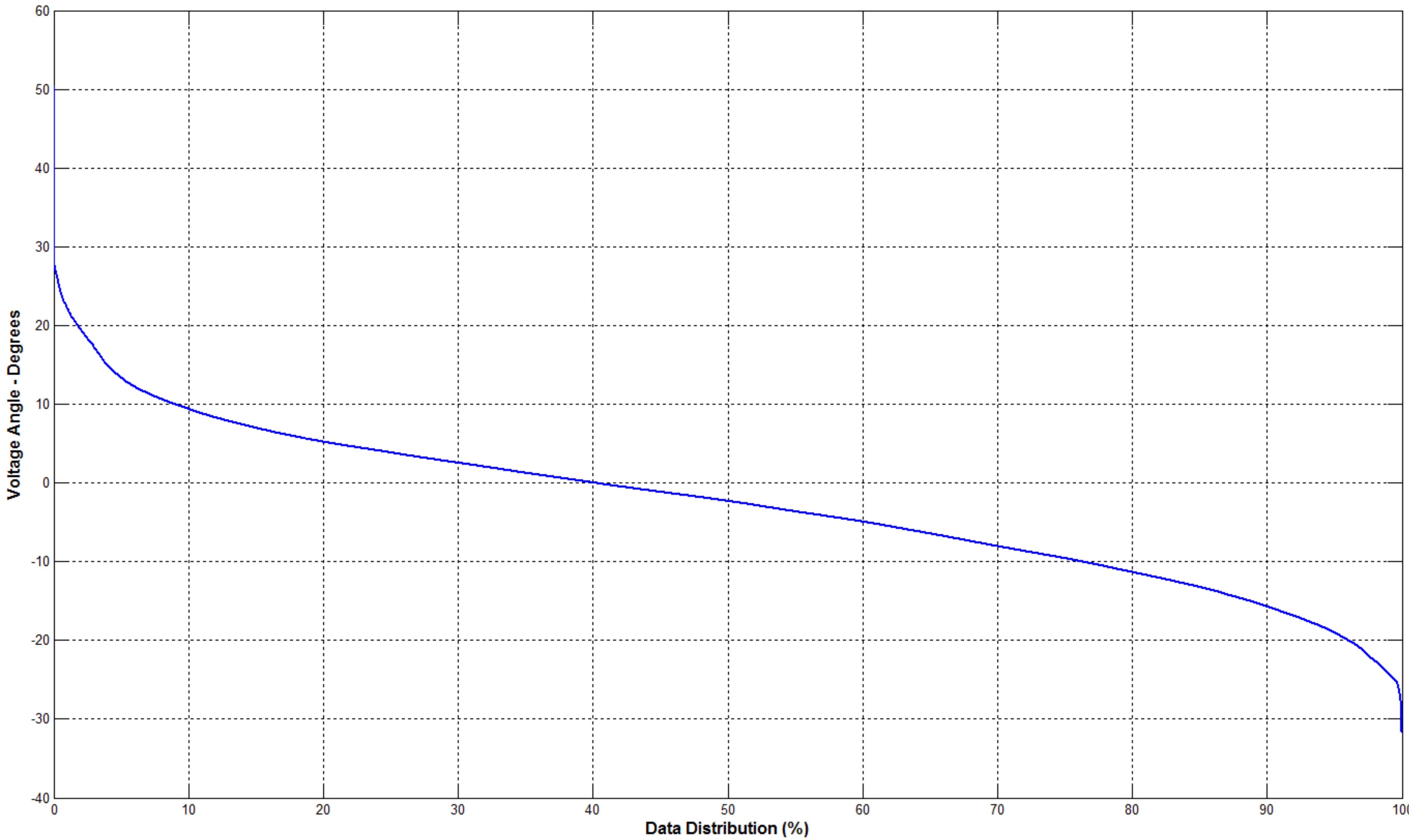


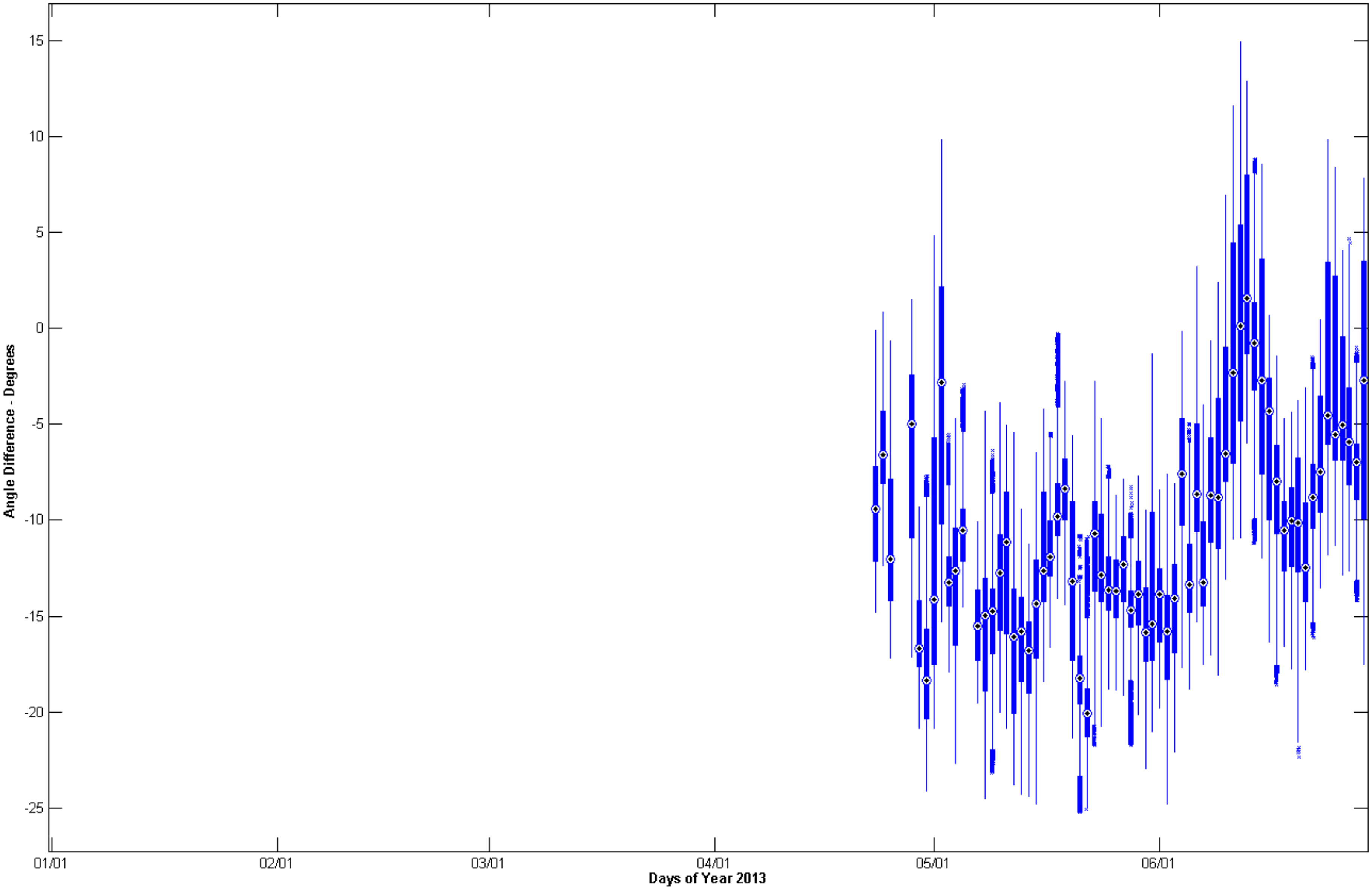
South 3 – Voltage Angle



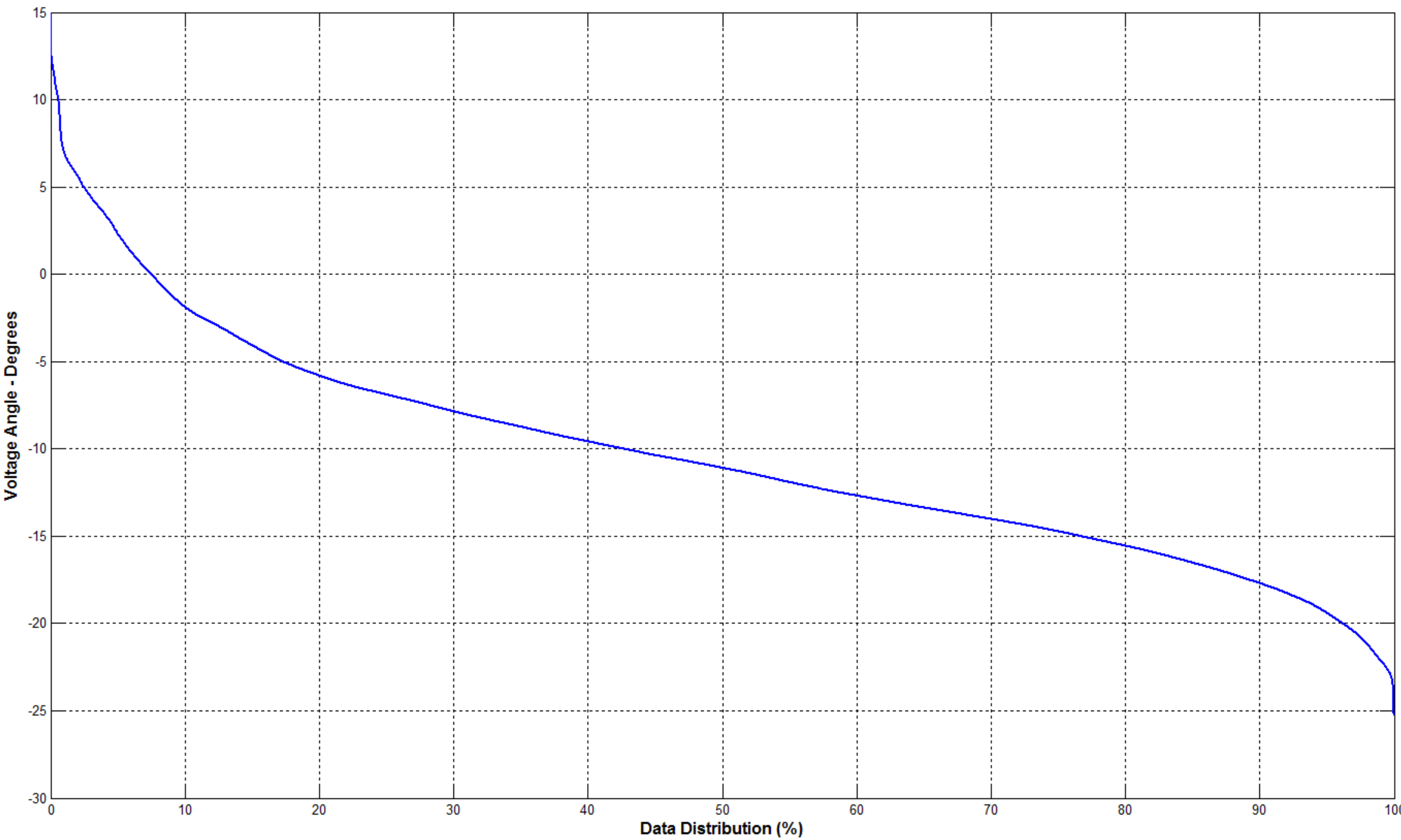
South 3 – Voltage Angle



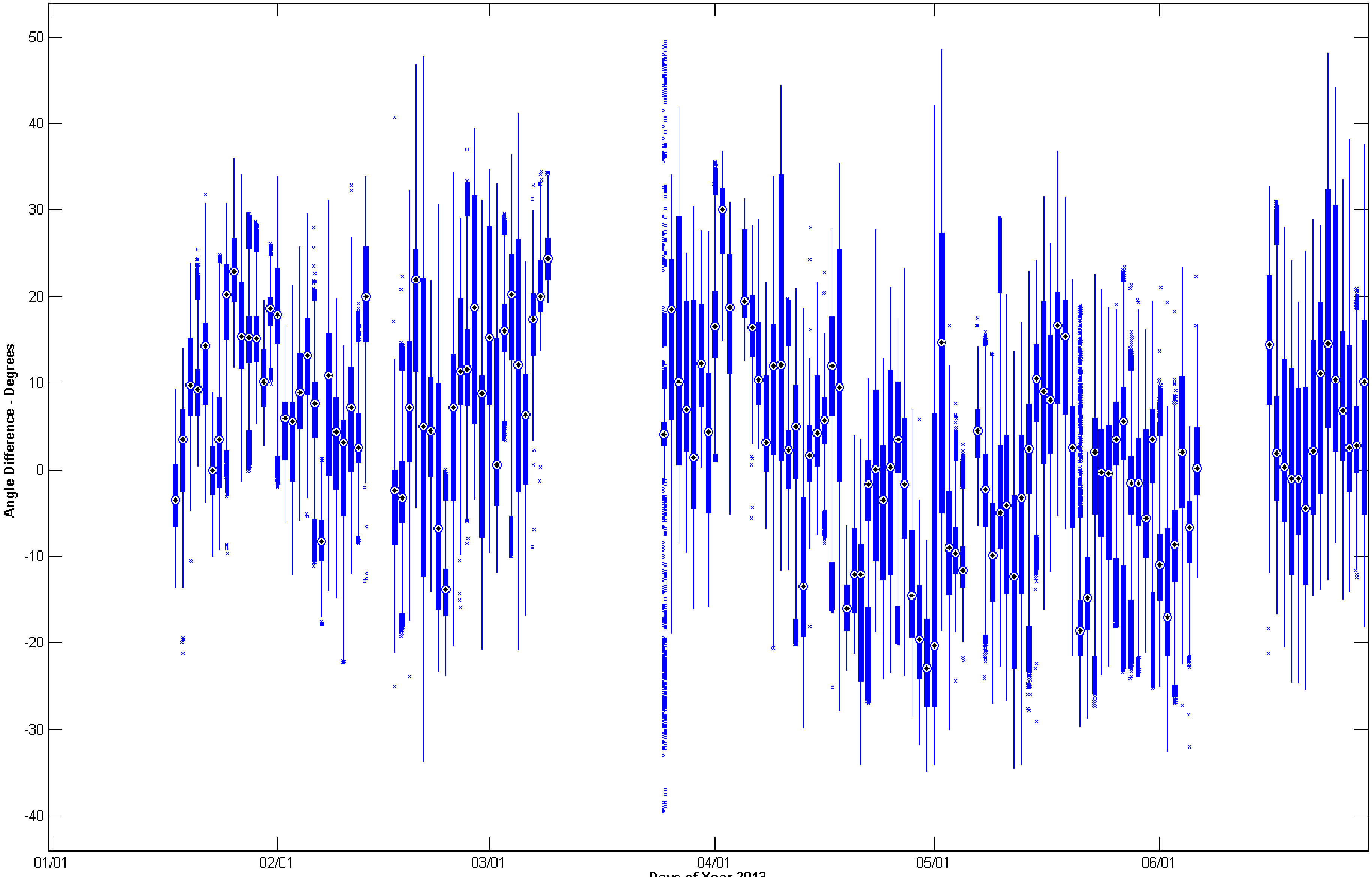
South 5 – Voltage Angle



South 5 – Voltage Angle



Coast 4 – Voltage Angle



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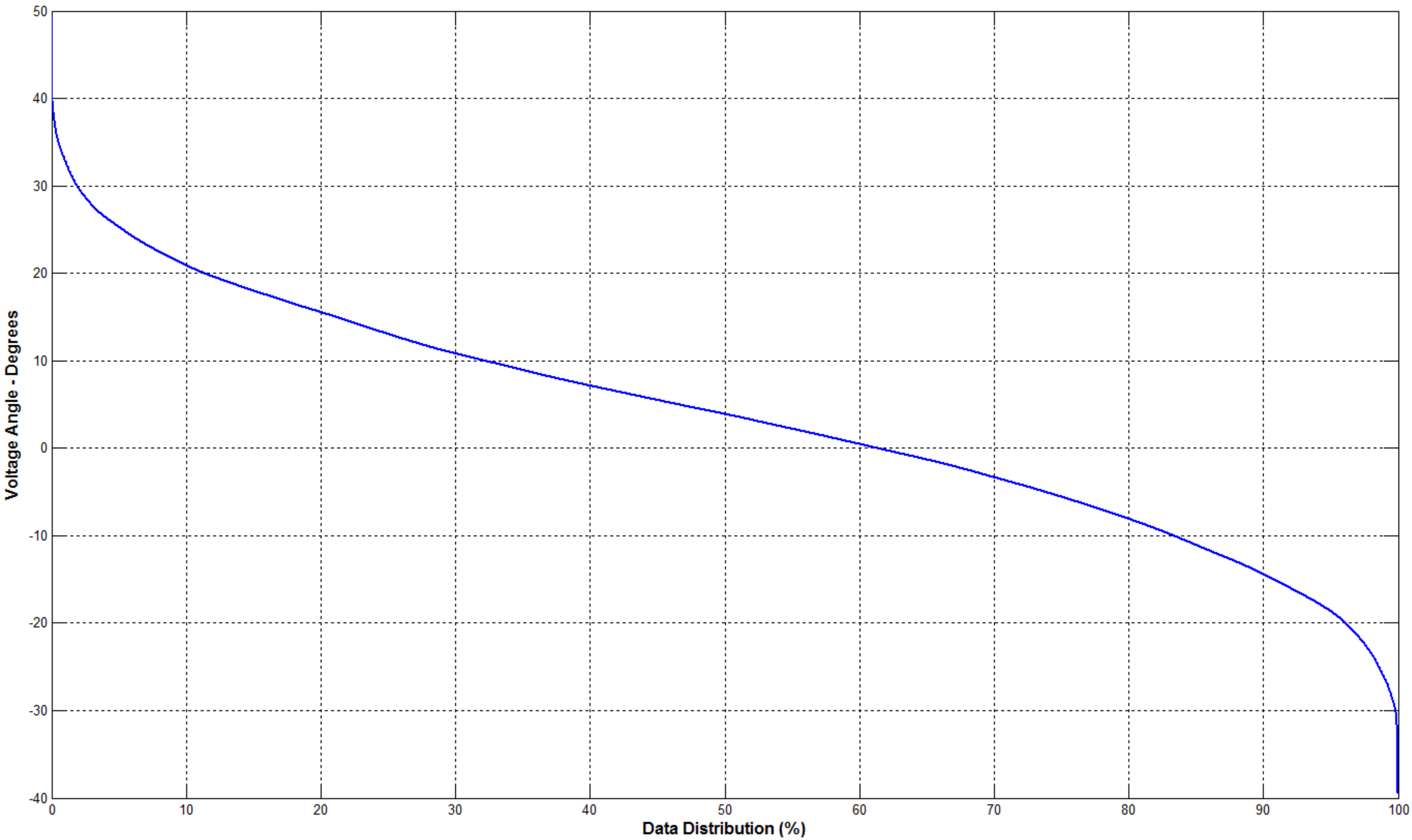
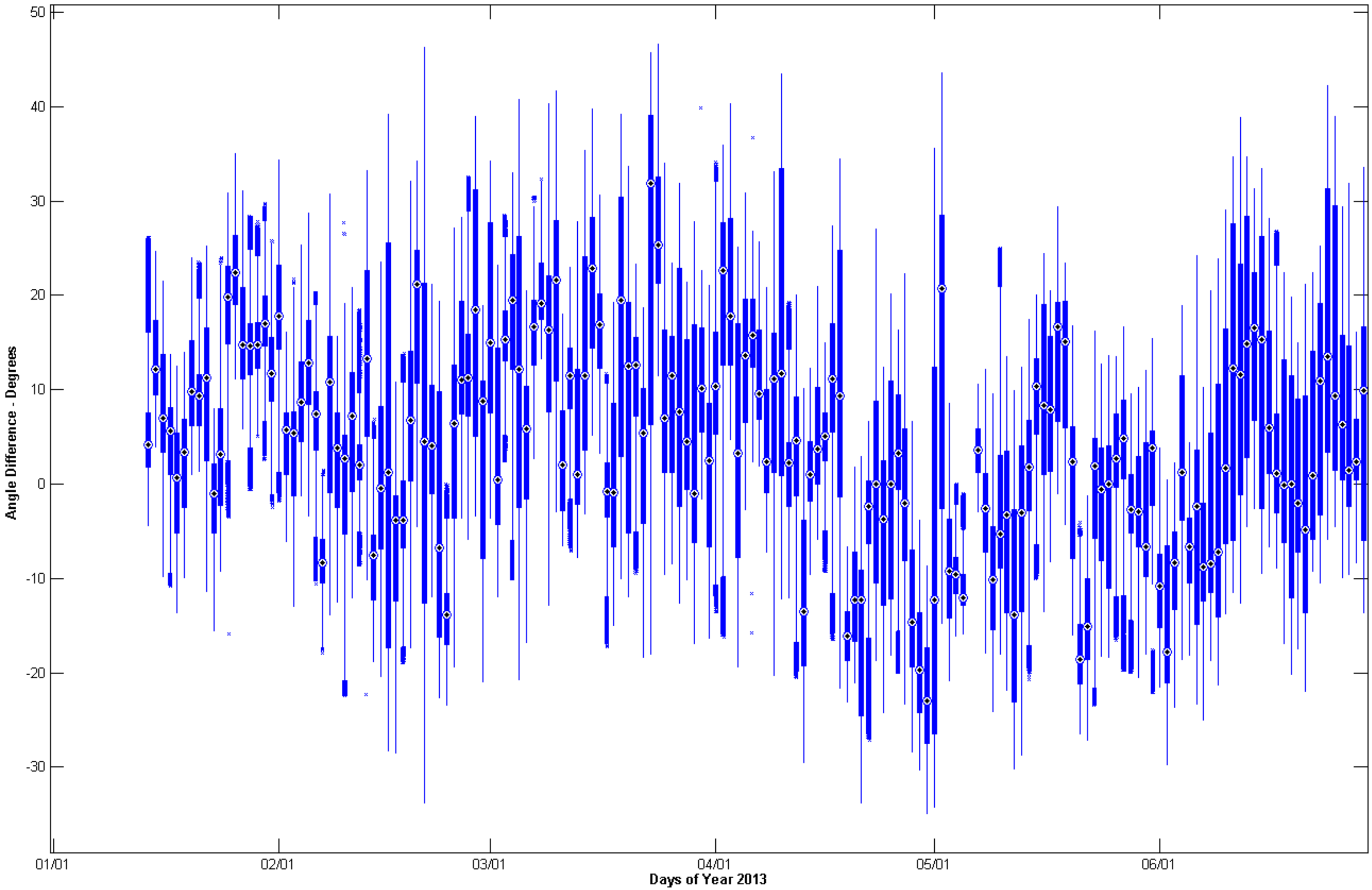
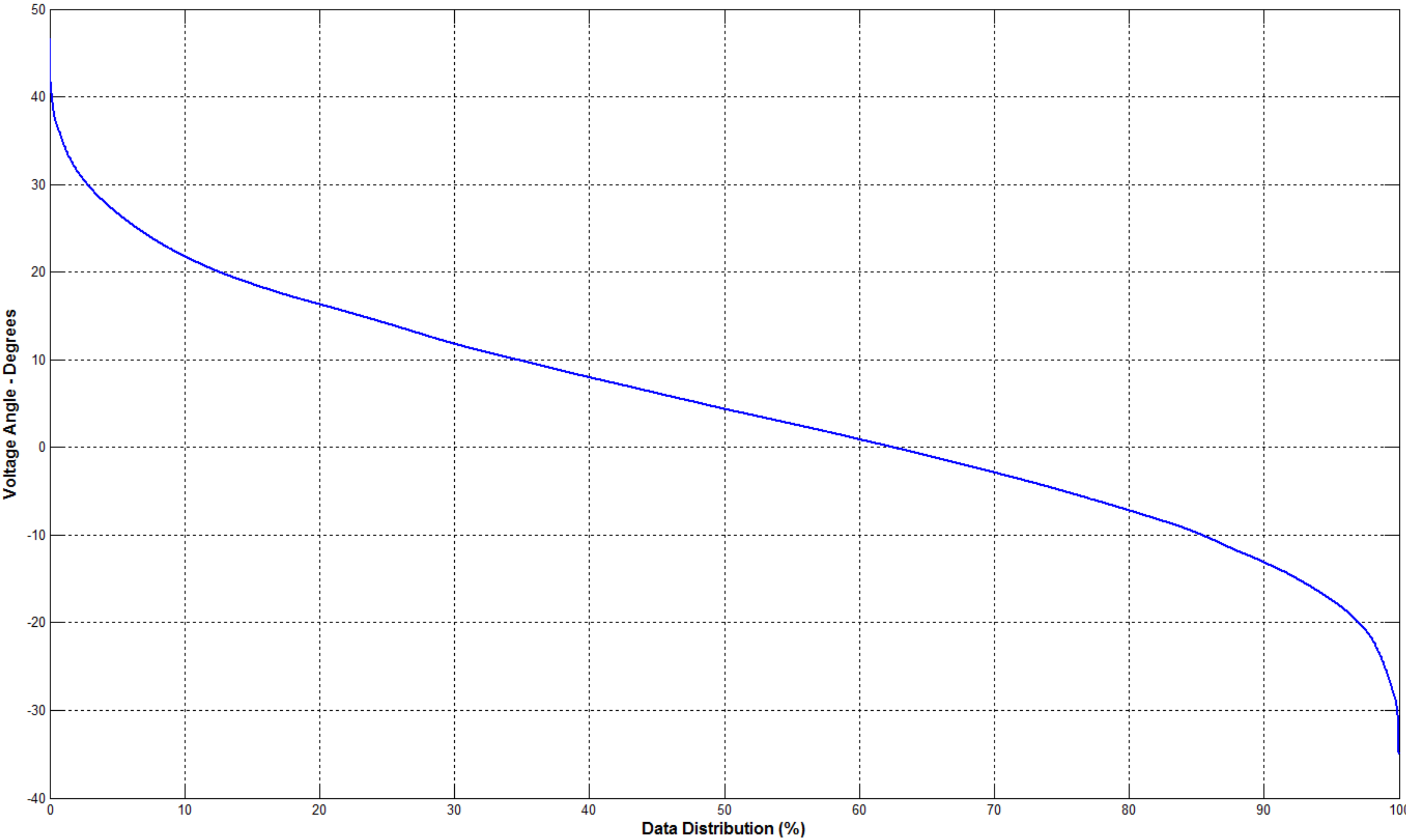


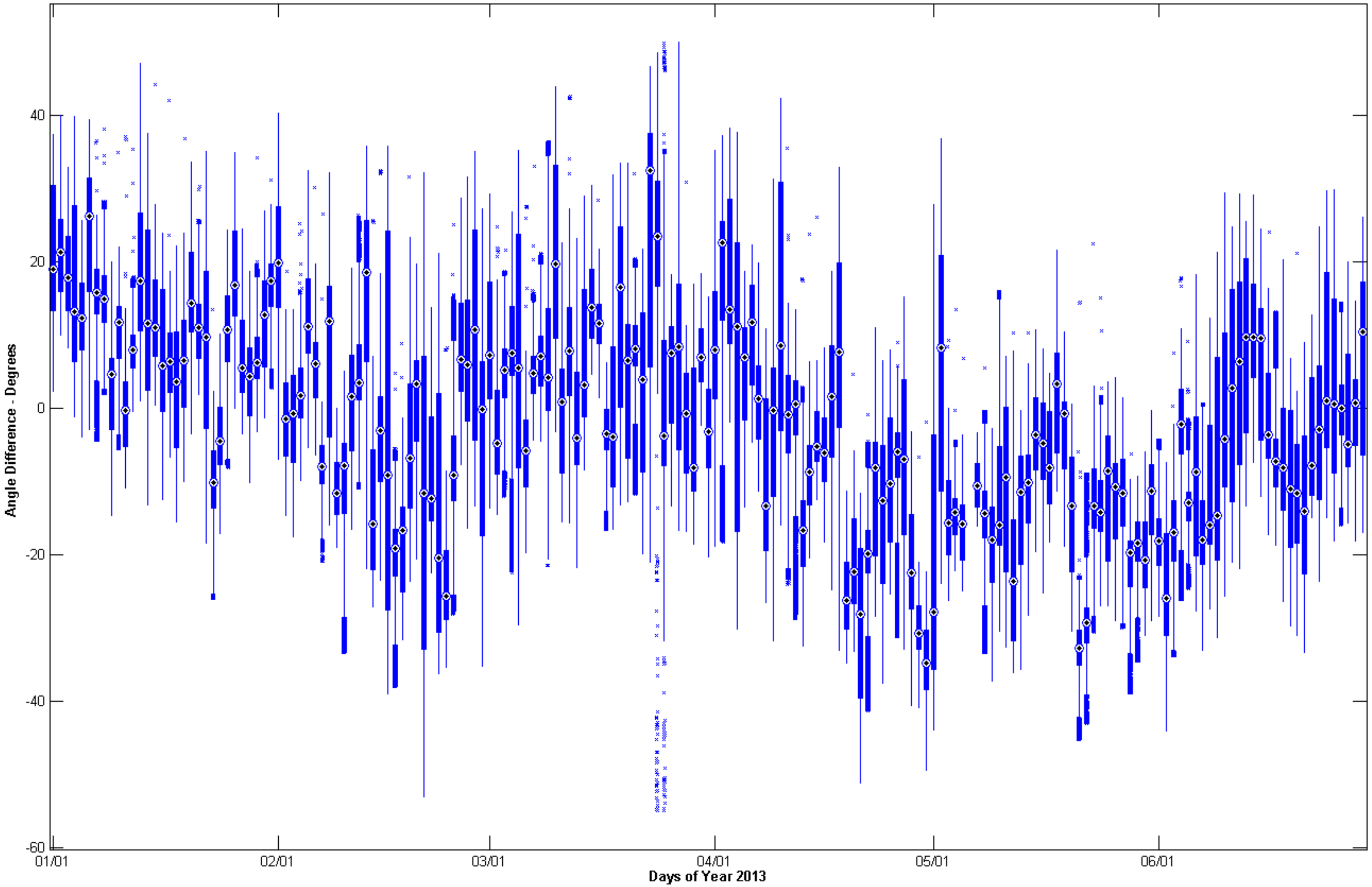
Coast 3 – Voltage Angle



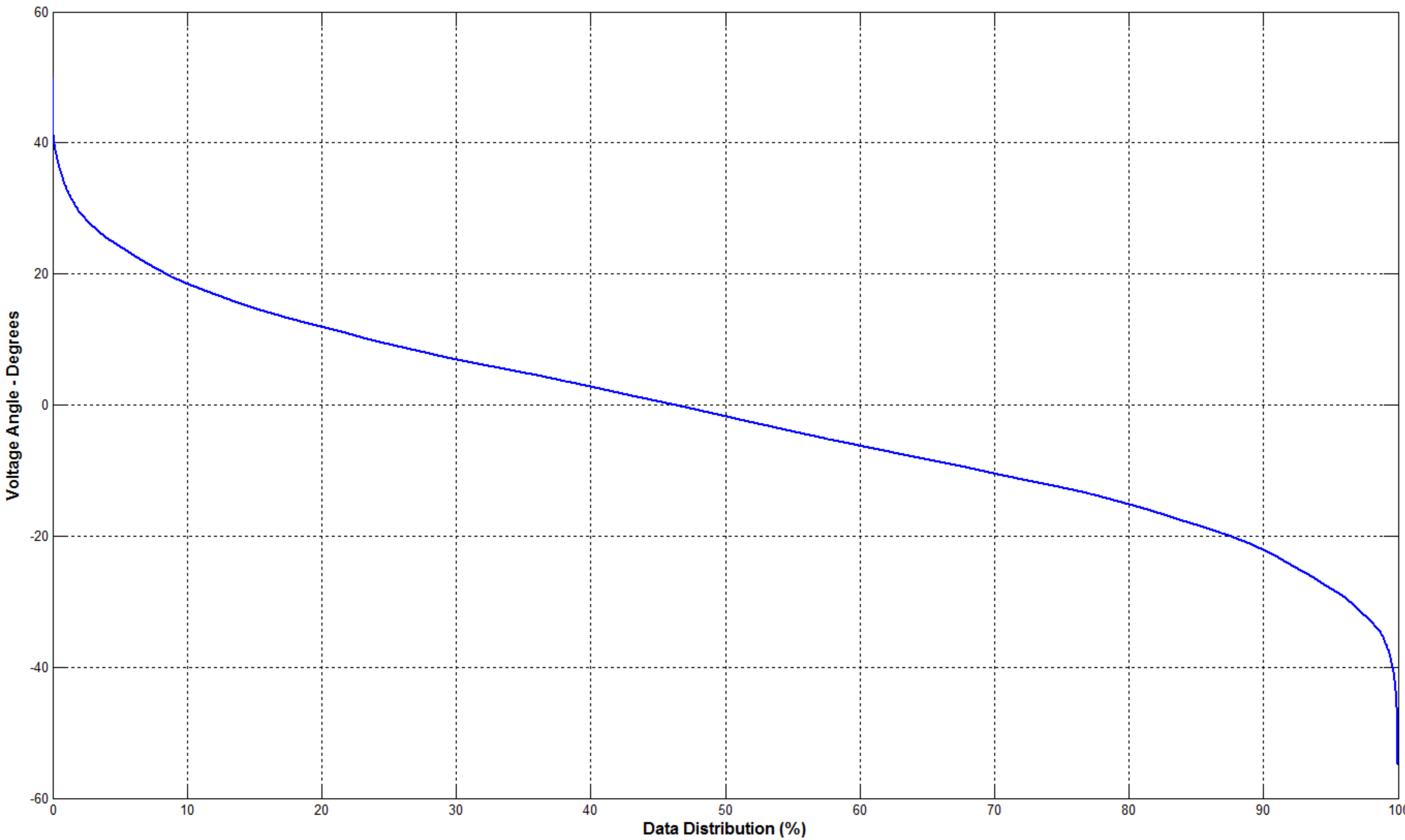
Coast 3 – Voltage Angle



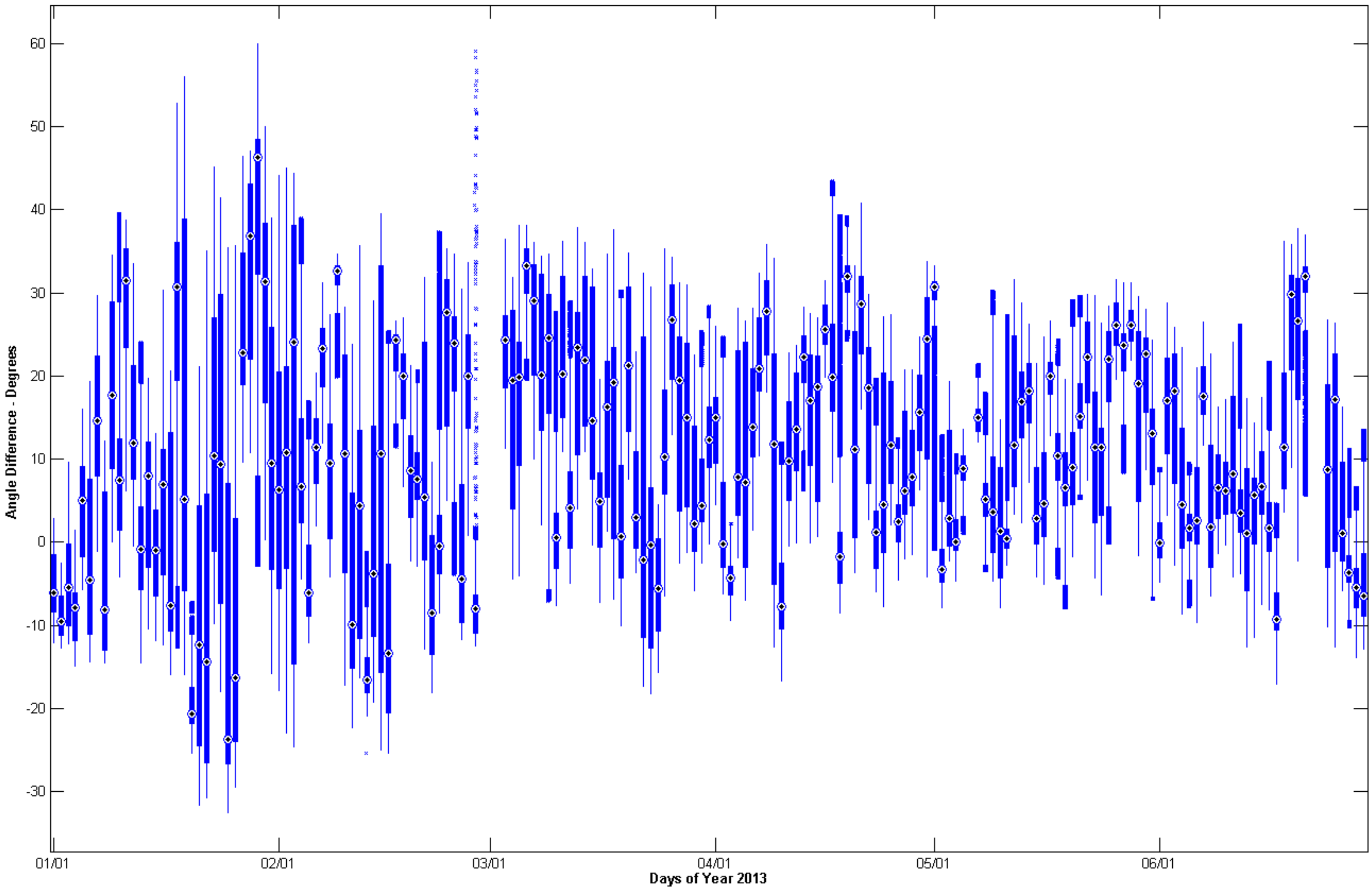
South 13 – Voltage Angle



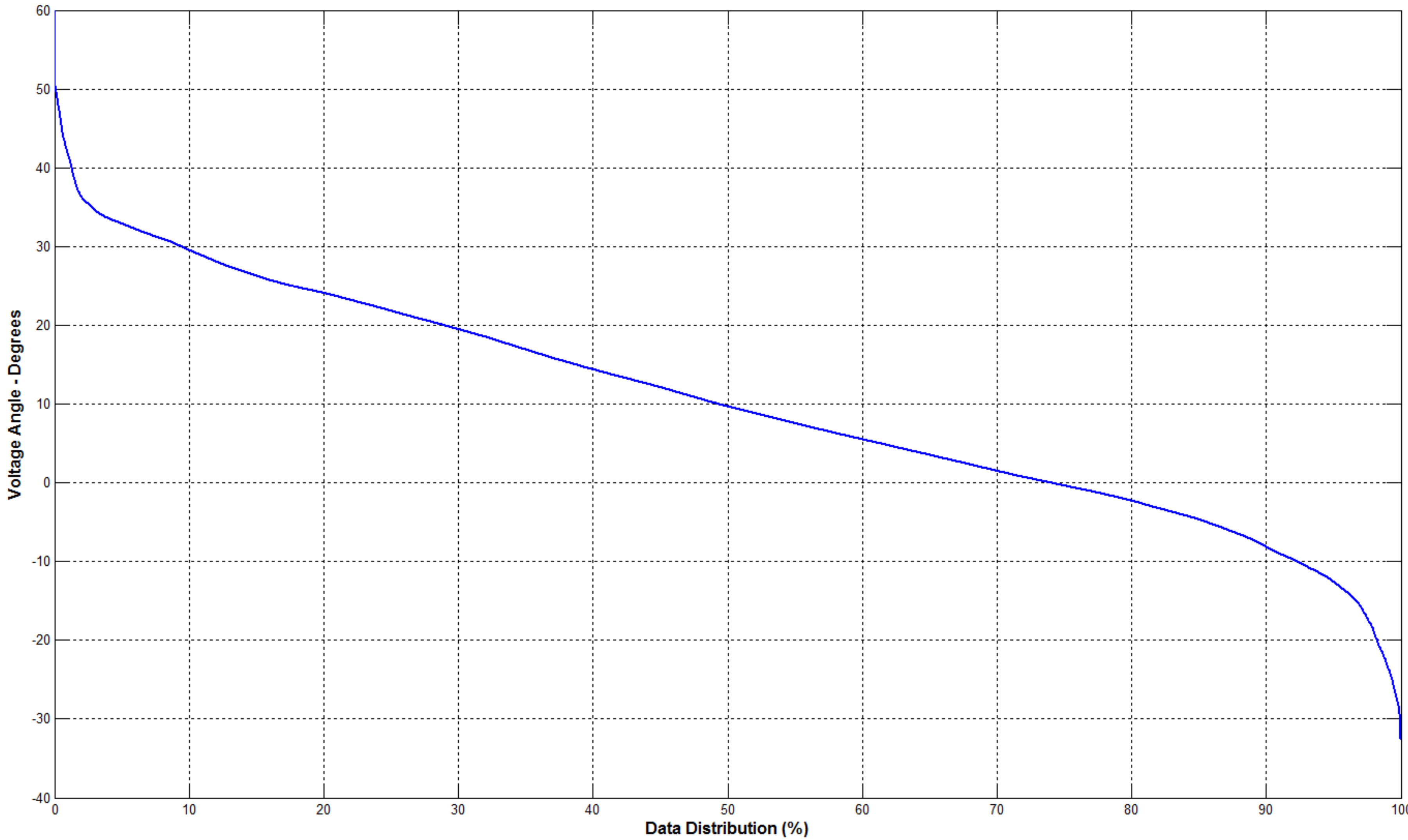
South 13 – Voltage Angle



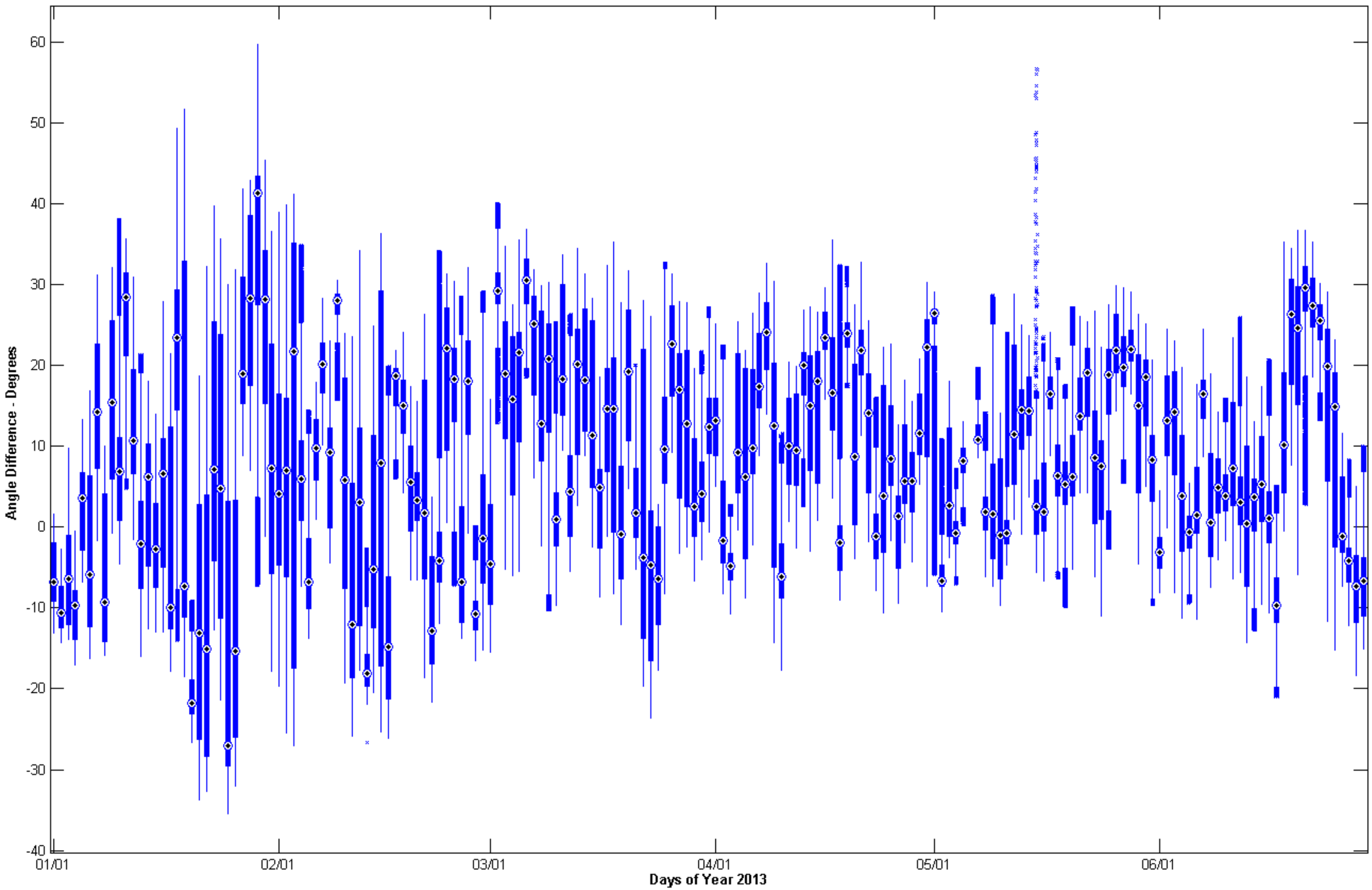
FarWest 4 – Voltage Angle



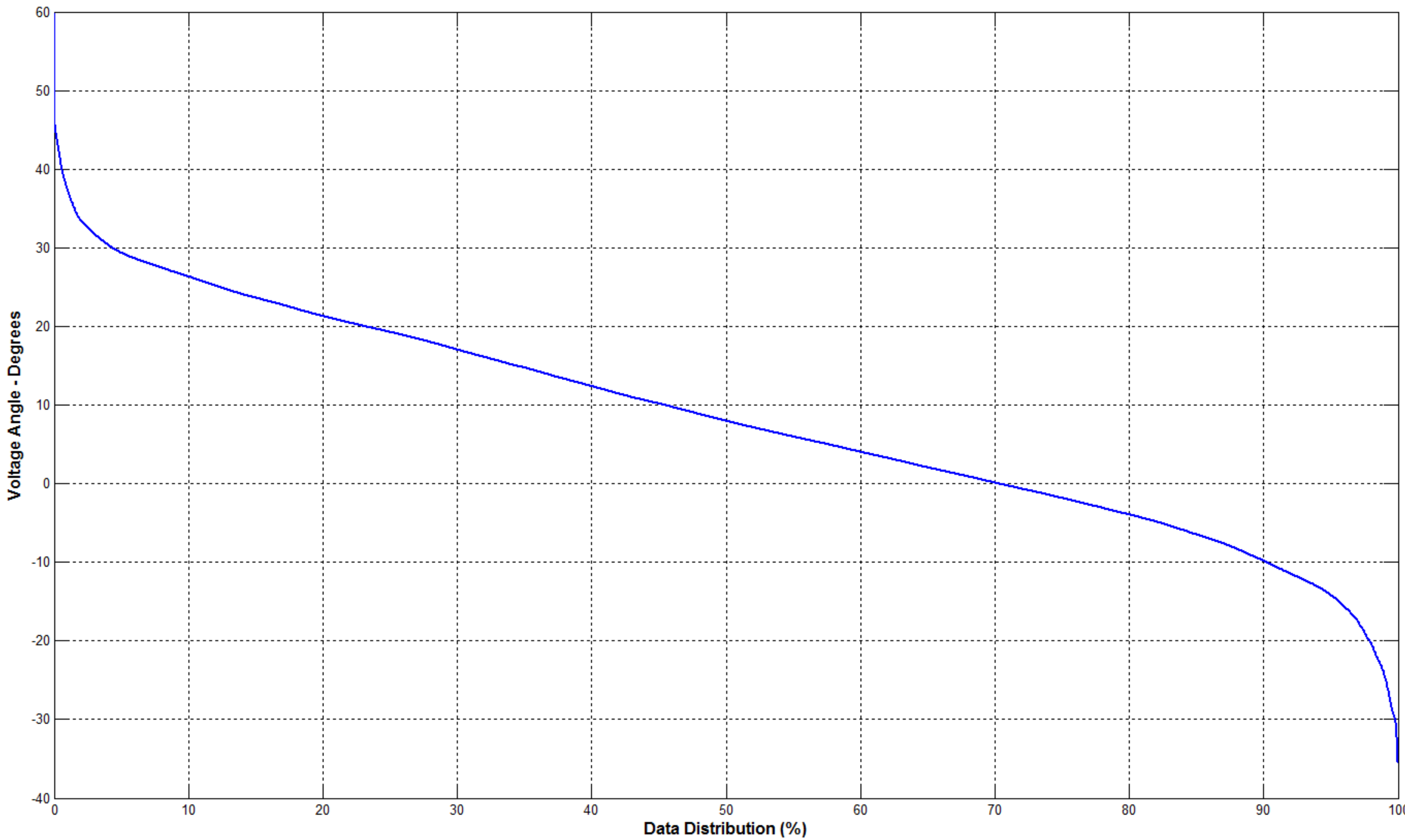
FarWest 4 – Voltage Angle



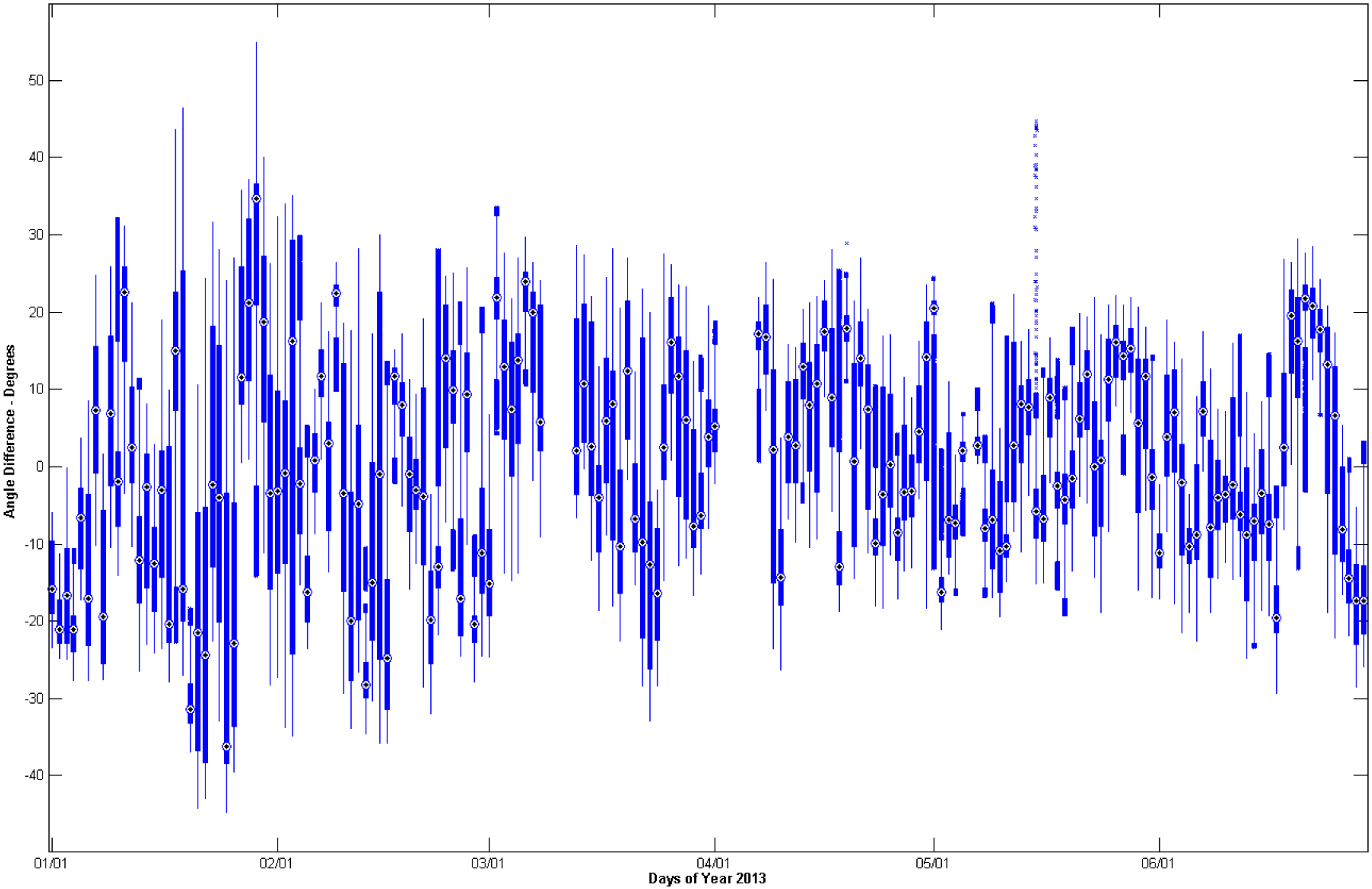
FarWest 7 – Voltage Angle



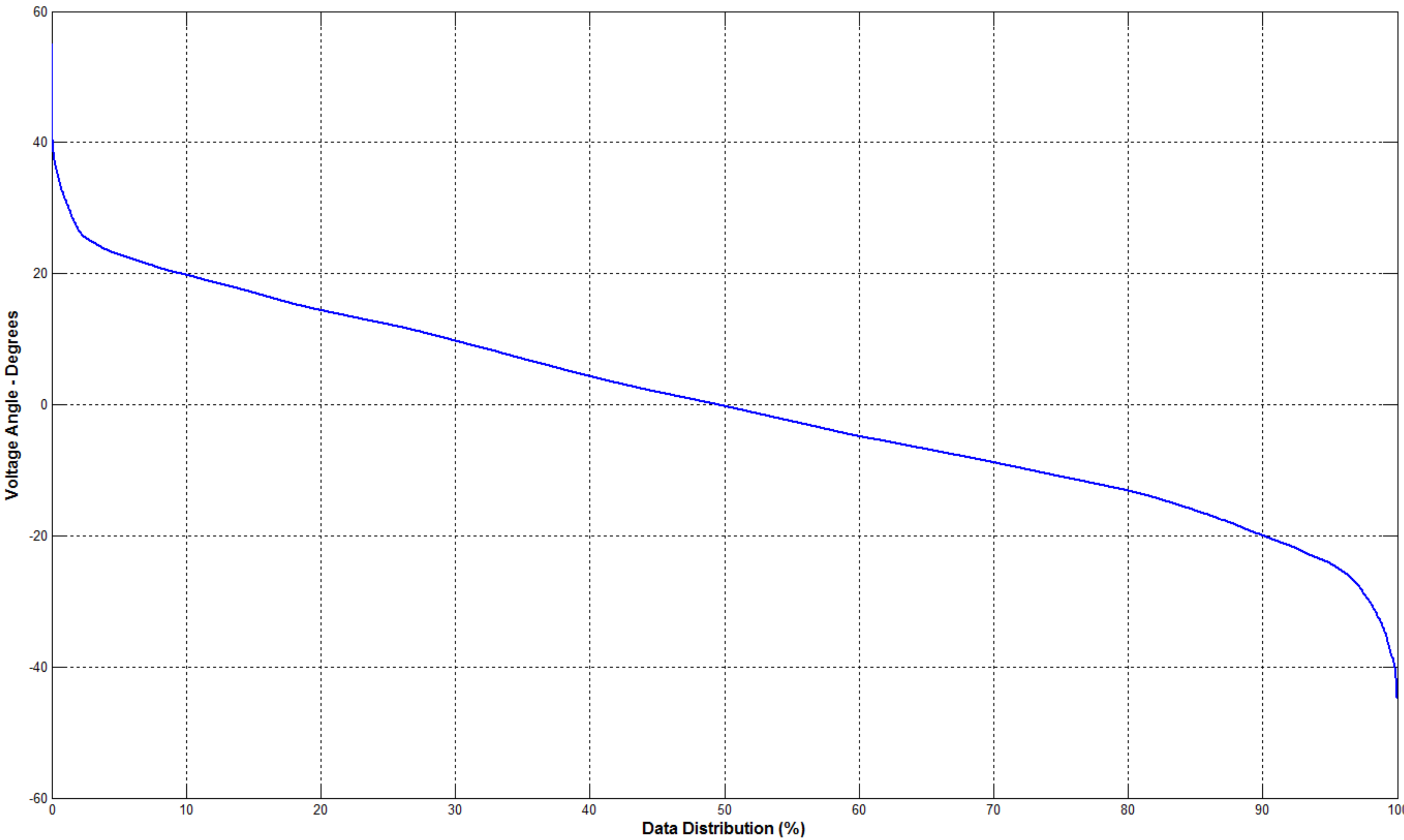
FarWest 7 – Voltage Angle



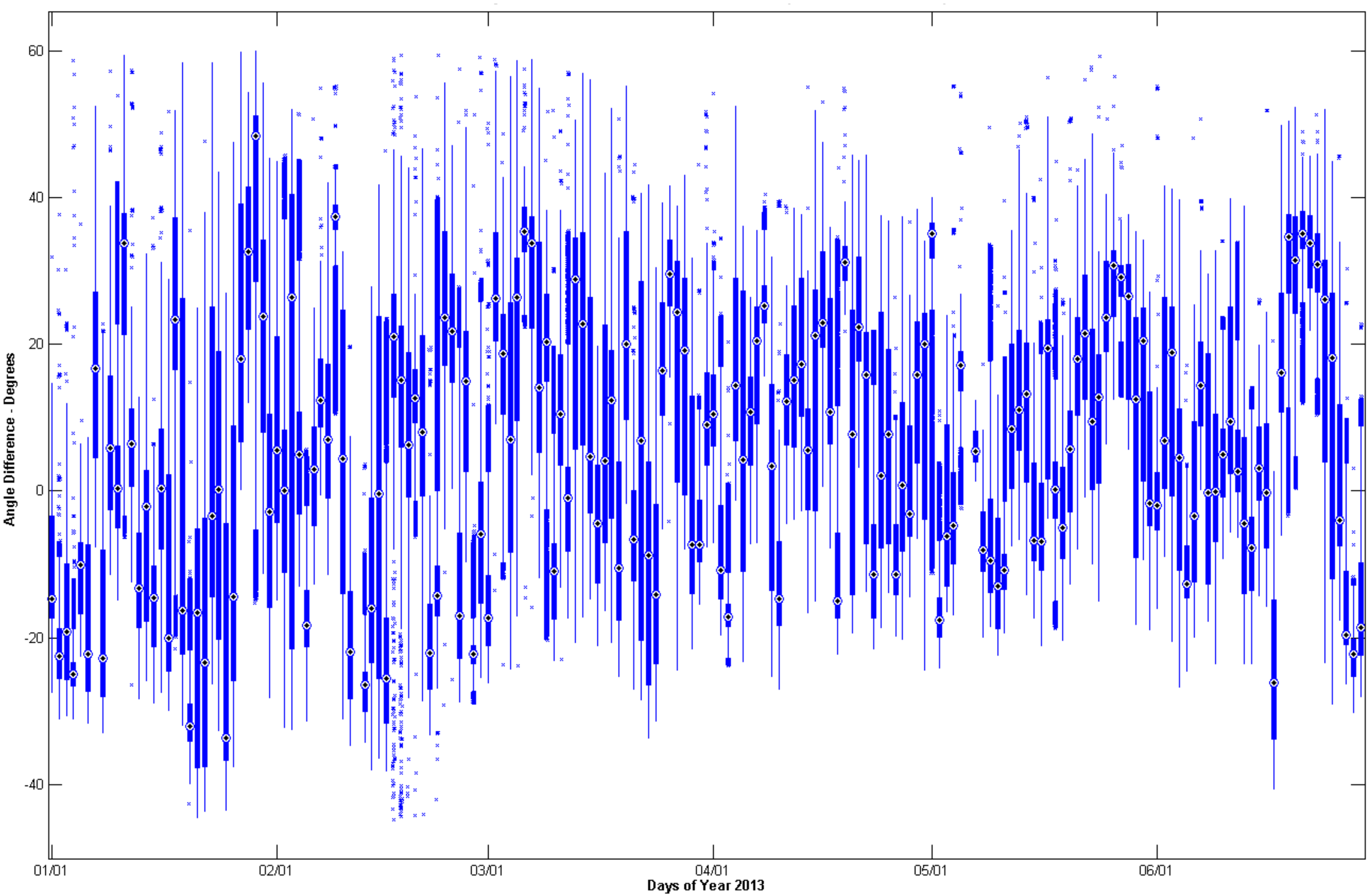
FarWest 8 – Voltage Angle



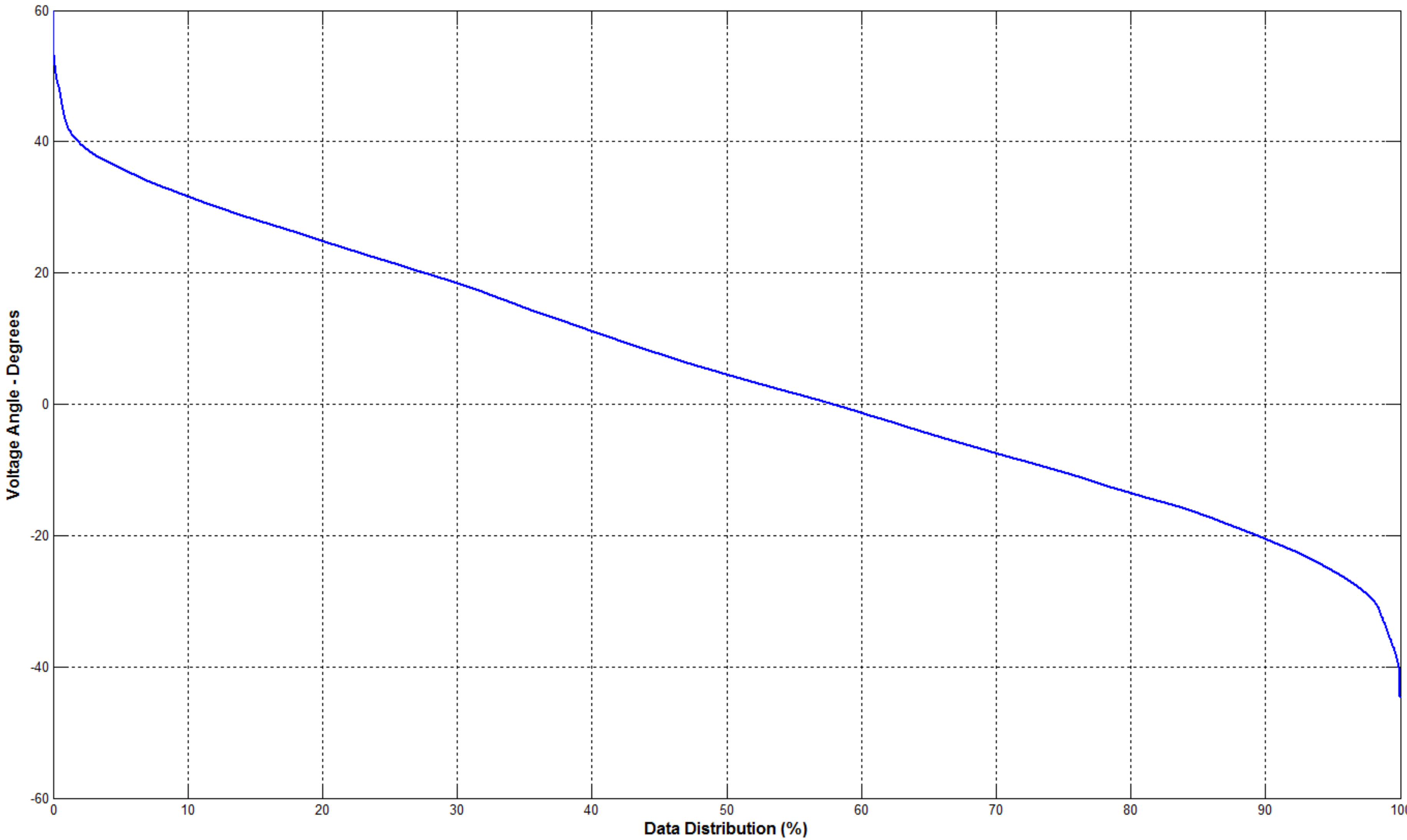
FarWest 8 – Voltage Angle



FarWest 9 – Voltage Angle



FarWest 9 – Voltage Angle



Appendix C
CCET Discovery Across Texas

Comparison of Median Values for Angle Difference Pairs – 2012 vs. 2013
(Reference: North 7)

Romulo Barreno - EPG
Ajay Das – EPG

External Version

Electric Power Group CCET ERCOT

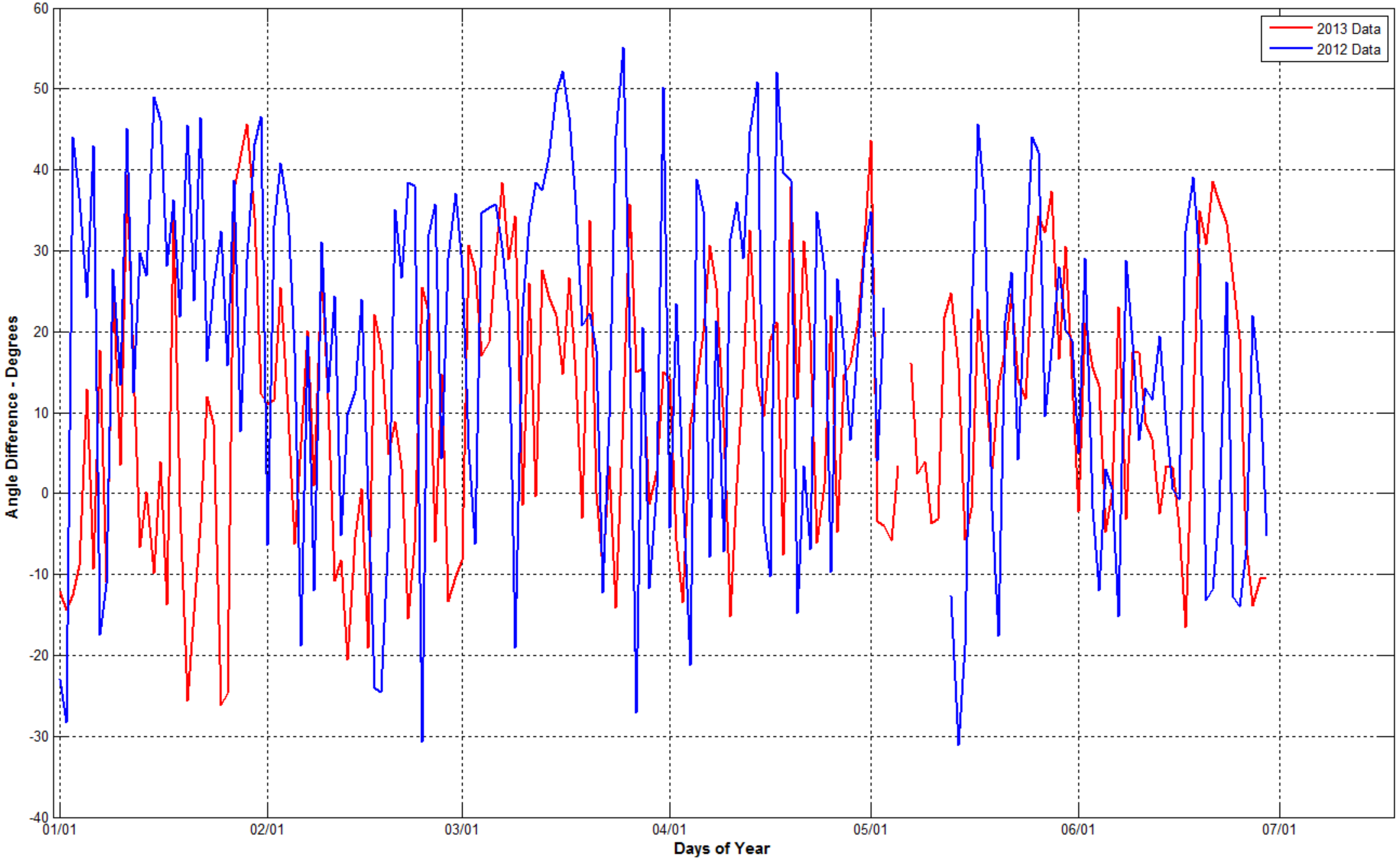
Overview

- Data plotted in the first graph are daily median values from January to June for 2012 and 2013.
- Box-whisker charts were prepared to identify the median for each angle pair selected for the first six months of 2012 and 2013.
- When data was not available for the entire six months period, the box-whisker charts were prepared using only the period(s) of time when data was available for BOTH years.
- Observation: in all the pairs analyzed, the median for 2013 was lower than that for 2012. This trend may be attributed to reduced system stress as a result of the addition of the CREZ lines to the ERCOT grid during the first six months of 2013.

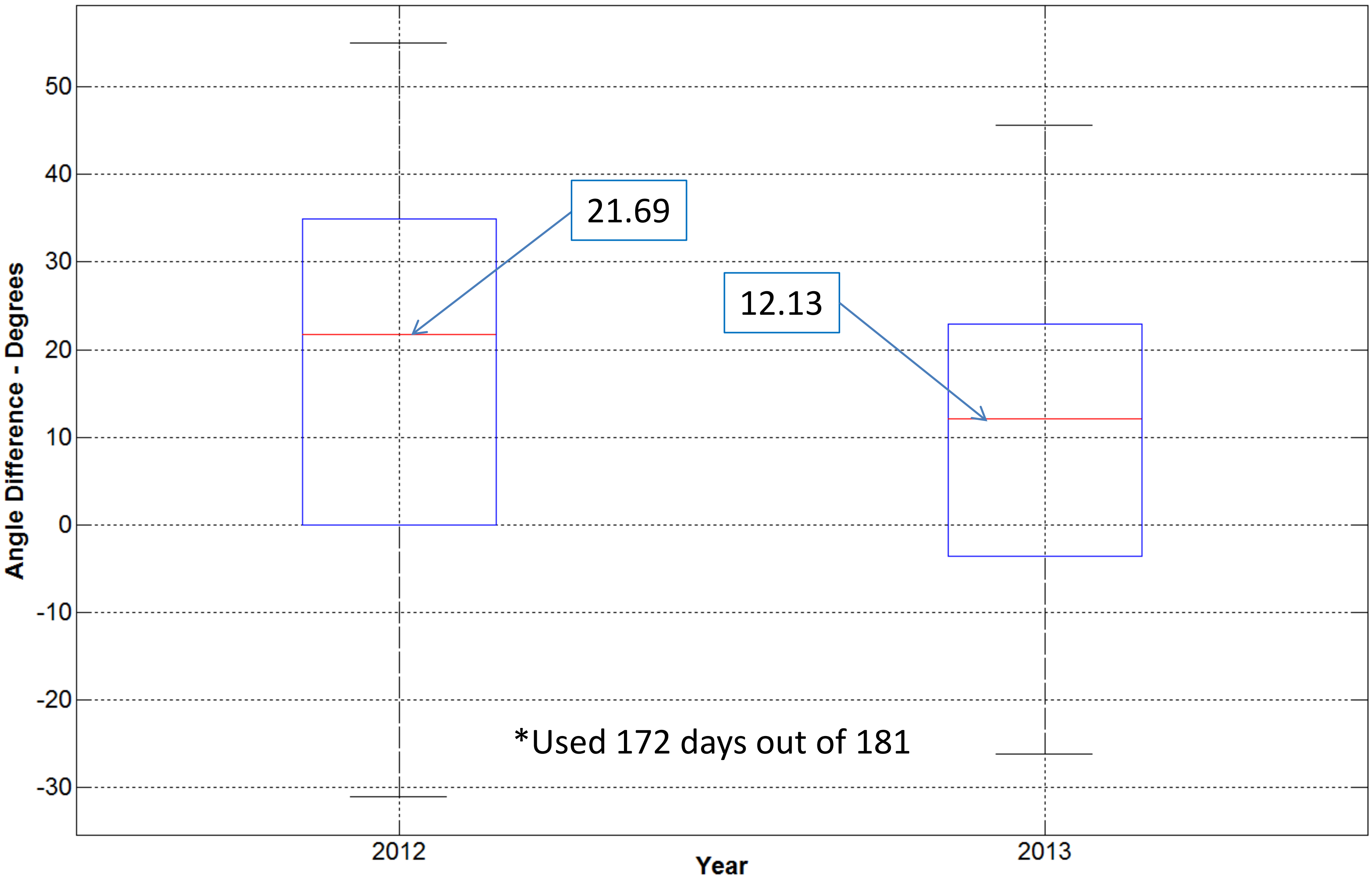
CREZ 345 kV LINES IN SERVICE THE FIRST SIX MONTHS 0F 2013 (Subject to Confirmation by ERCOT)

South 9	South 16	345	February 27, 2013
West 12	West 21	345	March 6, 2013
West 21	North 8	345	March 24, 2013
North 9	North 8	345	March 21, 2013
West 19	West 9	345	April 15, 2013
West 13	West 19	345	April 29, 2013
West 18	West 8	345	May 23, 2013
West 18	West 1	345	June 14, 2013
West 22	North 11	345	June 30, 2013
West 14	North 10	345	June 30, 2013

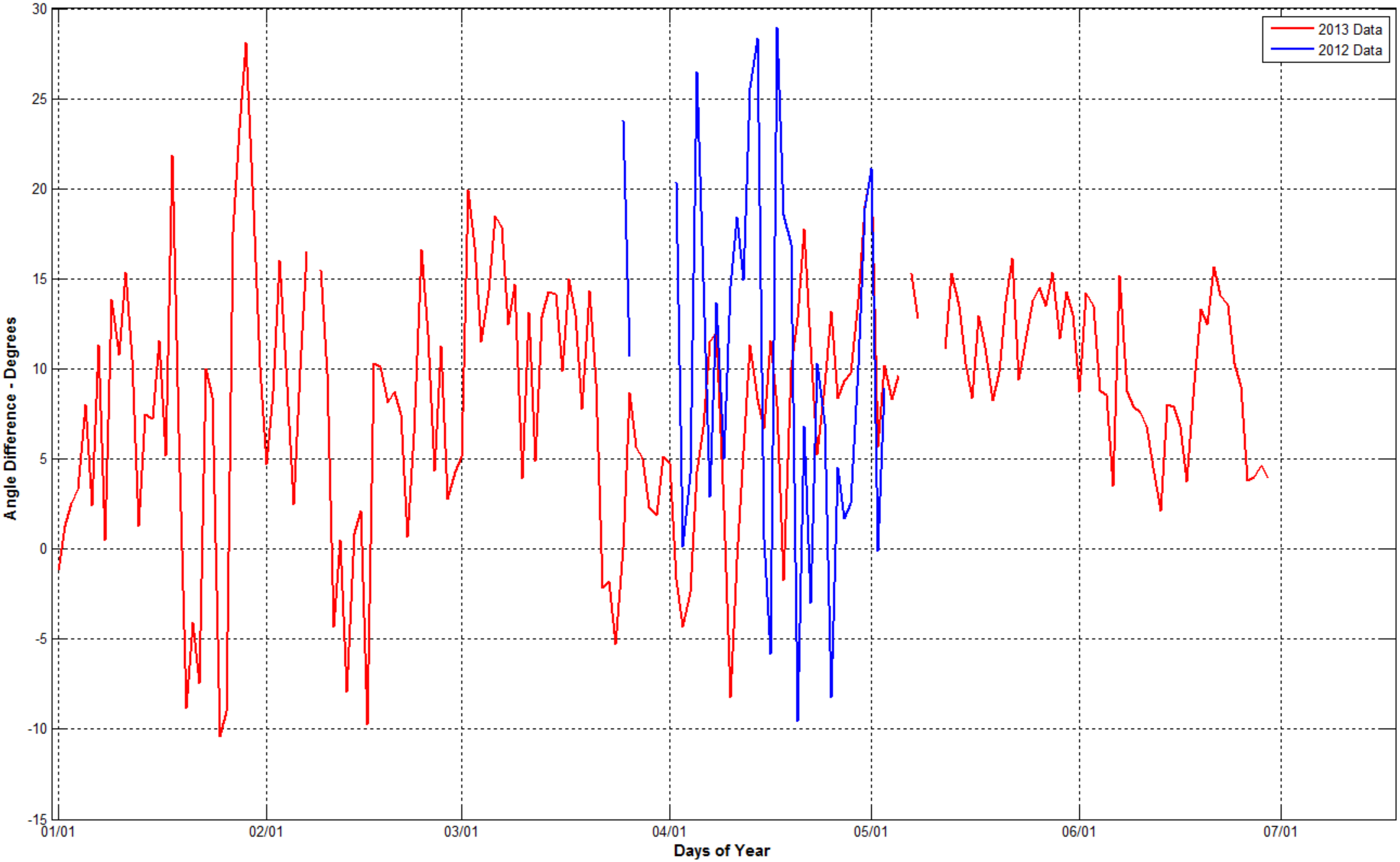
West 10 – North 7



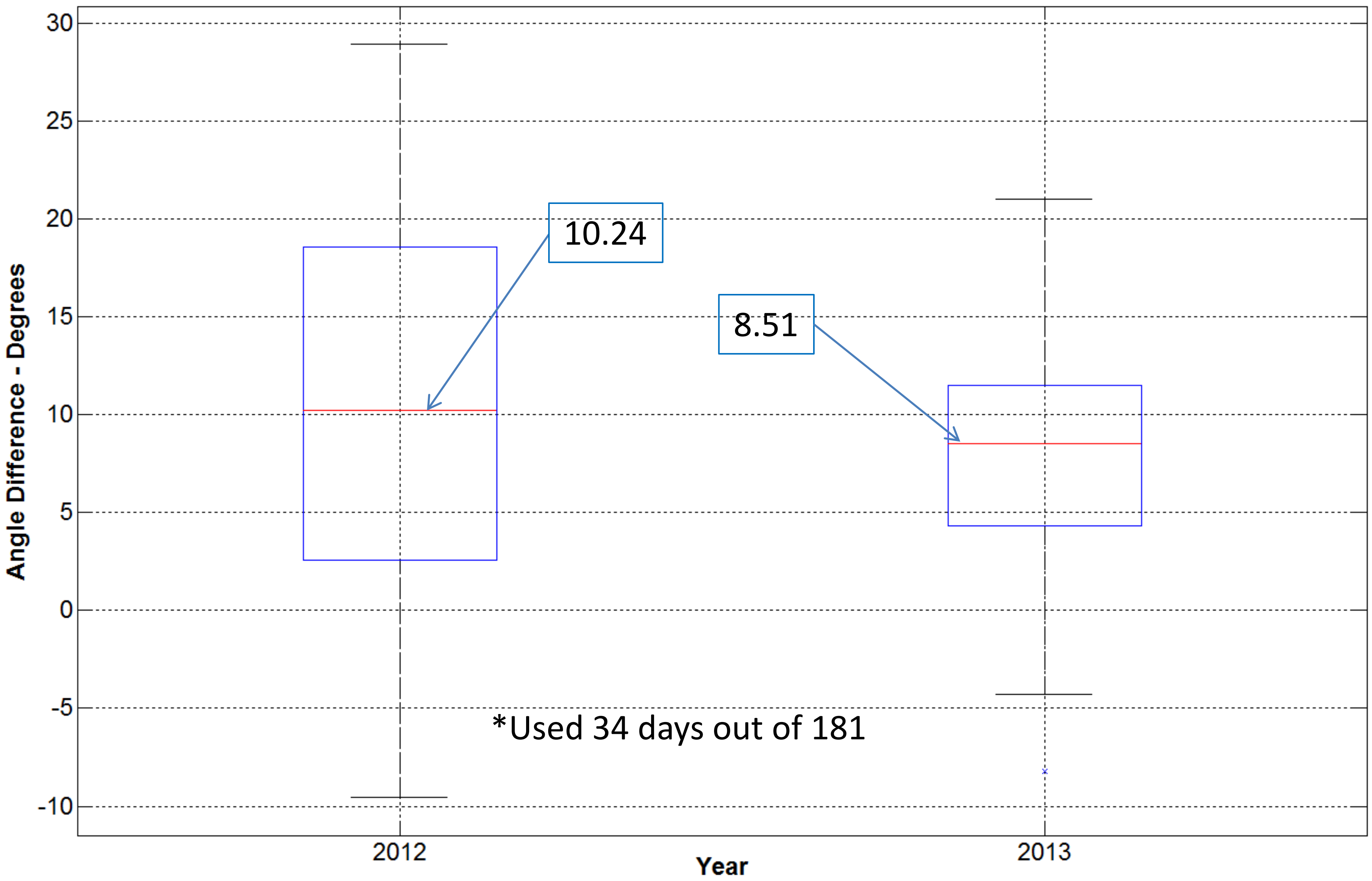
West 10 – North 7



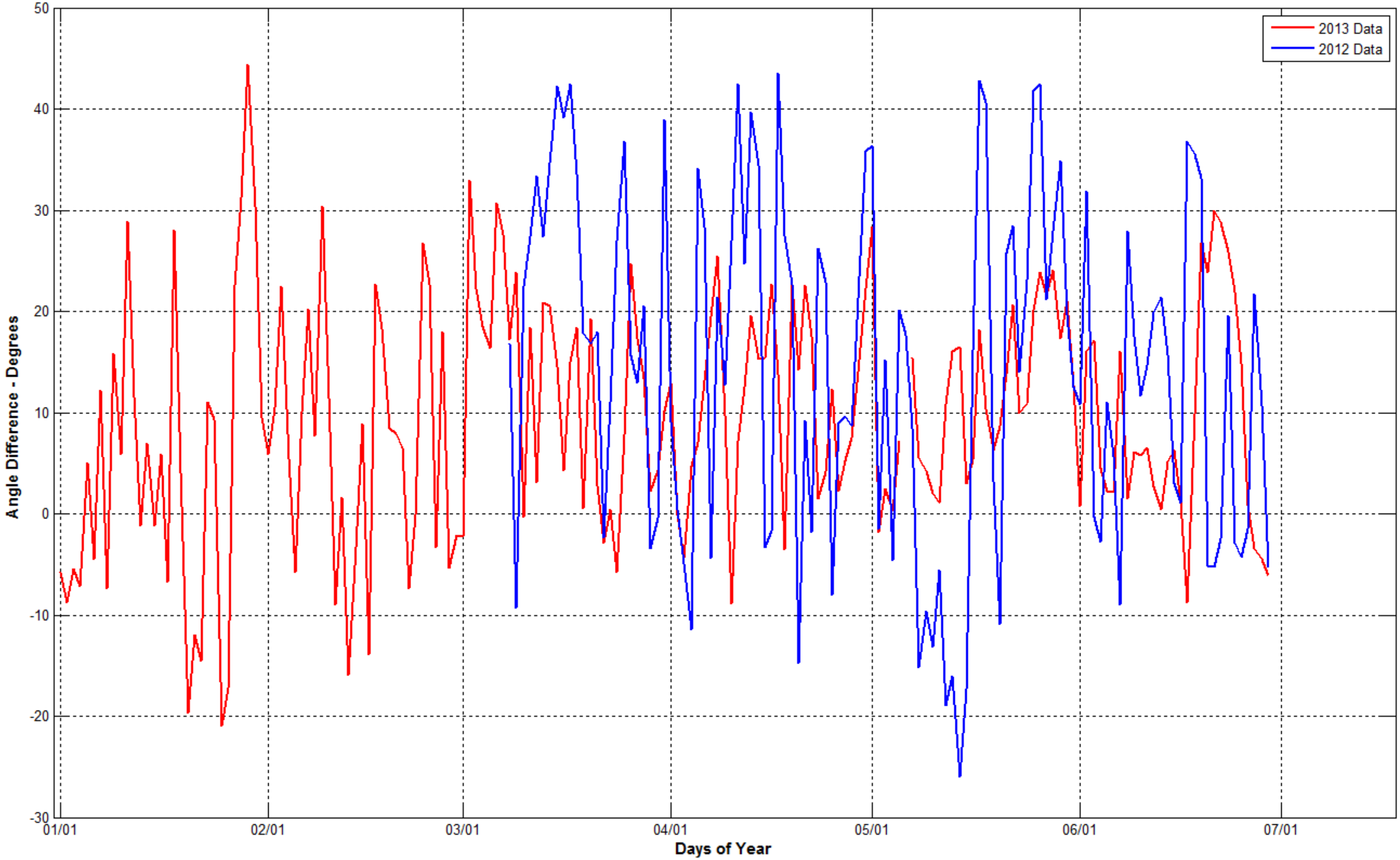
West 14– North 7



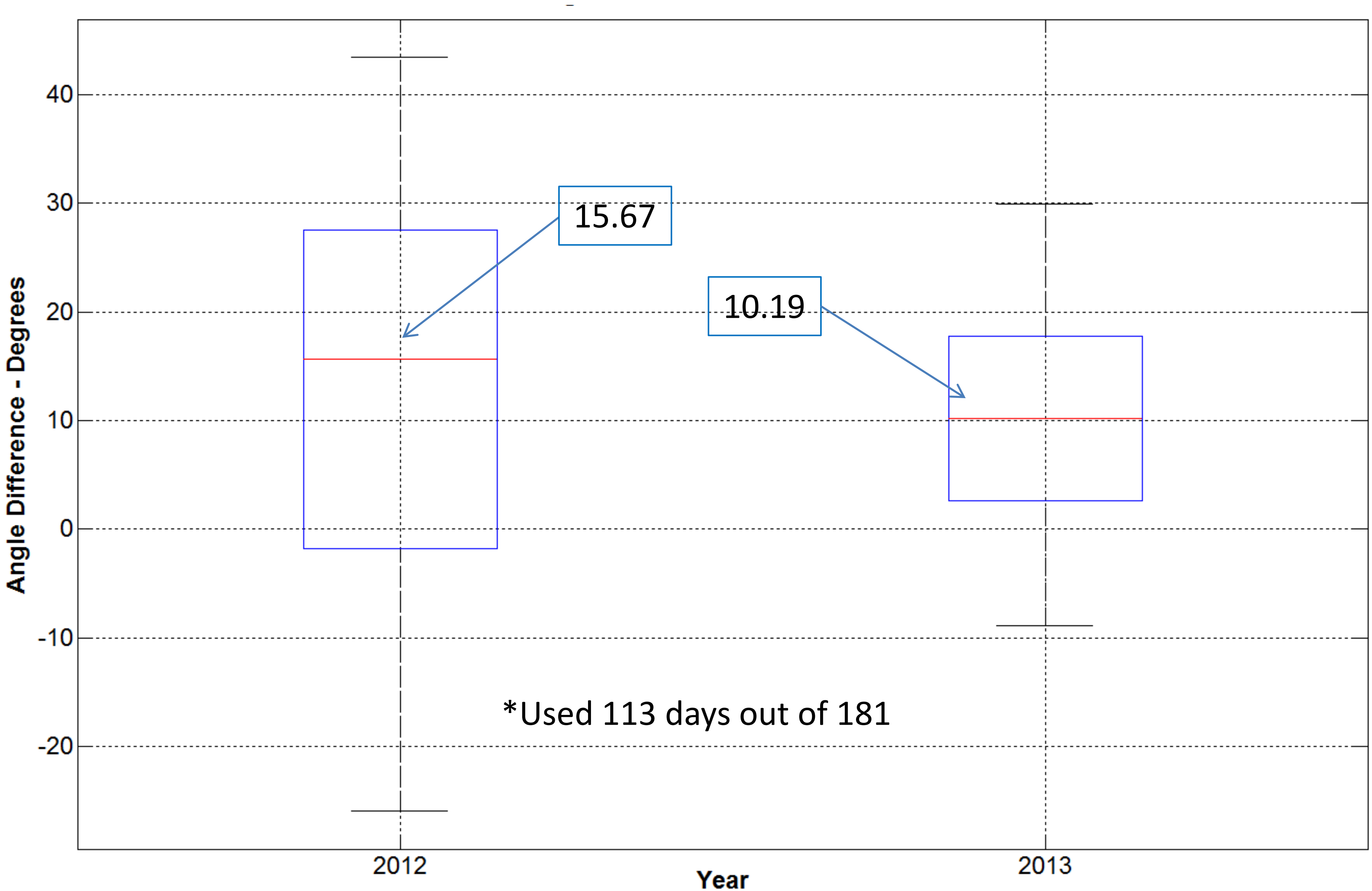
West 14 – North 7 *



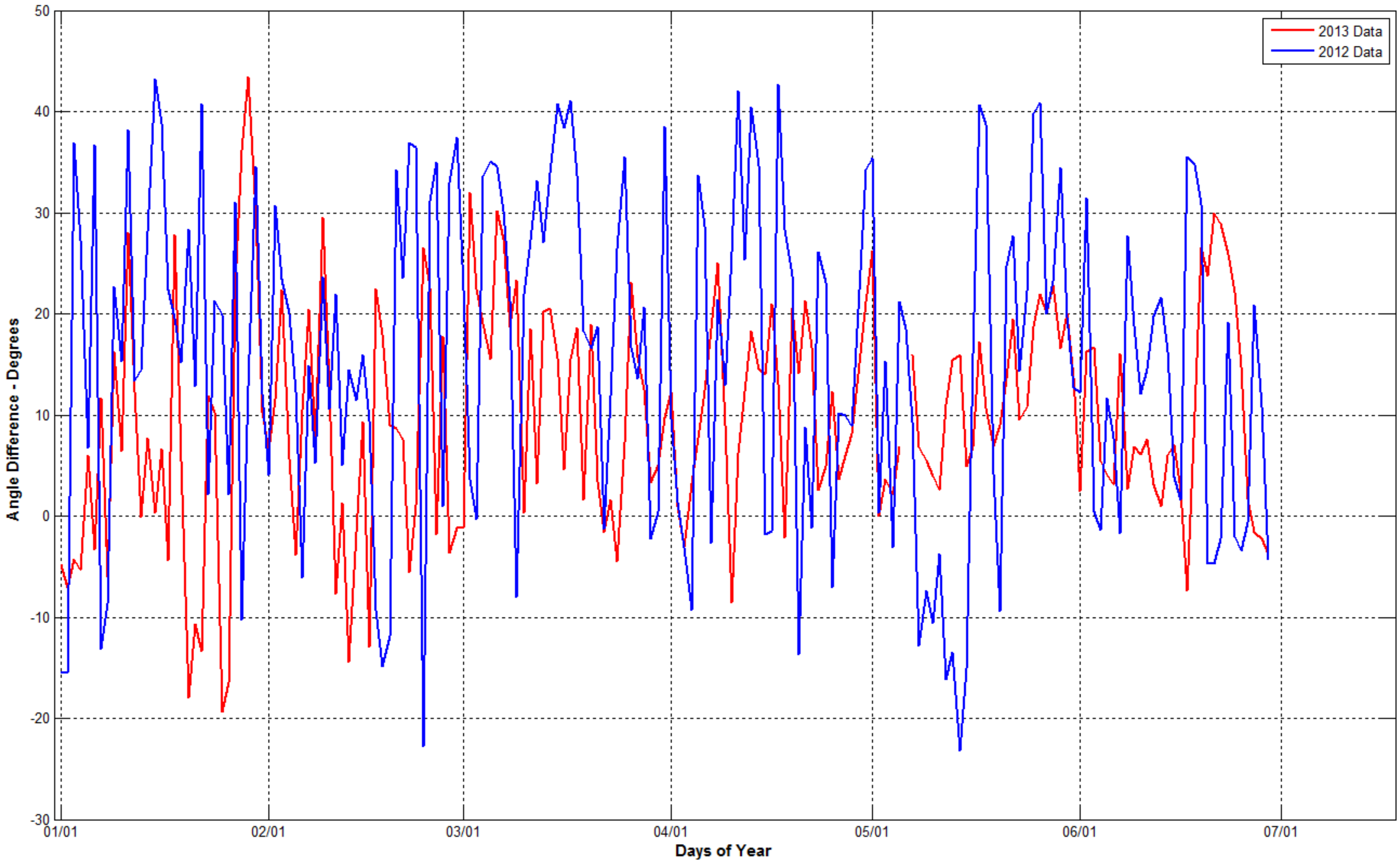
West 11– North 7



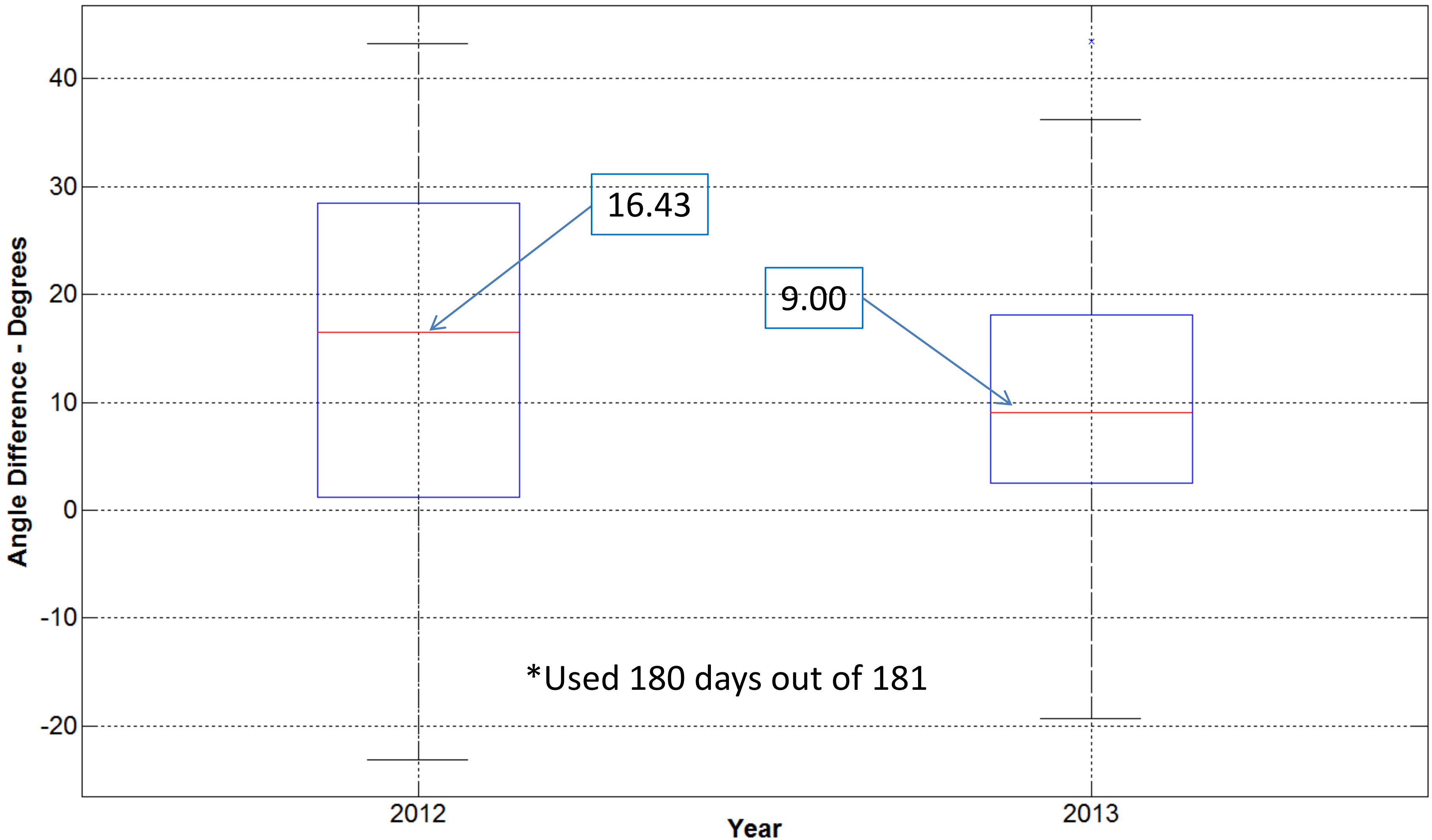
West 11– North 7 *



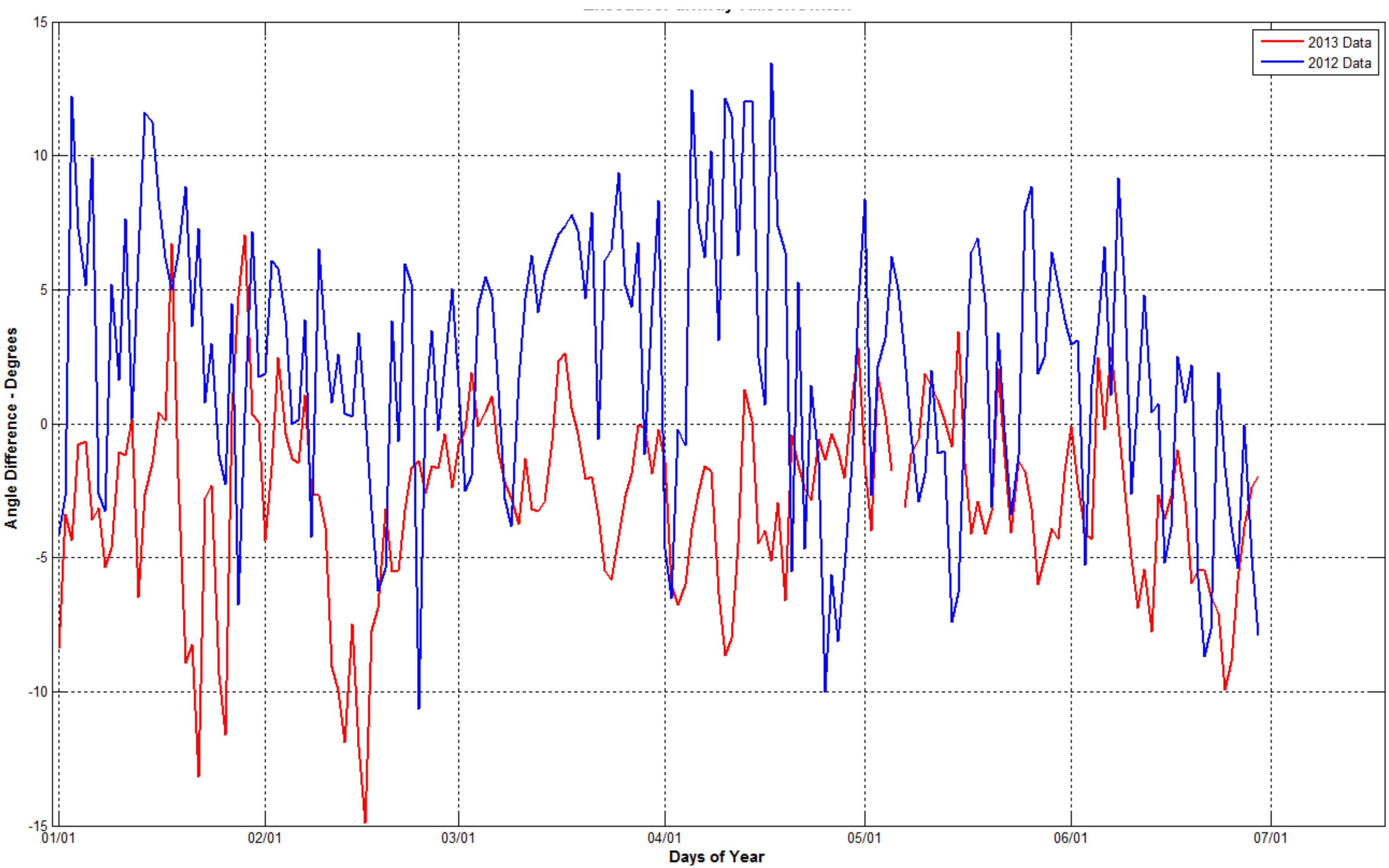
West 6 – North 7



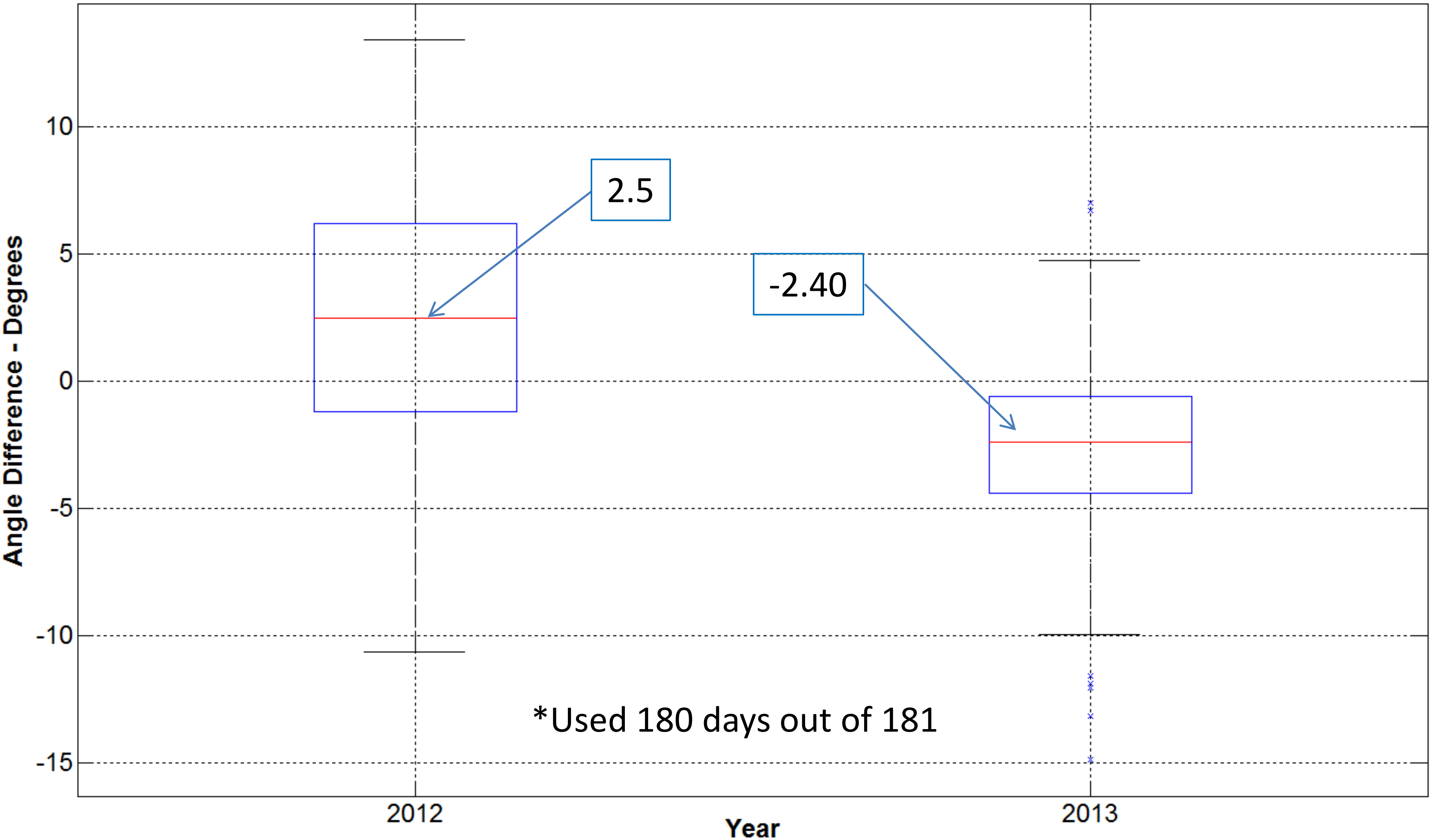
West 6 – North 7 *



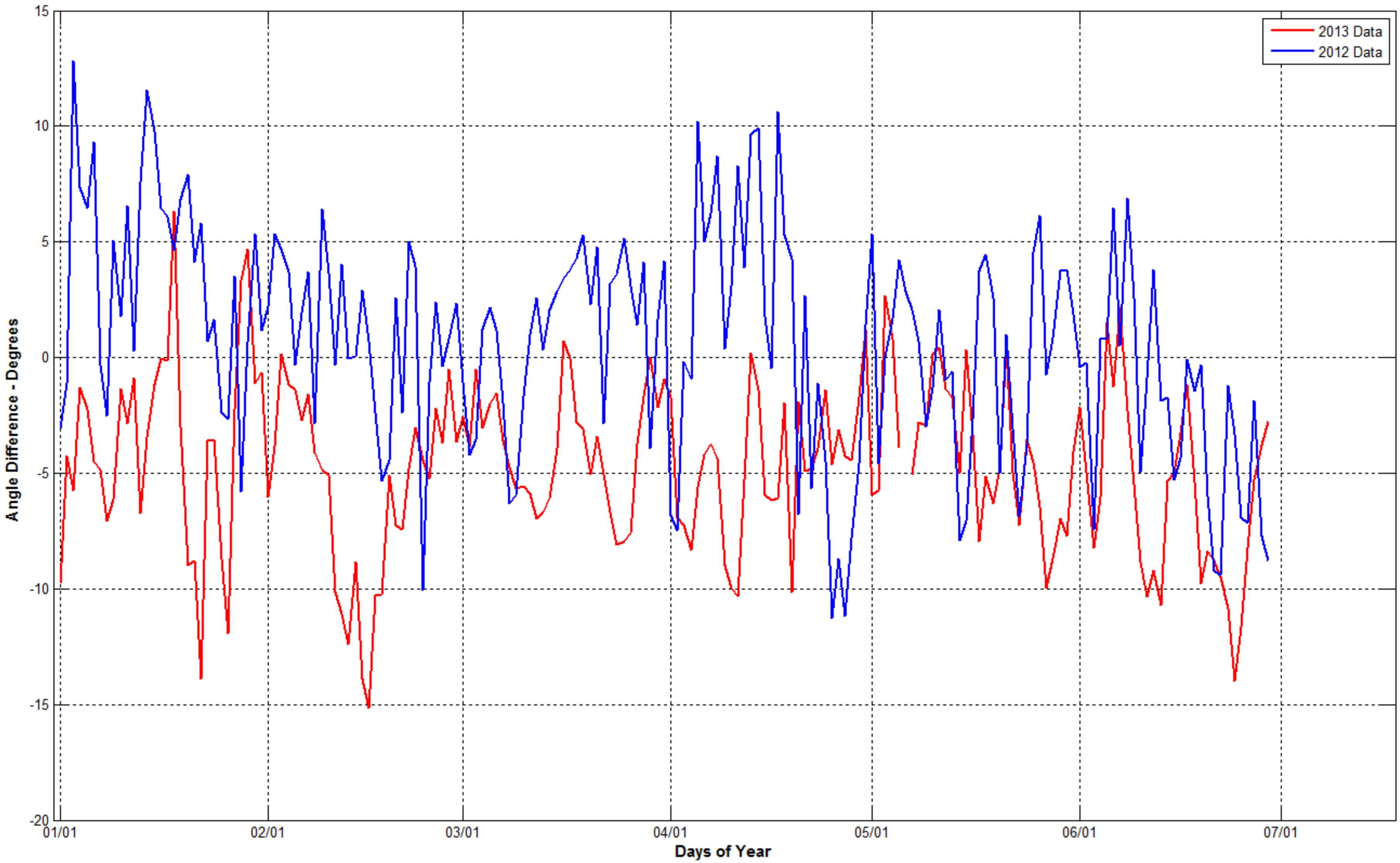
North 4 – North 7



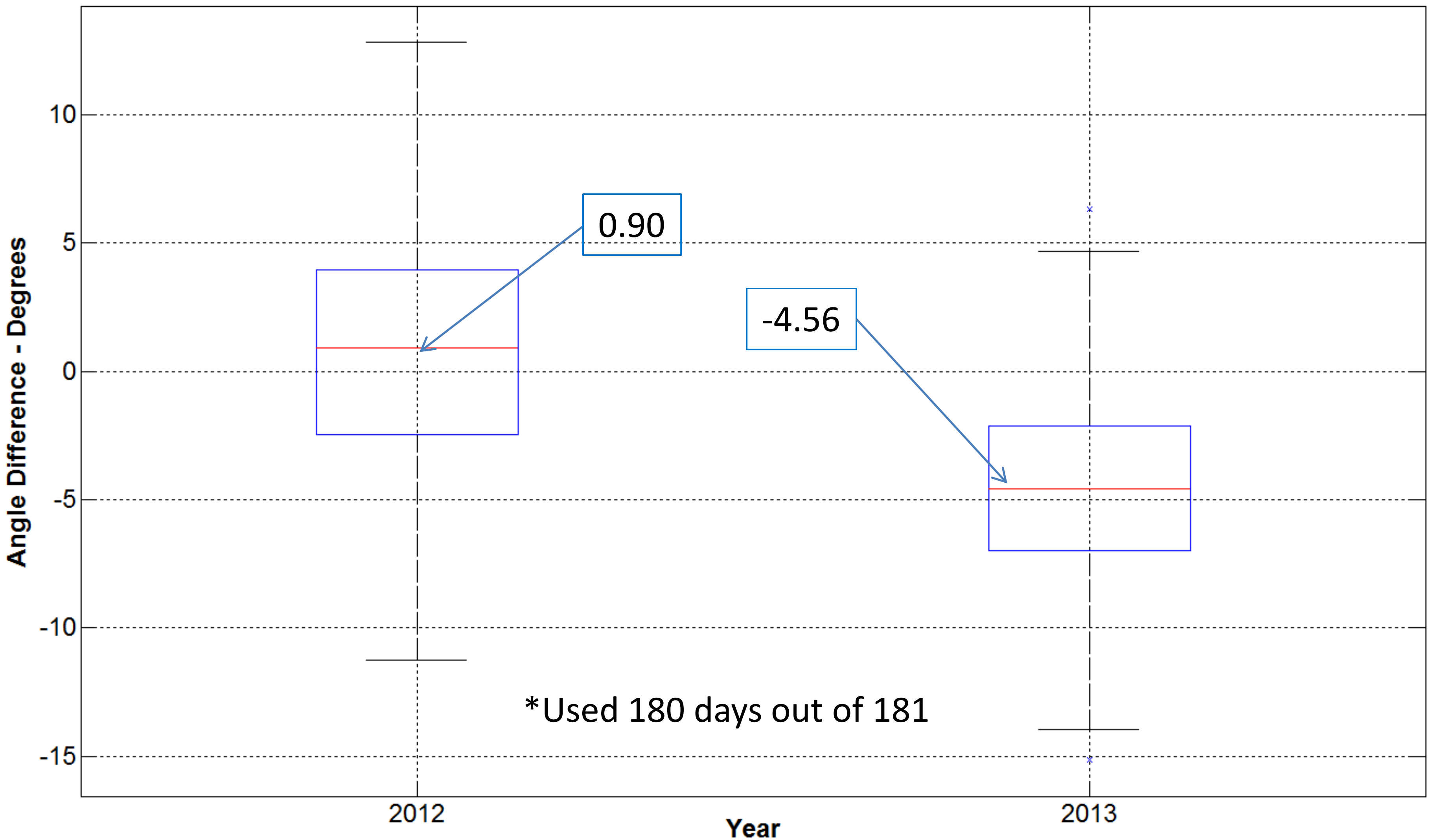
North 4 – North 7 *



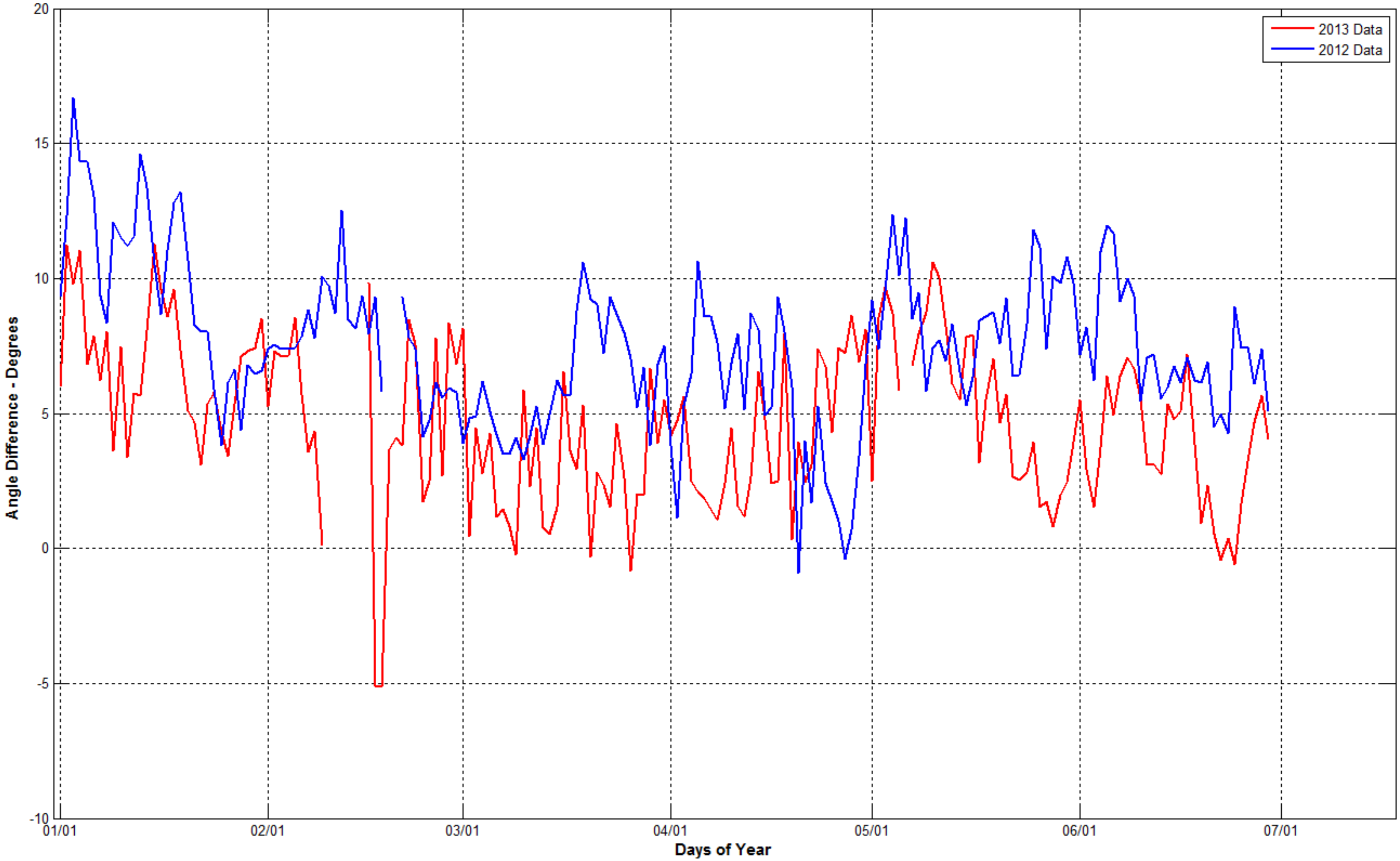
North 5 – North 7



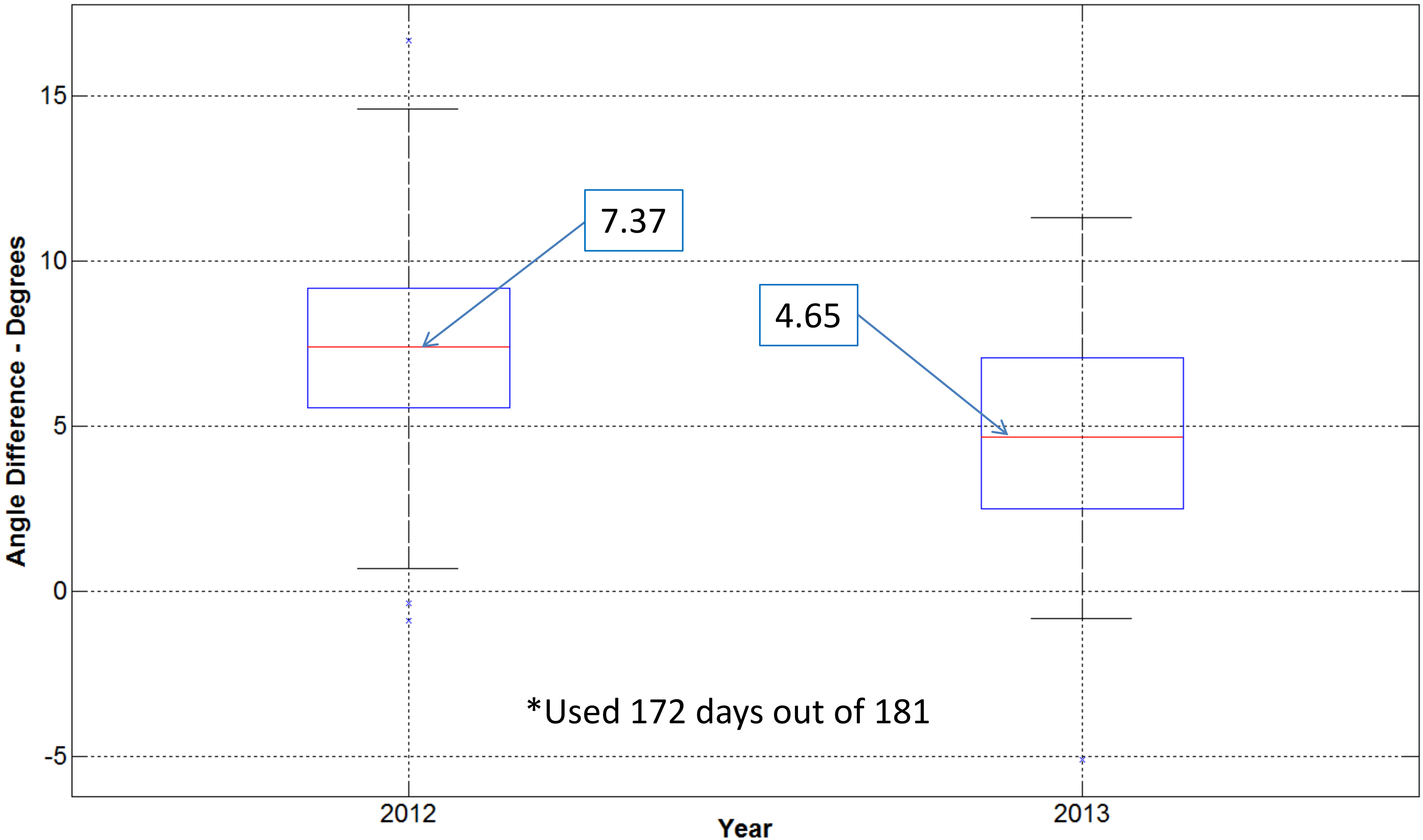
North 5 – North 7 *



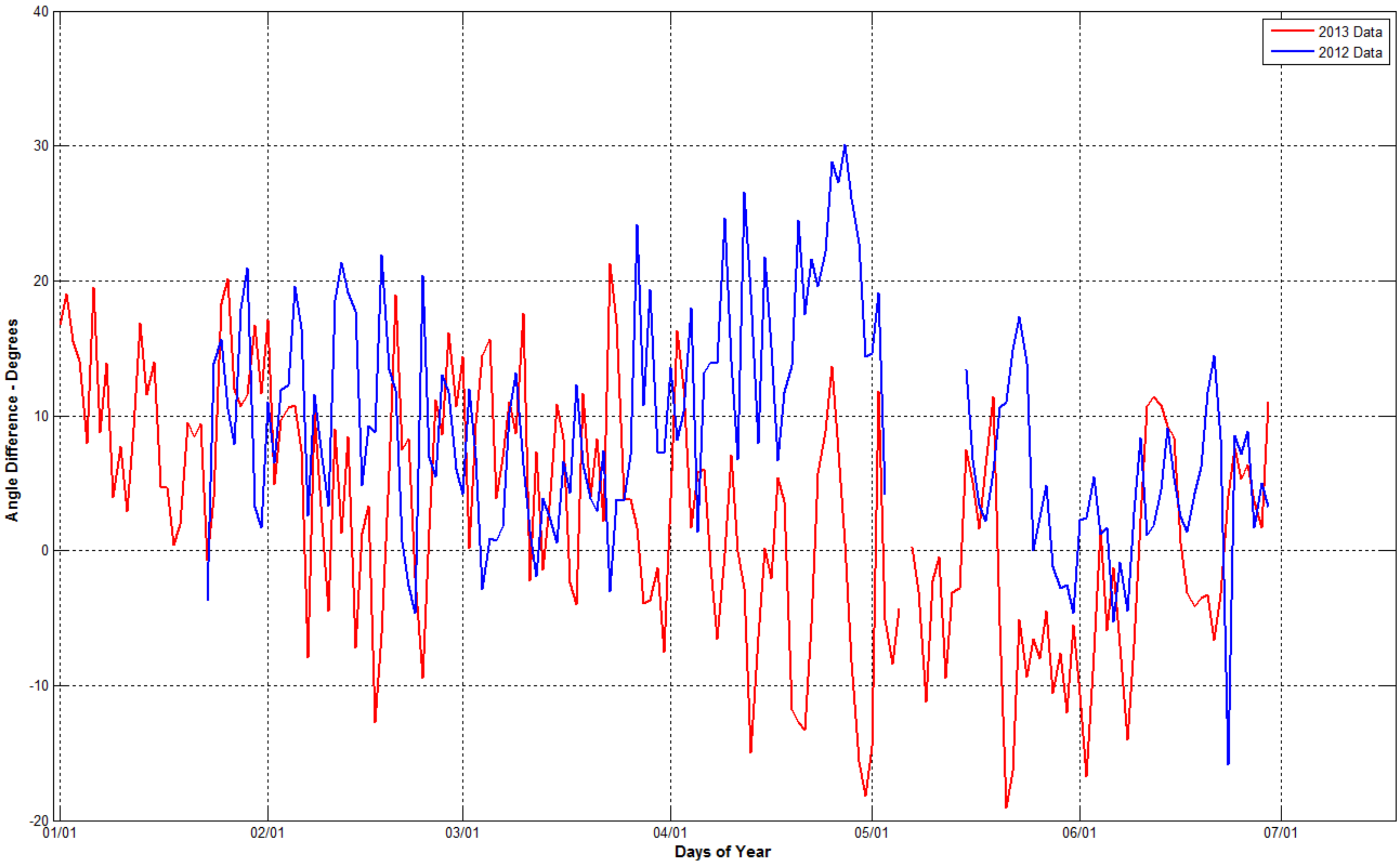
North 6 – North 7



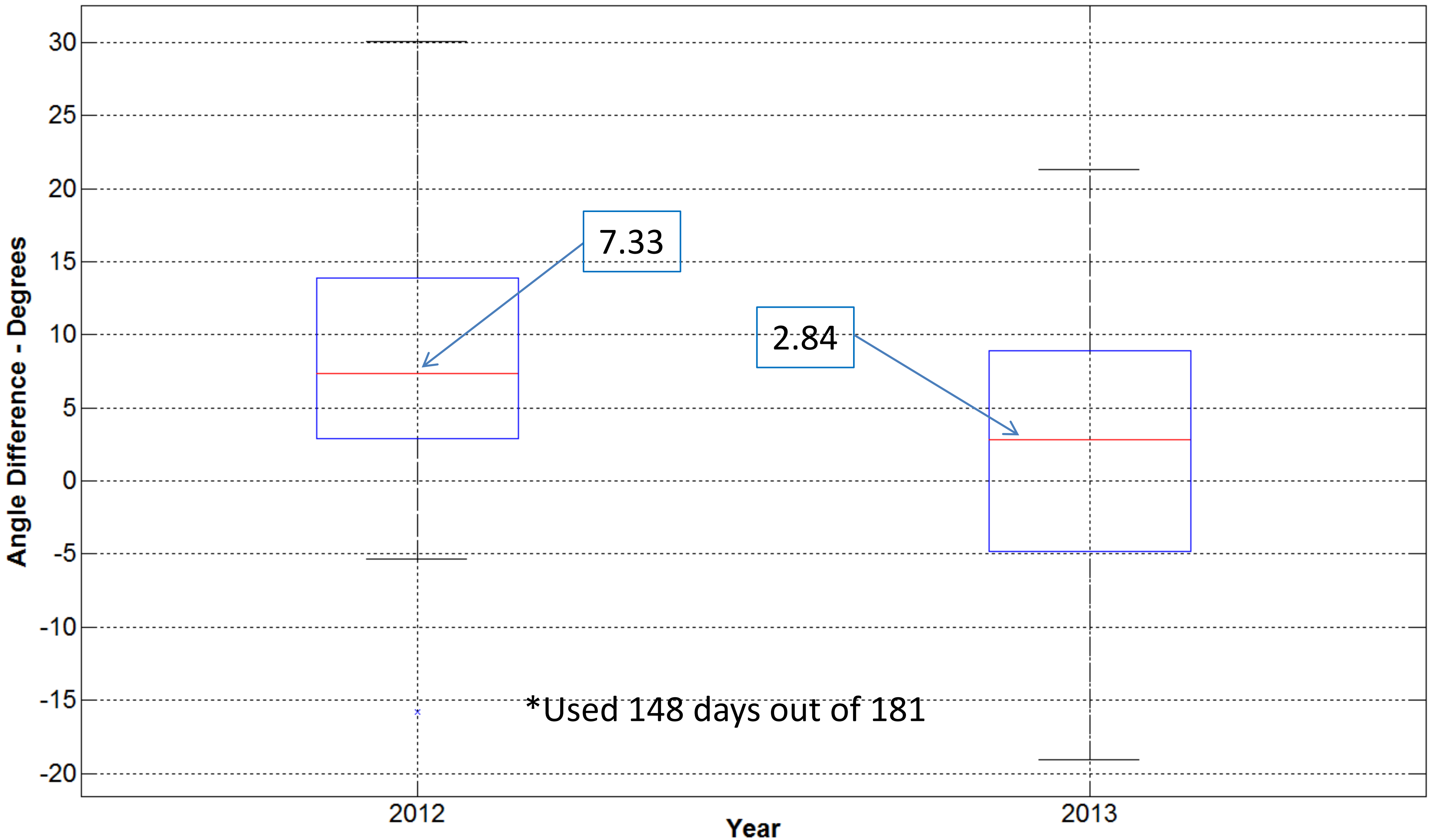
North 6 – North 7



Coast 1 – North 7



Coast 1 – North 7 *



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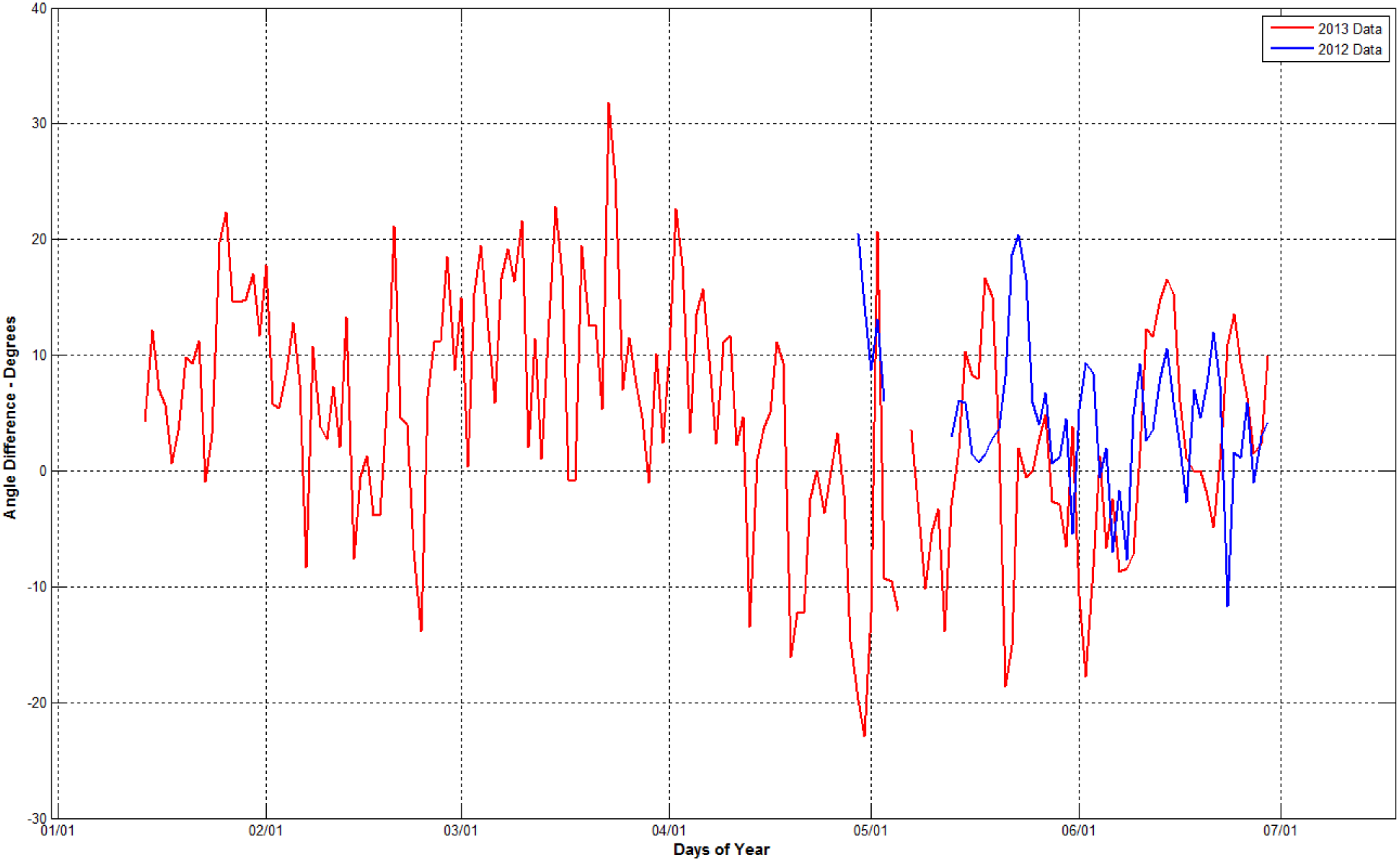

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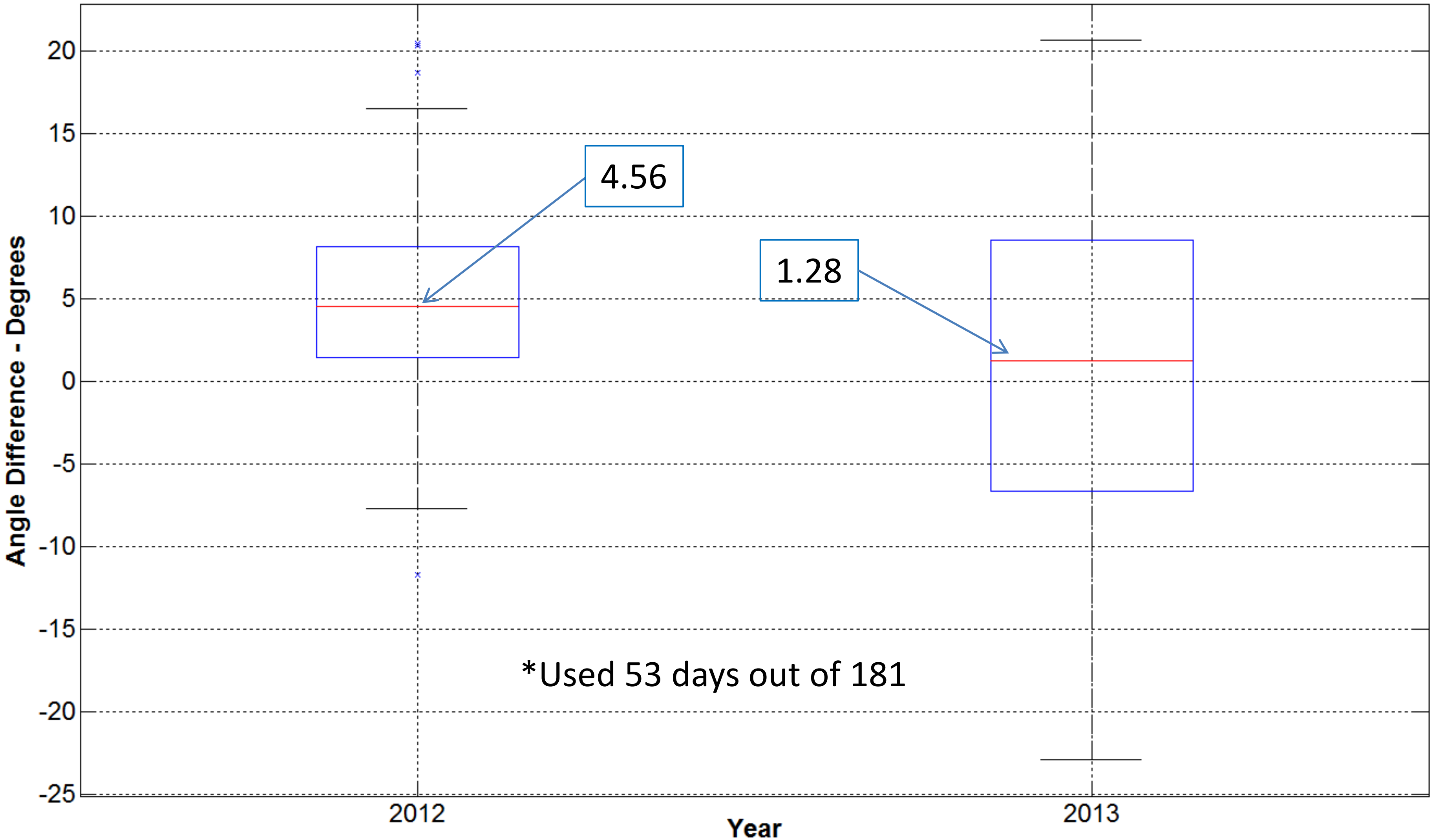
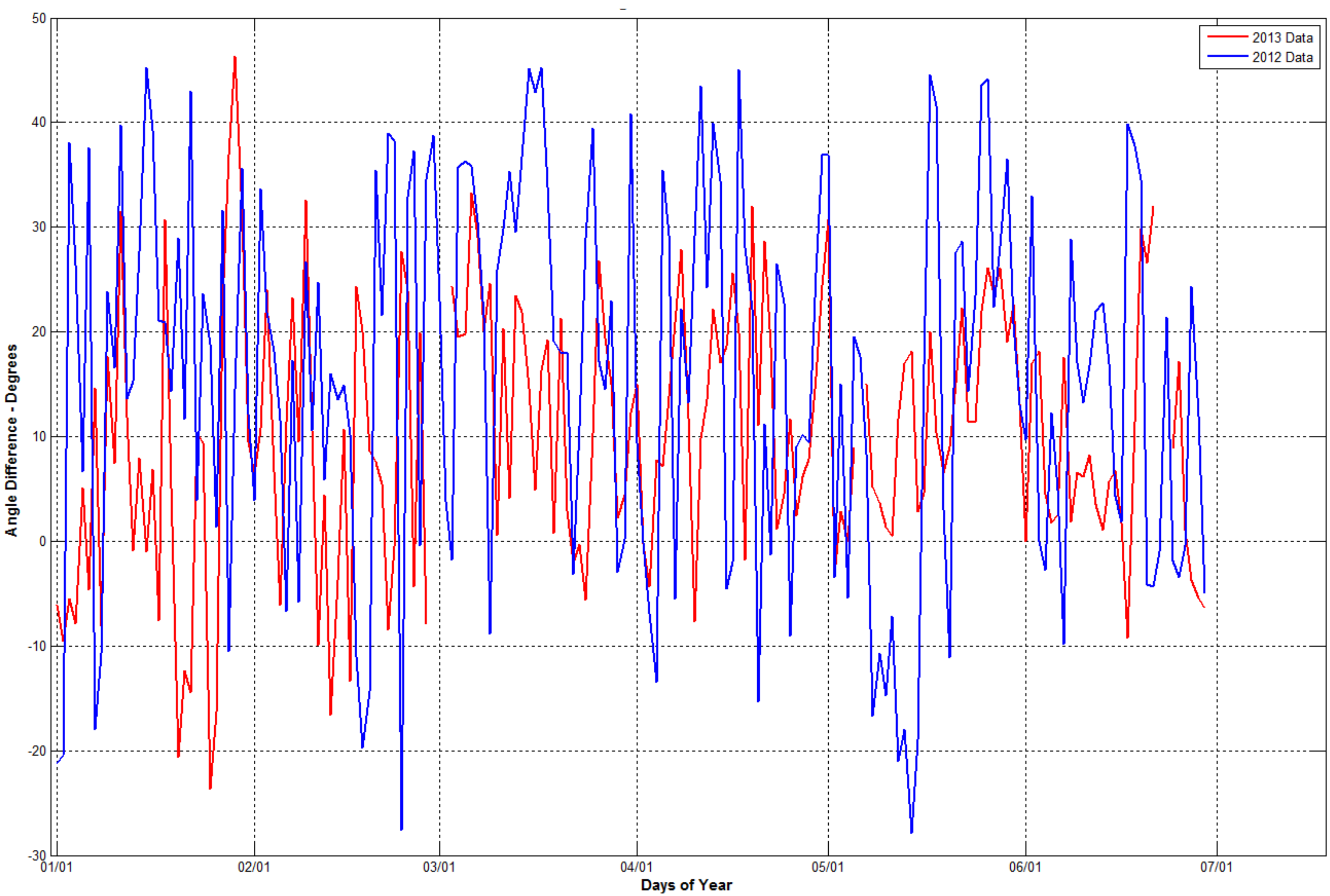


FarWest 4 – North 7



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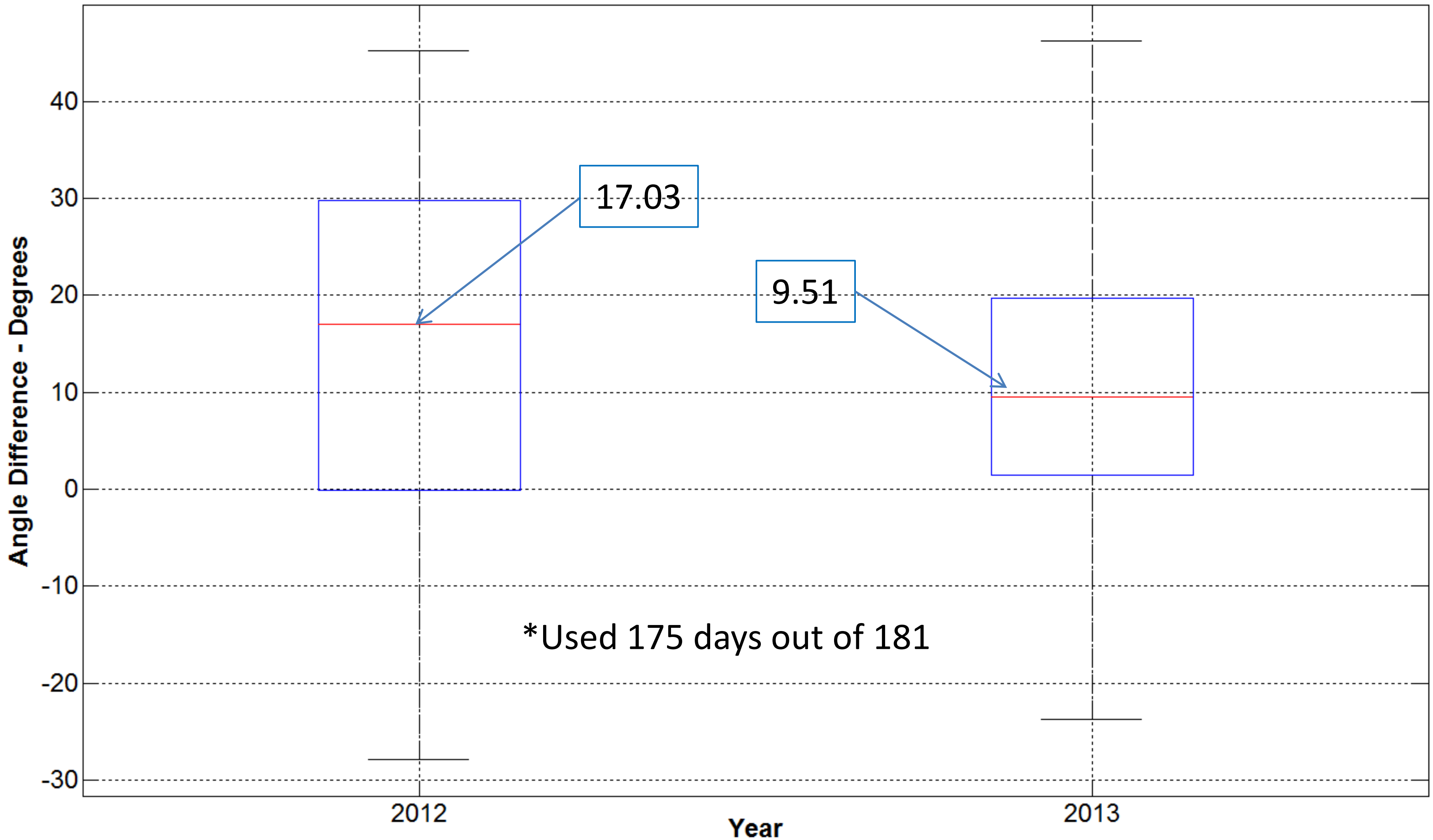

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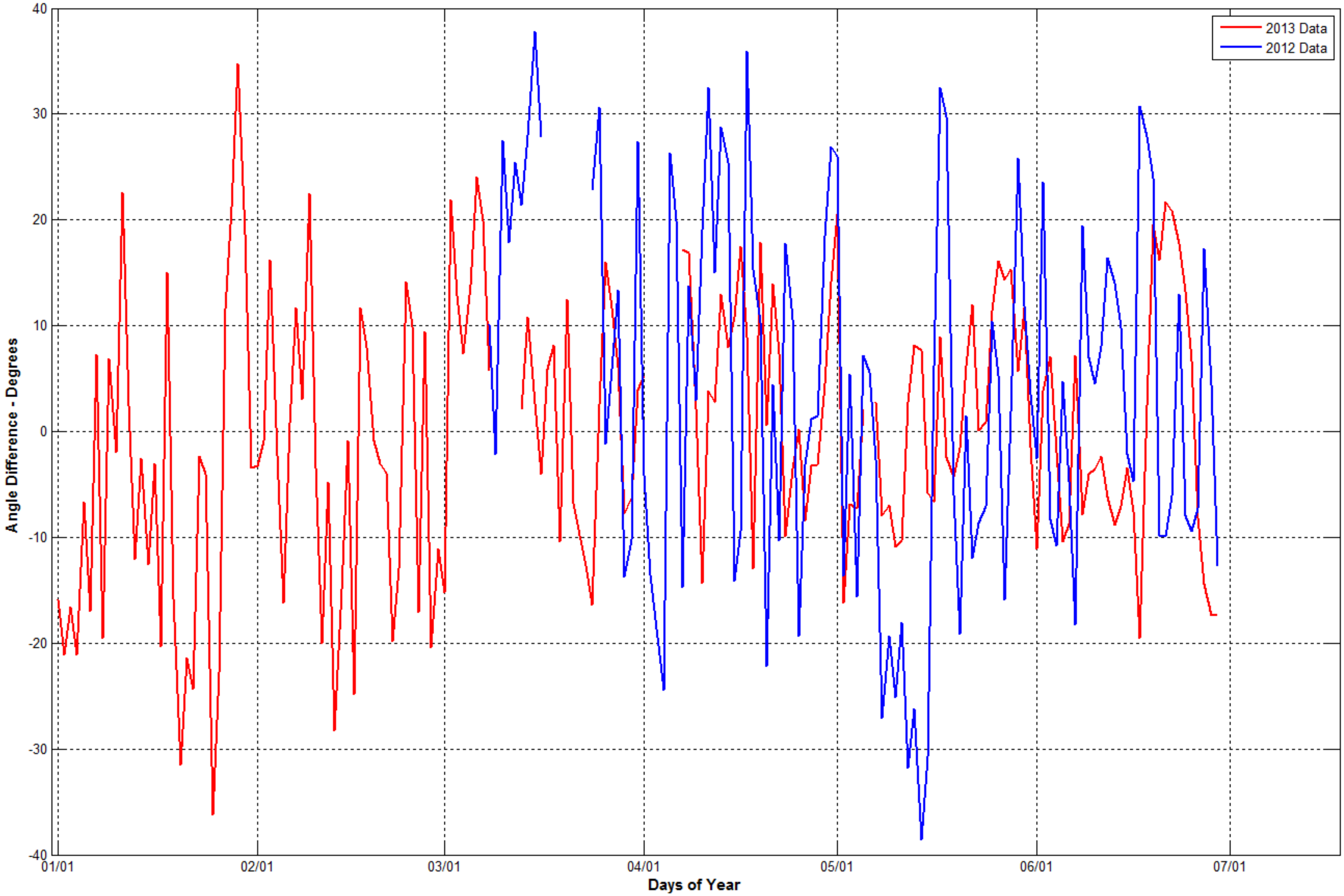

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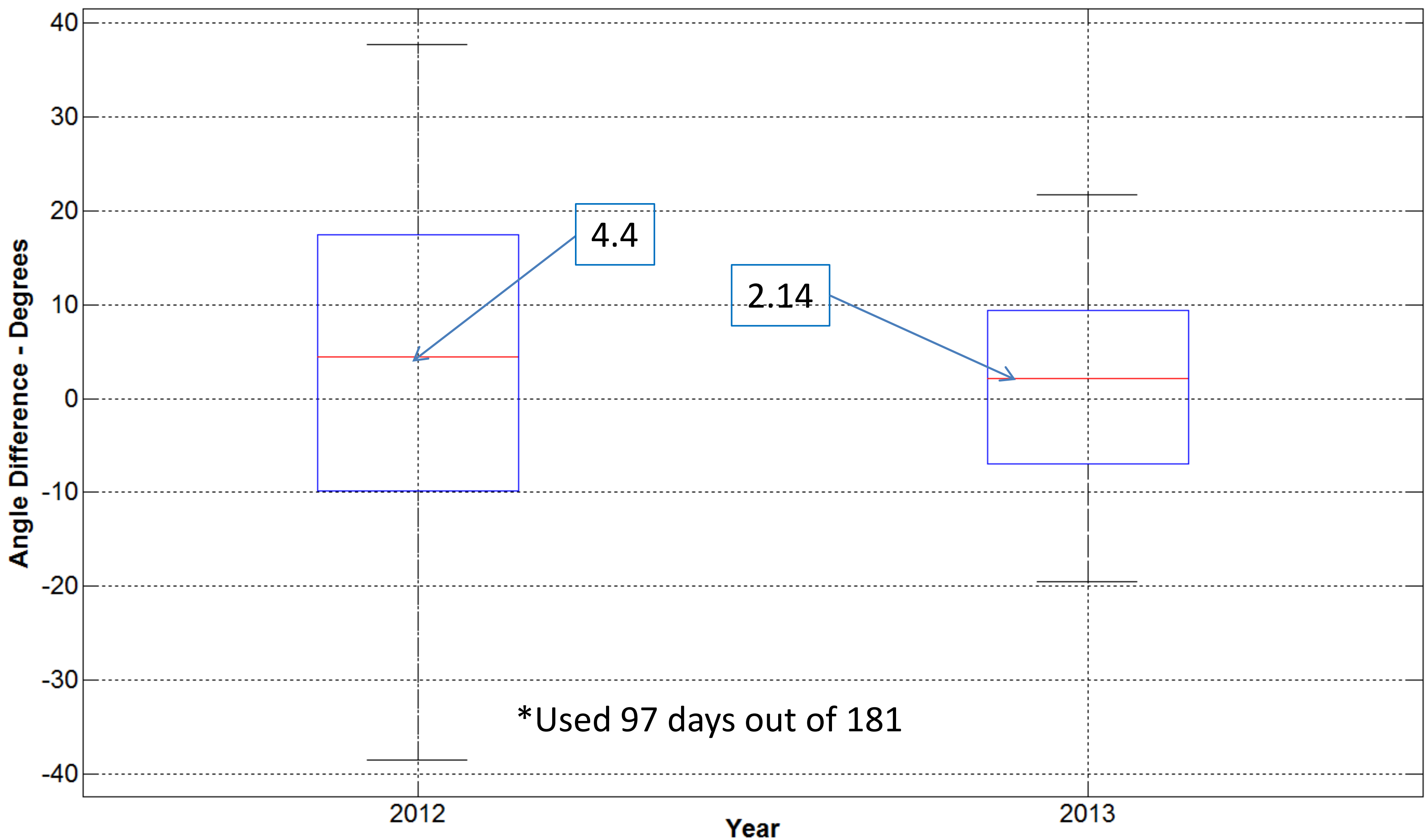

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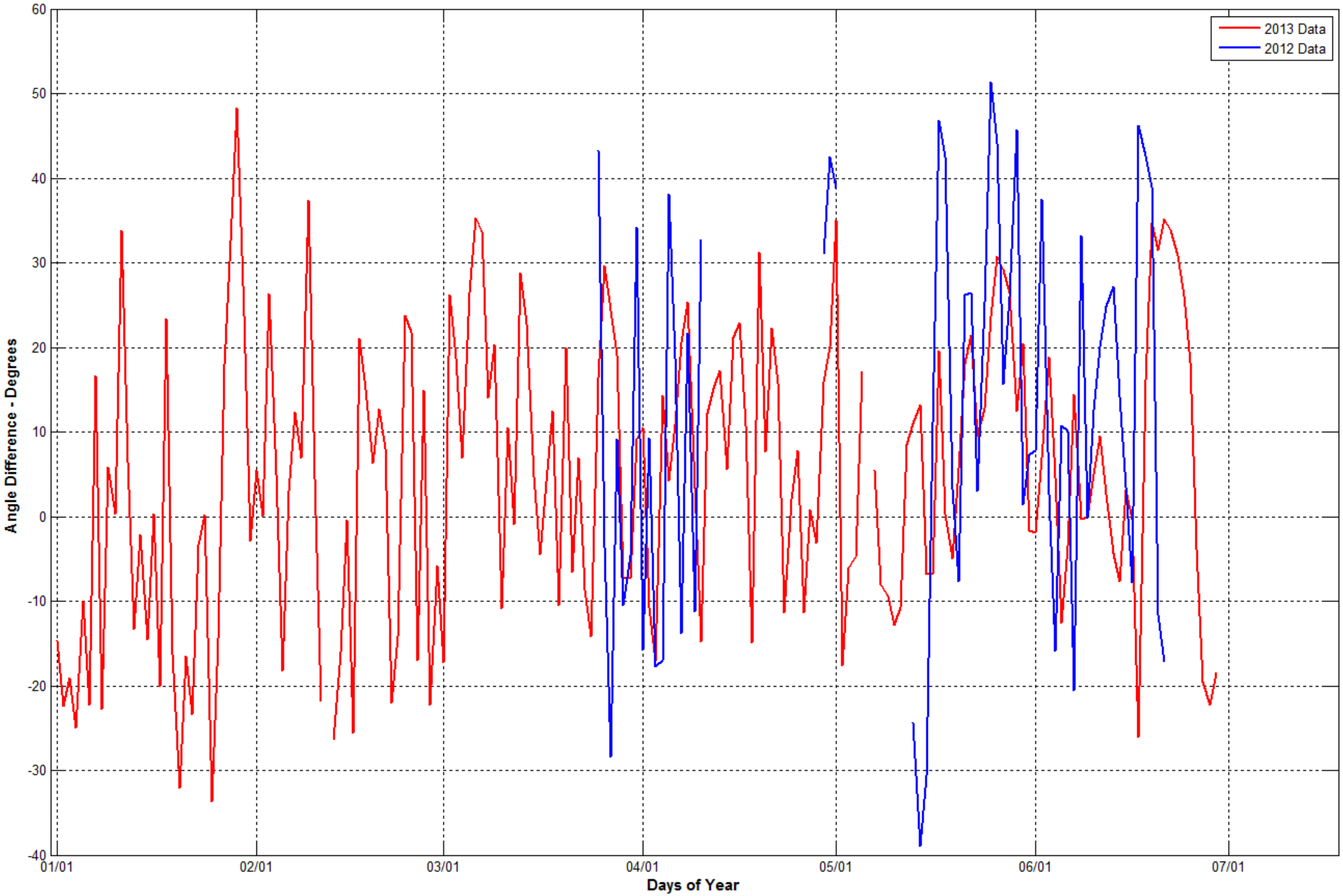

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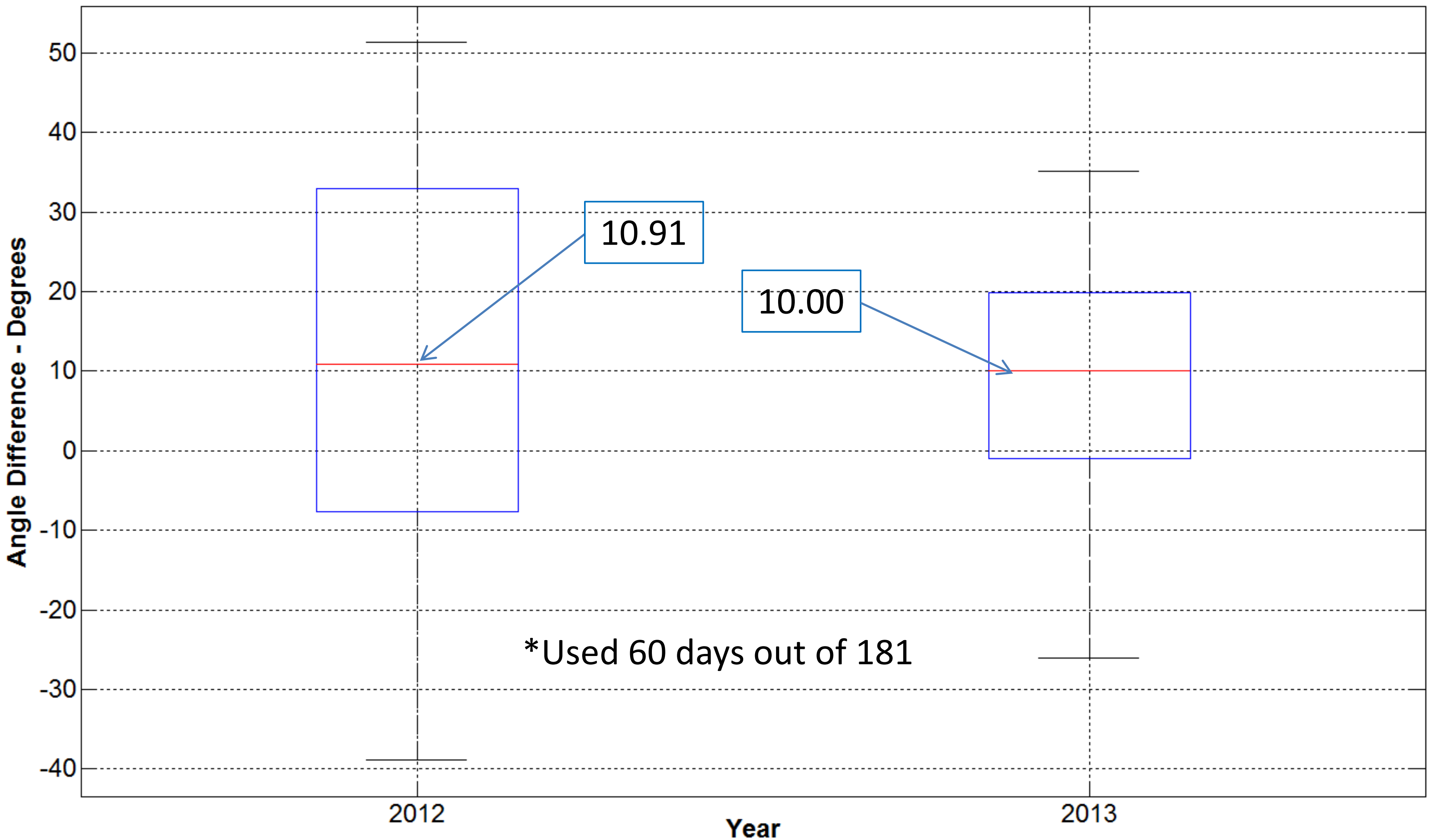


Appendix D – Part 1

CCET Discovery Across Texas project

Baseline Analysis Update – Angle Differences

<u>State Estimator Data</u>: January to June 2013

Box-Whisker Plots and Time Duration Curves

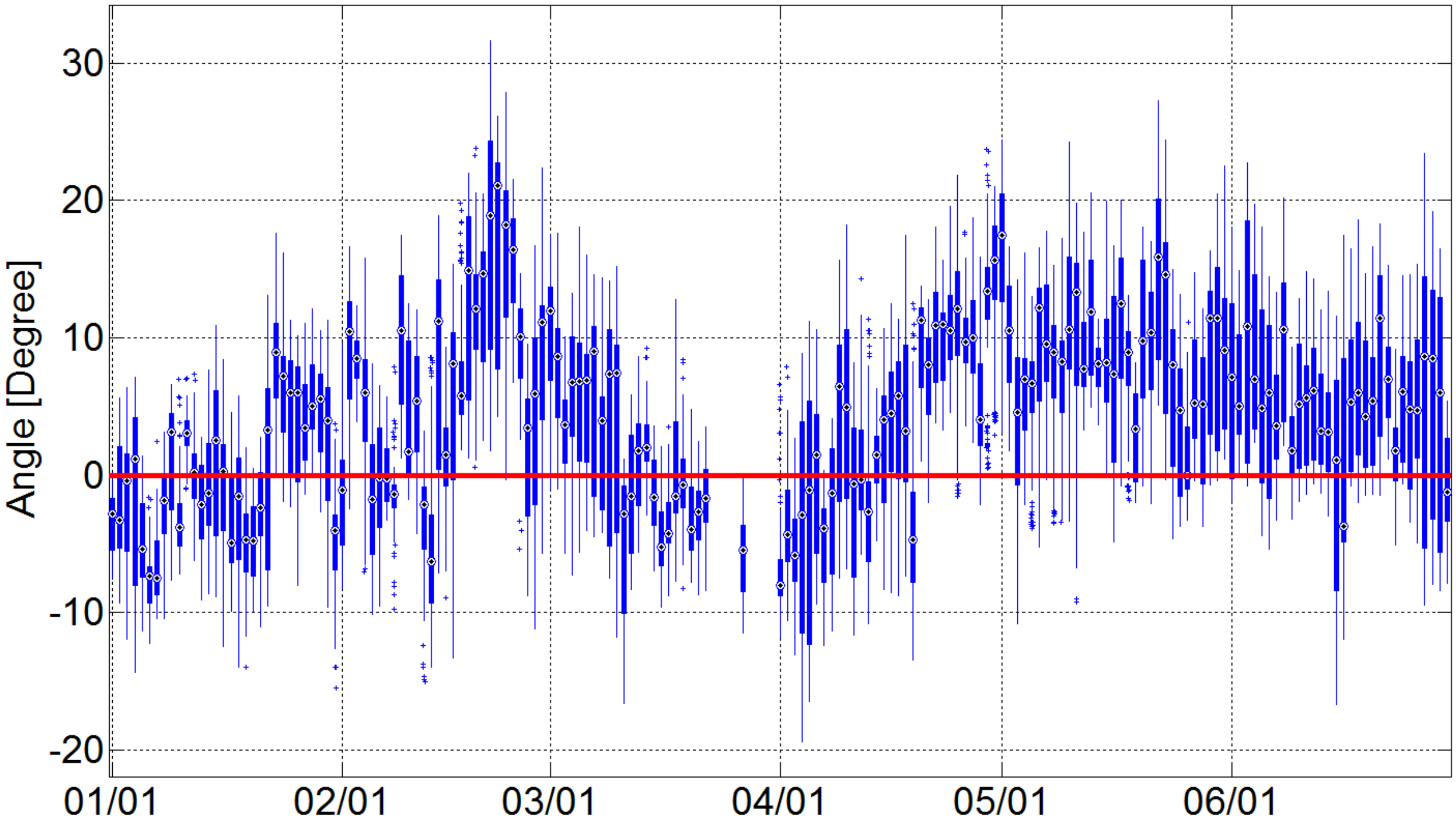
External Version

Electric Power Group

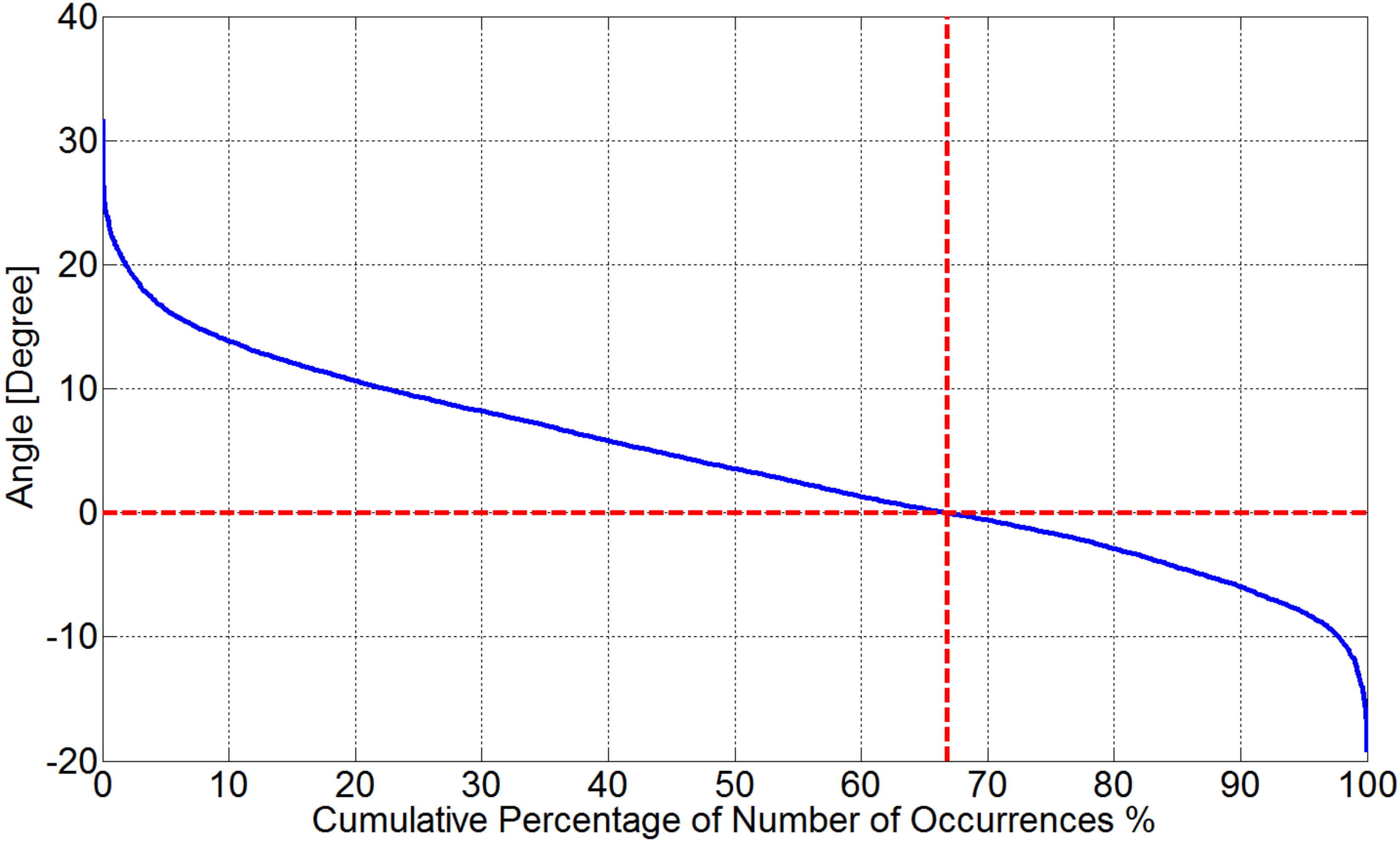
CCET

ERCOT

Coast 1-South 13



Coast 1-South 13



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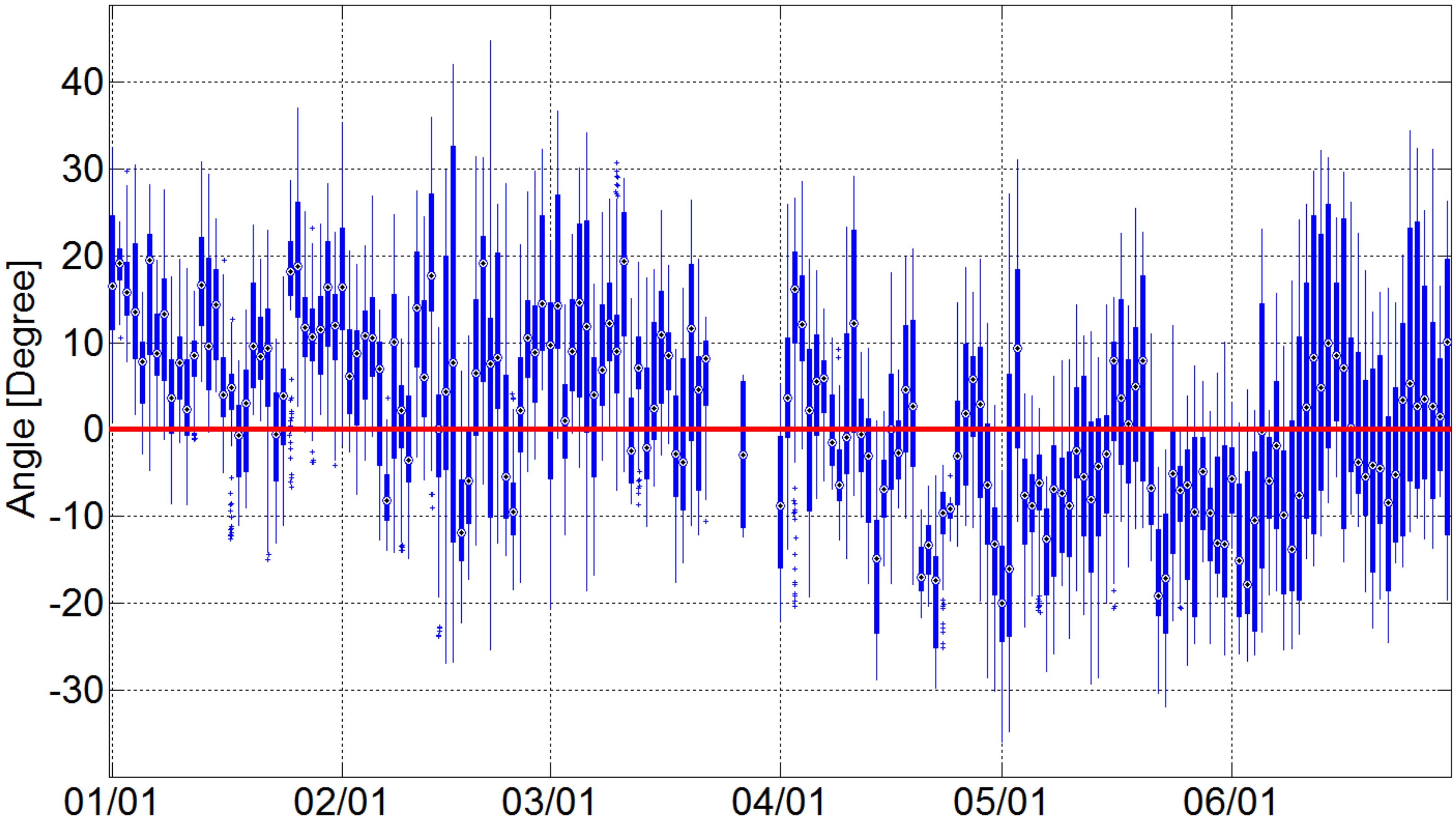

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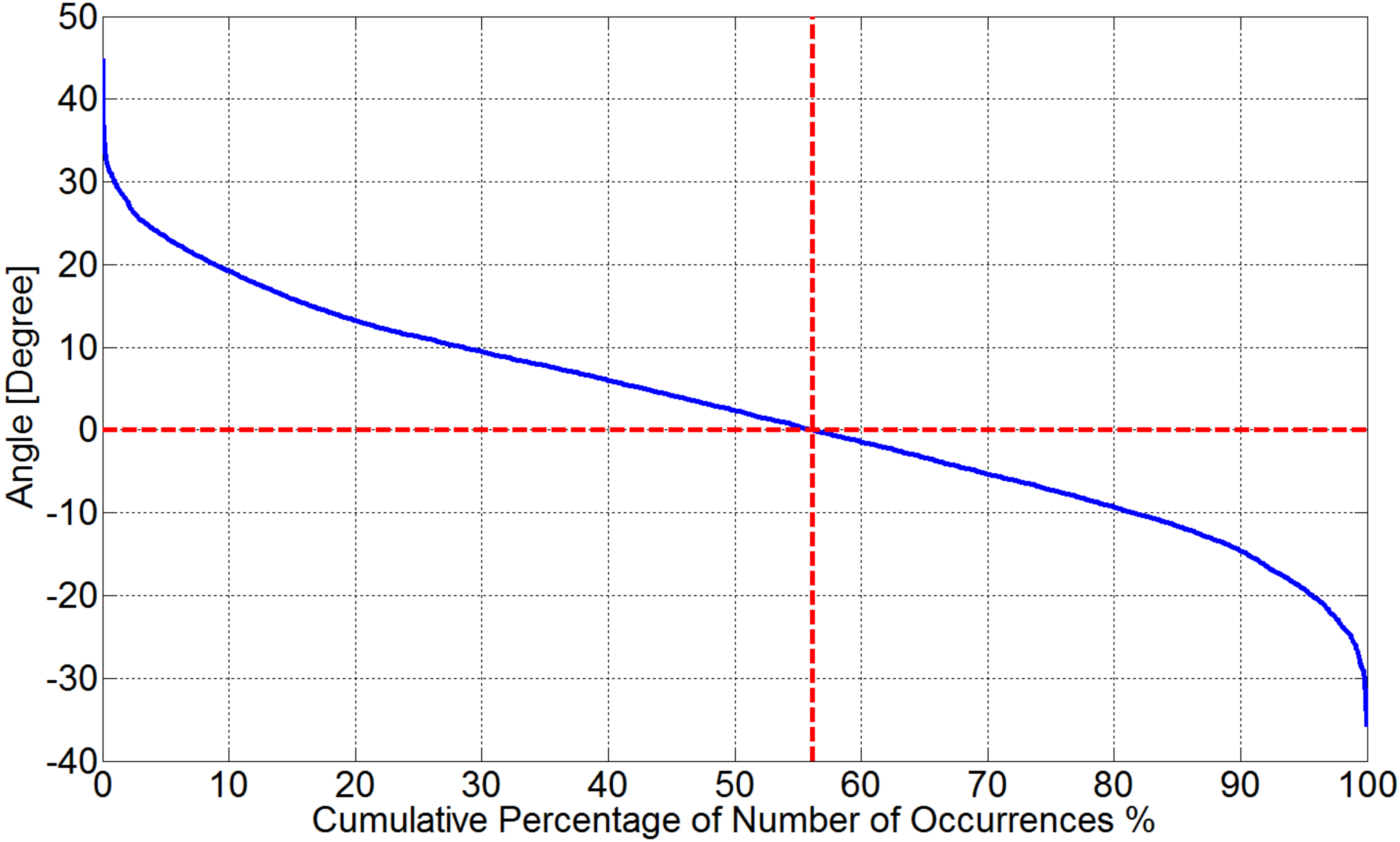

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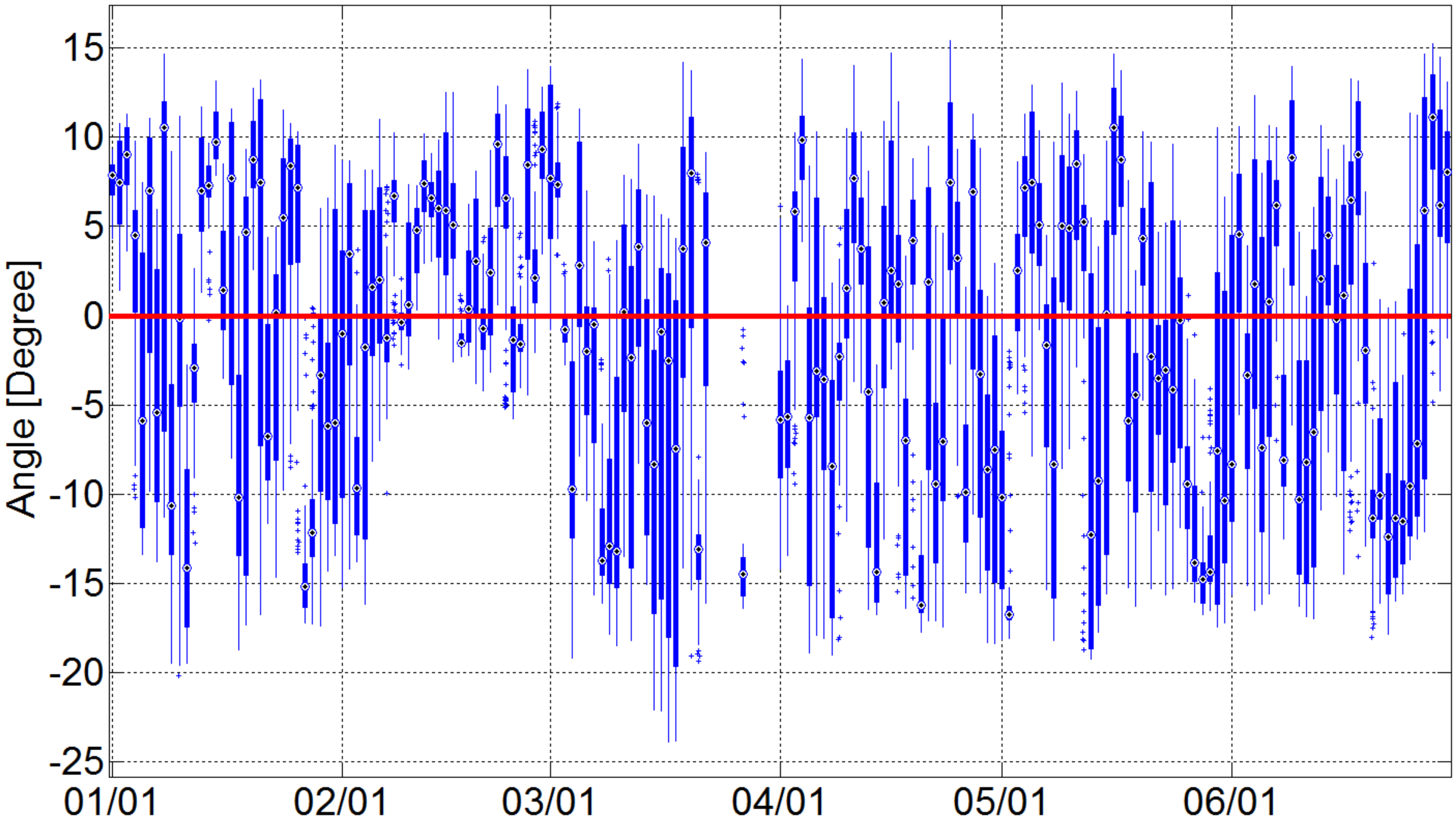

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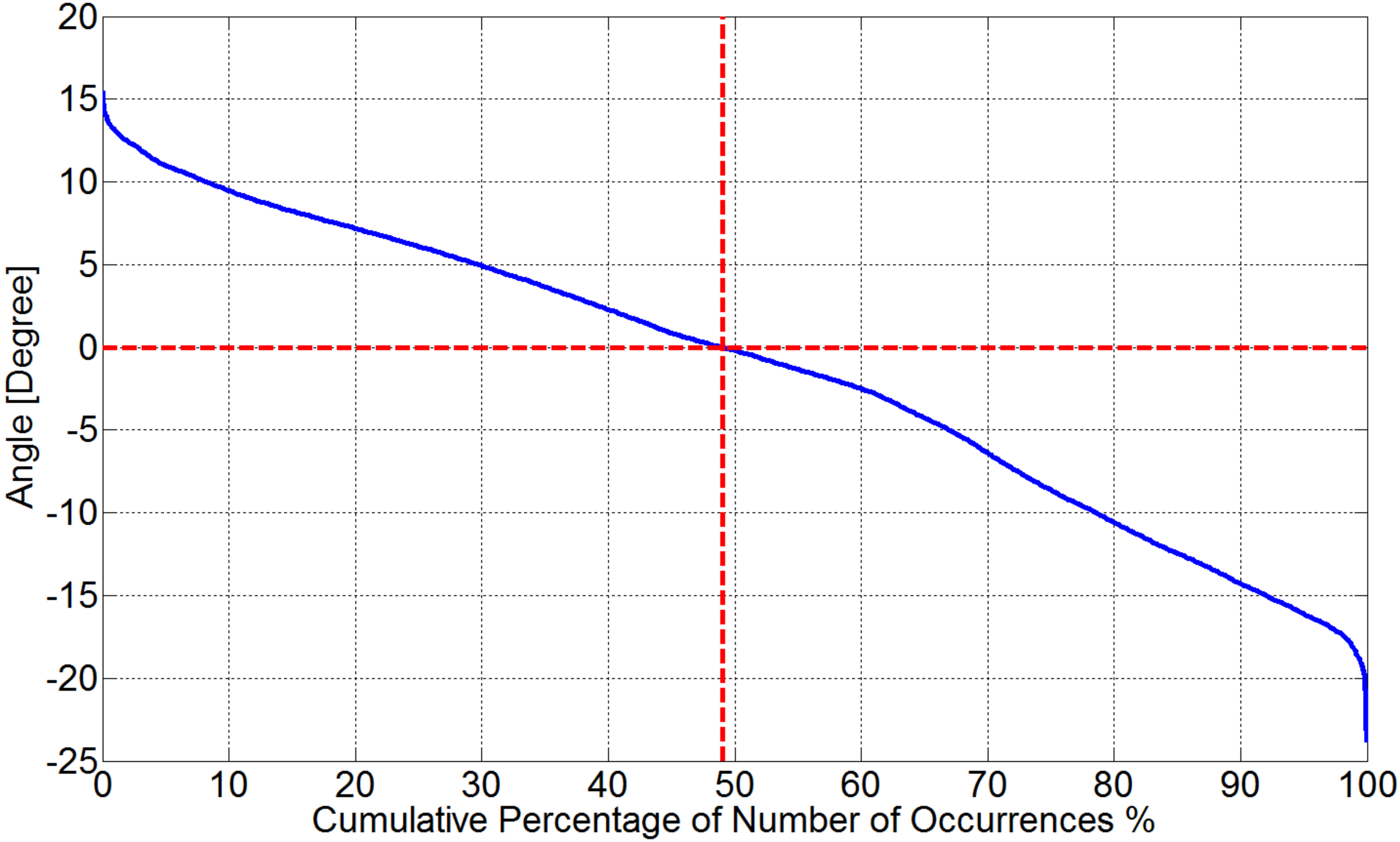

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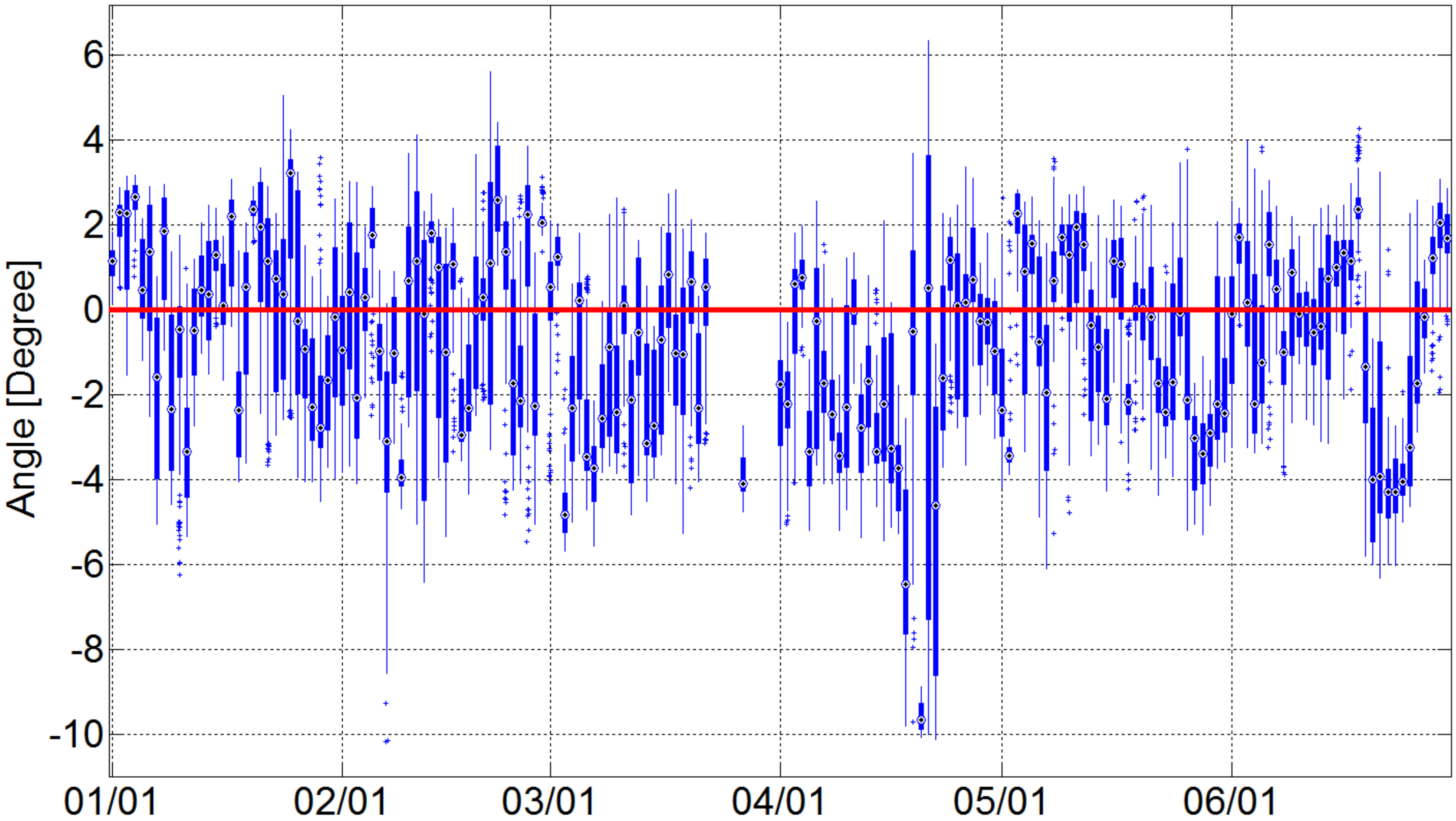

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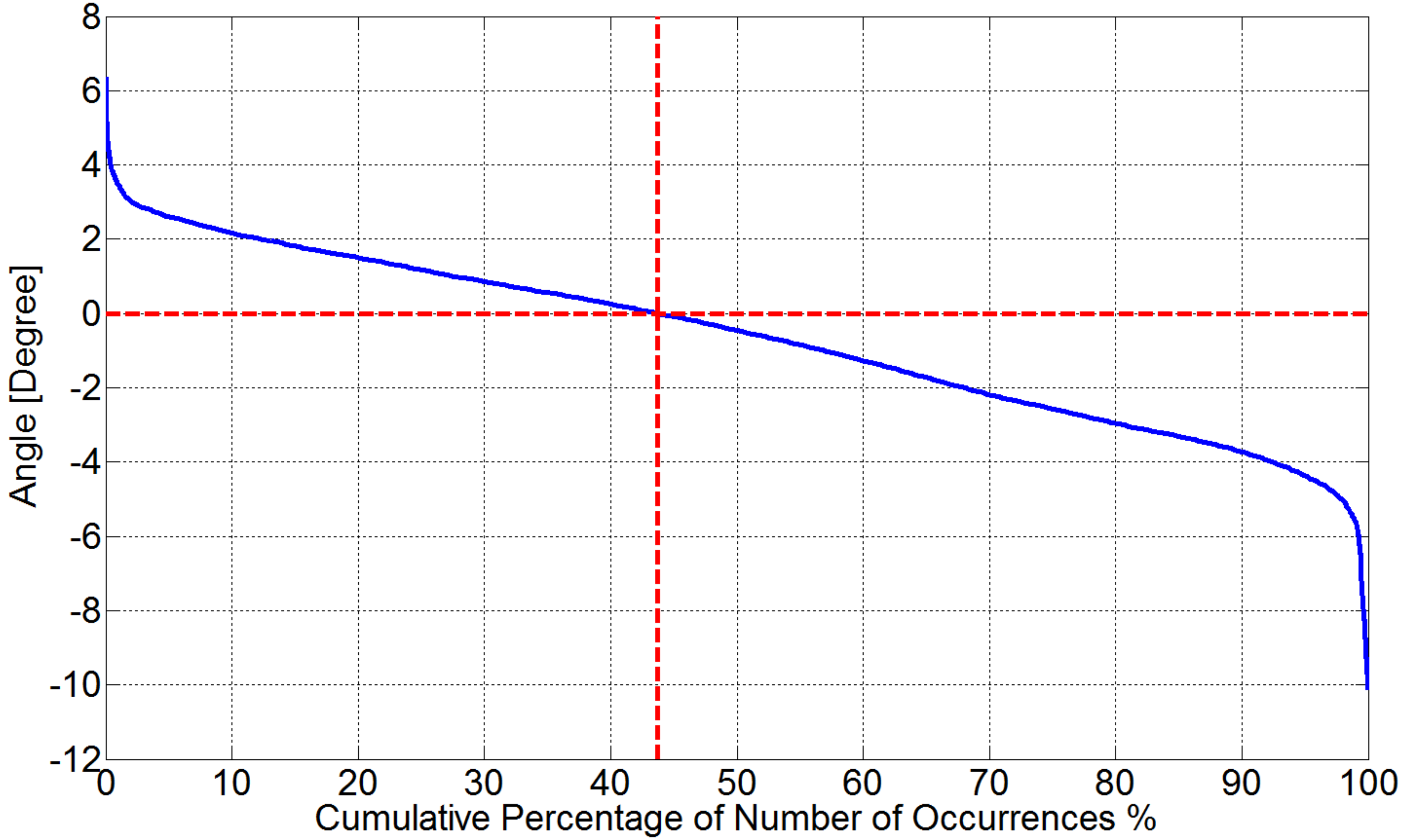

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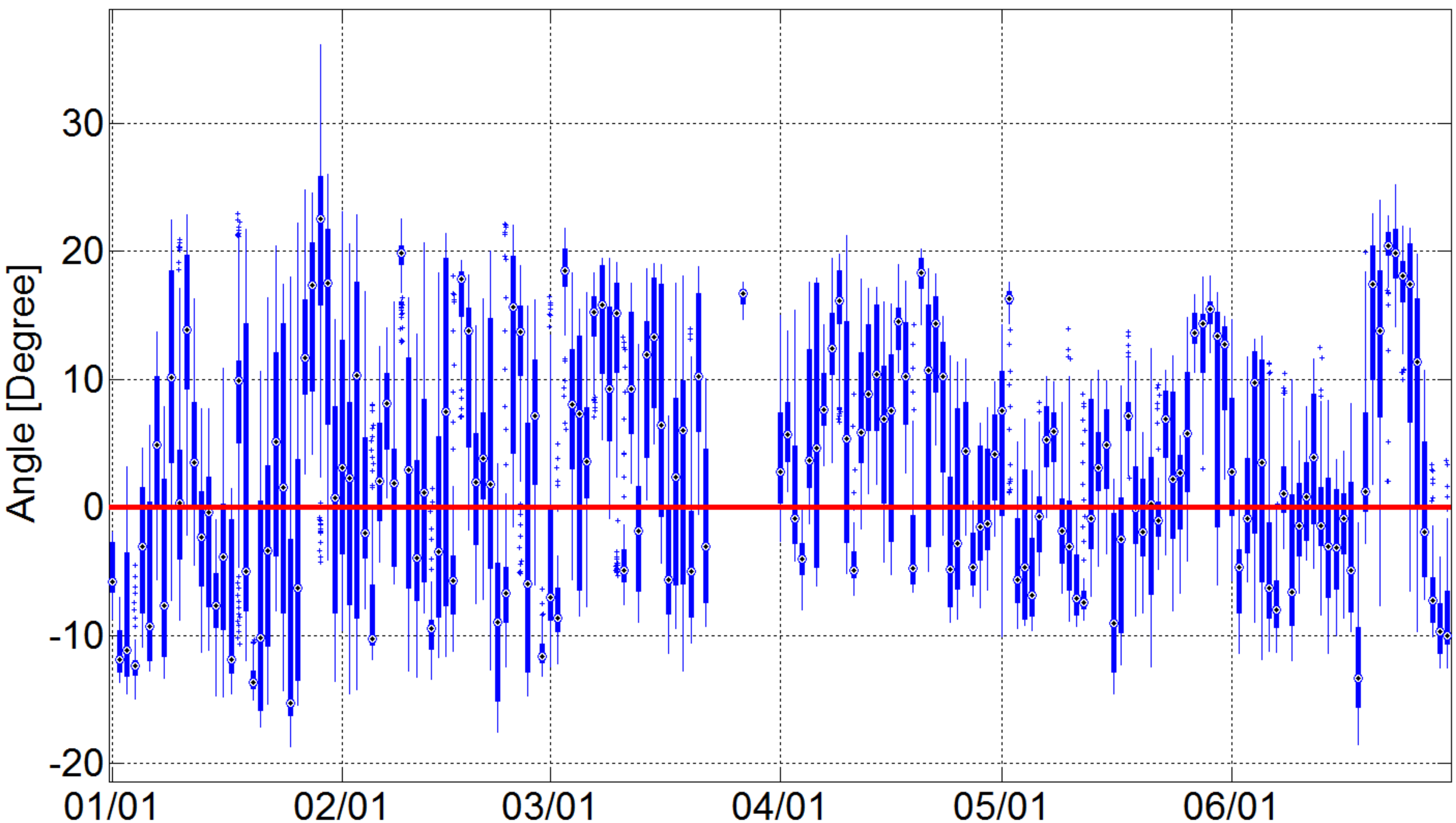

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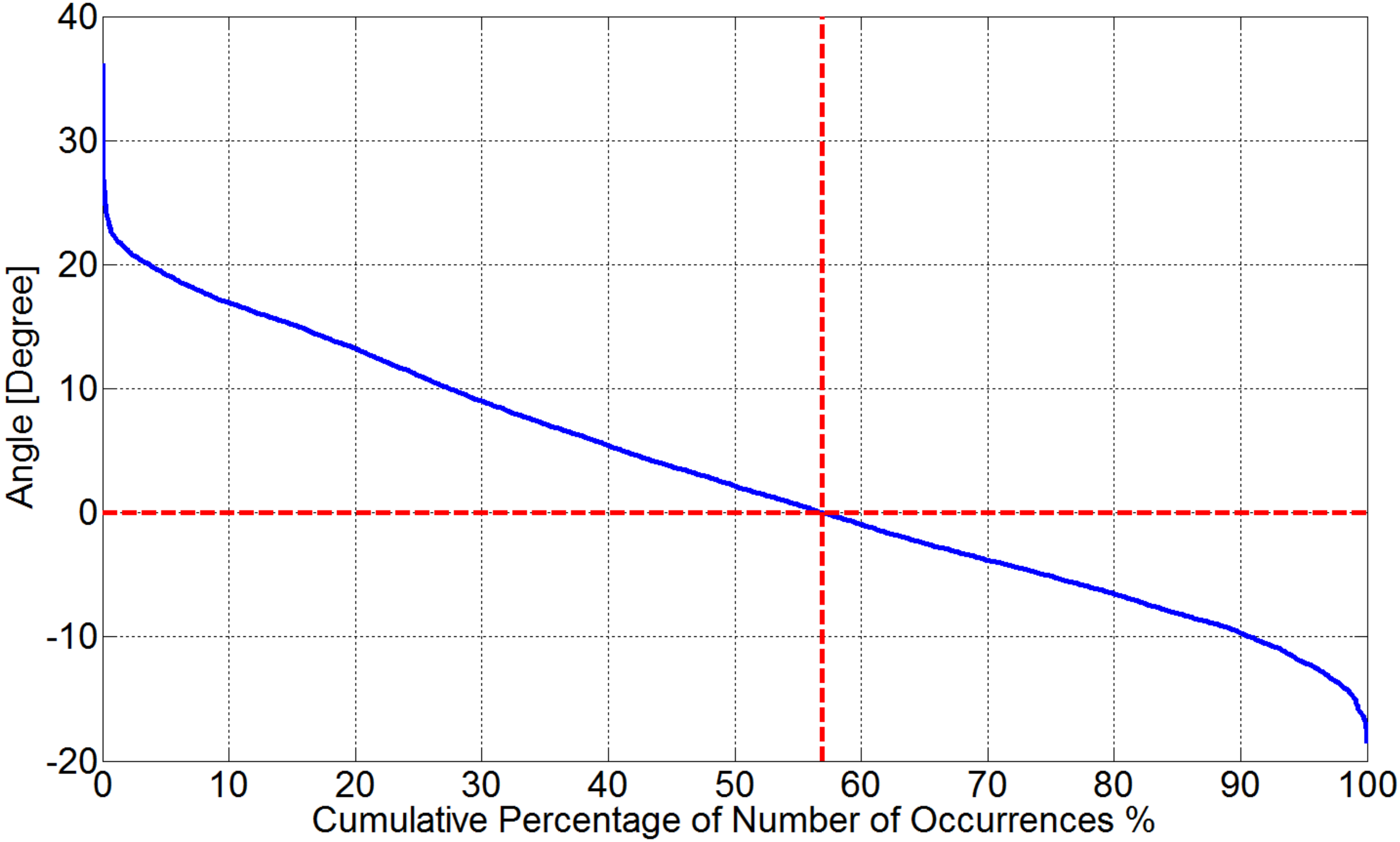

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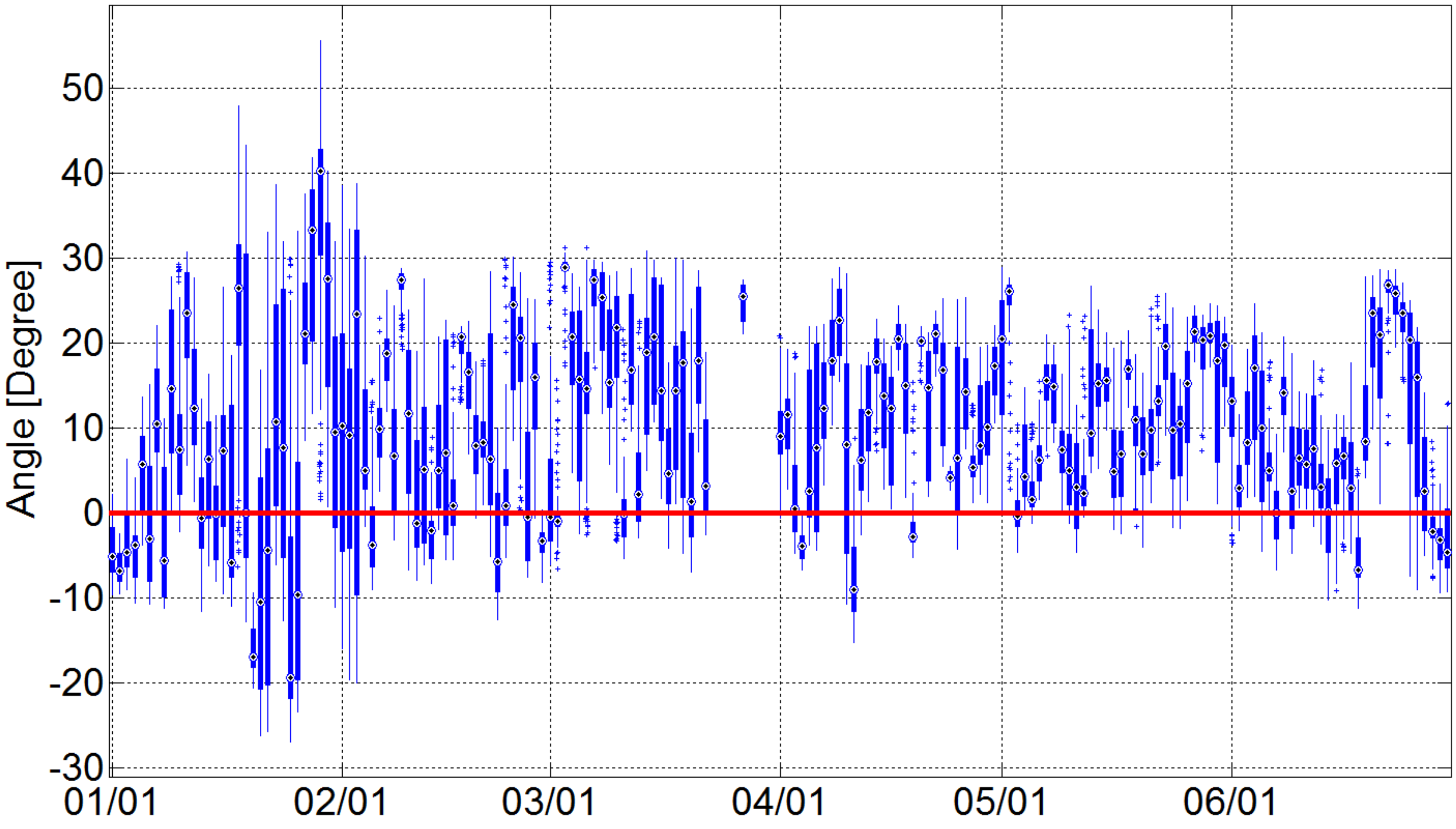

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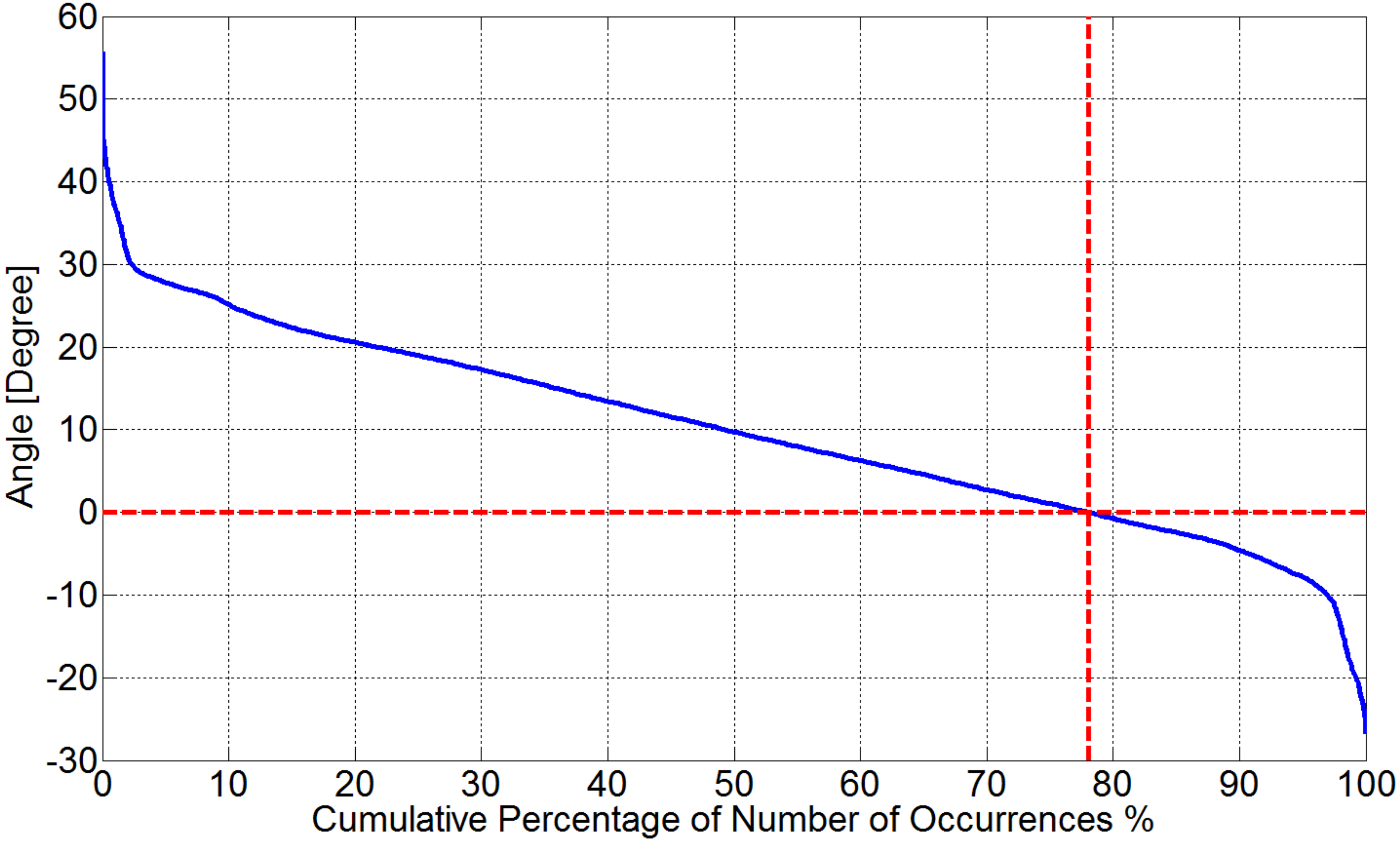

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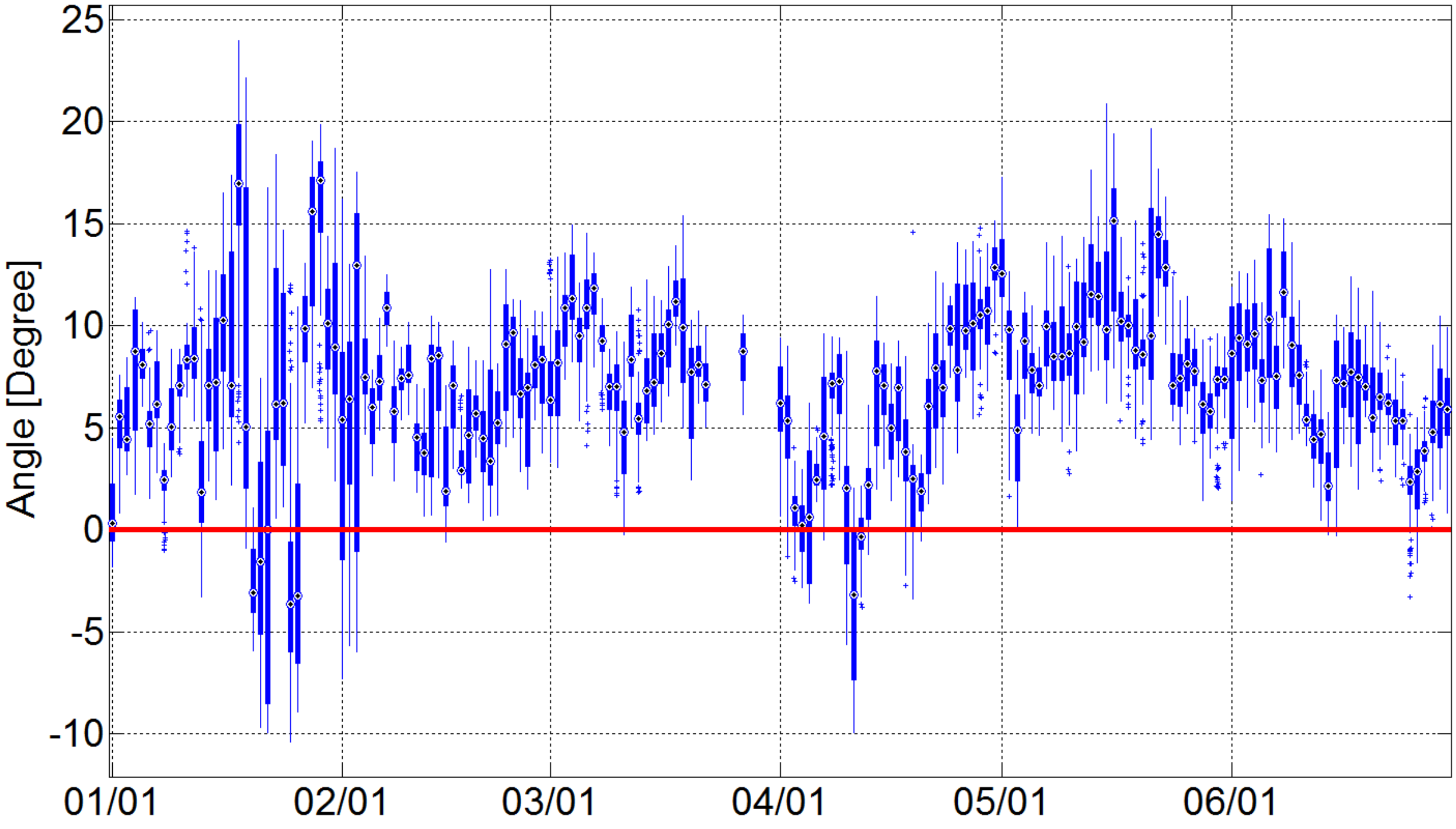

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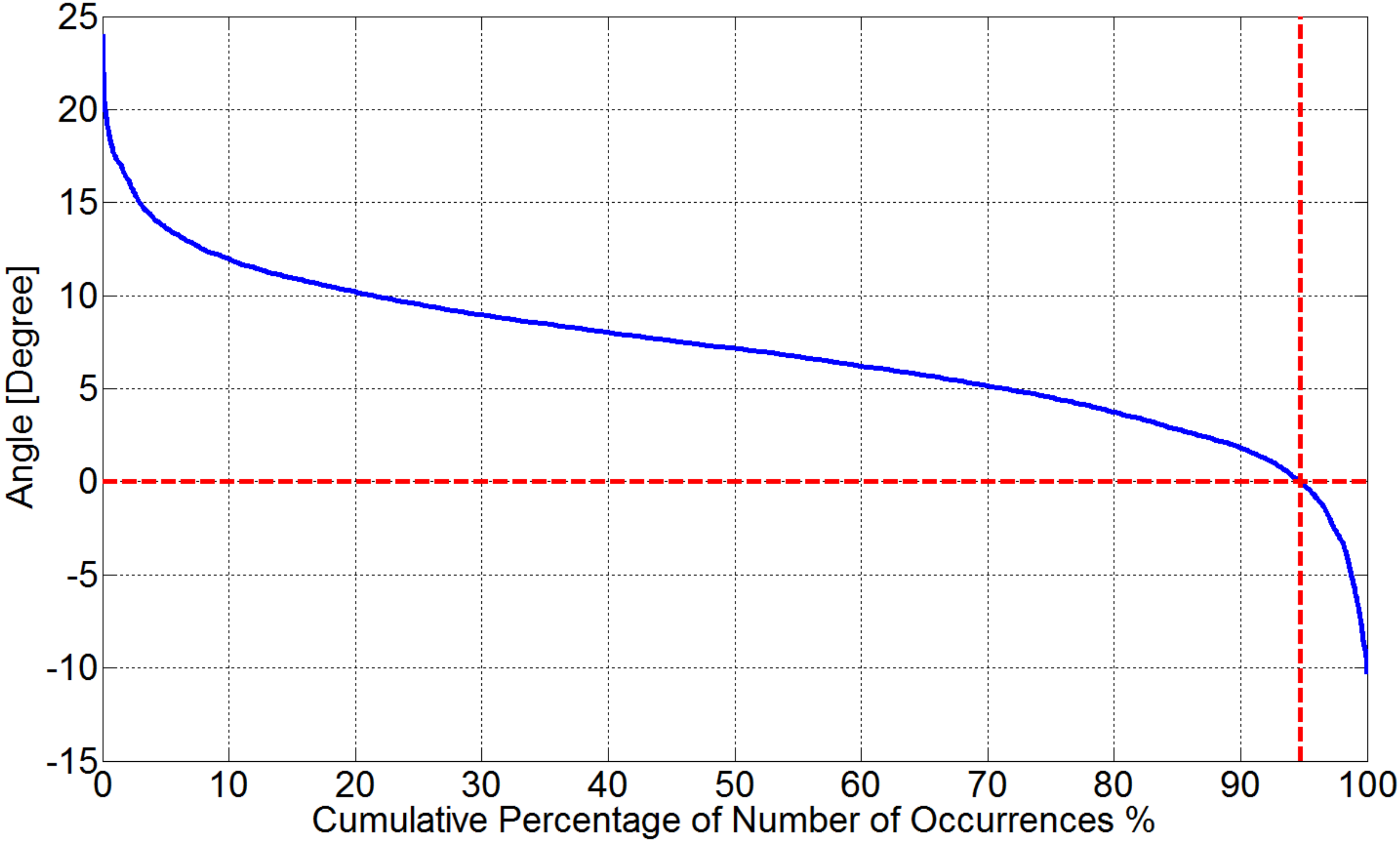

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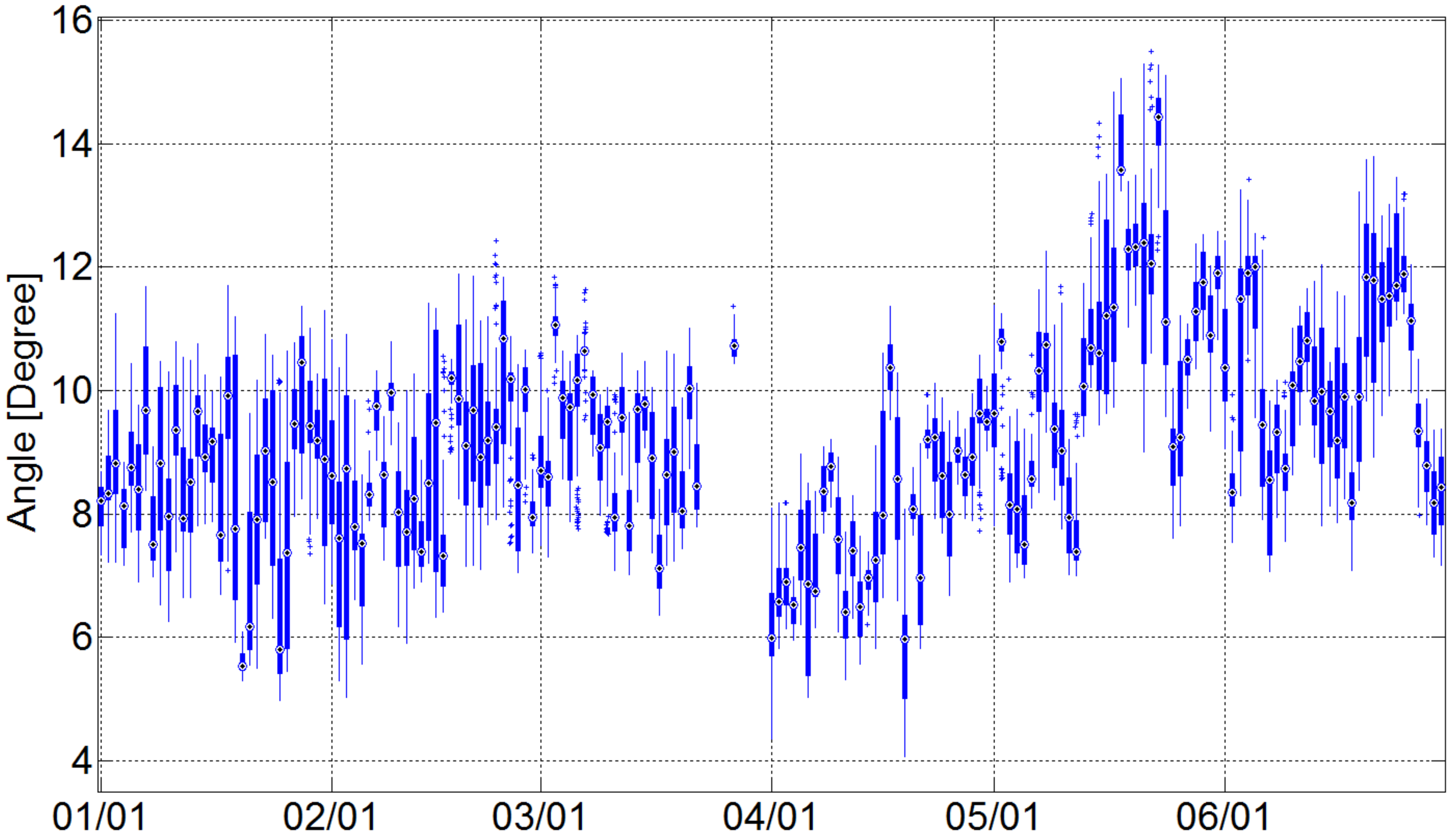

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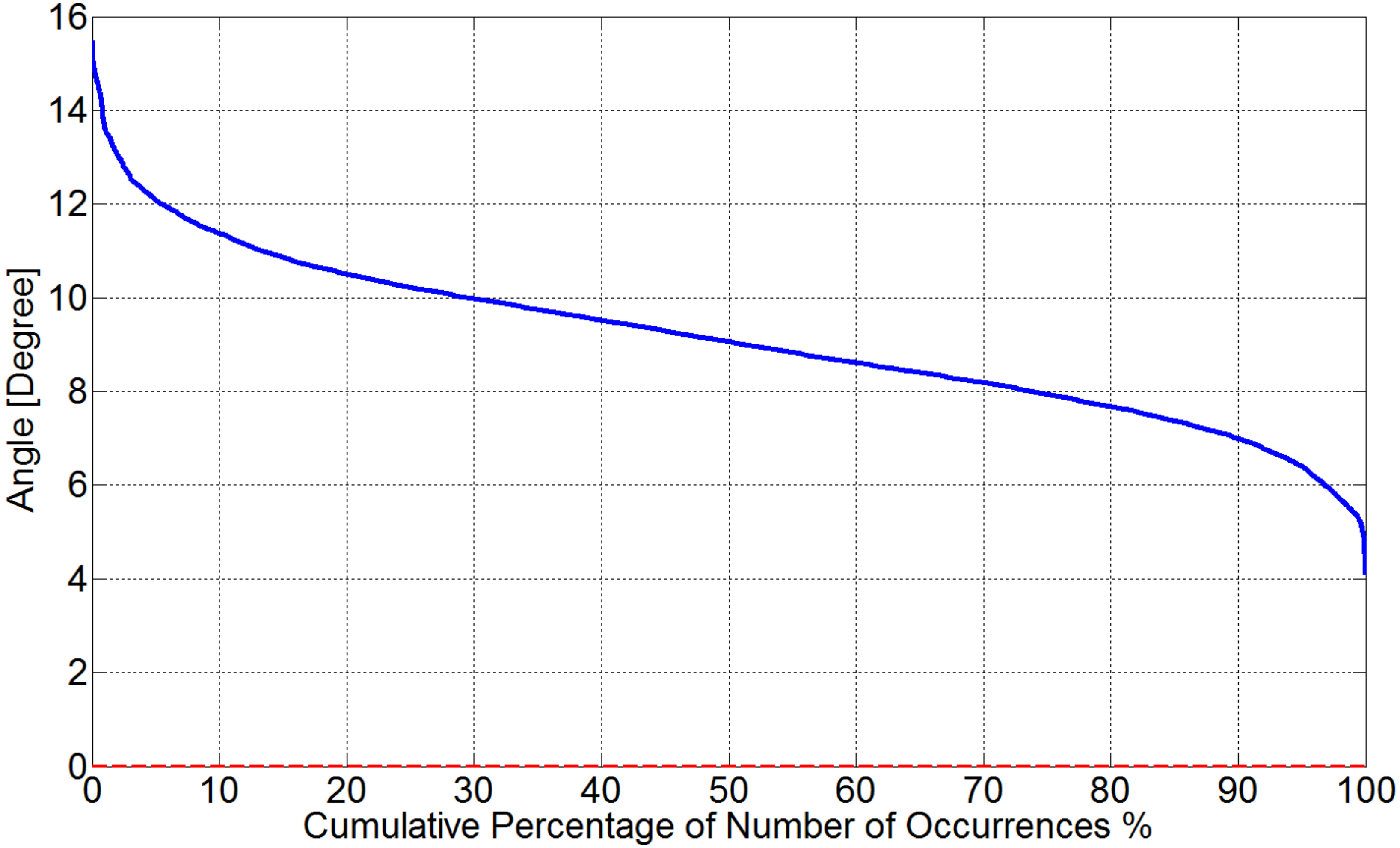

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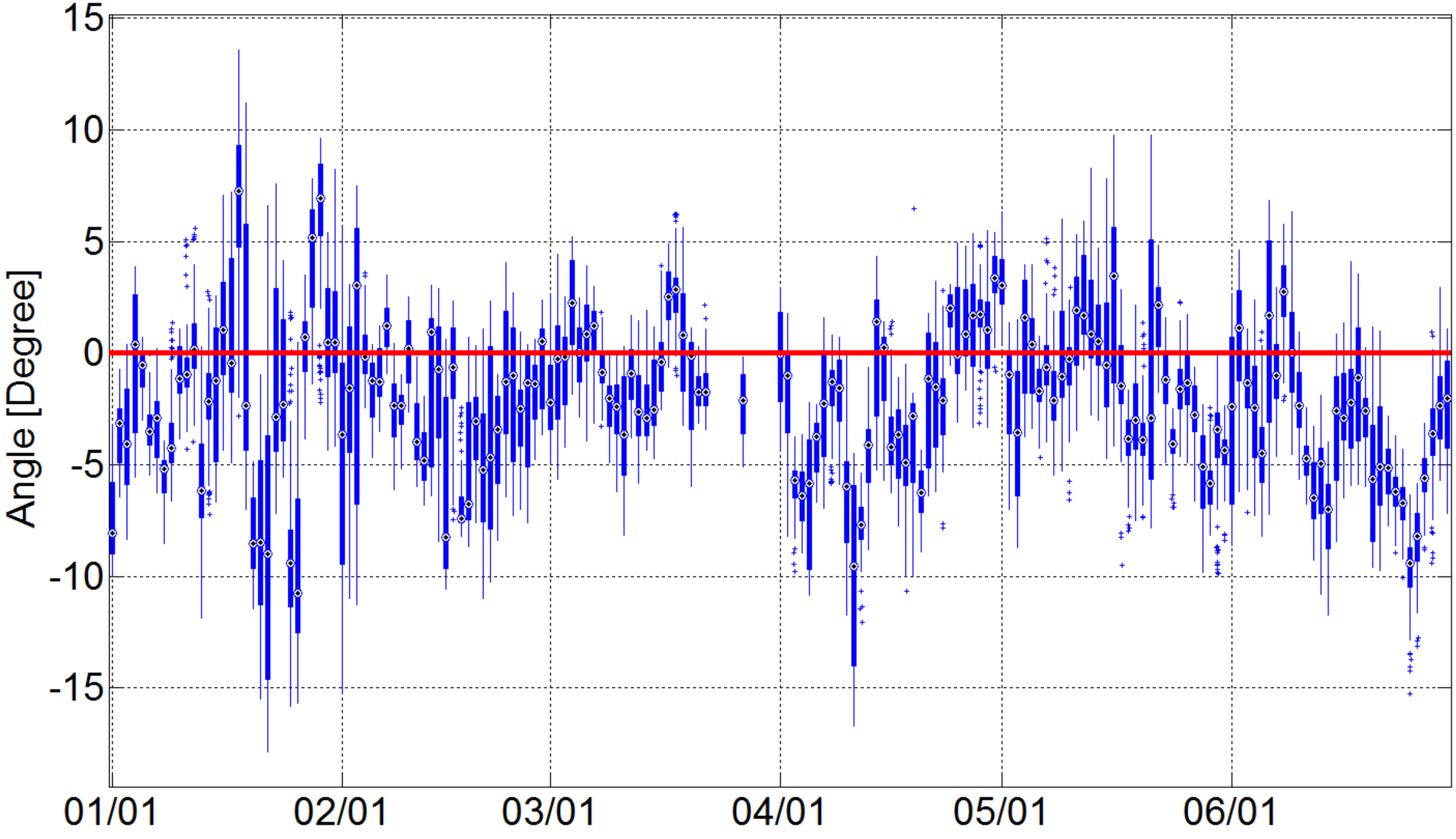

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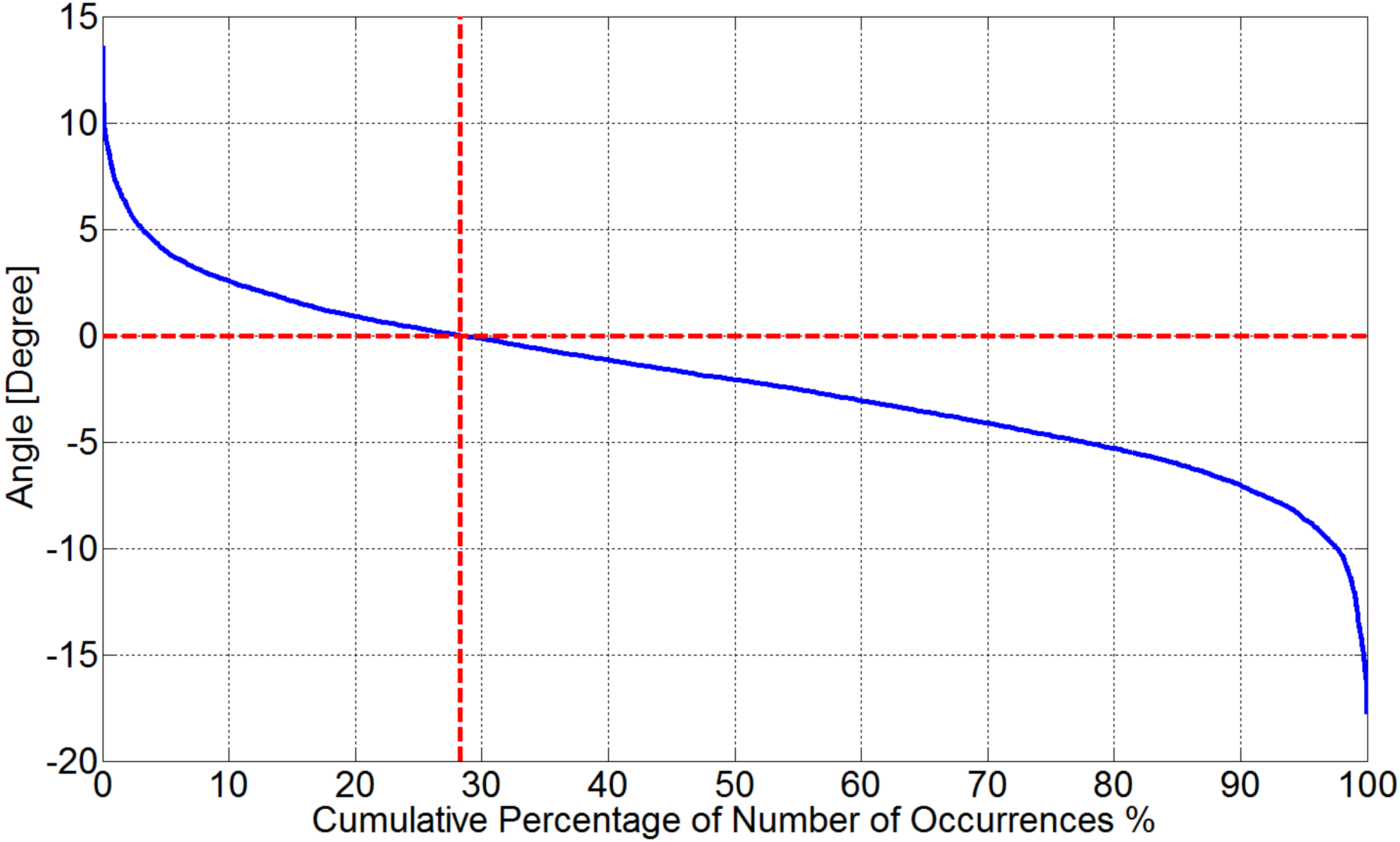

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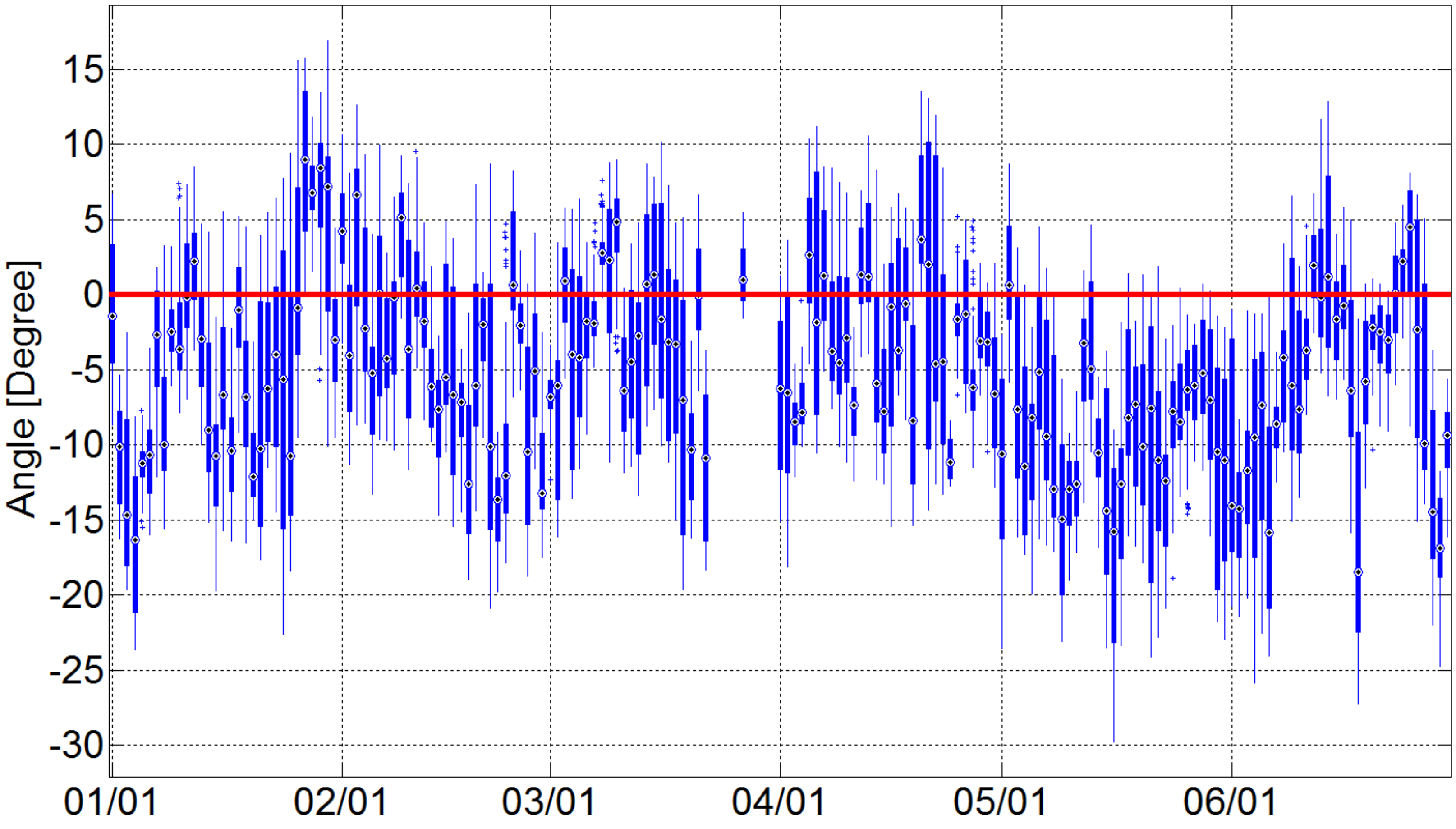

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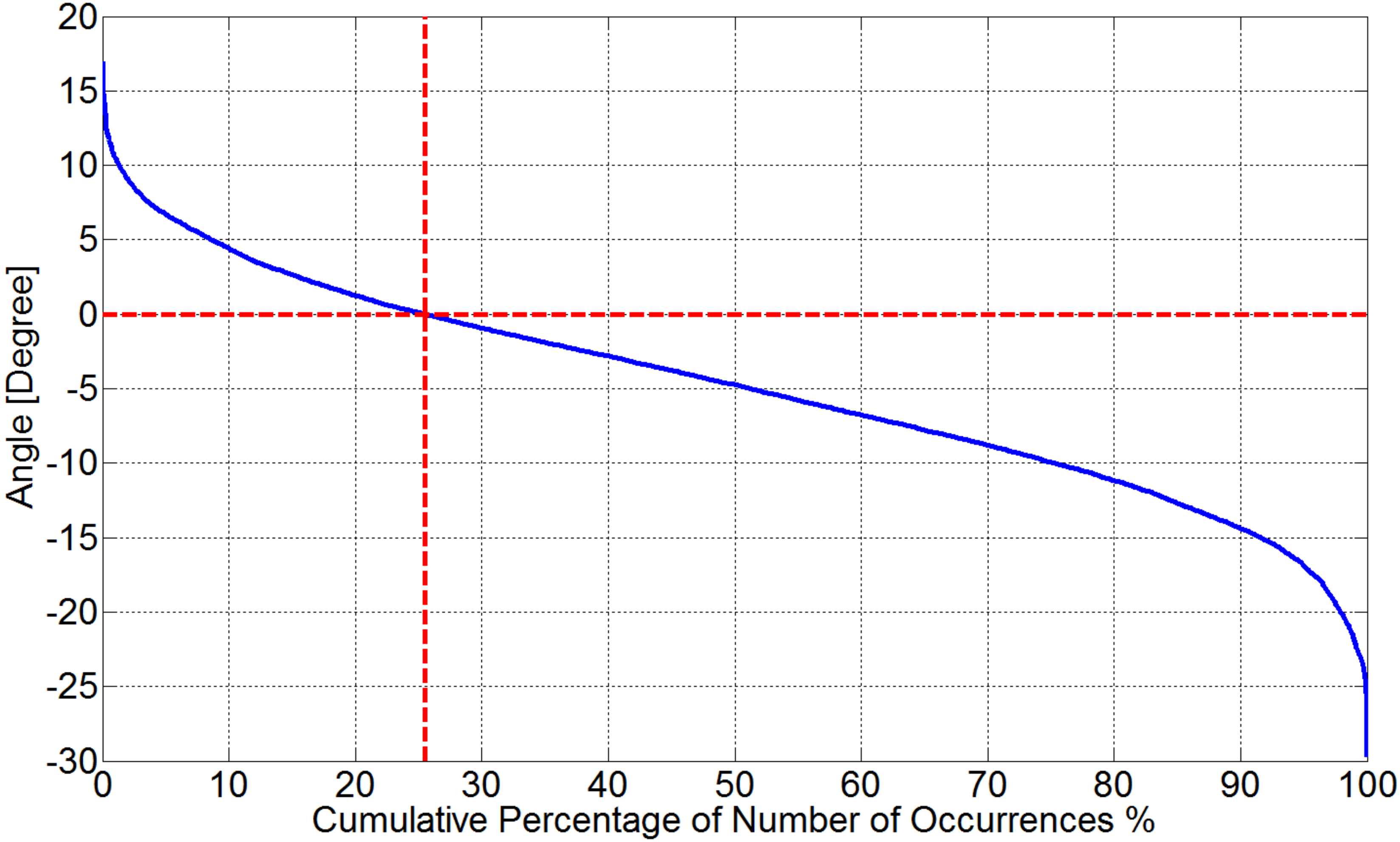

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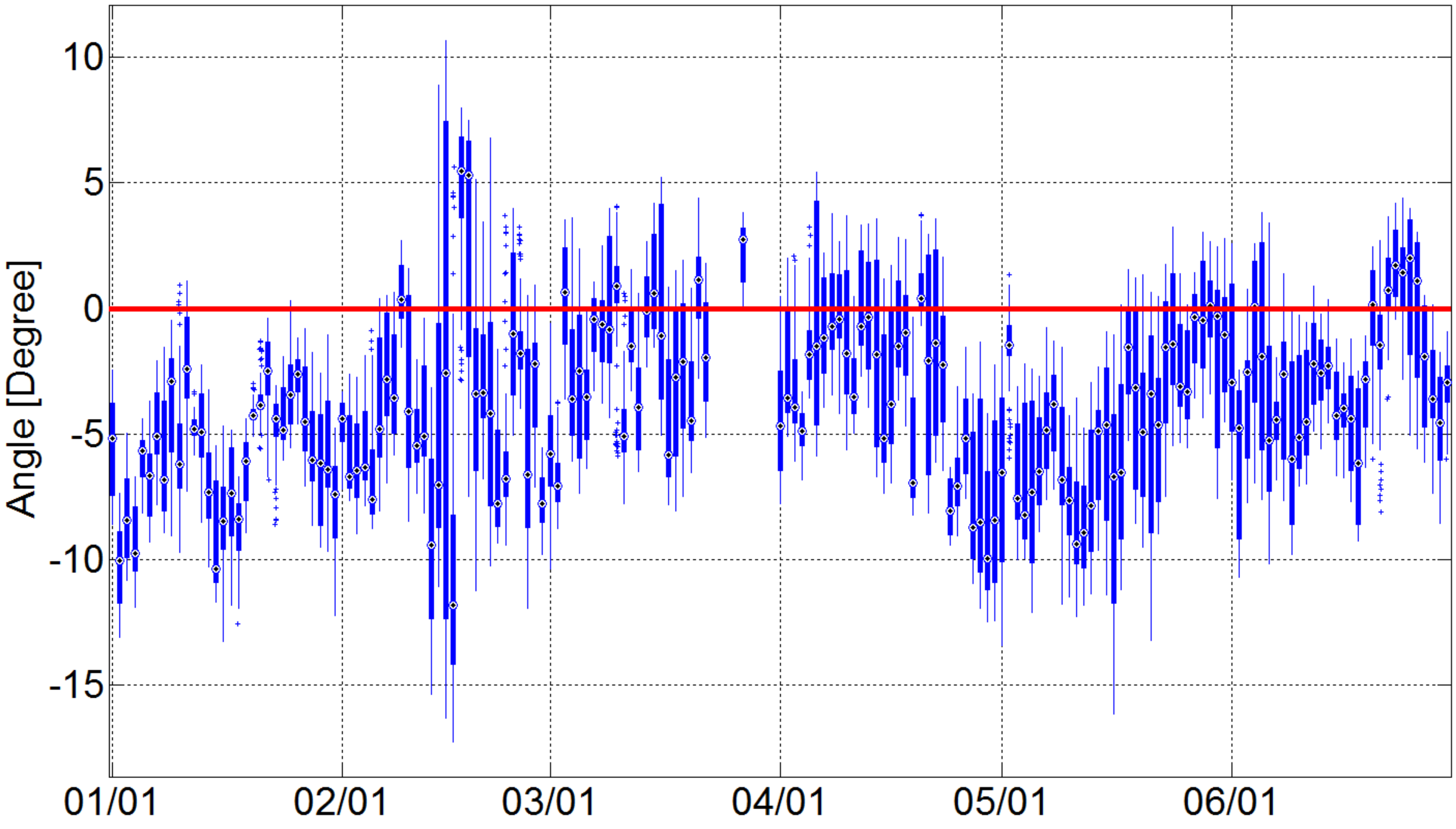

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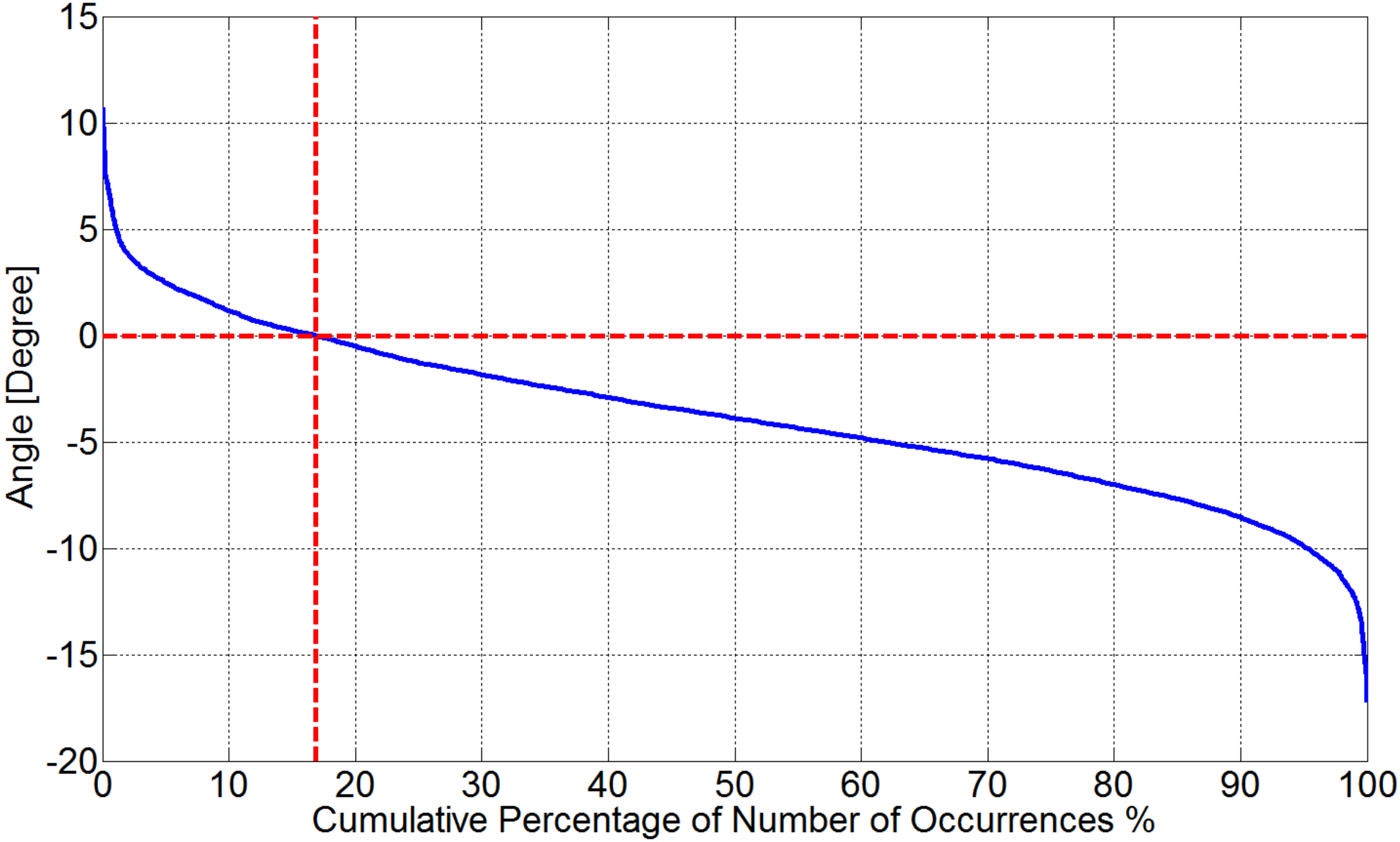

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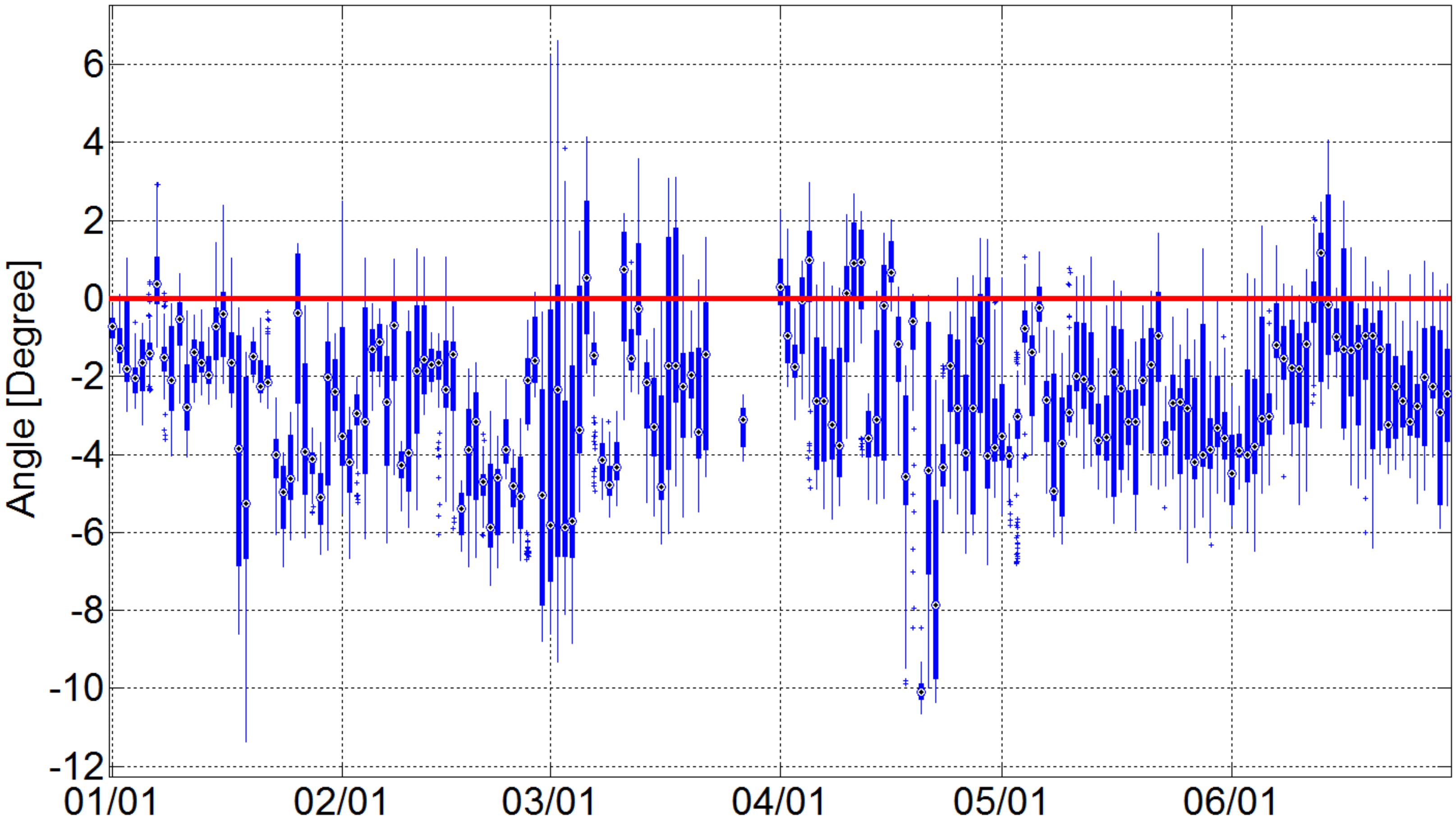

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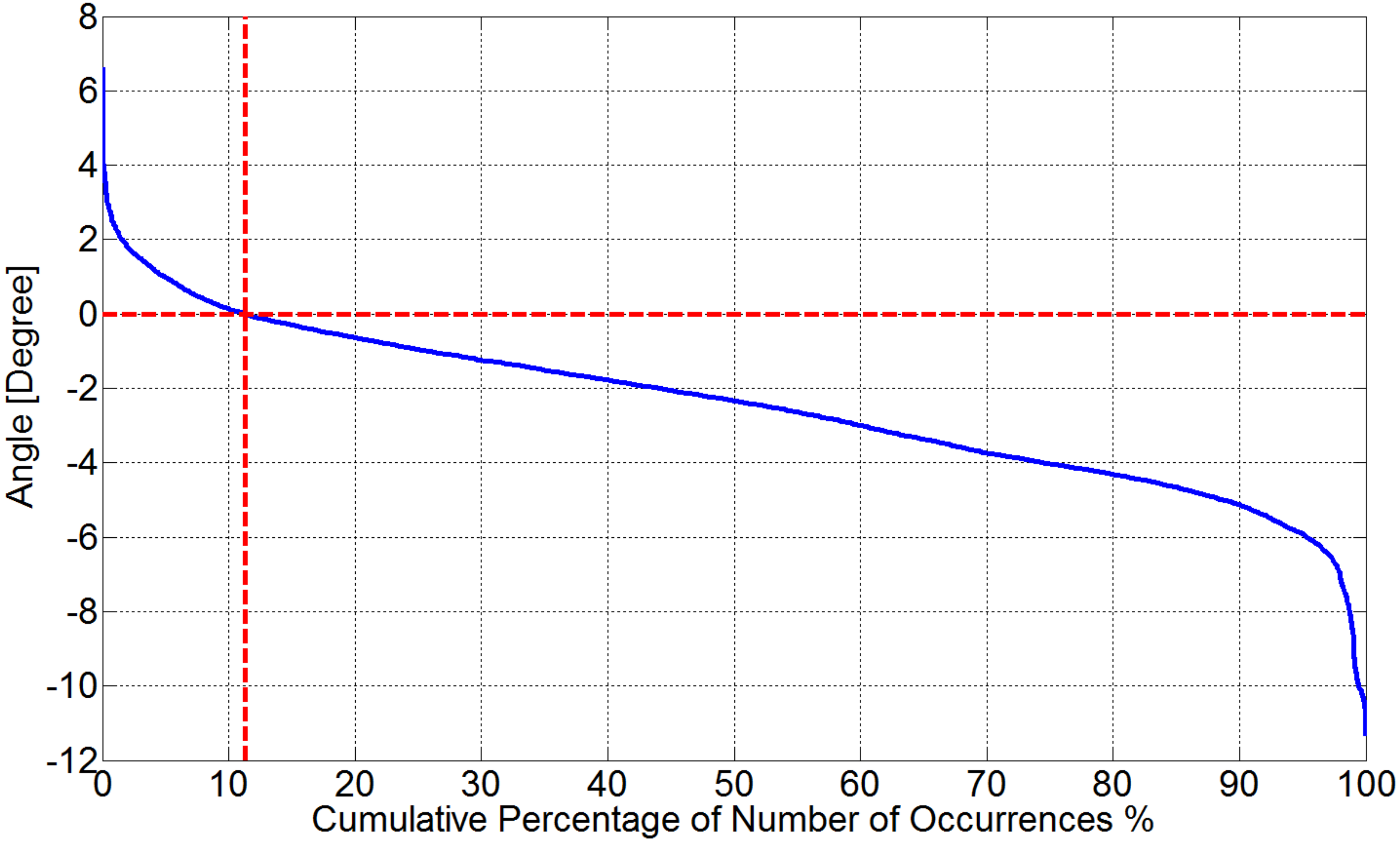
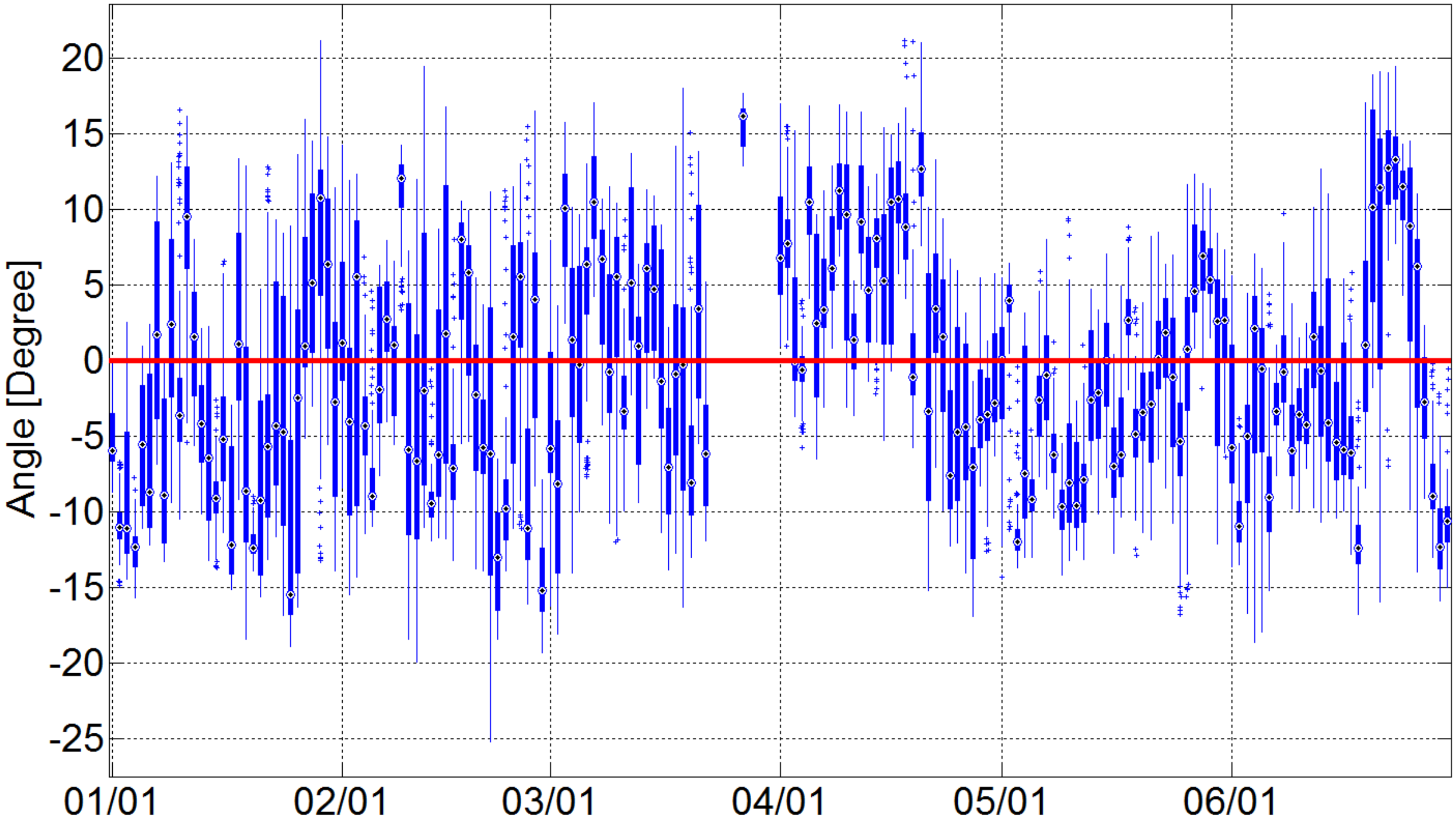


FarWest 7-West 14



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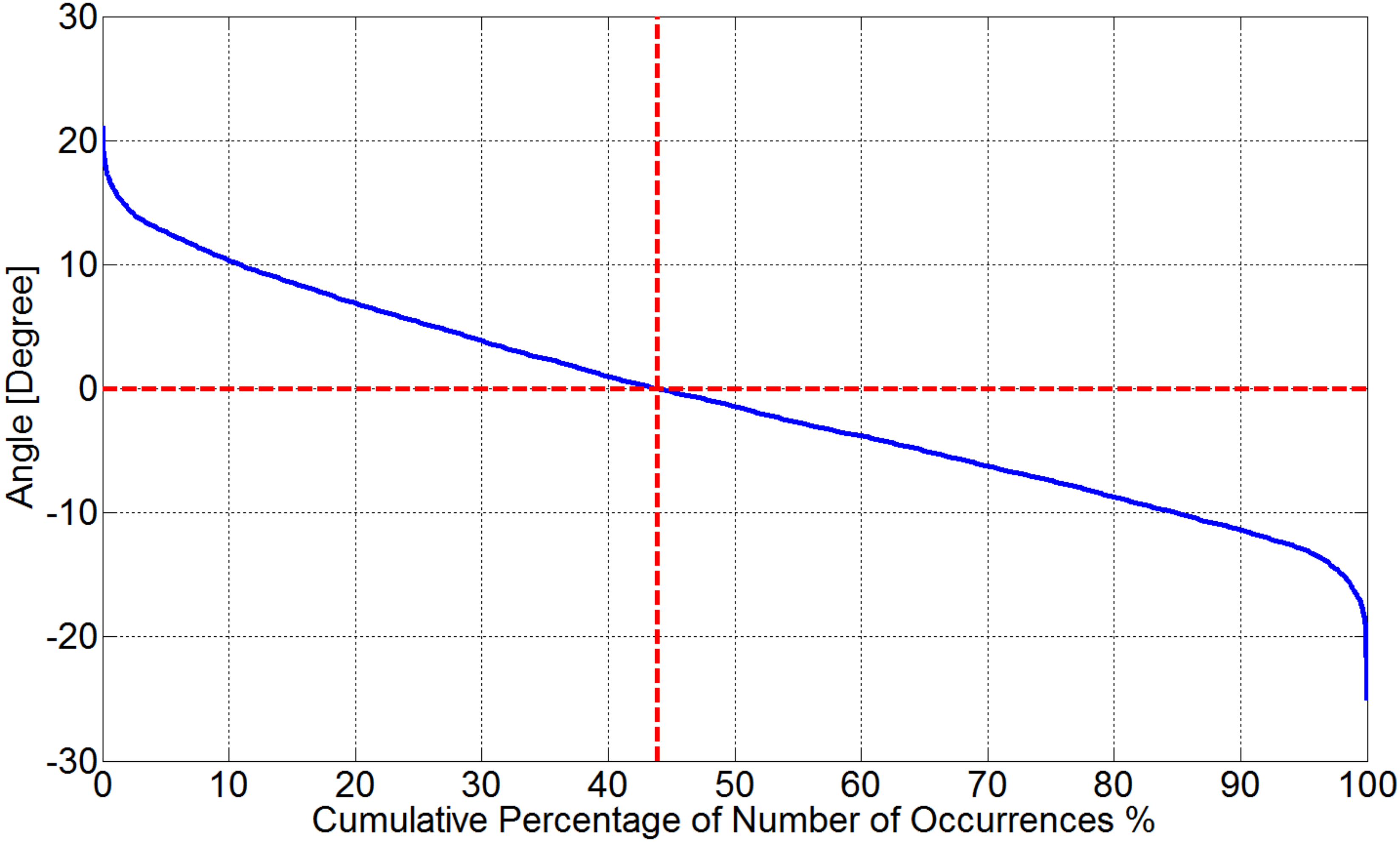

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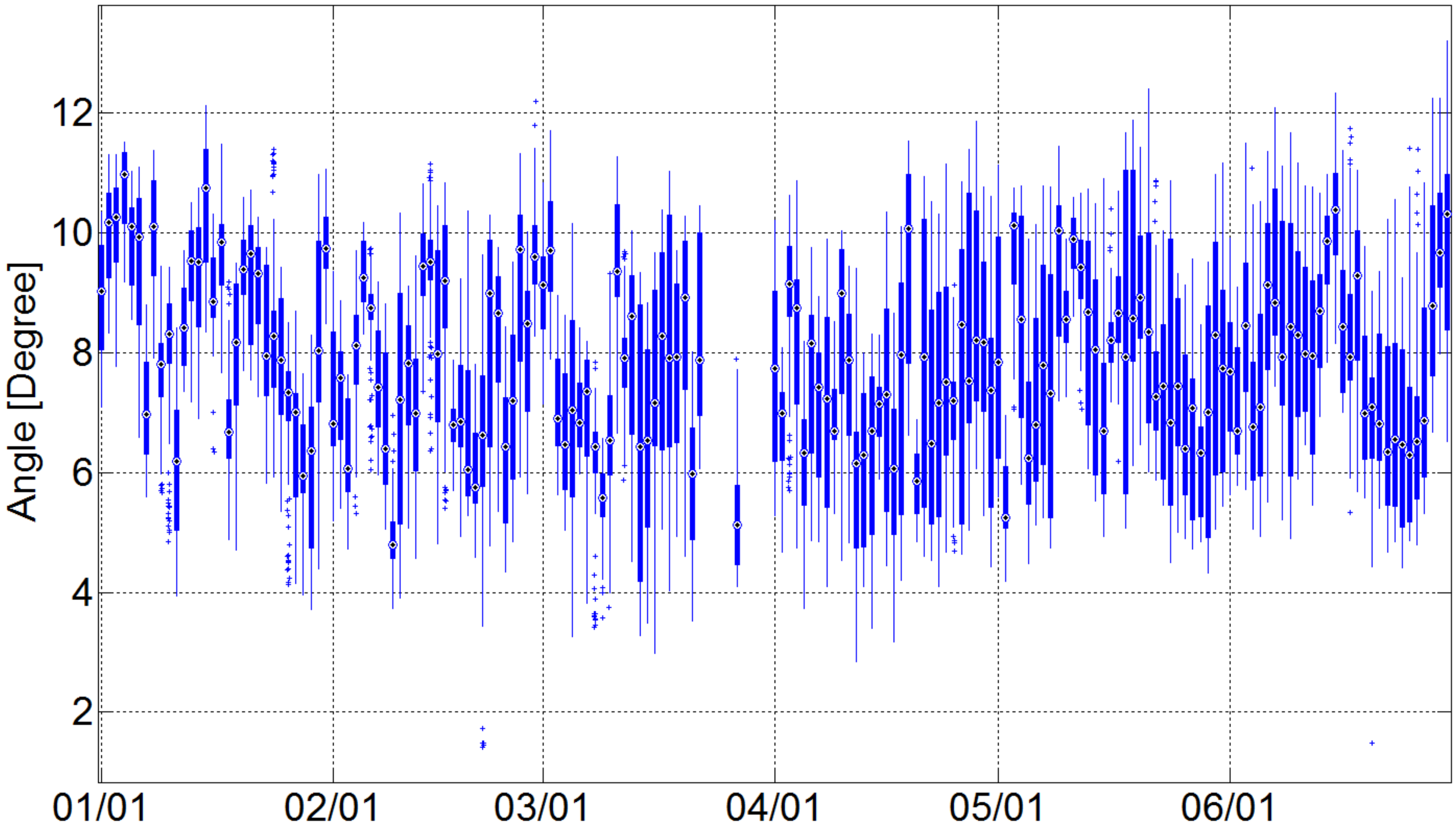

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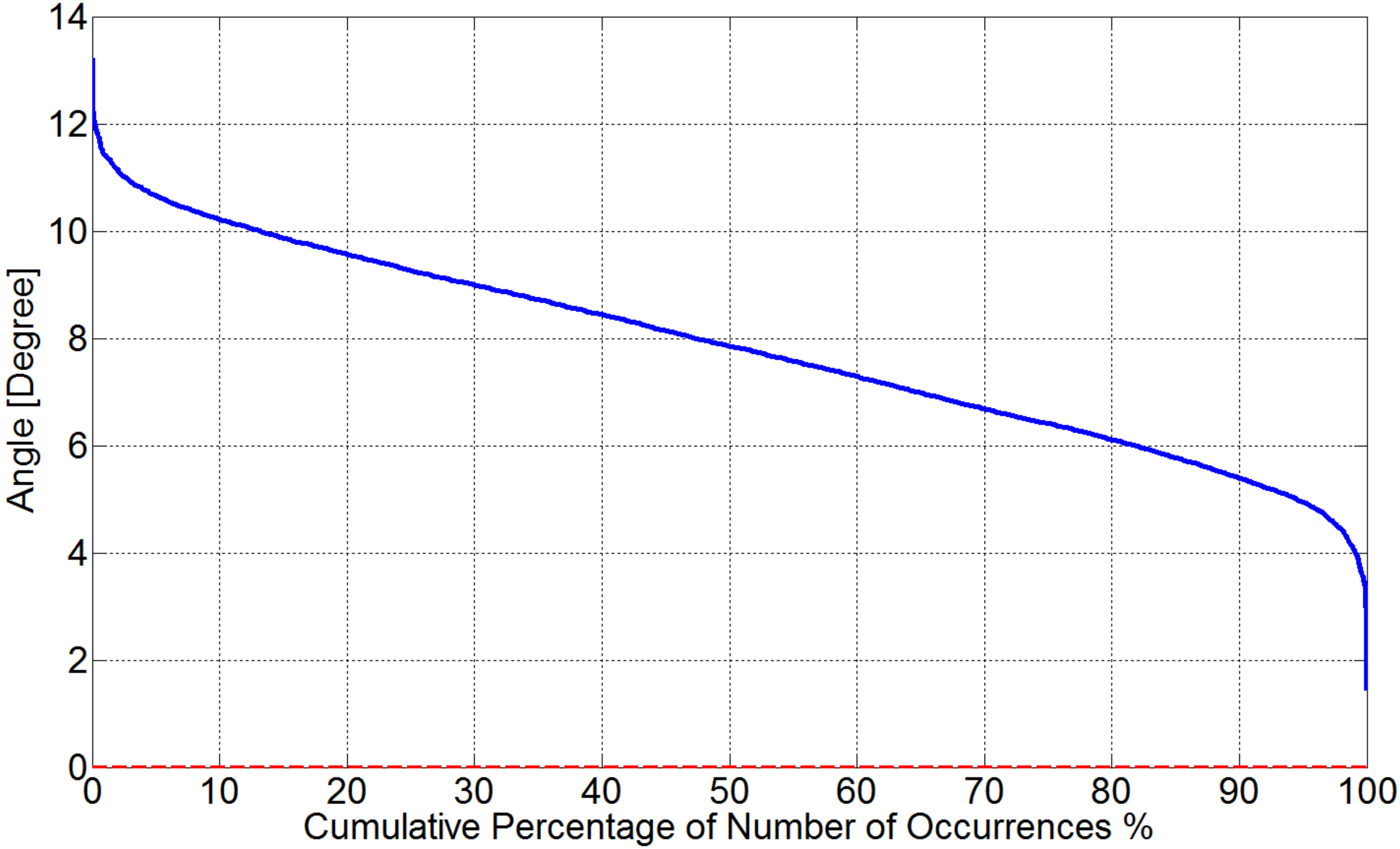

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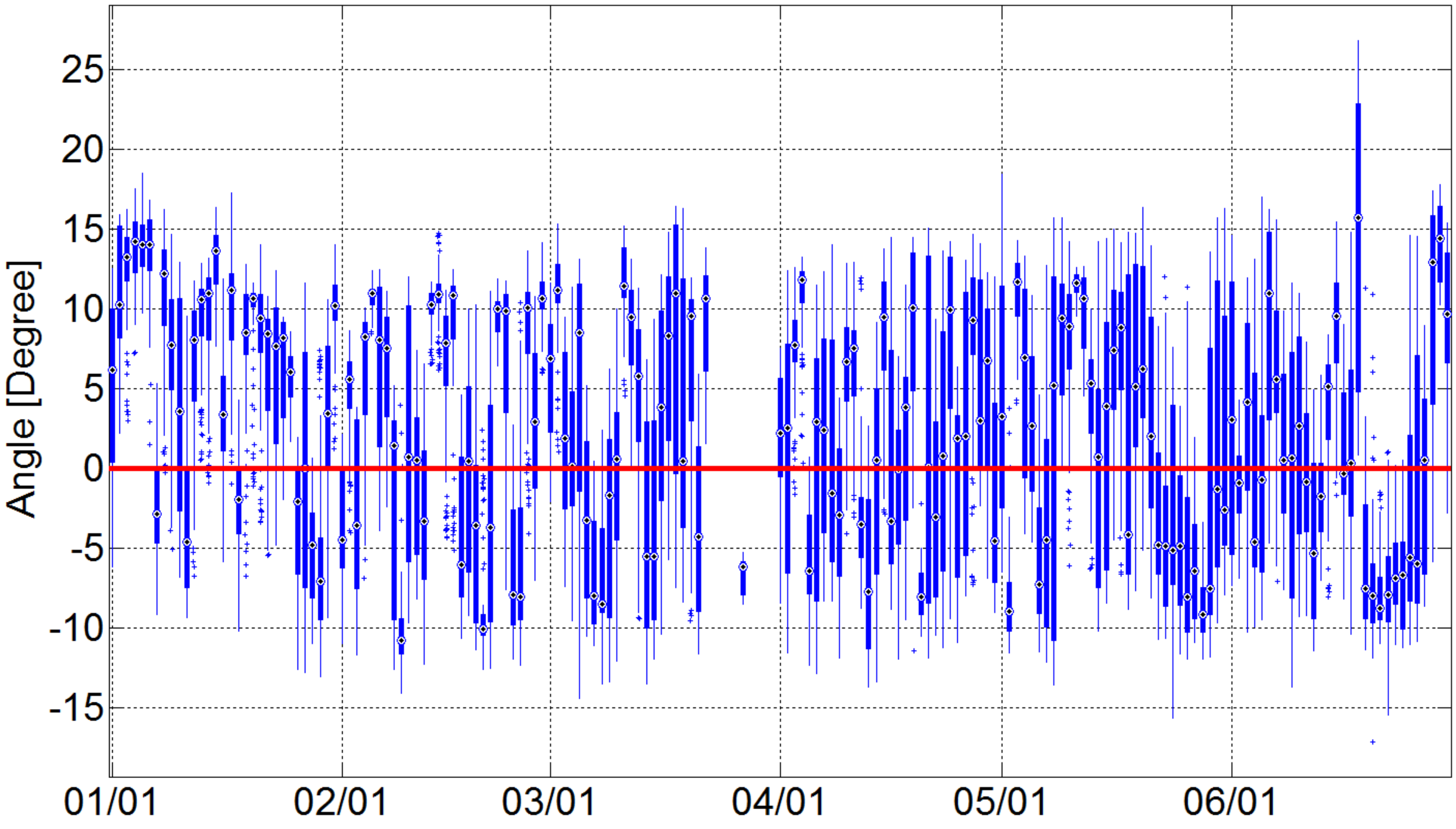

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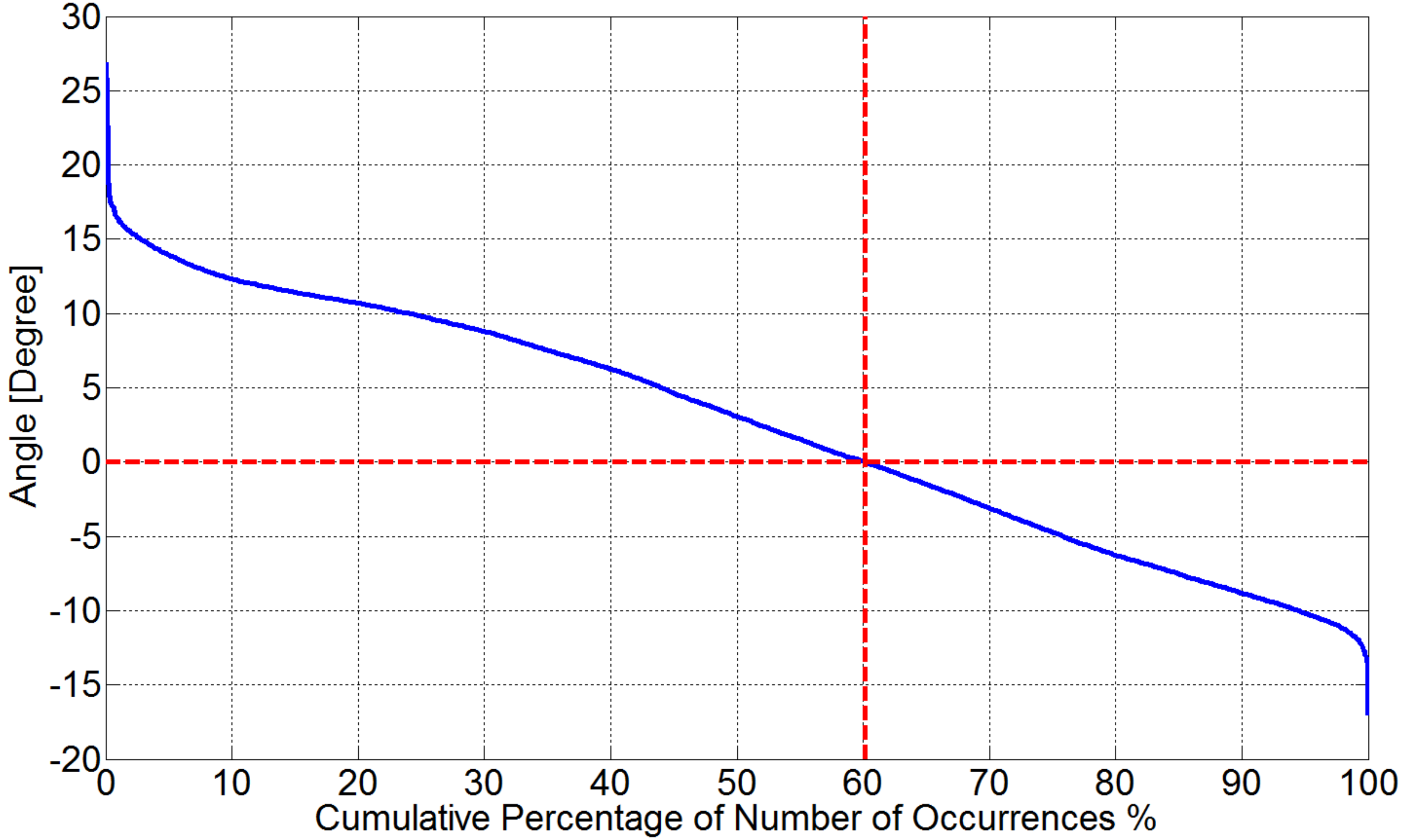

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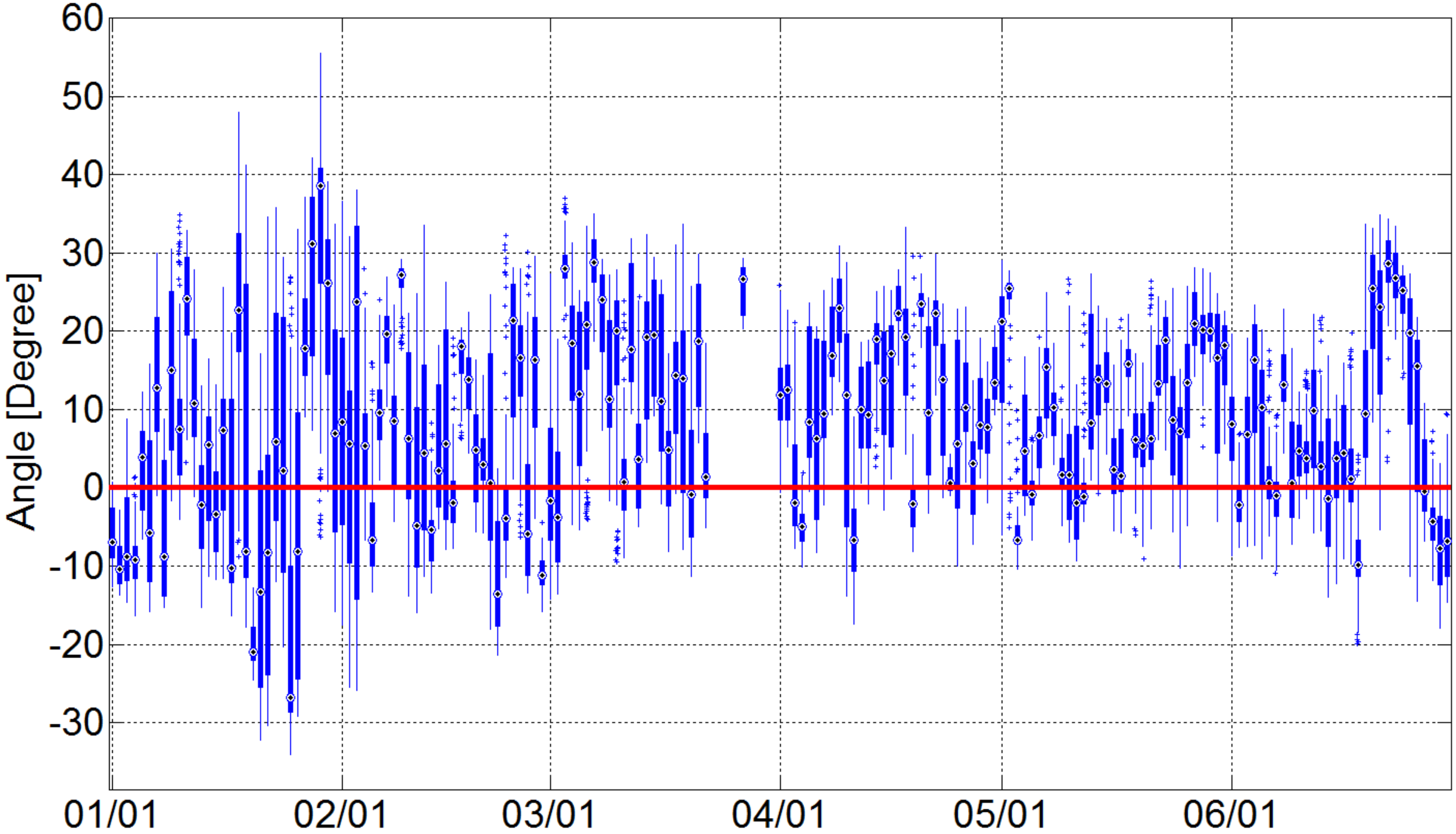

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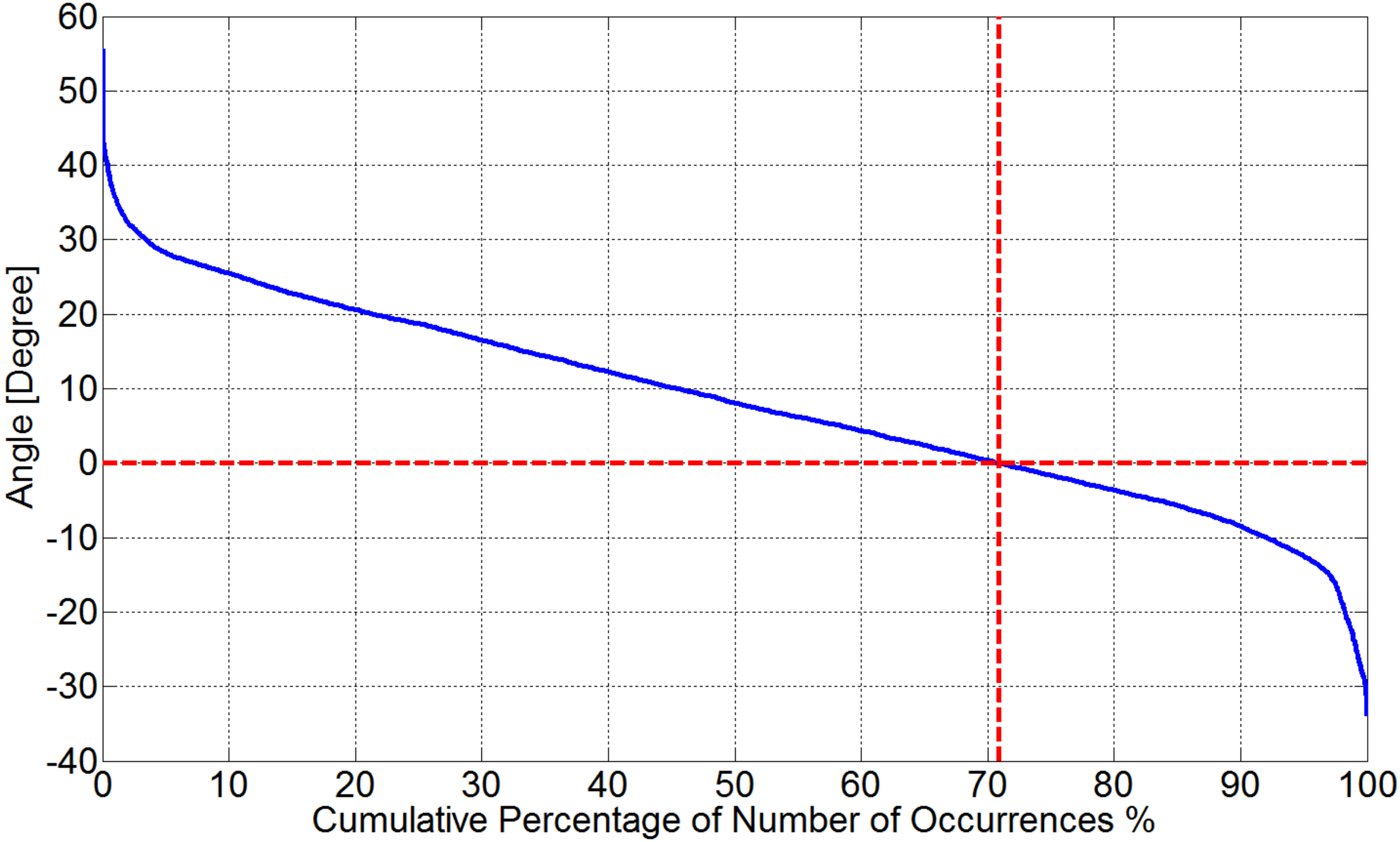

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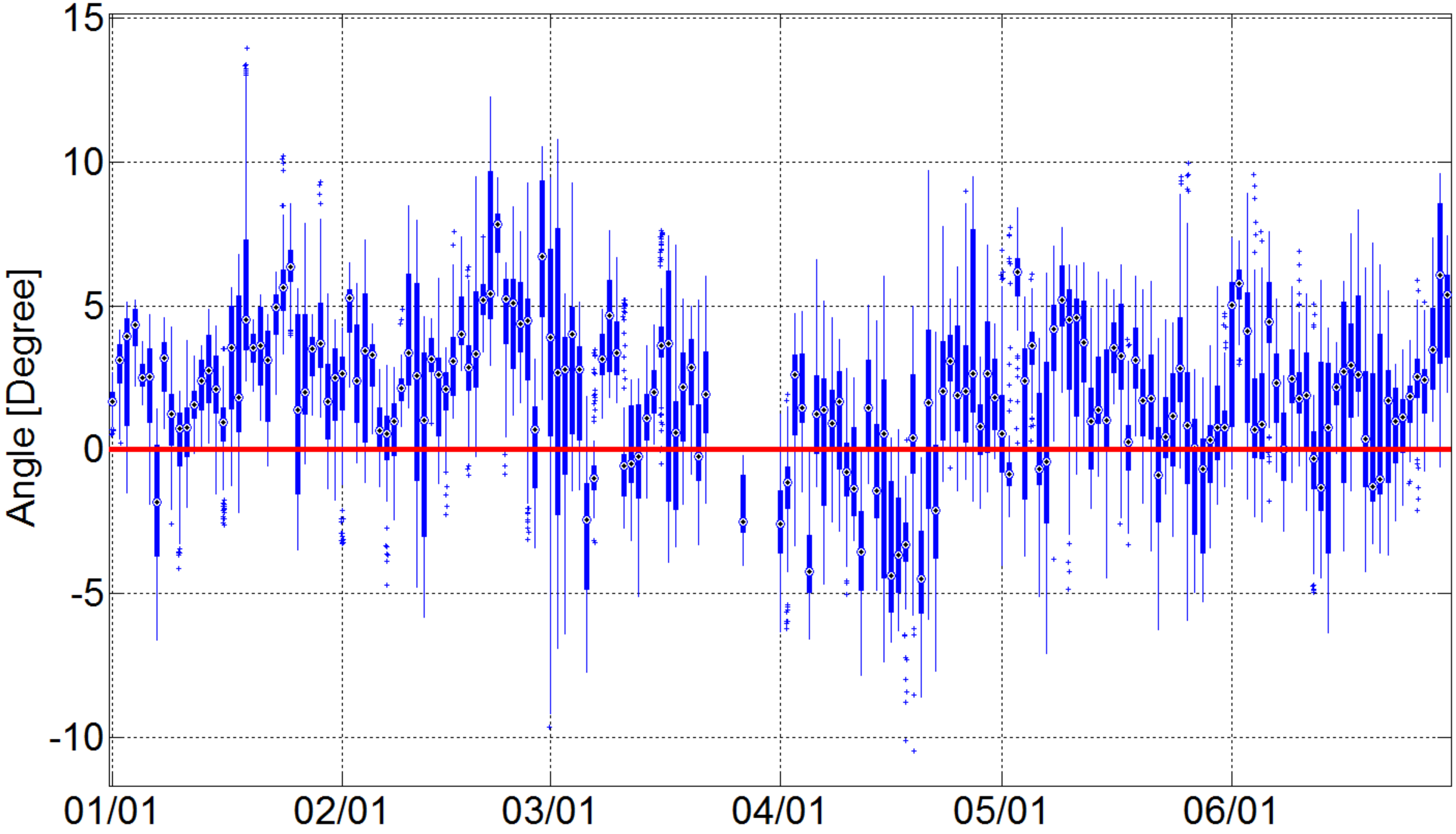

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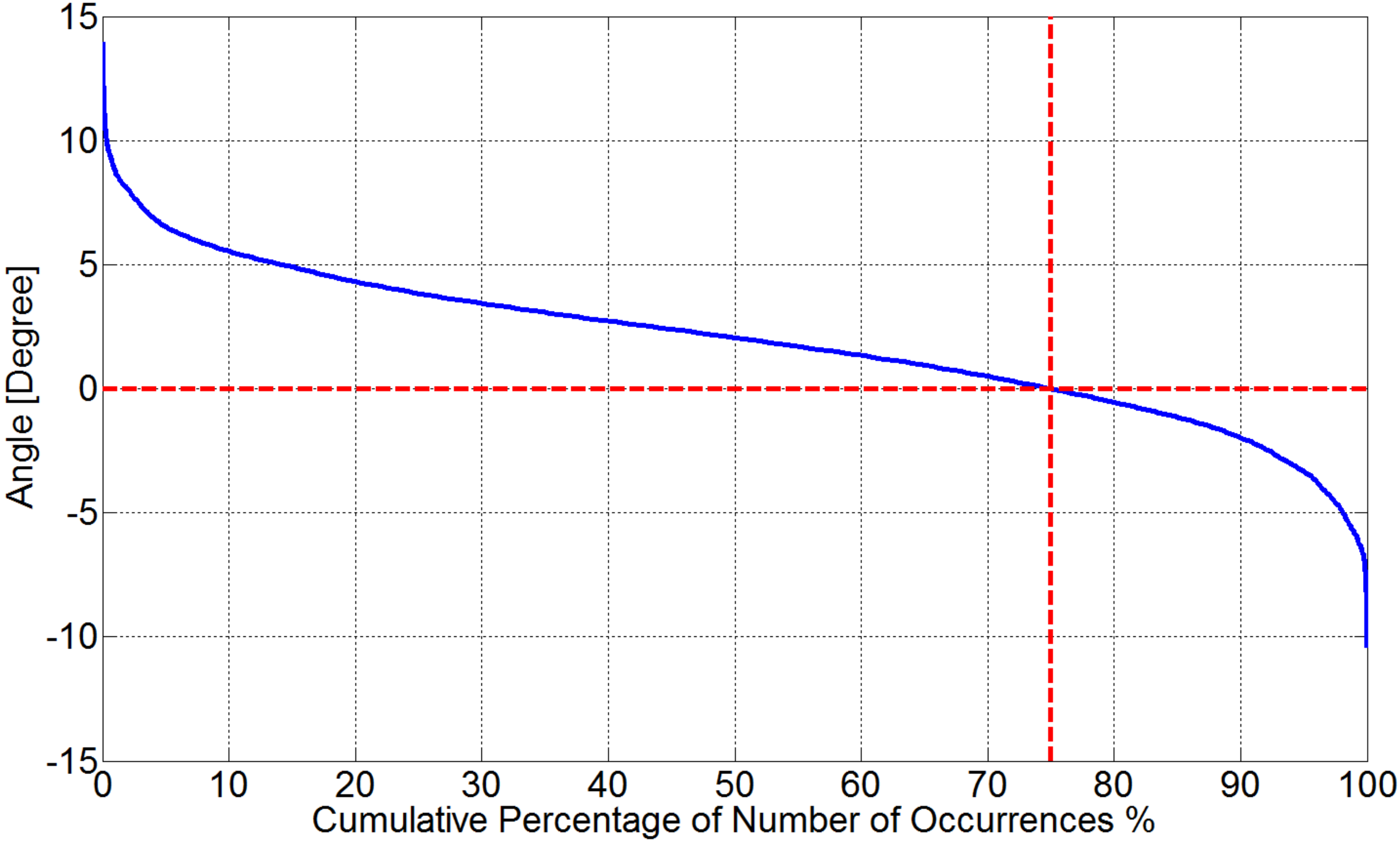

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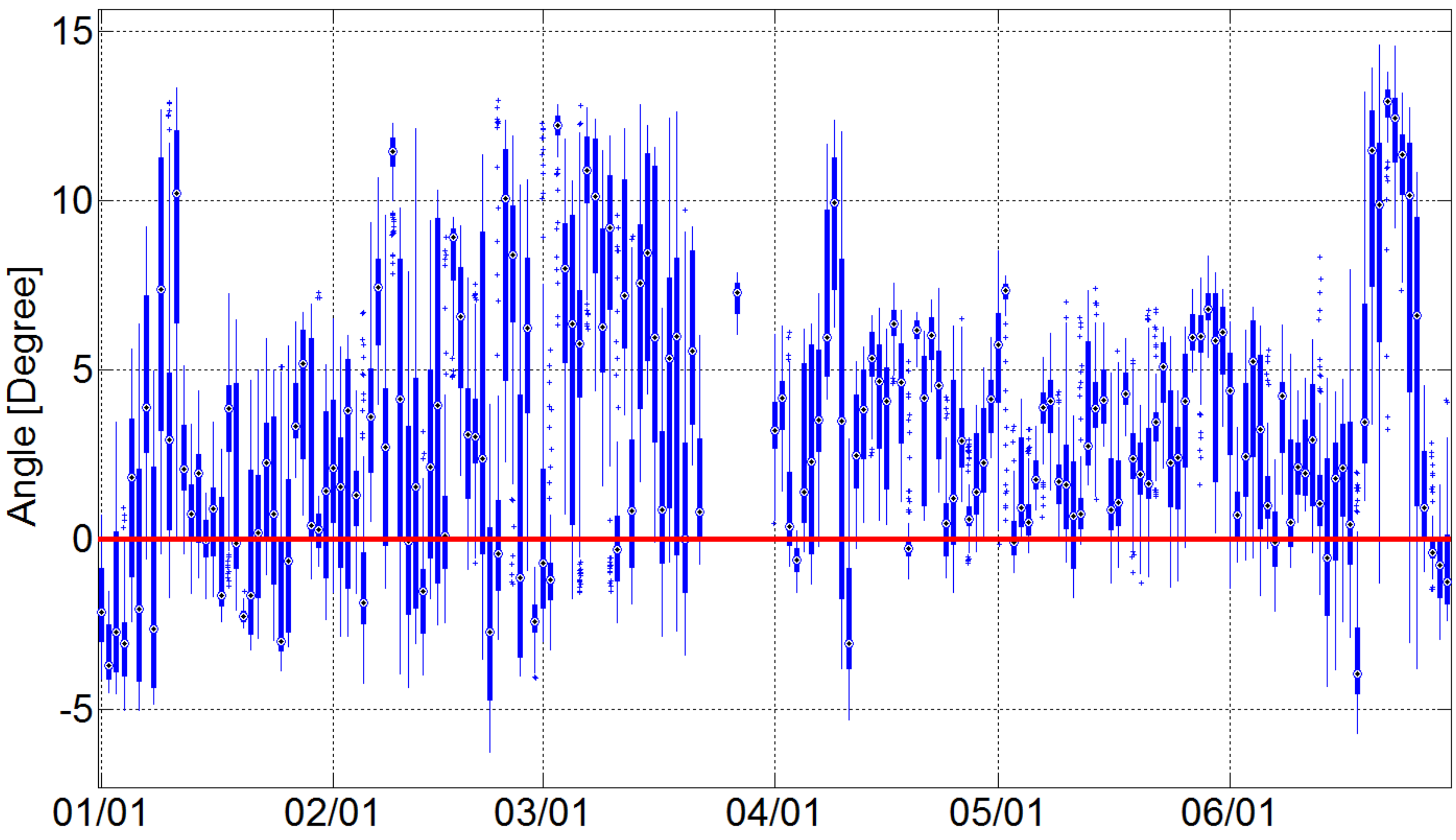

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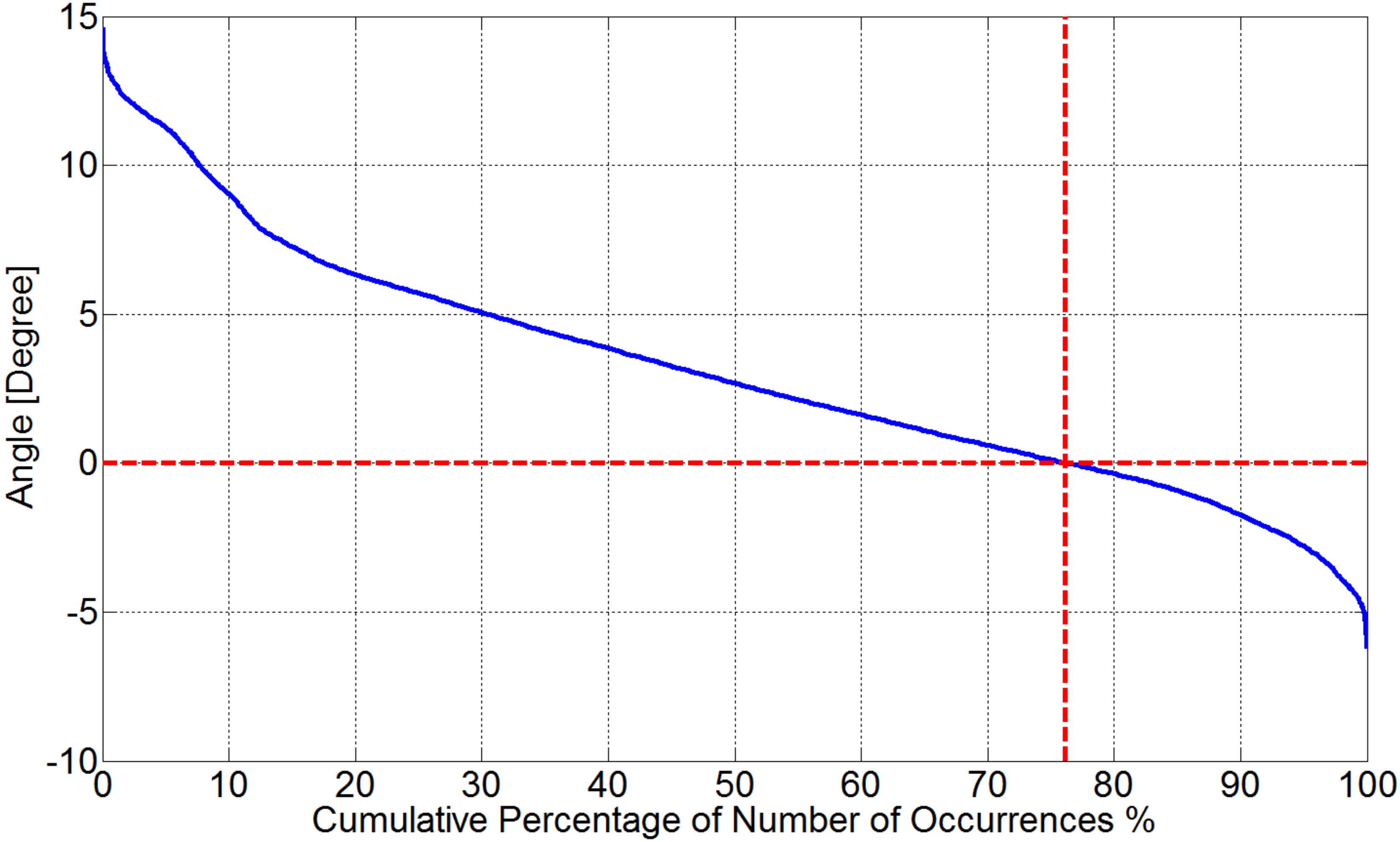

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-5
-10
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70
80
90
100
Angle [Degree]
Cumulative Percentage of Number of Occurrences %

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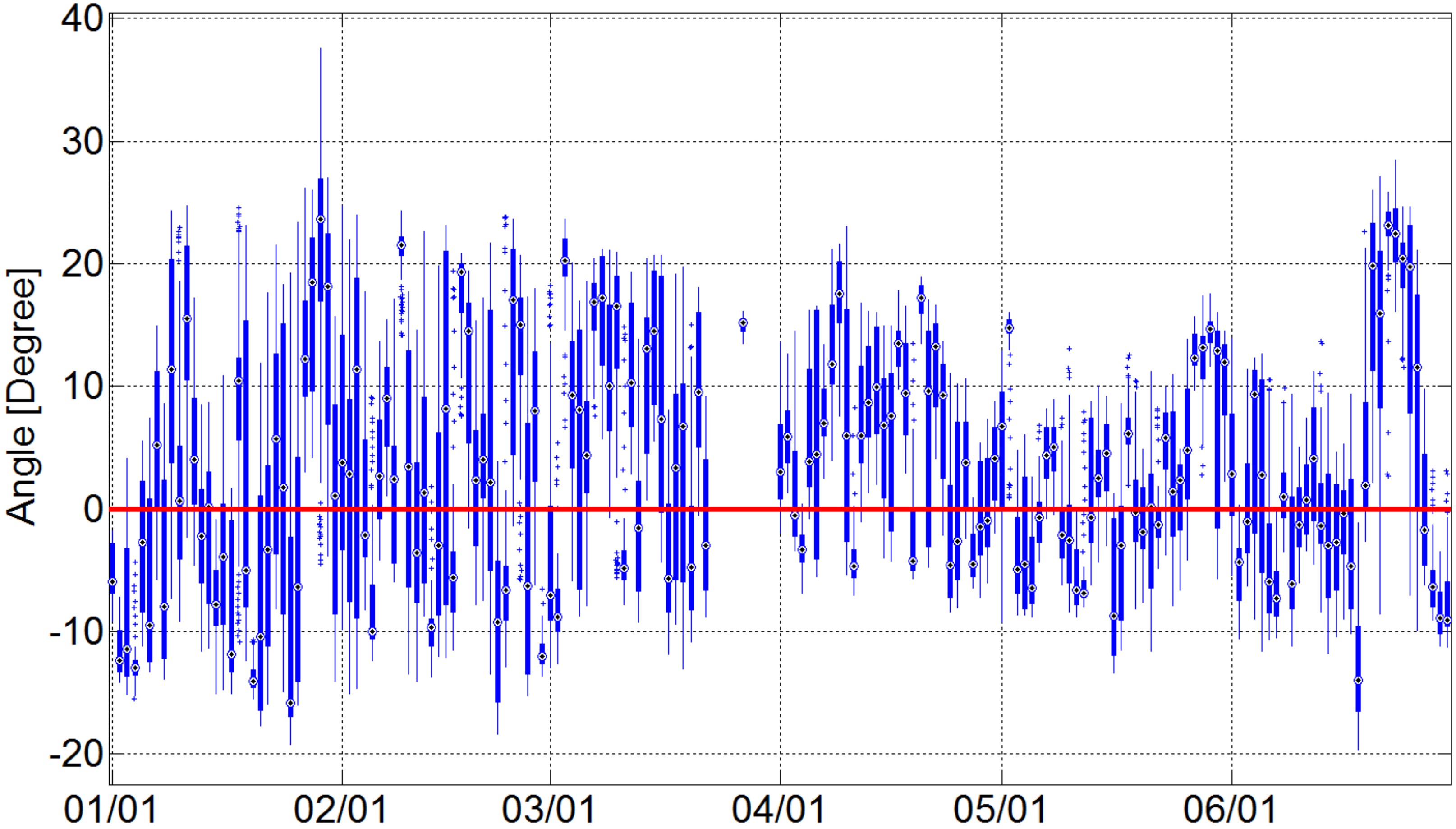

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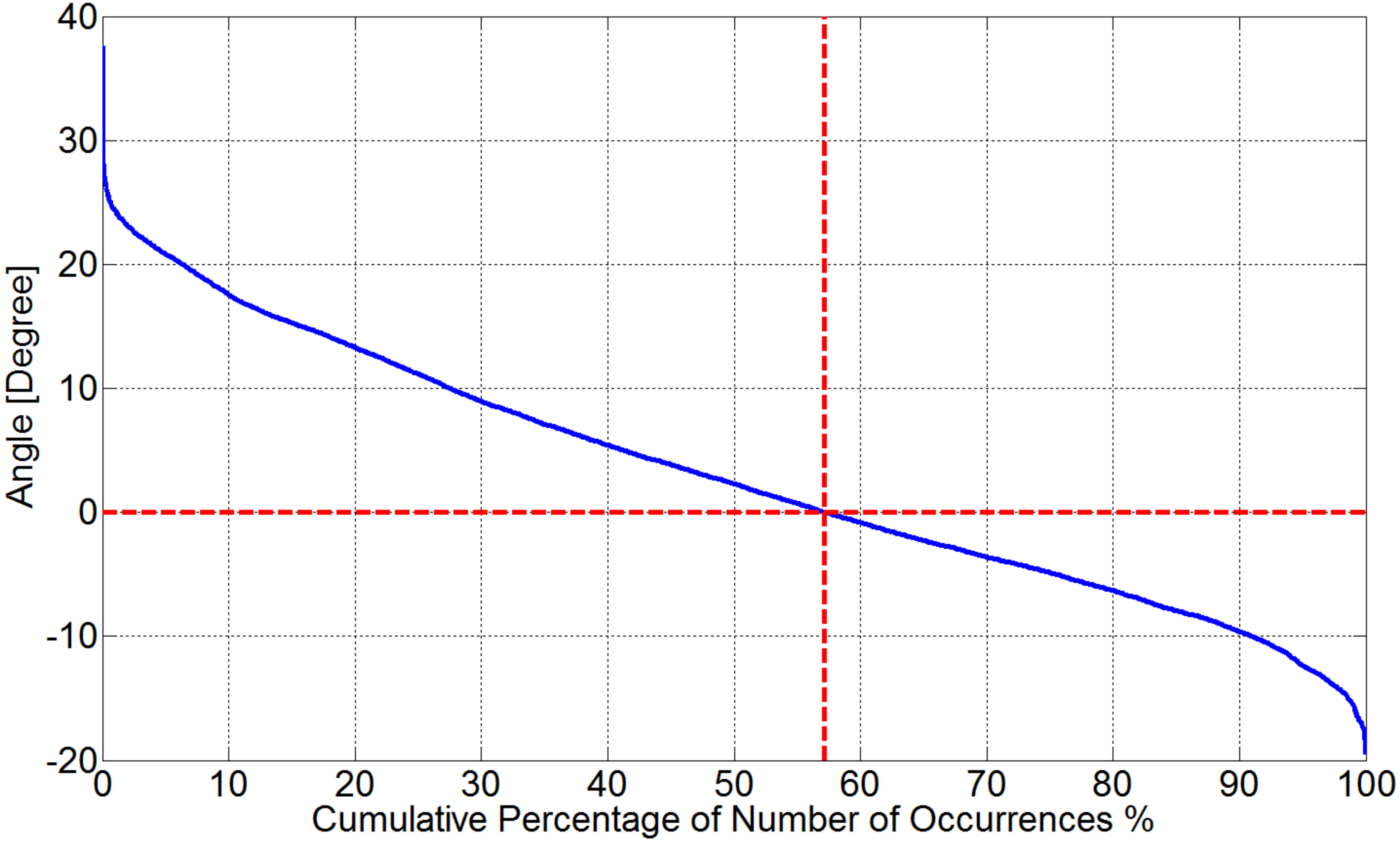

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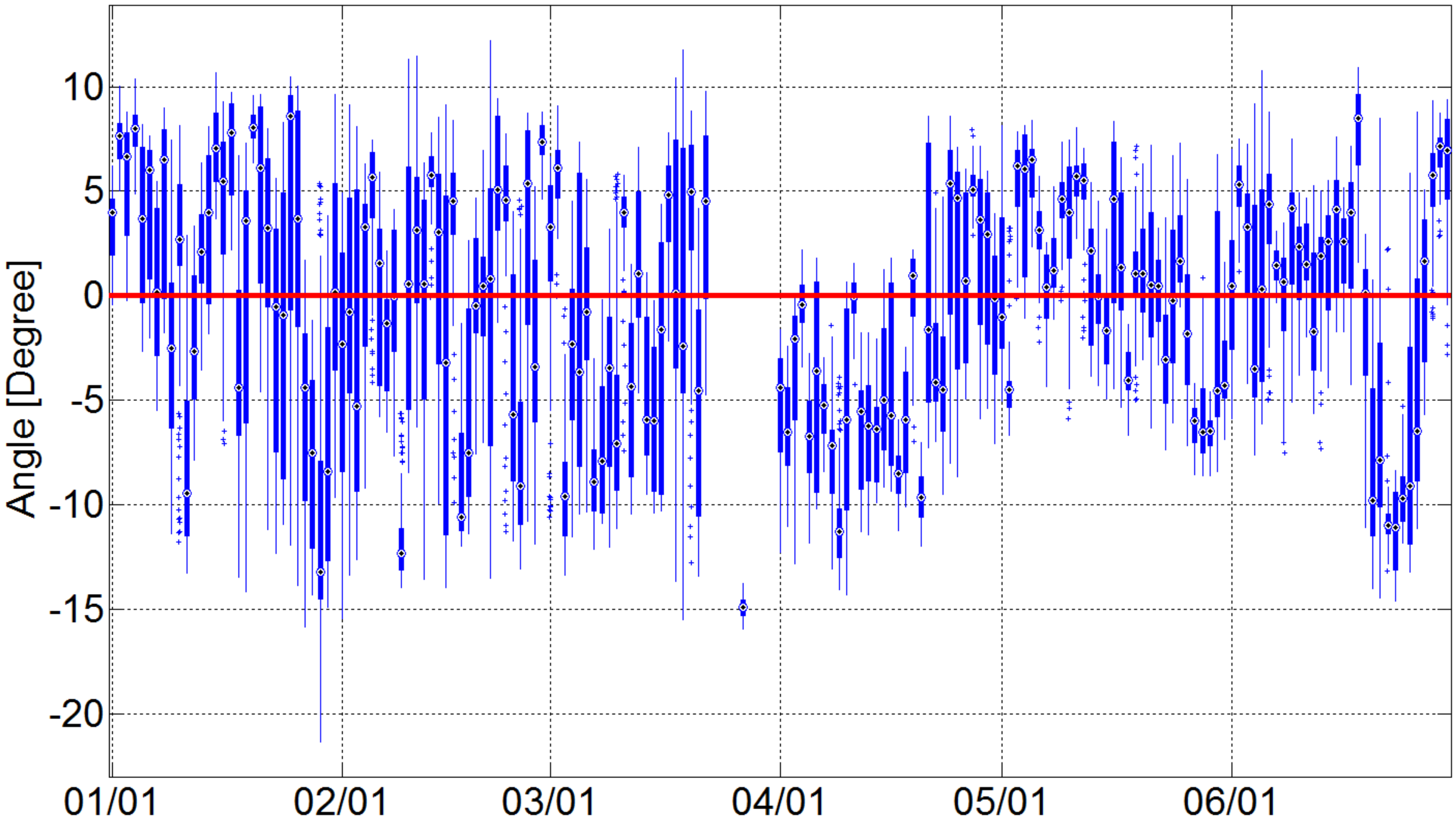

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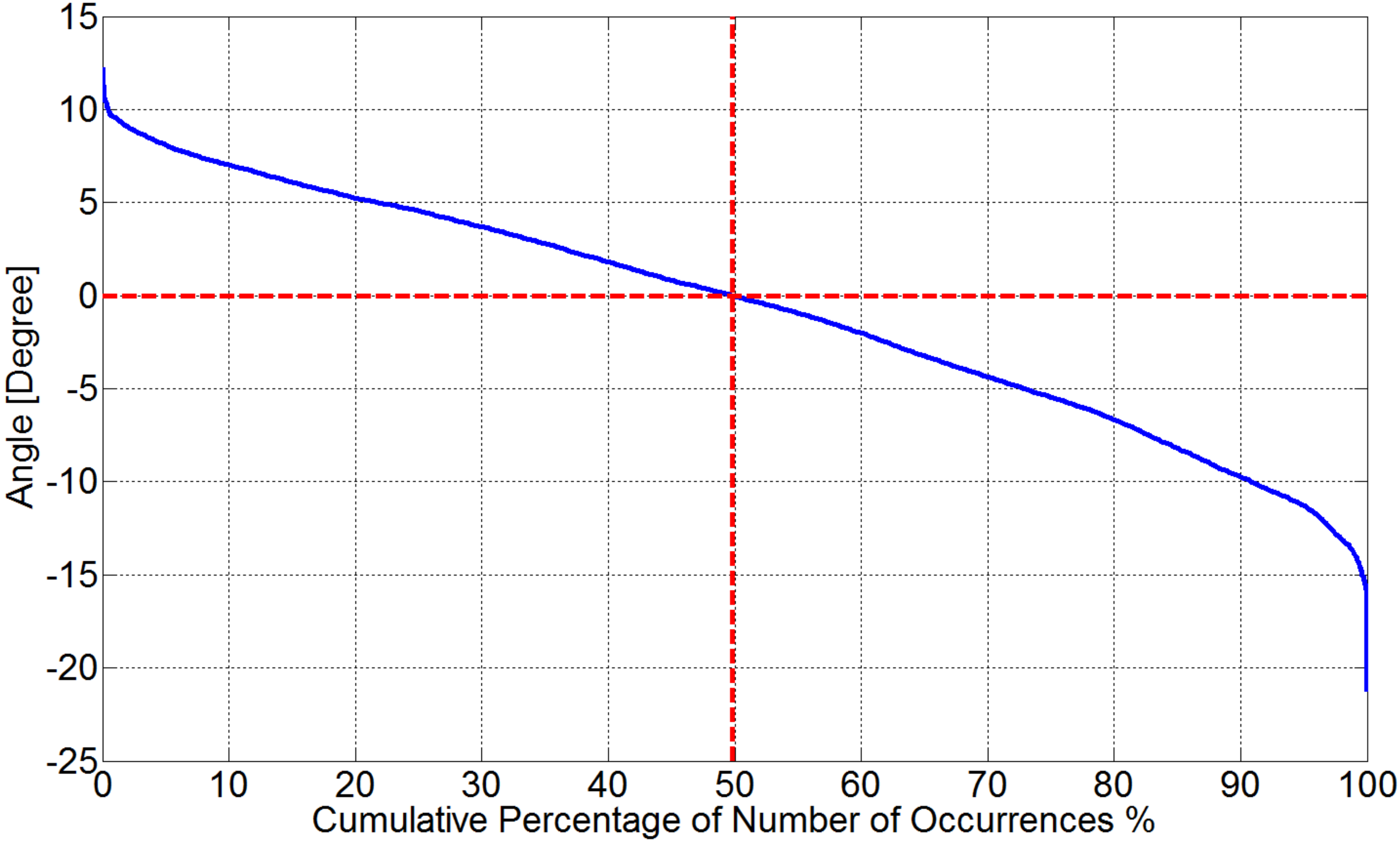

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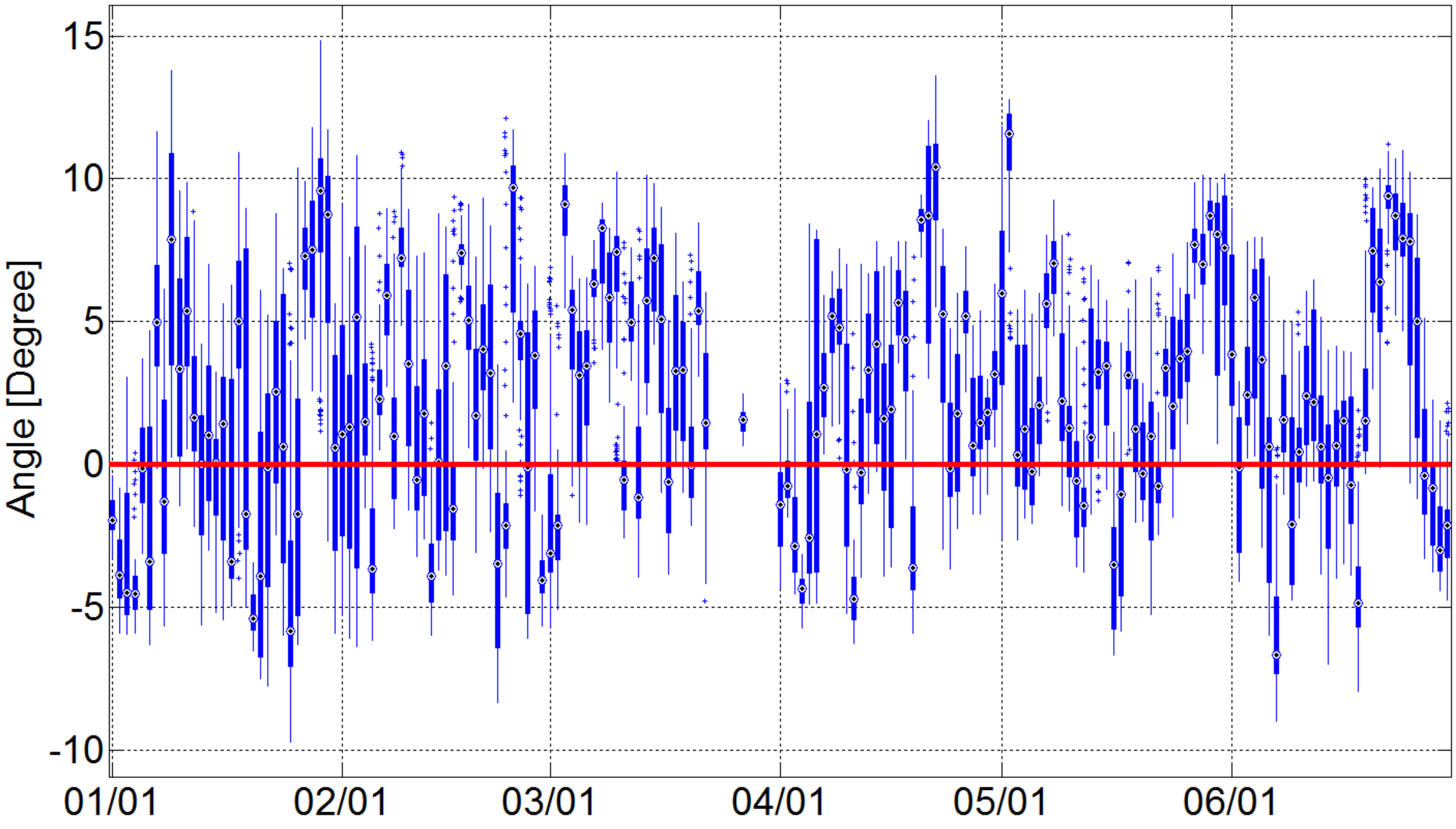

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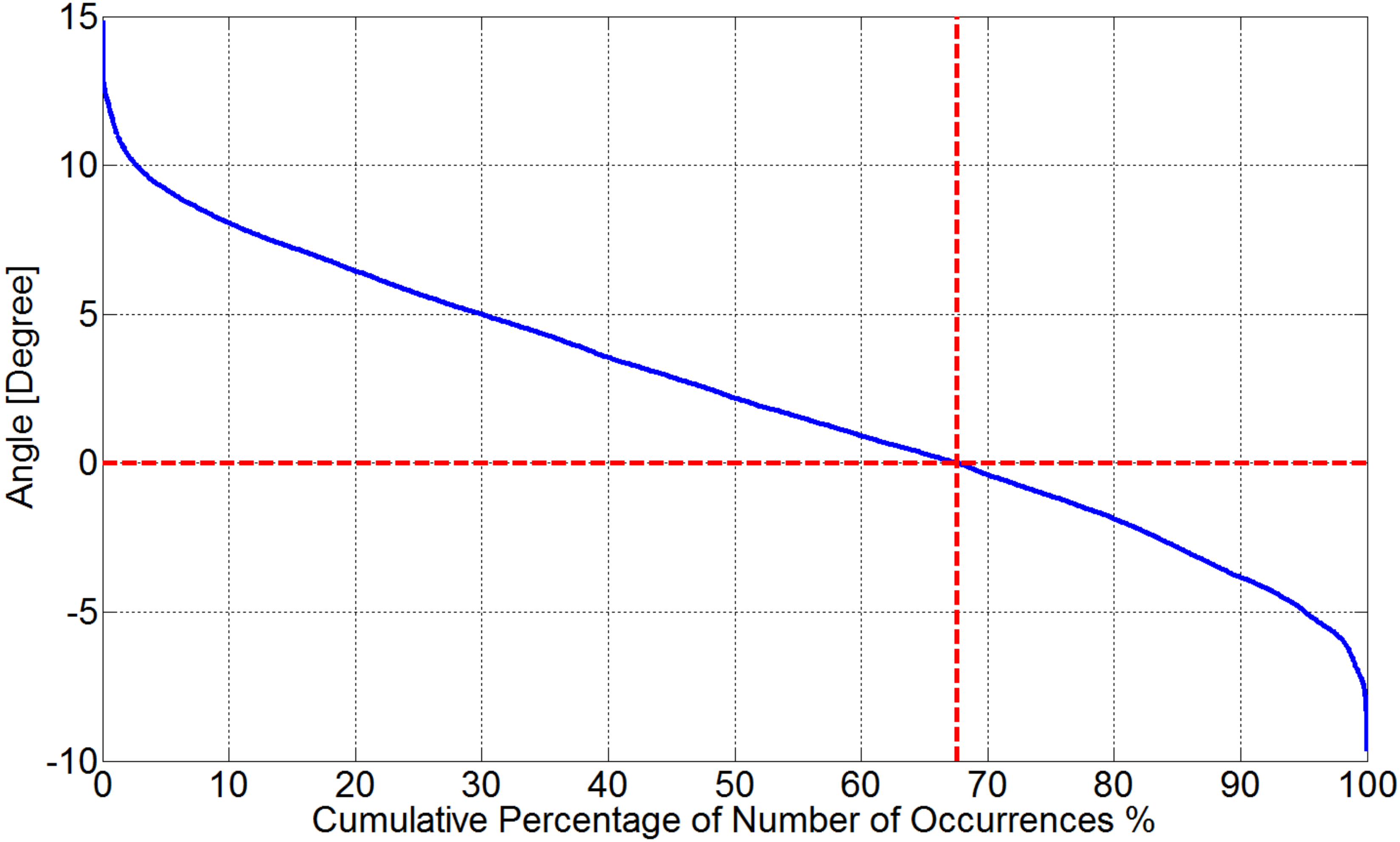

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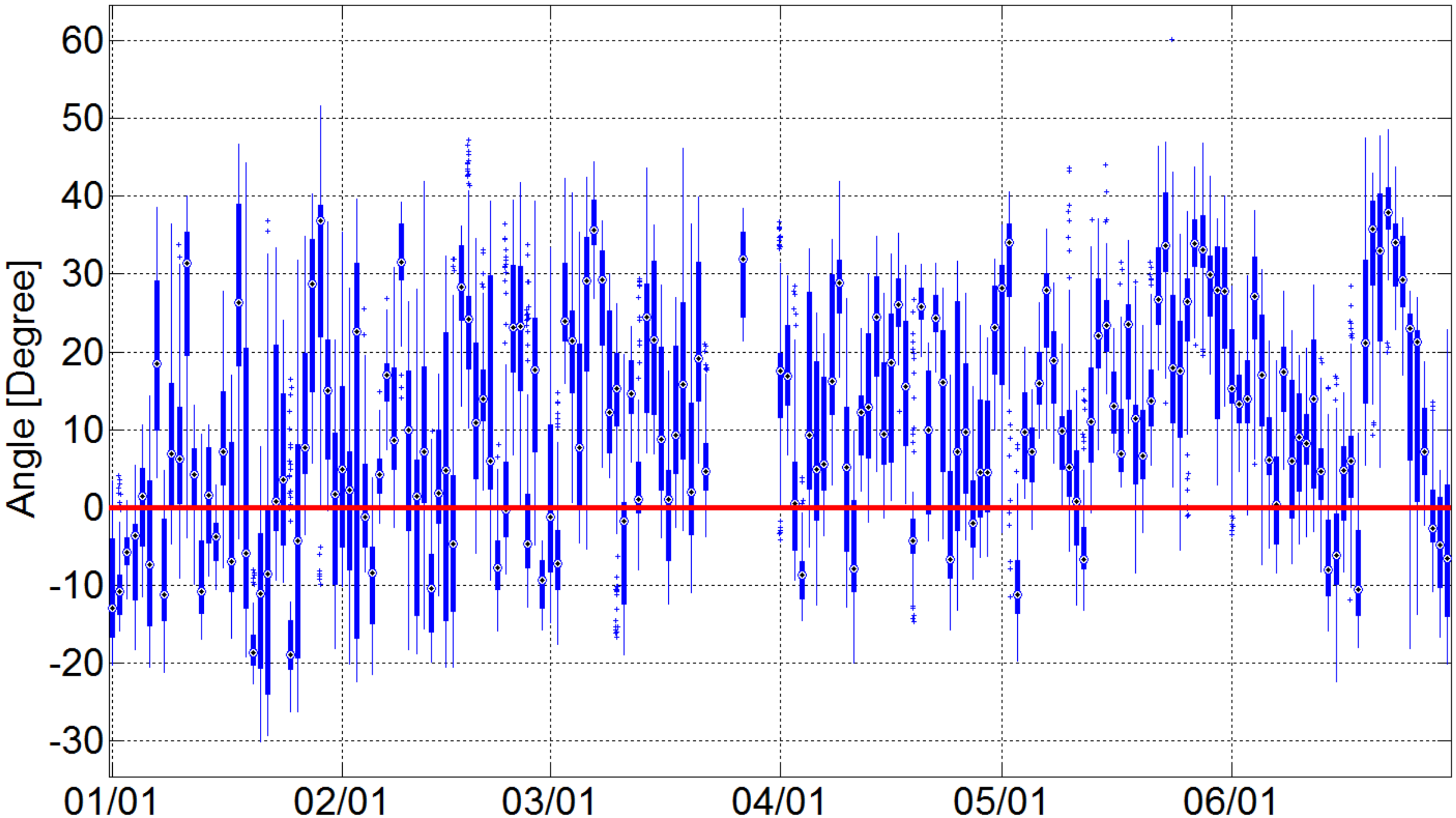

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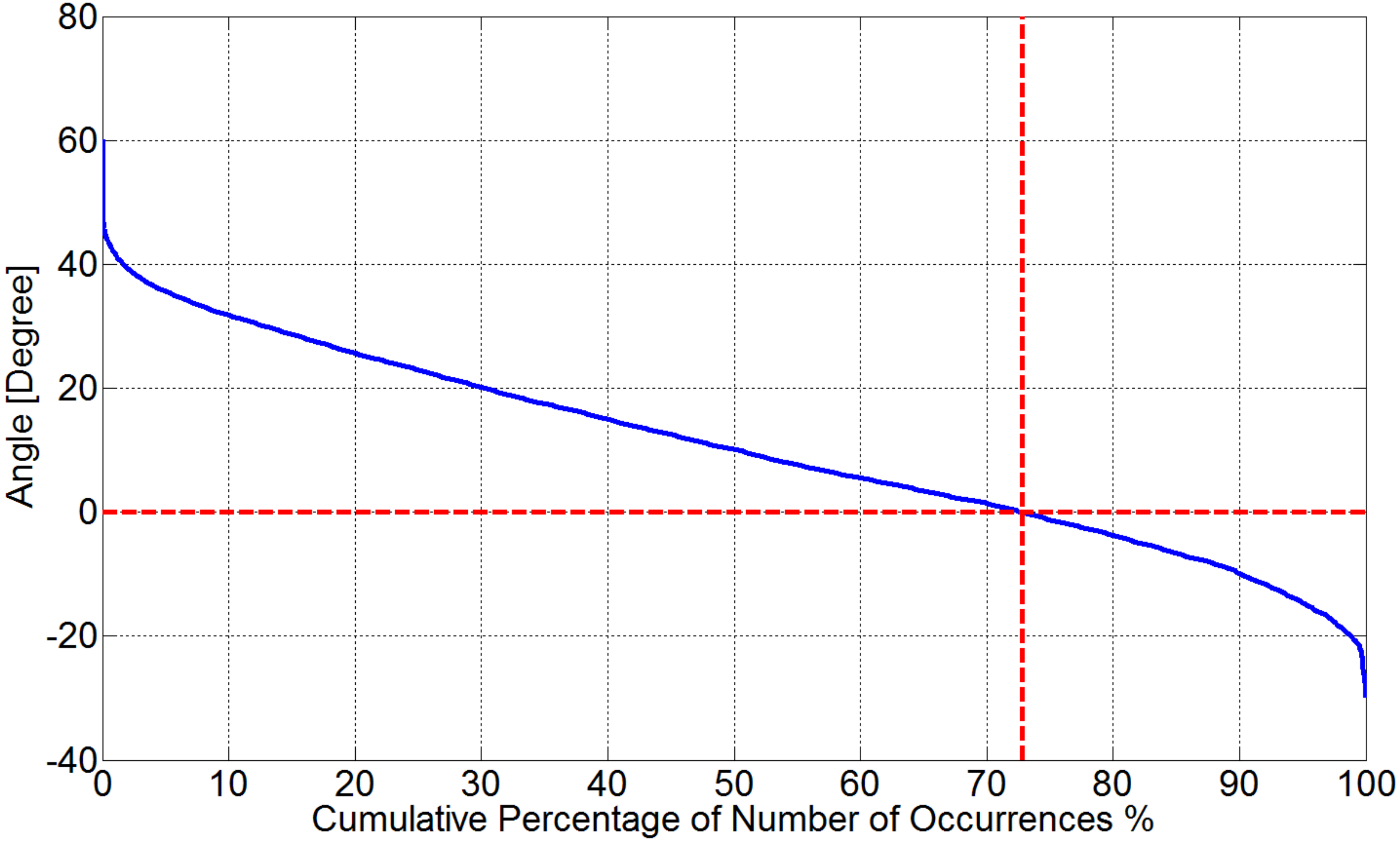
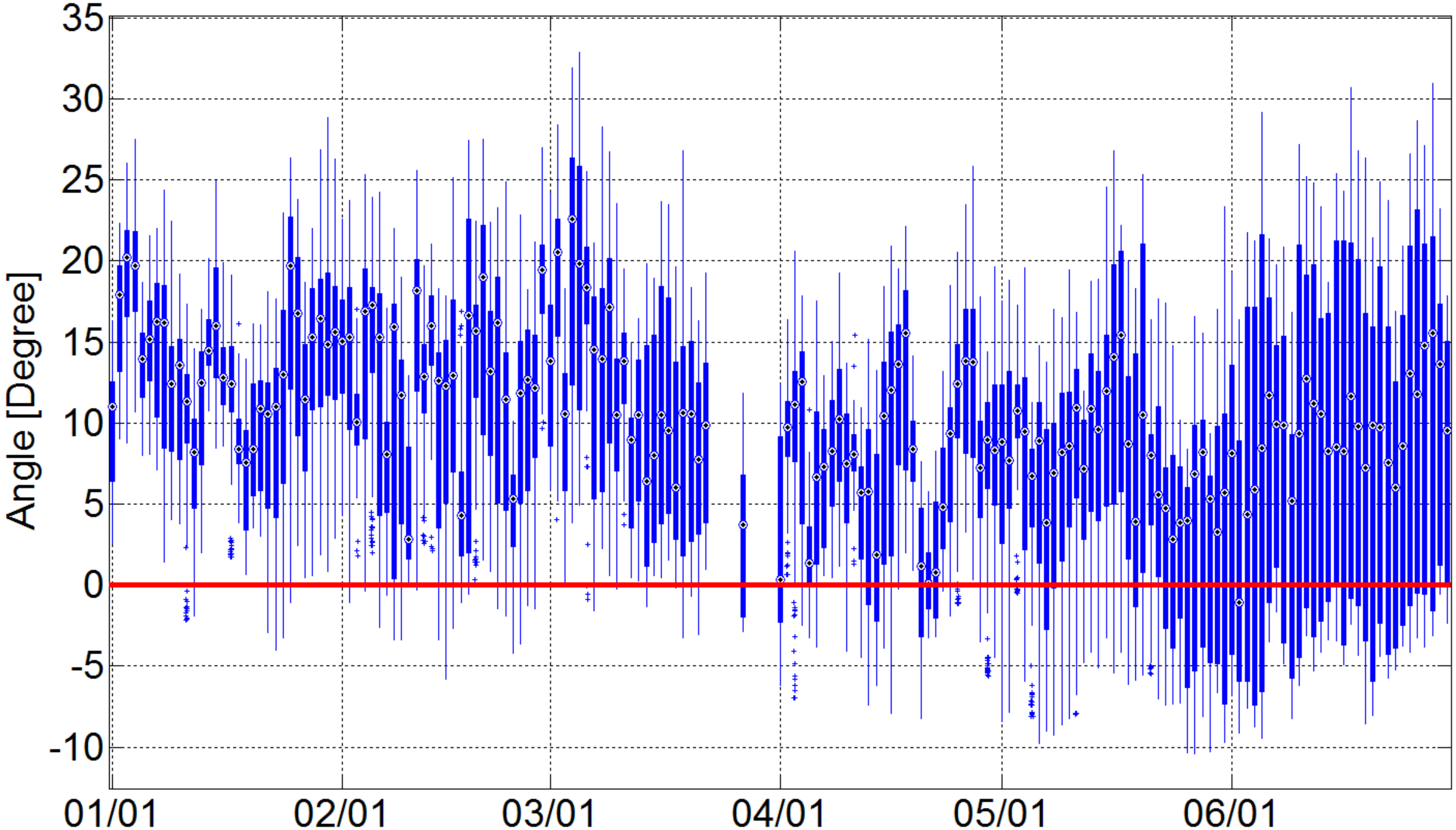


Coast 1-South 10*



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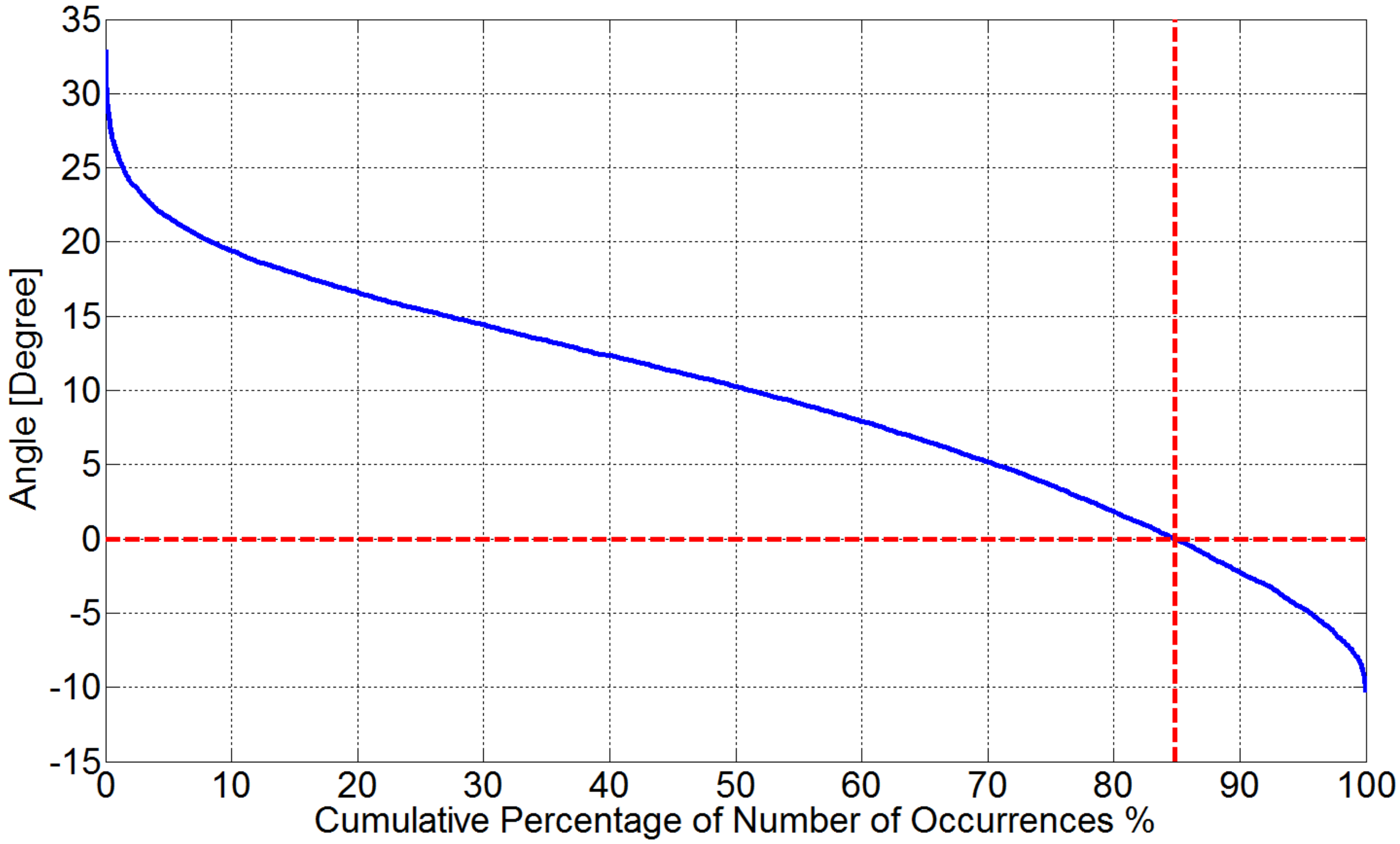

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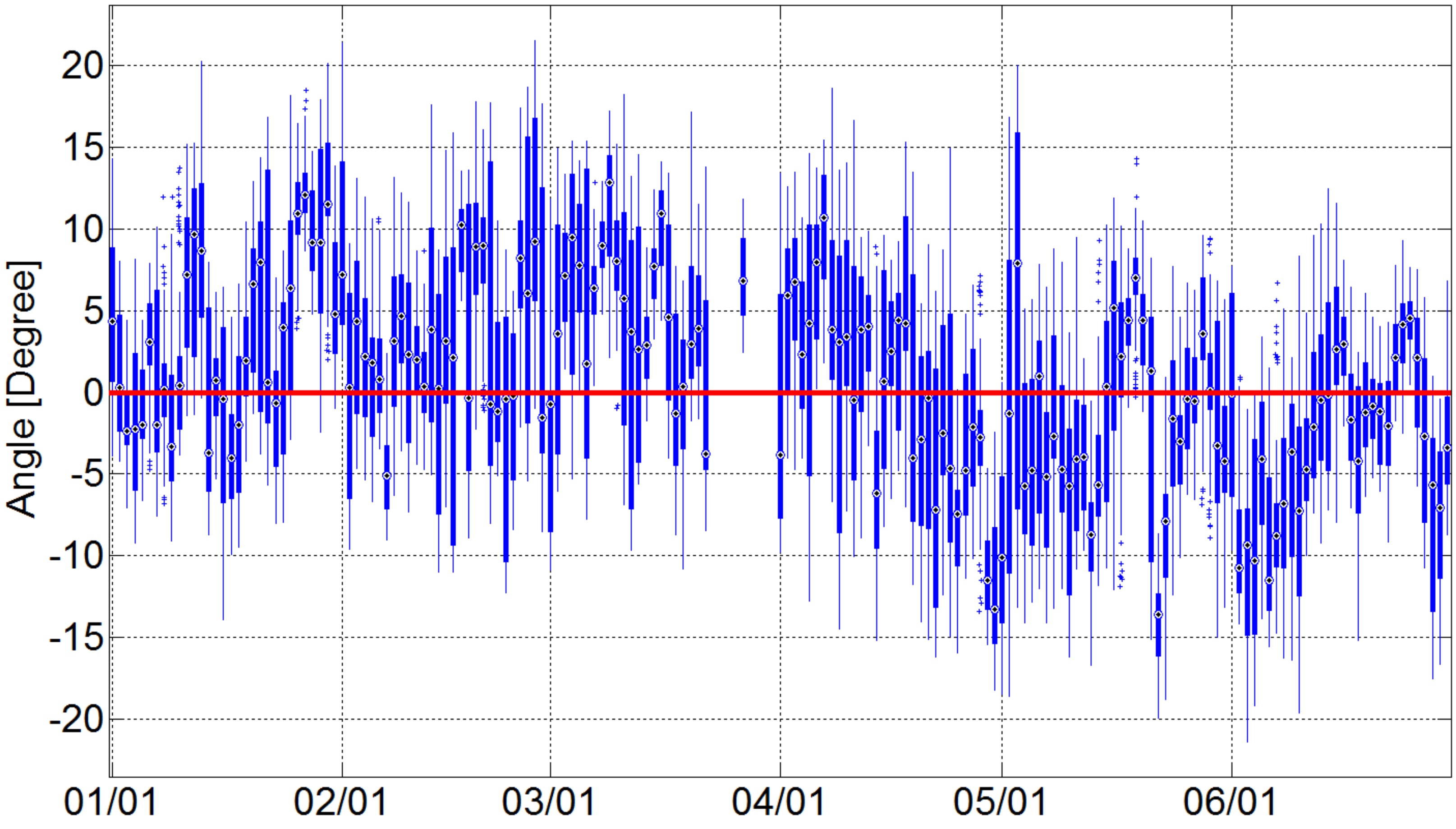

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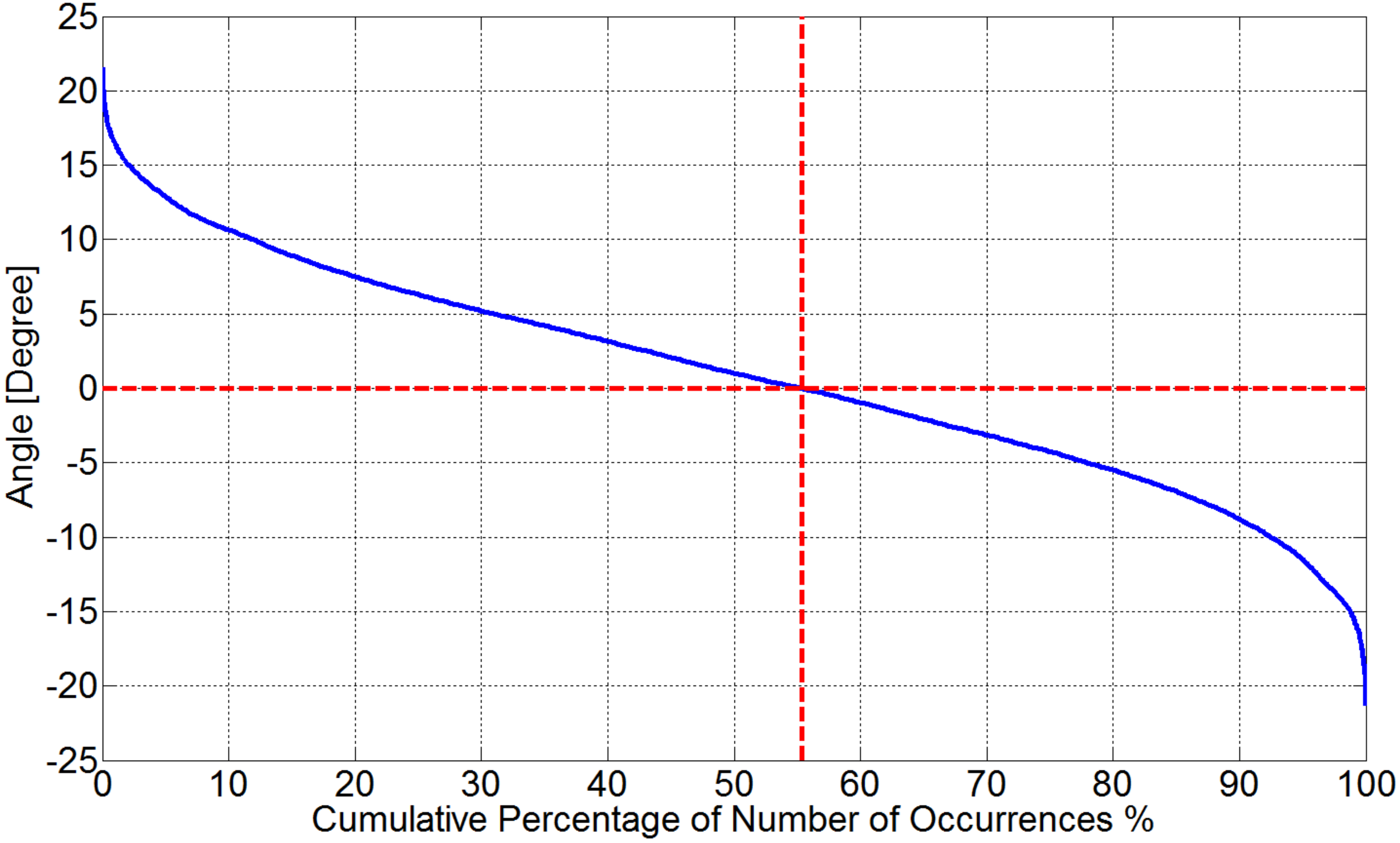

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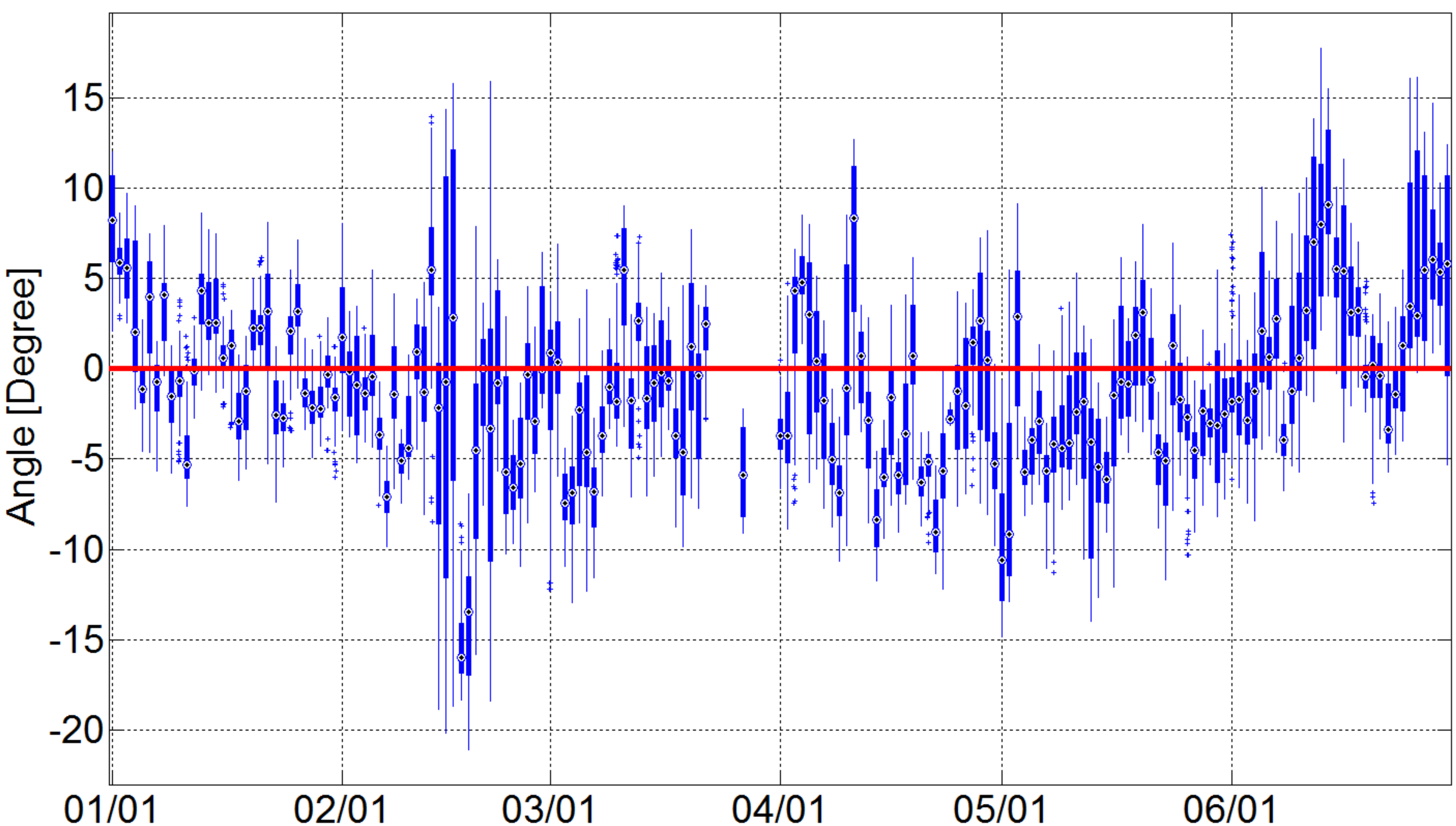

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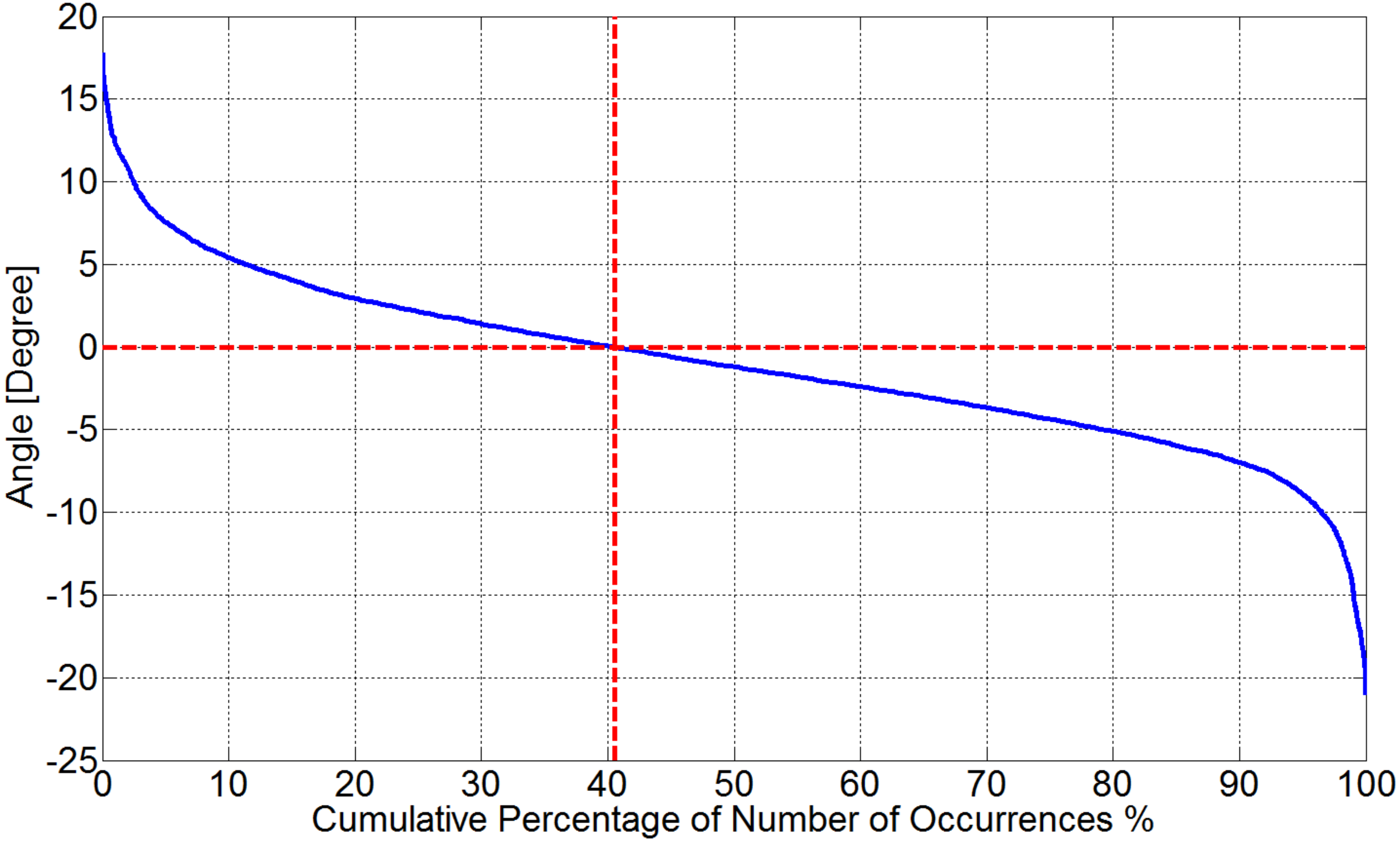

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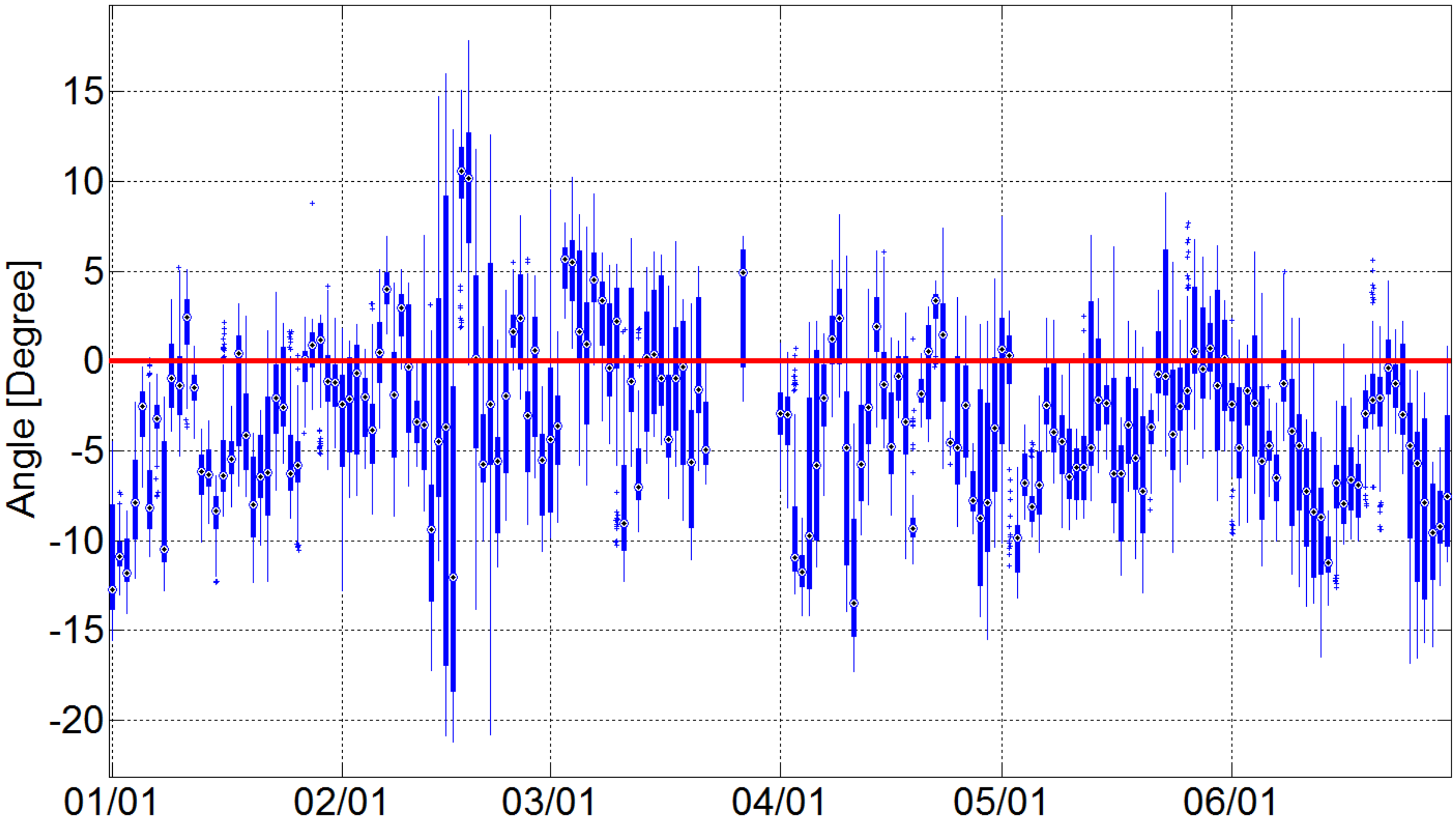

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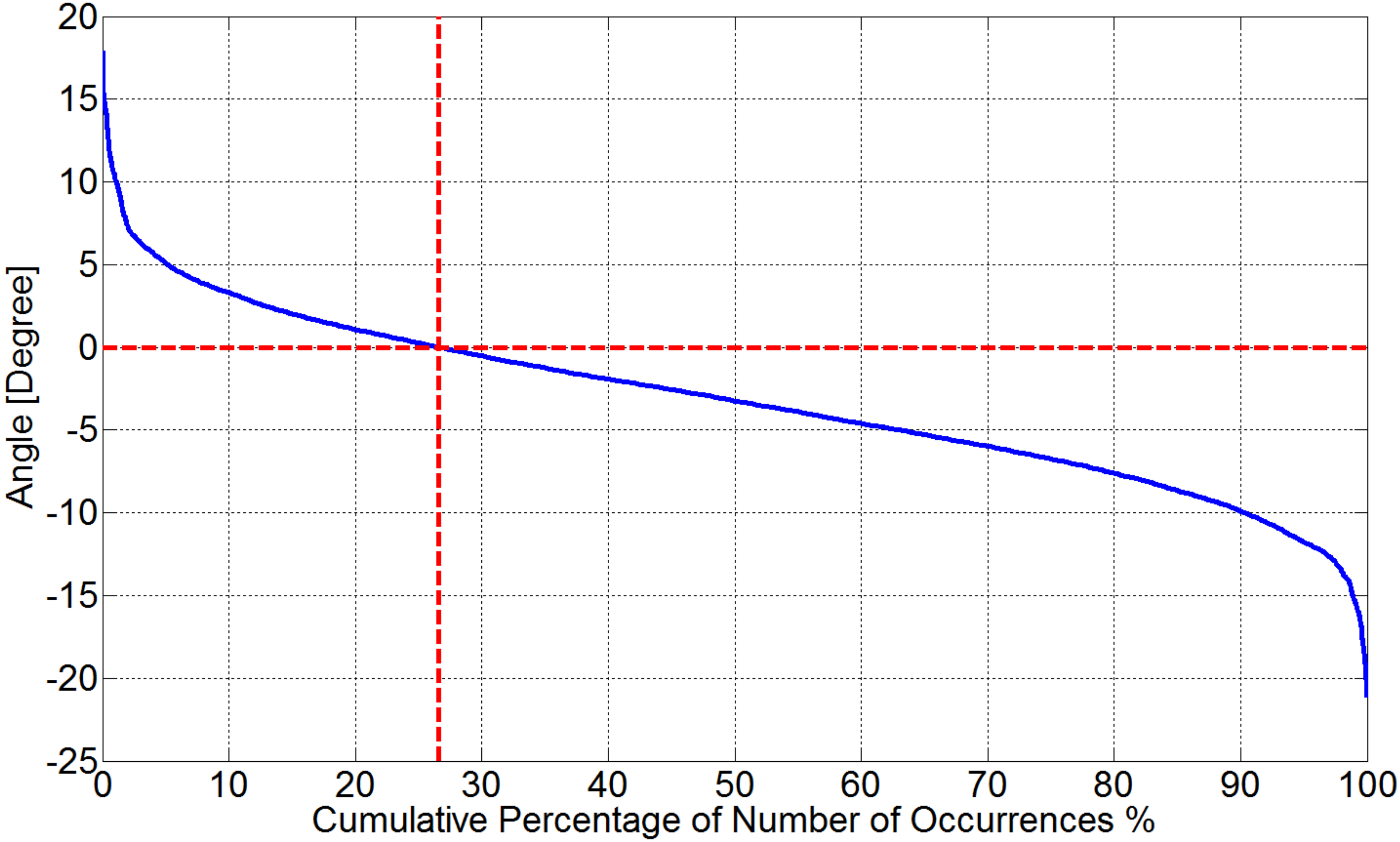

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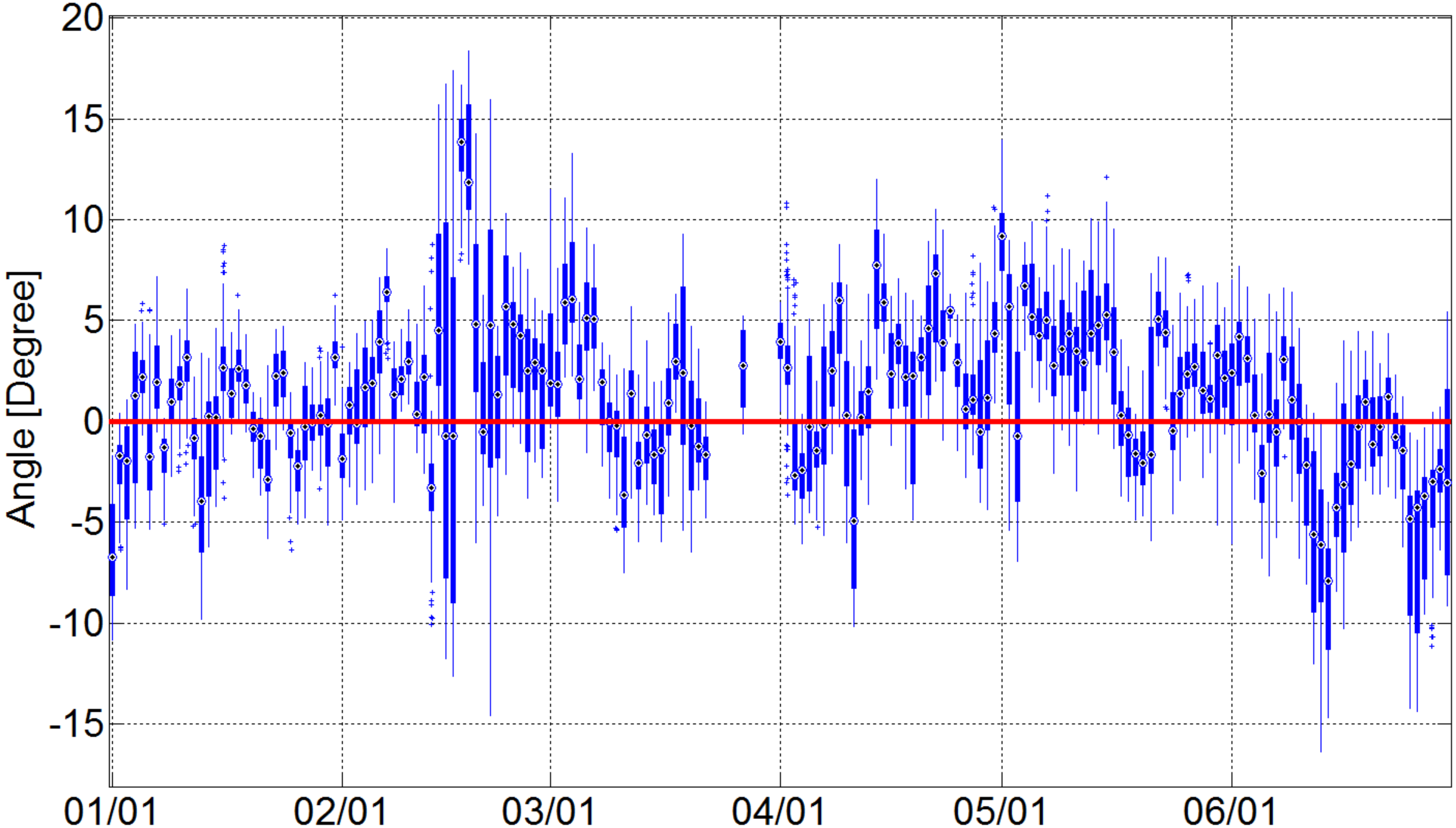

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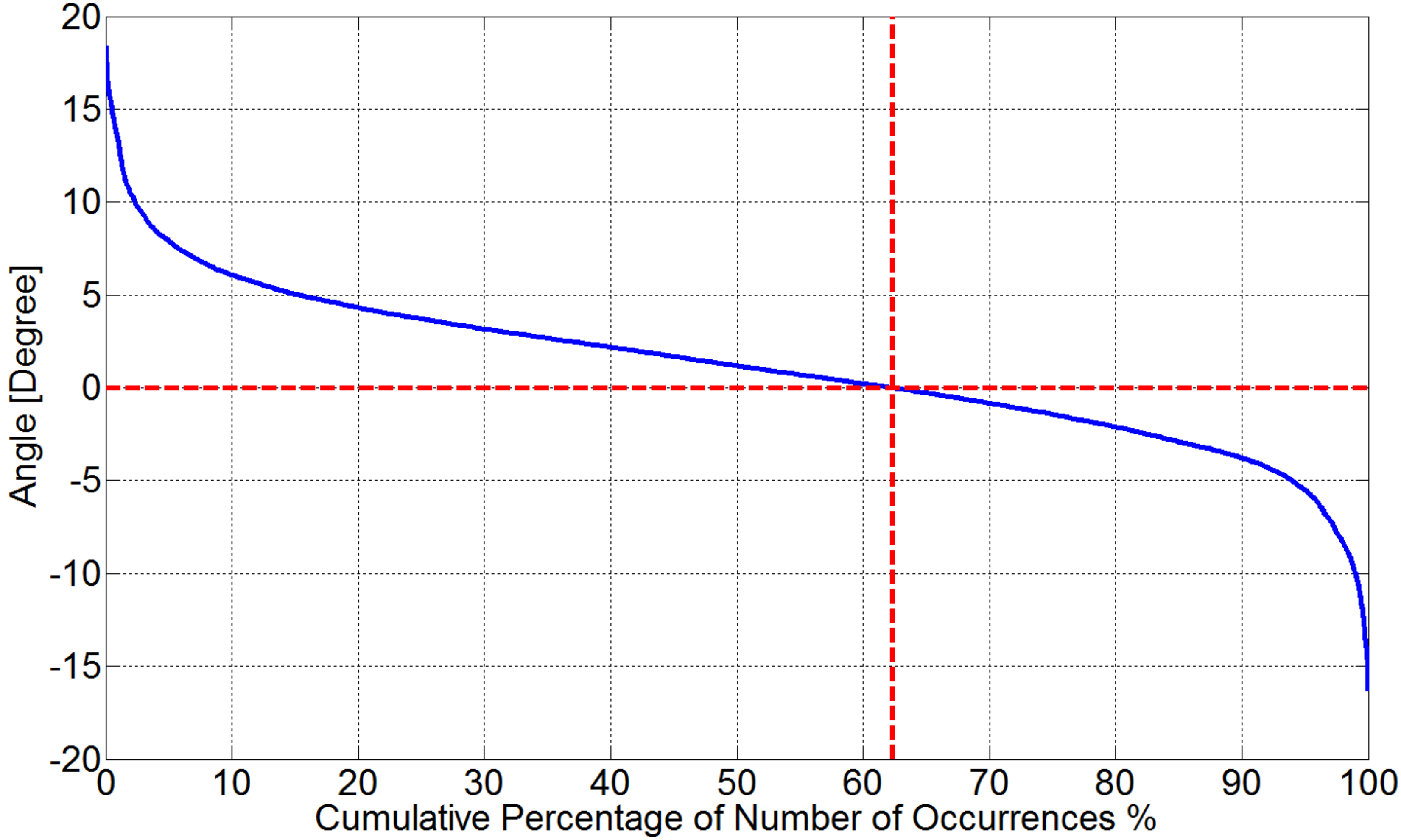

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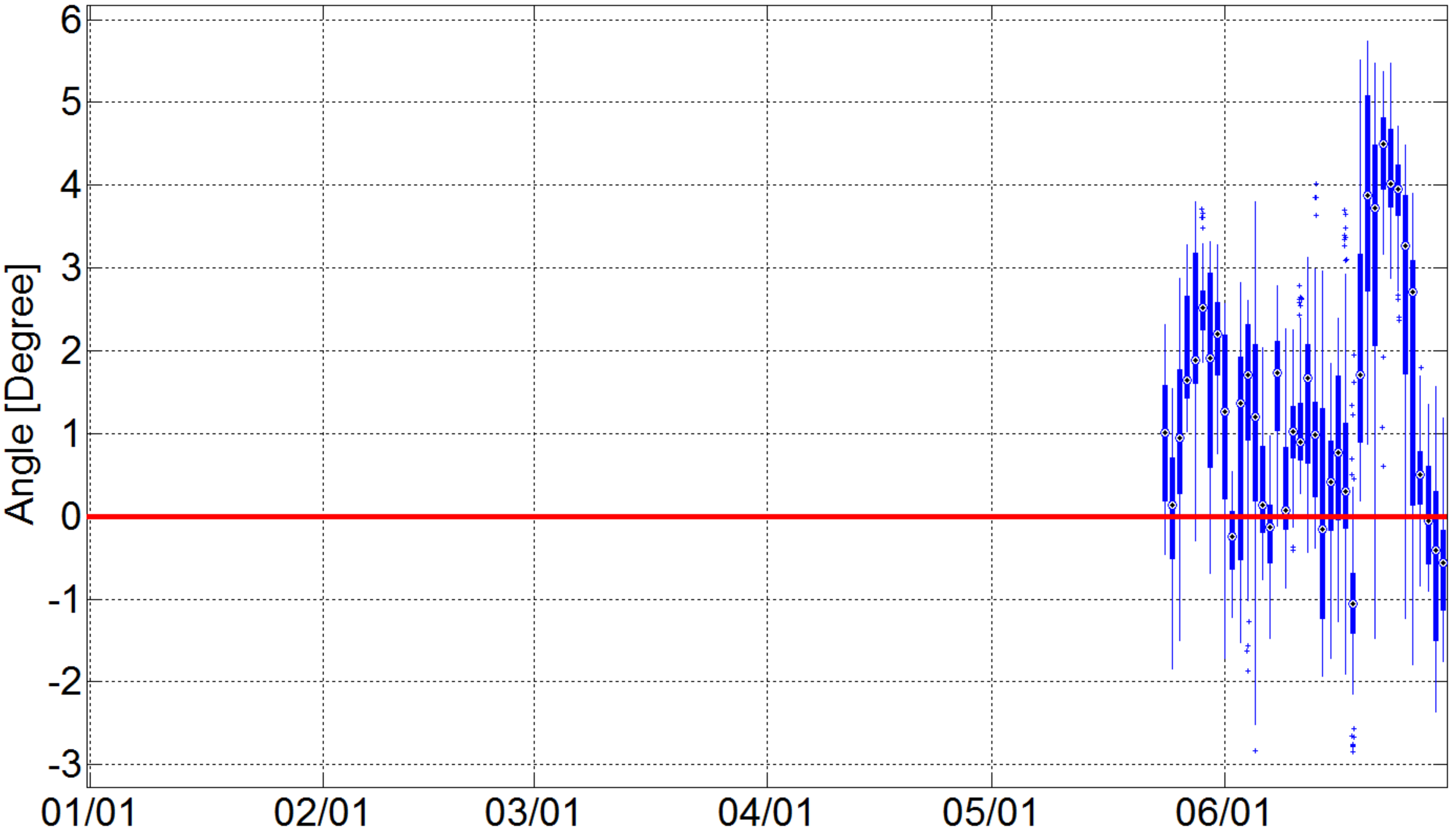

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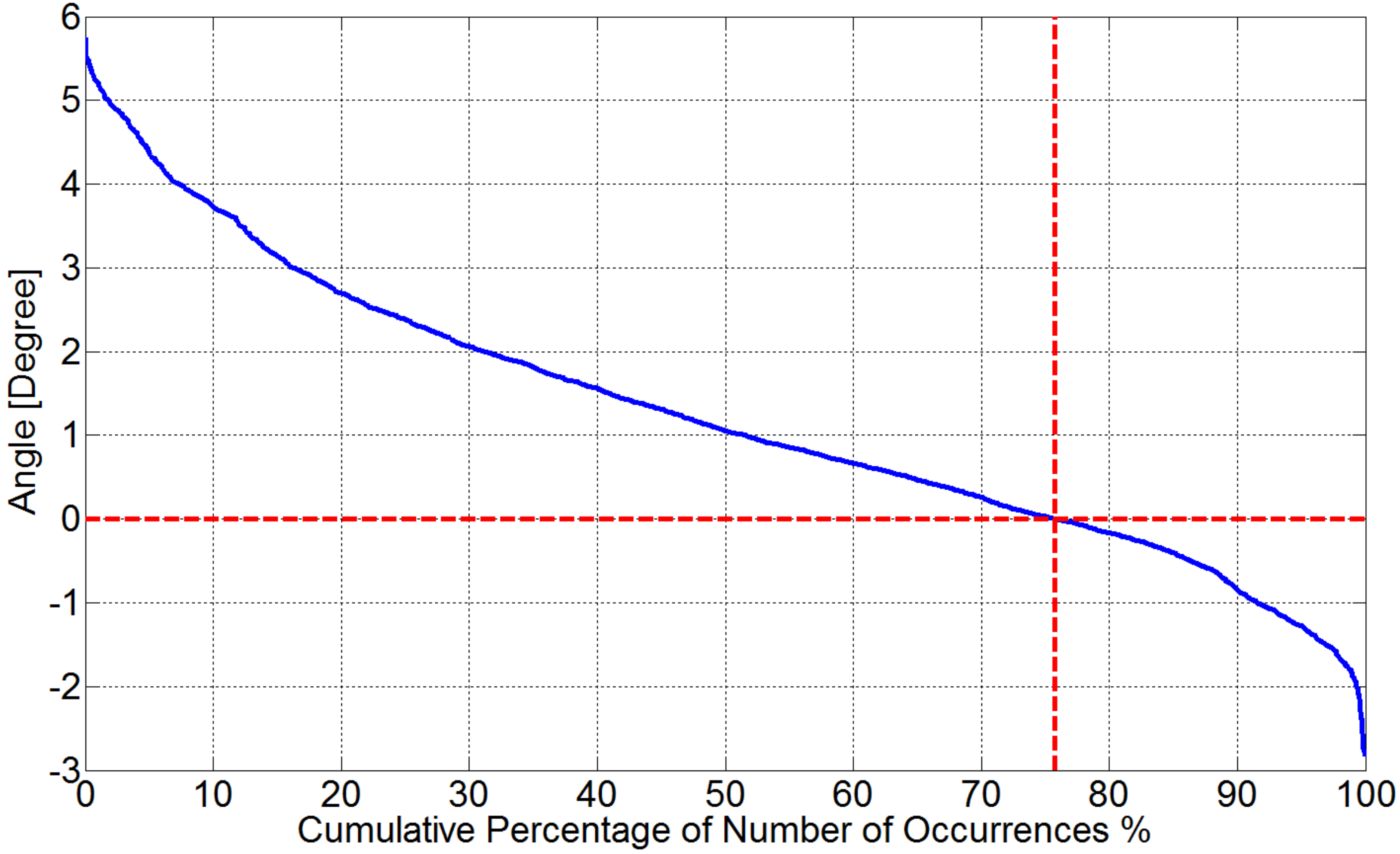

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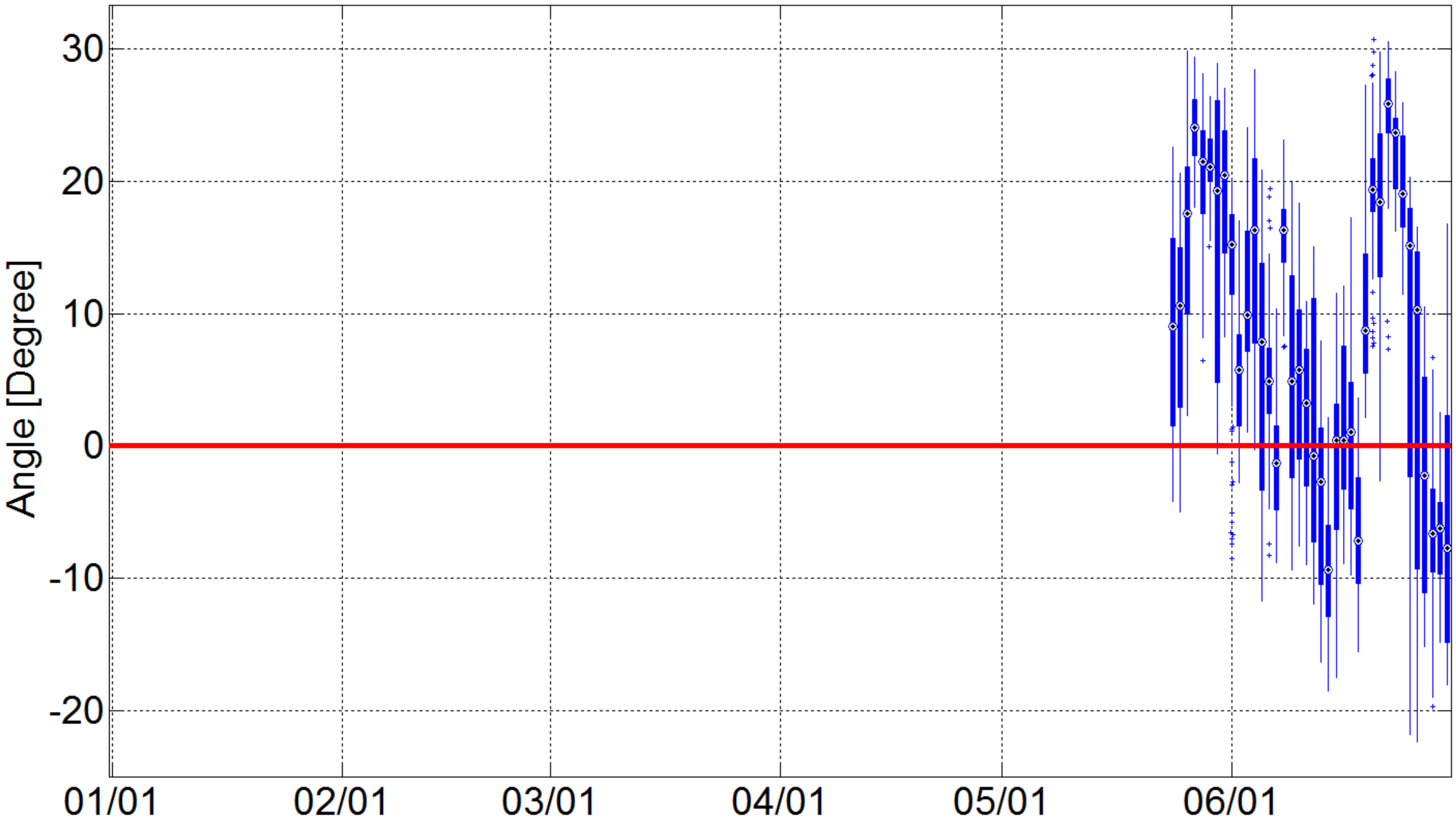

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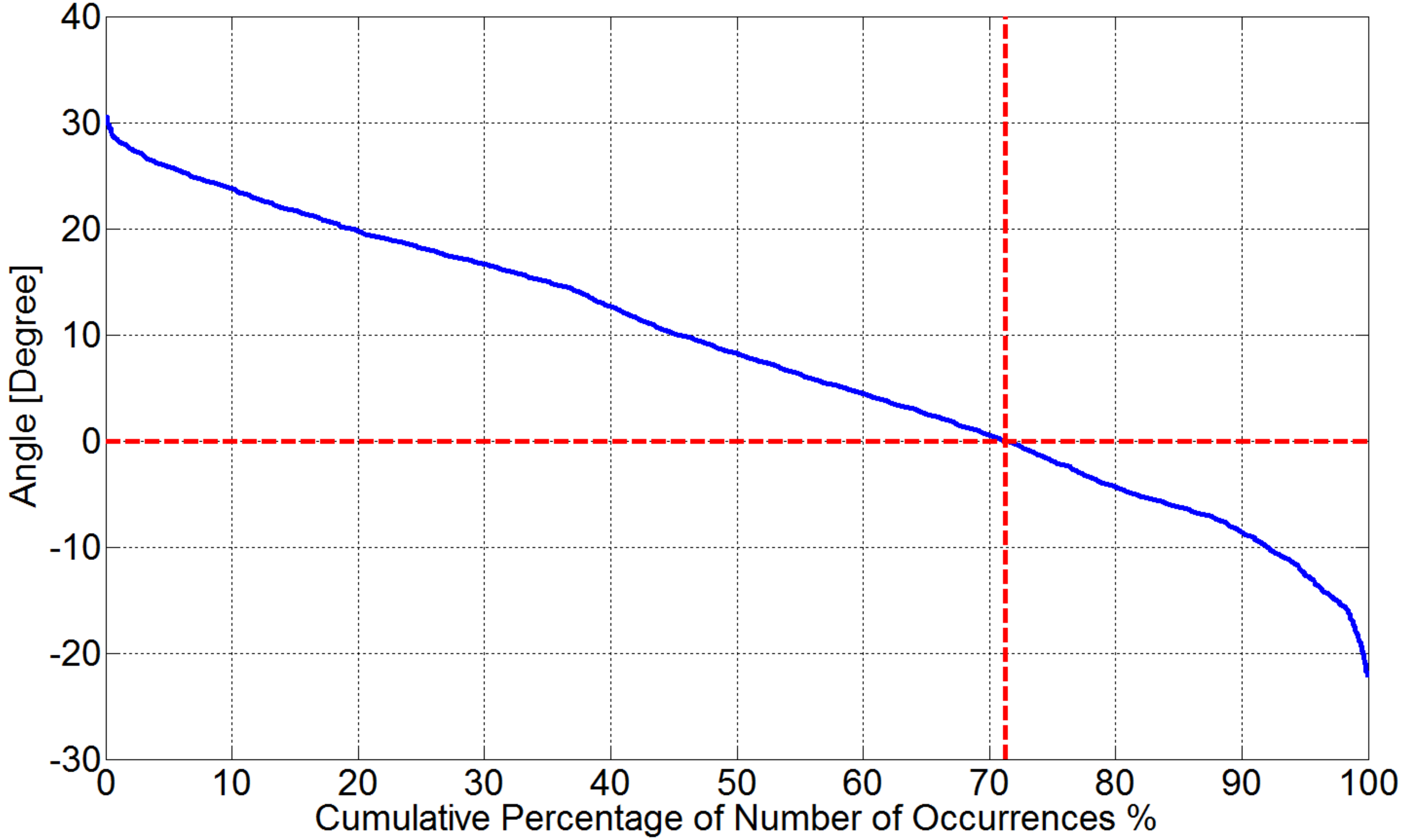

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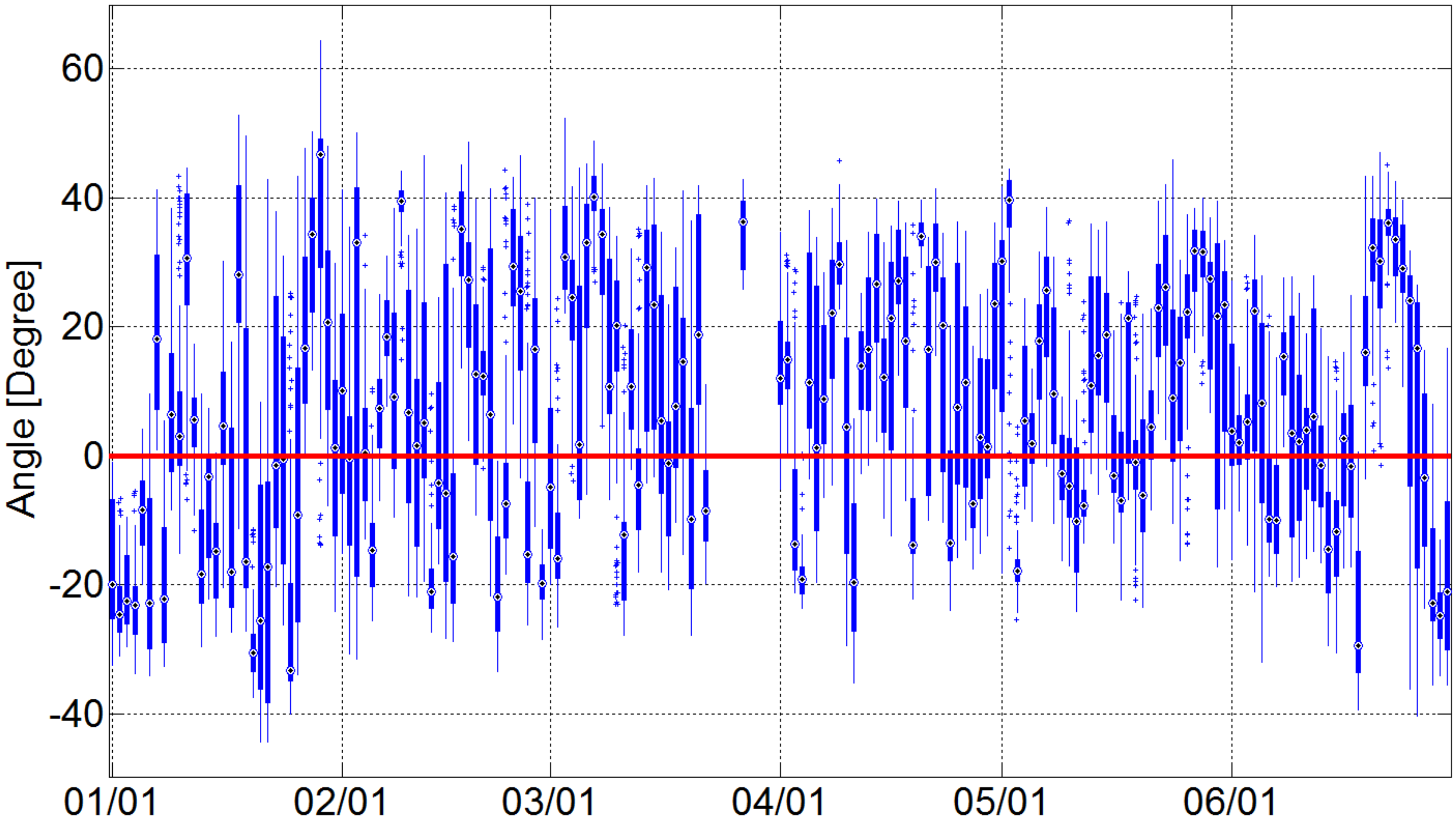

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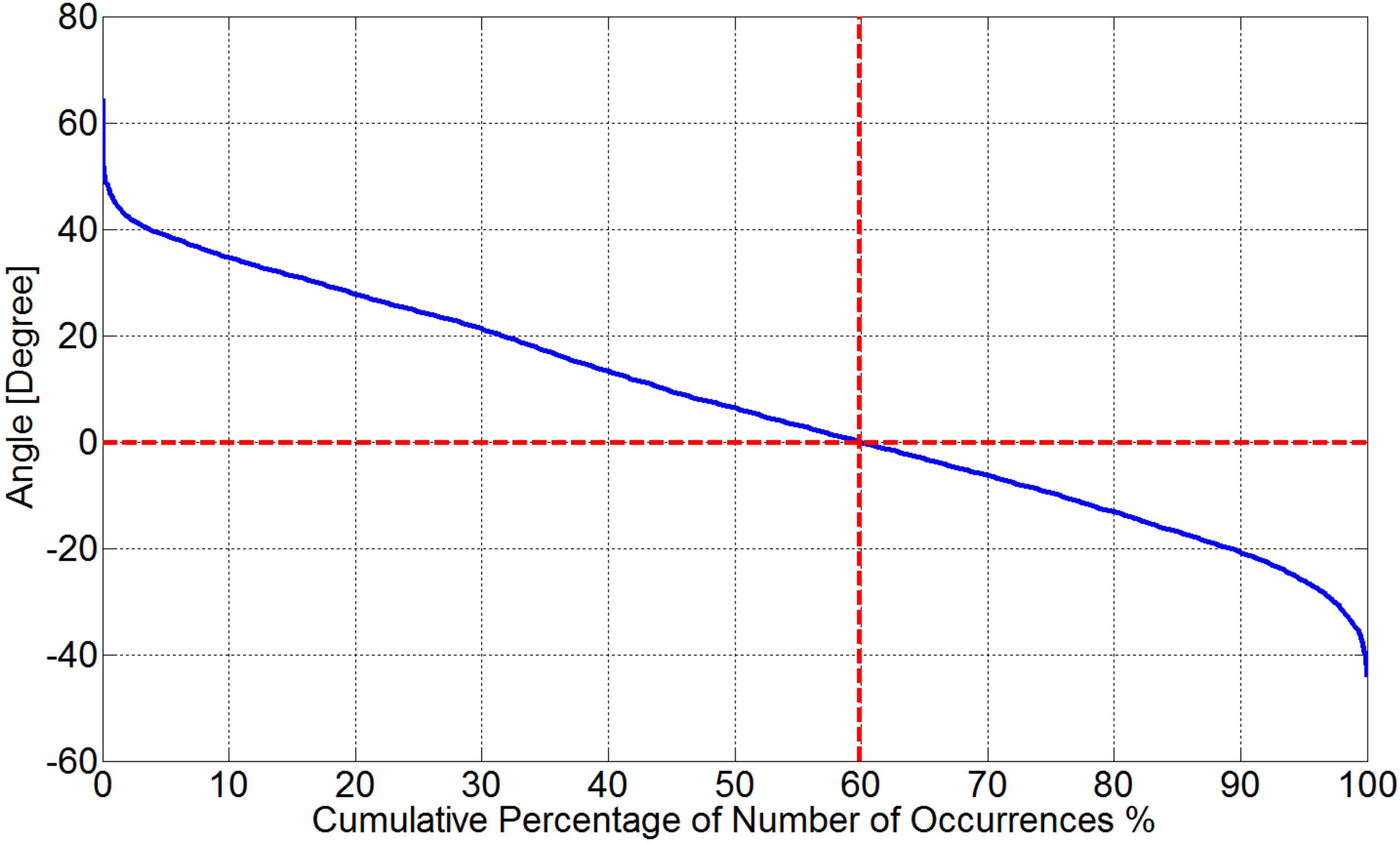


Appendix D – Part 2

CCET Discovery Across Texas project

Baseline Analysis Update – Angle Differences

Phasor Data: January to June 2013

Box-Whisker Plots and Time Duration Curves

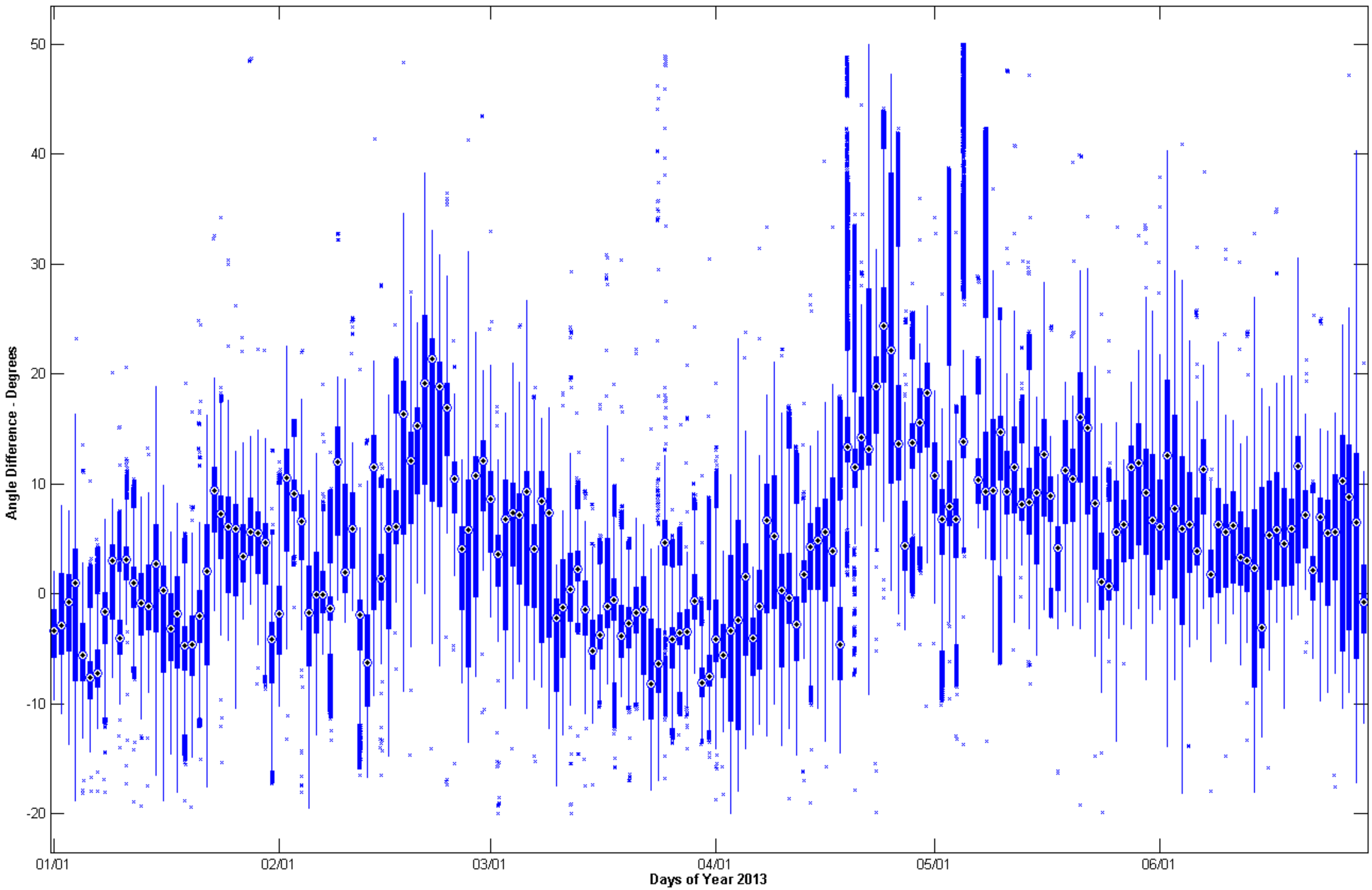
External Version

Electric Power Group

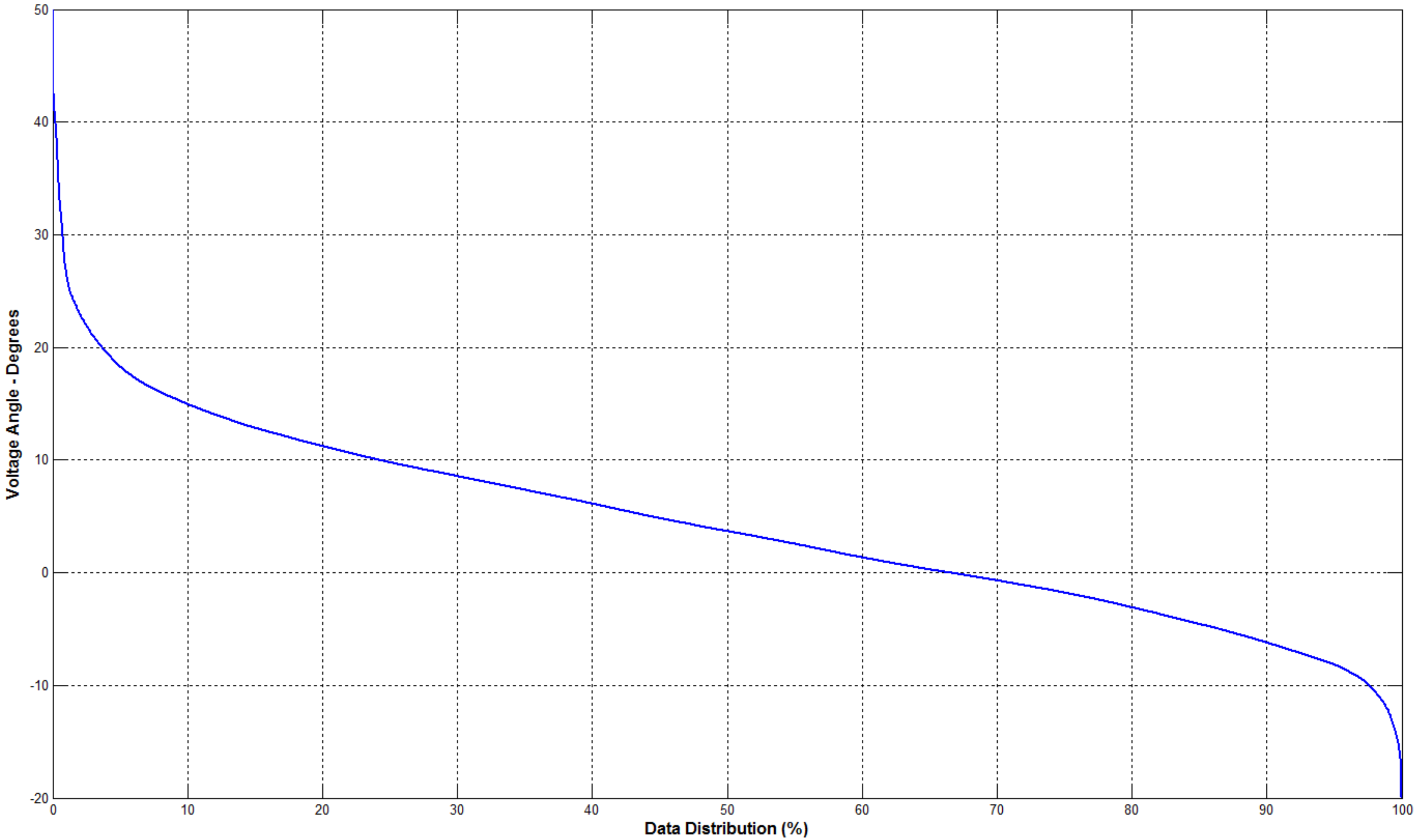
CCET

ERCOT

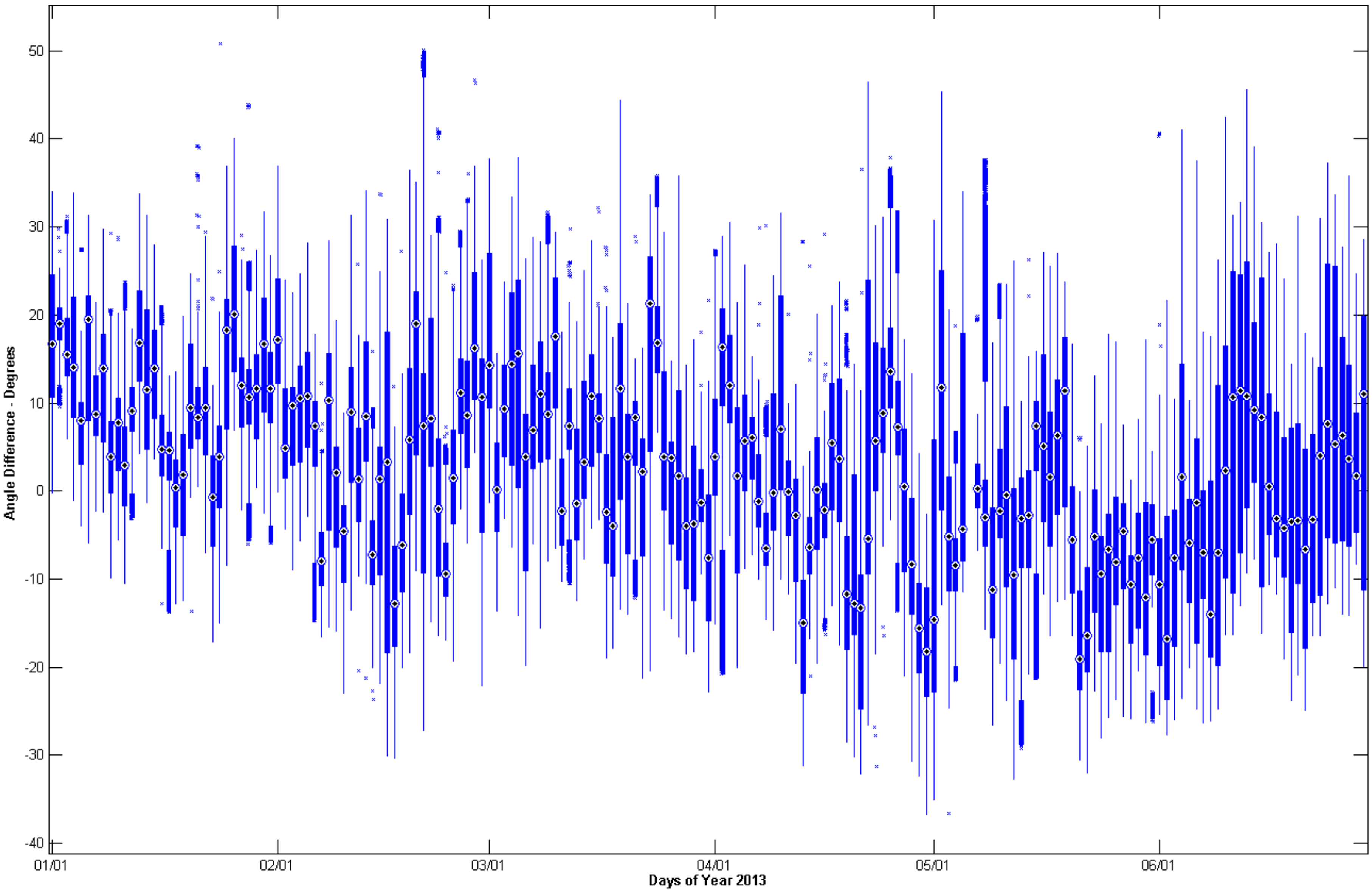
Coast 1 – South 13



Coast 1 – South 13



Coast 1 – North 7



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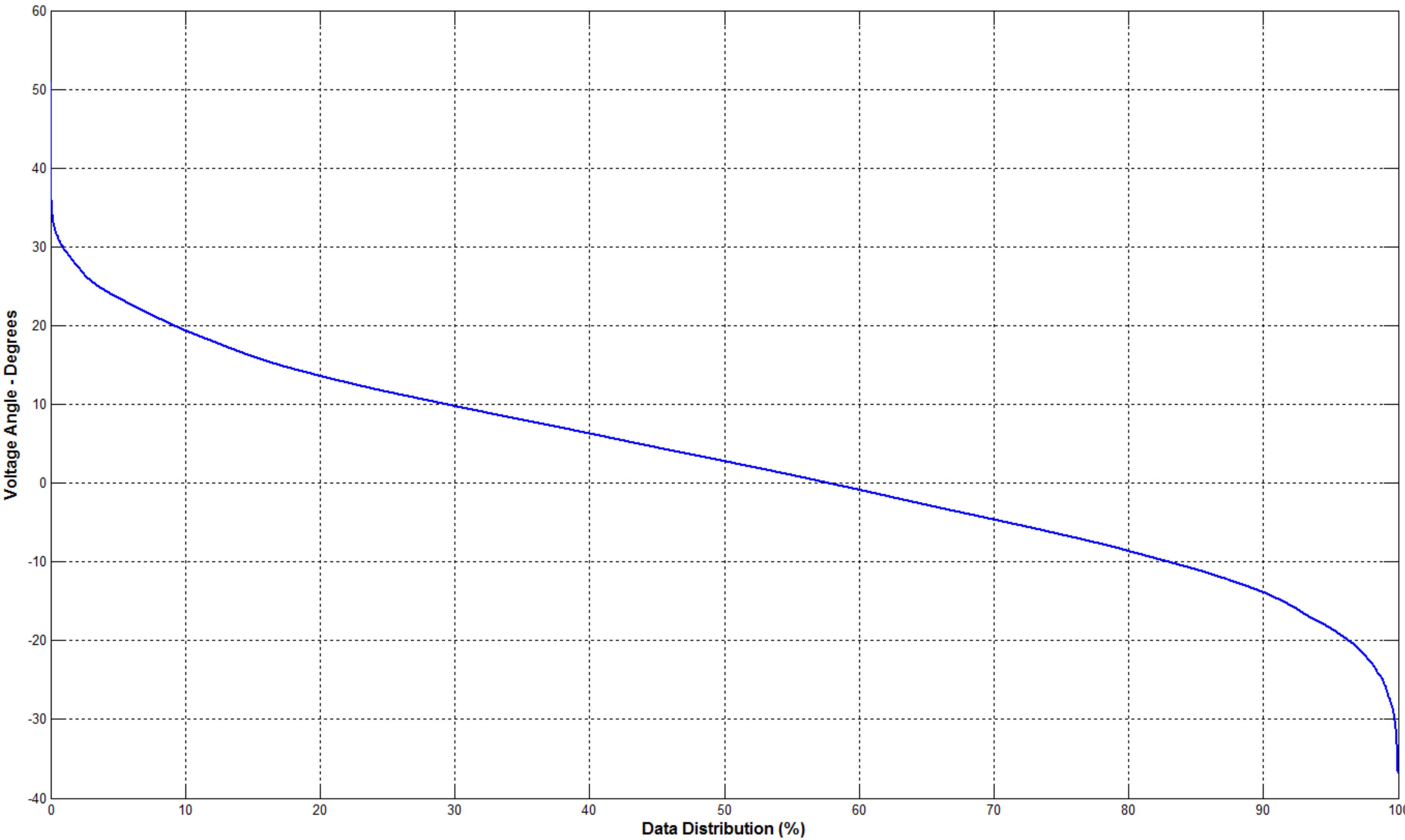

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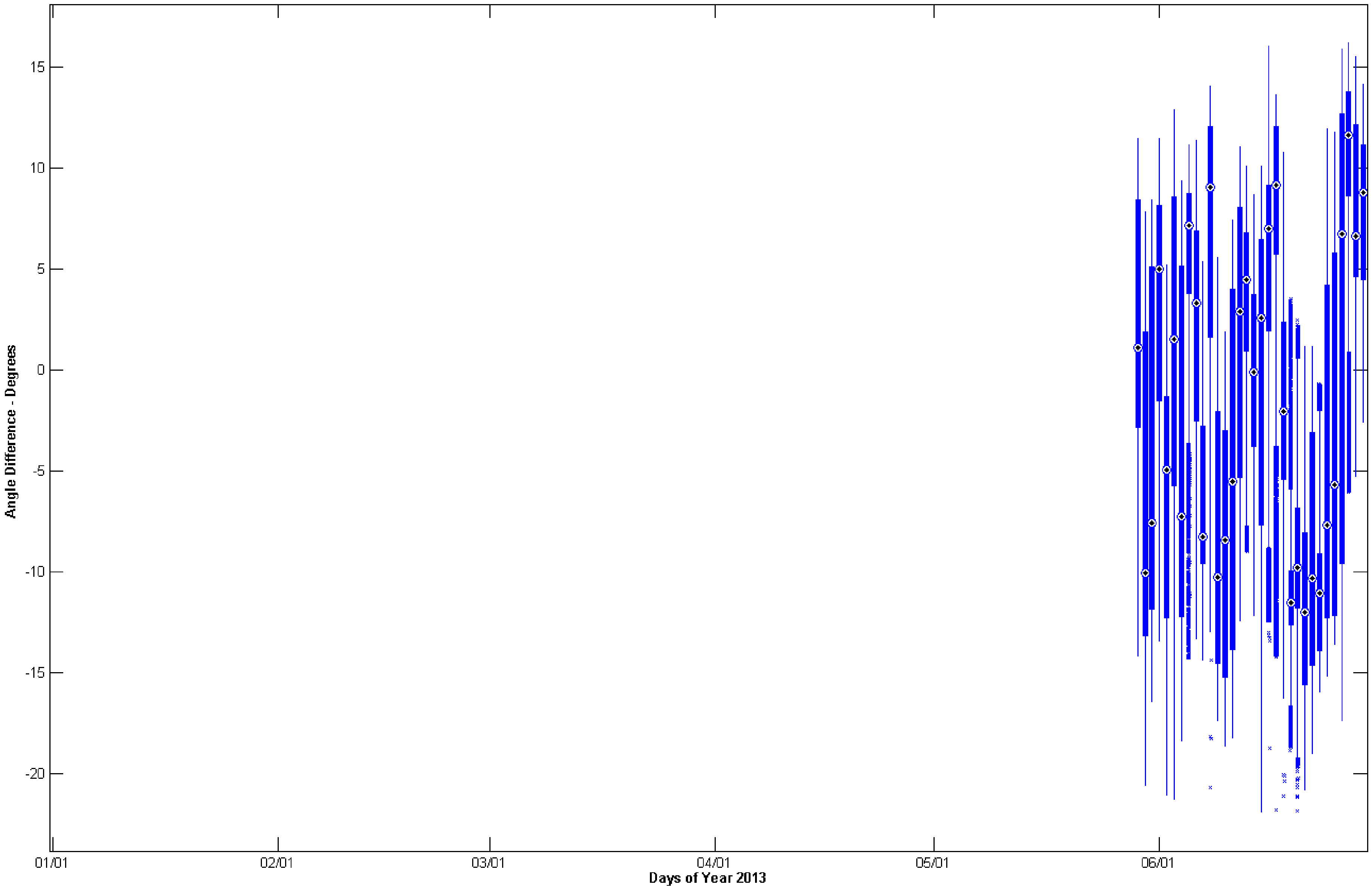

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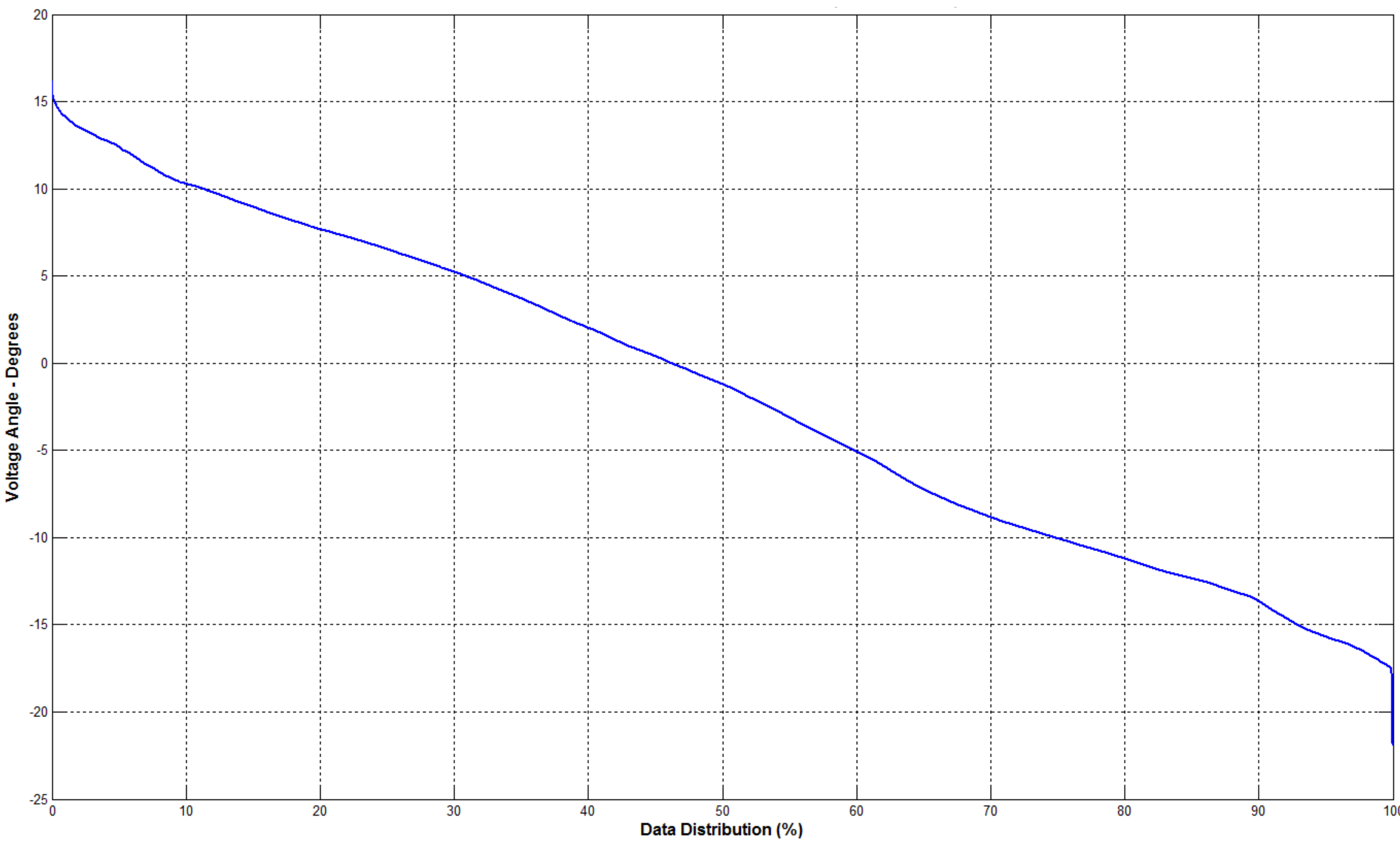

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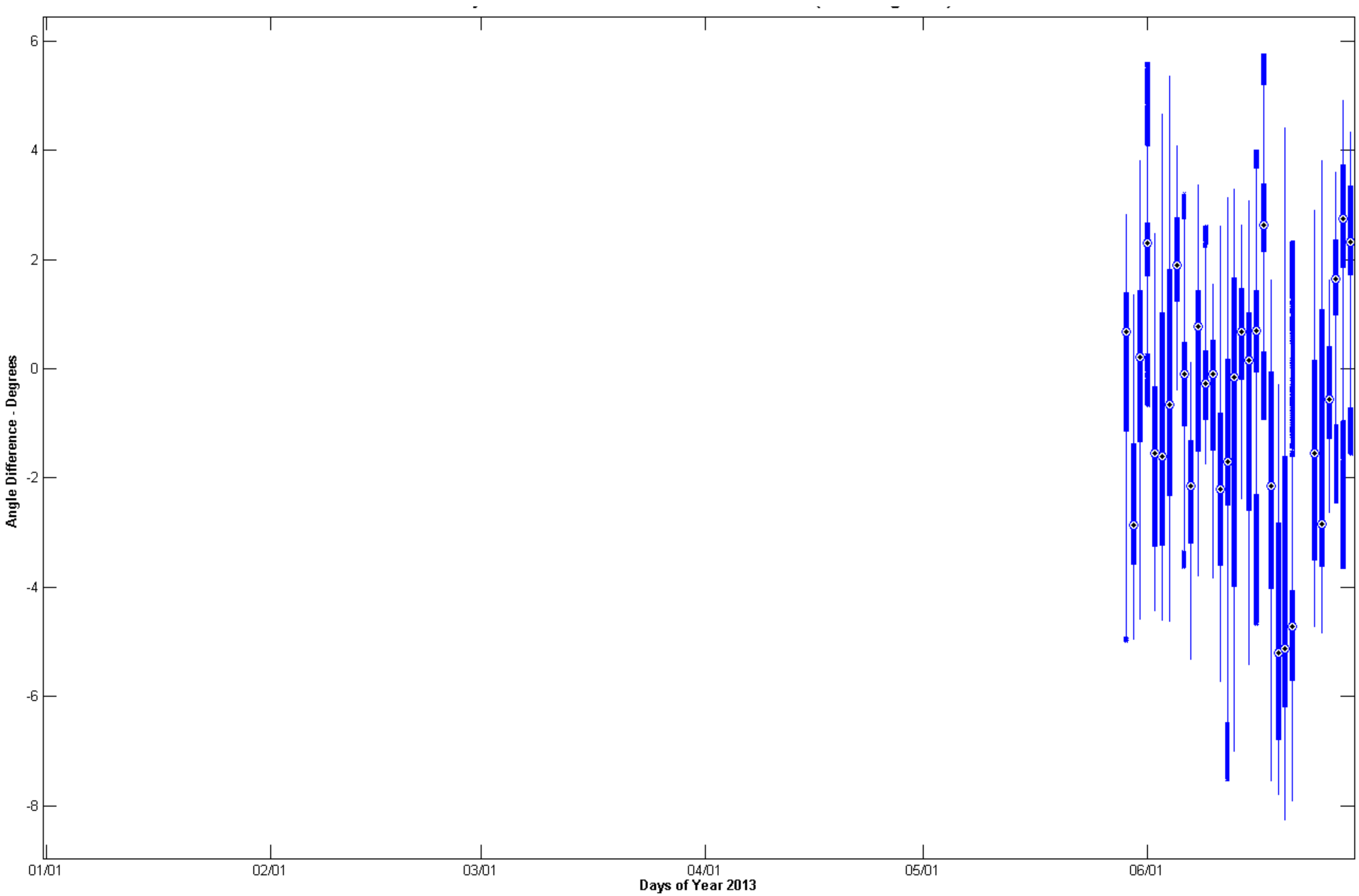

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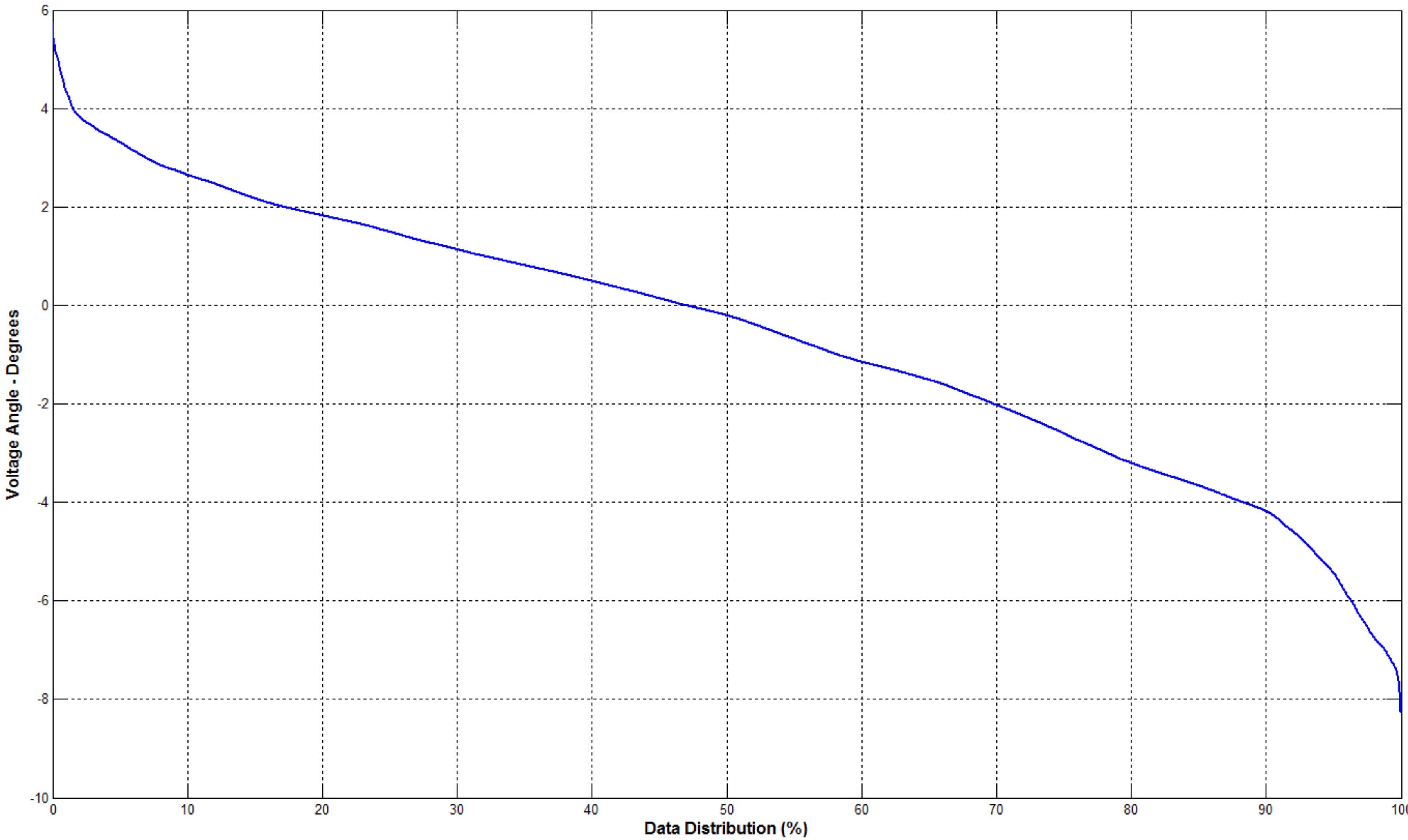

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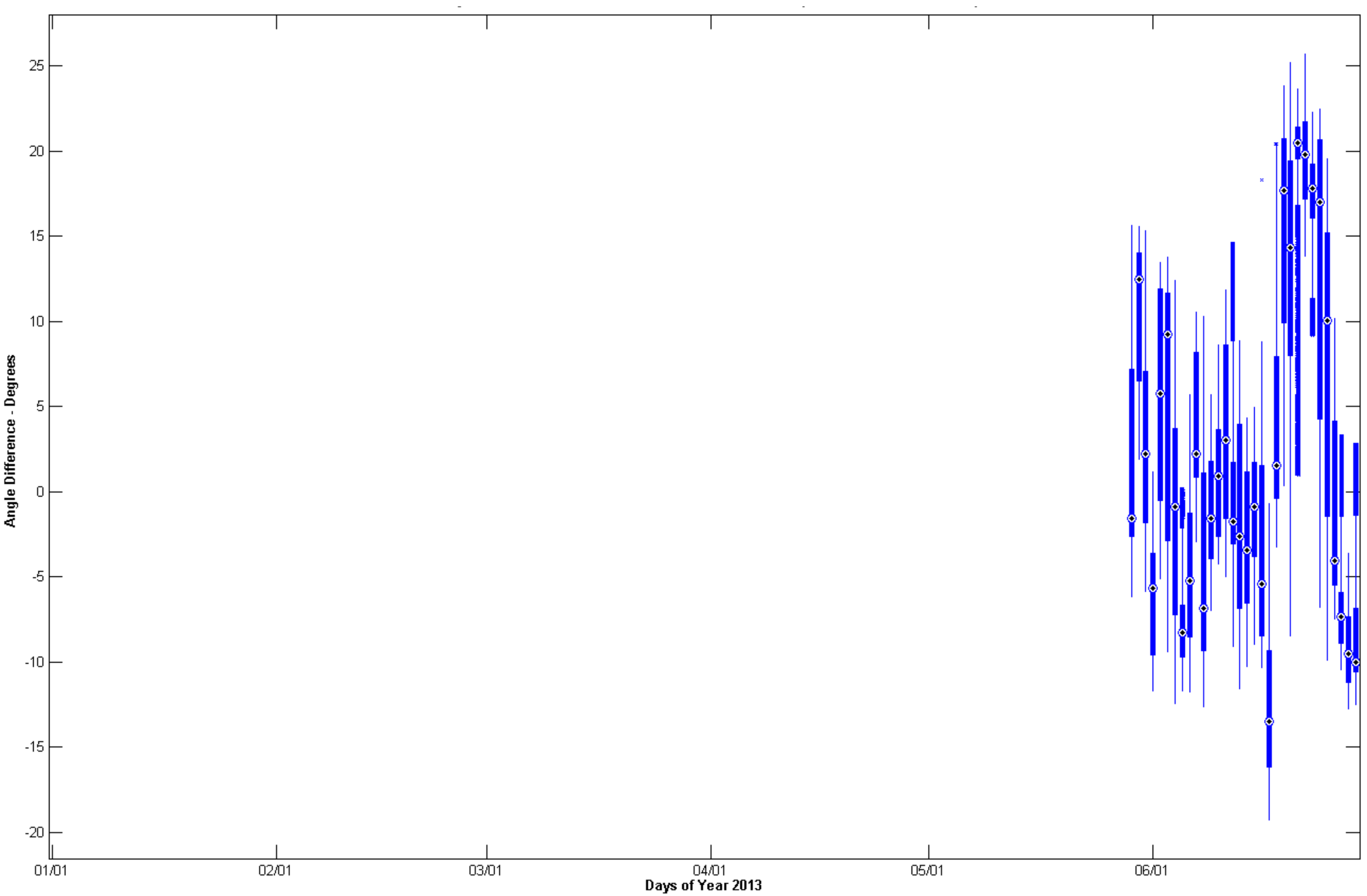

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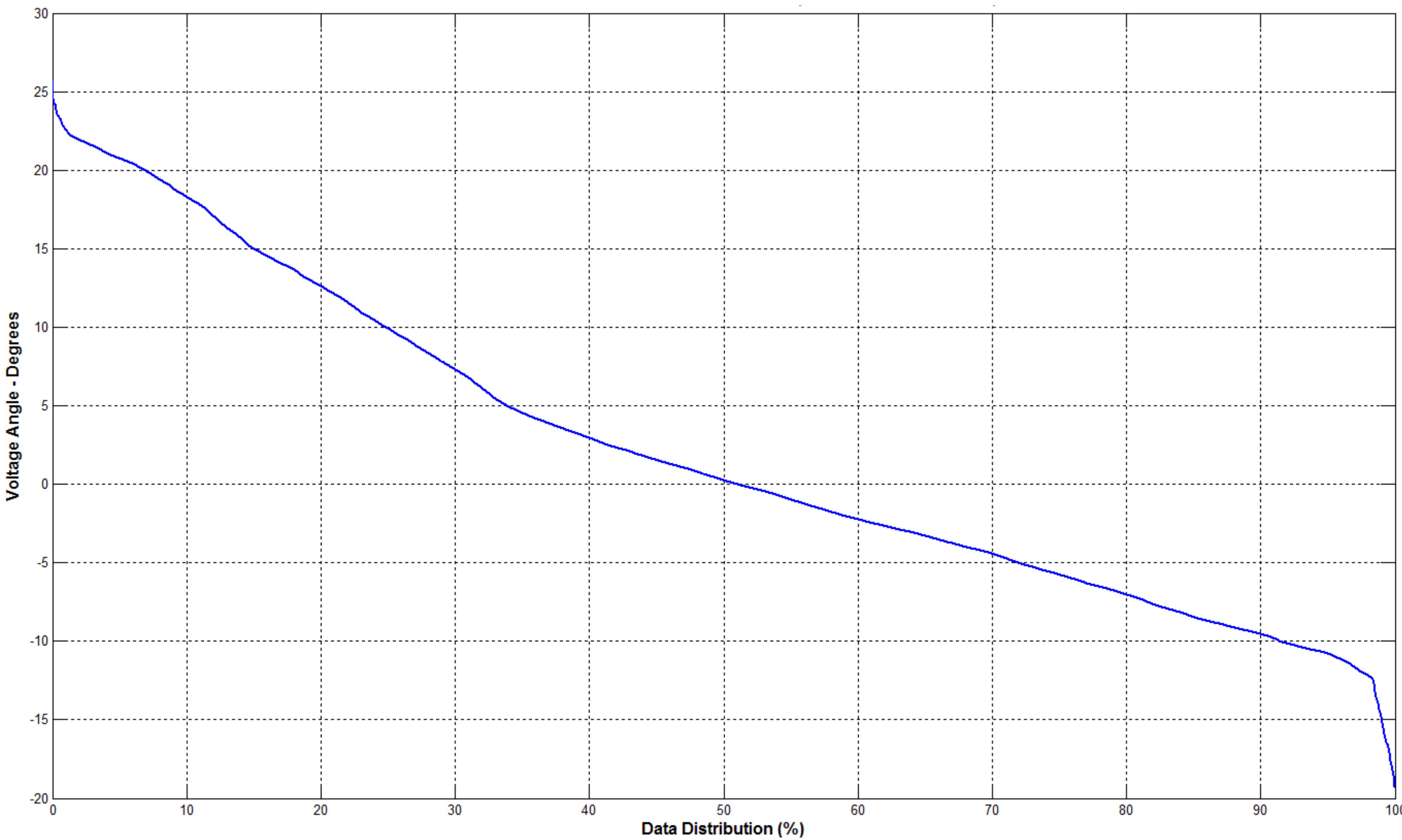

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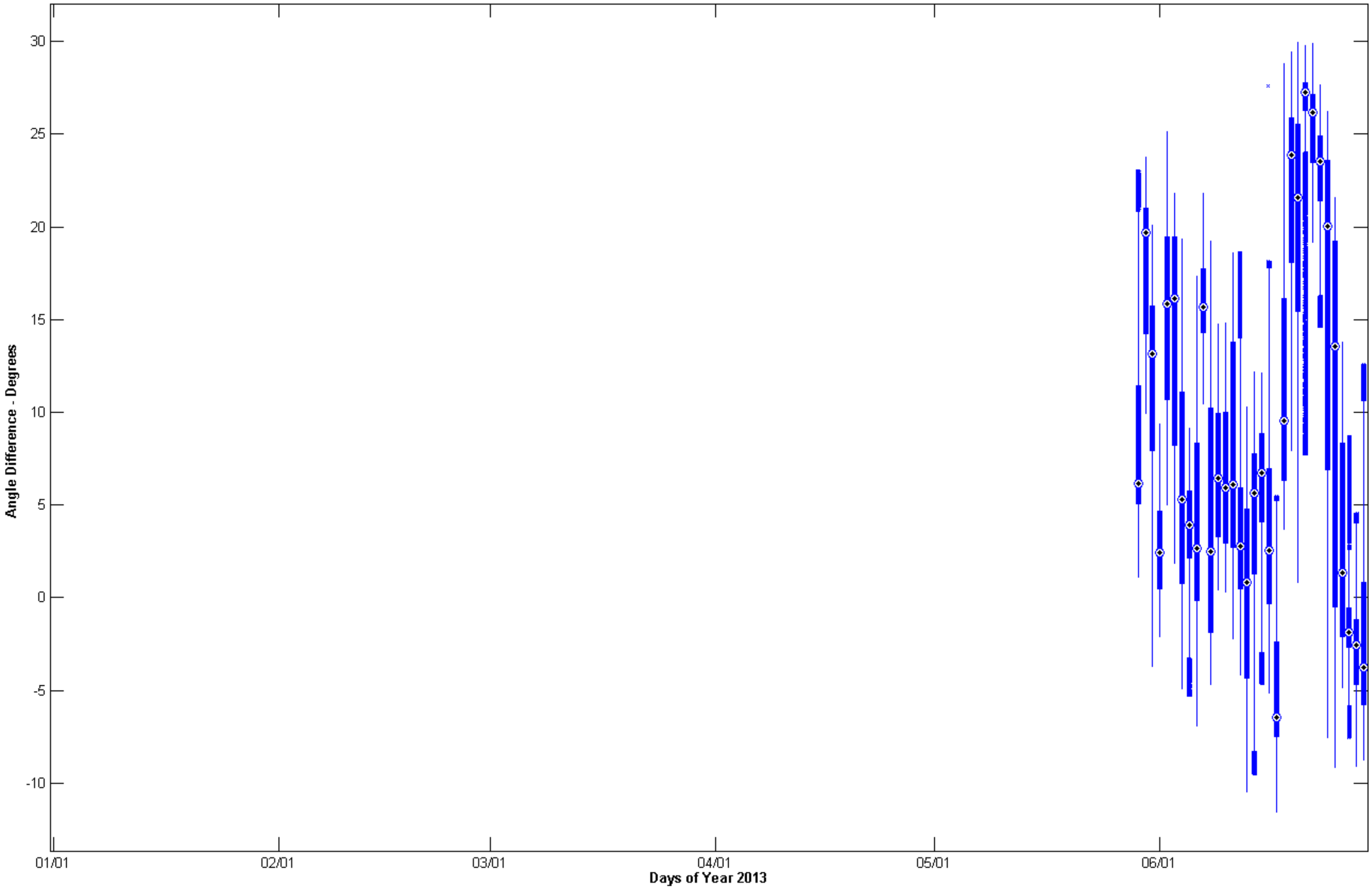

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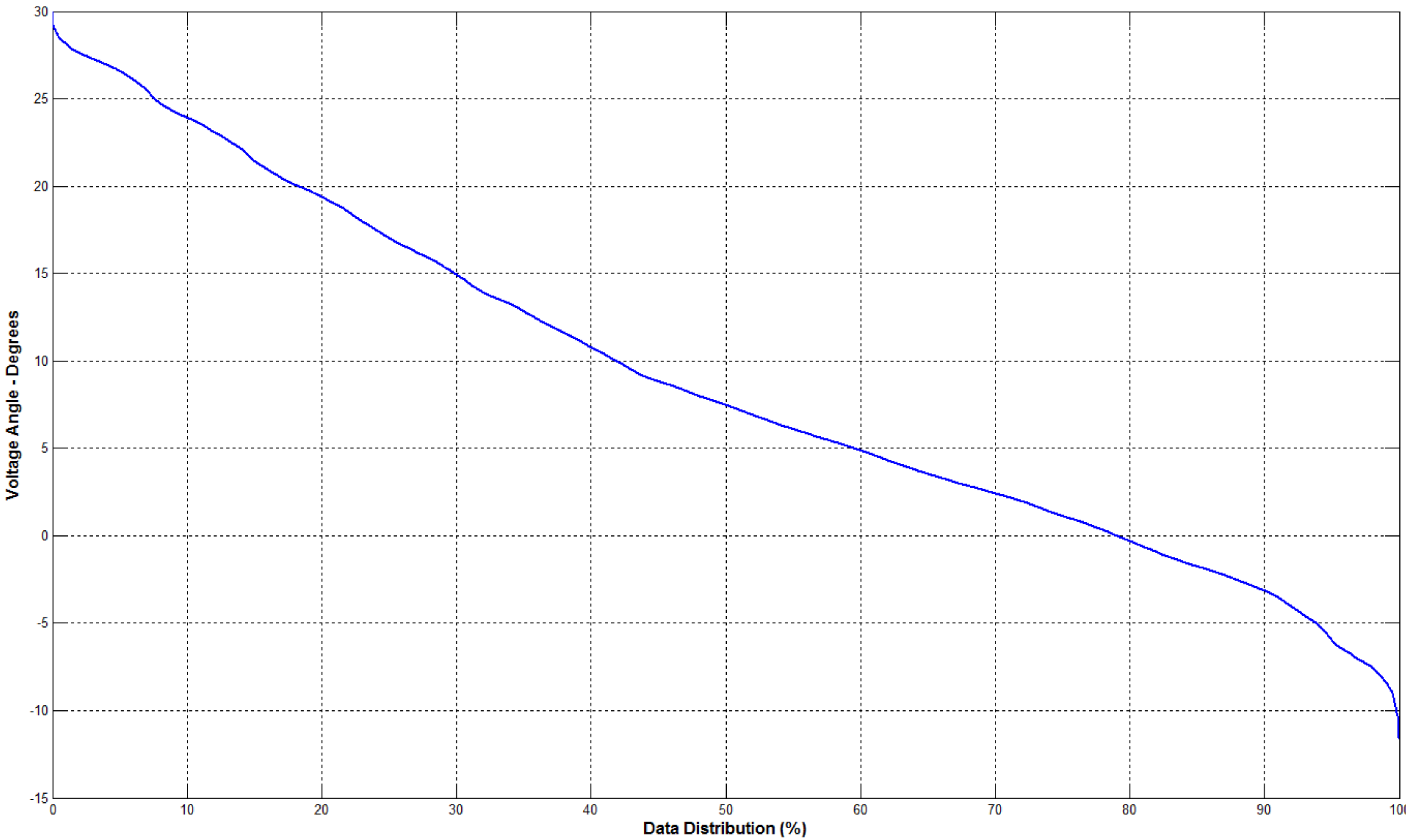

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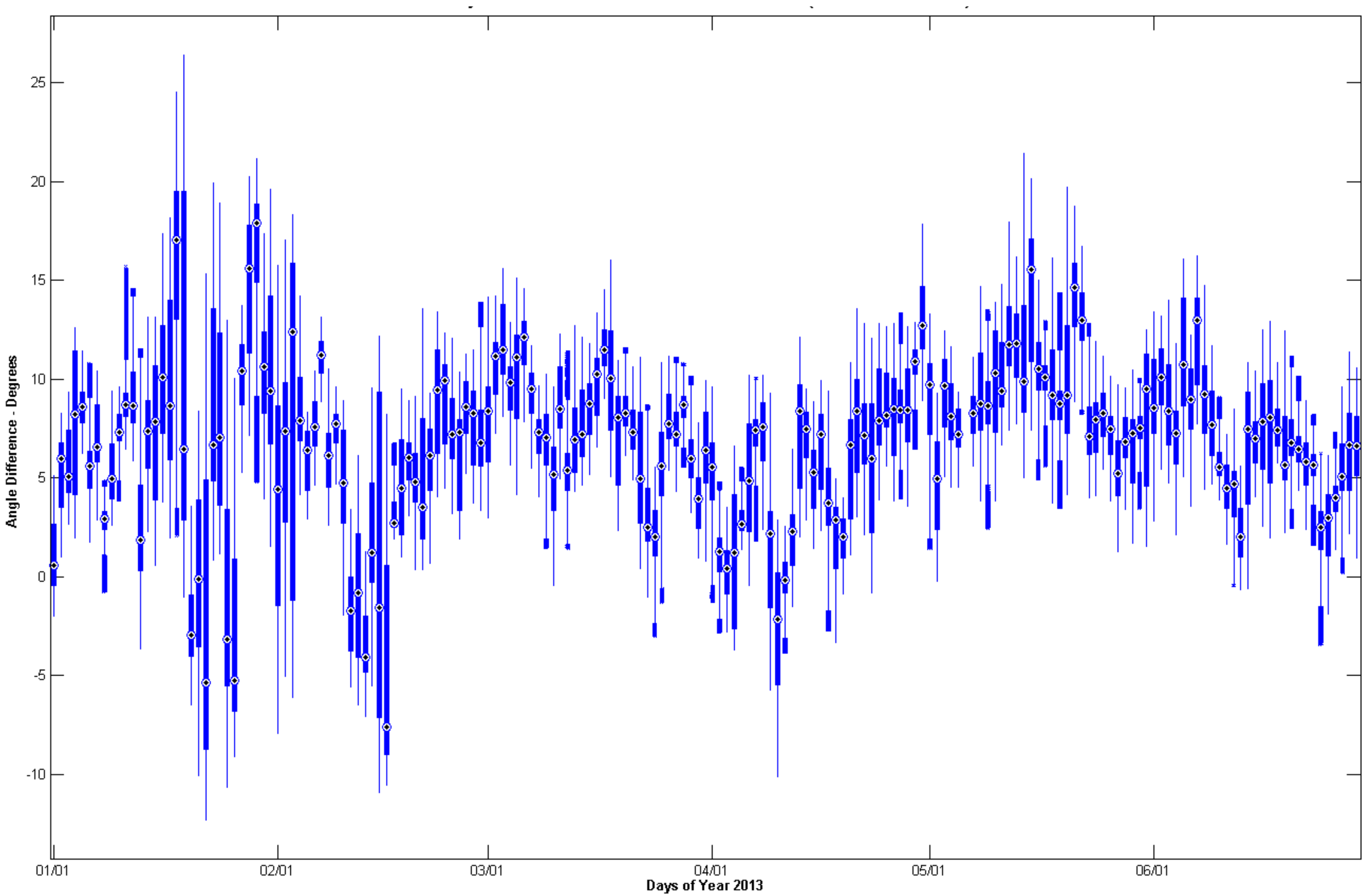

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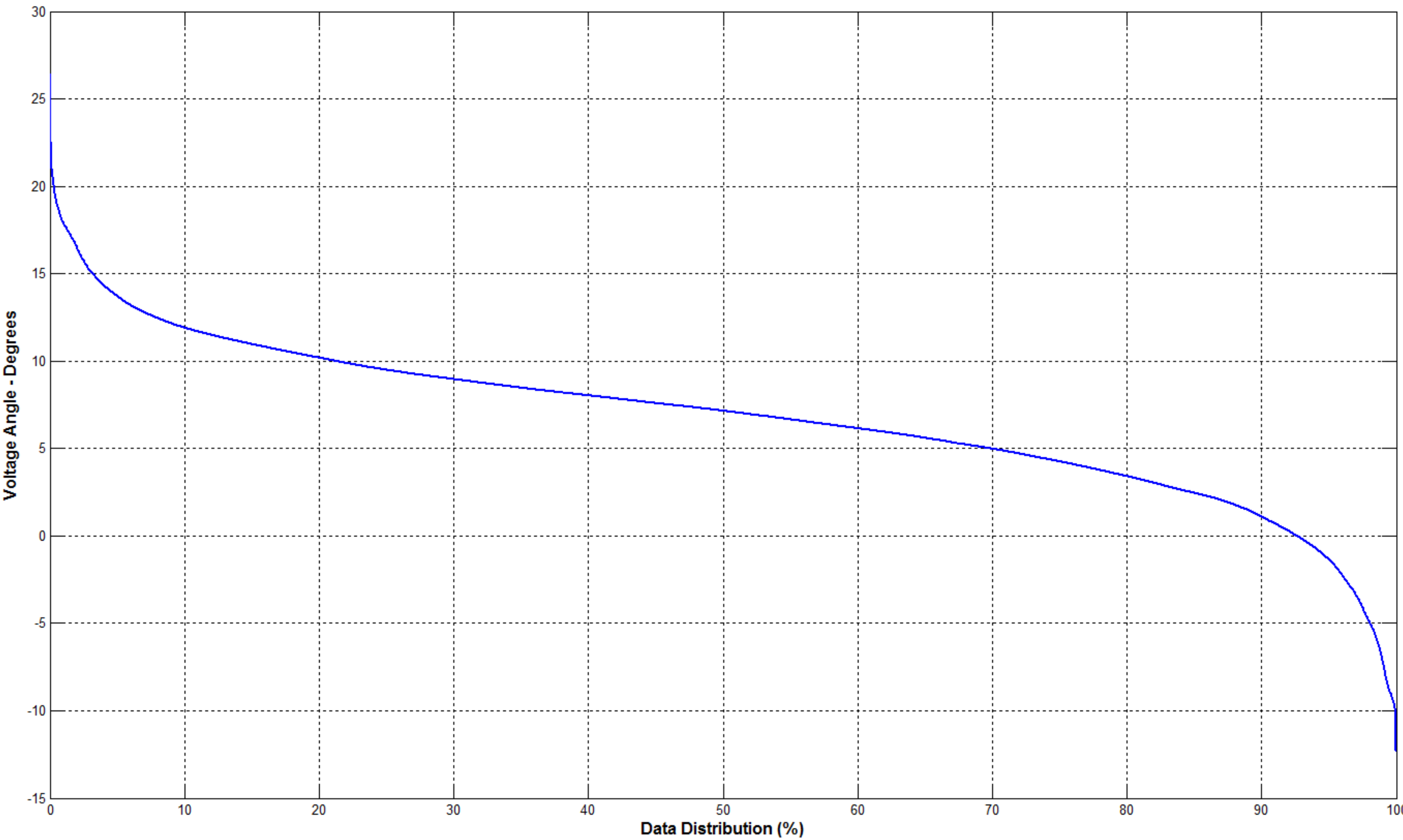

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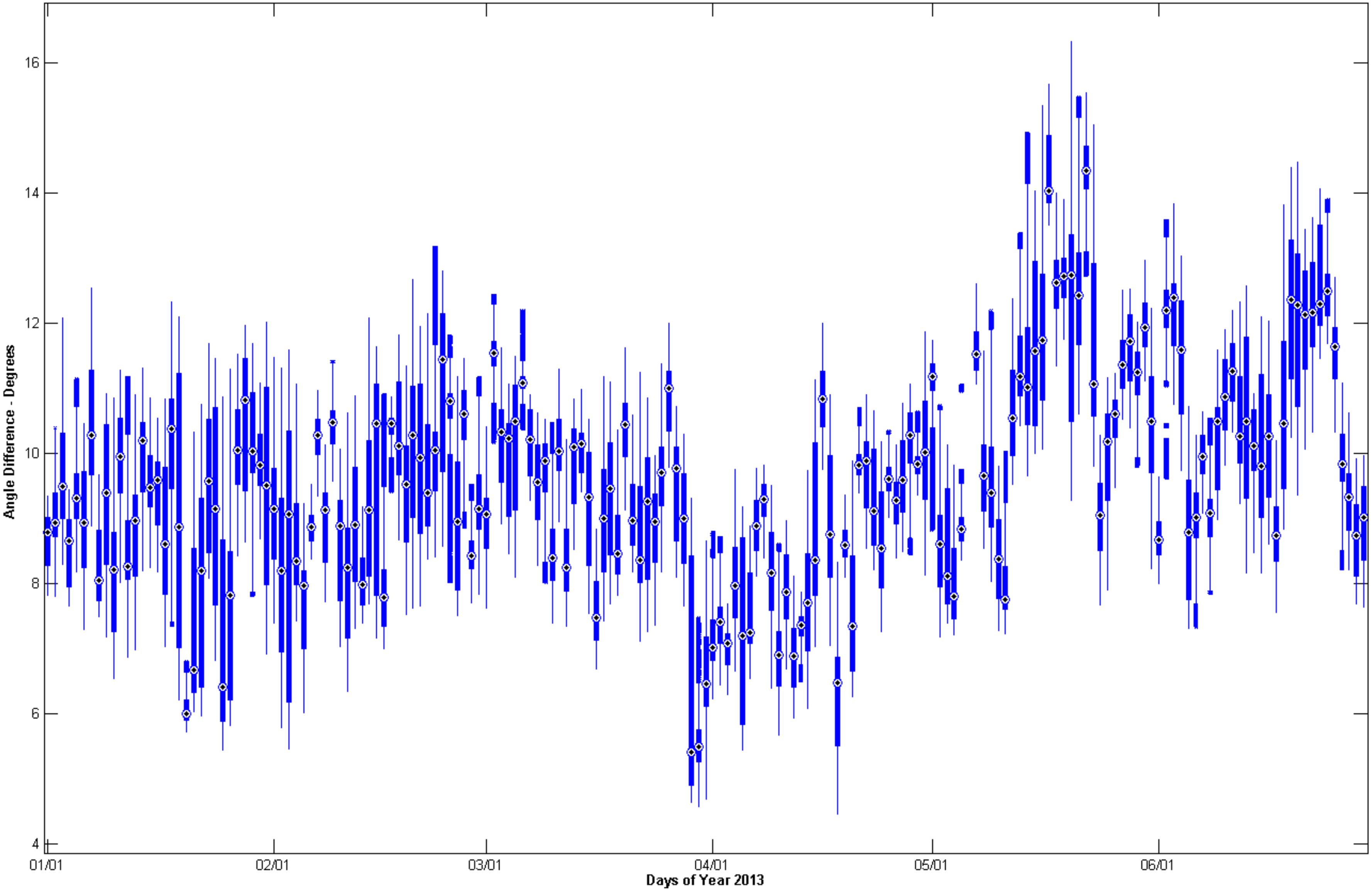

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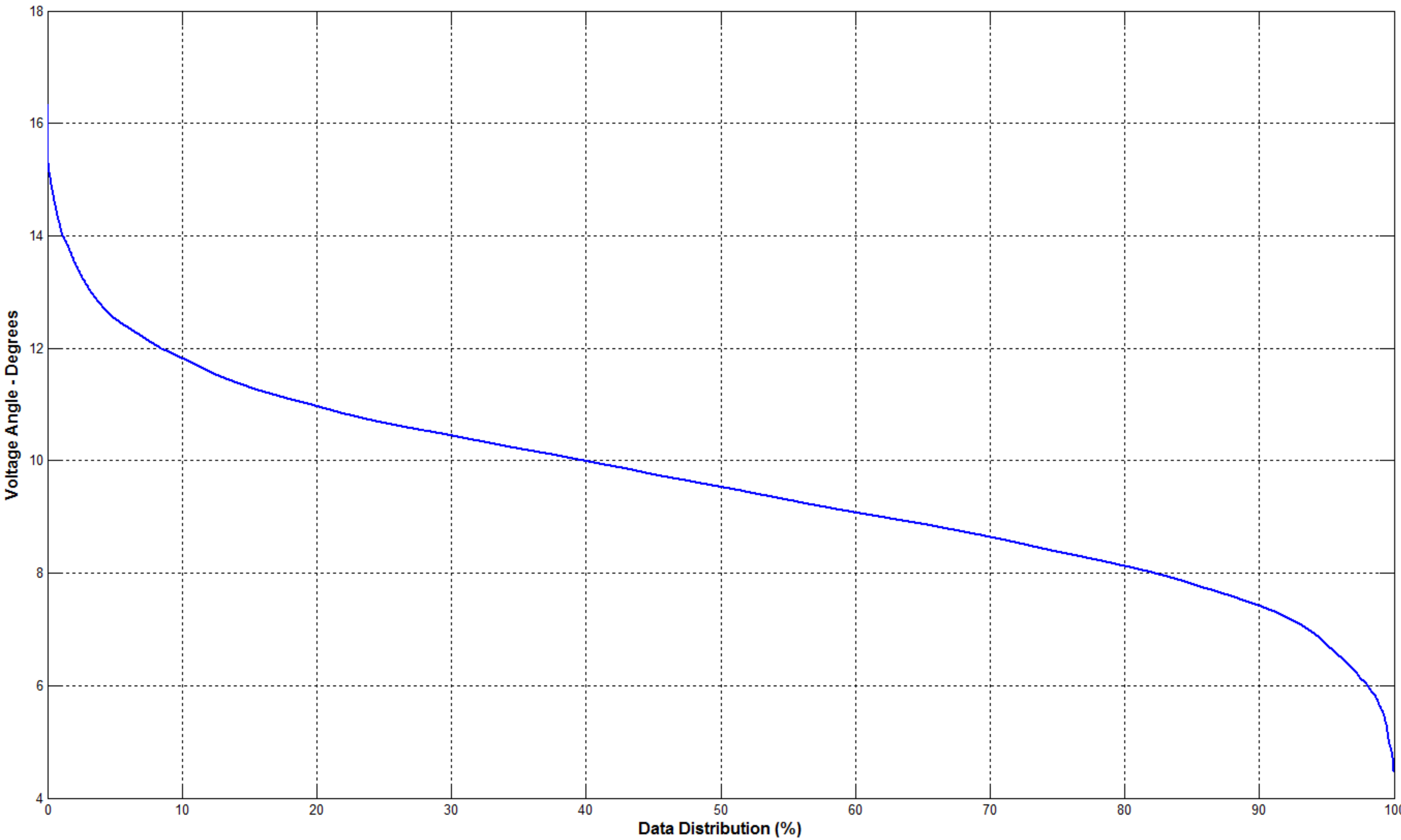

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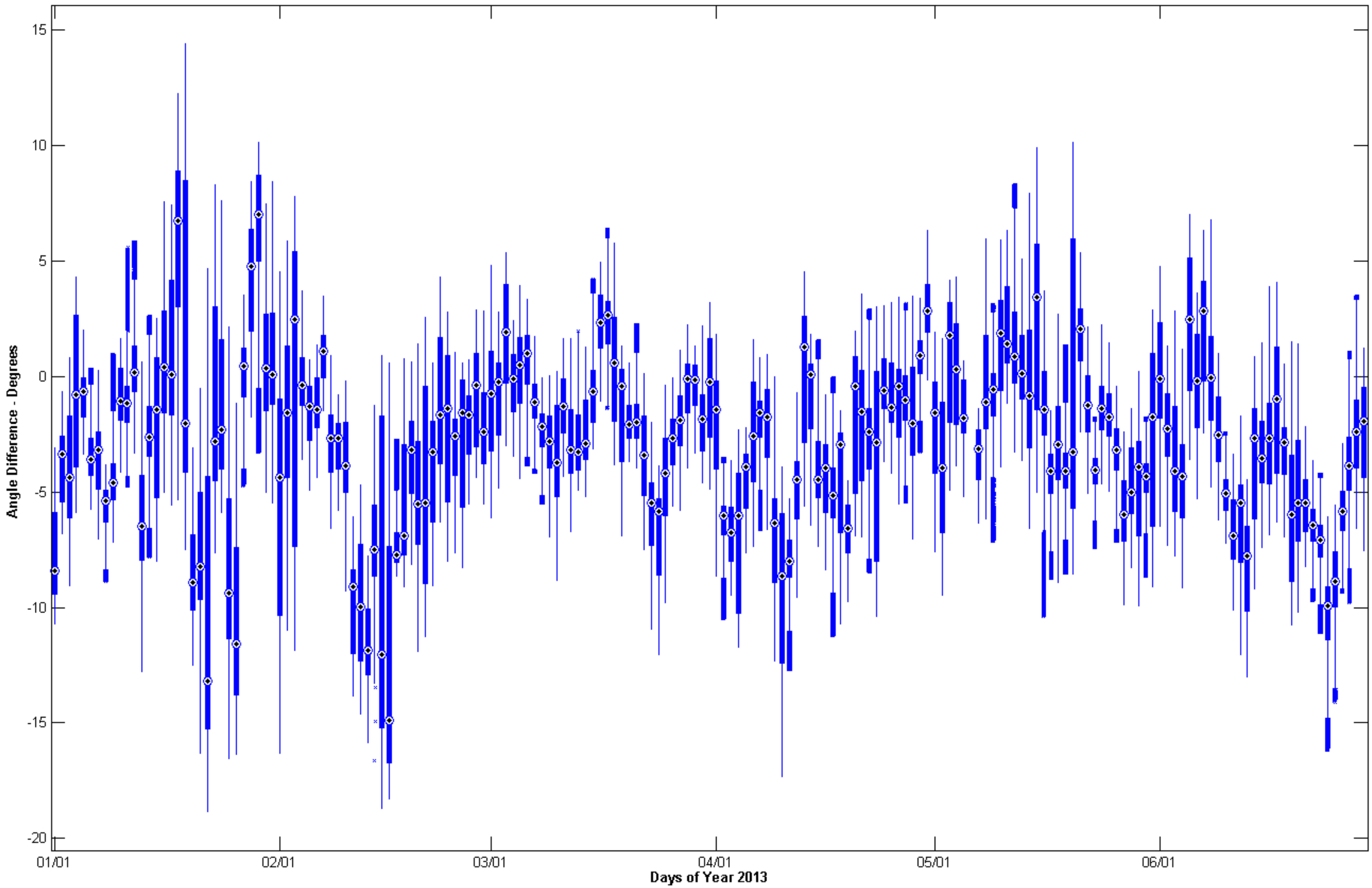

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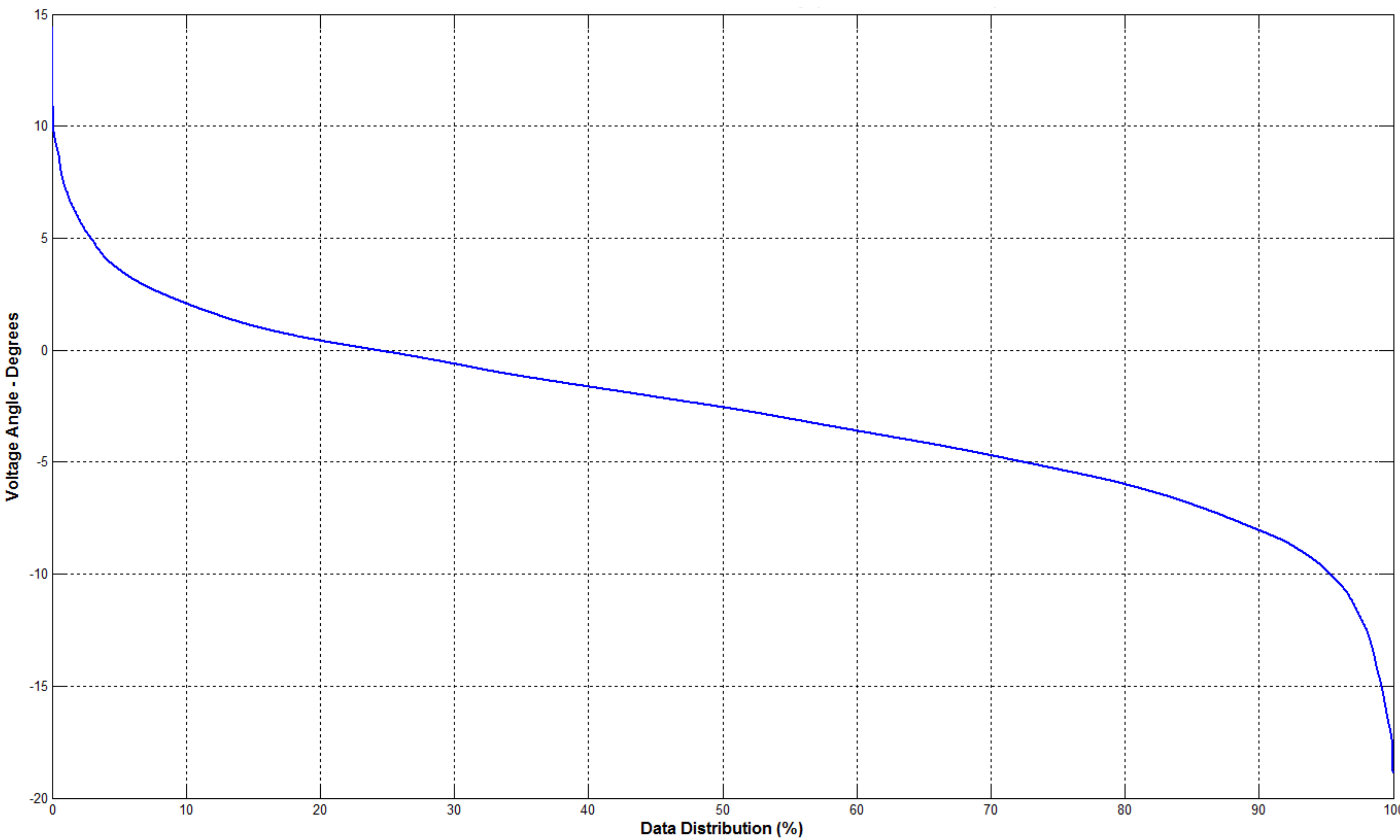

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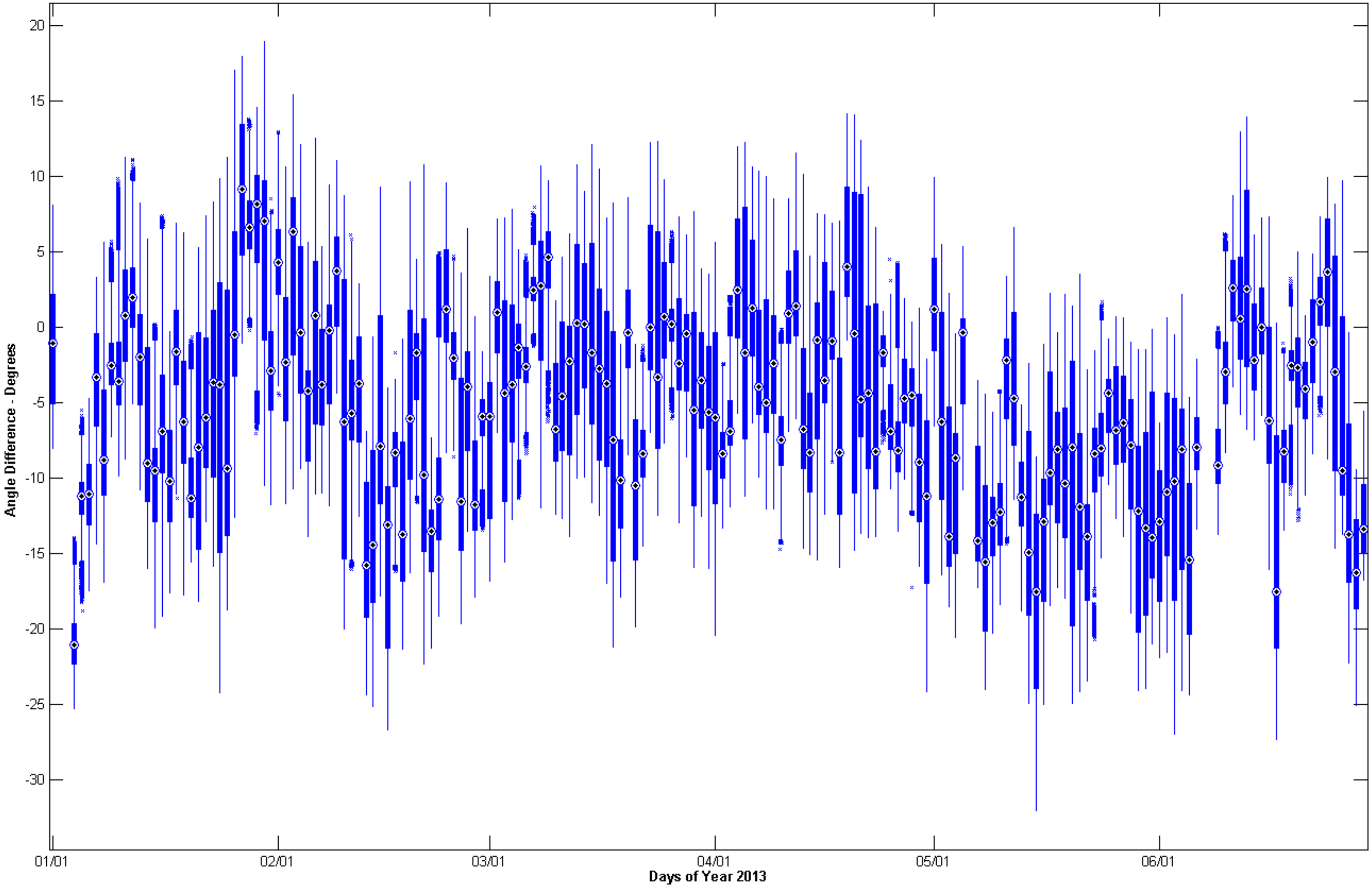

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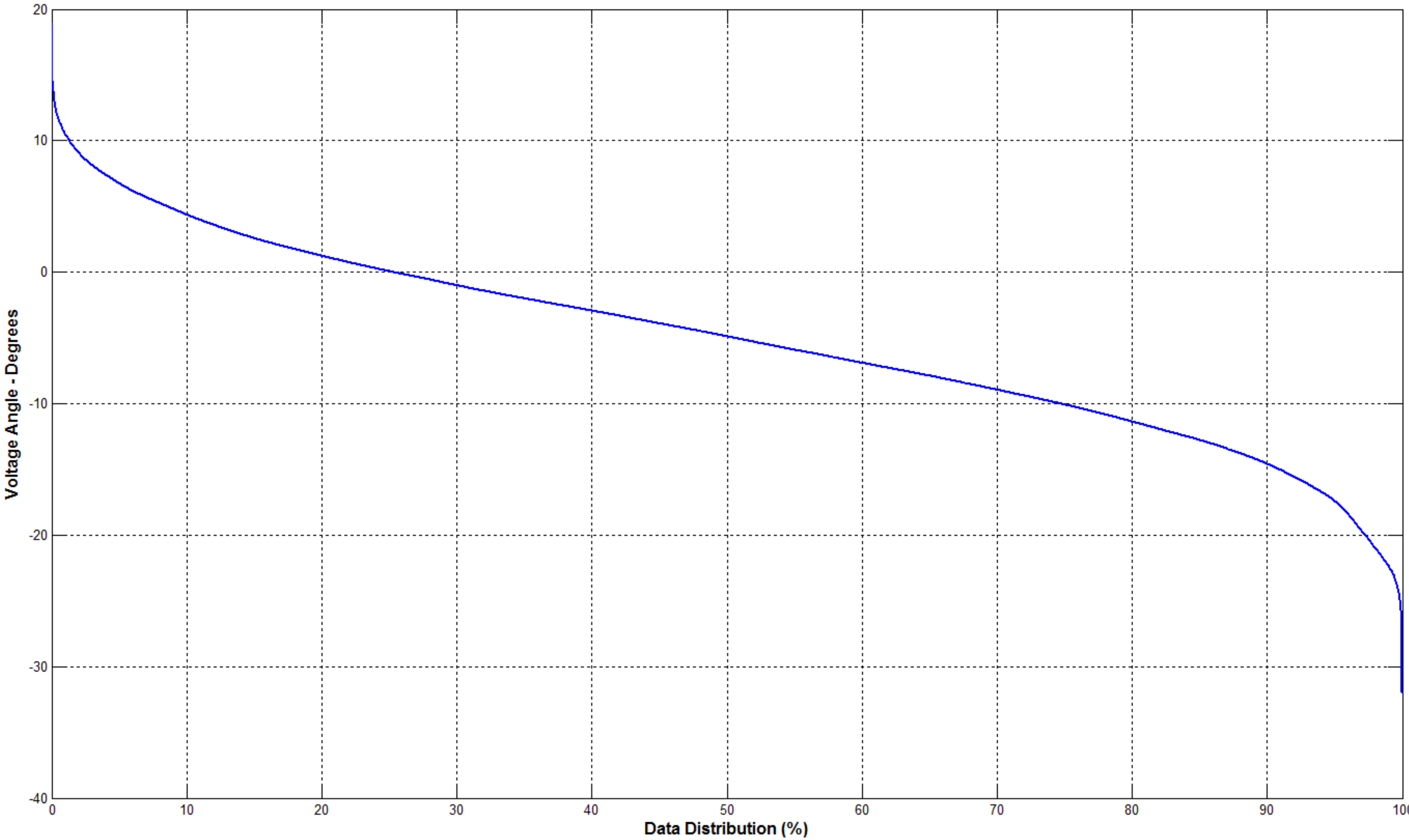

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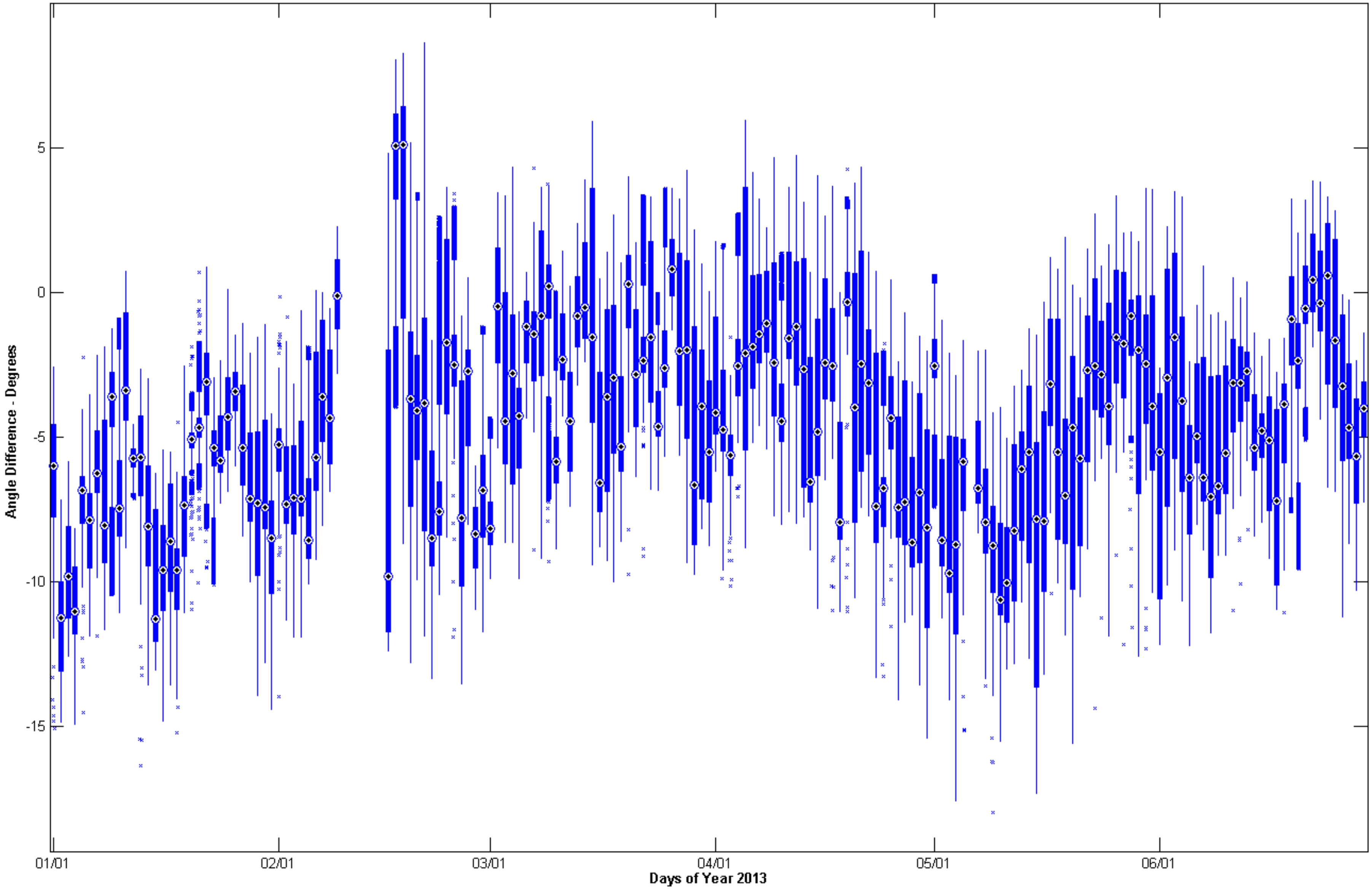

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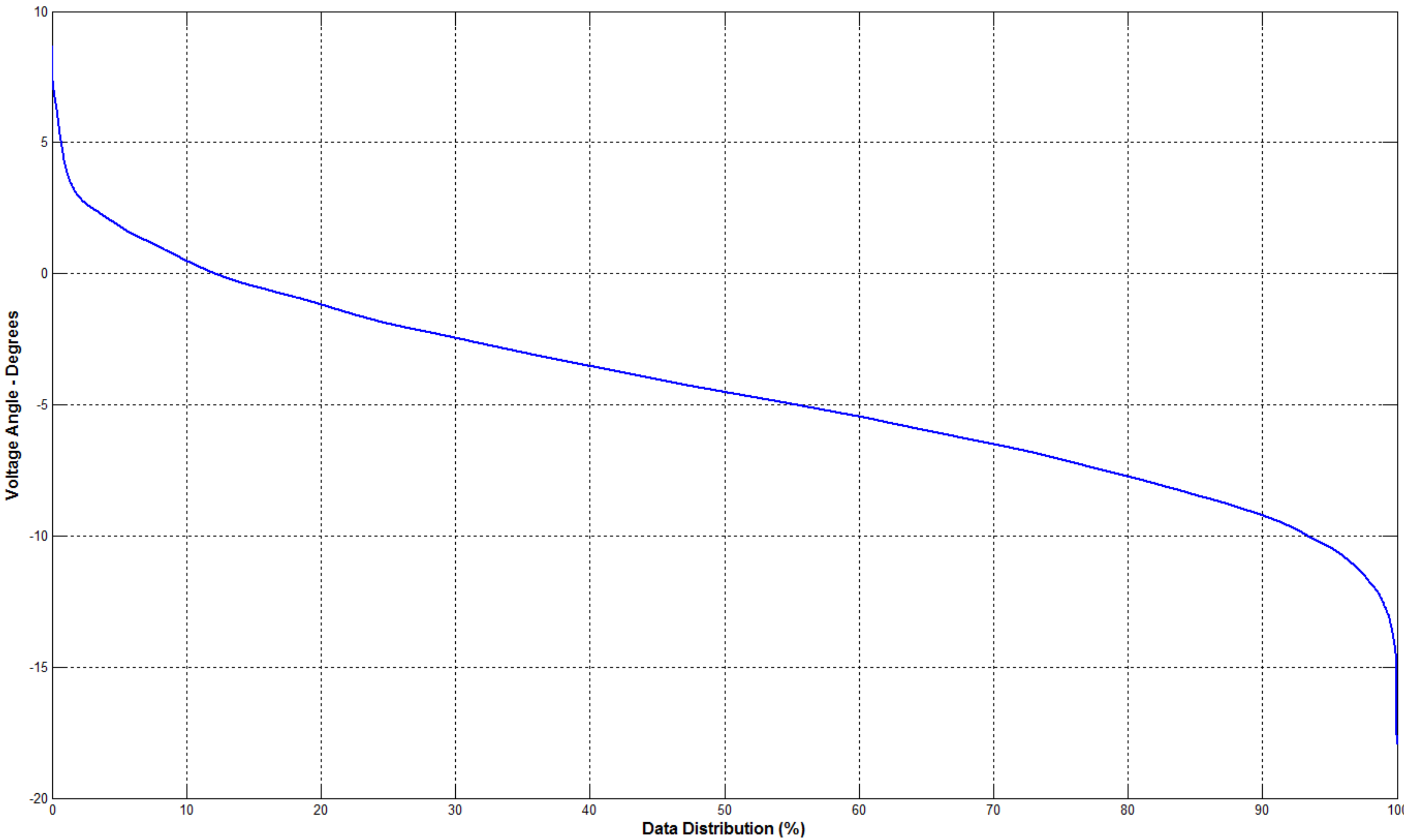

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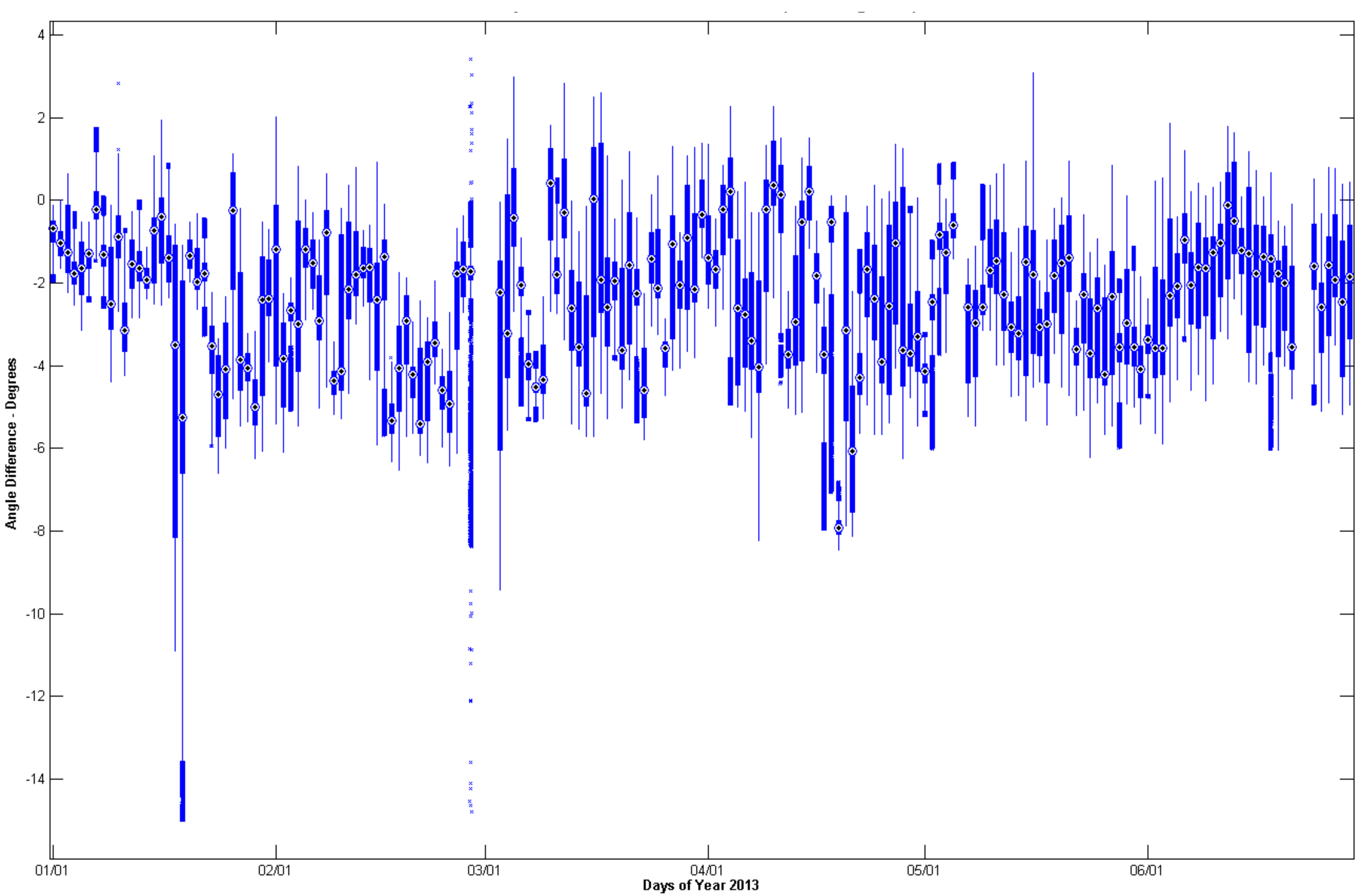

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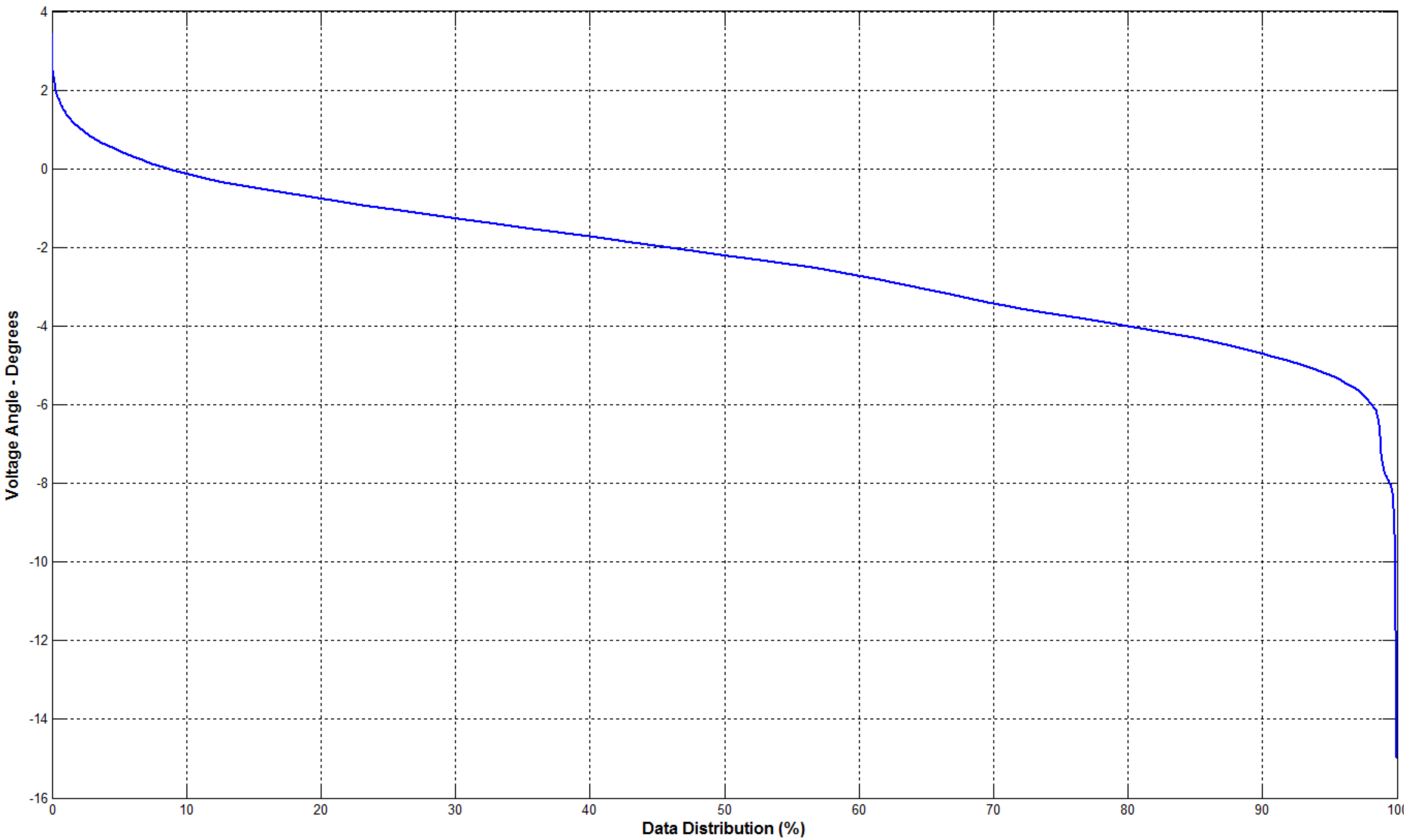

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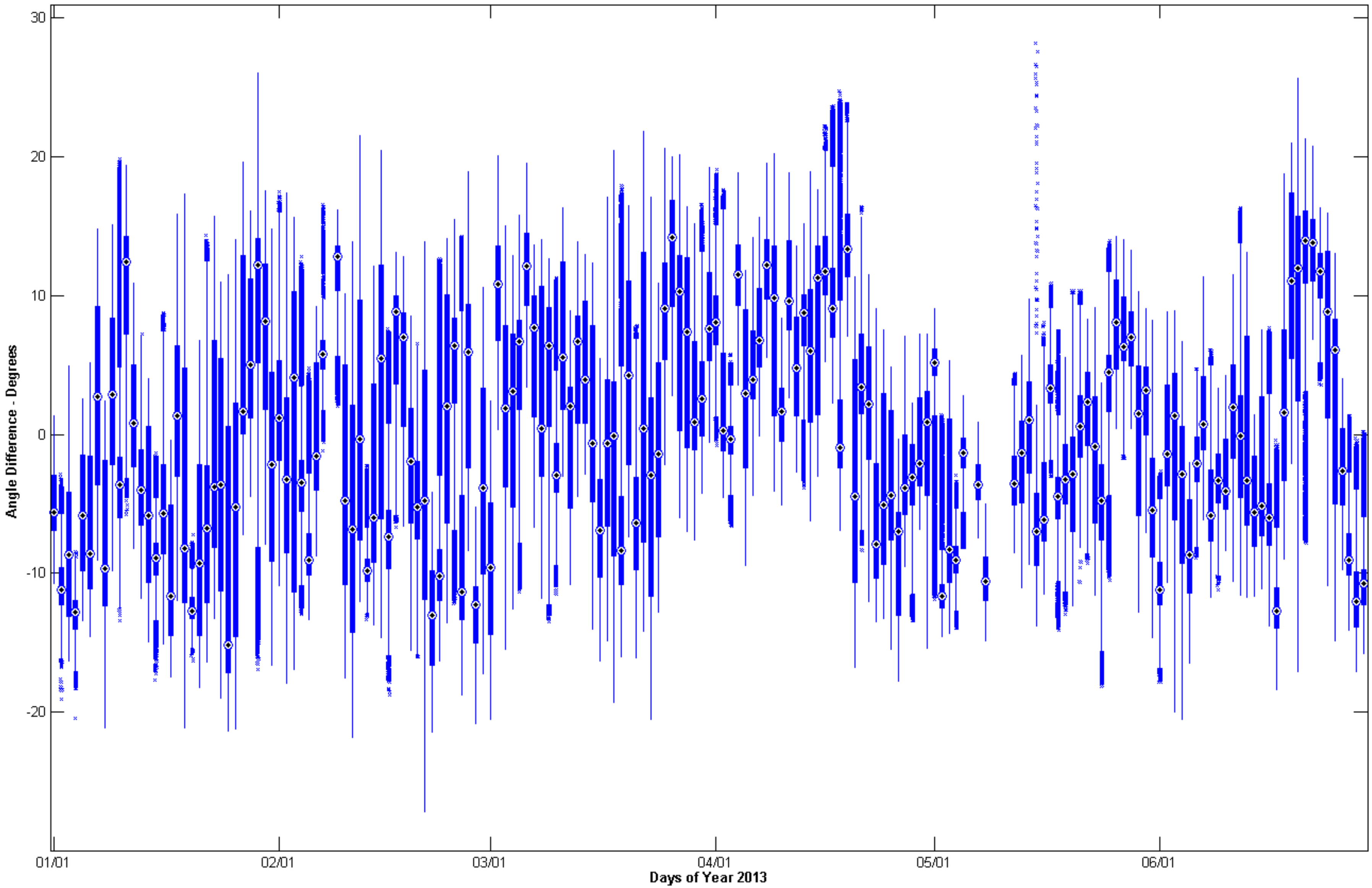

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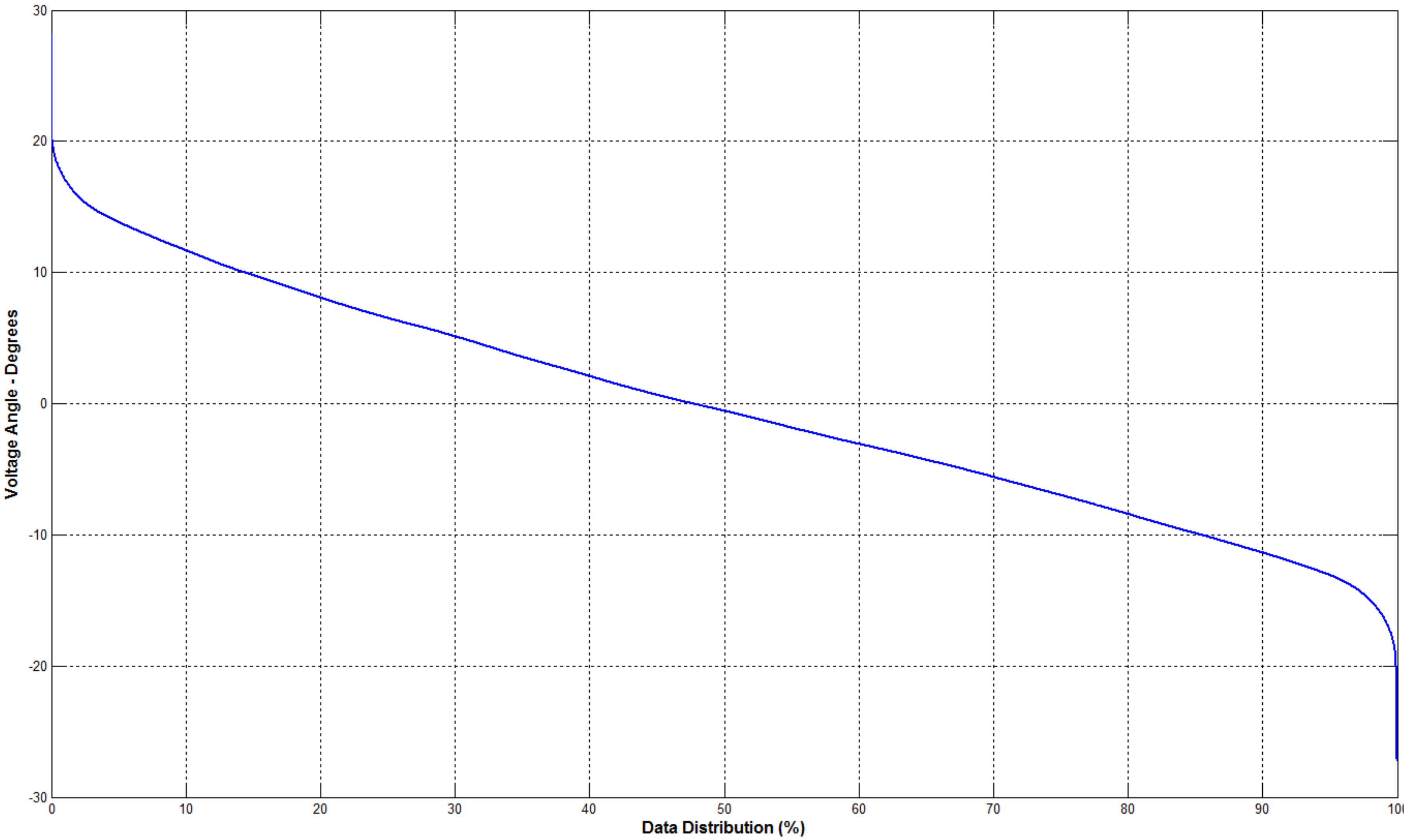
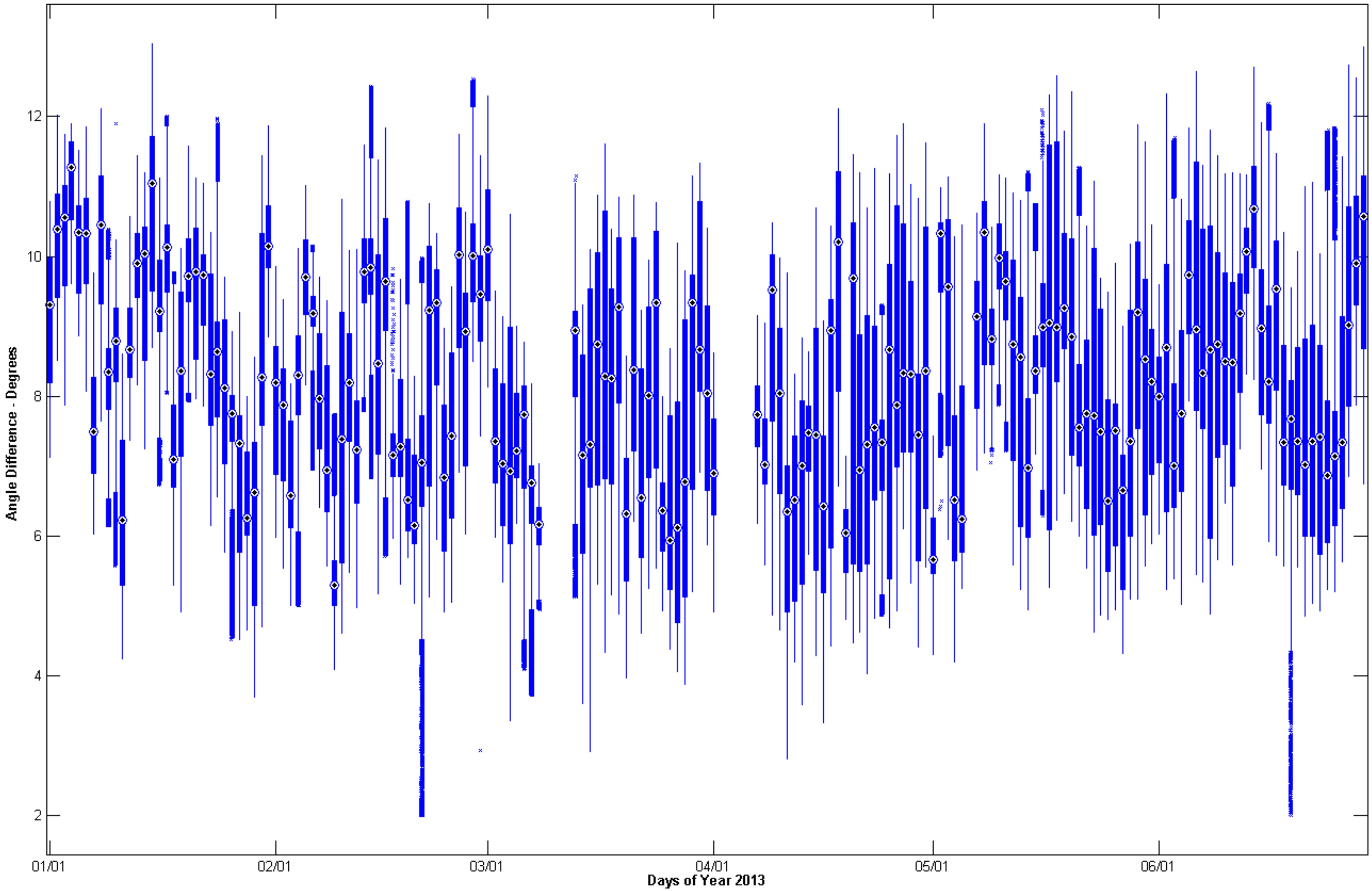


FarWest 7 – FarWest 8



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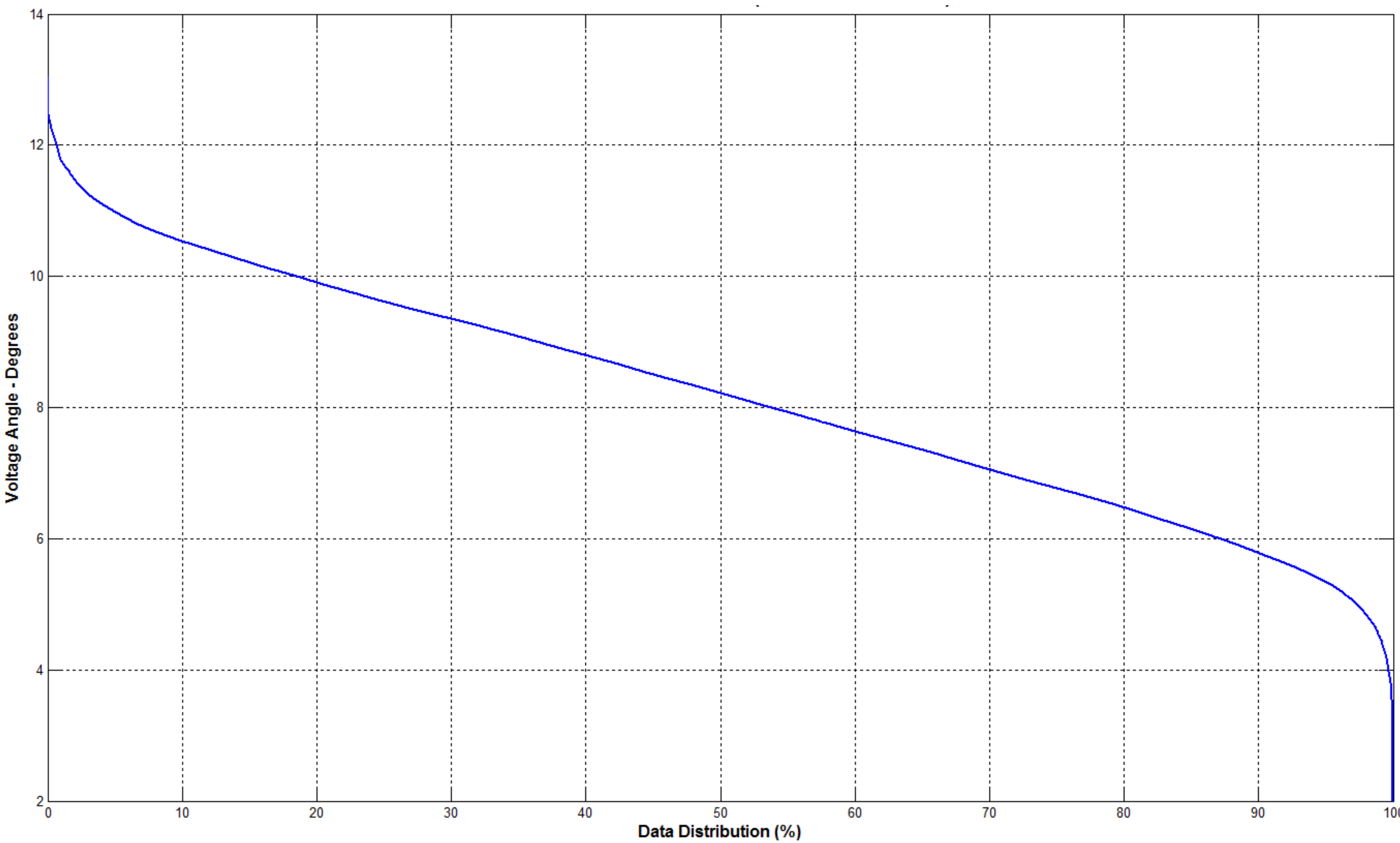
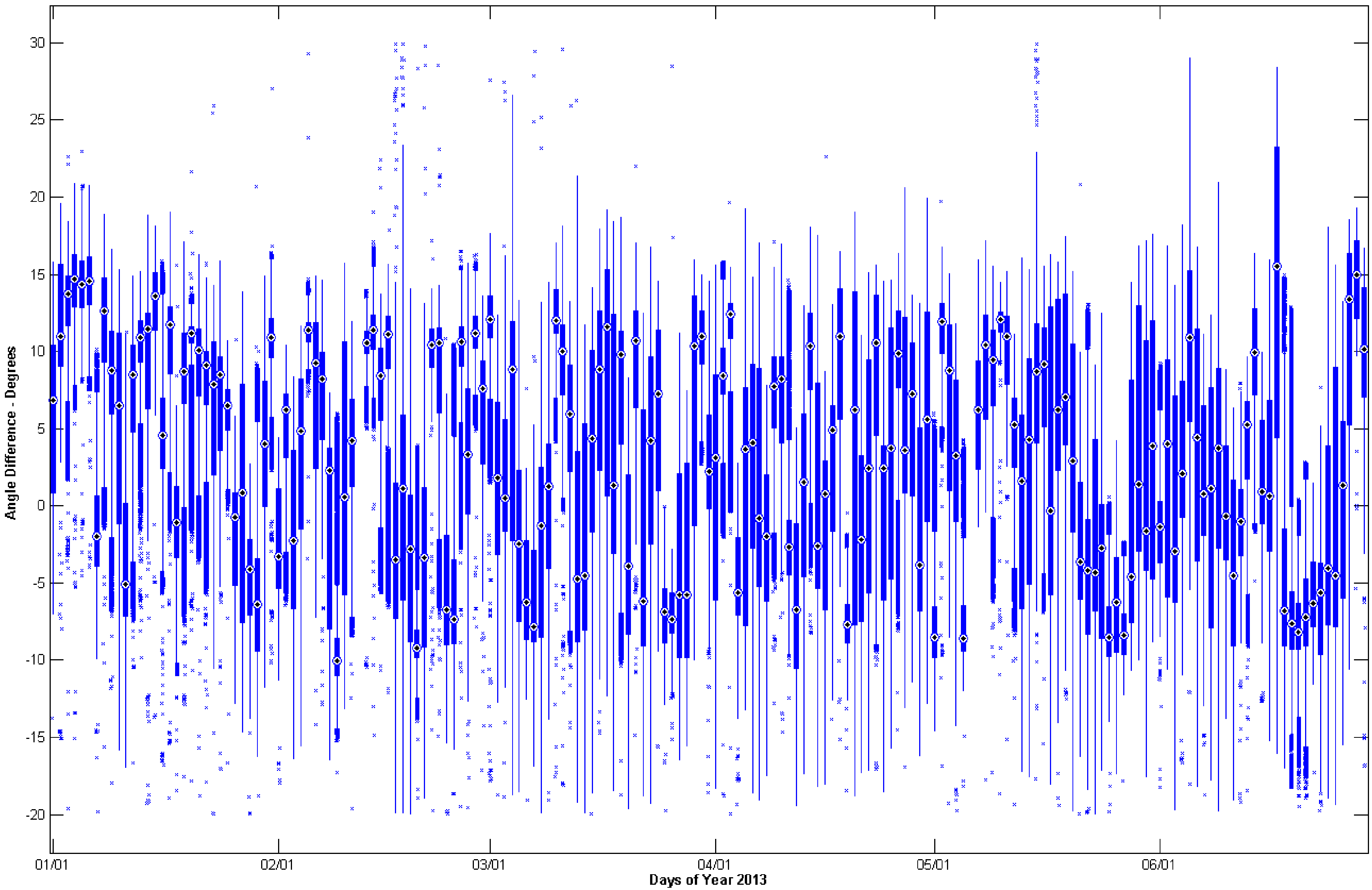


FarWest 7 – FarWest 9



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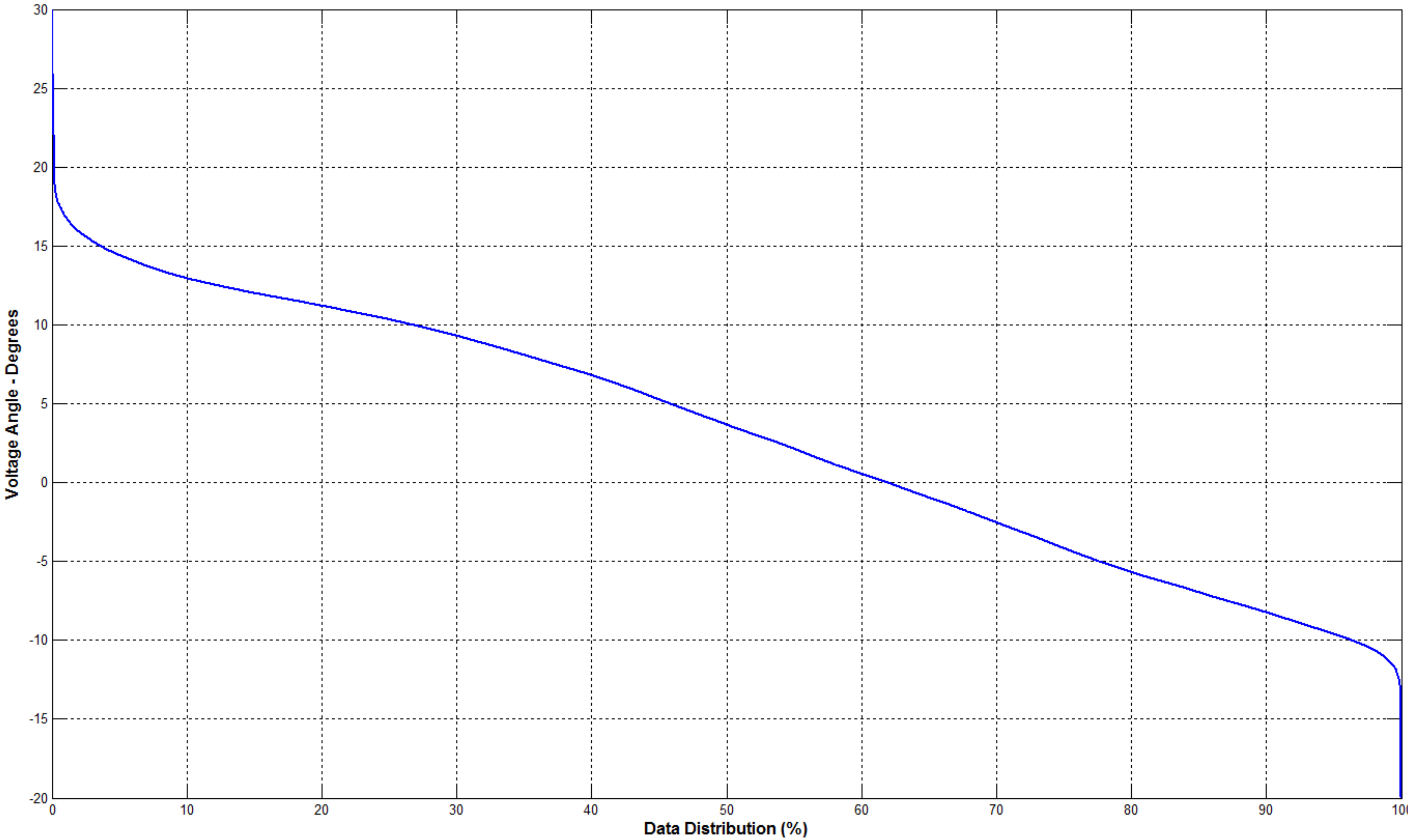

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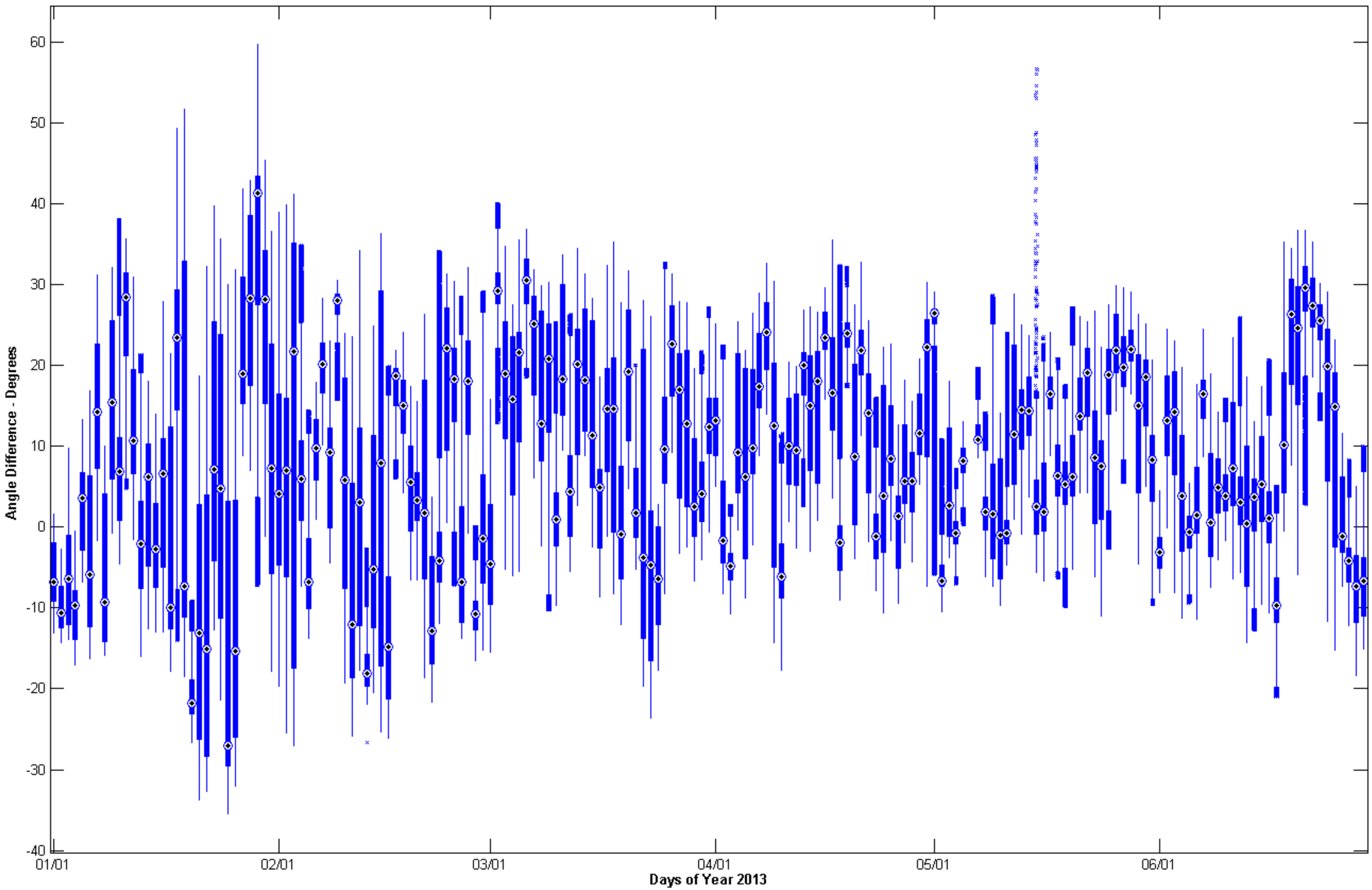
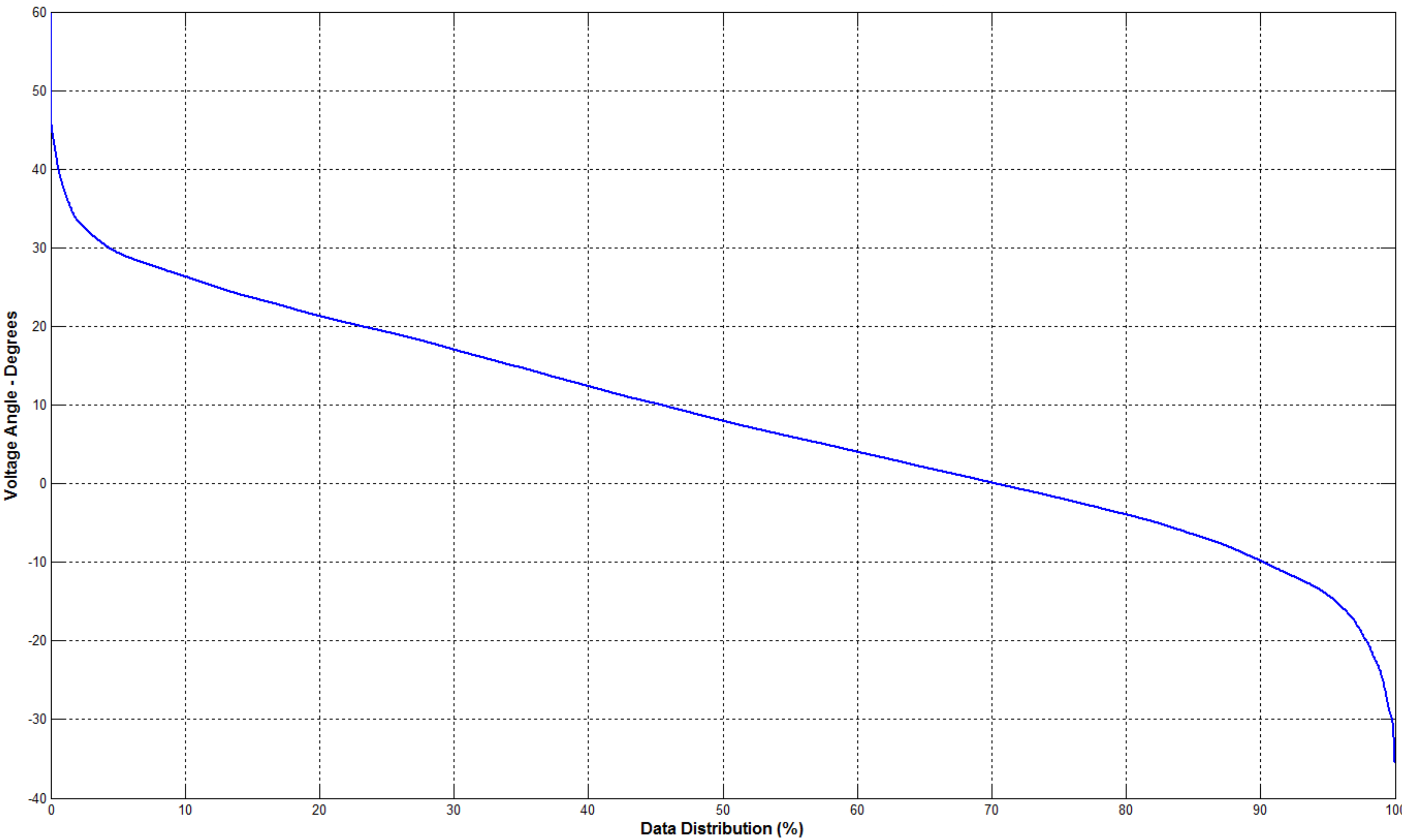
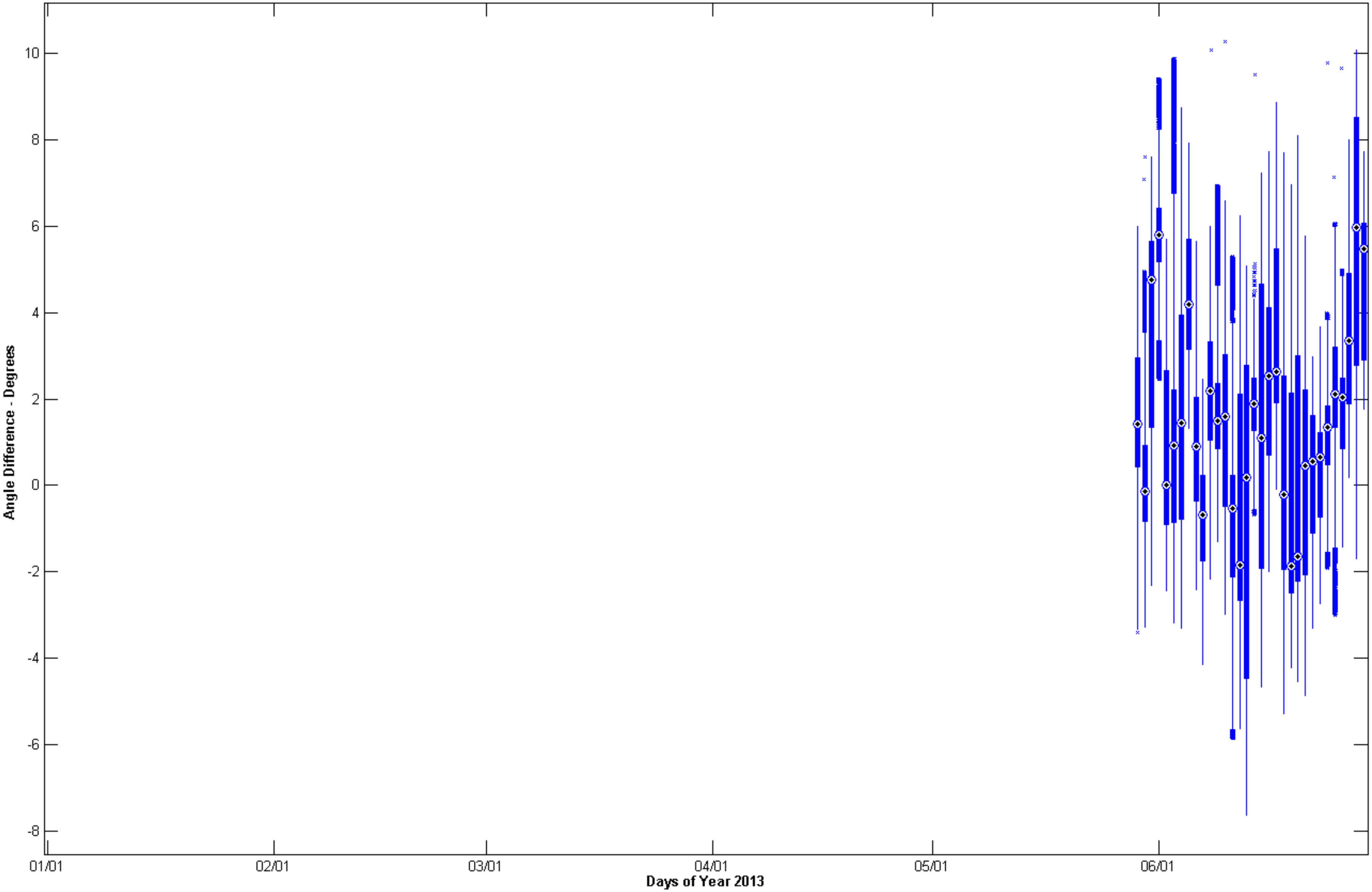


FarWest 7 – North 7



West 9 – FarWest 7



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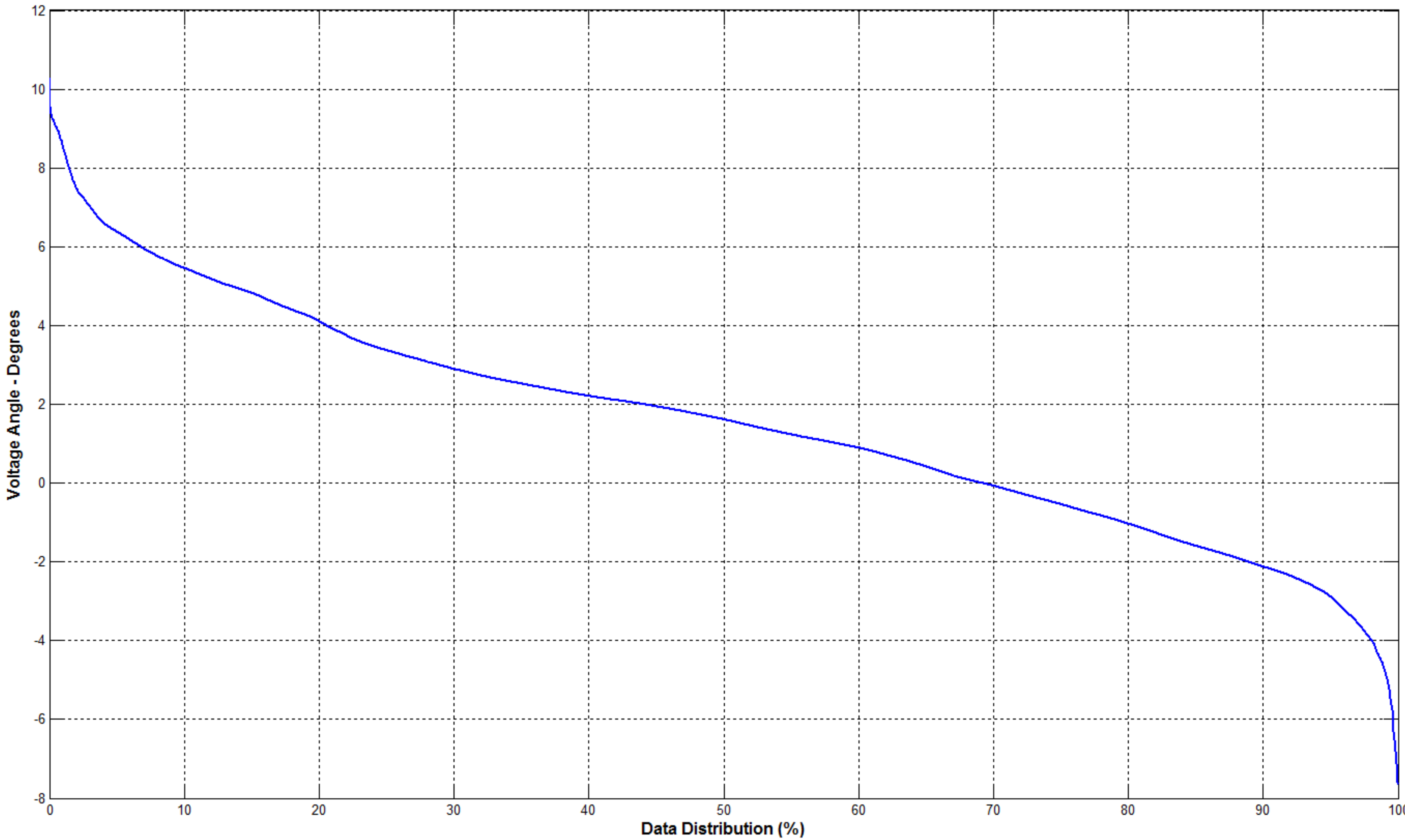

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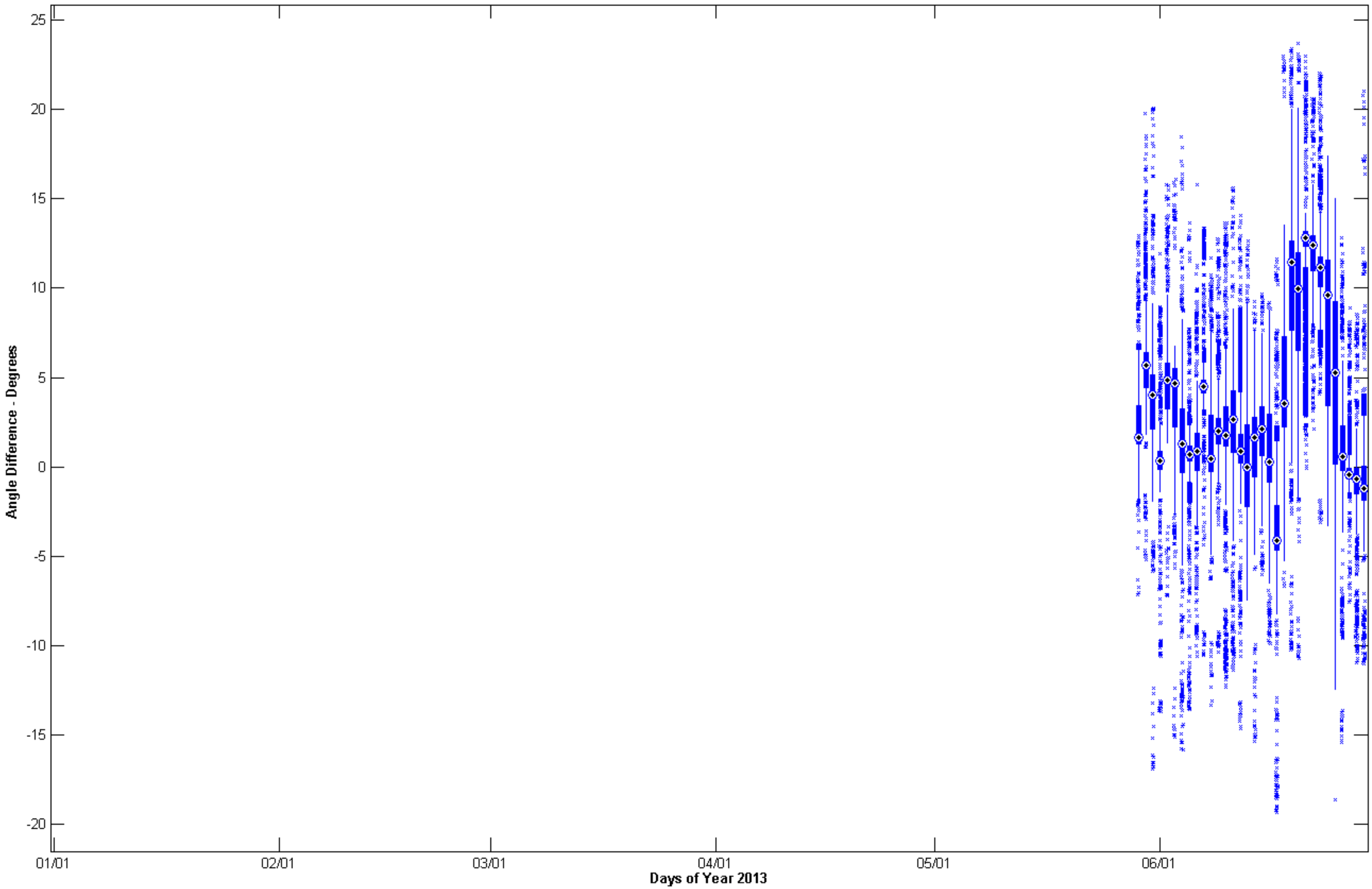
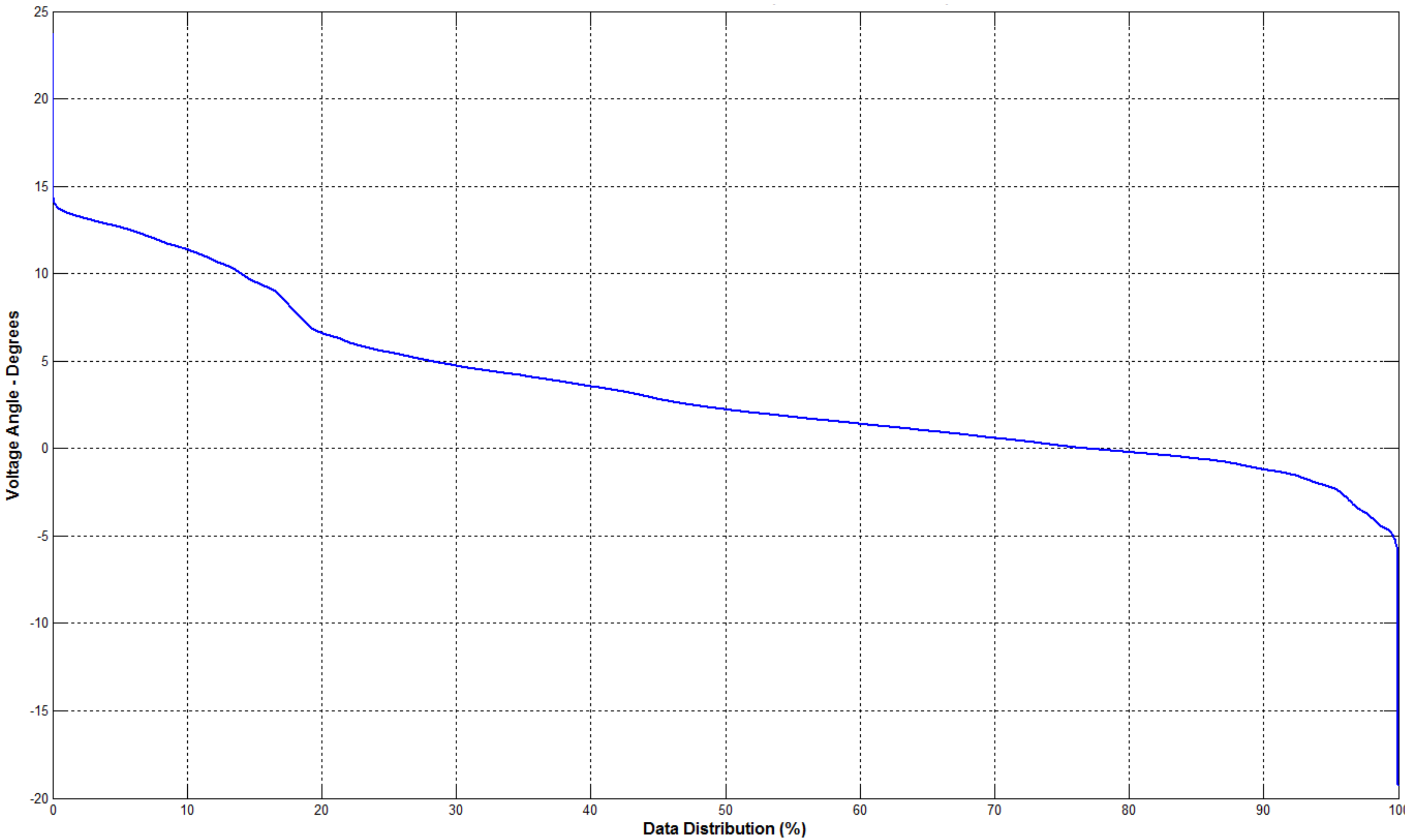


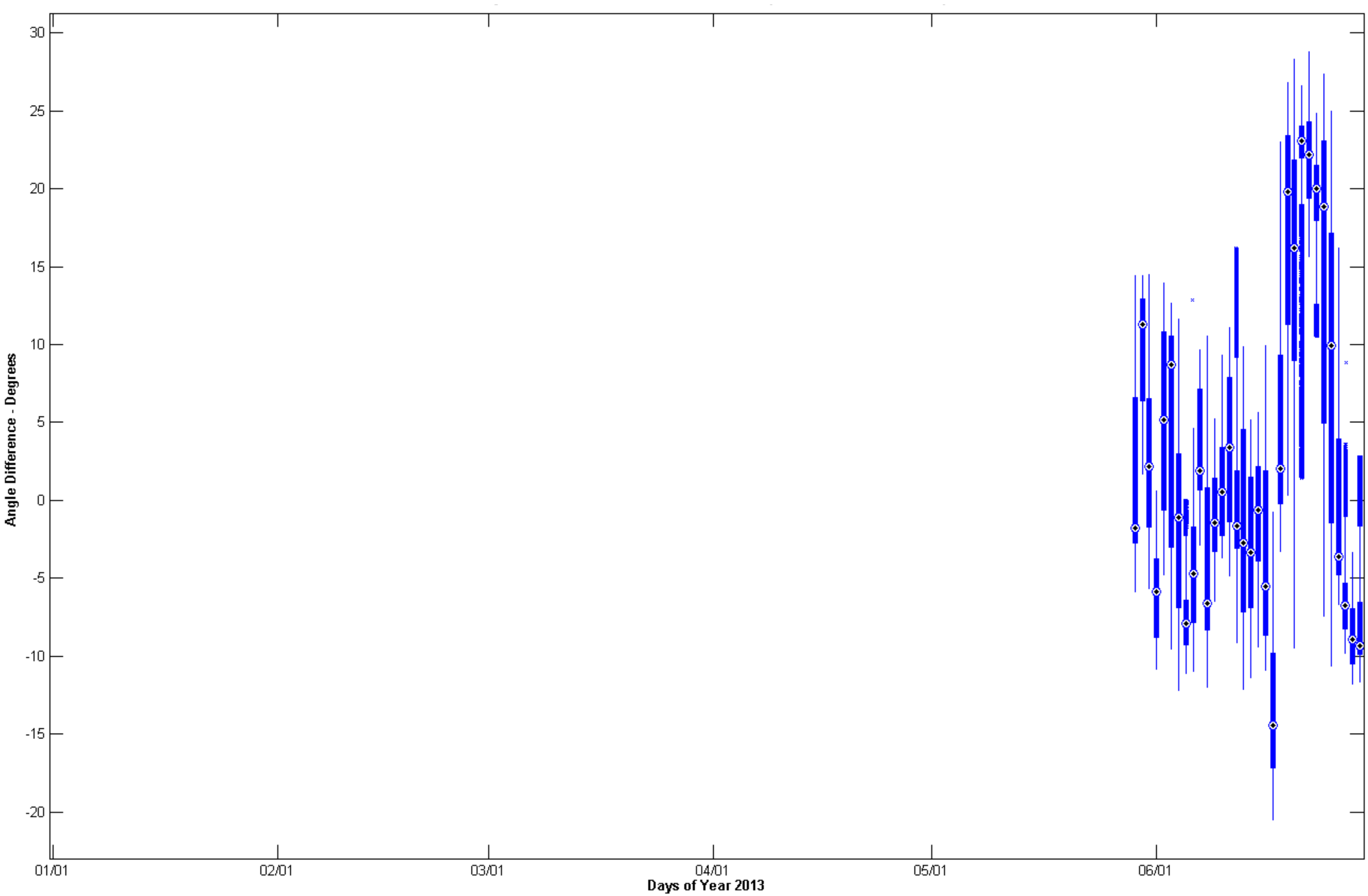
25
20
15
10
5
0
-5
-10
-15
-20
Angle Difference - Degrees
01/01
02/01
03/01
04/01
05/01
06/01
Days of Year 2013

West 9 – West 1



25
20
15
10
5
0
-5
-10
-15
-20
Voltage Angle - Degrees
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 9 – North 1



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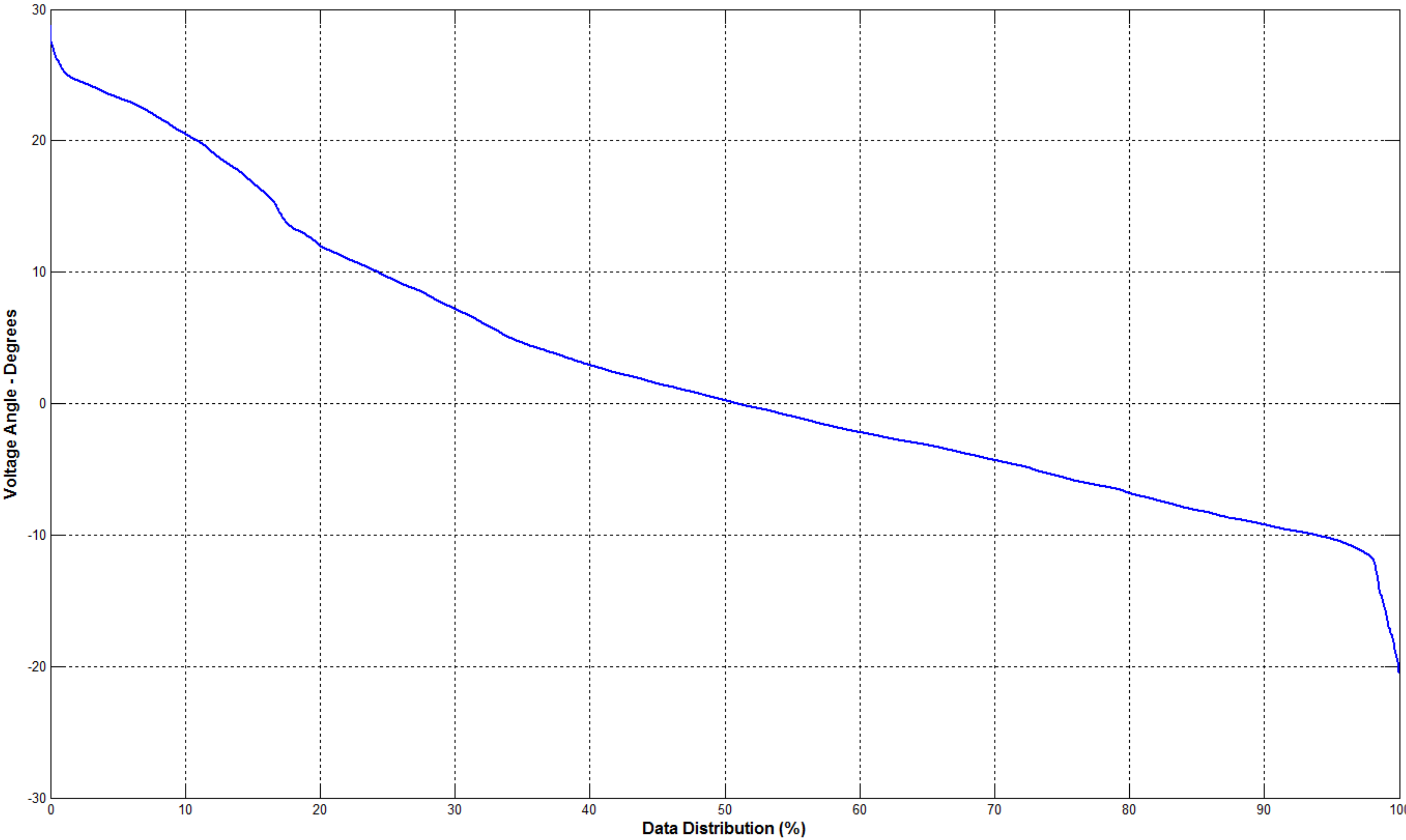
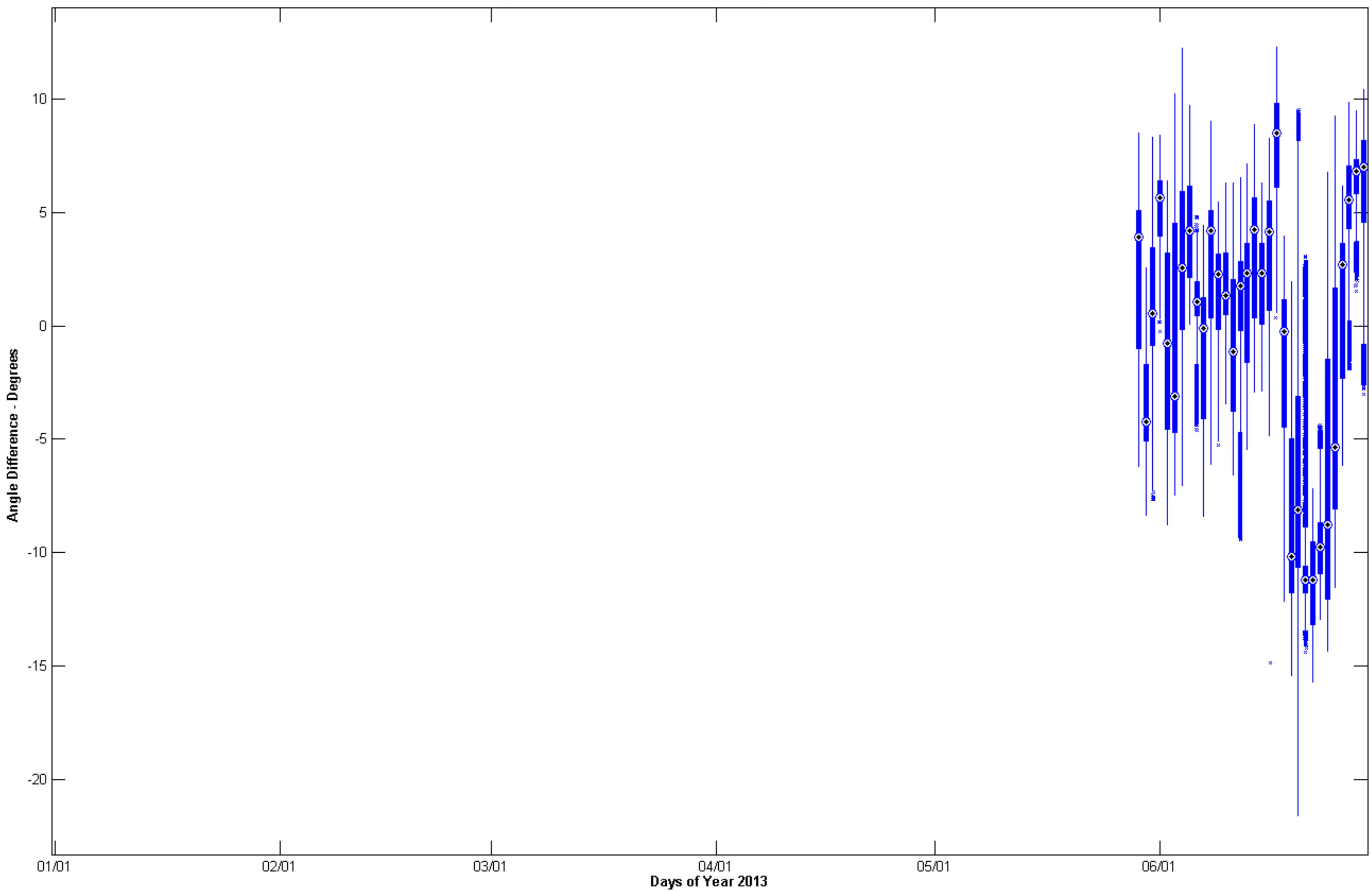
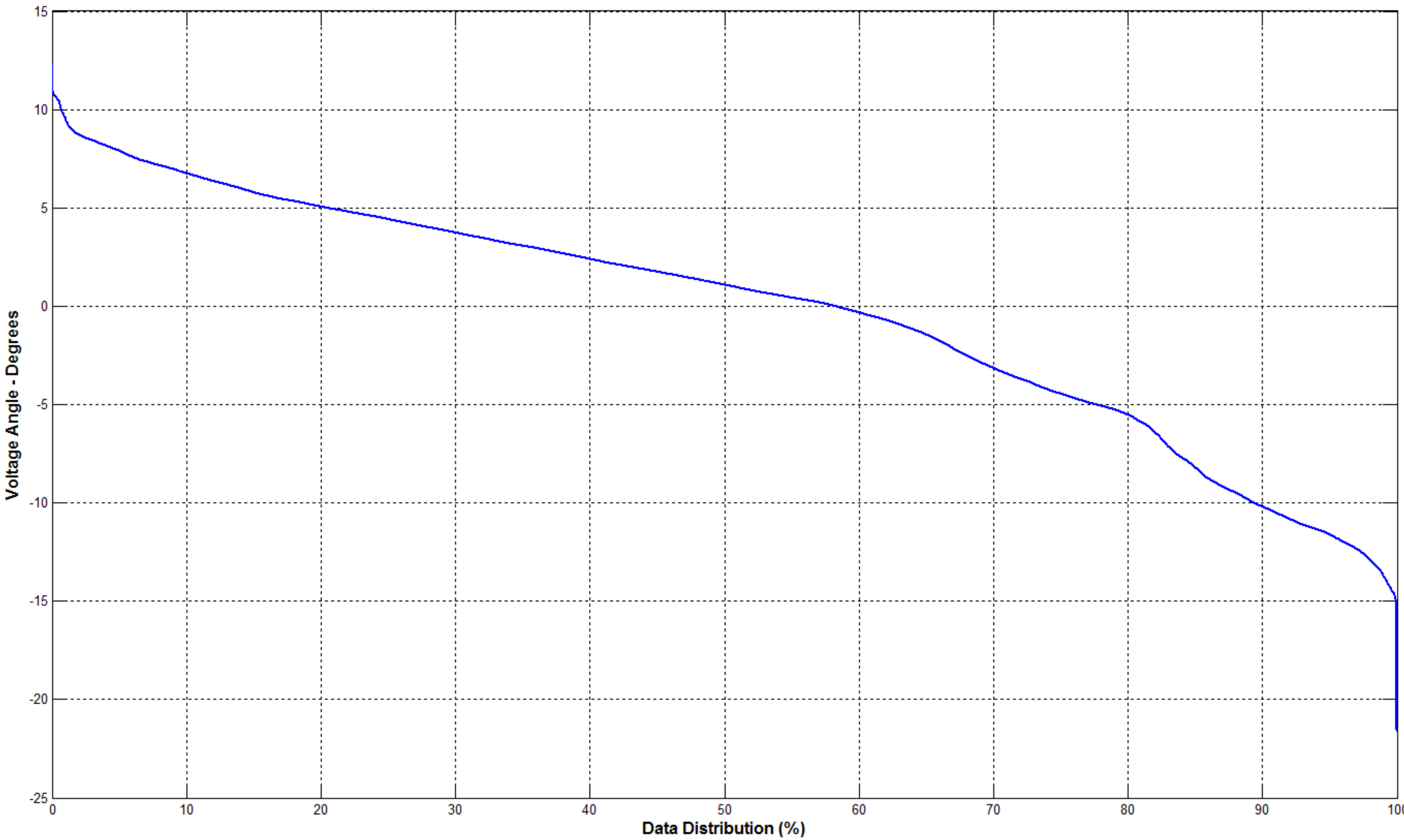


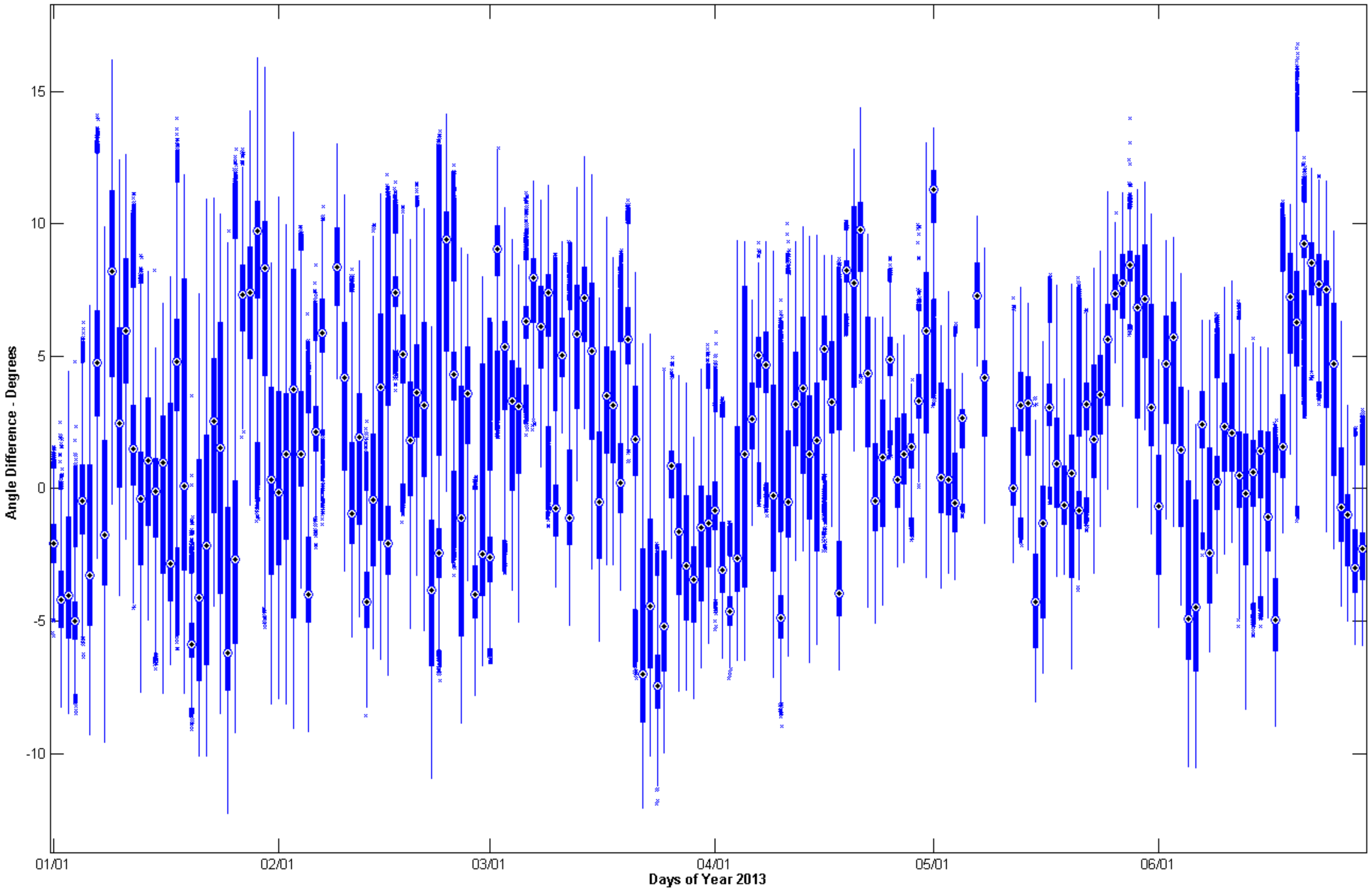
West 14 – West 5



West 14 – West 5



West 14 – North 1



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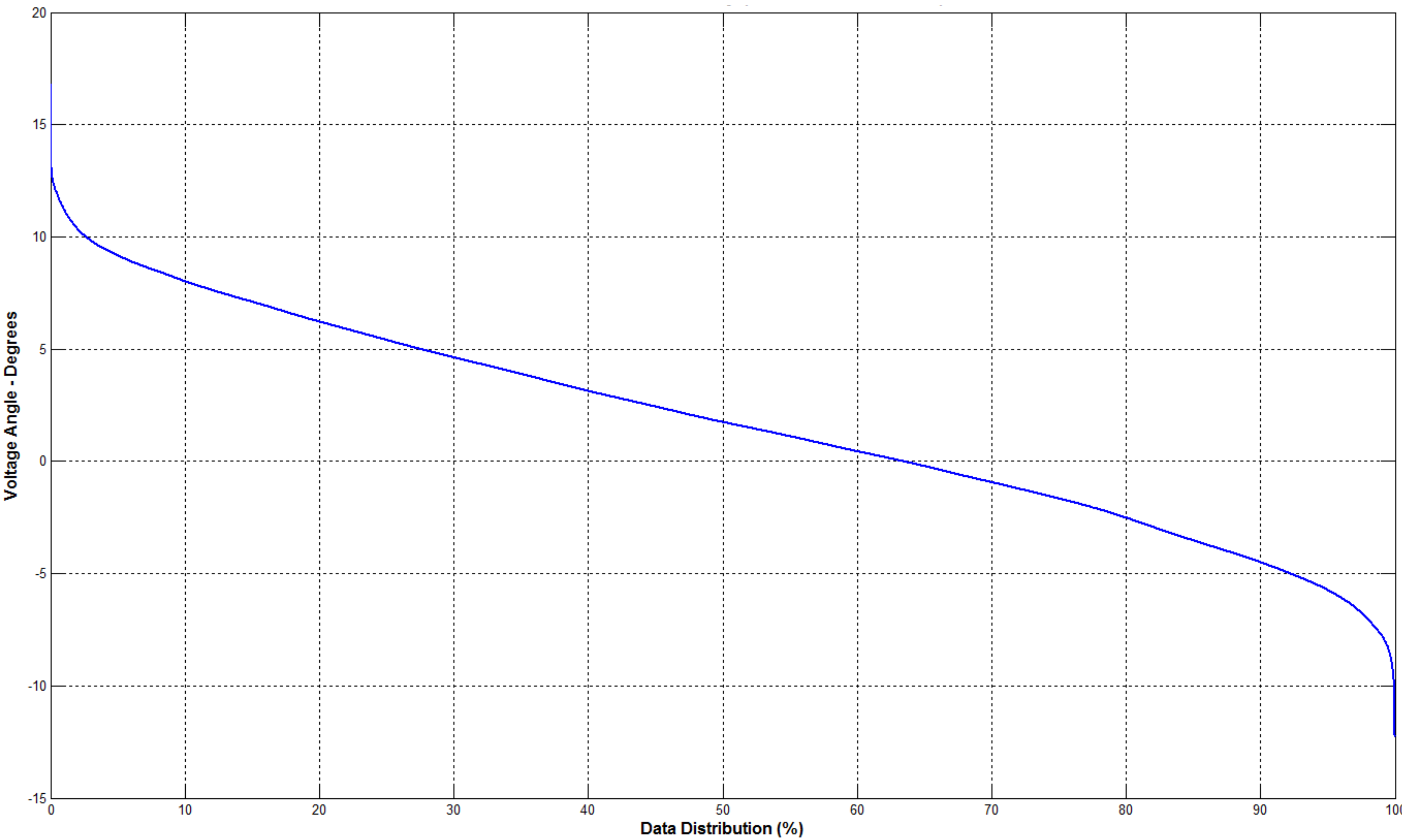
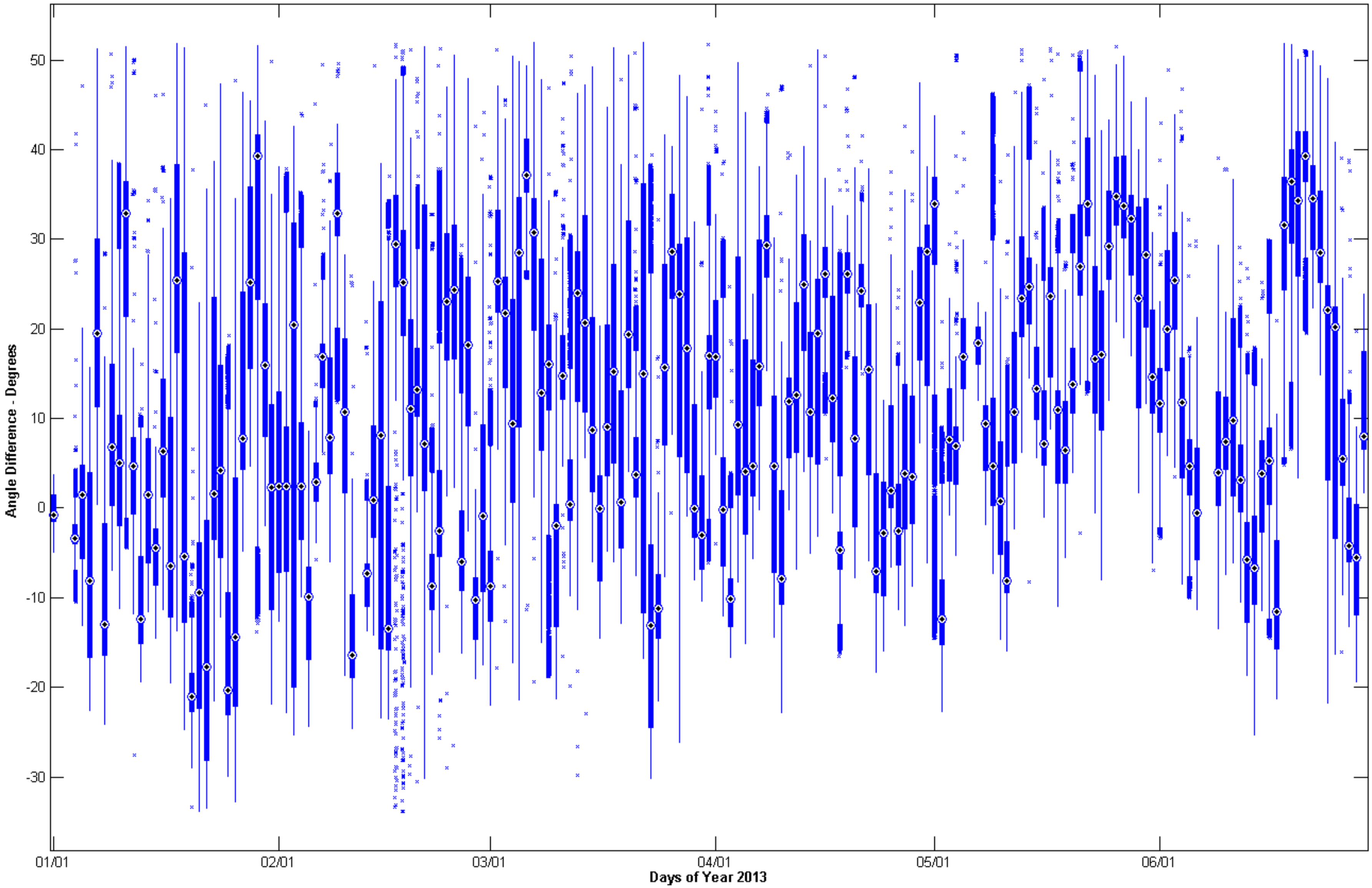
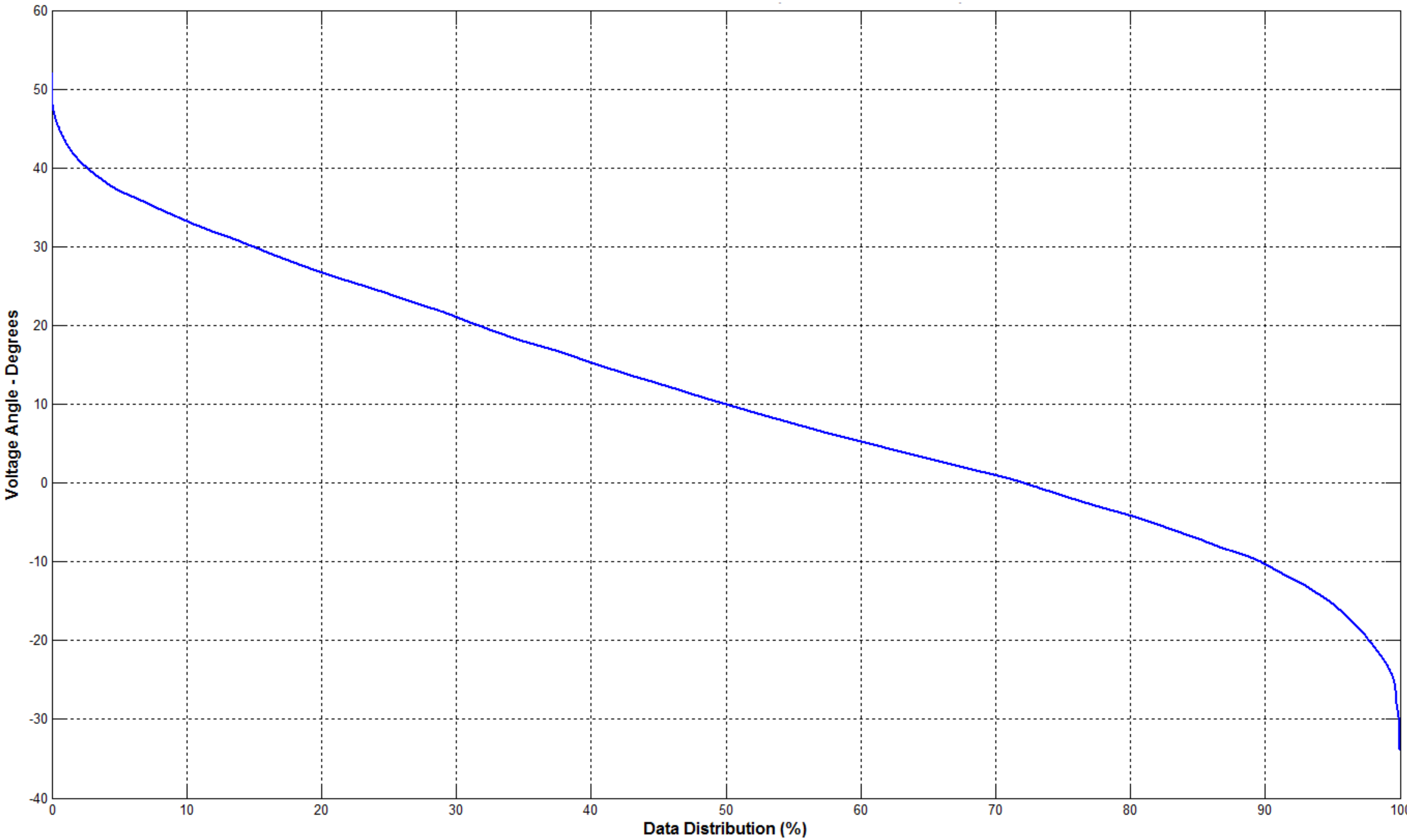


FarWest 9 – West 4



FarWest 9 – West 4



Attachment 4. Updated Baselining Study #2 for 2013

Baselining Analysis Update 2:

2013, 12-Months 2T Data

Discovery Across Texas Project

Submitted By:

Electric Power Group

John Ballance
Romulo Barreno
Ajay Das
Song Xue

June 30, 2014

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External Version

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APPENDICES (attached as separate documents)

1. INTRODUCTION

The Center for Commercialization of Electric Technologies (CCET) was awarded contract DE-OE0000194 by the Department of Energy to perform the Discovery Across Texas demonstration project. Electric Power Group, LLC (EPG) received a subaward from CCET to provide professional services to perform, among other things, a substation cluster analysis, comparison of phasor data versus state estimator data, and voltage and angle difference baselining. In October 2013, EPG completed a Baselining Study update (Update 1) using 2012 and January-June 2013 data that included the following: (1) grouped substations having phasor measurement units (PMUs), which are geographically close to each other, and performed a voltage and angle difference analysis for each group (cluster analysis); (2) performed a comparison of voltage and angle differences obtained using phasor measurements versus similar results using state estimator data (phasor vs. state estimator comparison); and, (3) performed a baseline analysis for voltages and angle differences for selected pairs of substations. Alarm limits were established and documented based on the baseline analysis.

Thirty new Competitive Renewable Energy Zone (CREZ) 345 kV lines were added to the Electric Reliability Council of Texas (ERCOT) system in 2013, which will change the results obtained with the 2012 data, particularly related to angle differences. Results shown in the Baselining Study Update 1 indicated that phasor data and state estimator data track very well and, therefore, EPG did not repeat that comparison study in this Baselining Update 2. Updated analysis was completed for the Baselining Analysis. The Cluster Analysis update will be completed as soon as EPG obtains peak load data and wind data from ERCOT.

This Baselining Analysis Update 2 report provides results from the update analysis to track the changes in voltage magnitudes and in voltage angles caused by the new345 kV lines added to the ERCOT system in the year 2013.

2. PROJECT SCOPE

A. Baseline Analysis for Voltage and Angle Differences

This study update analyzed historical performance of the ERCOT grid using State Estimator data plus phasor data from January 2012 to December 2013 to identify normal and abnormal voltages and angle limits across the grid. In this analysis, EPG compared the results obtained using 2013 data with those obtained using 2012 data and summarized the differences, if any, due to addition of the 345 kV lines added in 2013. Activities performed as part of this item:

1. Extracted key metric information (i.e., voltage, angles and angle differences).
2. Analyzed extracted data and developed a baseline understanding of voltage, phase angle, and angle difference patterns for key substations and key pairs of substations. Substations were selected based on current or projected availability of PMUs at those substations.
3. Monitored voltages and angle differences (pairs) and developed patterns and statistics in the form of box-whisker plots and load duration curves. Substations selected for analysis of voltages are listed in Table 1 below, and pairs of substations selected for analysis of angle differences are listed in Table 2 below.
4. Prepared baselining analysis results for the selected substations and pair of substations as Excel spreadsheet and charts, including:
   a. Voltage statistics (mean, maximum and minimum).
   b. Voltage phase angle difference statistics (mean, maximum and minimum).

c. Voltage and phase angle distribution functions.

5. Developed a comparison table to show the differences in results for voltages and angle differences using 2012 and 2013 data.
6. Prepared baselining analysis summary for discussion with ERCOT and the Synchrophasor Team.

B. Establishing Alarm Limits for Use in Operations

Based on the baselining analysis, EPG will prepare a preliminary recommendation of key substations and angle pairs for monitoring in the Real Time Dynamics Monitoring System[1] (RTDMS®), and voltage and angle difference alarm settings for use in RTDMS® to alert operators when grid stress is approaching limits.

The results presented in this report should be considered preliminary. Nineteen new 345 kV lines were added to the ERCOT system in the second half of 2013 as part of the CREZ project, changing significantly the distribution of power among the existing and new transmission lines. This will result in changes in limits for voltages, voltage angles, and particularly angle differences. Recommending alarm limits based on 2013 data will only be preliminary. As requested by ERCOT, EPG plans to conduct a Baselining Analysis Update 3 using data for the first five months of 2014. Please note that a few kV lines were added in late March 2014, which may change the alarm limits for a few pairs near those new lines. Final voltage and angle difference limits for use by operators should be reviewed with data collected from the months of April to September 2014; the ERCOT system will have no new CREZ lines added to it during this period, and the angle difference ranges base of alarm limits should be stable. Also, the data availability should be similar during this period for all the angle pairs being analyzed, resulting in a more current and accurate alarm limits.

3. DATA SOURCES

Two sources of data were utilized to perform the study update analysis of voltage and angle differences in the ERCOT network: phasor data and state estimator cases. A description of these sources of data is provided below.

A. Phasor Data

ERCOT provided EPG phasor data for the entire year 2013 with a resolution of 30 samples per second (SPS). EPG performed the following actions on the phasor data provided by ERCOT prior to using it for statistical analysis:

1. Downloaded the ERCOT data provided in MySQL format.
2. Converted the ERCOT binary format data into alphanumeric format.
3. Converted MySQL data to comma-separated value (CSV) data files for use in MatLab data analysis programs.
4. Linked ERCOT data though the MySQL server to the EPG local *enhanced* Phasor Data Concentrator (*e*PDC™) database tool to allow downloading as CSV files to the local computer.

[1]® Electric Power Group. Built upon GRID-3P platform, US Patent 7,233,843, US Patent 8,060259, and US Patent 8,401,710.

5. Down-sampled phasor data from 30 SPS to 1 SPS, and downloaded it to the local computer for analysis.
6. Applied status flag filtering to perform the first step in data cleaning.
7. Developed data filtering algorithms and wrote code in MatLab to perform the second step of data filtering.
8. Addressed small data dropouts by interpolation techniques or filled dropouts with blanks.

This process of data setup, downloading, cleaning, and data dropout fixing has now been automated to reduce the time taken to process the data from the time received to the time when the data is suitable for analysis. However, further manual cleaning is necessary to weed out remaining outliers. In some cases, the phasor data was simply not of good quality; in those cases, this report will point out those PMUs with bad data for review by their owners.

After the data was extracted and processed, another program, developed by EPG, was used to extract the information and compile it into a summary table, and two series of graphs. One graph (box-whisker) shows daily summaries of data, and the other, time duration curves, shows values versus percent time for each study variable. The time duration curves were used to obtain the metric values corresponding to 1% and 99% exceedance (the value which was less than 1% plus inflection or greater than 99% minus inflection).

Phasor Measurement Units (PMUs) Installed and Planned in ERCOT

As of December 2013, there were 69 PMUs installed in 31 locations across the ERCOT service area. Table 1 below shows the 31 substations equipped with PMUs.

The Baselining Study Update 2 was completed using data from the twelve months of 2013 that included state estimator data analysis for locations for which PMUs are installed, and for which PMUs are planned.

Table 1 – List of Substations with PMUs Currently Connected to the ERCOT Grid, as of March 10, 2014

TABLE 1 - List of Substations with PMUs Currently Connected to the ERCOT Grid As of March 10, 2014

#	Company	PMU Name	PMU Name in D. Base	Name of the Station where PMU is located	Date–data stream connected to ERCOT	Enabled	Base kV
1	AEP	Line_1	Line_1@ West 14	West 14	7/25/2012	Yes	345
2	AEP	Line_3	Line_3@West_4	West 4	7/2/2012	Yes	138
3	AEP	Coast 3 TR1-345	Coast_3 TR1-345	Coast 3	4/30/2012	Yes	345
4	AEP	Coast 4 TR1-345	Coast_4 TR1-345	Coast 4	3/26/2012	Yes	345
5	AEP	Line_1	Line_1@Coast_1	Coast 1	1/23/2012	Yes	138
6	AEP	Line_1	Line_1@FarWest_9	FarWest 9	3/26/2012	Yes	138
7	AEP	West_10	West_10	West 10	8/1/2008.	Yes	69
8	AEP	Line_1*	Line_1@West 15	West 15	9/16/2013	Yes	345
9	AEP	Line_1*	Line_1@West16	West 16	12/19/2013	Yes	345
10	AEP	Line_1*	Line_1@West_3	West 3	12/19/2013	Yes	345
11	AEP	Line_1	Line_1	Coast 2	?/2012	Yes	69
12	AEP	Line_1	Line_1@FarWest 2	FarWest 2	6/21/2013	Yes	69
13	AEP	Line_1	Line_1@South_3	South 3	6/21/2013	Yes	138
14	AEP	Line_1	Line_1@South_3	South 5	6/21/2013	Yes	69
15	AEP	Line_1	Line_1@West_7	West 7	6/21/2013	Yes	138
16	ONCOR	North_4	North_4	North 4	10/20/2010	Yes	138
17	ONCOR	North_5	North_5	North 5	10/20/2010	Yes	138
18	ONCOR	North_6	North_6	North 6	10/20/2010	Yes	138
19	ONCOR	North_7	North_7	North 7	10/20/2010	Yes	138
20	ONCOR	FarWest_4	FarWest_4	FarWest 4	10/20/2010	Yes	345
21	ONCOR	West_11	West_11	West 11	3/9/2012	Yes	345
22	ONCOR	FarWest_7	FarWest_7	FarWest 7	10/20/2010	Yes	345
23	ONCOR	FarWest_8	FarWest_8	FarWest 8	3/9/2012	Yes	138
24	ONCOR	West_6	West_6	West 6.	10/20/2010	Yes	345
25	ONCOR	North_1	North_1	North 1	11/28/2012	Yes	345
26	ONCOR	West_9	West_9	West 9	6/21/2013	Yes	345
27	ONCOR	West12	West12	West 12	6/21/2013	Yes	345
28	ONCOR	West_5	West_5	West 5	6/21/2013	Yes	345
29	ONCOR	West_2	West_2	West 2	6/21/2013	Yes	345
30	ONCOR	West_1	West_1	West 1	6/21/2013	Yes	345
31	SHARYLAND	South13	South13	South 13	8/10/2012	Yes	138

Note: * means new substations with PMU connected to ERCOT grid

B. State Estimator (SE) Data

ERCOT provided EPG with SE data for the 12 months of 2013. EPG used the PowerWorld simulator provided by ERCOT to extract approximately 23,708 SE cases. There were 126 days for which SE data was not available, as shown below:

Dates for Which SE Data was Not Available (12 Months of 2013)	
Dates	**Days**
All of January	31
03/23 to 03/26/2013, 03/28 to 03/31/2013	8
07/22	1
08/02-08/05, 08/20-08/31	16
09/01-09/28	28
11/06-11/11, 11/1-11/19, 11/22-11/30	22
12/03-12/10, 12/12-12/17, 12/26-12/31	19
Total	**126**

C. Data Availability

Data availability for the phasor data sources varied from substation to substation; the summary table of phasor-based results shows the percent availability for each substation or each pair analyzed. As shown in Table A-1, availability varies from substation to substation, and ranges from less than 20% for West 16, West 3, and West 15 (which were installed in late 2013) to greater than 90% for nine PMUs. No phasor data was reported for North 2 and South 6. Box-whisker plots in Appendix A provide a view of data availability on a day-by-day basis.

For state estimator (SE) data availability, ERCOT produces SE cases every 5 minutes for a total of 105,120 possible cases per year. EPG received approximately 23,708 cases, which means the availability of SE data for the 12 months of 2013 was approximately 22.6 % data availability. SE data availability for 2013 improved to almost double that of the 2012 SE data. However, as shown above, SE data availability can improve further by reducing to a minimum the number of days SE data is not available.

Below a summary of phasor data availability from Table A-1 for 2012 and for 2013:

2013

<20%	20% to 60%	61% to 80%	>80%
West 16	West 1	West 14	West 10
West 3	West 2	West 4	West 11
West 15	West 9	Coast 4	West 6
	West 12	Coast 3	North 1
	West 5		North 4
	FarWest 2		North 5
	South 3		North 6
	South 5		North 7
			Coast 2
			Coast 1
			South 13
			FarWest 4
			FarWest 7
			FarWest 8
			FarWest 9

2012

<40%	41% to 60%	61% to 80%	>80%
West 14	West 4	West 11	West 10
North 1	Coast 4	Coast 1	North 7
Coast 2	Coast 3	FarWest 8	North 2
South 6	South 13		North 4
FarWest 7	FarWest 9		North 5
			West 6
			North 6
			FarWest 4

4. BASELINE ANALYSIS FOR VOLTAGE MAGNITUDE AND VOLTAGE ANGLE (Ref: North 7)

This baseline analysis update for voltage magnitude and voltage angle was performed using the phasor data and state estimator data obtained from ERCOT for the 12 months of 2013. This data was processed to extract voltage magnitude and voltage angles. Minimum and maximum values for these variables were documented in summary tables; box-whisker plots and time duration curves were developed for each variable and for each type of data used. Below is an analysis of voltage magnitudes and voltage angles.

A. Methodology

For the pairs selected for study, the following work was performed:

1. Obtained and processed phasor data and state estimator data.
2. Extracted information to identify max, min, and average values from these data sources. Prepared summary tables showing results of all data, including data saved during events.
3. Used phasor and SE data to develop weekly box-whisker graphs and time duration curves for angle differences.
4. Identified limits corresponding to normal operation, excluding events and outages. To exclude extreme values corresponding to outliers and to events, values corresponding to the metrics within the 1% to 99% percent of the time range were identified for the entire study period as normal operating limits. A summary showing these normal operation limits was obtained using phasor and SE data and tabulated in the same table for comparison.
5. Analyzed results, identified limits, and reported results for each pair selected.

B. Study Approach

Electric Power Group used the following approach:

1. Obtained available phasor data and state estimator data from ERCOT.
2. Extracted phasor data and condition it for processing.
3. Solved state estimator cases and saved solved cases.
4. Selected substations and angle pairs of interest to ERCOT and the synchrophasor team members by choosing substations that have, or soon will have, PMUs installed.
5. Identified the substations and subsets of substations, and pairs, for which phasor data is available.
6. Developed statistical charts including time duration curves and box-whisker graphs for voltage magnitudes and angles, and for angle pairs.
7. Performed statistical analyses to identify angle differences limits for the selected pairs under all conditions. Summarized angle difference limits.
   - Established limits for normal operation based on the criteria described in the corresponding methodology. Summarized angle difference limits.
   - The limits for angle differences identified in this report shall be compared with ERCOT's criteria, if any, that apply to angle differences for the paths selected for this study.

5. BASELINE ANALYSIS FOR VOLTAGES MAGNITUDES

A. Substations Identified For Voltage Monitoring

Table 2 below shows the substations identified for monitoring.

Table 2 – Substations for Voltage Monitoring

Table 2 - SUBSTATIONS FOR VOLTAGE MONITORING			
#	SUBSTATION	kV	REGION
1	West 10	69	Panhandle
2	West 14	345	Panhandle
3	West 1	345	Central
4	West 2	345	Central
5	West 9	345	Central
6	West 11	345	Central
7	West 12	345	Central
8	West 5	345	Central
9	West 6	345	Central
10	North 1	345	Dallas
11	North 4	138	Dallas
12	North 5	138	Dallas
13	North 6	138	East
14	FarWest 2	69	West Texas
15	North 7	138	Central-East
16	West 4	138	SouthWest
17	Coast 2	69	Valley
18	Coast 1	138	Valley
19	South 3	138	Valley
20	South 5	138	Valley
21	Coast 4	345	Valley
22	Coast 3	345	Valley
23	South 13	138	Valley
24	FarWest 4	345	West Texas
25	FarWest 7	345	West Texas
26	FarWest 8	138	West Texas
27	FarWest 9	138	West Texas
28	West 16	345	Panhandle
29	West 3	345	Central
30	West 15	345	Panhandle
31	West 8*	345	Central
32	South 15*	345	Central
33	South 2*	345	Central-East
34	South 4*	345	Central-East
35	South 7*	345	Central-East
36	South 9*	345	Central-East
37	South 11*	345	Central-East
38	South 10*	138	Valley
39	West 17*	345	Panhandle
40	West 13*	345	Panhandle
NOTE:	* Means substations without PMUs connected to ERCOT		

B. Analysis of Data and Results

All Data Conditions: Data availability of SE data for the 12 months of 2013 was approximately 22.6%. SE data availability for these 12 months improved to 174% that of the 2012 SE data. Data availability was approximately 13% for all SE cases in 2012. Phasor data availability varies from bus to bus. Twelve PMUs were connected to the ERCOT system in 2013: nine in June, one in September, and two in December. As a result, data availability for these substations ranges from less than 10% to less than 60%. On the other hand, PMUs that were connected to the ERCOT system during the entire year 2013 have availability ranging from 66% to 93%. Two PMUs have no data available for 2013: North 2 and South 6.

Table A- 1 below summarizes the Min, Max, and average values for voltage magnitude for the selected substations. The largest Max-Min voltage spreads observed were 23.3 kV at the Coast 4 345 bus, and 10.1 kV for the West 4 138 kV bus. The maximum voltages observed were: 367.11 kV at West 14 345 kV, and 147.67 kV at South 3 138 kV. The highest average voltages observed were: 356.8 kV at West 14, and 142.7 kV at South 3.

The summary shown in Table A-1 below shows the results for all data, including events and outages.

Normal Conditions: Voltage magnitudes which could be expected during normal conditions were obtained by excluding values corresponding to events and outages by isolating the values that lie in the lowest one percent and in the highest one percent at the point of inflection in the time duration curve. The values of the remaining voltages obtained this way are considered to be the "normal points of operation", and are summarized in Table A- 2 below.

Table A- 1 –Summary of Voltage Magnitudes – All Data, Jan 1 to Dec 31, 2013

Table A-1 CCET DISCOVERY ACROSS TEXAS PROJECT - SUMMARY OF VOLTAGE MAGNITUDES - ALL DATA
JANUARY 1 TO DECEMBER 31, 2013

				PHASOR DATA					STATE ESTIMATOR DATA			
No	Substation	Base kV	Region	Min	Max	Average	Max-Min Spread	Percent Data Available	Min	Max	Average	Max-Min Spread
1	West 10	69	Panhandle	68.36	72.99	70.86	4.63	92.11	68.00	74.15	71.57	6.2
2	West 14	345	Panhandle	345.33	364.95	355.64	19.62	79.82	350.73	363.56	356.76	12.8
3	West 1	345	Central	346.05	362.77	355.76	16.72	52.90	345.17	362.80	354.57	17.6
4	West 2	345	Central	346.92	363.34	356.28	16.42	53.12	349.97	361.28	356.49	11.3
5	West 9	345	Central	345.34	362.27	354.34	16.93	52.43	345.52	362.84	353.92	17.3
6	West 11	345	Central	346.23	360.09	353.12	13.86	92.06	350.00	357.87	353.95	7.9
7	West 12	345	Central	346.40	362.85	355.39	16.45	53.09	347.62	361.28	354.48	13.7
8	West 5	345	Central	346.13	362.56	355.71	16.43	53.10	349.97	360.56	355.71	10.6
9	West 6	345	Central	347.74	360.56	354.30	12.82	88.08	349.14	360.35	354.82	11.2
10	North 1	345	Dallas	343.10	354.96	349.13	11.86	93.08	344.31	356.76	350.10	12.5
11	North 4	138	Dallas	138.73	144.31	142.04	5.58	93.20	138.39	143.44	141.28	5.1
12	North 5	138	Dallas	138.11	143.93	141.19	5.81	93.10	137.34	142.21	139.78	4.9
13	North 6	138	East	138.19	145.08	141.85	6.89	93.00	138.33	145.60	141.97	7.3
14	FarWest 2	69	Central-East	65.97	73.41	69.64	7.44	55.18	66.28	72.12	69.48	5.8
15	North 7	138	Central-East	138.24	145.04	142.55	6.80	91.95	137.85	144.86	141.37	7.0
16	West 4	138	SouthWest	134.09	148.22	142.00	14.13	73.35	136.68	146.75	141.78	10.1
17	Coast 2	69	Valley	66.70	73.10	70.24	6.40	84.74	66.01	73.24	69.91	7.2
18	Coast 1	138	Valley	139.75	144.25	142.40	4.50	87.30	138.40	145.18	142.00	6.8
19	South 3	138	Valley	141.44	142.90	142.24	1.46	56.38	137.70	147.67	142.68	10.0
20	South 5	69	Valley	68.58	71.77	70.38	3.20	46.02	67.84	73.46	70.65	5.6
21	Coast 4	345	Valley	343.83	364.41	354.05	20.57	66.23	342.86	366.15	354.49	23.3
22	Coast 3	345	Valley	343.24	363.58	353.34	20.34	79.42	342.79	365.60	354.19	22.8
23	South 13	138	Valley	137.04	146.80	141.85	9.76	83.75	137.70	146.27	142.00	8.6
24	FarWest 4	345	West Texas	348.58	360.23	354.18	11.65	90.74	350.52	358.83	354.65	8.3
25	FarWest 7	345	West Texas	342.31	355.88	350.65	13.57	92.96	344.86	356.04	351.20	11.2
26	FarWest 8	138	West Texas	137.35	145.47	142.13	8.12	82.33	137.24	143.52	140.59	6.3
27	FarWest 9	138	West Texas	136.77	144.39	141.25	7.62	86.16	137.37	144.47	140.95	7.1
28	West 16	345	Panhandle	PMUs installed in mid December: not enough phasor data for analysis					346.38	360.08	353.31	13.7
29	West 3	345	Panhandle						Not enough phasor data			
30	West 15	345	Panhandle	345.88	360.50	353.34	14.62	19.14	349.45	360.04	353.73	10.6
31	West 8*	345	Central	No PMUs installed at these substations. No phasor data available for the January to December 2013 period.					345.90	367.11	356.63	21.2
32	South 15*	345	Central						349.14	361.73	355.77	12.6
33	South 2*	345	Central-East						347.73	362.39	354.81	14.7
34	South 4*	345	Central-East						349.66	361.53	356.11	11.9
35	South 7*	345	Central-East						348.93	362.35	355.59	13.4
36	South 9*	345	Central-East						343.34	365.32	354.51	22.0
37	South 11*	345	Central-East						349.69	361.22	355.86	11.5
38	South 10*	138	Valley						139.05	144.83	141.81	5.8
39	West 17*	345	Panhandle						Not enough phasor data for analysis			
40	West 13*	345	Panhandle									

Note: Substations marked with * did not have PMU data for the January 1 to December 31, 2013 period.

Table A- 2 –Limits for Voltages – Normal Conditions

TABLE A-2 CCET DISCOVERY ACROSS TEXAS - LIMITS FOR VOLTAGES - NORMAL CONDITIONS

			Phasor Data			State Estimator Data - January 1 To December 31, 2013								SE Data		
No.	Bus Names	Base kV	Normal Min	Normal Max	Max-Min Spread	Normal Min-100%	100% or POI	99% Min	99% - POI	1% Max	1% + POI	Normal Max-0%	0% or POI	Normal Min	Normal Max	Max-Min Spread
1	West 10	69	69.08	72.33	3.25	68.36	99.97%	69.60	98.97%	73.56	1.07%	74.01	0.07%	68.36	74.01	5.65
2	West 14	345	349.40	360.90	11.50	351.54	99.98%	352.94	98.98%	361.54	1.04%	363.33	0.04%	351.54	363.33	11.79
3	West 1	345	346.70	362.00	15.30	345.42	99.98%	347.63	98.98%	358.97	1.02%	361.53	0.02%	345.42	361.53	16.10
4	West 2	345	349.80	360.00	10.20	350.50	99.91%	352.04	98.91%	359.46	1.05%	360.33	0.05%	350.50	360.33	9.83
5	West 9	345	348.00	360.30	12.30	346.84	99.90%	348.64	98.90%	359.48	1.04%	362.08	0.04%	346.84	362.08	15.24
6	West 11	345	349.10	357.20	8.10	350.23	99.95%	351.28	98.95%	356.24	1.07%	357.41	0.07%	350.23	357.41	7.19
7	West 12	345	349.50	359.90	10.40	348.02	99.93%	349.95	98.93%	358.65	1.03%	361.03	0.03%	348.02	361.03	13.01
8	West 5	345	349.20	359.30	10.10	350.22	99.97%	351.97	98.97%	358.80	1.02%	360.07	0.02%	350.22	360.07	9.85
9	West 6	345	348.80	358.30	9.50	349.42	99.96%	351.05	98.96%	358.34	1.03%	359.70	0.03%	349.42	359.70	10.28
10	North 1	345	344.30	354.40	10.10	344.59	99.99%	345.79	98.99%	355.14	1.05%	356.24	0.05%	344.59	356.24	11.65
11	North 4	138	139.10	143.70	4.60	138.42	99.94%	139.09	98.94%	142.65	1.03%	143.35	0.03%	138.42	143.35	4.93
12	North 5	138	138.50	143.20	4.70	137.43	99.97%	138.10	98.97%	141.26	1.05%	141.89	0.05%	137.43	141.89	4.46
13	North 6	138	139.50	144.50	5.00	138.61	99.98%	139.87	98.98%	144.62	1.02%	145.51	0.02%	138.61	145.51	6.90
14	FarWest 2	69	66.90	72.46	5.56	66.73	99.96%	67.51	98.96%	71.13	1.02%	71.80	0.02%	66.73	71.80	5.07
15	North 7	138	139.90	144.30	4.40	138.06	99.94%	139.29	98.94%	143.69	1.03%	144.72	0.03%	138.06	144.72	6.66
16	West 4	138	137.60	146.20	8.60	136.84	99.97%	138.41	98.97%	144.79	1.03%	146.33	0.03%	136.84	146.33	9.49
17	Coast 2	69	67.61	72.33	4.72	66.17	99.95%	67.19	98.95%	71.94	1.02%	72.75	0.02%	66.17	72.75	6.58
18	Coast 1	138	139.90	143.70	3.80	138.89	99.97%	139.61	98.97%	144.32	1.03%	145.07	0.03%	138.89	145.07	6.18
19	South 3	138	141.60	142.50	0.90	137.78	99.98%	139.94	98.98%	146.20	1.02%	147.57	0.02%	137.78	147.57	9.79
20	South 5	69	68.99	71.64	2.65	67.92	99.88%	69.09	98.88%	72.37	1.01%	73.40	0.01%	67.92	73.40	5.48
21	Coast 4	345	345.00	361.70	16.70	343.12	99.97%	346.63	98.97%	361.91	1.02%	366.10	0.02%	343.12	366.10	22.98
22	Coast 3	345	345.70	361.10	15.40	343.13	99.98%	346.62	98.98%	361.47	1.07%	365.37	0.07%	343.13	365.37	22.24
23	South 13	138	138.60	144.40	5.80	138.06	99.95%	139.24	98.95%	144.41	1.01%	146.03	0.01%	138.06	146.03	7.97
24	FarWest 4	345	350.30	356.70	6.40	350.62	99.95%	351.79	98.95%	356.87	1.08%	358.31	0.08%	350.62	358.31	7.70
25	FarWest 7	345	343.60	354.60	11.00	345.30	99.95%	347.02	98.95%	354.44	1.02%	355.66	0.02%	345.30	355.66	10.36
26	FarWest 8	138	139.50	144.60	5.10	137.41	99.96%	138.50	98.96%	142.41	1.02%	143.26	0.02%	137.41	143.26	5.85
27	FarWest 9	138	137.80	143.60	5.80	137.76	99.94%	138.67	98.94%	143.11	1.04%	144.03	0.04%	137.76	144.03	6.27
28	West 16	345	Not enough phasor data available for analysis			346.45	99.95%	346.95	98.95%	358.00	1.03%	360.05	0.03%	346.45	360.05	13.60
29	West 3	345				No PSSE data available for this period										
30	West 15	345	348.50	359.50	11.00	349.59	99.95%	350.05	98.95%	358.40	1.03%	360.00	0.03%	349.59	360.00	10.41
31	West 8*	345	PMUs not installed at these substations. No phasor data available for the year 2013.			346.03	99.96%	347.16	98.96%	360.48	1.04%	366.77	0.04%	346.03	366.77	20.74
32	South 15*	345				349.64	99.99%	351.11	98.99%	359.71	1.01%	361.48	0.01%	349.64	361.48	11.84
33	South 2*	345				347.92	99.94%	349.70	98.94%	359.14	1.01%	362.27	0.01%	347.92	362.27	14.35
34	South 4*	345				350.01	99.98%	351.48	98.98%	359.94	1.02%	361.41	0.02%	350.01	361.41	11.40
35	South 7*	345				349.71	99.98%	351.76	98.98%	359.08	1.08%	361.84	0.08%	349.71	361.84	12.13
36	South 9*	345				343.80	99.98%	346.41	98.98%	361.41	1.03%	364.66	0.03%	343.80	364.66	20.86
37	South 11*	345				350.04	99.97%	351.39	98.97%	359.47	1.01%	360.90	0.01%	350.04	360.90	10.86
38	South 10*	138				139.20	99.97%	140.00	98.97%	143.88	1.02%	144.73	0.02%	139.20	144.73	5.53
39	West 17*	345				These substations were not in service during the July to December 2013 period. No PSSE data available for this period.								No PSSE data available for this period		
40	West 13*	345														

NOTE: The substations market with * did not have PMUs installed in 2013: no phasor data available.

Note that the greater Max-Min voltage spreads occurred at Coast 4 345 kV and South 3 138 kV buses with 22.98 kV and 9.79 kV, respectively.

For both the SE data and the phasor data, box-whisker plots and time duration curves were developed for each of the substations listed above and were used to obtain the values in the Table A-2 above. Summaries of SE-based voltage pairs, with their corresponding box-whisker and time duration curves, as well as summaries of phasor-based voltage pairs, with their corresponding box-whisker and time duration curves, are presented in Appendix A, Parts 1 and 2.

C. Observations

1. Data availability: the availability for state estimator data was approximately 22.7%; the availability for phasor data was greater overall, but varied from 19.1% at West 15 to 93.20% at North 4. Eighteen PMUs show data availability greater than 70%.

2. State estimator data points to South 3 and West 8 as having the highest voltages in their class. The highest voltage spreads are found at Coast 4 345 kV and West 4 138 kV substations. Voltages at these substations are more volatile than at the other substations; the Max-Min ranges for these substations are 23.3 kV and 10.1 kV, respectively. Note that Coast 3 345 kV also has a high voltage spread (22.8 kV).
3. The lowest voltage spreads of 7.9 kV and 4.9 kV occurred at West 11 345 kV and North 5 138 kV substations, respectively.
4. Twenty-one substations show voltage spreads greater than 10 kV under all conditions.
5. Eighteen substations show voltage spreads greater than 10 kV under normal conditions. Voltage spreads under normal conditions are lower than those under all conditions, as expected.

D. Comparison of Alarm Limits for Voltages – 2012 vs. 2013 Data

The limits summarized in the two tables above reflect system performance after the addition of the CREZ lines in the 12 months of 2013. EPG has prepared a comparison table to identify the changes in voltage due to the addition of the new 345 kV lines. Table 3 shows a comparison of voltage magnitude averages as well as Max-Min spreads for 2012 and 2013.

Table 3 – Voltage Magnitudes – All Data Comparison 2012 vs. 2013 (Jan 1 – Dec 31)

Table 3 - CCET DISCOVERY ACROSS TEXAS PROJECT - VOLTAGE MAGNITUDES - ALL DATA COMPARISON 2012 vs. 2013 (January 1 to December 31)

				STATE ESTIMATOR DATA - 2012				STATE ESTIMATOR DATA - 2013			
No	Substation	Base kV	Region	Min	Max	Average	Max-Min Spread	Min	Max	Average	Max-Min Spread
1	West 10	69	Panhandle	68.03	73.13	71.03	5.1	68.00	74.15	71.57	6.2
2	West 14	345	Panhandle	348.07	362.15	355.89	14.1	350.73	363.56	356.76	12.8
3	West 1	345	Central	No data available				345.17	362.80	354.57	17.6
4	West 2	345	Central	348.17	366.11	357.56	17.9	349.97	361.28	356.49	11.3
5	West 9	345	Central	346.93	365.53	357.31	18.6	345.52	362.84	353.92	17.3
6	West 11	345	Central	347.73	361.28	355.14	13.6	350.00	357.87	353.95	7.9
7	West 12	345	Central	346.17	364.70	356.50	18.5	347.62	361.28	354.48	13.7
8	West 5	345	Central	347.83	365.77	356.95	17.9	349.97	360.56	355.71	10.6
9	West 6	345	Central	346.73	364.08	356.45	17.4	349.14	360.35	354.82	11.2
10	North 1	345	Dallas	340.69	353.14	347.70	12.5	344.31	356.76	350.10	12.5
11	North 4	138	Dallas	138.55	144.07	142.13	5.5	138.39	143.44	141.28	5.1
12	North 5	138	Dallas	137.34	141.75	139.80	4.4	137.34	142.21	139.78	4.9
13	North 6	138	East	138.88	143.53	141.59	4.7	138.33	145.60	141.97	7.3
14	FarWest 2	69	Central-East	67.32	71.53	69.27	4.2	66.28	72.12	69.48	5.8
15	North 7	138	Central-East	139.23	144.46	142.21	5.2	137.85	144.86	141.37	7.0
16	West 4	138	SouthWest	132.52	151.74	141.17	19.2	136.68	146.75	141.78	10.1
17	Coast 2	69	Valley	66.58	71.94	69.61	5.4	66.01	73.24	69.91	7.2
18	Coast 1	138	Valley	138.69	143.18	141.20	4.5	138.40	145.18	142.00	6.8
19	South 3	138	Valley	138.25	146.38	142.11	8.1	137.70	147.67	142.68	10.0
20	South 5	69	Valley	67.14	72.67	70.56	5.5	67.84	73.46	70.65	5.6
21	Coast 4	345	Valley	341.96	363.32	353.39	21.4	342.86	366.15	354.49	23.3
22	Coast 3	345	Valley	341.62	363.39	353.27	21.8	342.79	365.60	354.19	22.8
23	South 13	138	Valley	137.74	145.48	141.72	7.7	137.70	146.27	142.00	8.6
24	FarWest 4	345	West Texas	349.45	360.63	355.81	11.2	350.52	358.83	354.65	8.3
25	FarWest 7	345	West Texas	345.38	360.59	352.86	15.2	344.86	356.04	351.20	11.2
26	FarWest 8	138	West Texas	135.41	142.35	139.39	6.9	137.24	143.52	140.59	6.3
27	FarWest 9	138	West Texas	136.10	146.85	141.20	10.8	137.37	144.47	140.95	7.1
28	West 16	345	Panhandle	Not in service in 2012				346.38	360.08	353.31	13.7
29	West 3	345	Central					Not enough phasor data			
30	West 15	345	Panhandle					349.45	360.04	353.73	10.6
31	West 8*	345	Central	No data available				345.90	367.11	356.63	21.2
32	South 15*	345	Central	349.49	359.46	354.82	10.0	349.14	361.73	355.77	12.6
33	South 2*	345	Central-East	348.80	358.52	354.07	9.7	347.73	362.39	354.81	14.7
34	South 4*	345	Central-East	349.17	359.83	354.80	10.7	349.66	361.53	356.11	11.9
35	South 7*	345	Central-East	348.59	359.04	354.33	10.5	348.93	362.35	355.59	13.4
36	South 9*	345	Central-East	343.17	358.90	352.20	15.7	343.34	365.32	354.51	22.0
37	South 11*	345	Central-East	348.52	358.46	354.22	9.9	349.69	361.22	355.86	11.5
38	South 10*	138	Valley	138.59	144.49	141.46	5.9	139.05	144.83	141.81	5.8
39	West 17*	345	Panhandle	No data available				Not enough phasor data for analysis			
40	West 13*	345	Panhandle								

Note: The substations with * did not have PMUs installed in 2013.

Evaluation of Table 3 shows that voltages in the west Texas and Central areas were lower in 2013 than in 2012, probably due to the higher transfer of power from those areas to the rest of the ERCOT system. Voltages in the Central East, Valley, and Dallas areas increased in 2013 compared with 2012, possibly due to the relief the wind power provided to these areas.

Voltage spreads went higher in the areas where the voltage increased, and lower where the voltages decreased.

E. Analysis of the Box-Whisker VoltagePlots - 2013 Data

1. No state estimator (SE) data was available for the last third of March, for mid-August to late September, and for most of November and December 2013, for just about every substation included in Appendix A, Part 1.
2. Two voltage spikes at West 14: for one day, January 10, the voltage went up by about 3.5 kV, and again in mid-March by about 3.5 kV.
3. The voltage at West 1 fluctuated between 345 jV and 362 kV (17 kV range) during the first seven months of 2013.
4. The voltage at West 9 fluctuated within a 16 kV range (346 kV and 362 kV); the voltages at this substation spiked up by up to 4 kV during the first four months of 2013.
5. West 12 substation also experienced voltages operating within a wide range of 15 kV (347 kV to 361 kV). Voltage spiked several times during the first six-months of 2013, by up to 3 kV.
6. The voltage at North 1 varied somewhat erratically between 344 kV and 357 kV during the 12 months of 2013. During the month of April, the voltage jumped up 4 kV and operated in the neighborhood of 354 kV for most of the month. By the end of May, the voltage came down drastically to approximately 347 kV, and then day-by-day went up, and ended up operating around 354 kV by the end of June.
7. The voltage at North 5 was operated tightly between the 137.5 and 142 kV range.
8. The voltage at North 6 operated about 2 kV higher during May and part of June compared to the rest of 2013.
9. The voltage at West 4 fluctuated within a 10 kV bandwidth (136 kV to 146 kV) during the twelve months of 2013.
10. The voltage at Coast 1 operated at high levels during October 2013, around 144 kV.
11. Large fluctuations are seen at South 3 during the first five months of 2013: within a 139.5 to 147.5 kV bandwidth.
12. The voltage at Coast 4 operated within a 23 kV range. Several voltage spikes were observed throughout the year.
13. Similarly, the voltage at Coast 3 operated with a 23 kV range with several voltage spikes occurring throughout the year.
14. FarWest 4: one spike in April (358.5 kV) and four dips (340.5 kV).
15. FarWest 7: operated within a 10 kV range (345 kV to 355 kV) with large daily swings.
16. There was not enough data for West 16, West 15, and West 8. No meaningful conclusions can be reached from these plots.
17. South 2: operated within a 13 kV range (348 to 361 kV).
18. South 9: voltage fluctuated within a wide range from 344 kV to 365 kV (21 kV range), with a spike up around March 2.
19. South 10: the median voltage changes constantly with a few spikes occurring during May to August 2013.
20. The box-whisker plots for North 4, North 5, FarWest 8, Coast 1, FarWest 9, and FarWest 4 exhibit what appear to be a large number of outlier points.

6. BASELINE ANALYSIS FOR VOLTAGE ANGLES(REFERENCE: North 7 Bus)

A. Substations Identified for Voltage Angle Analysis

The following substations were selected for voltage angle analysis; the substation selected as reference was North 7.

Table 4 – Substations for Voltage Angle Difference Monitoring

Table 4 - SUBSTATIONS FOR VOLTAGE ANGLE DIFFERENCE MONITORING (Ref.: North 7)			
#	SUBSTATION	kV	REGION
1	West 10	69	Panhandle
2	West 14	345	Panhandle
3	West 1	345	Central
4	West 2	345	Central
5	West 9	345	Central
6	West 11	345	Central
7	West 12	345	Central
8	West 5	345	Central
9	West 6	345	Central
10	North 1	345	Dallas
11	North 2	138	Dallas
12	North 4	138	Dallas
13	North 5	138	Dallas
14	North 6	138	East
15	FarWest 2	69	West Texas
16	West 4	138	SouthWest
17	Coast 2	69	Valley
18	Coast 1	138	Valley
19	South 3	138	Valley
20	South 5	138	Valley
21	Coast 4	345	Valley
22	Coast 3	345	Valley
23	South 6	138	Valley
24	South 13	138	Valley
25	FarWest 4	345	West Texas
26	FarWest 7	345	West Texas
27	FarWest 8	138	West Texas
28	FarWest 9	138	West Texas
29	West 16	345	Panhandle
30	West 15	345	Panhandle
31	West 3	345	Central
32	West 8*	345	Central
33	South 15*	345	Central
34	South 2*	345	Central-East
35	South 4*	345	Central-East
36	South 7*	345	Central-East
37	South 9*	345	Central-East
38	South 11*	345	Central-East
39	South 10*	138	Valley
40	West 17*	345	Panhandle
41	West 13*	345	Panhandle

NOTE: * Means substations without PMUs connected to ERCOT

B. Summary of Results - All Data Included

The voltage angle results obtained from all all solved SE cases, and all phasor data, are summarized in Table B- 1 below.

These results were obtained using all data available, including event and outage conditions. Under these conditions, voltage angles would be expected to be larger than under normal conditions because, during event and outage conditions, the angles tend to increase in absolute magnitude to reflect the changes in system conditions or changes in system configuration. The maximum Max-Min spreads observed were 104.1 degrees for FarWest 9 138 kV substation, and 90.8 degrees for FarWest 4 345 kV substation. Note also that the substations close to the wind farms in groups 1 and 2 shown in yellow have over 73 degrees Max-Min spreads, and the angles for these substations are positive more than 71% of the time; that is, the power flows from these substations towards North 7 most of the time. These spreads are lower than the maximum spreads found in the 2012 baselining study; this is expected since the grid is now tighter with the addition of most CREZ 345 kV lines. The lowest spread of 28 degrees was seen at North 6. The phasor data for FarWest 2 appears to be unreliable given the inconsistent results (average of -127.5 degrees).

Table B- 1 – Baselining Analysis – Voltage Angles – ALL Conditions

Table B-1: CCET DISCOVERY ACROSS TEXAS- BASELINING ANALYSIS - VOLTAGE ANGLES - ALL CONDITIONS (Reference: North 7)

			Phasor Data - 1/1/13 to 12/31/13						State Estimator Data - 1/1/13 to 12/31/13				
No	Angle Pair FROM - TO	Base kV	Min	Max	Average	% Positive	Max Min Spread	% Data Available	Min	Max	Average	Percent Positive	Max Min Spread
1	West 10	69	-40.45	70.08	6.70	57.58	110.53	91.62	-37.25	66.38	8.40	62.13%	103.6
2	West 14	345	-21.43	37.65	6.73	82.71	59.08	78.79	-18.97	32.46	5.63	81.63%	51.4
3	West 1	345	-19.92	33.07	3.25	66.43	52.99	52.88	-24.06	38.14	5.41	74.43%	62.2
4	West 2	345	-15.05	28.80	3.98	61.75	43.85	53.07	-26.31	46.74	7.10	71.62%	73.1
5	West 9	345	-16.94	33.07	4.43	65.36	50.01	52.40	-27.52	49.71	7.76	73.28%	77.2
6	West 11	345	-30.72	62.04	6.49	65.08	92.76	91.79	-29.63	58.64	7.45	68.41%	88.3
7	West 12	345	-16.89	33.07	4.48	64.45	49.96	53.06	-27.52	49.71	7.78	72.76%	77.2
8	West 5	345	-16.47	30.23	4.43	62.61	46.70	53.07	-26.90	48.06	7.42	71.00%	75.0
9	West 6	345	-28.43	60.40	7.17	69.42	88.83	87.84	-27.52	49.71	7.68	71.45%	77.2
10	North 1	345	-12.33	26.41	6.53	93.29	38.74	92.78	-11.20	24.01	6.49	93.78%	35.2
11	North 4	138	-18.85	14.43	-2.88	23.27	33.28	92.91	-17.84	13.60	-2.47	25.23%	31.4
12	North 5	138	-20.35	14.99	-4.67	14.60	35.34	92.81	-19.99	11.56	-4.73	13.69%	31.6
13	North 6	138	-8.67	17.99	5.15	91.50	26.65	90.77	-10.70	17.25	3.82	85.15%	28.0
14	FarWest 2	69	-160.79	-78.92	-127.46	0.00	-81.88	54.90	-26.50	10.39	-7.46	5.97%	36.9
15	West 4	138	-35.00	18.95	-6.24	19.98	53.95	72.70	-32.46	16.94	-6.18	20.45%	49.4
16	Coast 2	69	-31.96	29.99	-5.62	25.14	61.95	84.14	-31.46	24.56	-5.80	23.39%	56.0
17	Coast 1	138	-36.75	50.83	3.92	59.74	87.58	86.45	-35.89	44.81	3.28	59.30%	80.7
18	South 3	138	-32.04	34.44	-0.27	46.37	66.47	56.00	-31.00	32.95	0.32	51.22%	64.0
19	South 5	138	-28.71	15.31	-8.39	9.96	44.02	45.72	-29.57	14.61	-7.20	10.56%	44.2
20	Coast 4	345	-34.98	60.00	5.23	63.91	94.97	62.59	-33.40	53.07	5.82	65.99%	86.5
21	Coast 3	345	-39.98	59.99	5.45	63.16	99.97	78.43	-33.40	52.41	5.53	65.55%	85.8
22	South 13	138	-53.93	54.99	0.27	50.77	108.92	83.26	-51.34	46.50	-0.24	50.62%	97.8
23	FarWest 4	345	-32.57	60.00	7.04	65.46	92.57	90.49	-30.54	60.24	7.82	68.15%	90.8
24	FarWest 7	345	-35.49	59.79	5.30	61.92	95.28	92.78	-34.04	55.59	5.80	63.63%	89.6
25	FarWest 8	138	-44.79	54.96	-3.09	38.49	99.75	82.09	-42.34	51.30	-2.11	42.58%	93.6
26	FarWest 9	138	-44.80	59.98	2.21	50.40	104.77	85.43	-40.92	63.14	2.80	52.74%	104.1
27	West 16	345	PMUs installed in mid December; not enough phasor data for analysis						New substations; Not enough data available for analysis.				
28	West 3	345											
29	West 15	345	-13.74	22.74	3.82	72.24	36.47	19.07					
30	West 8*	345/138	No phasor data available for these substations for the year 2013. PMUs not in service.						-13.09	27.27	4.15	61.04%	40.4
31	South 15*	345/138							-18.62	16.09	0.31	50.90%	34.7
32	South 2*	345/138							-14.44	18.32	2.48	74.48%	32.8
33	South 4*	345/138							-19.22	17.53	0.31	50.35%	36.8
34	South 7*	345/138							-16.09	21.19	3.85	78.73%	37.3
35	South 9*	345/138							-18.41	16.37	-0.13	46.84%	34.8
36	South 11*	345/138							-21.08	18.56	0.06	48.18%	39.6
37	South 10*	138							-35.17	24.79	-6.64	18.13%	60.0
38	West 17*	345/138							Substations not in service during the January to December 2013 period.				
39	West 13*	345/138											

NOTE: * Means substations without PMUs connected to ERCOT; no phasor data available

C. Summary of Results – Normal Conditions (Events and Outages Excluded)

The voltage angle results obtained from excluding extreme values based on analysis of the box-whisker plots and time duration curves are shown in Table B-2 below.

Table B- 2 – Baselining Analysis Update – Voltage Angles – Normal Conditions (Ref: 138 kV North 7)

Table B-2: CCET DISCOVERY ACROSS TEXAS- BASELINING ANALYSIS UPDATE- VOLTAGE ANGLES - NORMAL CONDITIONS (Reference: 138 kV North 7)

			DATA ANALYSIS RESULTS														
			Phasor-Normal			State Estimator Data - 1/1/13 to 12/31/13									SE Data-Normal		
No	Angle Pair FROM - TO	Base kV	Min Angle	Max Angle	Max-Min Spread	Percent Positive	Min Angle at POI or 100%	Percent (POI or 100%)	Min Angle at 99% or POI - 1%	Percent (99% or POI - 1%)	Max Angle at 1% or POI +1%	Percent (1% or POI +1%)	Max Angle at POI or 0%	Percent (POI or 0%)	Min Angle	Max Angle	Max-Min Spread
1	West 10	69	-36.64	52.43	89.1	62.13%	-32.08	99.78%	-23.12	98.78%	44.57	1.02%	59.73	0.02%	-32.08	59.73	91.8
2	West 14	345	-17.69	29.69	47.4	81.63%	-16.66	99.95%	-10.85	98.95%	20.66	1.09%	27.62	0.09%	-16.66	27.62	44.3
3	West 1	345	-9.48	24.51	34.0	74.43%	-20.62	99.85%	-12.39	98.85%	26.79	1.07%	37.02	0.07%	-20.62	37.02	57.6
4	West 2	345	-12.78	26.80	39.6	71.62%	-23.76	99.94%	-14.85	98.94%	31.45	1.07%	44.10	0.07%	-23.76	44.10	67.9
5	West 9	345	-12.71	31.40	44.1	73.28%	-24.51	99.93%	-15.57	98.93%	33.08	1.10%	45.22	0.10%	-24.51	45.22	69.7
6	West 11	345	-27.33	49.82	77.2	68.41%	-26.61	99.94%	-17.84	98.94%	34.46	1.02%	47.50	0.02%	-26.61	47.50	74.1
7	West 12	345	-13.86	31.47	45.3	72.76%	-24.06	99.89%	-15.46	98.89%	32.93	1.10%	45.07	0.10%	-24.06	45.07	69.1
8	West 5	345	-13.74	29.25	43.0	71.00%	-23.57	99.89%	-14.85	98.89%	31.54	1.09%	44.00	0.09%	-23.57	44.00	67.6
9	West 6	345	-21.94	49.22	71.2	71.45%	-24.14	99.90%	-15.28	98.90%	32.66	1.09%	45.22	0.09%	-24.14	45.22	69.4
10	North 1	345	-9.99	20.95	30.9	93.78%	-9.23	99.94%	-5.26	98.94%	16.42	1.08%	20.83	0.08%	-9.23	20.83	30.1
11	North 4	138	-17.60	9.86	27.5	25.23%	-16.06	99.95%	-12.42	98.95%	6.49	1.02%	11.33	0.02%	-16.06	11.33	27.4
12	North 5	138	-18.02	9.39	27.4	13.69%	-19.03	99.92%	-14.79	98.92%	5.52	1.05%	9.47	0.05%	-19.03	9.47	28.5
13	North 6	138	-4.34	14.90	19.2	85.15%	-7.77	99.89%	-4.09	98.89%	11.59	1.06%	15.68	0.06%	-7.77	15.68	23.5
14	FarWest 2	69	-155.10	-89.68	65.4	5.97%	-23.99	99.84%	-17.58	98.84%	3.54	1.05%	8.25	0.05%	-23.99	8.25	32.2
15	West 4	138	-25.20	12.92	38.1	20.45%	-31.32	99.97%	-22.92	98.97%	10.04	1.05%	14.66	0.05%	-31.32	14.66	46.0
16	Coast 2	69	-26.54	22.13	48.7	23.39%	-28.89	99.91%	-24.35	98.91%	15.49	1.06%	21.42	0.06%	-28.89	21.42	50.3
17	Coast 1	138	-28.49	38.43	66.9	59.30%	-33.45	99.95%	-24.68	98.95%	32.72	1.01%	42.06	0.01%	-33.45	42.06	75.5
18	South 3	138	-26.25	29.59	55.8	51.22%	-27.01	99.95%	-21.13	98.95%	22.85	1.01%	31.16	0.01%	-27.01	31.16	58.2
19	South 5	138	-23.63	13.35	37.0	10.56%	-27.71	99.95%	-21.02	98.95%	9.19	1.05%	13.81	0.05%	-27.71	13.81	41.5
20	Coast 4	345	-30.53	49.53	80.1	65.99%	-30.80	99.95%	-24.15	98.95%	37.38	1.06%	47.52	0.06%	-30.80	47.52	78.3
21	Coast 3	345	-29.75	47.56	77.3	65.55%	-31.05	99.96%	-24.24	98.96%	36.71	1.03%	48.11	0.03%	-31.05	48.11	79.2
22	South 13	138	-41.02	43.43	84.5	50.62%	-41.43	99.83%	-33.33	98.83%	31.74	1.06%	42.97	0.06%	-41.43	42.97	84.4
23	FarWest 4	345	-28.73	50.97	79.7	68.15%	-27.47	99.94%	-19.69	98.94%	35.81	1.07%	47.69	0.07%	-27.47	47.69	75.2
24	FarWest 7	345	-30.47	45.89	76.4	63.63%	-29.21	99.89%	-22.39	98.89%	33.08	1.04%	43.20	0.04%	-29.21	43.20	72.4
25	FarWest 8	138	-39.07	41.67	80.7	42.58%	-39.09	99.92%	-31.70	98.92%	27.01	1.02%	40.23	0.02%	-39.09	40.23	79.3
26	FarWest 9	138	-40.15	49.82	90.0	52.74%	-37.81	99.89%	-31.60	98.89%	39.71	1.06%	50.63	0.06%	-37.81	50.63	88.4
27	West 16	345	Not enough phasor data available for analysis			81.45%	-11.53	99.93%	-9.00	98.93%	16.80	1.08%	19.41	0.08%	-11.53	19.41	30.9
28	West 3	345															
29	West 15	345				81.97%	-11.49	99.92%	-9.13	98.92%	17.18	1.06%	19.36	0.06%	-11.49	19.36	30.8
30	West 8*	345	No Phasor Data Available the first half of 2013			61.04%	-12.44	99.92%	-9.67	98.92%	25.28	1.04%	27.03	0.04%	-12.44	27.03	39.5
31	South 15*	345				50.90%	-17.35	99.92%	-10.37	98.92%	12.13	1.11%	14.70	0.11%	-17.35	14.70	32.0
32	South 2*	345				74.48%	-12.64	99.83%	-6.67	98.83%	12.31	1.17%	15.76	0.17%	-12.64	15.76	28.4
33	South 4*	345				50.35%	-17.69	99.89%	-10.95	98.89%	12.87	1.08%	15.84	0.08%	-17.69	15.84	33.5
34	South 7*	345				78.73%	-15.05	99.94%	-7.70	98.94%	15.38	1.08%	19.62	0.08%	-15.05	19.62	34.7
35	South 9*	345				46.84%	-15.74	99.84%	-10.40	98.84%	11.64	1.12%	13.93	0.12%	-15.74	13.93	29.7
36	South 11*	345				48.18%	-19.39	99.96%	-12.27	98.96%	12.80	1.20%	15.70	0.20%	-19.39	15.70	35.1
37	South 10*	138				18.13%	-29.58	99.77%	-25.06	98.77%	14.27	1.09%	18.42	0.09%	-29.58	18.42	48.0
38	West 17*	345				Substations not in service during the Jannuary to December 2013 period.									PSSE data not available for 2013.		
39	West 13*	345															

Note: The substations market with * did not have PMUs installed in 2013: no phasor data available.

Summaries of voltage angle pairs with their corresponding box-whisker and time duration curves based on state estimator data, and based on phasor data, are presented in Appendix B, Parts 1 and 2.

D. Observations

1. Voltage angles vary over a wide-range for several substations. The largest variation of 88.4 degrees (-37.8 to 50.6 degrees) occurred at FarWest 9 138 kV substation. Among the 345 kV substations, the largest angle variation over the 12 months of 2013 occurred at Coast 3, with a range of 79.2 (-31.05 to 48.11) degrees. The lowest angle variation occurred at North 6 (23.5 degrees).

2. The largest angle variations occurred among the substations in the southern part of the state, namely: South 13, Coast 3, Coast 4, and Coast 1.
3. The next largest angle variations occurred in the Central and Western part of the state, namely: FarWest 7, West 11, West 6, FarWest 8, FarWest 9, FarWest 4, West 2, West 9, and West 5.
4. The two largest normal angles observed were at Coast 3 345 kV and FarWest 9 138 kV substations with 48.11 and 50.63 degrees, respectively.
5. The minimum angles occurred at Coast 3 345 and South 13 138 kV substations with 31.05 and 41.43 degrees, respectively.
6. Angle spreads were lower for normal conditions than for all conditions, as expected.

7. COMPARISON OF VOLTAGE ANGLES (Ref.: North 7) – 2012 vs. 2013

A. Goal:

EPG performed a comparison of voltage angles for a number of pairs to determine the effect the new CREZ lines had on the performance of the ERCOT grid. Following are the results of that comparison.

B. Pairs Selected For Comparison

Twelve pairs were selected to compare voltage angles between the 2012 and 2013 conditions. They are listed in Table 5 below.

Table 5 – Angle Pairs for Voltage Angle Comparison (Monthly Median for 2012 and 2013)

TABLE 5: ANGLE PAIRS FOR VOLTAGE ANGLE COMPARISON (Monthly Median for 2012 and 2013)

#	Substation A	Substation B	From Region	To Region
1	West 10	North 7	Panhandle	Central-East
2	West 14	North 7	Panhandle	Central-East
3	West 9	North 7	Panhandle	Central-East
4	West 5	North 7	Panhandle	Central-East
5	FarWest 7	North 7	West Texas	Central-East
6	FarWest 7	South 9	West Texas	Central-East
7	West 11	North 7	West Texas	Central-East
8	North 5	North 7	Dallas	Central-East
9	North 6	North 7	East	Central-East
10	Coast 1	North 7	Valley	Central-East
11	South 13	South 11	Valley	Valley
12	West 4	South 11	Valley	Valley
13	FarWest 9	South 11	West Texas	Valley
14	South 11	North 7	Valley	Central-East

C. Procedure

This monthly median comparison was completed using median values to avoid, as much as possible, distortions in the comparison. State Estimator data was collected for the 12 months of 2012 and 2013, and analyzed to produce monthly median comparison values shown in Table 6 below.

In addition to these daily median graphs, box-whisker plots were developed for each pair using median values. These box-whisker plots produced a new median for 2012 and for 2013.

D. Results

The results of the comparison are shown in Table 6 below. Observation of these results shows that, for most of the angle pairs analyzed, the 2013 median voltage angle differences (relative to North 7) were lower than the 2012 monthly median values. Two angle pairs show an increase in monthly median values. More details are in the section below.

Table 6 – Voltage Angle Comparison (Monthly Median), 2012 vs. 2013

Table 6 - VOLTAGE ANGLE COMPARISON (MONTHLY MEDIAN) 2012 vs. 2013

		VOLTAGE ANGLE MEDIAN		
#	Angle Pair	2012 Median	2013 Median	Difference
1	West 10-North 7	14.1	7.3	6.8
2	West 14-North 7	9.4	9.7	-0.3
3	West 9-North 7	10.8	6.6	4.2
4	West 5-North 7	10.5	6.4	4.1
5	FarWest 7-North 7	8.6	5.1	3.6
6	FarWest 7-South 9	7.3	5.4	1.9
7	West 11-North 7	10.4	6.3	4.2
8	North 5-North 7	-2.7	-4.7	2.0
9	North 6-North 7	5.4	4.0	1.4
10	Coast 1-North 7	8.8	3.4	5.4
11	South 13-South 11	2.3	0.2	2.1
12	West 4-South 11	-8.4	-6.3	-2.0
13	FarWest 9-South 11	4.7	1.5	3.2
14	South 11-North 7	2.2	-0.2	2.4

E. Review of Table 6 Shows the Following:

i. All pairs in the list, except the West 14 and North 5 to North 7 pairs, had a decrease in angle median.
ii. The largest difference occurred on the West 10, West 9, West 5, West 11, and Coast 1 to North 7 pairs. All these substations are located in West Texas, except for Coast 1.
iii. The FarWest 7 and North 6 to North 7 pairs had the lowest reduction: 1.9 and 1.4 degrees, respectively.
iv. The West 14 and North 5 to North 7 pairs had an increase in angle median of 0.3 and 2.0 degrees, respectively.
v. The Coast 1 to North 7 pair had a reduction of 5.4 degrees. This reduction is significant, though EPG is not aware of new lines added between the Valley and the North 7 area in 2013. This could be explained by an increase in wind power from the northwest part of Texas, resulting in lower power transfer (lower angles) from the south.

F. Conclusions

i. The new transmission lines added since July, 2012, have tightened the ERCOT system. This is reflected by the voltage angle differences for twelve pairs being lower in 2013 than in 2012.
ii. These voltage angles may change again with the addition of wind resources in west Texas and the Panhandle.
iii. Some angle pairs are expected to change with the addition of a few more CREZ lines added in January and March of 2014. This analysis will be revised using data for the first six months of 2014.

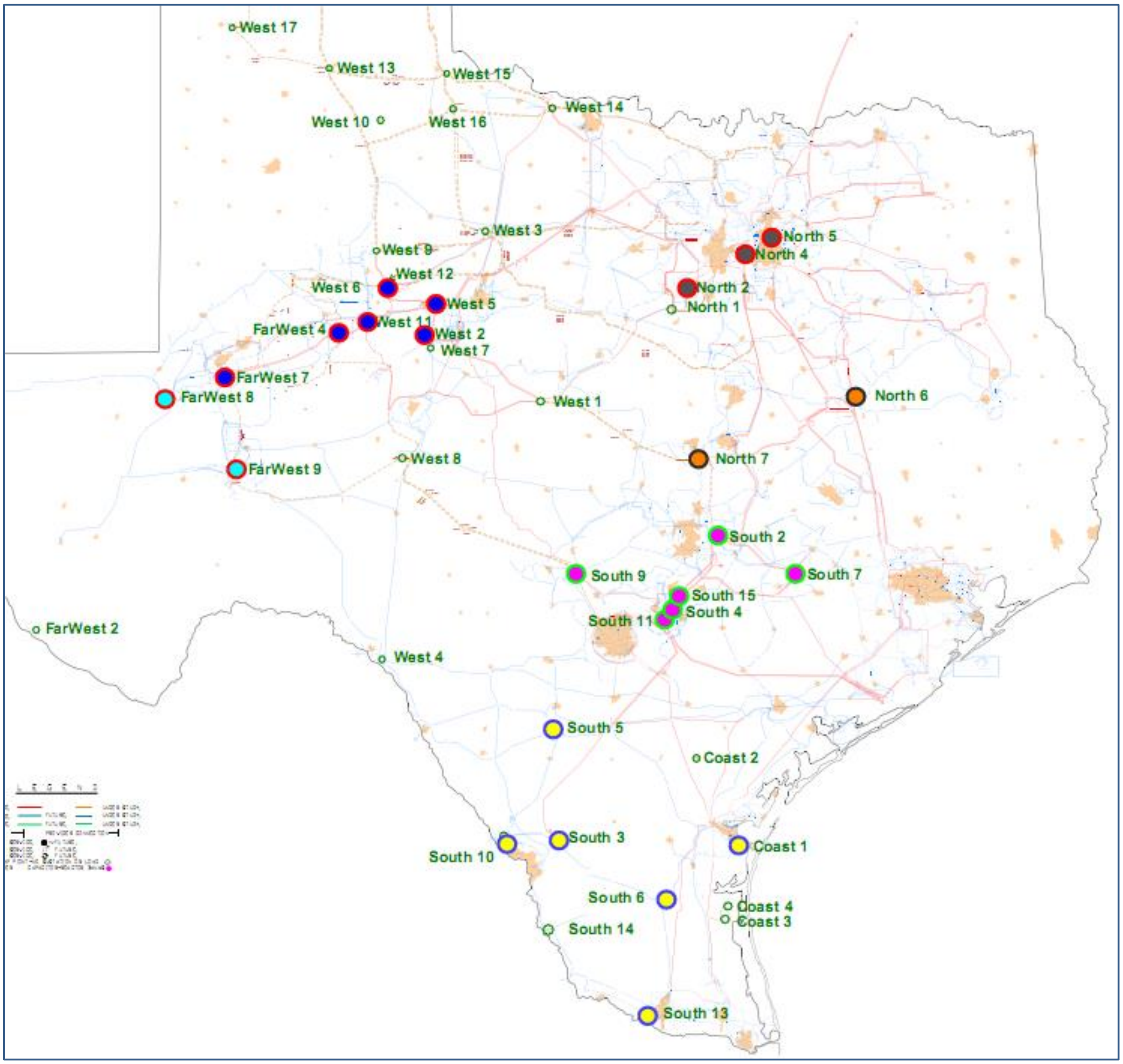
8. BASELINE ANALYSIS FOR ANGLE DIFFERENCES

A. Pairs of Substations Identified for Angle Difference Analysis

The following pairs of substations were selected to perform the angle difference analysis (also see map below):

Table 7 – Angle Pairs for Angle Differences Analysis Update 2

TABLE 7: ANGLE PAIRS FOR ANGLE DIFFERENCES ANALYSIS UPDATE #2				
	PAIRS WITH PHASOR DATA AVAILABLE			
#	Substation A	Substation B	From Region	To Region
1	Coast 1	South 13	Valley	Valley
2	Coast 1	North 7	Valley	Central-East
3	West 5	West 10	Central	Panhandle
4	West 5	FarWest 4	Central	West Texas
5	West 5	North 1	Central	Central
6	West 5	North 7	Central	Central-East
7	North 1	North 7	Dallas	Central-East
8	North 1	North 4	Dallas	Central
9	North 4	North 7	Central	Central-East
10	North 7	North 6	Central-East	East
11	North 4	North 6	Central	East
12	FarWest 7	FarWest 4	West Texas	West Texas
13	FarWest 7	West 14	West Texas	Panhandle
14	FarWest 7	FarWest 8	West Texas	West Texas
15	FarWest 7	FarWest 9	West Texas	West Texas
16	FarWest 7	North 7	West Texas	Central-East
17	West 12	FarWest 7	Central	West Texas
18	West 12	West 1	Central	Central-East
19	West 12	North 1	Central	Dallas
20	West 14	West 5	Panhandle	Central
21	West 14	North 1	Panhandle	Dallas
22	FarWest 9	West 4	West Texas	Southwest
23	West 4	North 7	SouthWest	Central-East
24	West 16	West 3	Panhandle	Panhandle
25	West 16	West 14	Panhandle	Panhandle
26	West 15	West 14	Panhandle	Panhandle
	PAIRS WITHOUT PHASOR DATA AVAILABLE			
27	Coast 1	South 10*	Valley	Valley
28	South 3	South 11*	Valley	Central-East
29	South 11*	North 7	Valley	Central-East
30	North 7	South 7*	Central-East	Central-East
31	North 7	South 9*	Central-East	Central-East
32	West 11	West 8*	Central	Central
33	West 8	South 9*	Central	Central-East
34	FarWest 7	South 9*	West Texas	Central-East
35	FarWest 9	South 9*	West Texas	Central-East
36	West 19*	West 9	Panhandle	Panhandle
	* Denotes substations without existing PMUs or w/o phasor data stream			



B. Summary of Results – All Data Included

Table C-1 below contains angle difference results for all those angle pairs selected for study. Several PMUs were connected to the ERCOT grid during the year 2013 and were streaming phasor data. As a result, 26 pairs with phasor data were included in the analysis (total of 36). Table C-1 shows min, max and average values for angle differences obtained from all data received for the 12 months of 2013 (all solved SE cases and all phasor data, normal and contingency conditions). Phasor data was not available for some of the pairs selected for study; no phasor results are provided for those pairs.

Data availability for those pairs which had at least one PMU recently added, shows low values because the availability is calculated based on the entire 12 months.

Observation of Table C-1 results shows the following:

1. Five pairs show Max-Min angle spreads greater than 80 degrees: Coast 1-North 7, FarWest 7-North 7, FarWest 9-West 4, FarWest 7-South 9, and FarWest 9-South 9.
2. Max-Min angle spread of less than 15 degrees occurred on the following pairs: North 1 to North 4, FarWest 7 to FarWest 8, and West 11 to West 8.
3. Sixteen pairs have spreads between 15 and 40 degrees, and nine pairs have Max-Min spreads of between 40 to 80 degrees.
4. Four pairs have maximum angles greater than 50 degrees: FarWest 7-North 7, FarWest 9-West 4, FarWest 7-South 9, and FarWest 9-South 9.
5. Six pairs have minimum angles lower than -30 degrees: Coast 1-North 7, FarWest 7-North 7, FarWest 9-West 4, West 4-North 7, FarWest 7-South 9, and FarWest 9-South 9.

Table C- 1 – Baselining Analysis – Summary of Angle Differences – All Data

Table C-1 -CCET DISCOVERY ACROSS TEXAS- BASELINING ANALYSIS- SUMMARY OF ANGLE DIFFERENCES - ALL DATA

			Phasor Data - 1/1/13 to 12/31/13					State Estimator Data - 1/1/13 to 12/31/13				
	Angle Pair	Base kV	Min	Max	Max-Min	Percent Positive	% Data Available	Min	Max	Max-Min	Percent Positive	Max-Min Spread
1	Coast 1-South 13	138kV	-20.00	49.99	69.99	66.01	77.74	-19.37	31.69	3.19	65.4%	51.1
2	Coast 1-North 7	138kV	-36.75	50.83	87.58	59.74	86.45	-35.89	44.81	3.28	59.3%	80.7
3	West 5-West 10	345/69kV	-24.97	24.99	49.96	57.71	52.23	-23.88	15.88	-0.72	51.7%	39.8
4	West 5-FarWest 4	345kV	-11.49	9.39	20.88	51.47	51.99	-10.50	9.15	-0.32	48.4%	19.7
5	West 5-North 1	345kV	-19.30	25.72	45.01	33.51	53.04	-18.64	36.19	0.93	48.5%	54.8
6	West 5-North 7	345/138kV	-16.47	30.23	46.70	62.61	53.07	-26.90	48.06	7.42	71.0%	75.0
7	North 1-North 7	345/138 kV	-12.33	26.41	38.74	93.29	92.78	-11.20	24.01	6.49	93.8%	35.2
8	North 1-North 4	345/138kV	4.33	16.34	12.01	100.00	92.77	4.05	15.49	8.96	100.0%	11.4
9	North 4-North 7	138kV	-18.85	14.43	33.28	23.27	92.91	-17.84	13.60	-2.47	25.2%	31.4
10	North 7-North 6	138kV	-17.31	8.29	25.60	8.50	90.77	-17.25	10.70	-3.82	14.8%	28.0
11	North 4-North 6	138kV	-27.48	4.69	32.18	2.41	90.77	-20.43	5.04	-6.30	4.9%	25.5
12	FarWest 7-FarWest 4	345kV	-9.99	3.99	13.98	13.13	89.95	-10.51	4.60	-2.27	10.9%	15.1
13	FarWest 7-West 14	345kV	-27.18	26.65	53.82	43.63	78.67	-25.16	21.19	-1.17	43.4%	46.4
14	FarWest 7-FarWest 8	345/138kV	2.00	13.83	11.83	100.00	81.95	2.84	13.58	7.91	100.0%	10.7
15	FarWest 7-FarWest 9	345/138kV	-19.98	29.94	49.92	68.20	85.31	-17.09	26.89	3.01	64.7%	44.0
16	FarWest 7-North 7	345/138kV	-35.49	59.79	95.28	61.92	92.78	-34.04	55.59	5.80	63.6%	89.6
17	West 12-FarWest 7	345kV	-12.82	14.12	26.95	67.85	52.93	-9.64	13.59	1.99	74.5%	23.2
18	West 12-West 1	345kV	-15.99	20.96	36.95	61.02	52.85	-7.01	14.62	2.28	69.9%	21.6
19	West 12-North 1	345kV	-20.51	28.79	49.30	33.05	53.02	-19.59	37.65	1.09	48.3%	57.2
20	West 14-West 5	345kV	-21.62	12.90	34.52	59.60	41.69	-21.33	12.24	-0.64	50.1%	33.6
21	West 14-North 1	345kV	-13.00	16.81	29.81	45.93	78.58	-10.03	14.86	1.99	65.6%	24.9
22	FarWest 9-West 4	138kV	-34.84	54.94	89.79	70.66	70.41	-30.09	60.11	8.89	71.6%	90.2
23	West 4-North 7	138kV	-35.00	18.95	53.95	19.98	72.70	-32.46	16.94	-6.18	20.5%	49.4
24	West 16-West 3	345kV	PMUs at new West 16, West 3 and West 15 substations had less than 16% data available; not enough data.					Not enough data available				
25	West 16-West 14	345kV										
26	West 15-West 14	345kV										
27	Coast 1-South 10*	138kV	PMUs at the stations market with * are not available. Phasor data is not available for these pairs					-10.38	33.67	9.92	84.6%	44.1
28	South 3-South 11*	138kV						-21.35	21.54	0.26	50.4%	42.9
29	South 11*-North 7	345/69kV						-21.08	18.56	0.06	48.2%	39.6
30	North 7-South 7*	138/345kV						-21.19	16.09	-3.85	21.2%	37.3
31	North 7-South 9*	138/345kV						-16.37	18.41	0.13	53.1%	34.8
32	West 11-West 8*	345kV						-2.84	5.75	0.68	64.8%	8.6
33	West 8-South 9*	345kV						-24.69	30.69	3.26	57.8%	55.4
34	FarWest 7-South 9*	345kV						-37.01	56.88	6.05	64.1%	93.9
35	FarWest 9-South 9*	138/345kV						-44.29	64.43	3.04	53.0%	108.7
36	West 19*-West 9	345kV						Not enough data available				

* Denotes substations without existing PMUs or w/o data stream

C. Criteria to Identify Normal Operations Limits for Angle Differences

The data received, both phasor and state estimator, provides information for all conditions during the study period, including those conditions where the system experienced outages of lines or generators. This study is intended to provide angle difference limits that can be expected during normal operations; that is, when all facilities are in service. The following criteria were used to determine the angle difference limits expected during normal operations for the selected substation pairs.

i. If the angle difference time duration curves show only positive angles, then two limits will be identified: one corresponding to the angle difference that occurred at about one percent of the time, and the other corresponding to the maximum value observed.

ii. If the angle difference time duration curves show positive as well as negative angles, then four limits will be identified, two for one direction of flow, and two for the opposite direction of flow, based on the criteria below:
   - The first limit in either direction will be set using state estimator results by selecting the maximum (or minimum) angle difference observed on the corresponding time duration curves if the box-whisker and time duration plots show no extreme values (outliers or extreme values due to events in the system). If extreme values or outliers are present, a point of inflection will be determined, and the maximum or minimum angle will be set at the angle corresponding to the point of inflection.
   - The second maximum limit will be set at the angle difference which occurred 1% more time than the time corresponding to the selected maximum limit, based on the time duration curve. The second minimum limit will be set at the angle difference corresponding to 1% less time than the time corresponding to the selected minimum limit.

iii. In some cases, such as when there was an extended outage, EPG reproduced the time duration curve, excluding those days when the extended outage occurred, to determine the angle differences corresponding to normal conditions.

iv. The 1% values can be used to set alarms for the operators to be notified of impending maximum angle differences. The maximum and minimum values can be used to set alarms notifying the operator that expected maximum or minimum values have been reached.

v. The alarms should be monitored for a year against actual values observed during operation. If maximum values are exceeded, the observed values should be logged and documented for further analysis.

vi. Maximum and minimum angle differences will change as major changes occur in the system, such as the addition of 345 kV CREZ lines to the ERCOT system. This analysis should be revised based on at least six-months of historical data obtained with all the new transmission lines in place. Maximum and minimum values can also be estimated from many power flow cases representing different system conditions of the year. After all the CREZ lines are added to the ERCOT system, around the end of March 2014, this study and conclusions should be updated to reflect the impact of those significant additions.

D. Summary of Results – Normal Conditions

The angle difference results for normal conditions are summarized in Table C-2 below, which was developed based on the criteria described above.

Box-whisker and time duration curves were developed for each of the pairs analyzed. Angle differences, that may be the results of contingencies, were excluded by reviewing points of inflection; that is, points that significantly deviated from the normal operation trend observed in the box-whisker plots. The value of angle difference at the point of inflection was considered to be the maximum angle during normal conditions. If no outlier points were identified, then the angle corresponding to the 0% or 100% time points will represent the maximum and minimum angles reached during normal operations in either direction of flow. SE-based voltage angle pairs, with their corresponding box-whisker and time duration curves, as well as phasor-based voltage angle pairs, with their corresponding box-whisker and time duration curves, are presented in Appendix C.

Table C- 2 – Baselining Analysis – Summary of Angle Differences – Normal Data

Table C-2 BASELINING ANALYSIS - SUMMARY OF ANGLE DIFFERENCES - NORMAL CONDITIONS

				DATA RESULTS													
				Phasor Data		State Estimator Data - 1/1/13 to 12/31/13									SE Data-Normal		
No	Angle Pair FROM	Angle Pair TO	Base kV	Min Angle	Max Angle	Percent Positive	Min Angle at POI or 100%	Percent (POI or 100%)	Min Angle at 99% or POI - 1%	Percent (99% or POI - 1%)	Max Angle at 1% or POI +1%	Percent (1% or POI +1%)	Max Angle at POI or 0%	Percent (POI or 0%)	Min Angle	Max Angle	Max-Min Spread
1	Coast 1	South 13	138	-15.49	42.6	65.43%	-16.65	99.91%	-12.21	98.91%	20.56	1.03%	23.50	0.03%	-16.65	23.50	40.1
2	Coast 1	North 7	138	-28.49	38.43	59.30%	-30.03	99.89%	-24.50	98.89%	32.61	1.08%	38.83	0.08%	-30.03	38.83	68.9
3	West 5	West 10	345/69	-19.73	18.44	51.65%	-21.03	99.91%	-17.86	98.91%	13.70	1.17%	15.00	0.17%	-21.03	15.00	36.0
4	West 5	FarWest 4	345	-9.51	5.83	48.44%	-9.39	99.89%	-5.23	98.89%	4.67	1.13%	5.10	0.13%	-9.39	5.1	14.5
5	West 5	North 1	345	17.00	23.53	48.46%	-16.93	99.87%	-15.73	98.87%	21.53	1.04%	26.96	0.04%	-16.93	26.96	43.9
6	West 5	North 7	345/138	-13.74	29.25	71.00%	-22.79	99.84%	-14.51	98.84%	31.53	1.09%	43.95	0.09%	-22.79	43.95	66.7
7	North 1	North 7	345/138	-9.99	20.95	93.78%	-8.02	99.77%	-4.82	98.77%	16.32	1.14%	19.85	0.14%	-8.02	19.85	27.9
8	North 1	North 4	345/138	4.47	15.32	100.00%	4.23	99.82%	5.42	98.82%	13.05	1.17%	14.76	0.17%	4.23	14.76	10.5
9	North 4	North 7	138	-17.60	9.86	25.23%	-15.52	99.88%	-12.32	98.88%	6.35	1.12%	9.50	0.12%	-15.52	9.50	25.0
10	North 7	North 6	138	-14.73	7.64	14.79%	-15.74	99.94%	-11.59	98.94%	4.09	1.11%	7.90	0.11%	-15.74	7.90	23.6
11	North 4	North 6	138	-22.75	3.43	4.88%	-19.16	99.90%	-16.56	98.90%	2.16	1.03%	4.33	0.03%	-19.16	4.33	23.5
12	FarWest 7	FarWest 4	345	-8.34	3.11	10.90%	-10.16	99.86%	-7.15	98.86%	1.96	1.06%	3.90	0.06%	-10.16	3.90	14.1
13	FarWest 7	West 14	345	-21.62	20.34	43.37%	-19.65	99.90%	-16.97	98.90%	15.62	1.08%	19.05	0.08%	-19.65	19.05	38.7
14	FarWest 7	FarWest 8	345/138	3.75	13.52	100.00%	3.25	99.94%	4.30	98.94%	11.51	1.11%	13.04	0.11%	3.25	13.04	9.8
15	FarWest 7	FarWest 9	345/138	-12.85	18.66	64.70%	-13.50	99.96%	-11.41	98.96%	16.25	1.07%	17.50	0.07%	-13.50	17.50	31.0
16	FarWest 7	North 7	345/138	-30.47	45.89	63.63%	-29.05	99.87%	-22.30	98.87%	33.11	1.03%	40.70	0.03%	-29.05	40.70	69.7
17	West 12	FarWest 7	345	-7.70	9.66	74.53%	-7.03	99.87%	-5.06	98.87%	8.79	1.23%	10.20	0.23%	-7.03	10.20	17.2
18	West 12	West 1	345	-7.27	14.26	69.91%	-5.86	99.78%	-4.62	98.78%	12.27	1.11%	13.58	0.11%	-5.86	13.58	19.4
19	West 12	North 1	345	-17.25	26.48	48.32%	-17.95	99.92%	-15.86	98.92%	23.24	1.14%	26.64	0.14%	-17.95	26.64	44.6
20	West 14	West 5	345	-16.75	11.37	50.06%	-15.54	99.87%	-13.62	98.87%	9.62	1.03%	11.90	0.03%	-15.54	11.90	27.4
21	West 14	North 1	345	-10.24	13.22	65.58%	-9.36	99.83%	-7.23	98.83%	10.90	1.21%	12.47	0.21%	-9.36	12.47	21.8
22	FarWest 9	West 4	138	-29.80	48.48	71.57%	-26.48	99.89%	-19.65	98.89%	39.74	1.07%	46.01	0.07%	-26.48	46.01	72.5
23	West 4	North 7	138	-25.20	12.92	20.45%	-29.03	99.88%	-22.77	98.88%	9.92	1.13%	13.97	0.13%	-29.03	13.97	43.0
24	West 16	West 3	345	Not enough data		One or more substations are new with not enough data									Not enough data		
25	West 16	West 14	345														
26	West 15	West 14	345														
27	Coast 1	South 10*	138	NO PHASOR DATA AVAILABLE FOR THESE PAIRS		84.56%	-8.68	99.82%	-6.82	98.82%	26.65	1.06%	30.76	0.06%	-8.68	30.76	39.4
28	South 3	South 11*	138/345			50.43%	-18.22	99.86%	-14.79	98.86%	15.32	1.11%	18.88	0.11%	-18.22	18.88	37.1
29	South 11*	North 7	138/345			48.18%	-16.54	99.63%	-11.21	98.63%	12.89	1.15%	16.02	0.15%	-16.54	16.02	32.6
30	North 7	South 7*	138/345			21.21%	-18.05	99.83%	-15.22	98.83%	7.38	1.14%	14.37	0.14%	-18.05	14.37	32.4
31	North 7	South 9*	138/345			53.07%	-13.80	99.88%	-11.63	98.88%	10.55	1.10%	16.39	0.10%	-13.80	16.39	30.2
32	West 11	West 8*	345			64.80%	-2.31	99.85%	-1.71	98.85%	4.88	1.11%	5.47	0.11%	-2.31	5.47	7.8
33	West 8	South 9*	345			57.84%	-23.88	99.91%	-19.73	98.91%	27.17	1.19%	29.36	0.19%	-23.88	29.36	53.2
34	FarWest 7	South 9*	345			64.13%	-31.48	99.88%	-23.21	98.88%	36.74	1.13%	42.77	0.13%	-31.48	42.77	74.3
35	FarWest 9	South 9*	138/345			52.96%	-39.57	99.87%	-32.87	98.87%	42.59	1.12%	49.40	0.12%	-39.57	49.40	89.0
36	West 19*	West 9	345			One or more substations are new with not enough data									Not enough data		

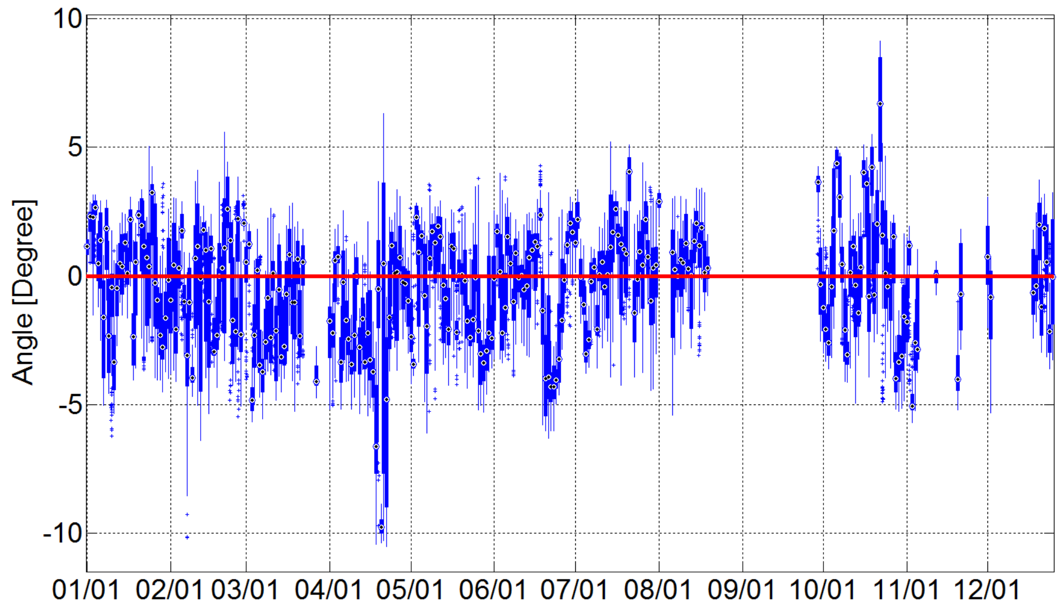
NOTE: These results were obtained with 2013 data.

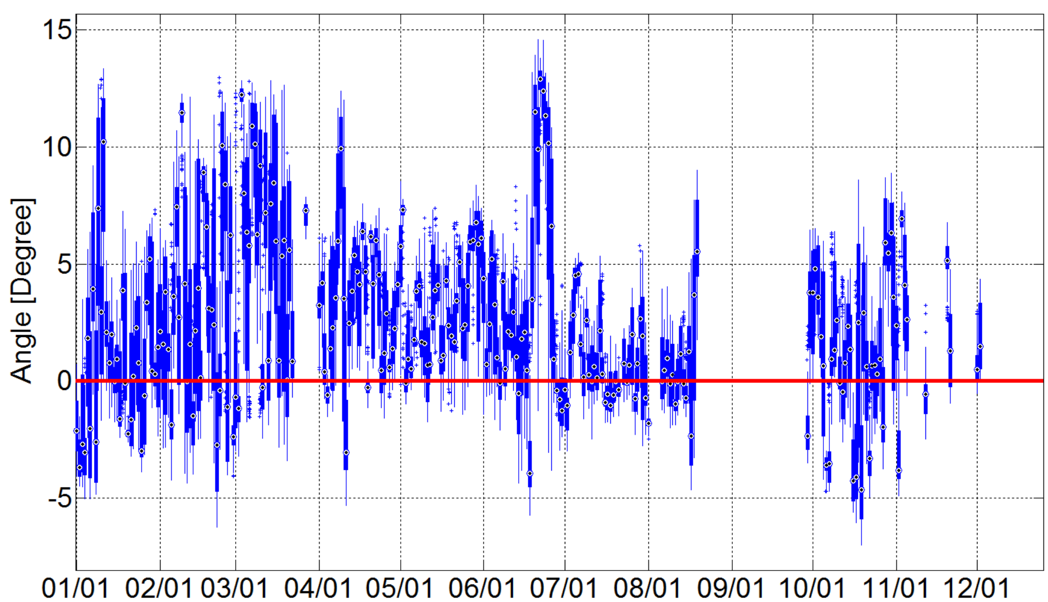
E. Observations from Table C-2

1. The maximum Max-Min angle spreads under normal conditions occurred at FarWest 9-Hamilton (72.5), FarWest 7-South 9 (74.5), and FarWest 9-South 9 (89).
2. The angle pairs with Max-Min spreads less than 10 degrees are FarWest 7-FarWest 8 (9.8) and West 11-West 8 (7.8).
3. The maximum voltage angles under normal conditions occurred at FarWest 9-West 4 (46.01) and FarWest 9-South 9 (49.4). Minimum angles occurred at Coast 1-North 7 (-30.03), FarWest 7-South 9 (-31.48), and FarWest 9-South 9 (-39.57).
4. Fourteen pairs had maximum angles of less than 15 degrees, and the rest had angles between 15 and 49.4 degrees. Nine substations had minimum angles lower than -20 degrees.

F. Observations from Box-Whisker Plots (Appendix C - Part 1)

1. State Estimator (SE) data is missing for the last 10 days of March, mid-August to late September, and for most of November and December for most substations.
2. SE data for FarWest 7-West 14, West 14-West 5, and West 14-North 1 is missing for the great majority of the July through December period. Since West 14 is the common substation for these three pairs, it is reasonable to suspect that the EMS data at West 14 needs to be checked.
3. SE data for West 16-West 14 and West 15-West 14 is available for only a few days at the beginning of October 2013; this is not enough data for analysis.
4. SE data for West 11-West 8 and West 8-South 9 is available only for June, July, and part of August; SE data is missing for the rest of the year 2013.
5. Several angle pairs exhibit abrupt changes in angle that may be due to outages or construction work. Some of these changes lasted several days before returning to the original values. If the abrupt changes are due to construction/maintenance work, then the "normal operations" angle differences may need to be revisited with feedback from ERCOT operations personnel. Examples: Coast 1-South 13, West 5-FarWest 4, West 5-North 1, West 5-North 7, North 1-North 7, North 1-North 4, North 4-North 7, North 7-North 6, FarWest 7-FarWest 4, FarWest 7-West 14, FarWest 7-North 7, West 12-West 1, West 12-North 1, West 4-North 7, South 11-North 7, North 7-South 7, North 7-South 9, and FarWest 7-South 9.
6. If there were extended outages, the angles corresponding to the outage time should be excluded from the data used to establish normal operation alarm limits.
7. Examples of these abrupt angle changes are shown for West 5-FarWest 4 and West 12-West 1 below:





9. PAIRS FOR REAL-TIME MONOTORING

A. Criteria for Selection of Angle Pairs for Real-Time Monitoring

1. Choose a few transmission paths (pairs) from the wind areas to monitor wind power delivery.
2. Choose a load center, such as North 1, and select transmission paths serving such loads.
3. Choose transmission paths delivering power from the Valley.

4. Choose transmission paths connecting the load centers such as the Dallas, Austin, San Antonio, and Houston areas (no PMUs in the Houston area at this time).

NOTE: Because there are not enough PMUs installed in the system, EPG chose pairs that meet the criteria as closely as possible.

B. Transmission Paths (Pairs) Selected for Real-Time Monitoring

The transmission paths selected for monitoring are shown in Table 8 below:

Table 8 – Angle Pairs Selected for Real-time Monitoring (Based on PMU Availability)

TABLE 8: ANGLE PAIRS SELECTED FOR REAL TIME MONITORING (Based on PMU Availability)				
	PAIRS WITH PHASOR DATA AVAILABLE			
#	Substation A	Substation B	From Region	To Region
1	Coast 1	South 13	Valley	Valley
2	Coast 1	North 7	Valley	Central-East
3	Coast 4	North 7	Valley	Central-East
4	South 3	South 11*	Valley	Valley
5	South 11*	North 7	Valley	Central-East
6	North 6	North 7	East	Central-East
7	North 4	North 7	Dallas	Central-East
8	West 14	North 1	Panhandle	Dallas
9	West 5	North 1	Central	Dallas
10	North 1	North 7	Dallas	Central-East
11	West 3	North 7	Central	Central-East
12	West 14	West 5	Panhandle	Central
13	West 5	North 7	Central	Central-East
14	West 12	FarWest 7	Central	West Texas
15	West 12	West 1	Central	Central
16	West 1	North 7	Central	Central-East
17	FarWest 7	North 7	West Texas	Central-East
18	FarWest 7	South 9*	West Texas	Valley
19	FarWest 7	FarWest 9	West Texas	West Texas
20	FarWest 9	West 4	West Texas	Southwest
21	West 4	North 7	Southwest	Central-East
22	West 15	West 14	Panhandle	Panhandle
23	West 16	West 14	Panhandle	Panhandle
24	West 16	West 3	Panhandle	Central
25	West 19*	West 9	Panhandle	Central
*	Means PMUs are planned for this substation, but not available at this time.			

C. Proposed Alarm Limits

Table 9 below shows the proposed angle limits for the paths (pairs) selected for real-time monitoring. These proposed limits were selected from the results for normal conditions shown in Table B- 2 and Table C- 2 of this report. These results are based on the data for the 12 months of 2013 provided by ERCOT. Most of the planned CREZ 345 kV lines were added by the end of 2013. Additional 345 kV lines were added to the ERCOT system in January and March 2014, which will further tighten electrically the ERCOT system. EPG expects the alarm limits proposed in this section, based on 2013 data, to tighten once the ERCOT system operates for several months with all the CREZ lines in service. Alarm limits will be revised using data obtained for a period of time (about six-months) when all CREZ transmission lines are in service.

By monitoring these angle pairs, the ERCOT grid operators should have a good overview of power flow from generation centers to the load centers, and between load centers. It will provide them with a good idea of ongoing power flows among the different regions of the ERCOT grid.

EPG suggests that operators document anytime these limits are exceeded, noting the reason, if known, for the deviations, such as line or generation outages.

Table 9 – Baselining Analysis – Alarm Limits for Real-time Monitoring

Table 9 - BASELINING ANALYSIS - ALARM LIMITS FOR REAL TIME MONITORING

				ALARM LIMITS - NORMAL CONDITIONS								
				Phasor Data		RECOMMENDED ALARM LIMITS				SE Data-Normal		
No	Angle Pair FROM	Angle Pair TO	Base kV	Min Angle	Max Angle	MINIMUM ALARM LIMIT	MINIMUM ALARM ALERT	MAXIMUM ALARM ALERT	MAXIMUM ALARM LIMIT	Min Angle	Max Angle	Max-Min Spread
1	Coast 1	South 13	138	-15.49	42.6	-16.65	-12.21	20.56	27.19	-16.65	23.50	40.1
2	Coast 1	North 7	138	-28.49	38.43	-33.45	-24.68	32.72	42.06	-33.45	42.06	75.5
3	Coast 4	North 7	345	-30.53	49.53	-30.80	-24.15	37.38	47.52	-30.80	47.52	78.3
4	South 3	South 11*	138/345	No PMUs at South 11		-18.22	-14.79	15.32	18.88	-18.22	18.88	37.1
5	South 11*	North 7	345			-19.39	-12.27	12.80	15.70	-19.39	15.70	35.1
6	North 6	North 7	138	-4.34	14.90	-7.77	-4.09	11.59	15.68	-7.77	15.68	23.5
7	North 4	North 7	138/345	-17.60	9.86	-16.06	-12.42	6.49	11.33	-16.06	11.33	27.4
8	West 14	North 1	345	-10.24	13.22	-9.36	-7.23	10.90	12.47	-9.36	12.47	21.8
9	West 5	North 1	345	17.00	23.53	-16.93	-15.73	21.53	26.96	-16.93	26.96	43.9
10	North 1	North 7	345	-9.99	20.95	-9.23	-5.26	16.42	20.83	-9.23	20.83	30.1
11	West 3	North 7	345	No data		Not enough data				Not enough data		
12	West 14	West 5	345	-16.75	11.37	-15.54	-13.62	9.62	11.90	-15.54	11.90	27.4
13	West 5	North 7	345	-13.74	29.25	-23.57	-14.85	31.54	44.00	-23.57	44.00	67.6
14	West 12	West 1	345	-7.27	14.26	-5.86	-4.62	12.27	13.58	-5.86	13.58	19.4
15	West 12	FarWest 7	345	-7.70	9.66	-7.03	-5.06	8.79	12.86	-7.03	10.20	17.2
16	West 1	North 7	345	-9.48	24.51	-20.62	-12.39	26.79	37.02	-20.62	37.02	57.6
17	FarWest 7	North 7	345	-30.47	45.89	-29.21	-22.39	33.08	43.20	-29.21	43.20	72.4
18	FarWest 7	South 9*	345	No PMUs at Ken		-31.48	-23.21	36.74	42.77	-31.48	42.77	74.3
19	FarWest 7	FarWest 9	345/138	-12.85	18.66	-13.50	-11.41	16.25	25.04	-13.50	17.50	31.0
20	FarWest 9	West 4	138	-29.80	48.48	-26.48	-19.65	39.74	46.01	-26.48	46.01	72.5
21	West 4	North 7	138/345	-25.20	12.92	-31.32	-22.92	10.04	14.66	-31.32	14.66	46.0
22	West 15	West 14	345	Not enough data		New substations - Not enough data - No PMUs at West 19				Not enough data		
23	West 16	West 14	345									
24	West 16	West 3	345									
25	West 19*	West 9	345									

NOTE: These alarm limits were developed based on 2013 data.

Note that all the pairs in Table 9 have two negative alarm limit values and two positive alarm limit values. The negative values apply in the TO to FROM direction and the positive values apply in the FROM to TO direction.

10. CONCLUSIONS

a. Data Availability was Improved in 2013

State estimator data provided by ERCOT for 2013 had availability of 22.6% which was significantly higher than the 13% availability rate for 2012. Phasor data availability ranged from 19.1% to 93.2%. Those substations with the lower availability rates were those that began transmitting data to ERCOT at the end of the twelve-month study period.

b. Phasor Data Availability for 2013

Several PMUs were installed in 2013, some of them in late 2013. As a result, the phasor data availability for pairs involving these new PMUs was incomplete. This resulted in some discrepancies in results obtained with phasor data versus results obtained with the more complete SE data.

c. Highest Voltage Spreads at 138 kV and 345 kV Locations

State estimator data points to West 4 138 kV and Coast 4 345 kV as having the greatest voltage spreads in their class.

d. Substations with High Voltage Spreads

Six substations have voltage spreads higher than 15 kV: West 1, West 9, Coast 4, Coast 3, West 8, and South 9.

e. Voltage Angle Variability at 345 kV and 138 kV Substations (Reference: North 7)

Voltage angles vary over a wide range for several substations. The greatest variation of 104.1 degrees (-40.9 to 63.2) occurred at FarWest 9 138 kV substation. Among the 345 kV substations, the greatest angle variation over the twelve months of 2013 occurred at FarWest 4 with a spread of 90.8 (-30.6 to 60.2) degrees.

i. The greatest variations occurred among the substations in the western part of the state, namely: FarWest 7, West 11, West 6, FarWest 8, FarWest 9, FarWest 4, West 2, West 9, West 12, and West 5.

ii. The next greatest angle variation occurred in the south part of the state, namely: South 13, Coast 3, Coast 4, and Coast 1.

iii. The two greatest angles under normal conditions (Reference: North 7) were observed at West 10 and FarWest 9 with 59.73 and 50.63 degrees, respectively.

iv. The maximum Max-Min angle spreads under normal conditions occurred at West 10-North 7, FarWest 9-South 9, and Coast 3-North 7 with 91.8, 89.0 and 79.2 degrees, respectively.

f. Maximum Voltage Angles under Normal Conditions

The maximum voltage angles under normal conditions occurred at West 10-North 7, FarWest 9-North 7, FarWest 4-North 7, and Coast 4-North 7 with 59.73, 50.63, 47.69 and 47.52 degrees, respectively.

g. Voltage Spreads are Smaller in 2013

The voltage spreads obtained with 2013 data are smaller than those obtained with 2012 data. This is an indication of the ERCOT system's increased tightness due to the addition of the many new 345 kV CREZ lines.

h. Alarm Limits for Voltage Angles

CREZ lines have been added during several months of 2013, changing the angle values as lines were added to the ERCOT system. The alarm limits obtained with 2013 data will change once all CREZ lines are added, and the ERCOT system gets a chance to normalize. A few additional CREZ lines were added, in January and March of 2014, which will contribute to changes in angle differences among pairs near those lines. ERCOT operators can use the alarm limits established in this report to monitor real-time operations, keeping in mind that these limits will be conservative until the alarm limits are revised with 2014 data.

11. RECOMMENDATIONS

a. Data Monitoring and Data Integrity

Many gaps in data were observed during this analysis. EPG recommends that ERCOT and PMU owners monitor the state estimator and phasor data to find and fix problems associated with missing data. Alarm limits will be a true reflection of system performance, if the data upon which they are based is as complete as possible.

b. Monitoring Locations

EPG has produced alarm limits for 25 pairs for real-time monitoring as shown in Section 9 of this report. EPG will propose, after this report is completed, a number of pairs to be shown in the RTDMS daily reports.

c. Panhandle Wind Output Monitoring

There are four new CREZ lines connecting the Panhandle new 345 kV system with the rest of the ERCOT system: West 15-West 14, West 16-West 14, West 16-West 3, and West 19-West 9. The flow and angle on these four lines should provide a tool to monitor the wind output from that area. EPG recommends that ERCOT monitor this interface by including these four pairs in the RTDMS daily report. Note, however, that there are no PMUs installed at the West 19 substation; all the other substations in the interface are equipped with PMUs.

d. PMU at West 19

The Panhandle-North ERCOT interface mentioned above has PMUs installed at all the substations, except for West 19. EPG recommends that PMUs be installed at this substation to be able to monitor voltage angle and power on all four lines comprising the interface.

e. Need for an Alarm Limits Update

The CREZ project was completed in March 2014. The alarm limits proposed in this report should be updated with phasor data and state estimator data for the first six months of 2014. EPG will perform this update. However, an annual update should be performed with all 2014 data to obtain a more accurate set of alarm limits to be used during real-time normal conditions.

Appendix A – Part 1

CCET Discovery Across Texas project

Baseline Analysis Update - Voltage Magnitudes

State Estimator Data: January to December 2013

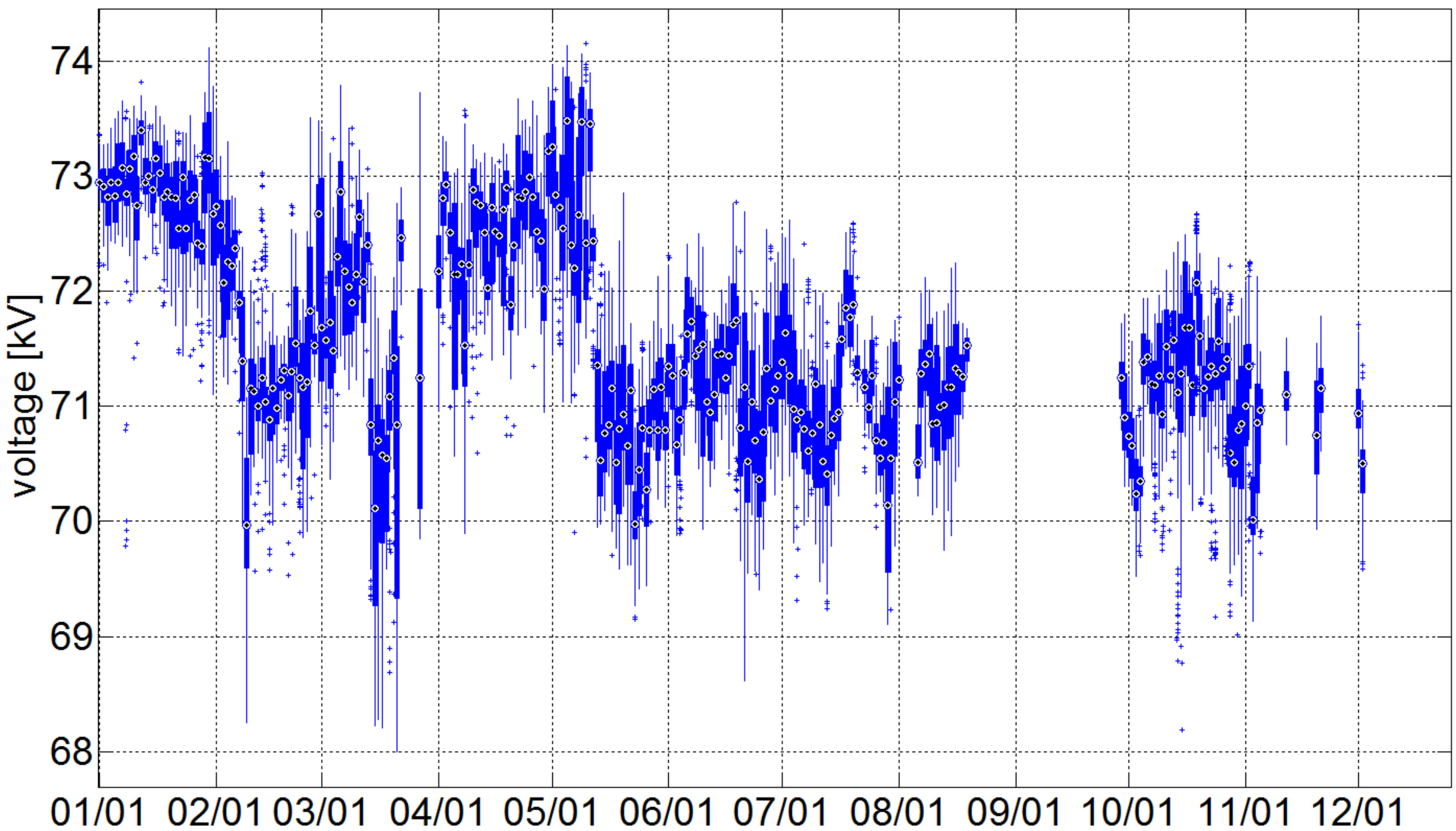
Box-Whisker Plots and Time Duration Curves

Electric Power Group

CCET

ERCOT

West 10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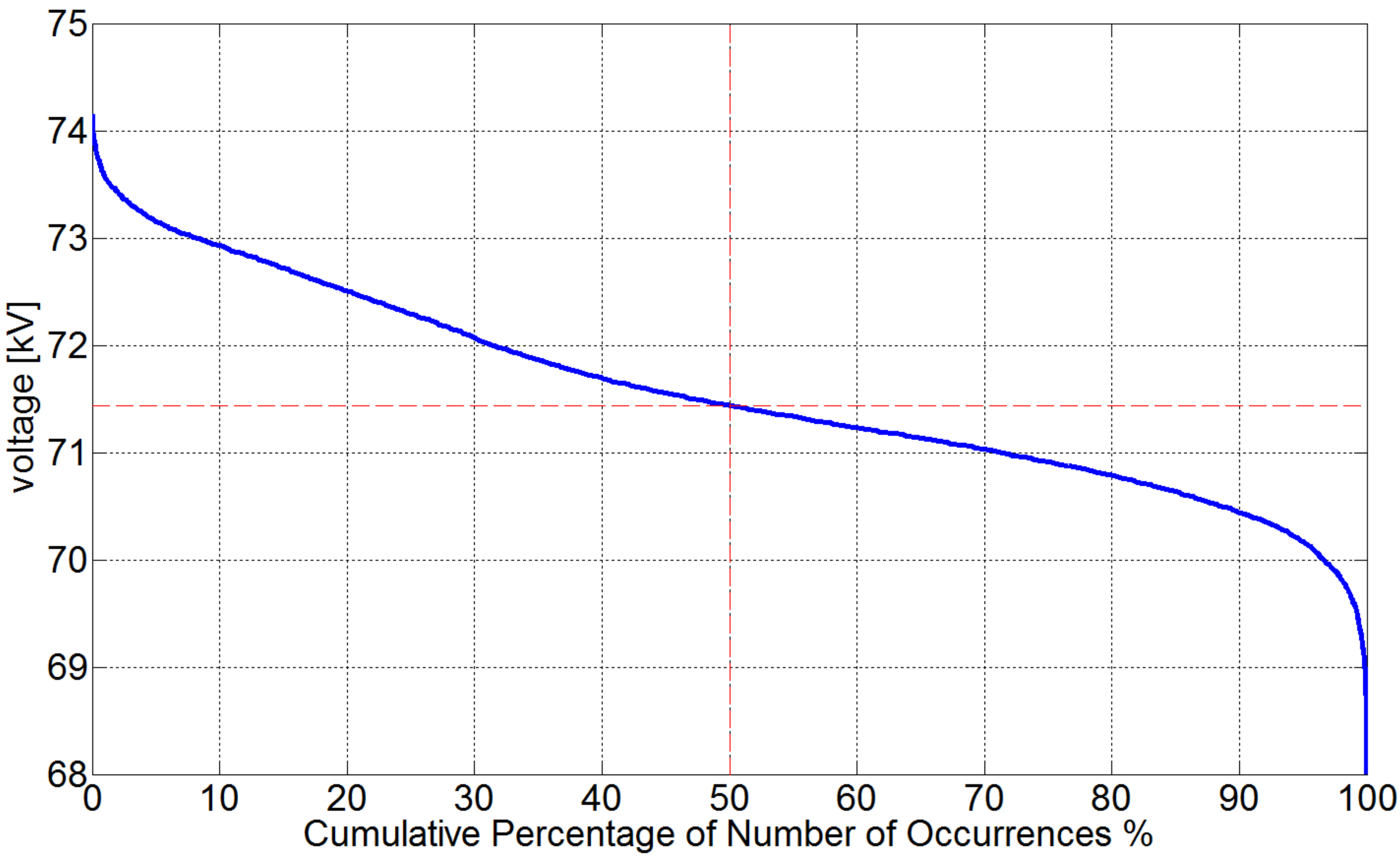
West 10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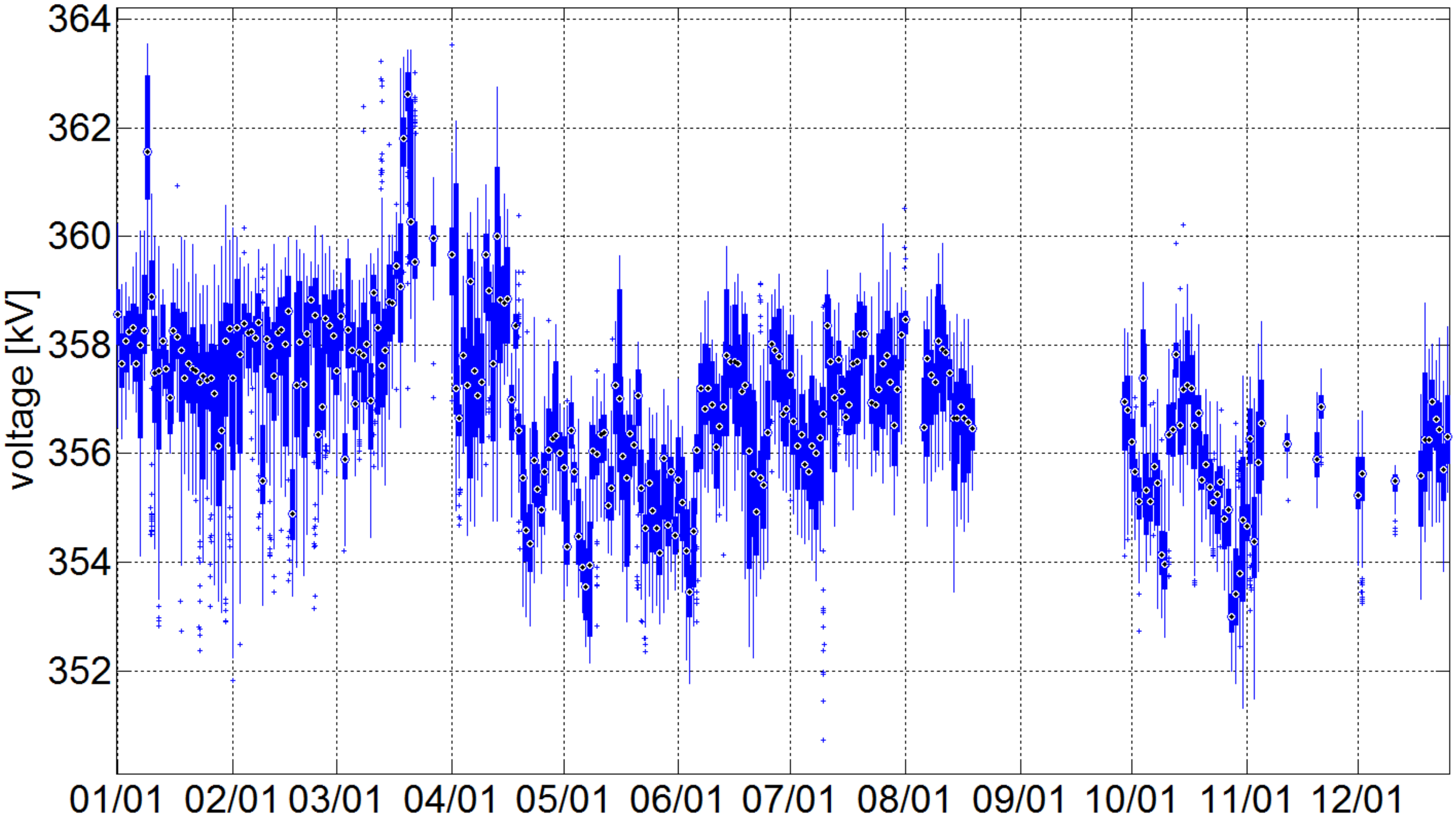
Cumulative Percentage of Number of Occurrences %

West 14



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voltage [kV]
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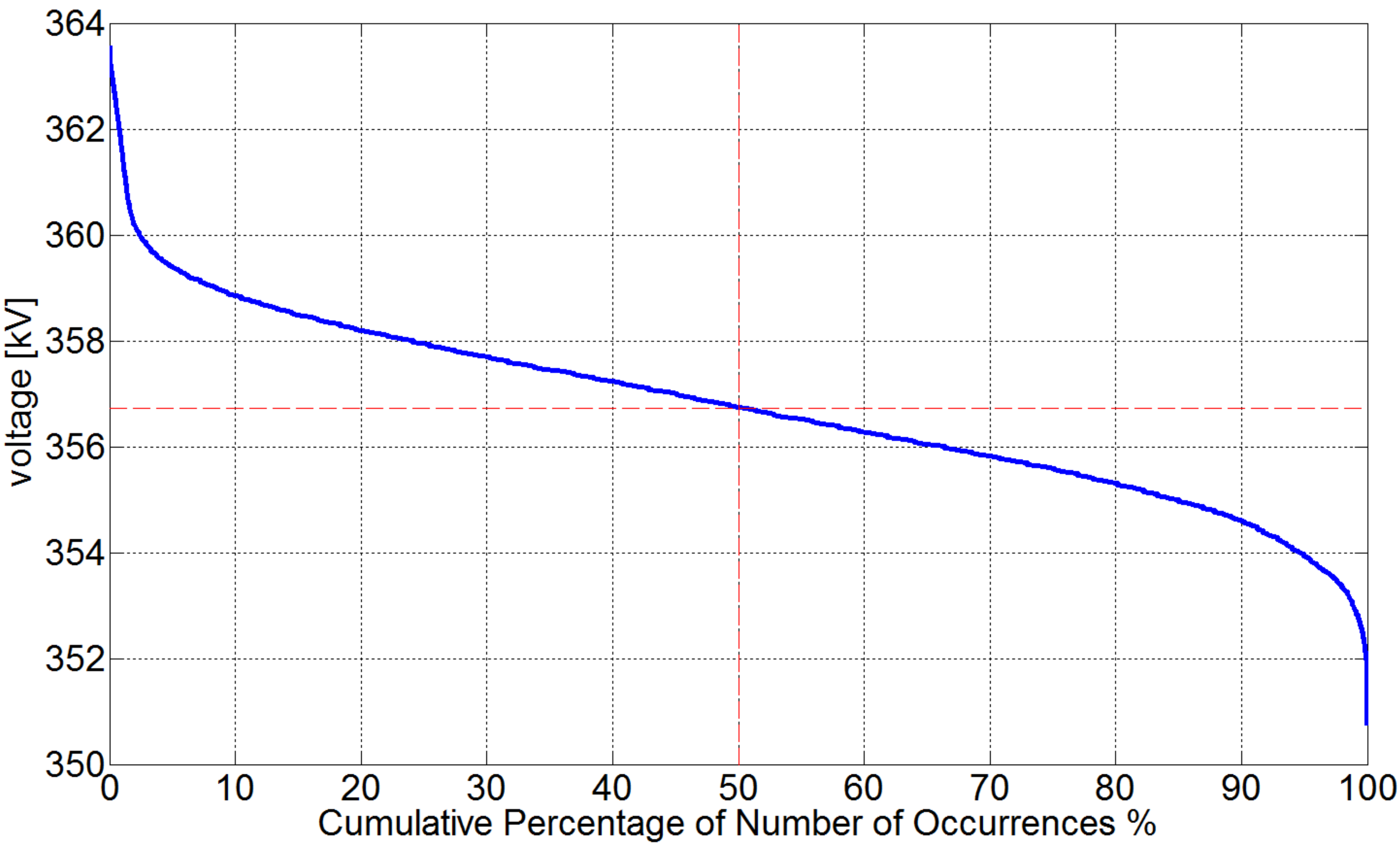
West 14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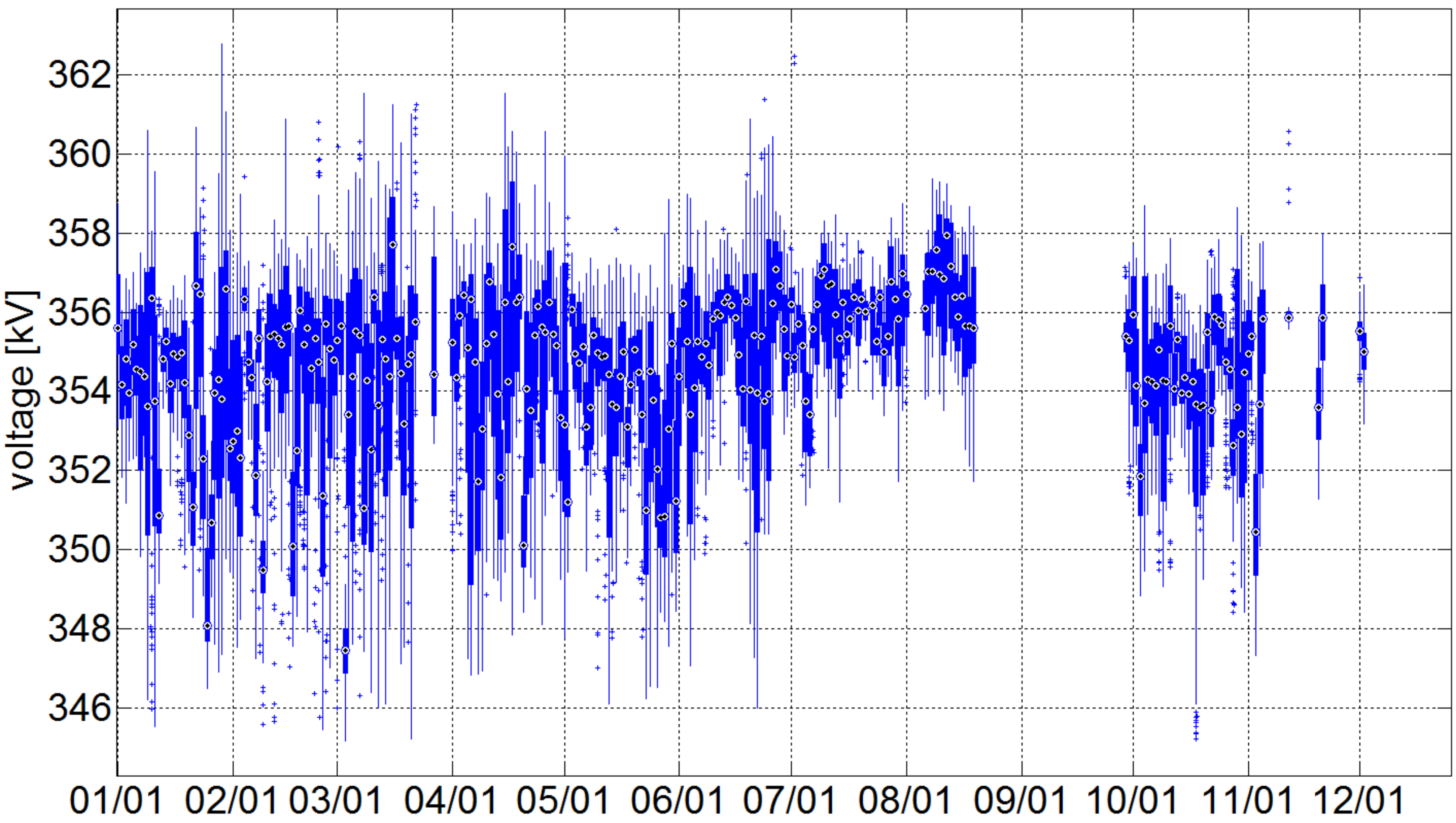
Cumulative Percentage of Number of Occurrences %

West 1



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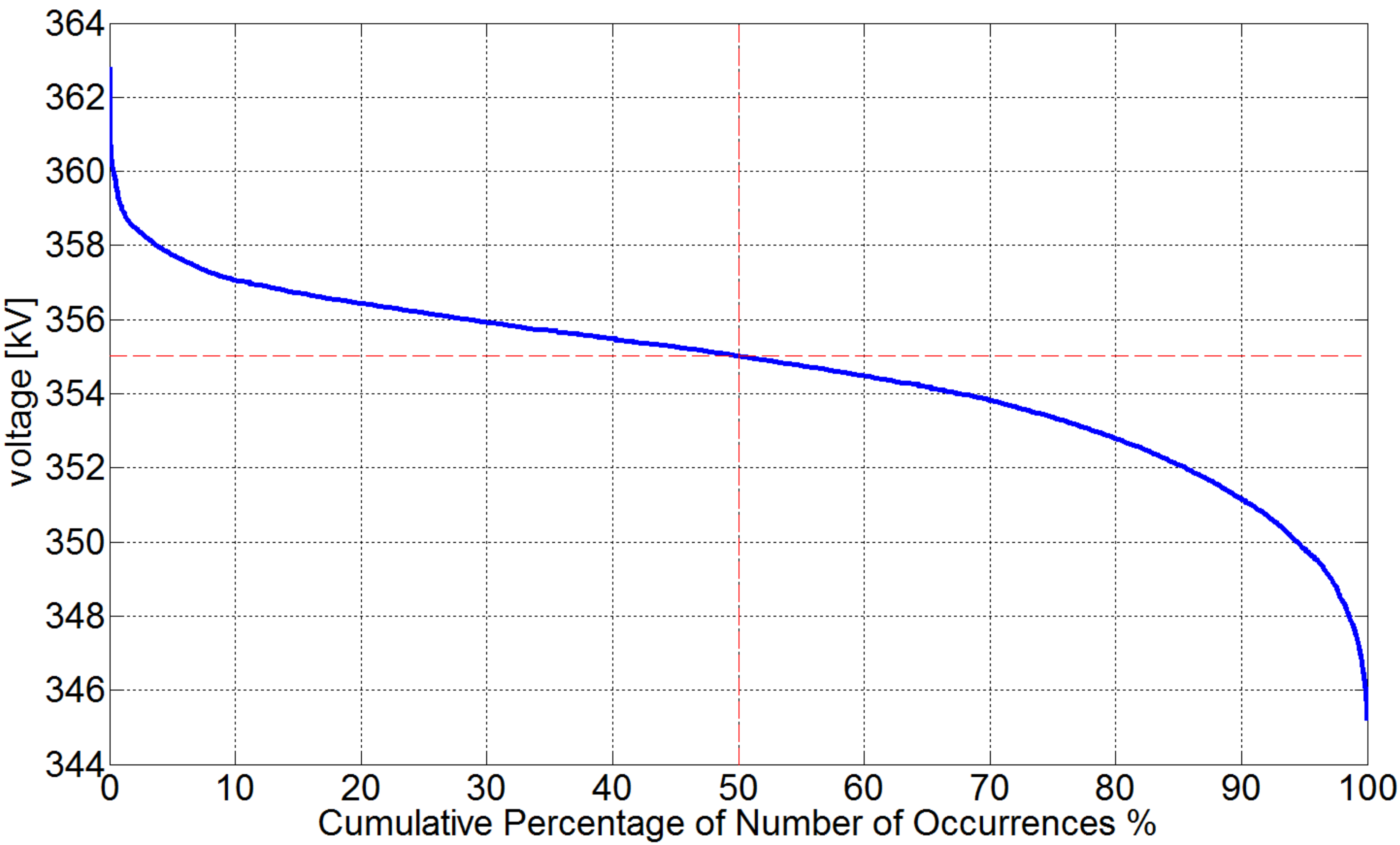
West 1



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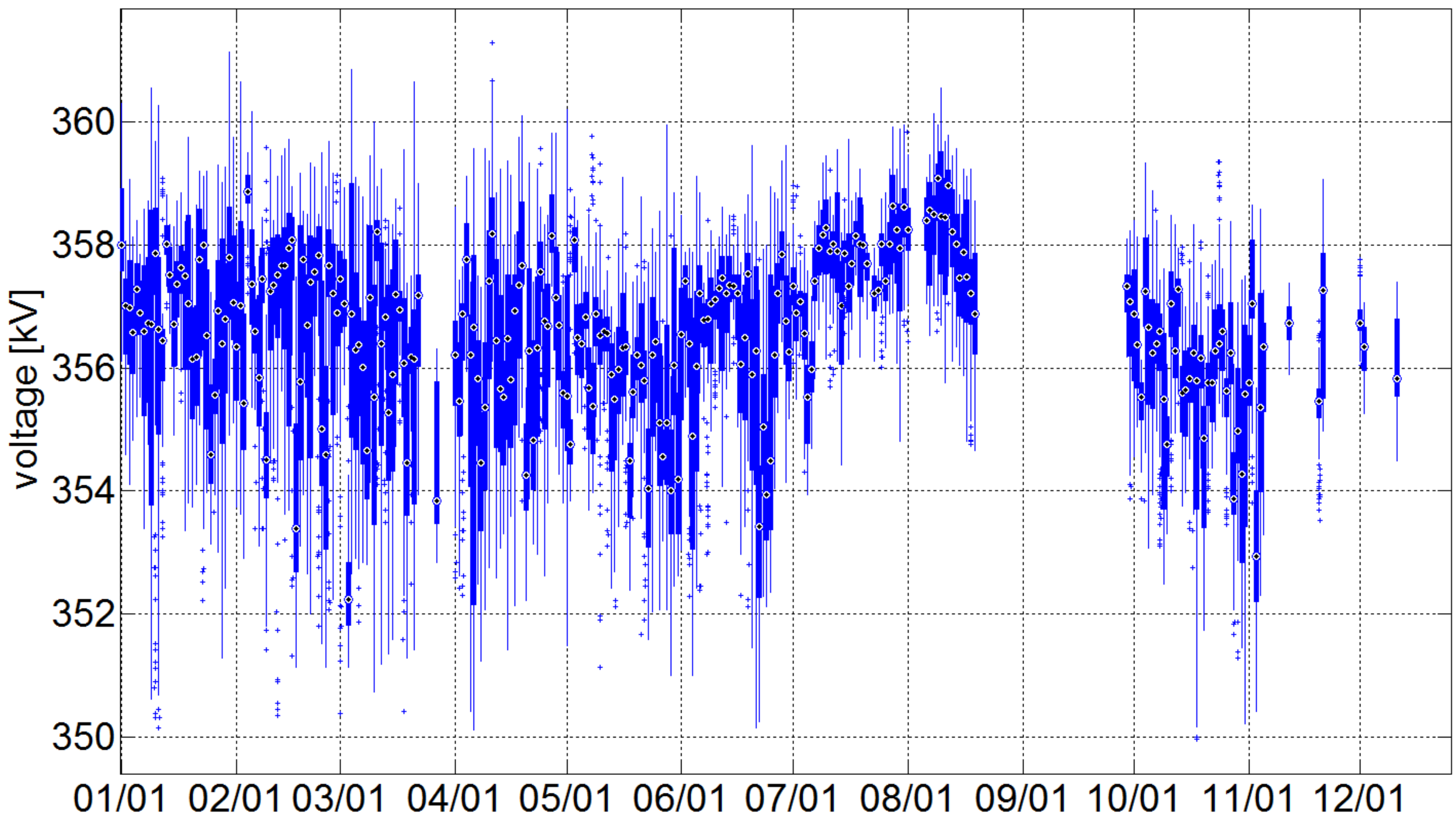
Cumulative Percentage of Number of Occurrences %

West 2



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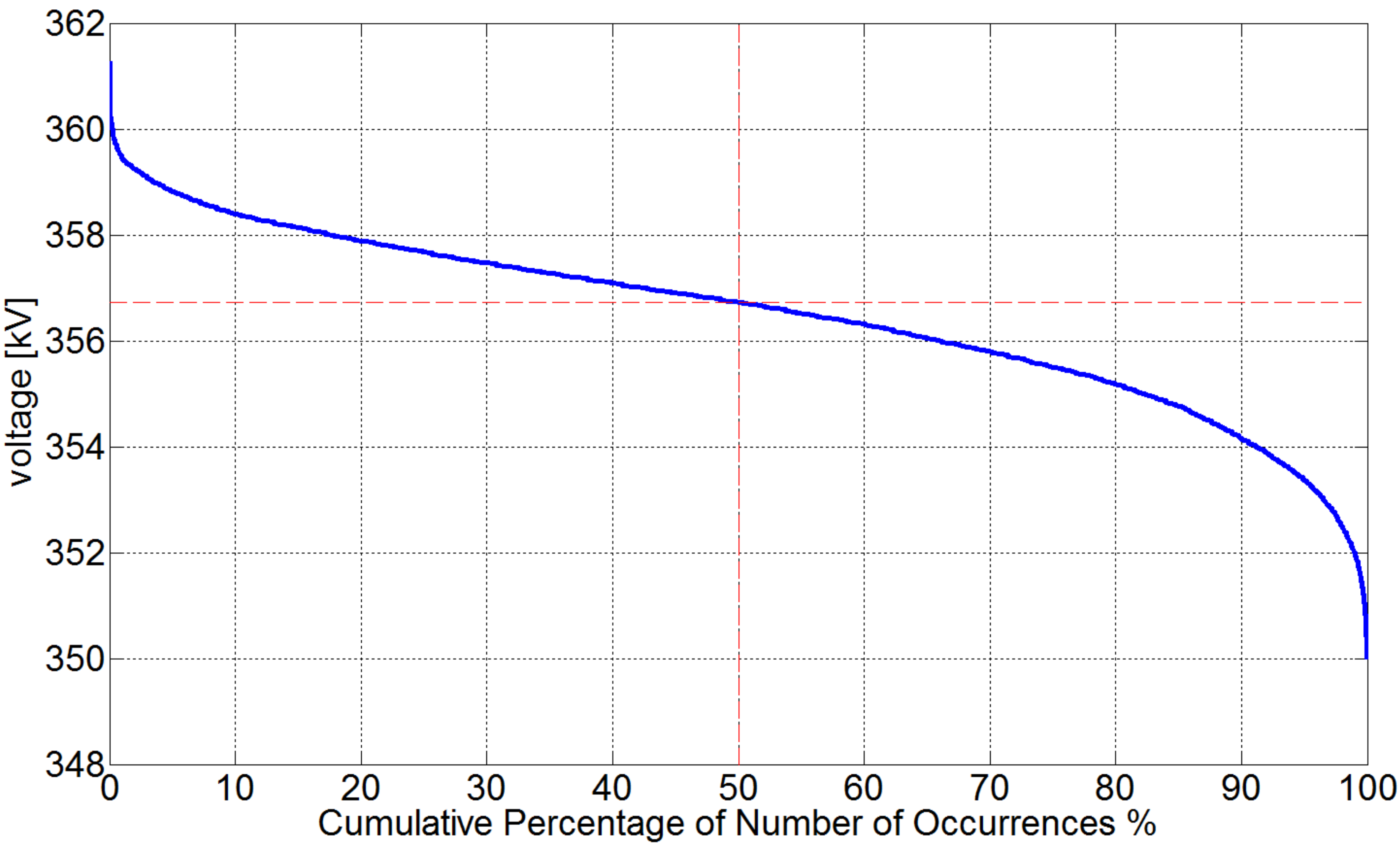
West 2



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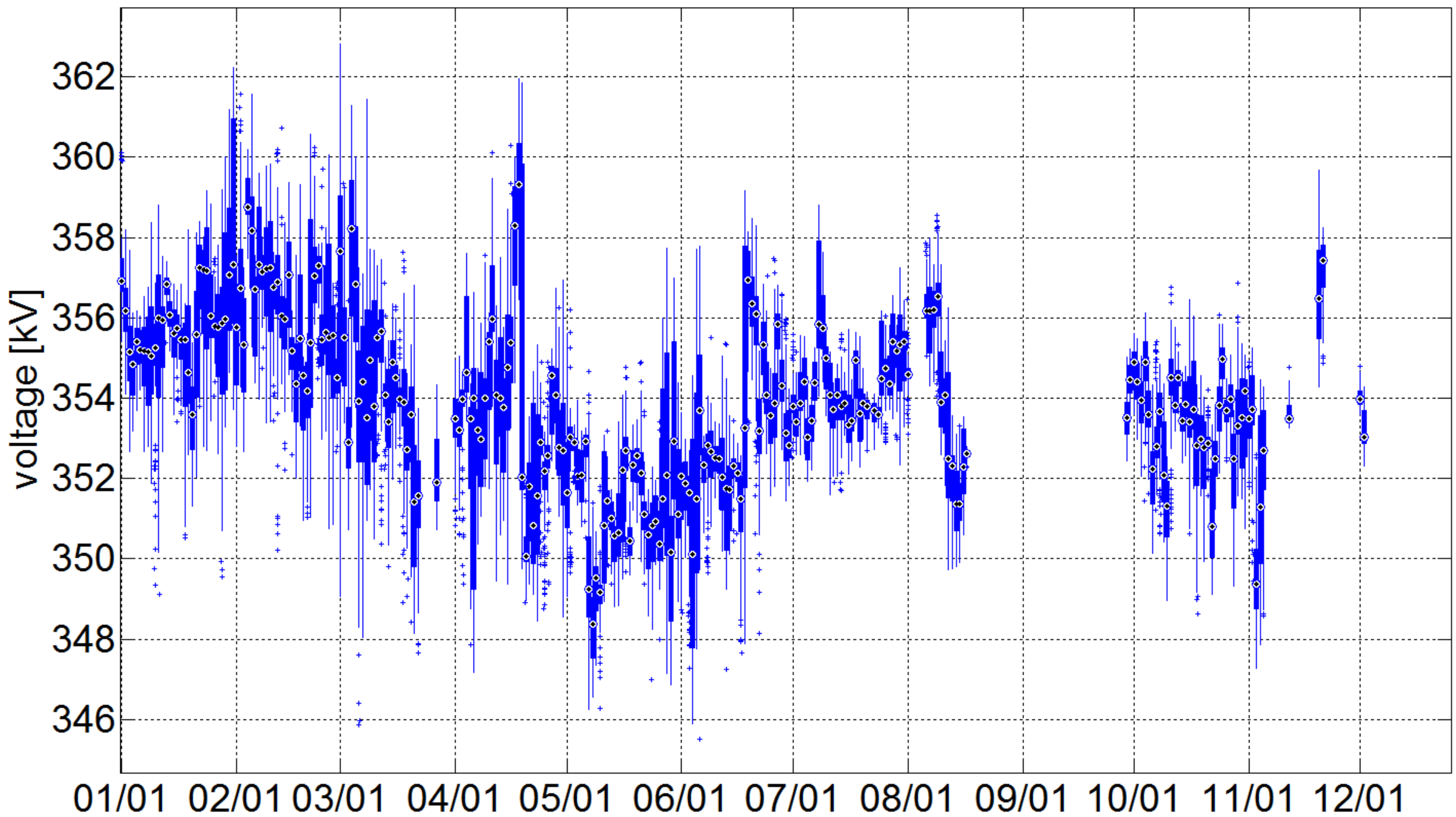
voltage [kV]
Cumulative Percentage of Number of Occurrences %

West 9*



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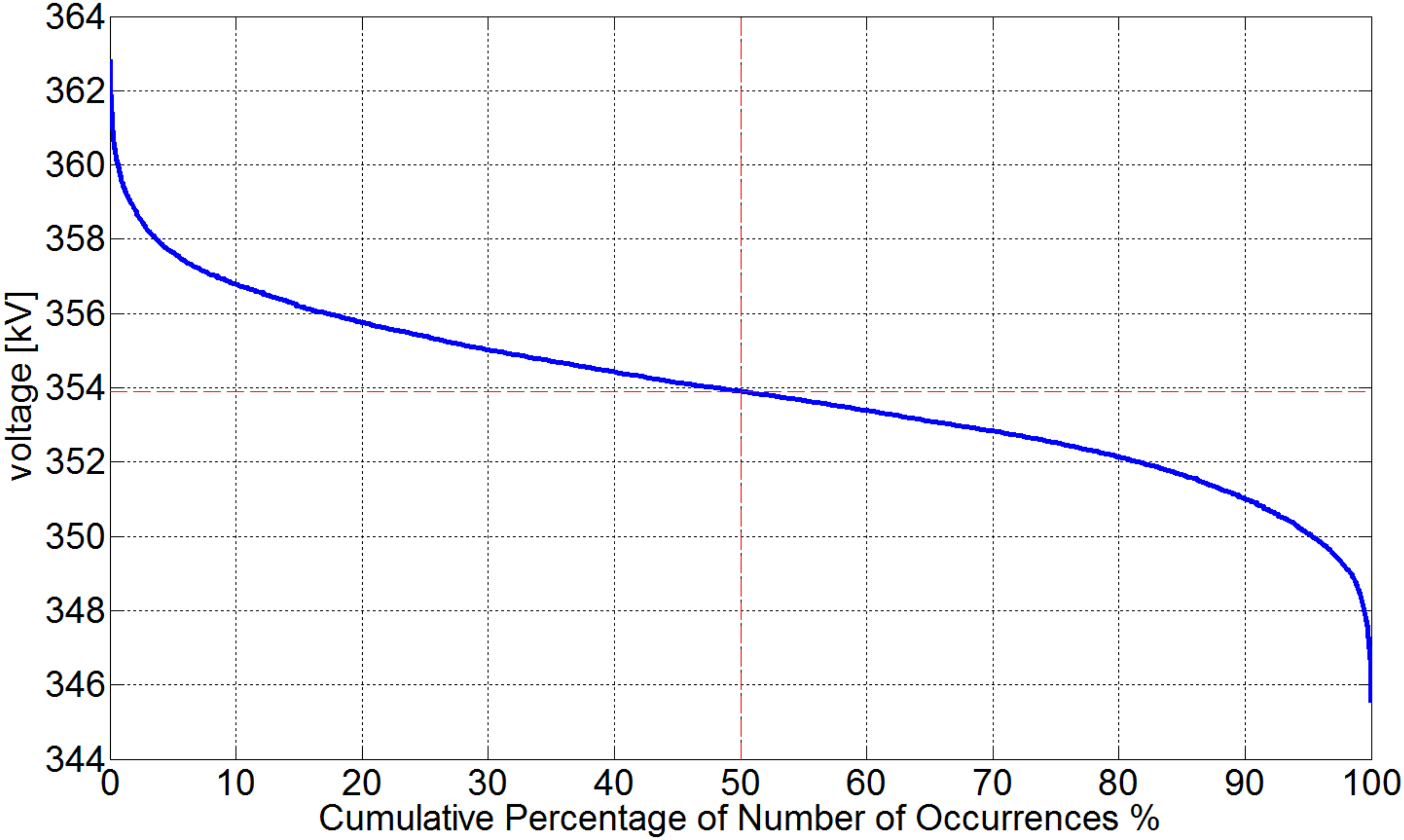
12/01

West 9*



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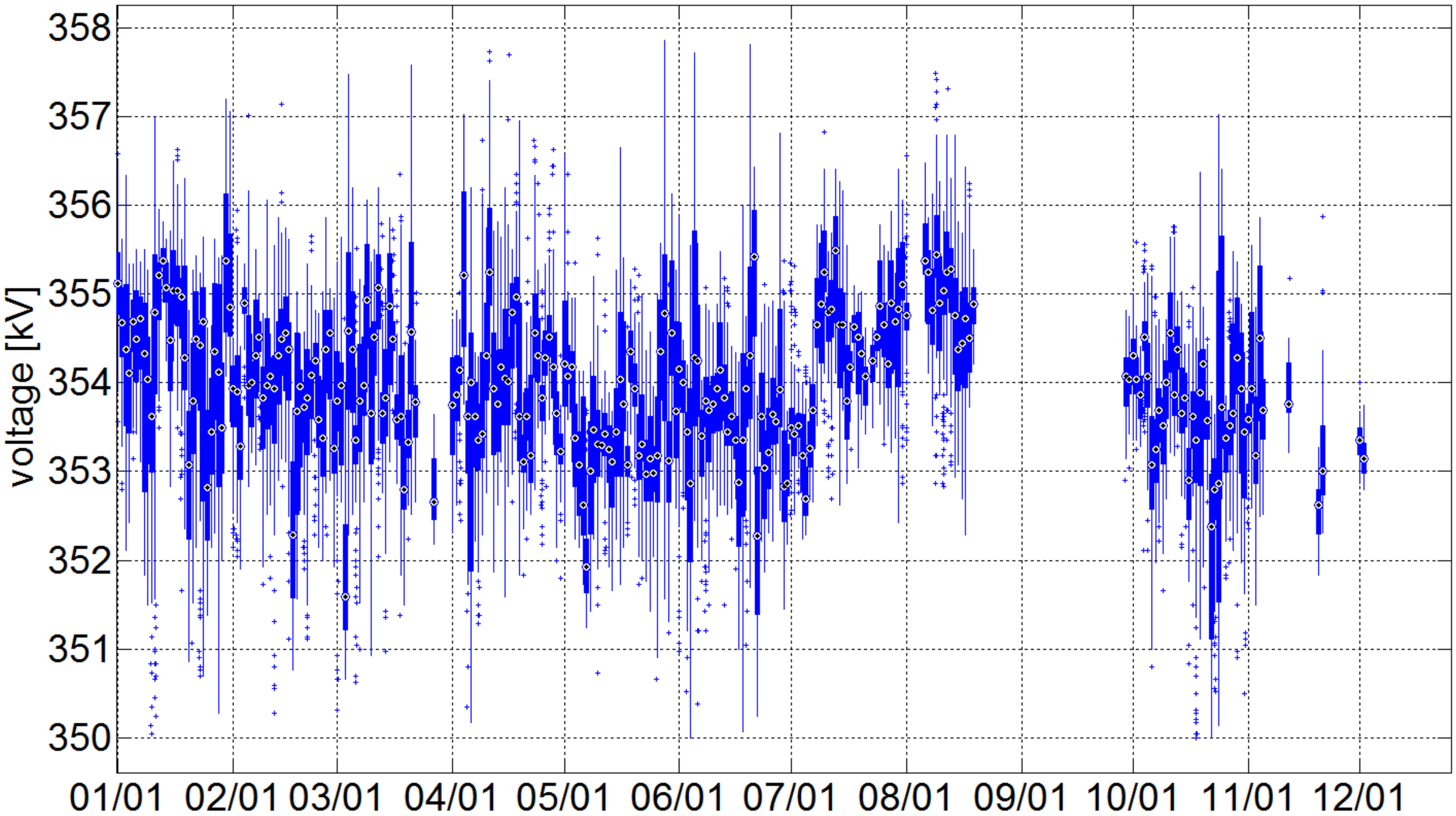
Cumulative Percentage of Number of Occurrences %

West 11



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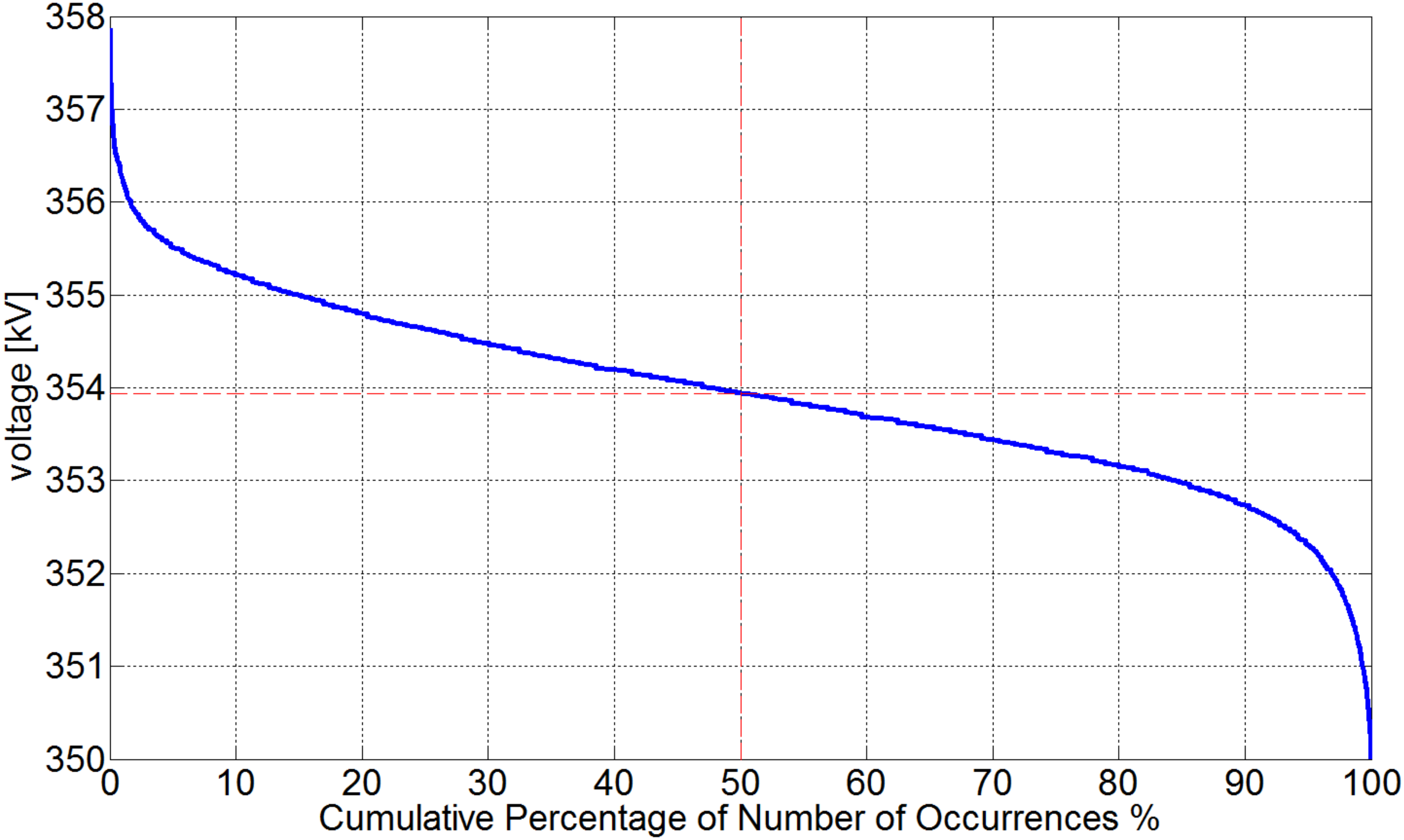
West 11



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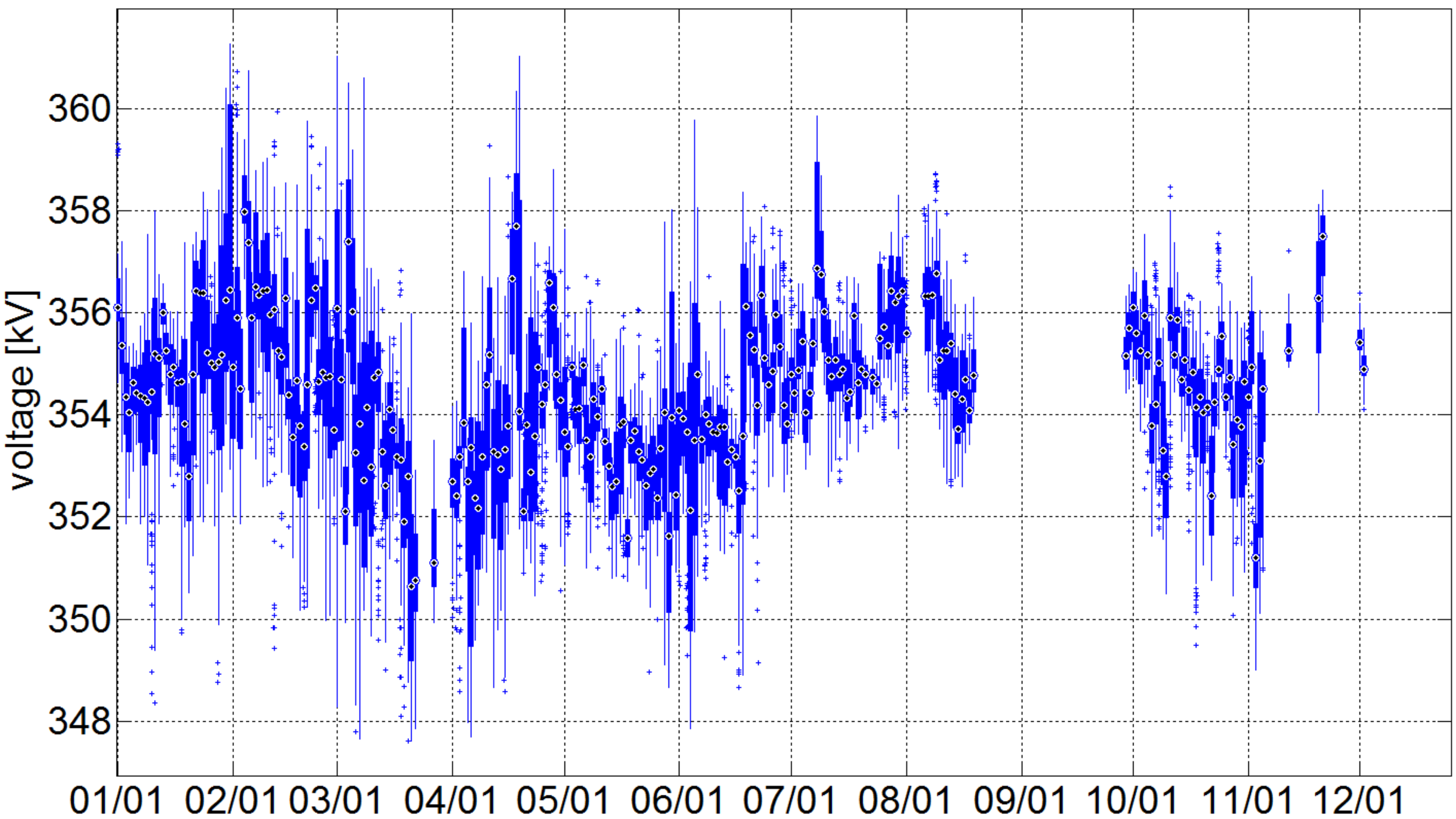
Cumulative Percentage of Number of Occurrences %

West 12



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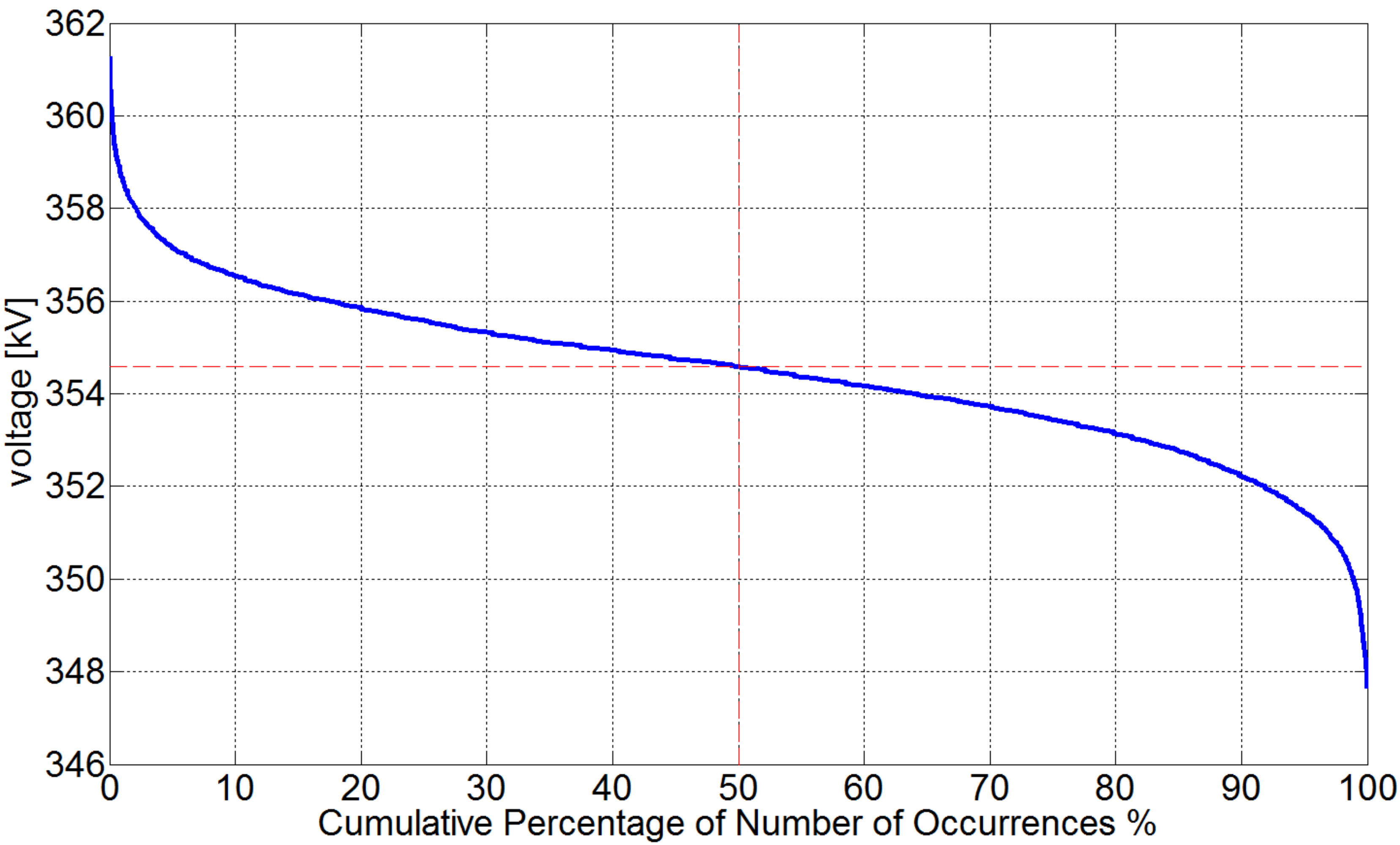
West 12



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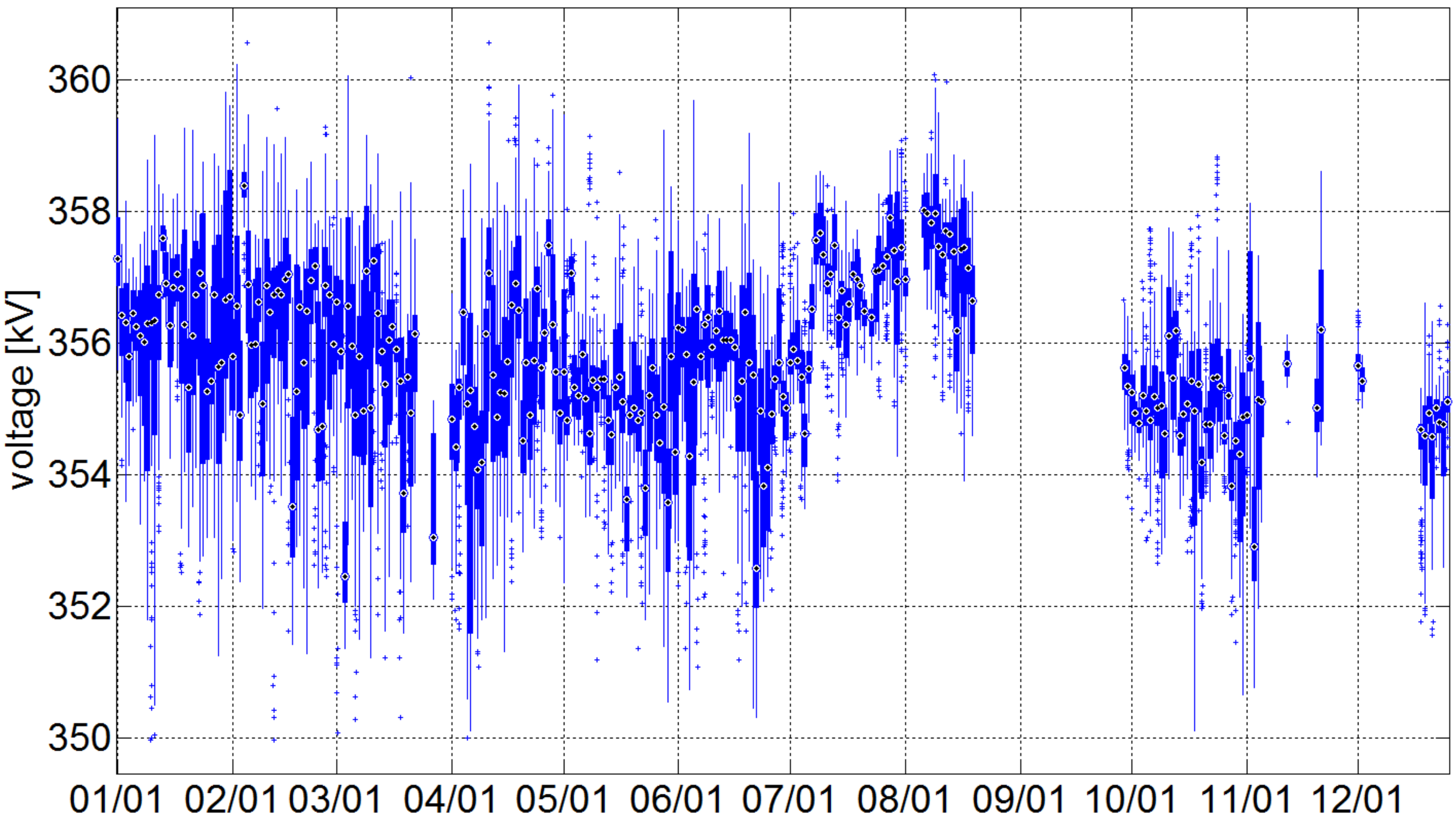
Cumulative Percentage of Number of Occurrences %

West 5



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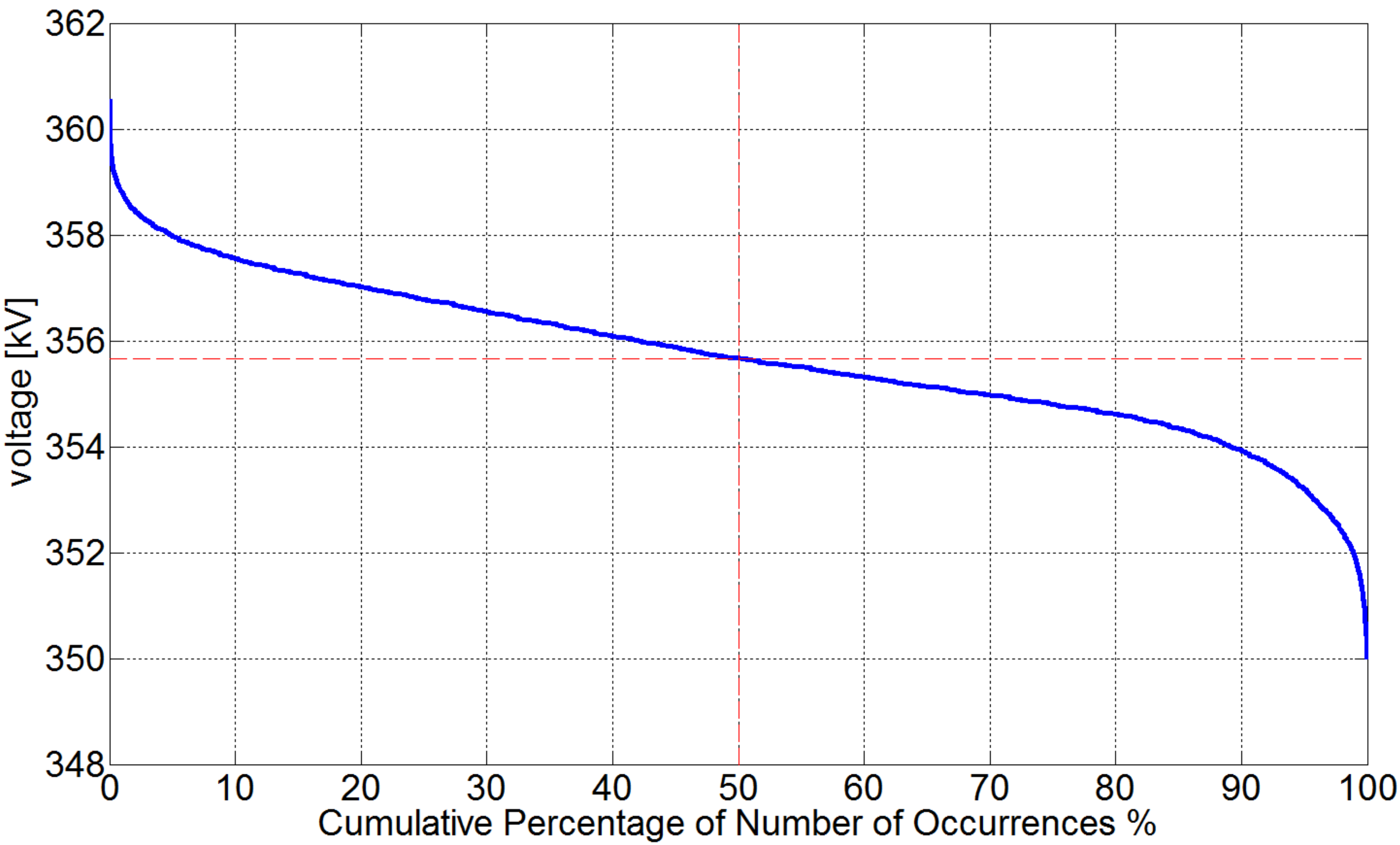
West 5



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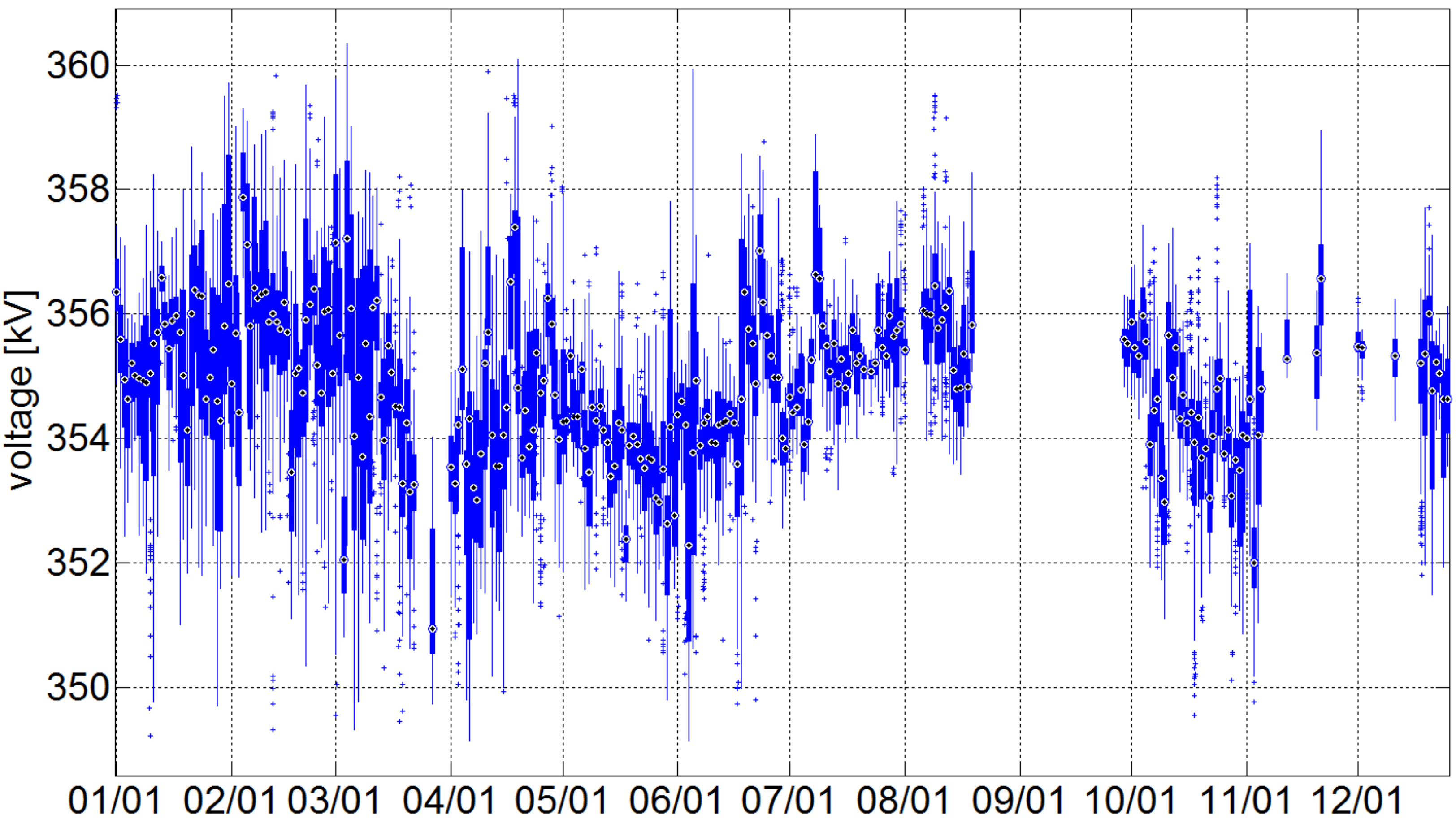
Cumulative Percentage of Number of Occurrences %

West 6



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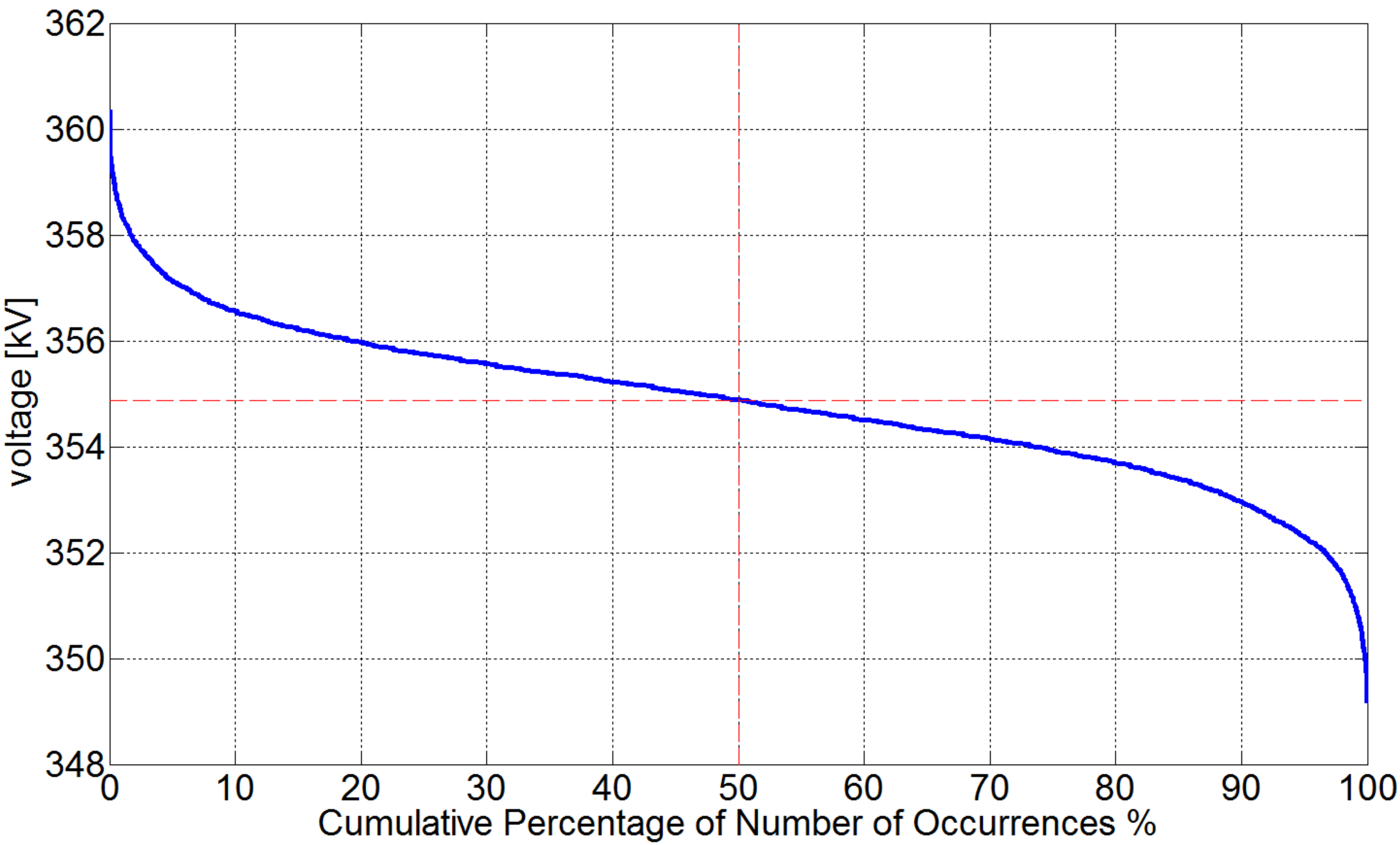
West 6



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voltage [kV]
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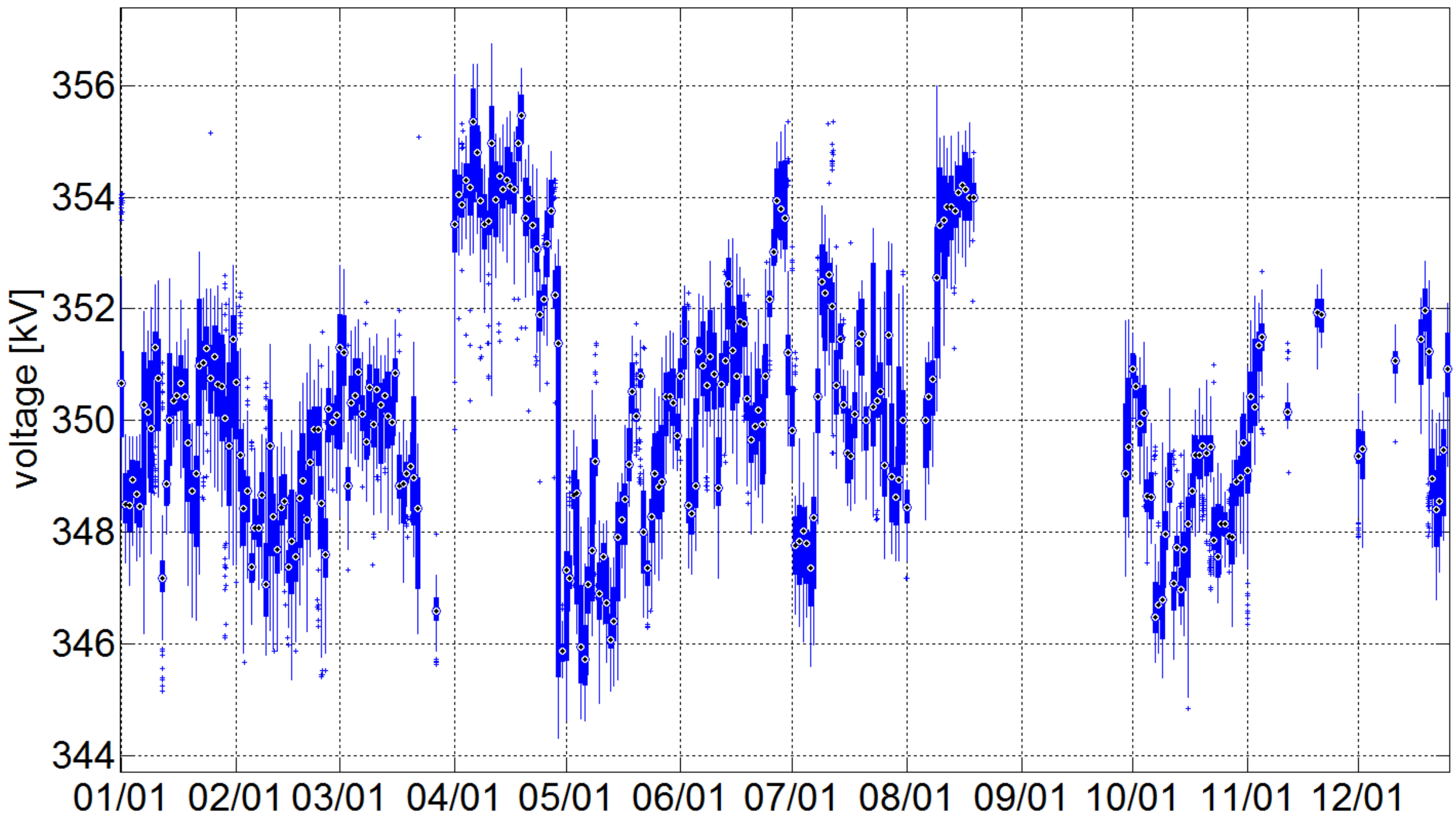
Cumulative Percentage of Number of Occurrences %

North 1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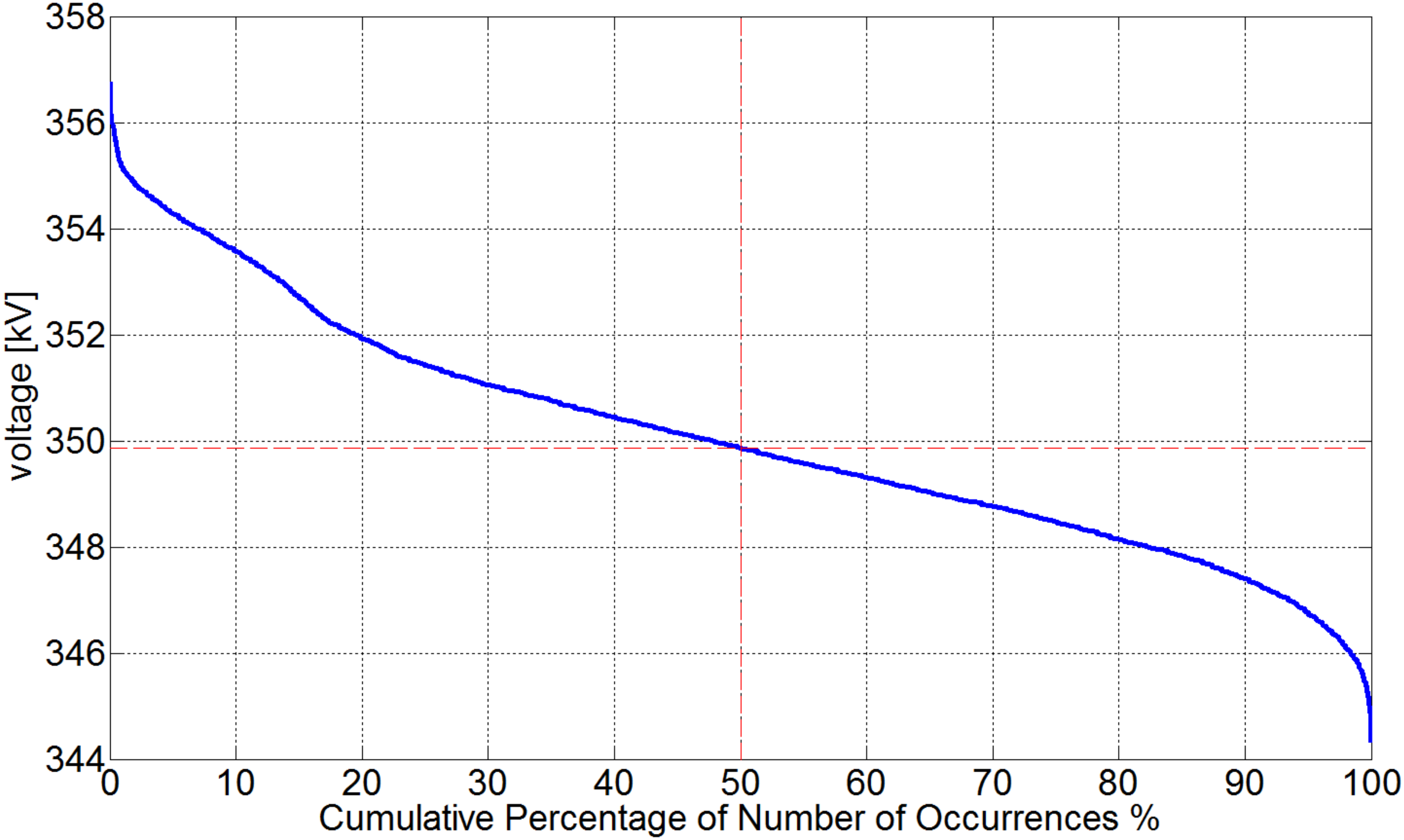
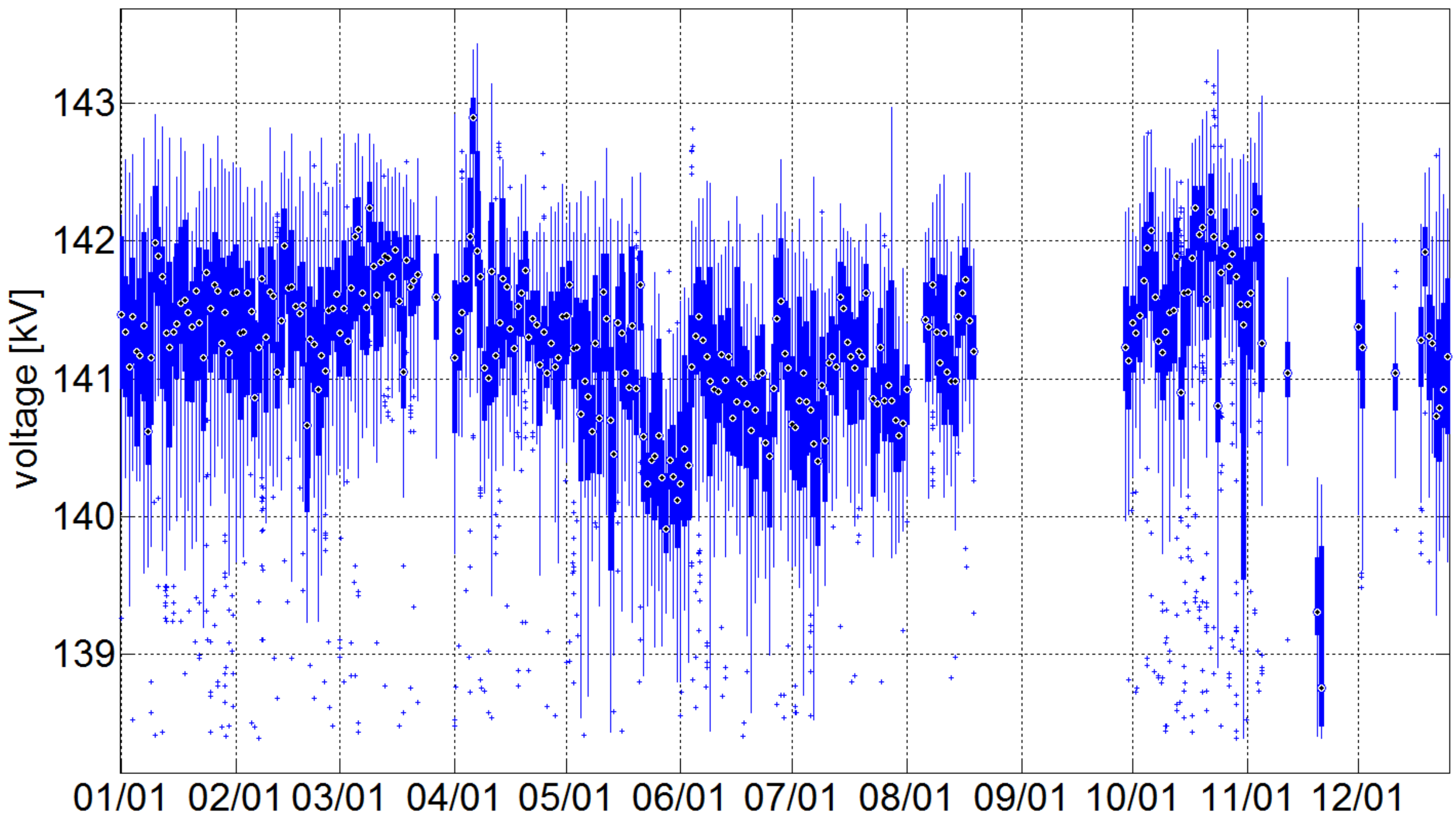
11/01
12/01

North 1



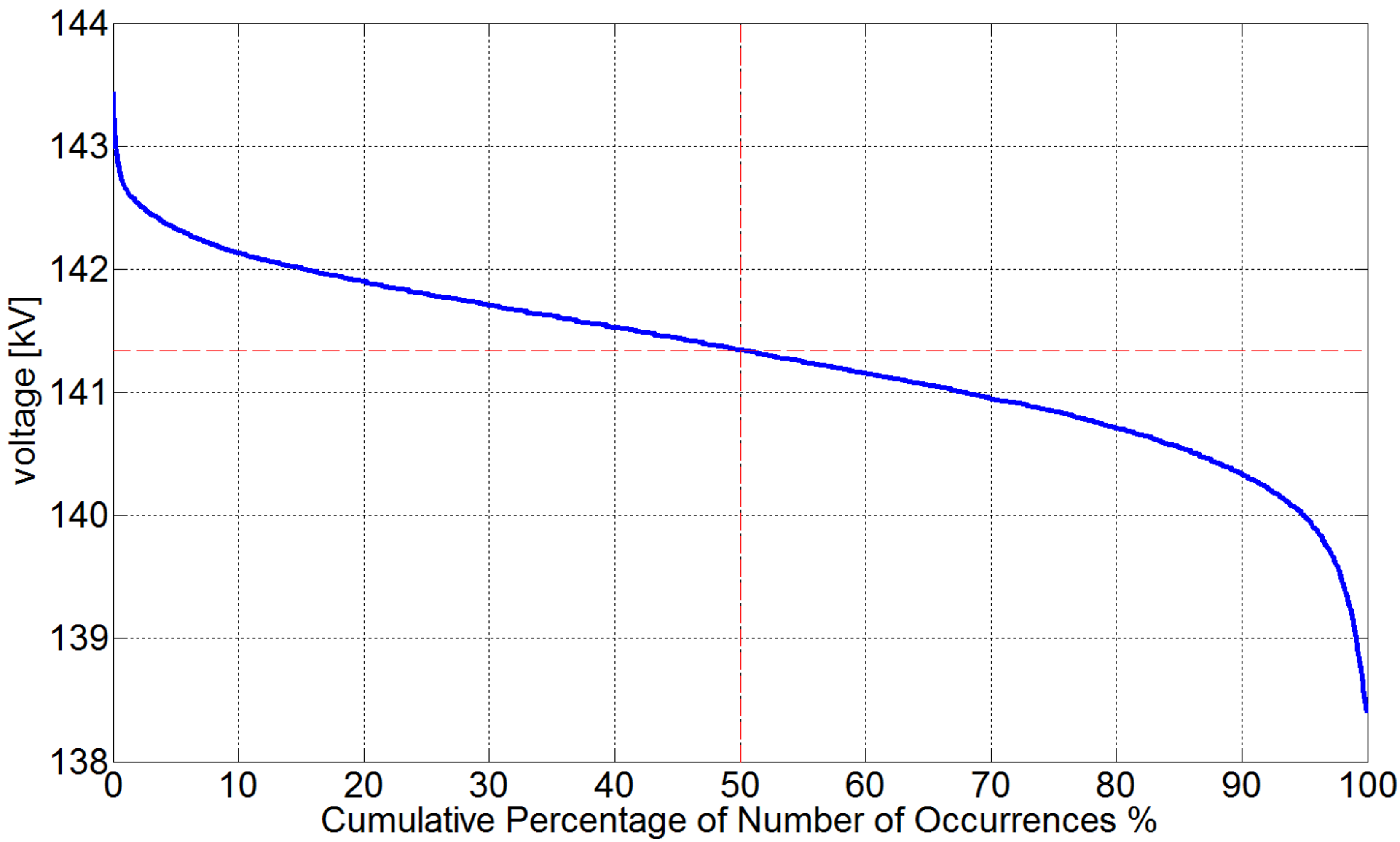
358
356
354
352
350
348
346
344
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

North 4



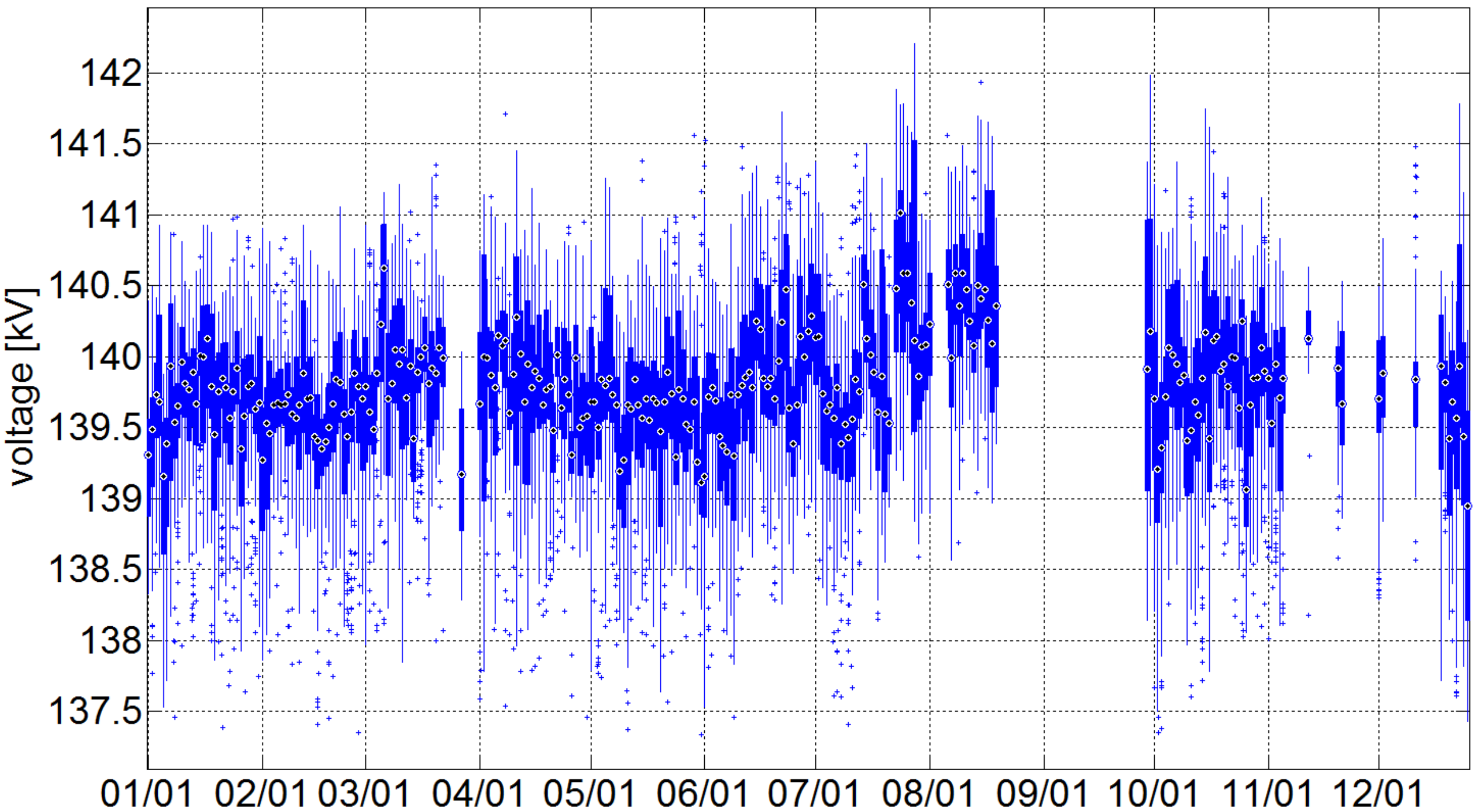
voltage [kV]
143
142
141
140
139
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

North 4



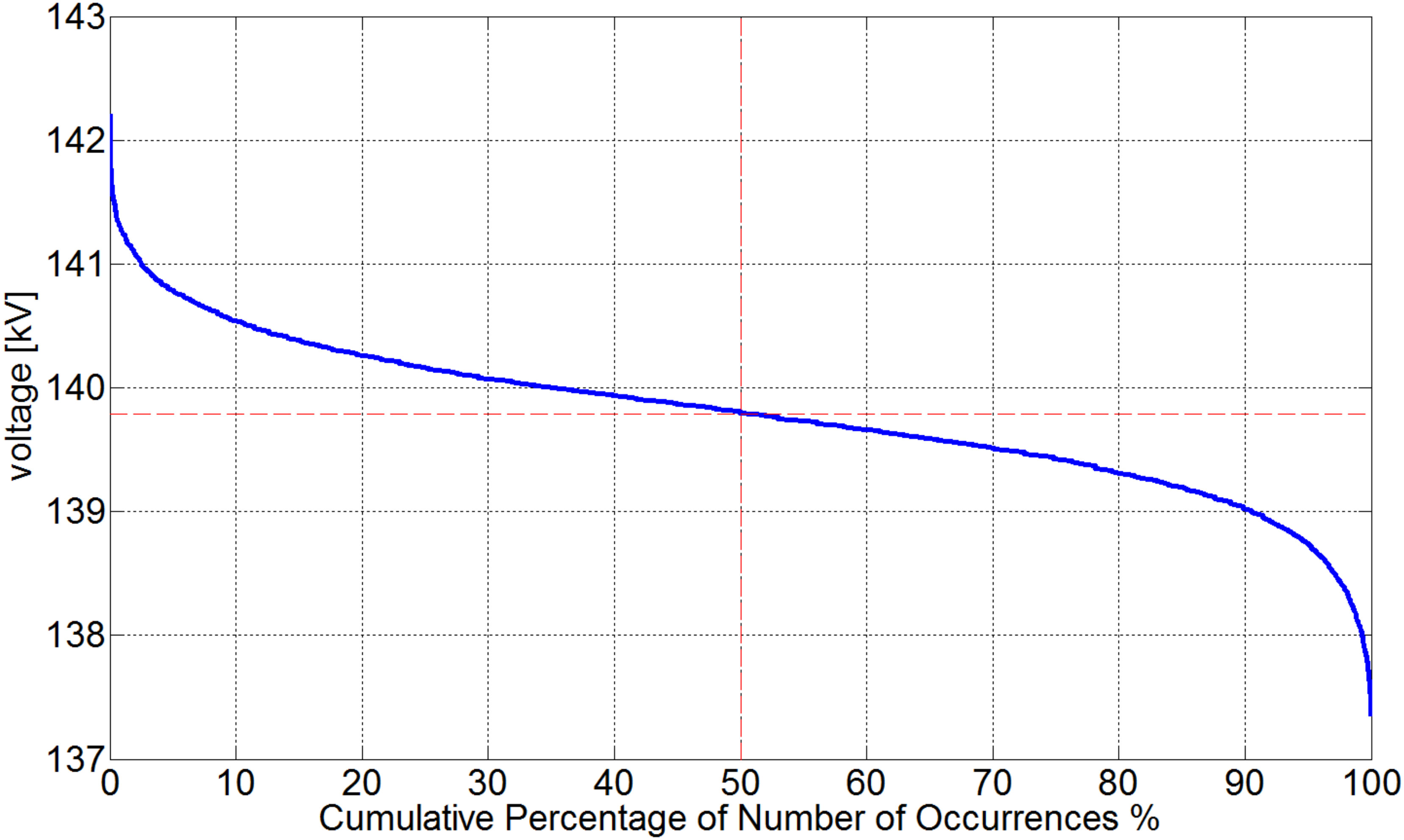
144
143
142
141
140
139
138
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

North 5

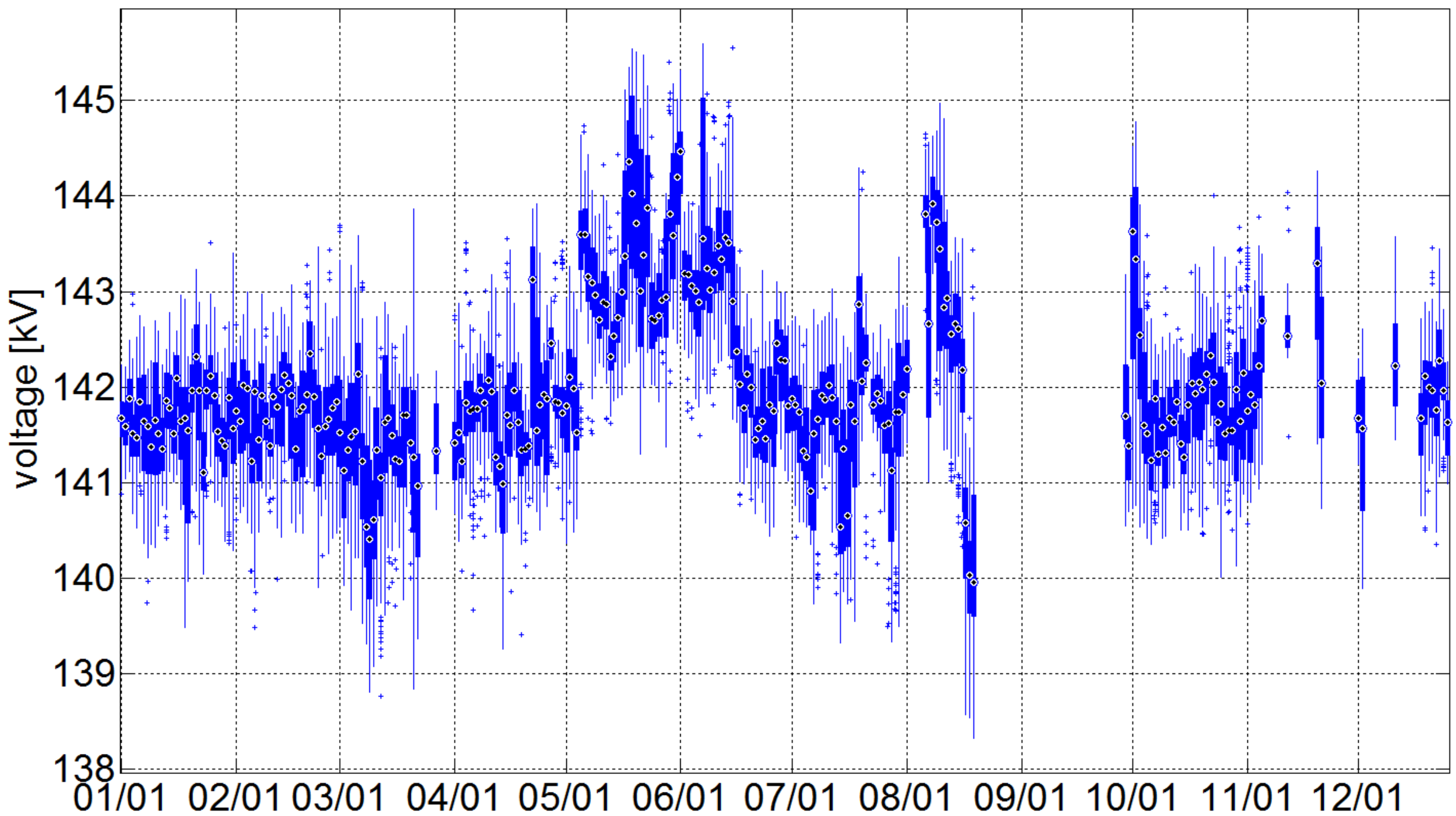


voltage [kV]
142
141.5
141
140.5
140
139.5
139
138.5
138
137.5
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

North 5

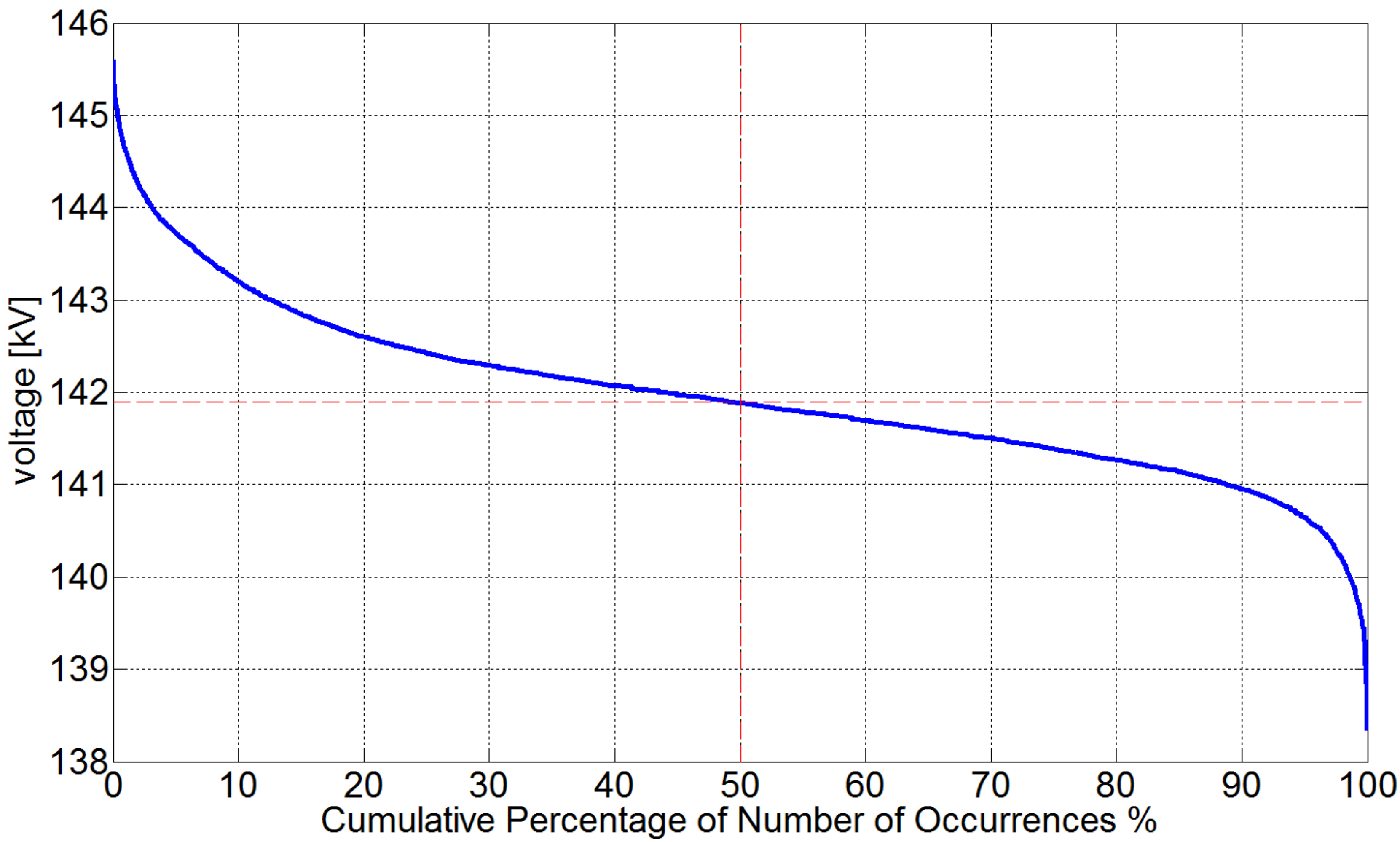

143
142
141
140
139
138
137
0
10
20
30
40
50
60
70
80
90
100
voltage [kV]
Cumulative Percentage of Number of Occurrences %

North 6

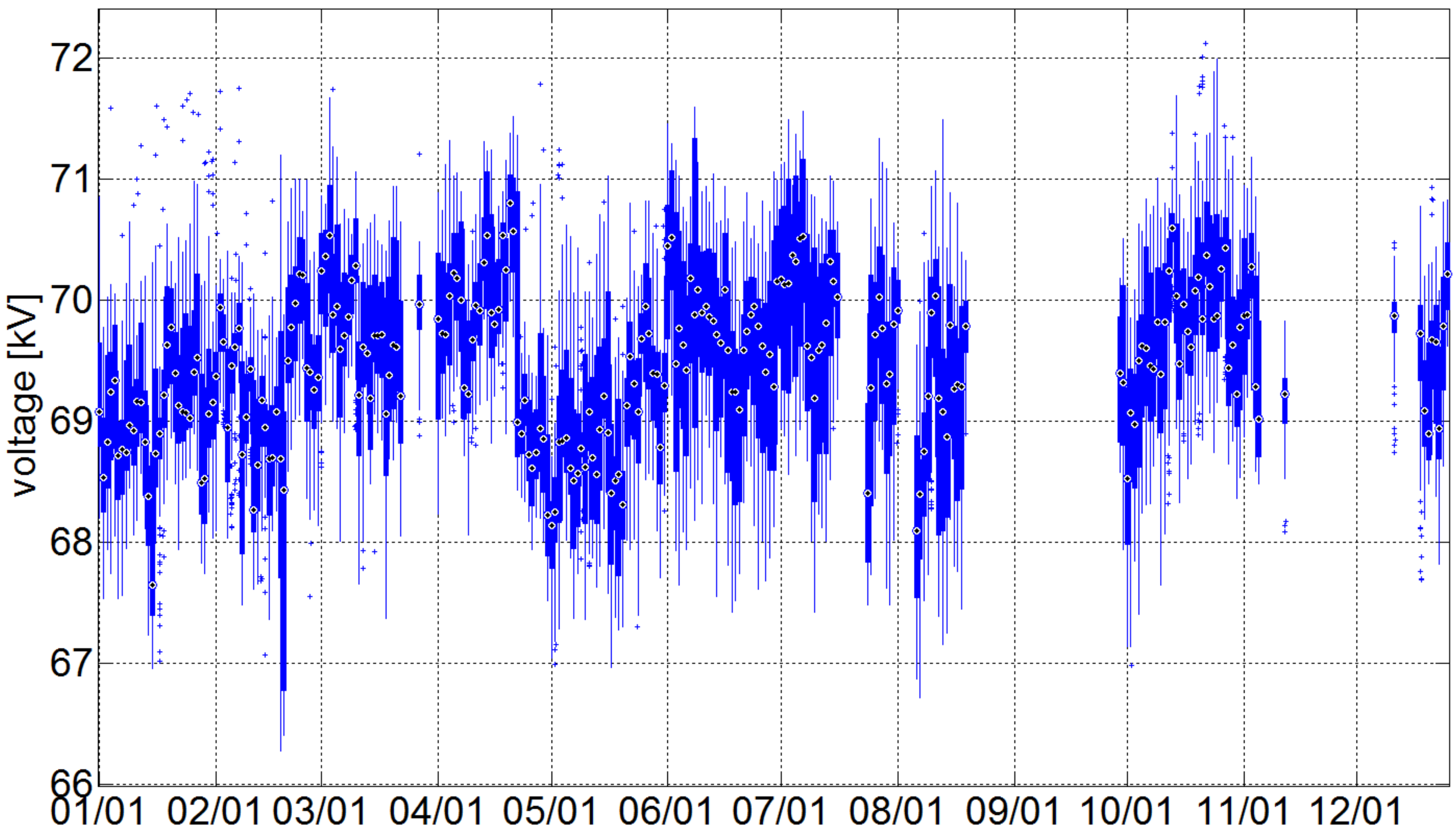


voltage [kV]
145
144
143
142
141
140
139
138
01/01 02/01 03/01 04/01 05/01 06/01 07/01 08/01 09/01 10/01 11/01 12/01

North 6

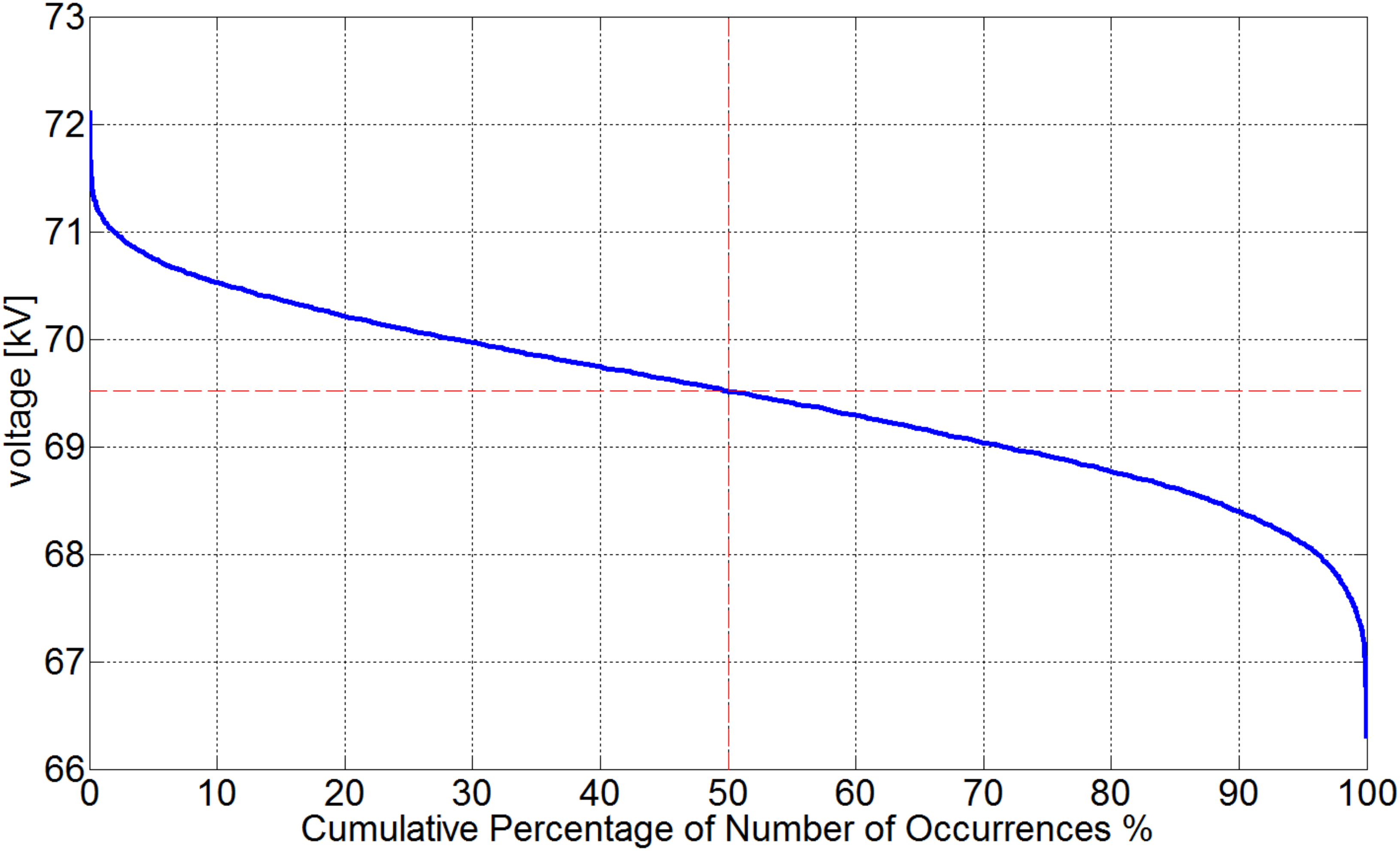

146
145
144
143
142
141
140
139
138
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

FarWest 2



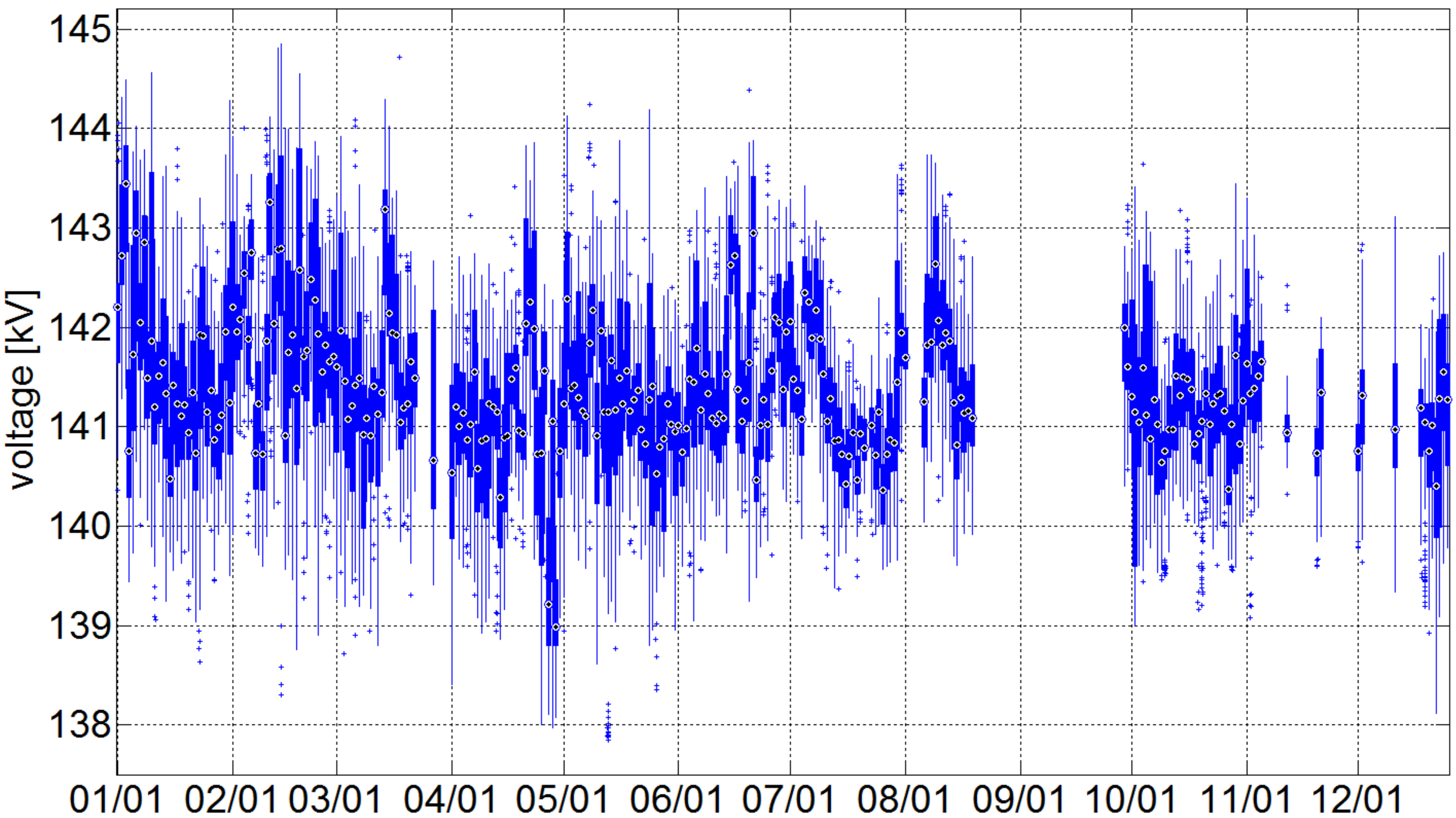
voltage [kV]
72
71
70
69
68
67
66
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

FarWest 2



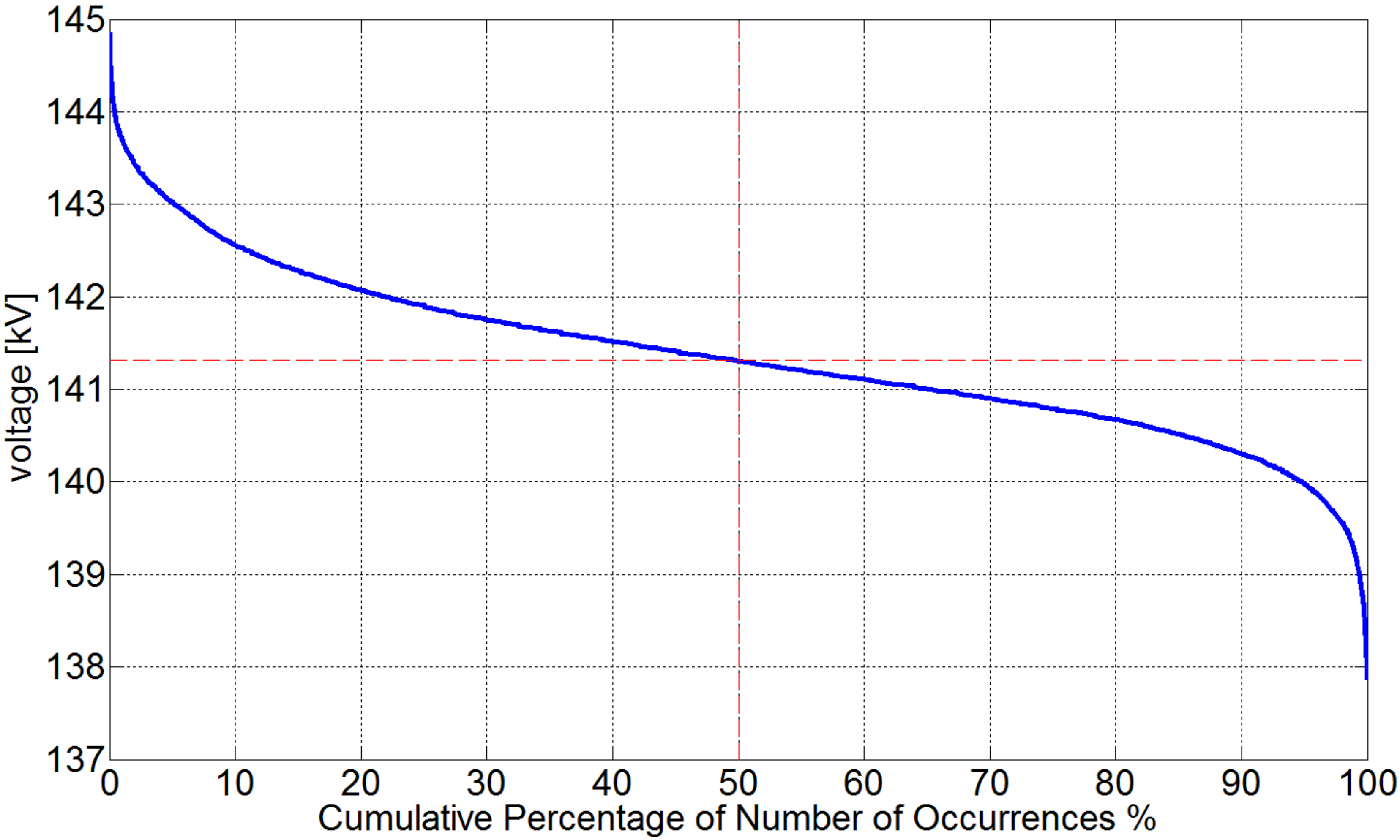
73
72
71
70
69
68
67
66
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

North 7



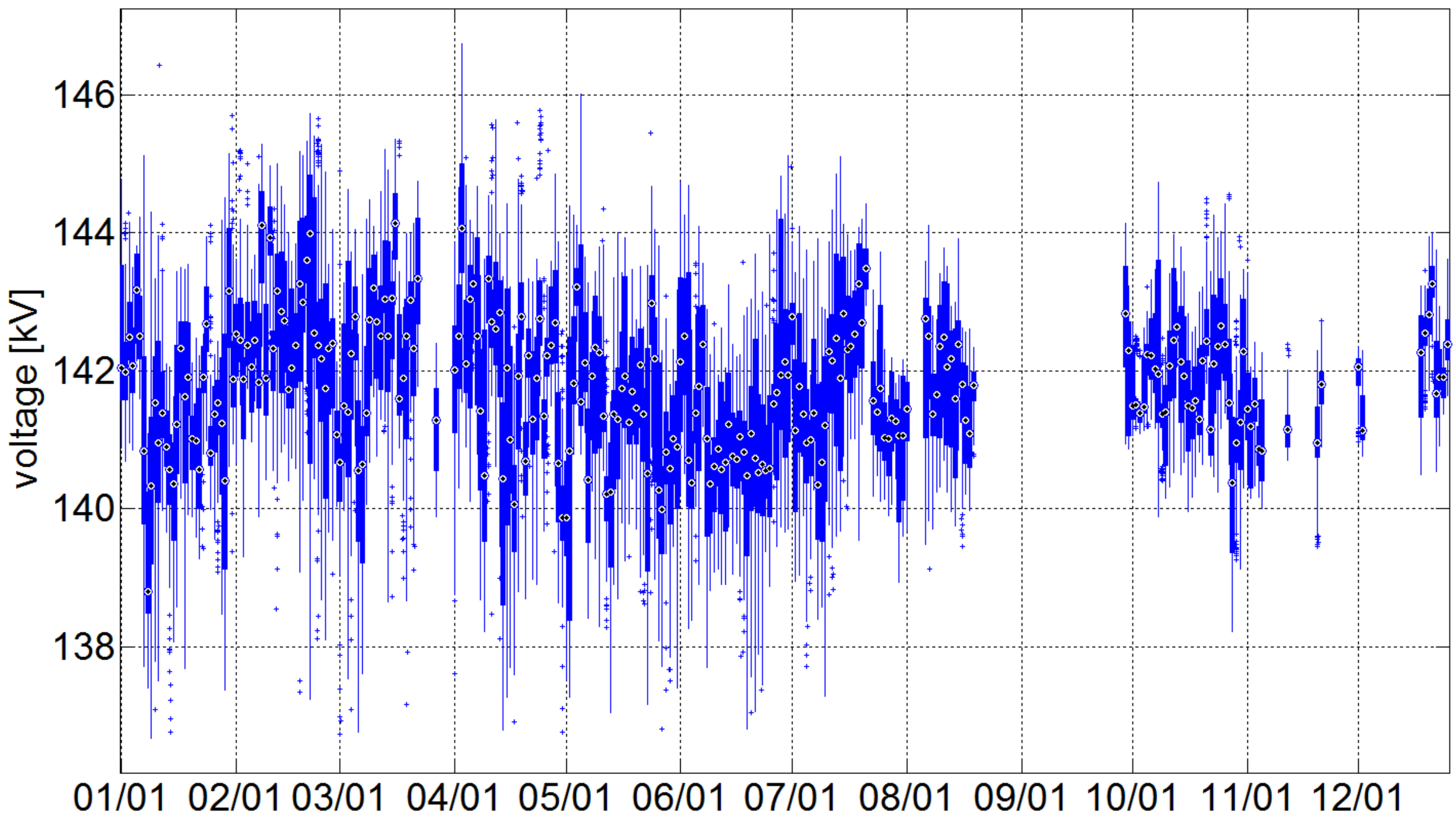
voltage [kV]
145
144
143
142
141
140
139
138
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

North 7



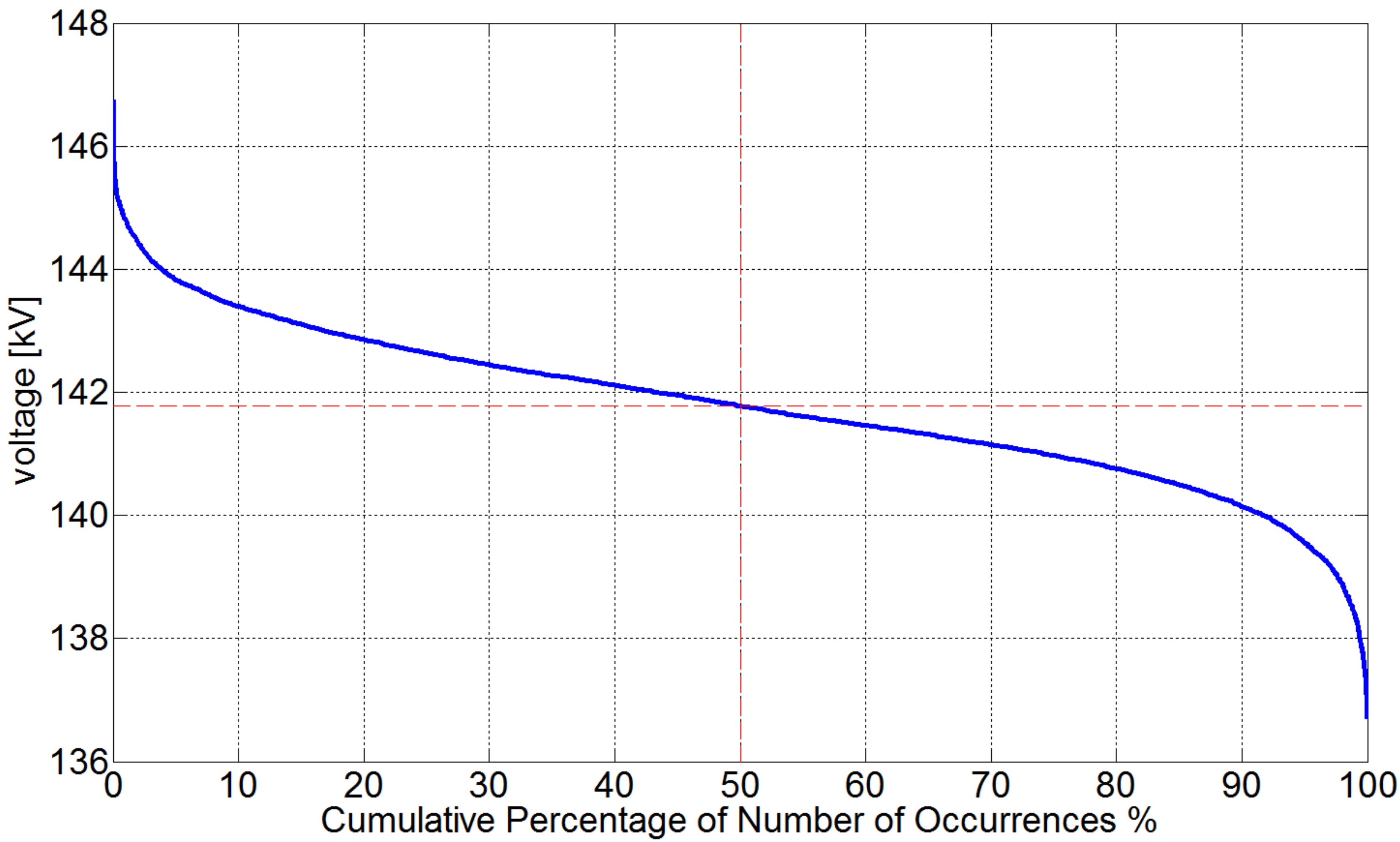
145
144
143
142
141
140
139
138
137
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

West 4



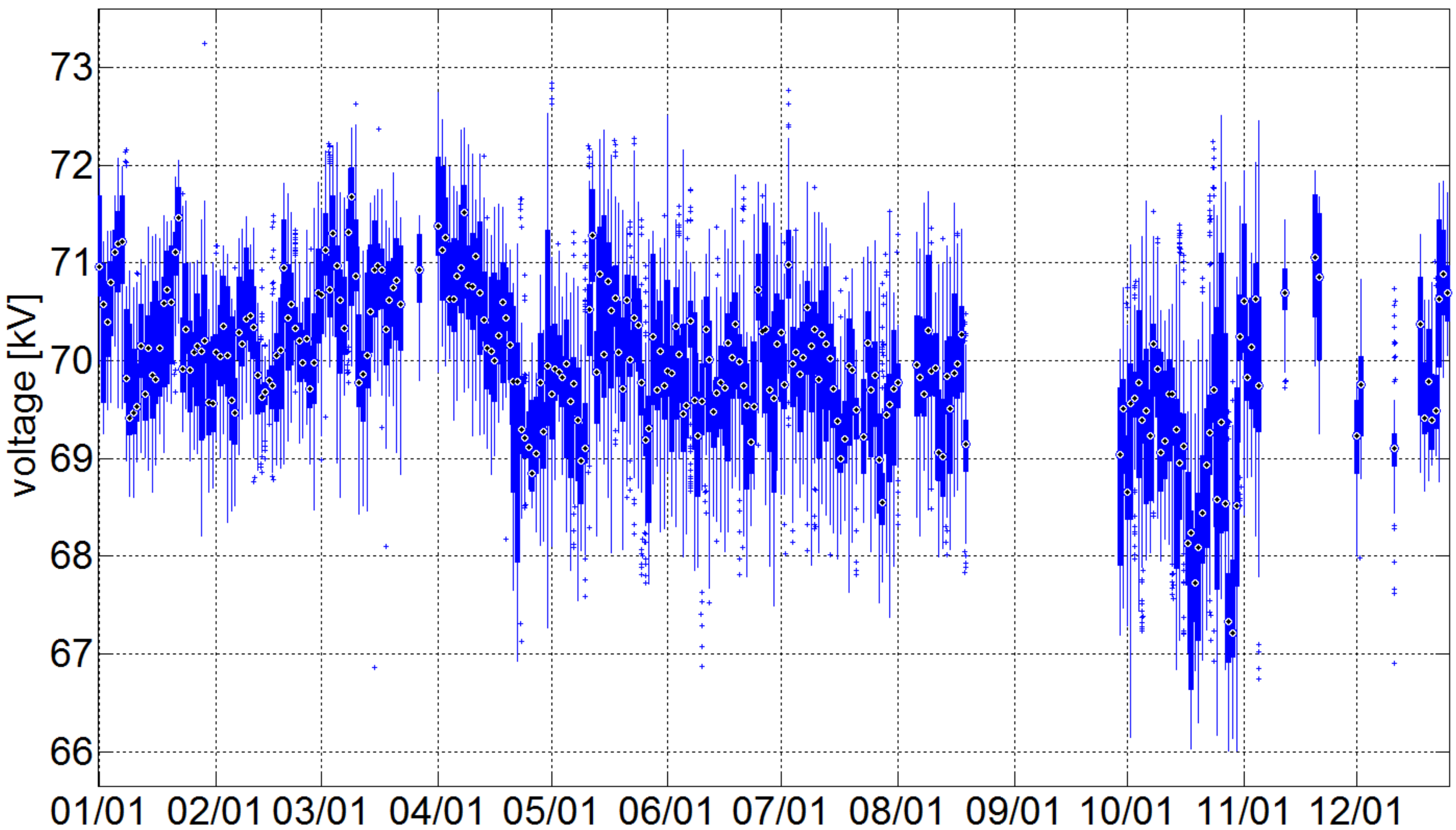
146
144
142
140
138
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

West 4



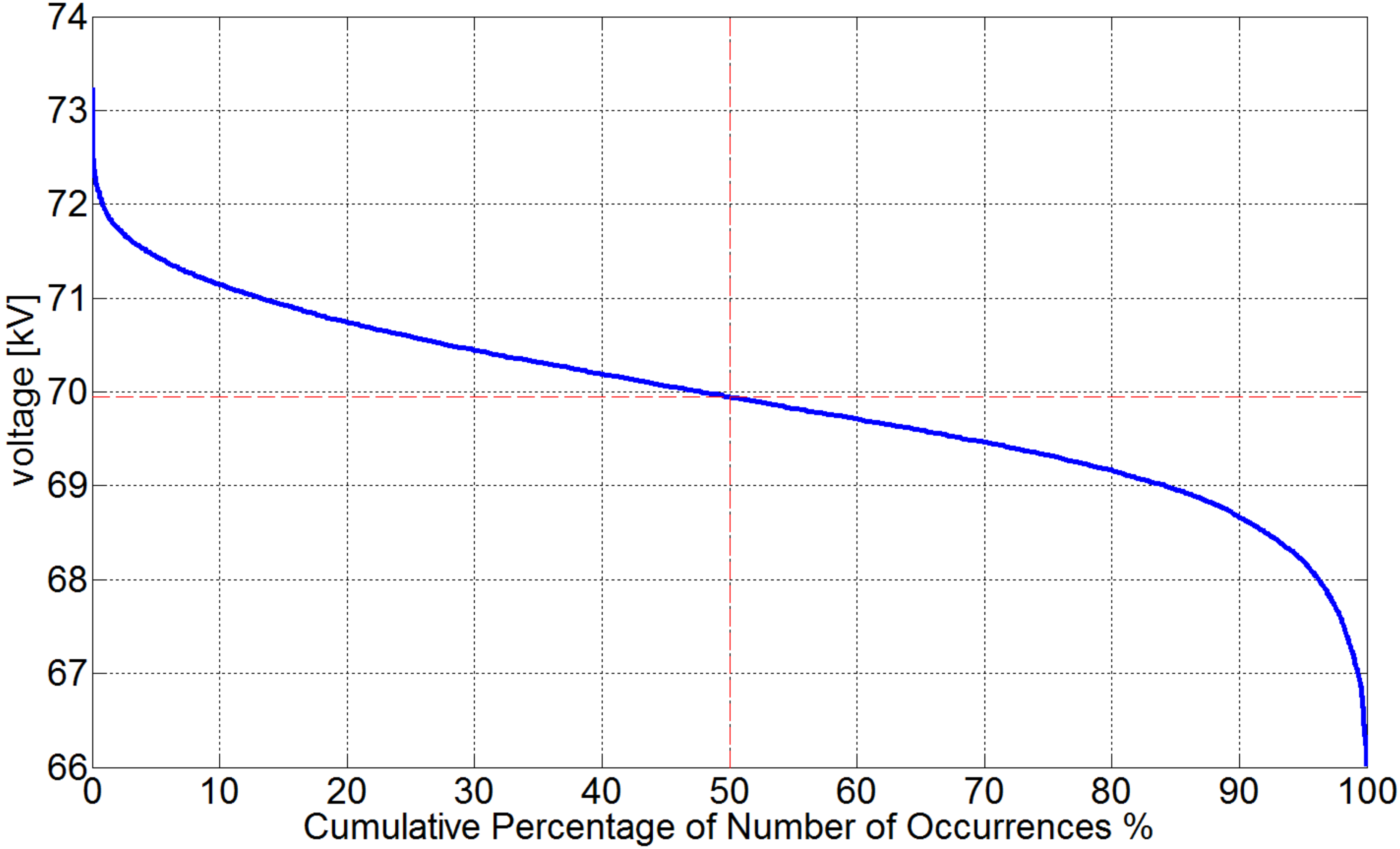
148
146
144
142
140
138
136
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

Coast 2

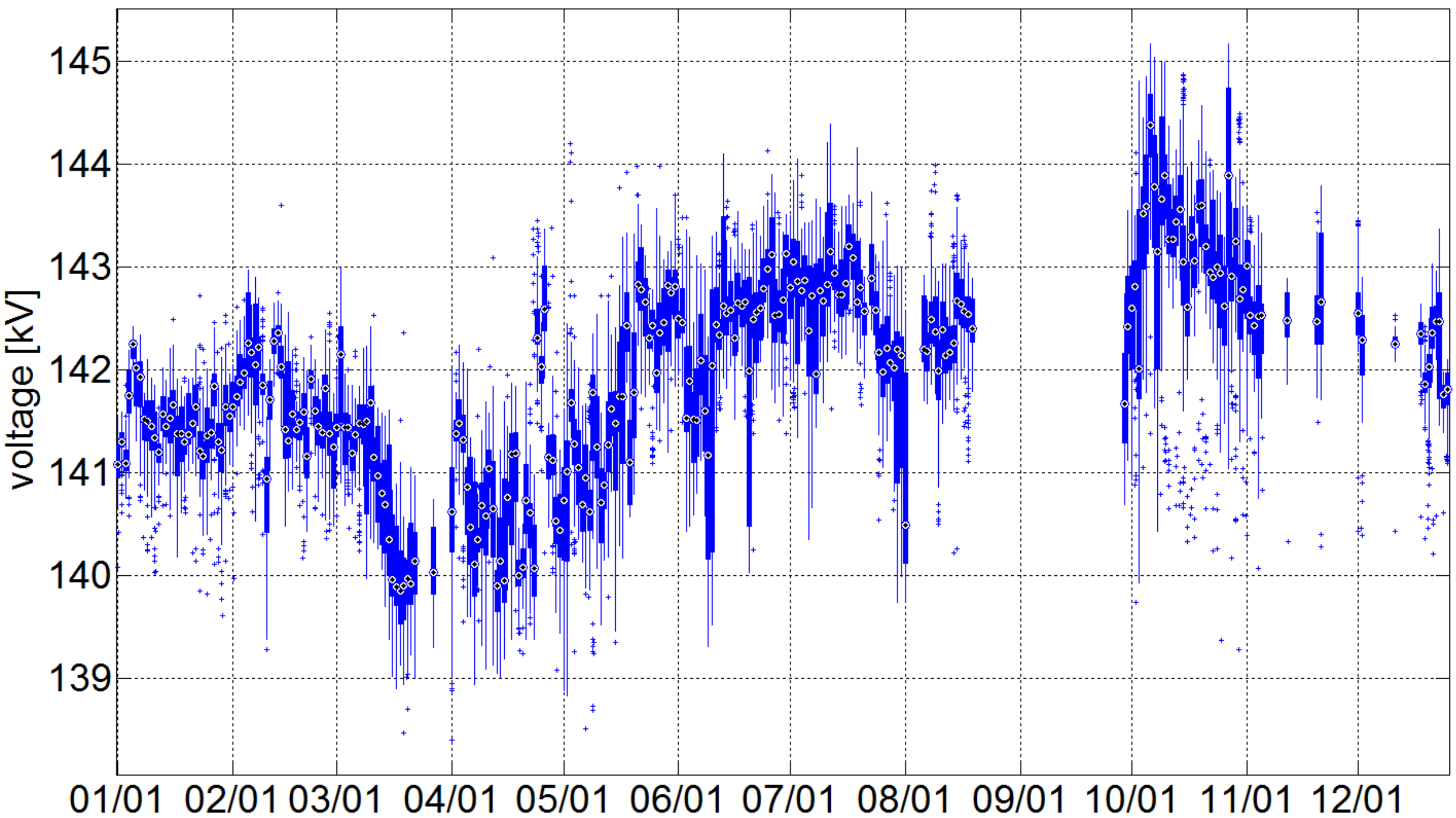


voltage [kV]
73
72
71
70
69
68
67
66
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

Coast 2

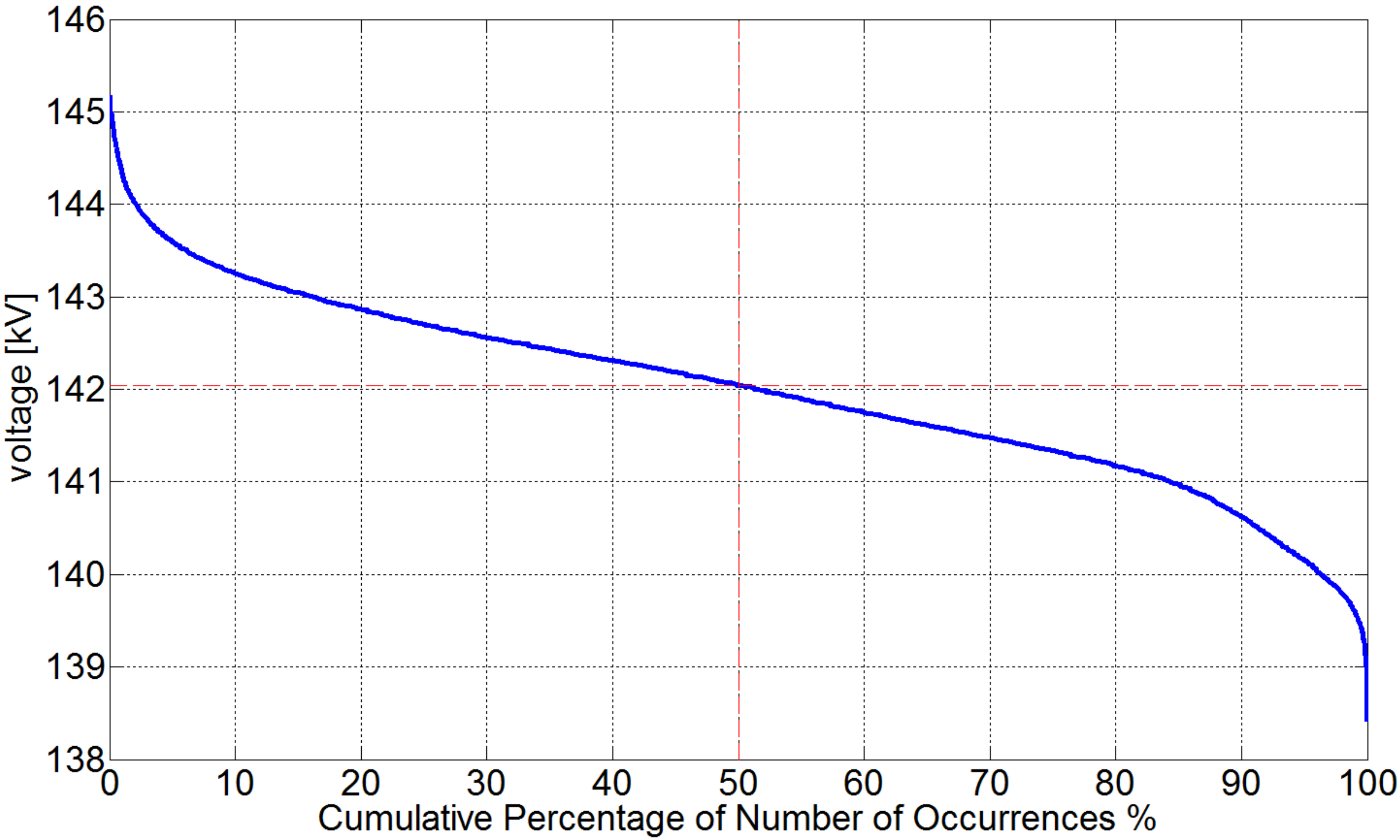

74
73
72
71
70
69
68
67
66
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

Coast 1



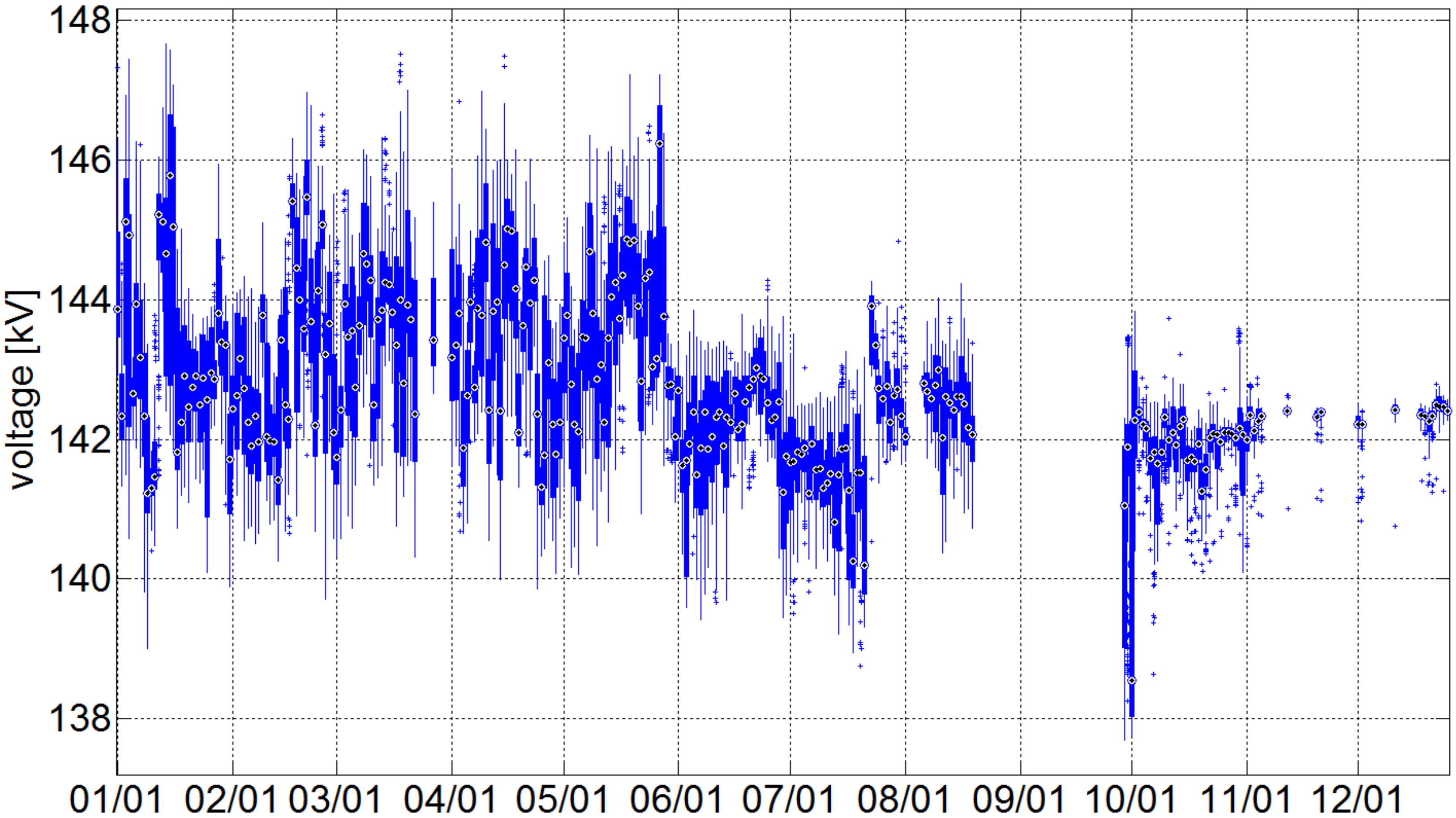
voltage [kV]
145
144
143
142
141
140
139
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

Coast 1



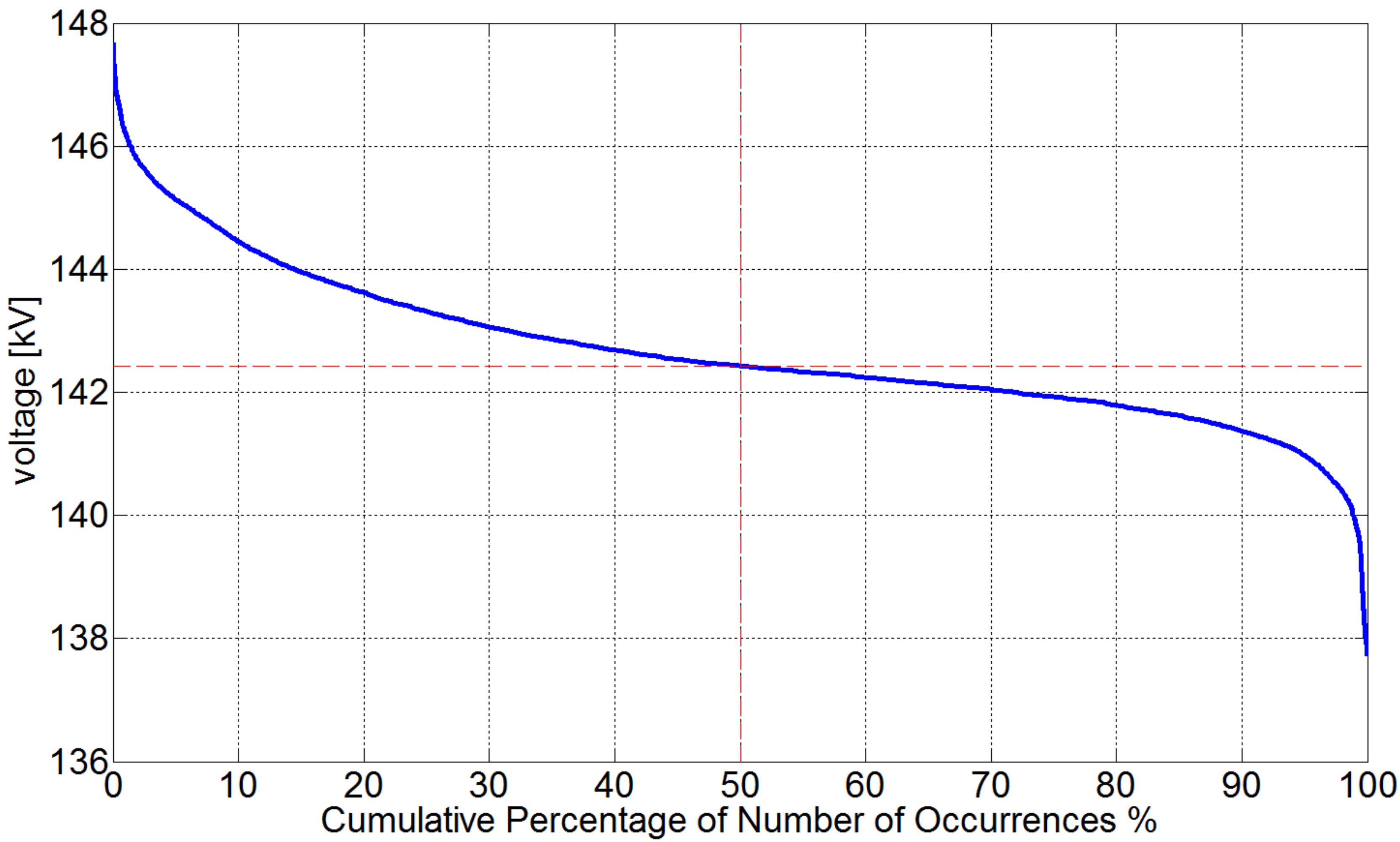
146
145
144
143
142
141
140
139
138
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 3



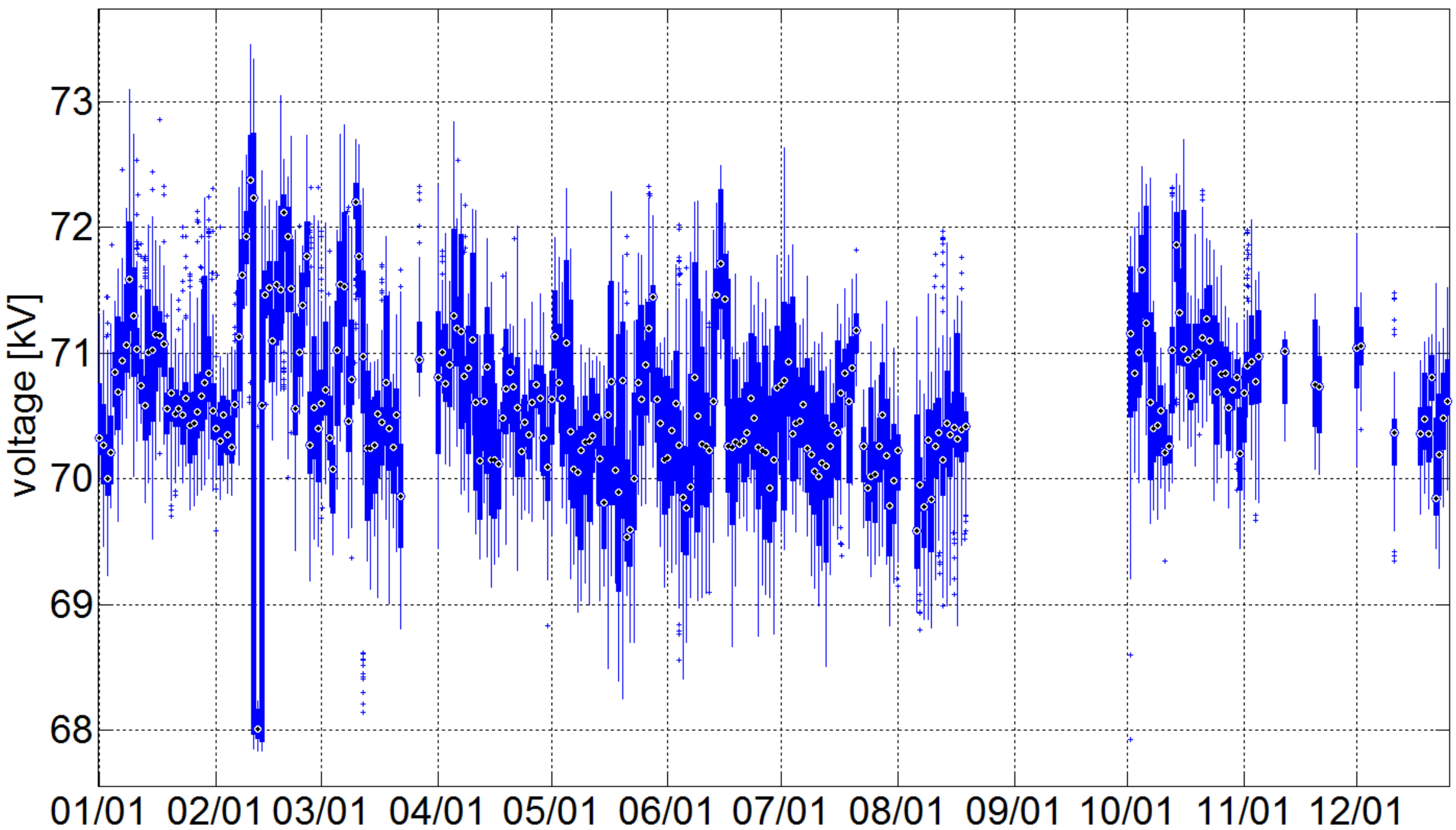
148
146
144
142
140
138
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

South 3



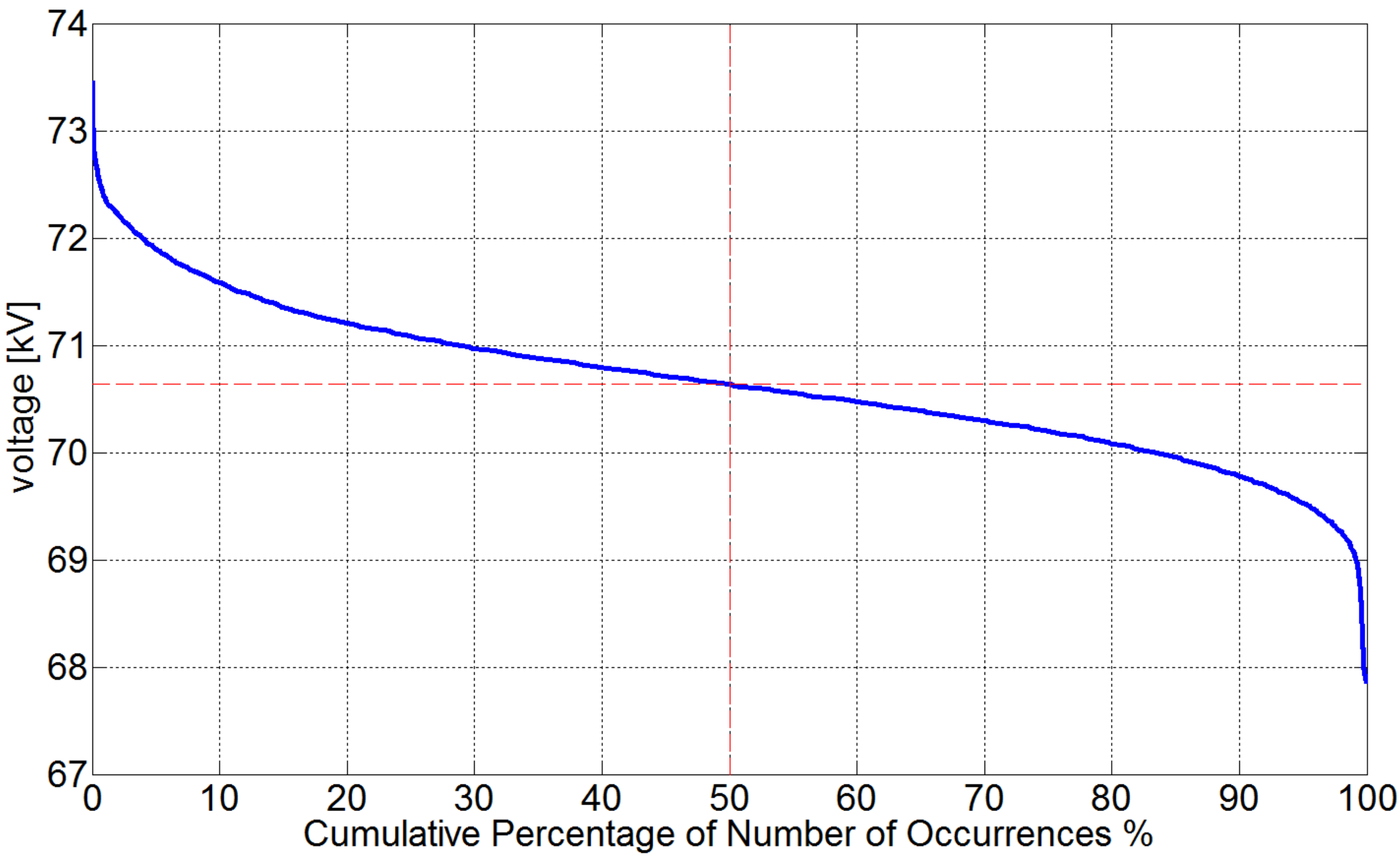
148
146
144
142
140
138
136
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 5



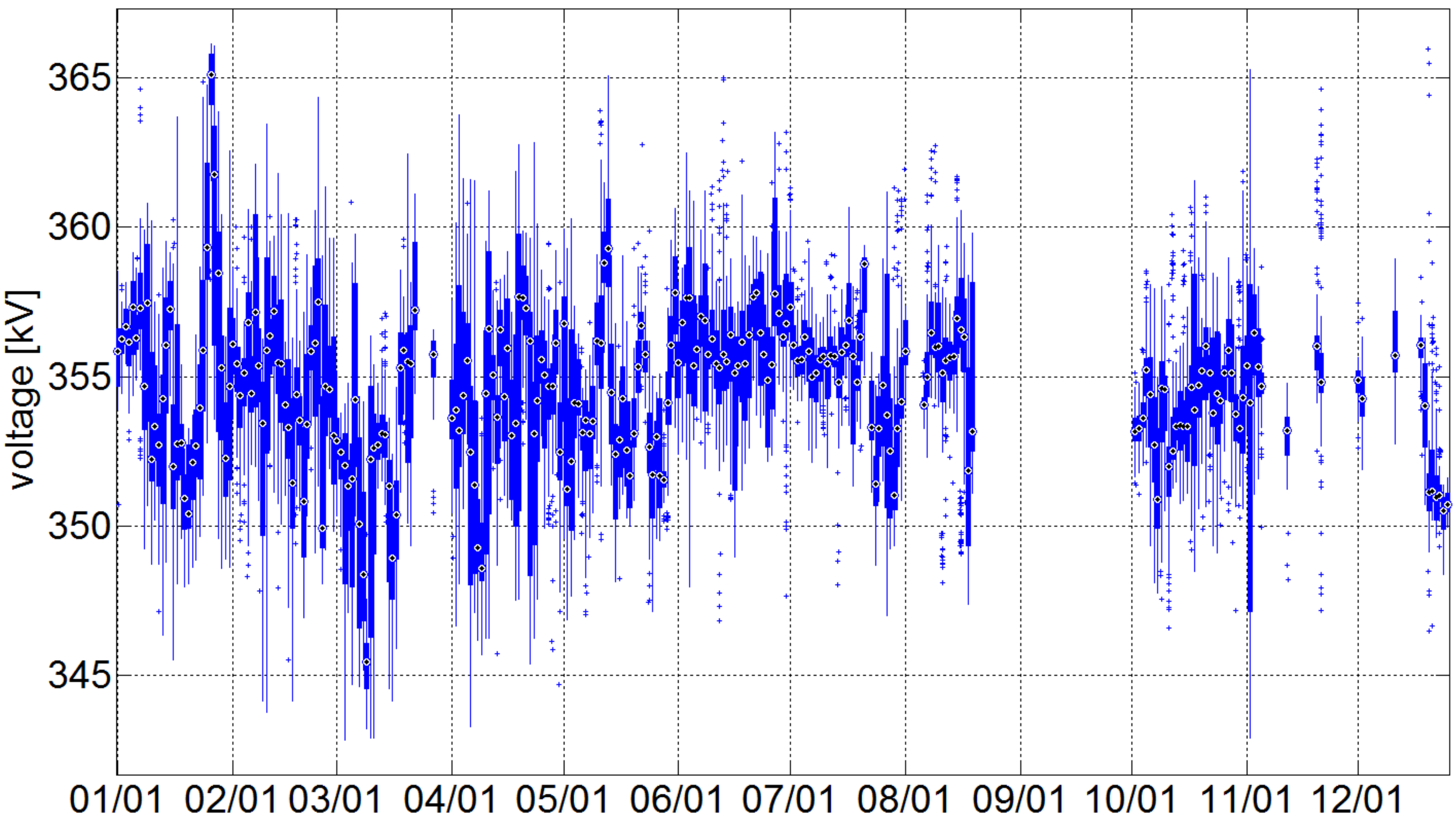
voltage [kV]
73
72
71
70
69
68
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

South 5



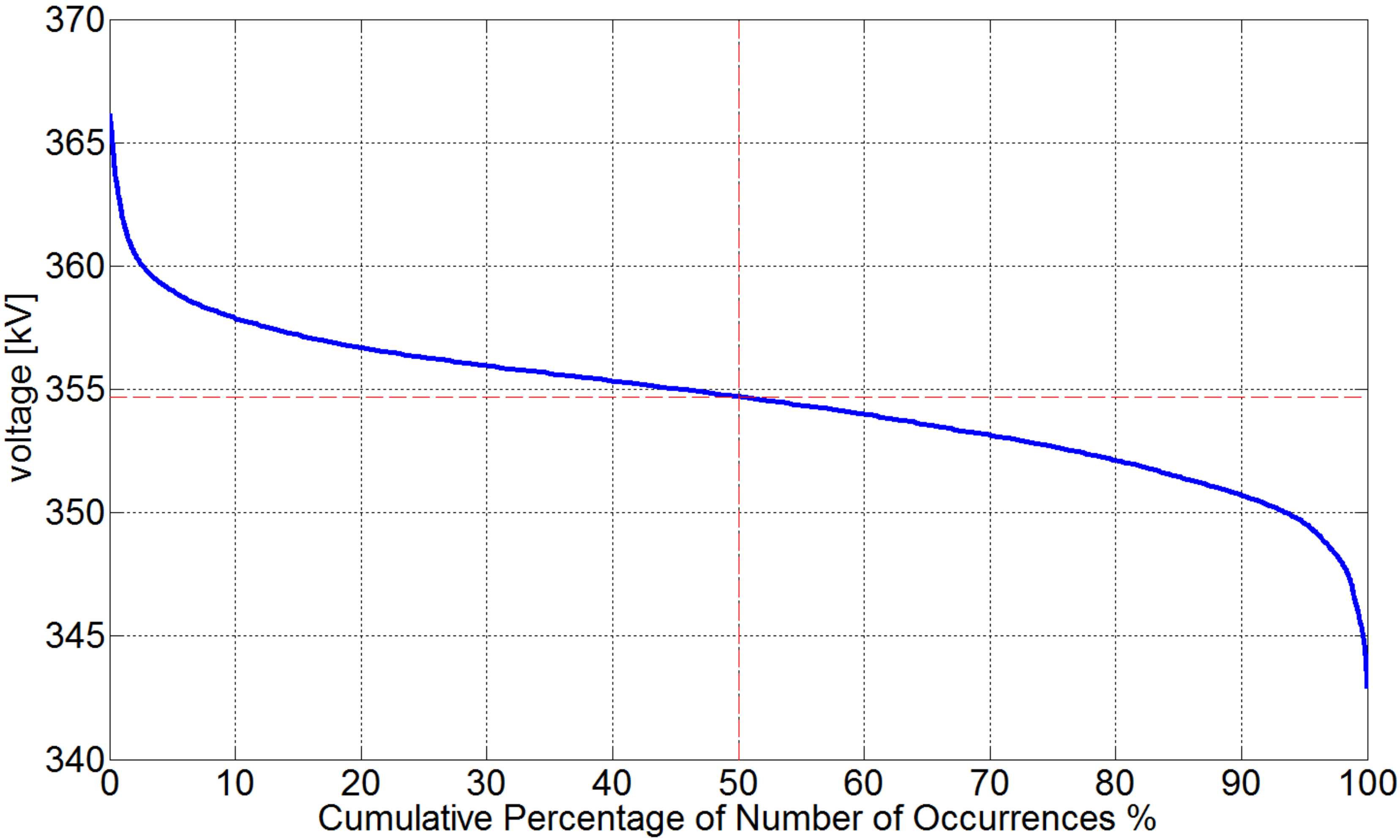
74
73
72
71
70
69
68
67
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

Coast 4



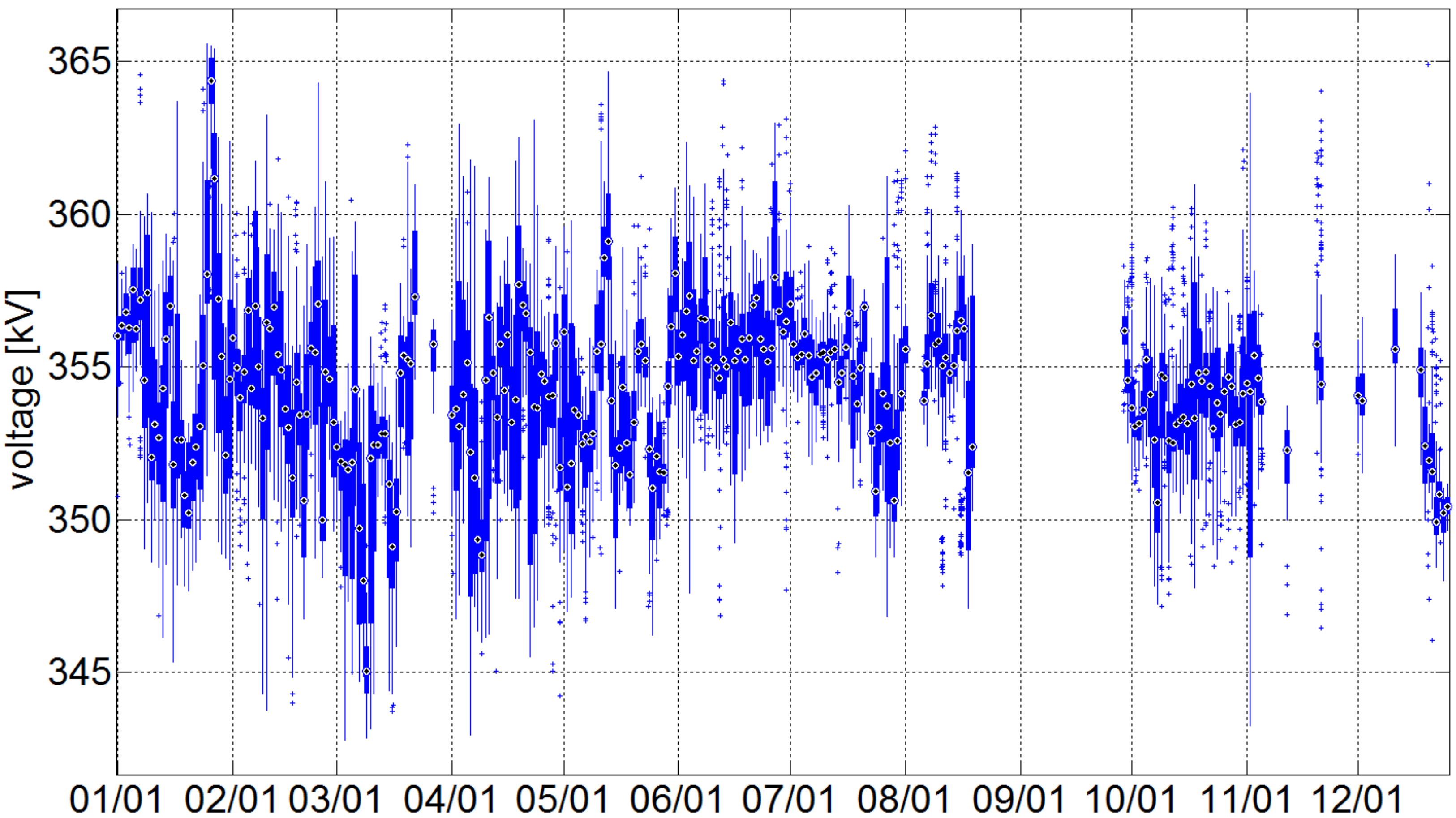
365
360
355
350
345
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

Coast 4

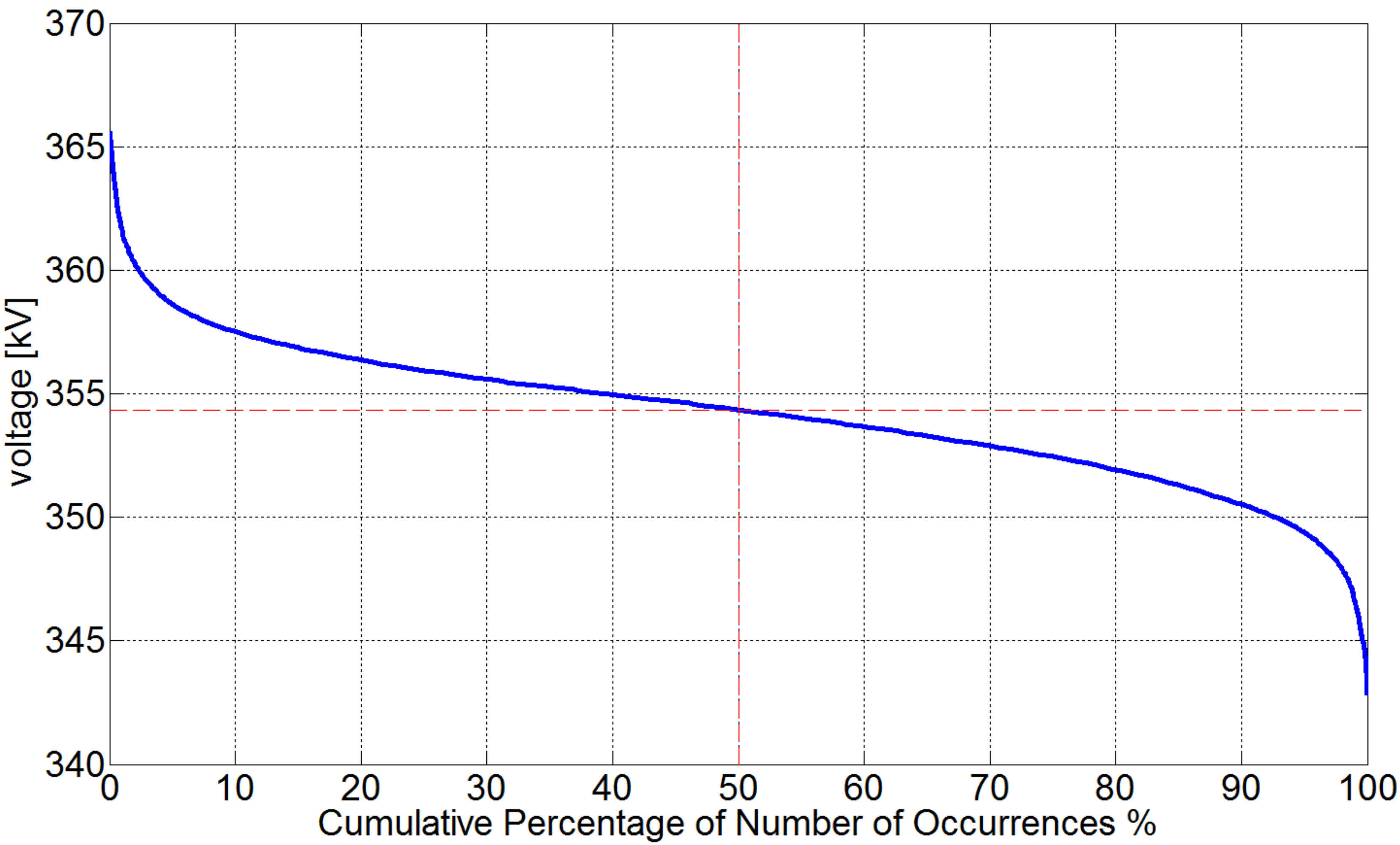


370
365
360
355
350
345
340
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

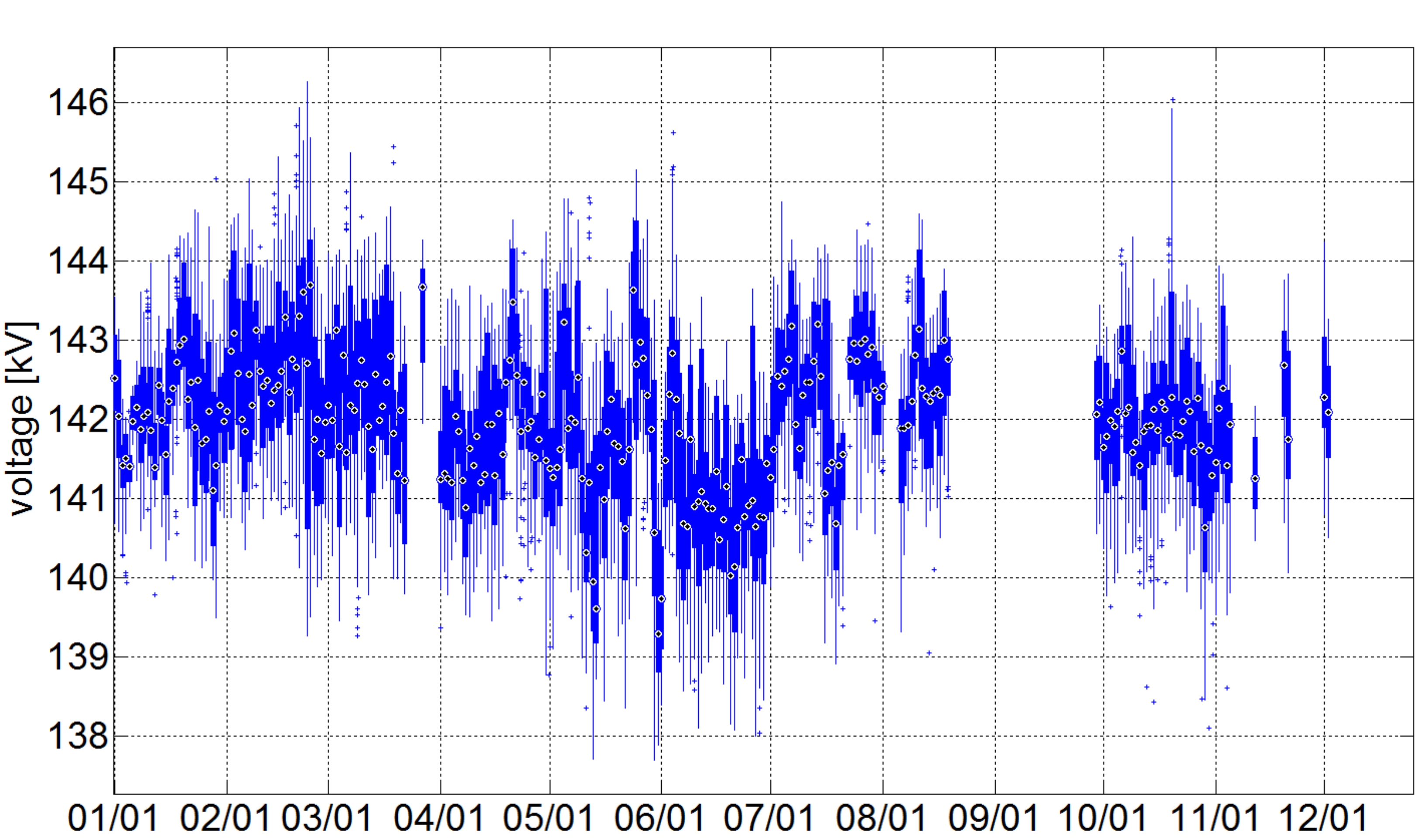
Coast 3


voltage [kV]
365
360
355
350
345
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

Coast 3

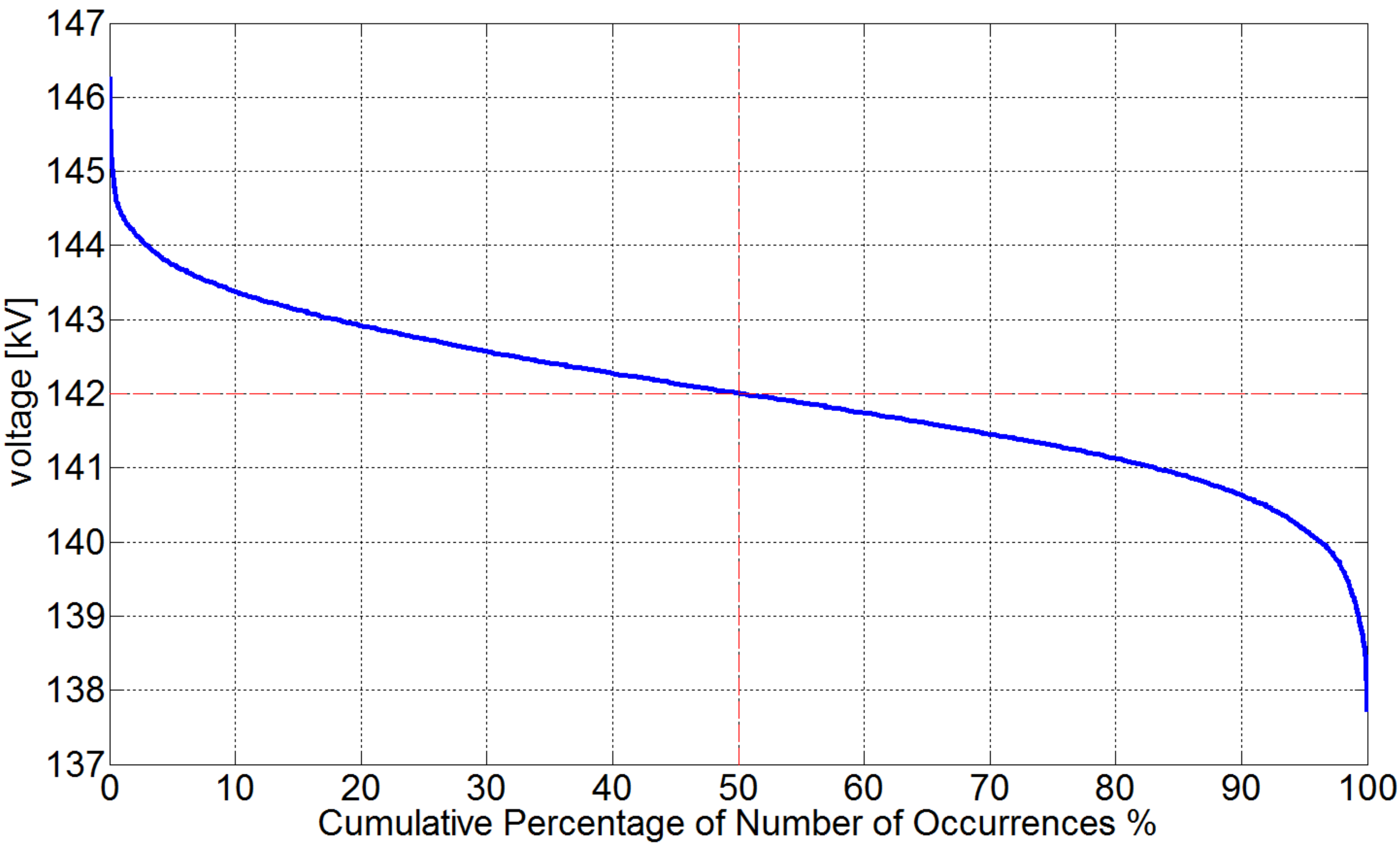

370
365
360
355
350
345
340
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 13

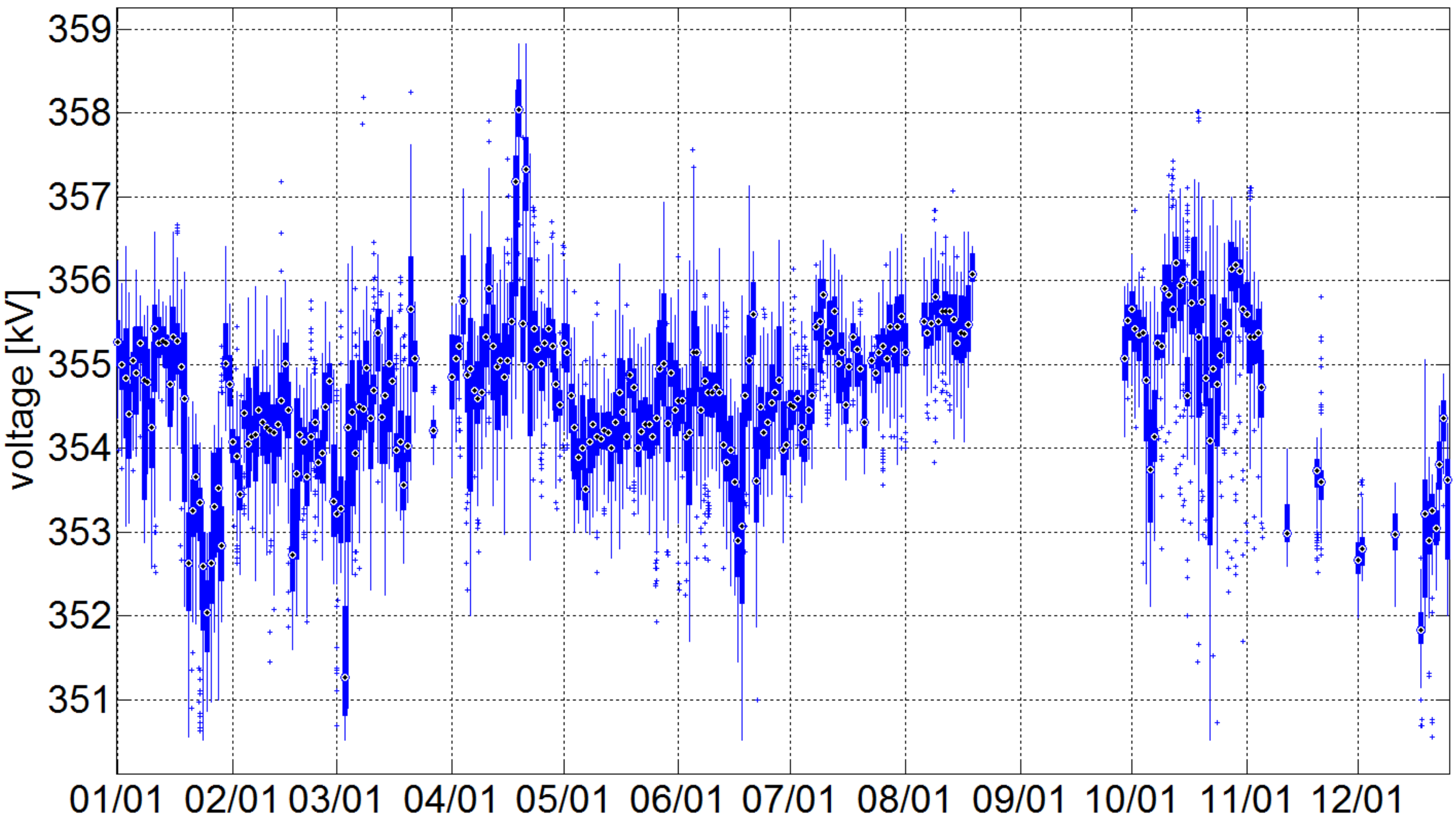


voltage [kV]
146
145
144
143
142
141
140
139
138
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

South 13

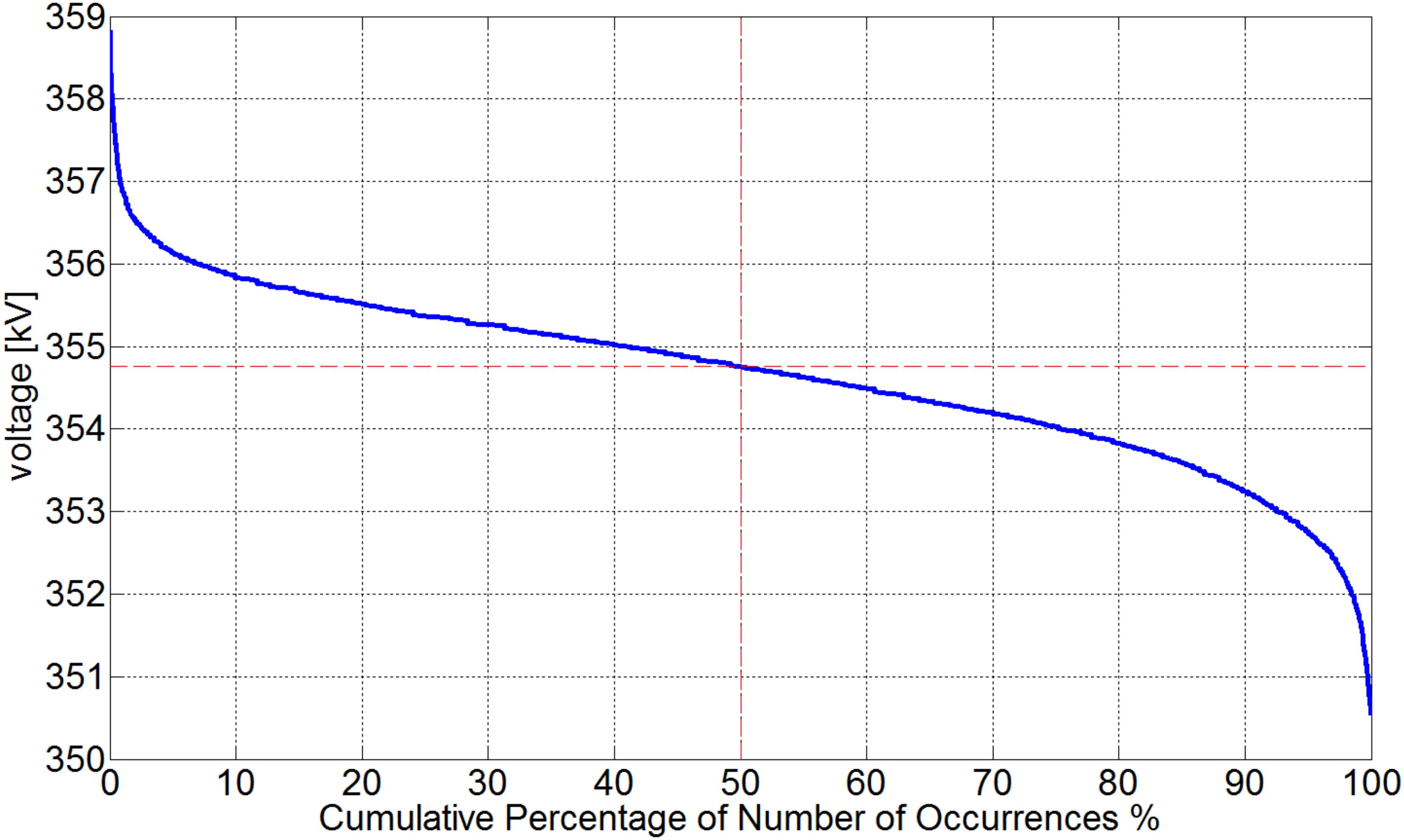

147
146
145
144
143
142
141
140
139
138
137
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

FarWest 4



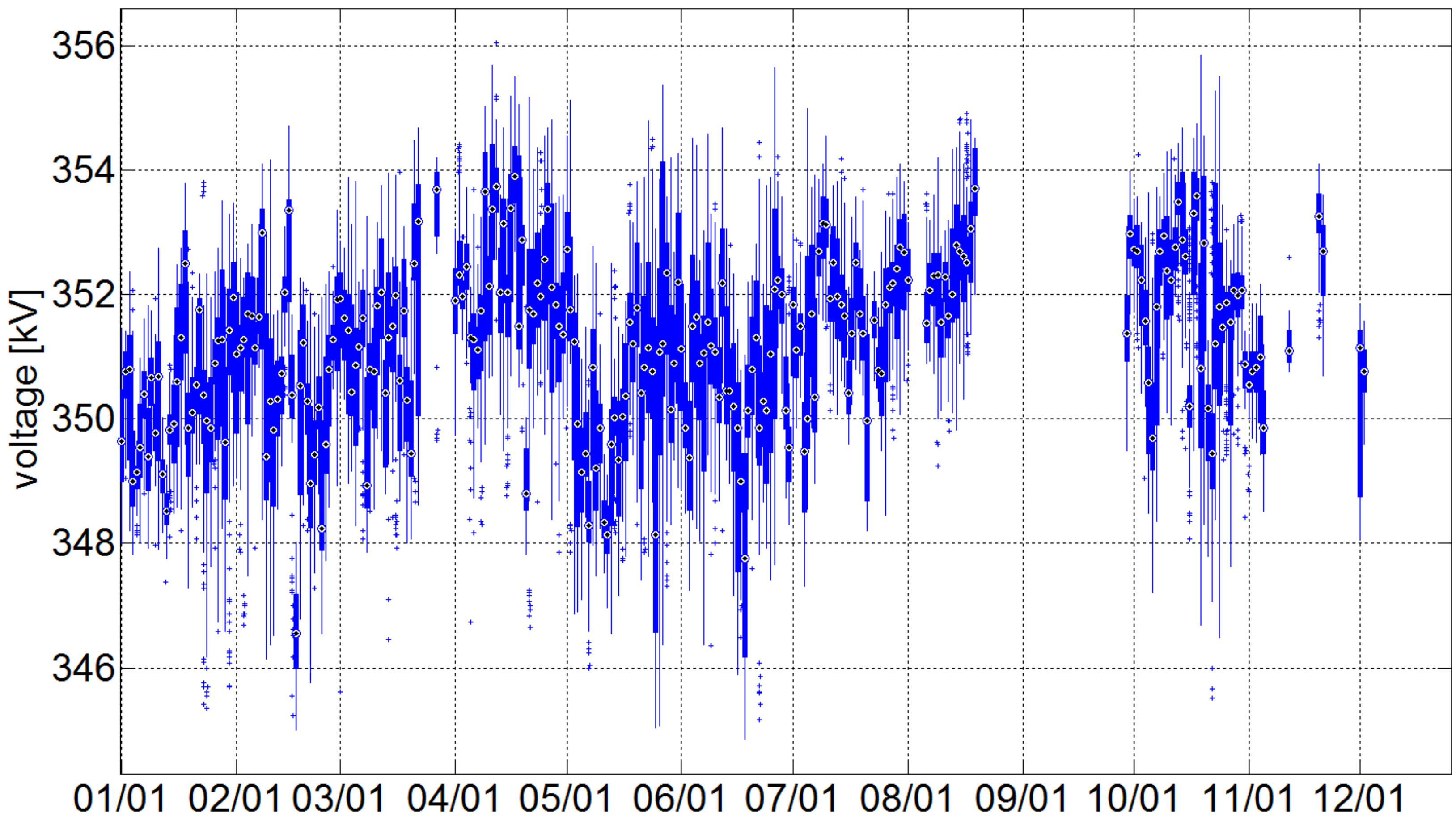
359
358
357
356
355
354
353
352
351
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

FarWest 4

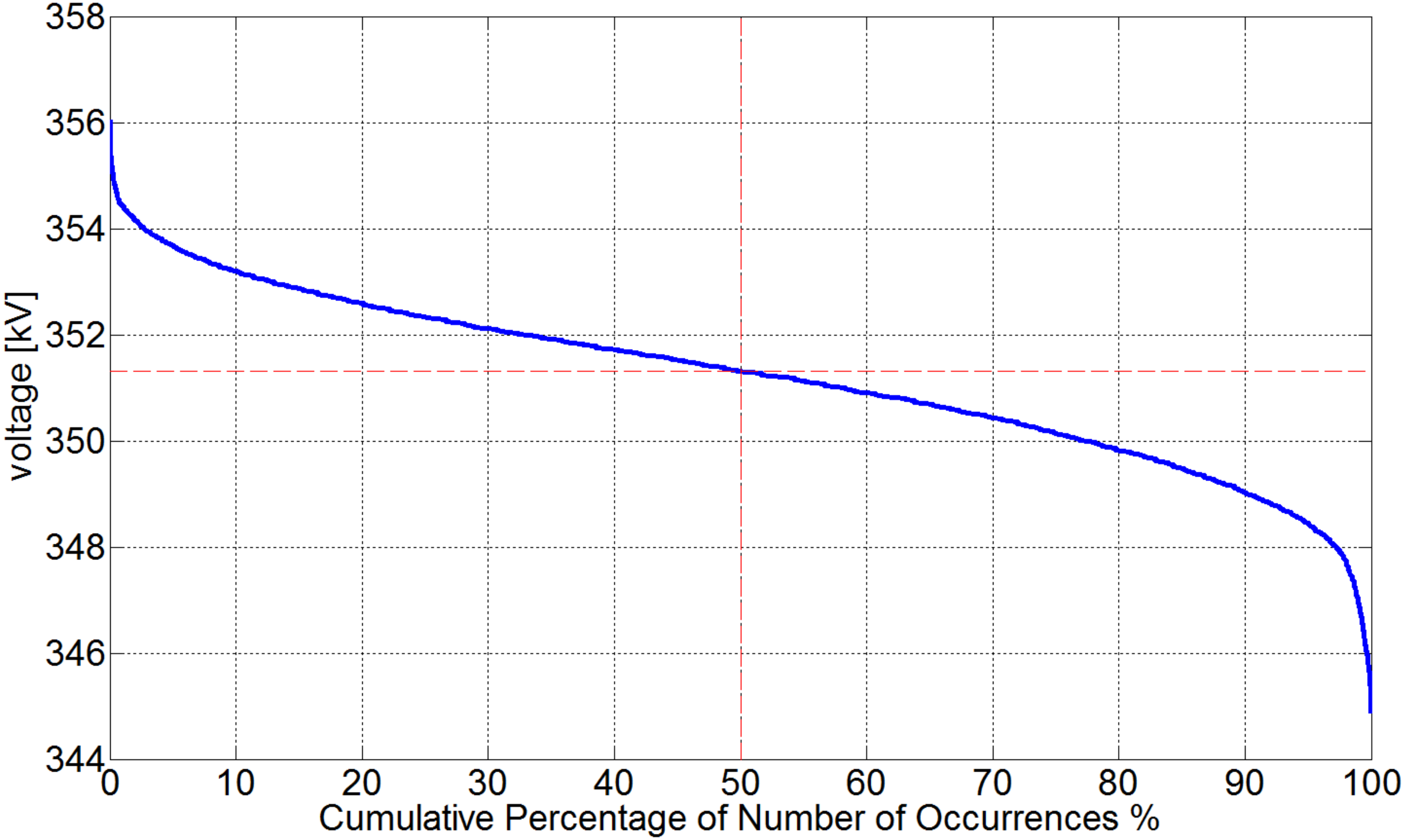


359
358
357
356
355
354
353
352
351
350
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

FarWest 7

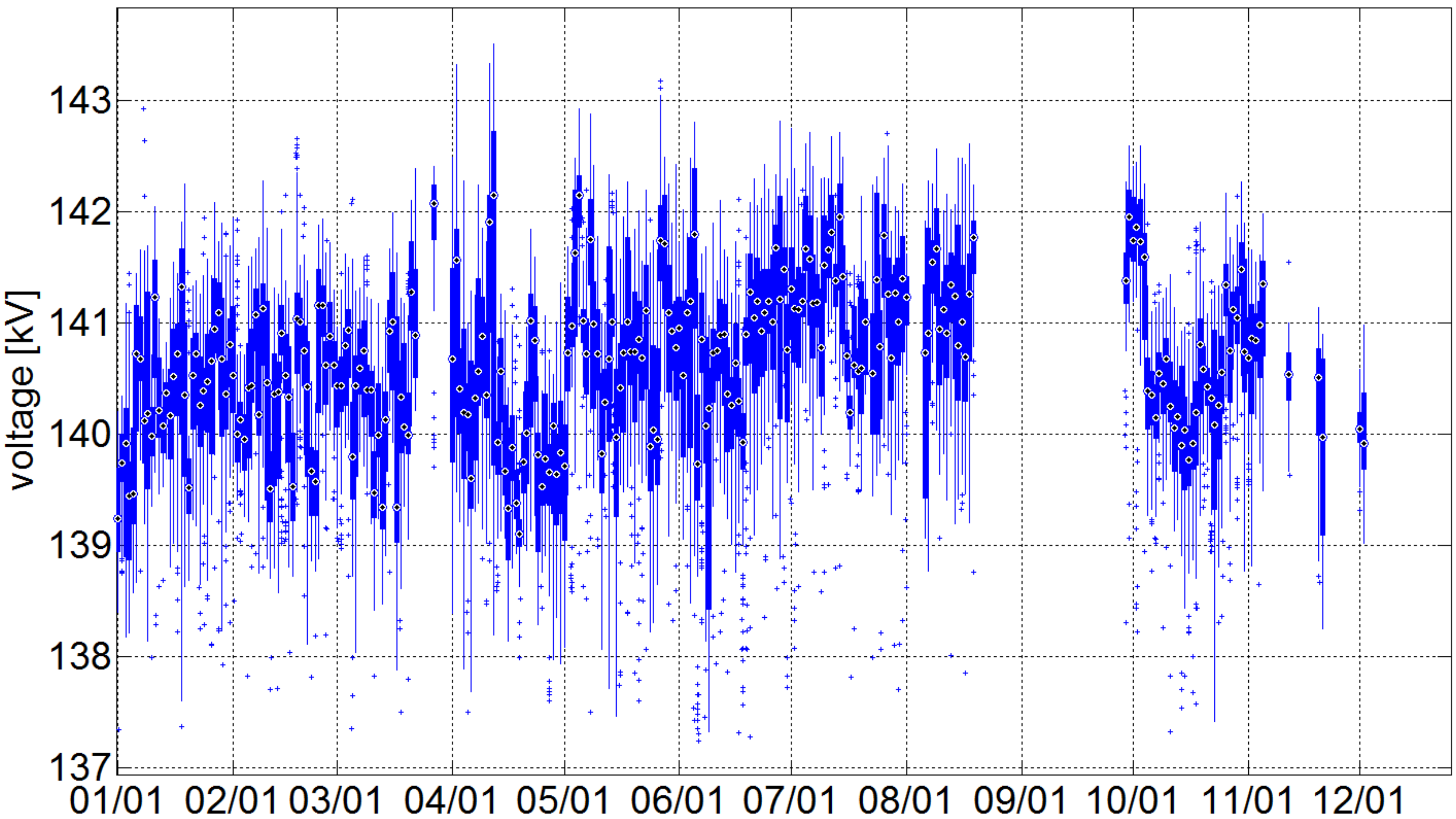

356
354
352
350
348
346
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

FarWest 7



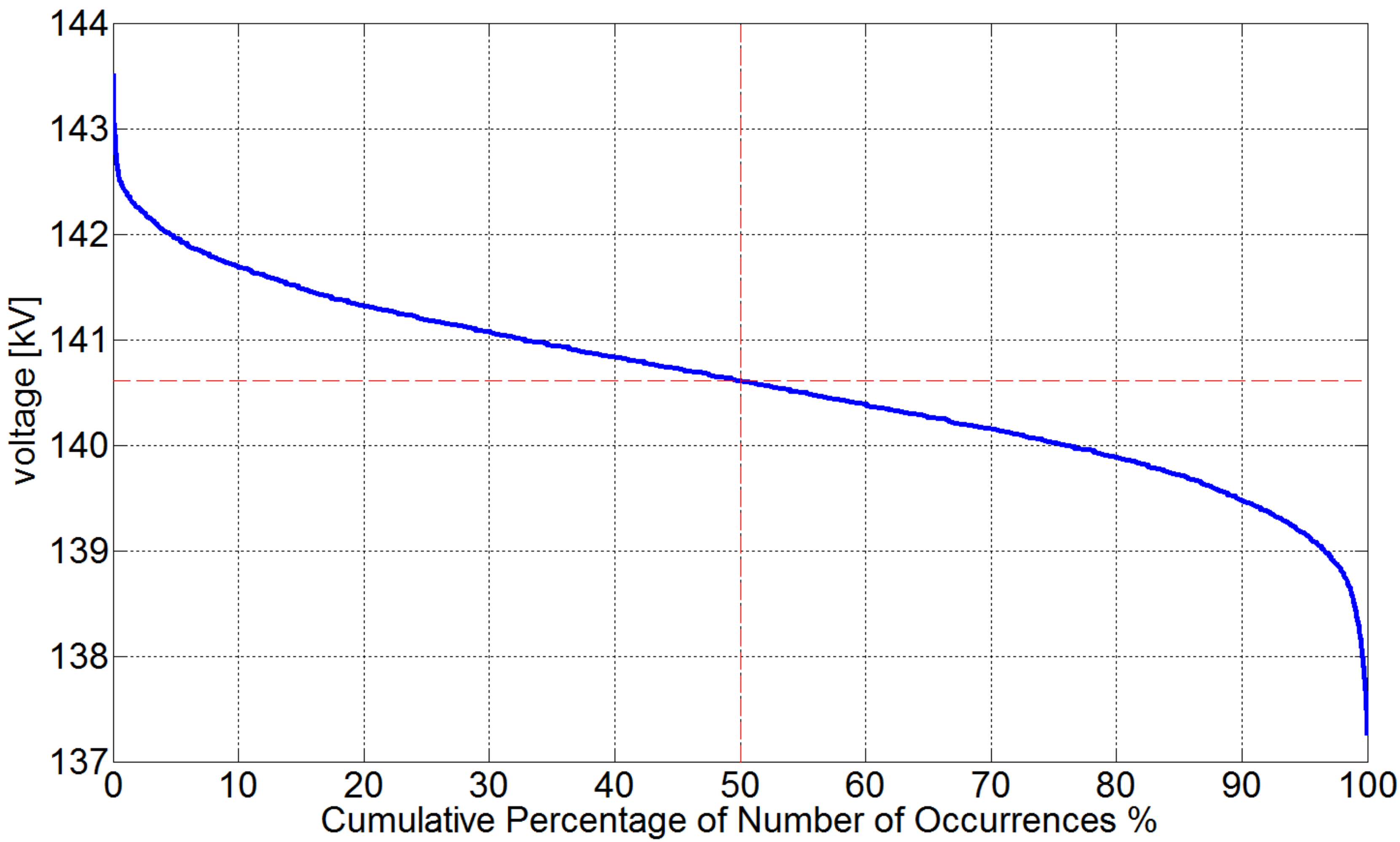
358
356
354
352
350
348
346
344
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

FarWest 8

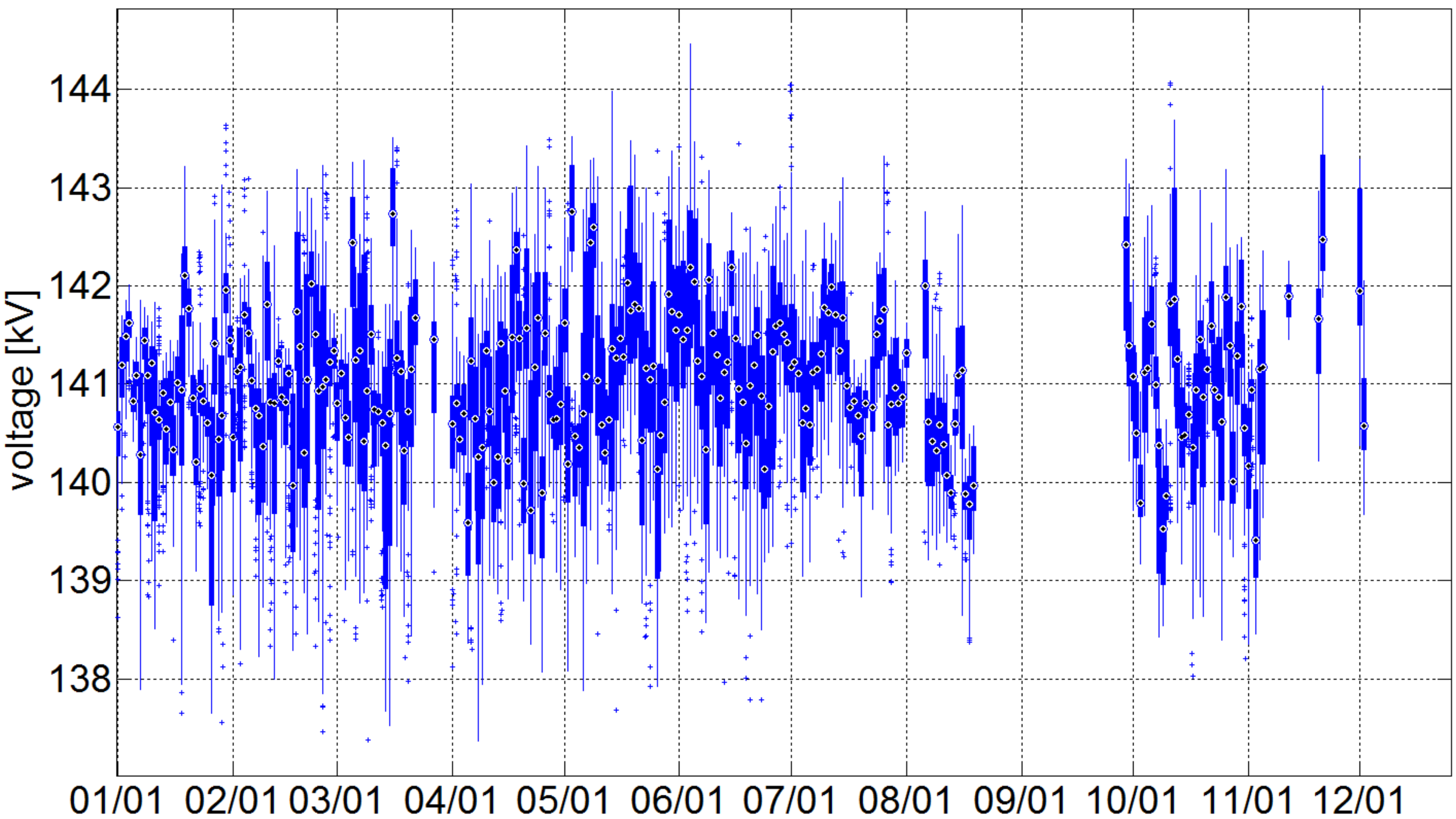


voltage [kV]
143
142
141
140
139
138
137
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

FarWest 8

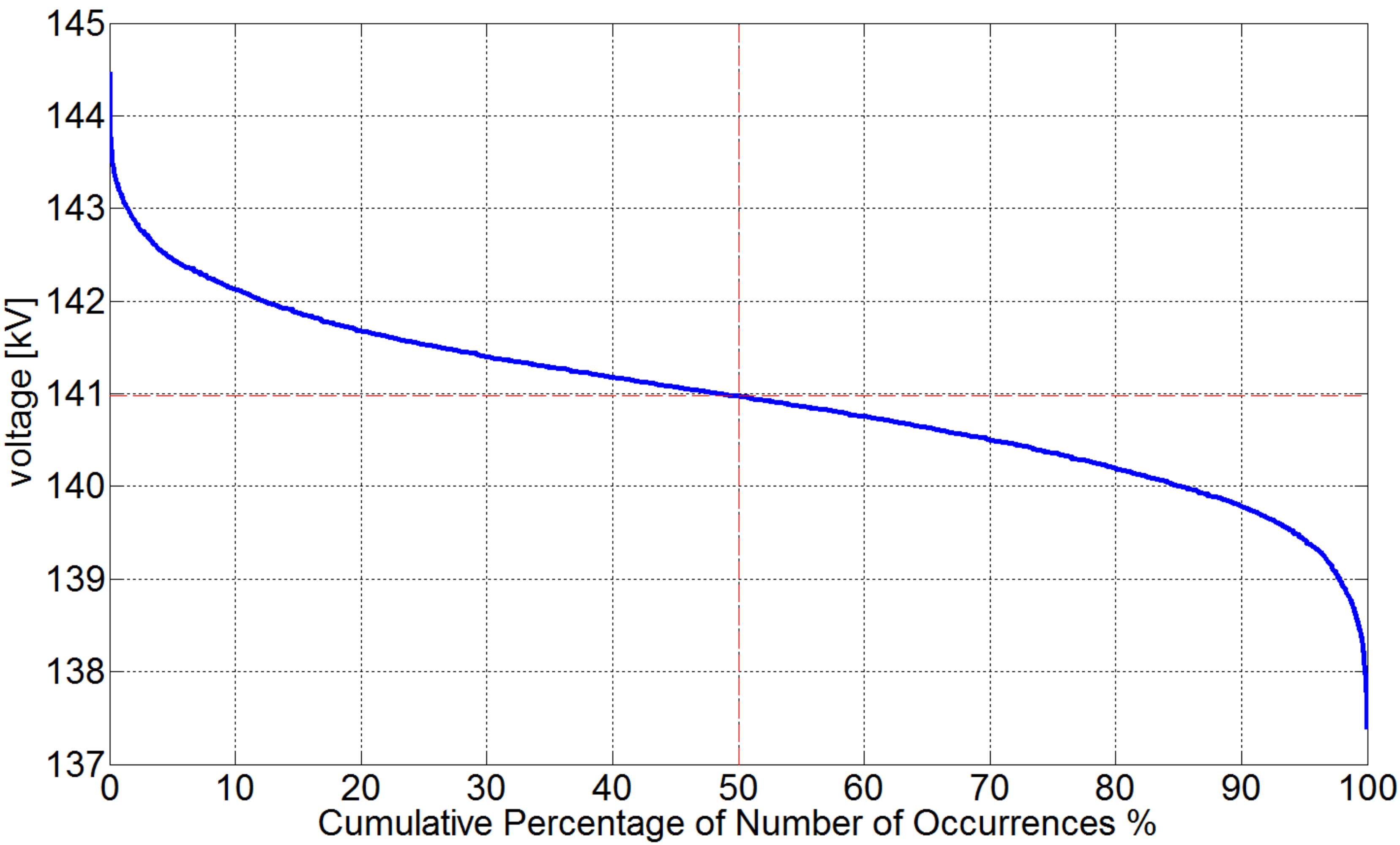

144
143
142
141
140
139
138
137
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

FarWest 9



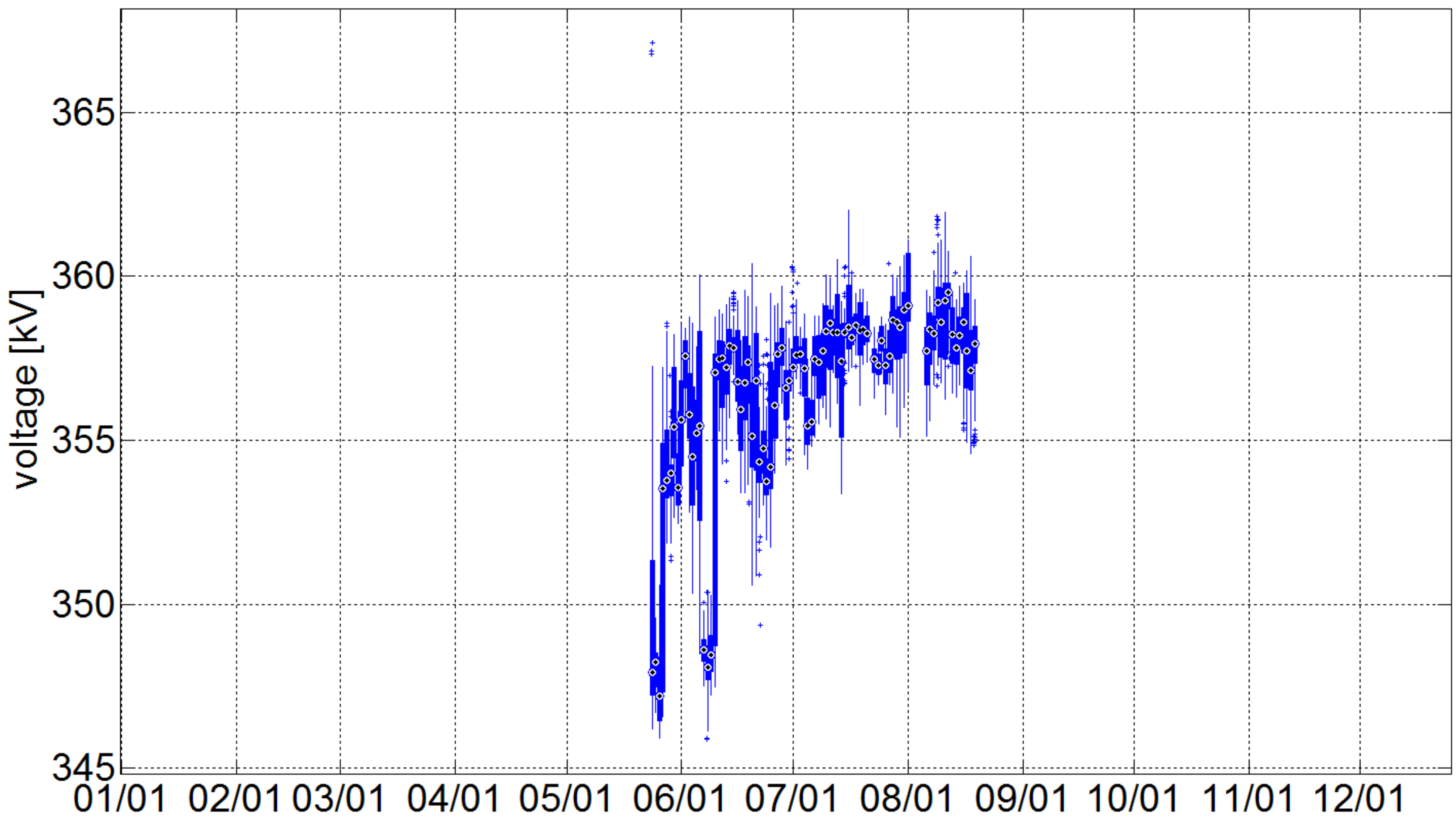
144
143
142
141
140
139
138
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

FarWest 9



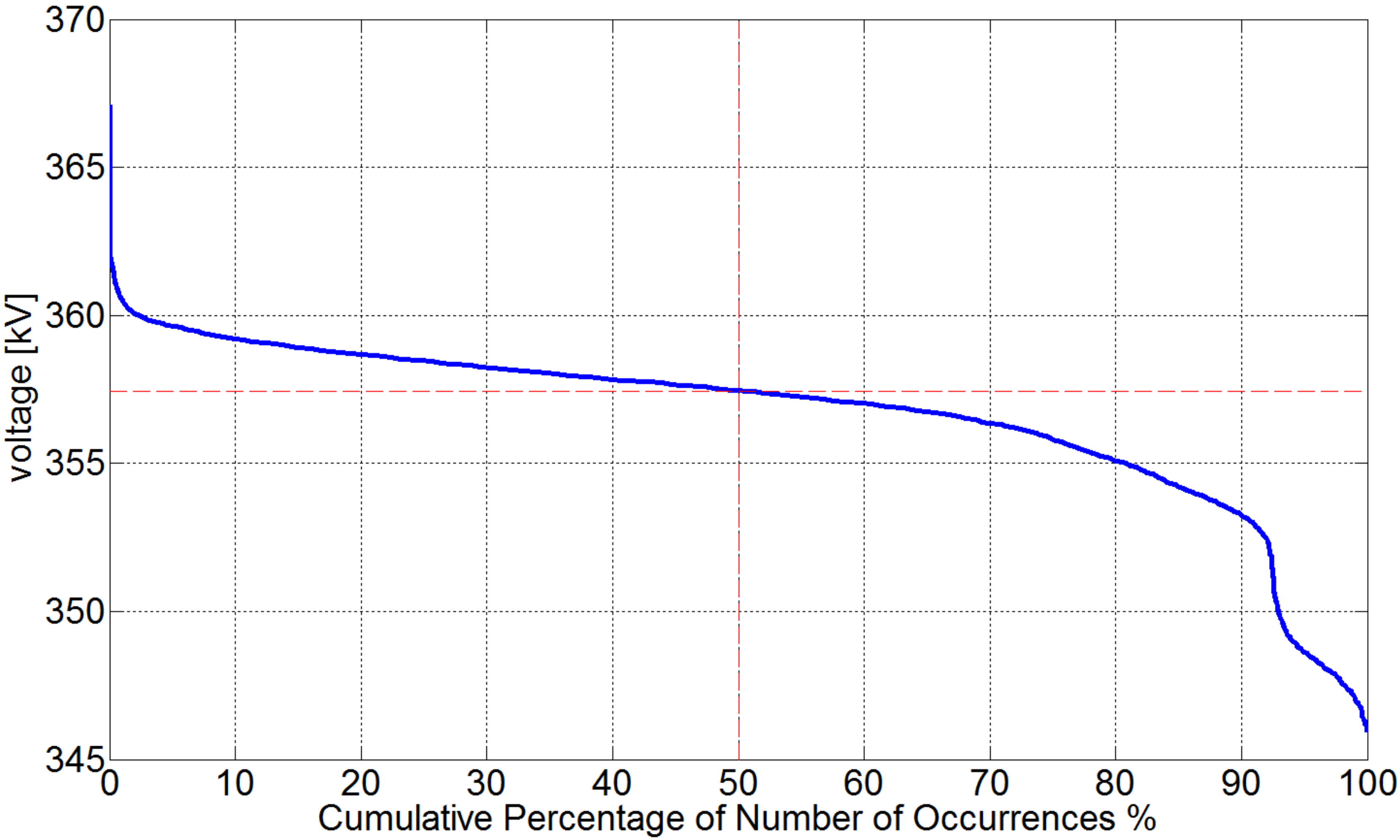
145
144
143
142
141
140
139
138
137
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

West 8



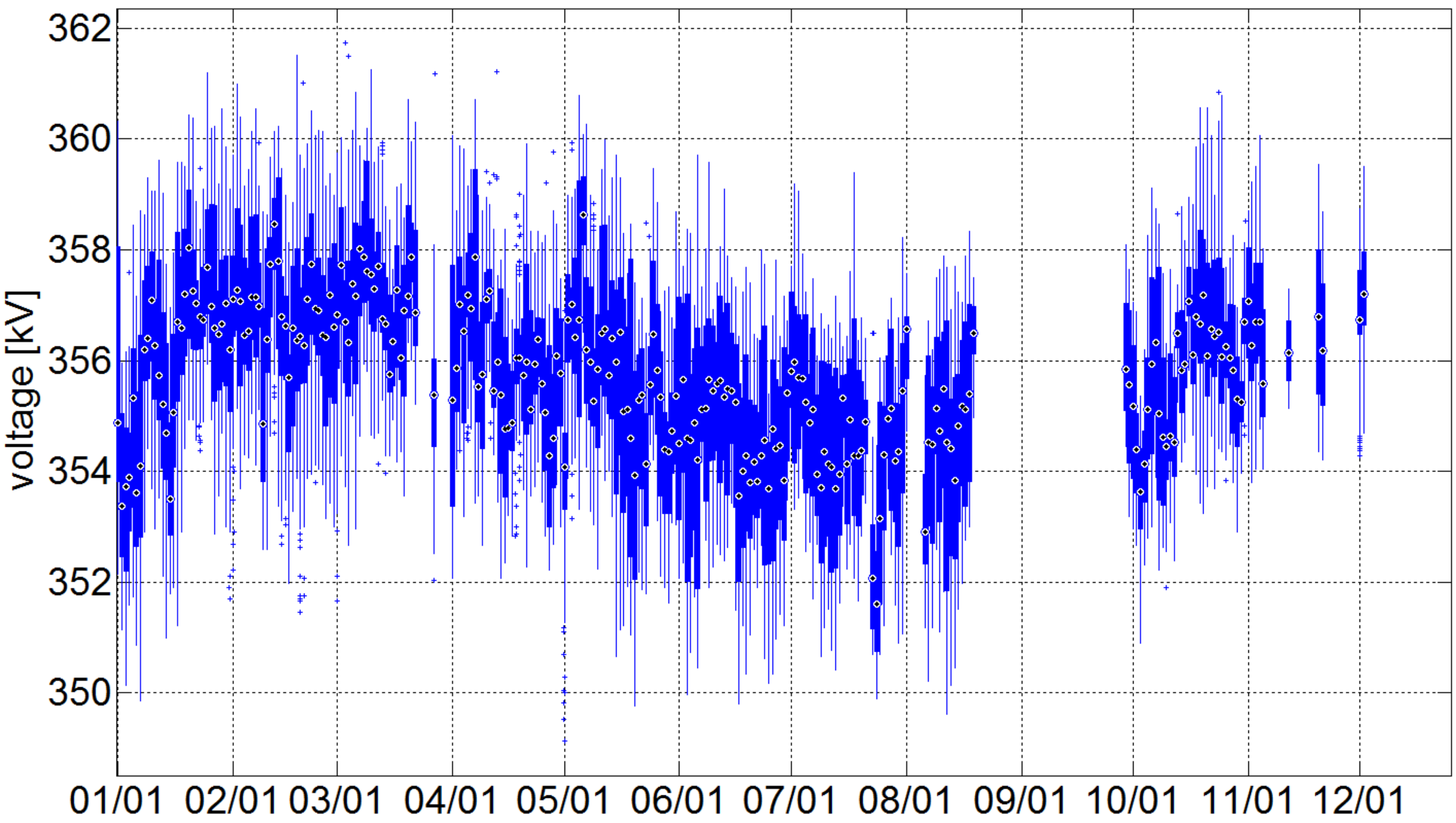
voltage [kV]
365
360
355
350
345
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

West 8



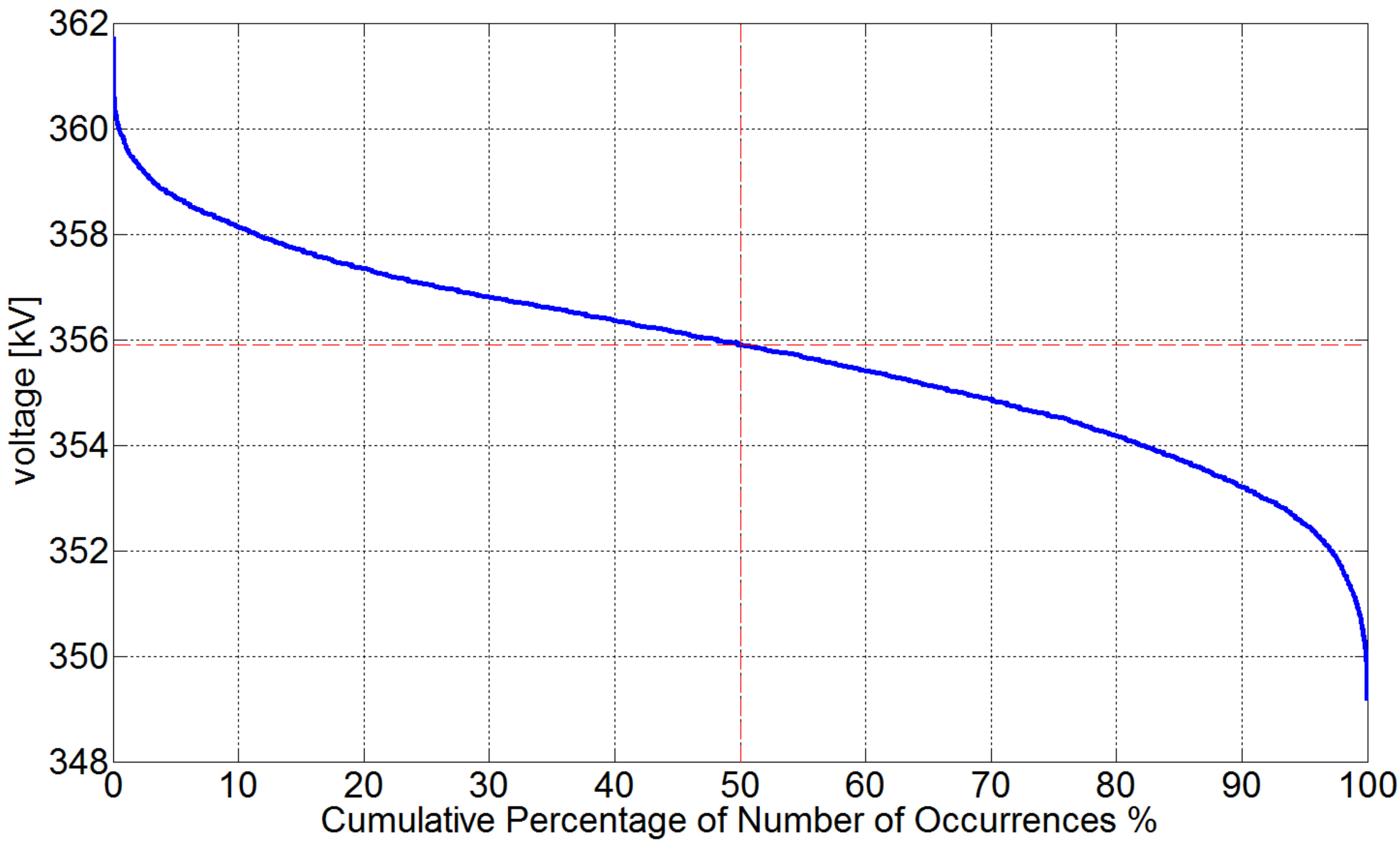
370
365
360
355
350
345
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 15*



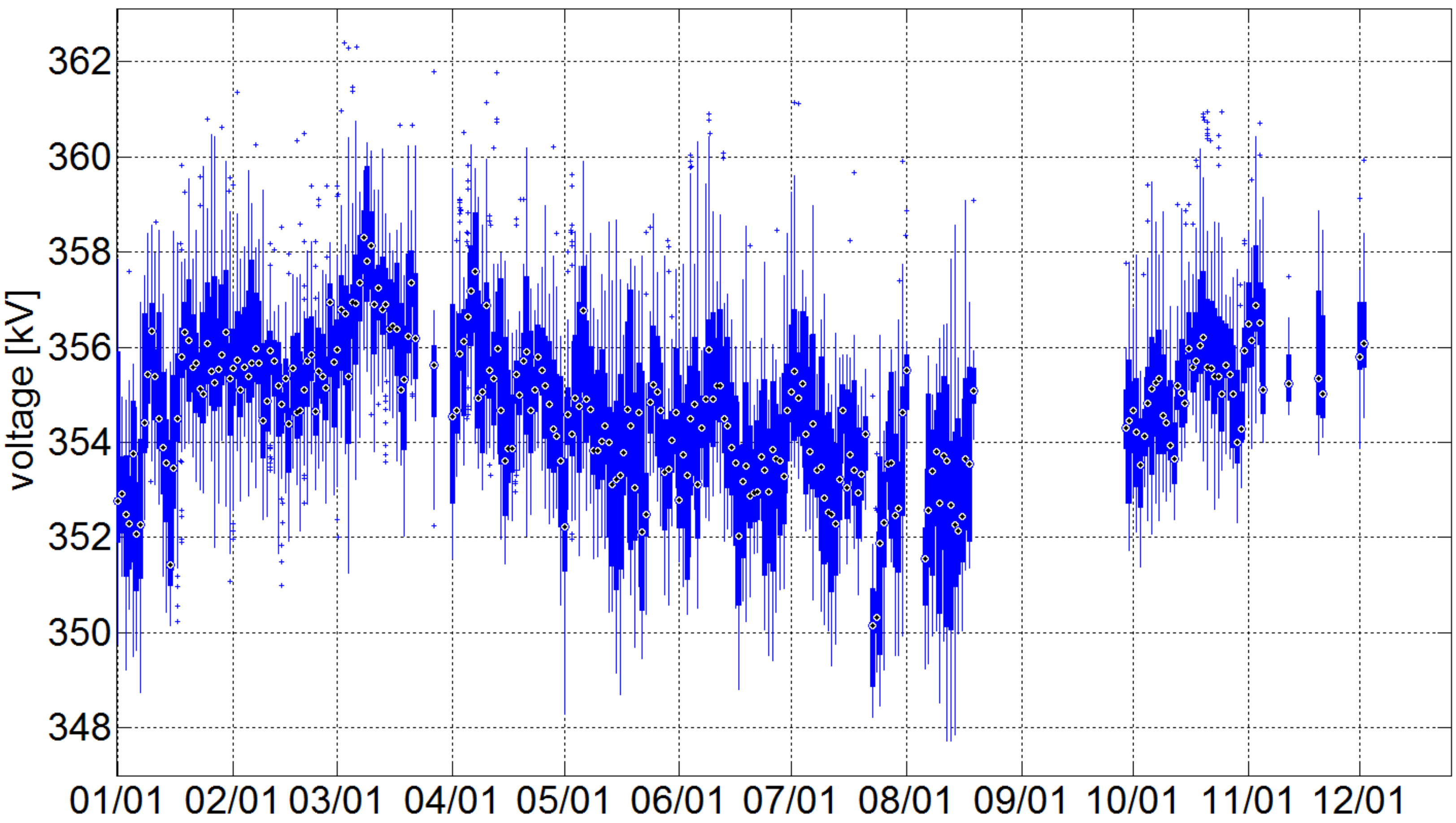
voltage [kV]
362
360
358
356
354
352
350
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

South 15*

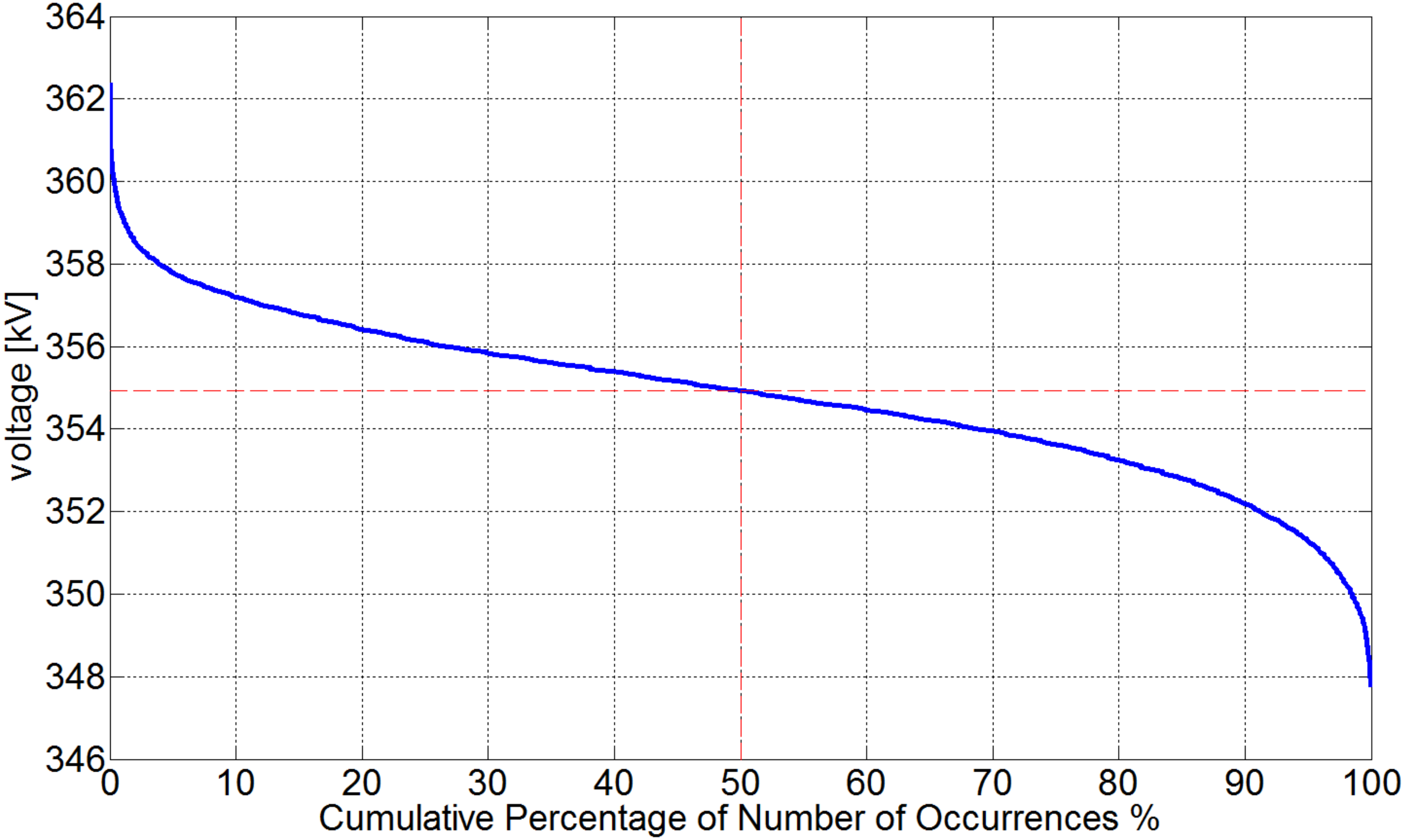


362
360
358
356
354
352
350
348
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 2*

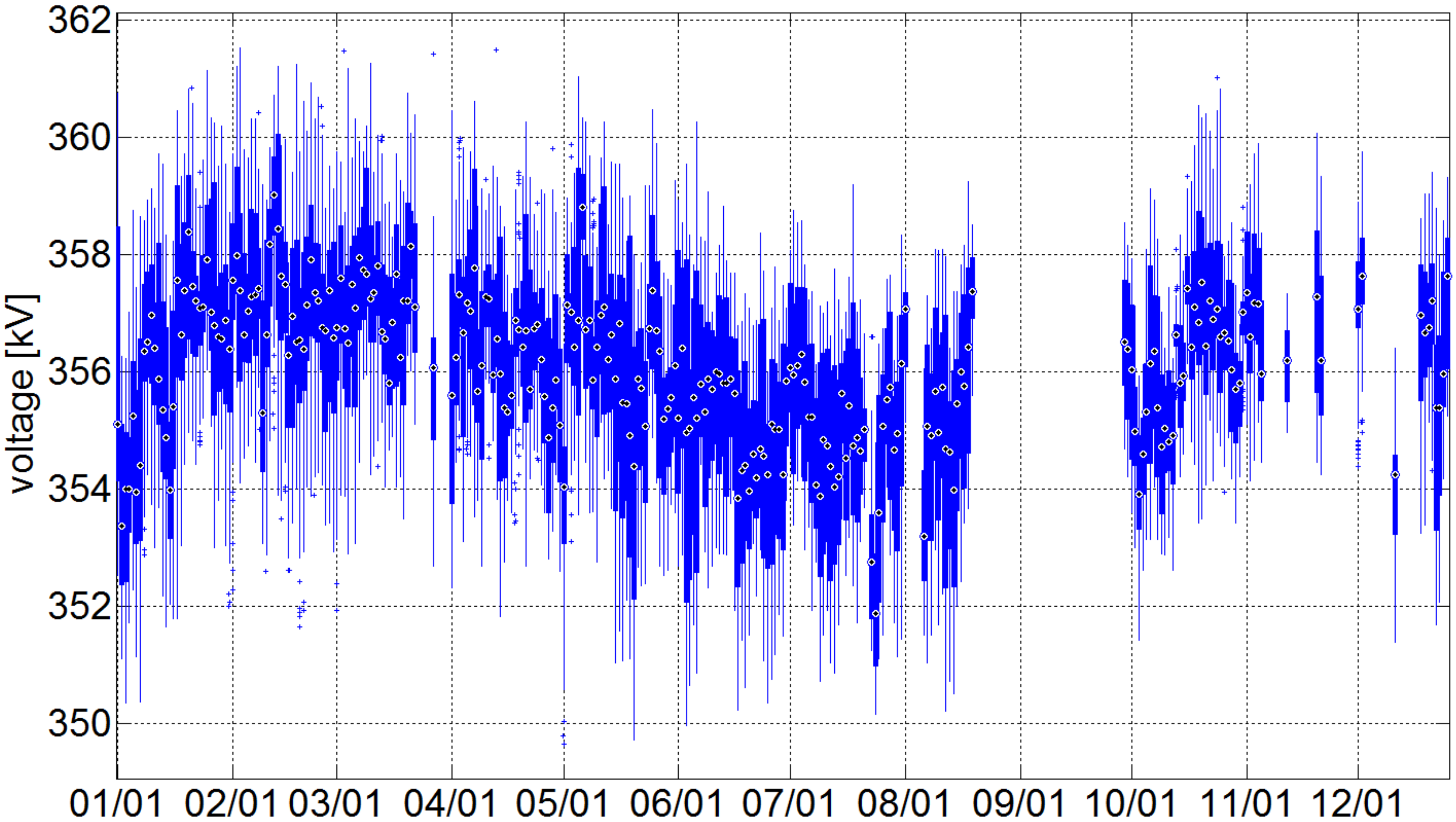

362
360
358
356
354
352
350
348
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

South 2*



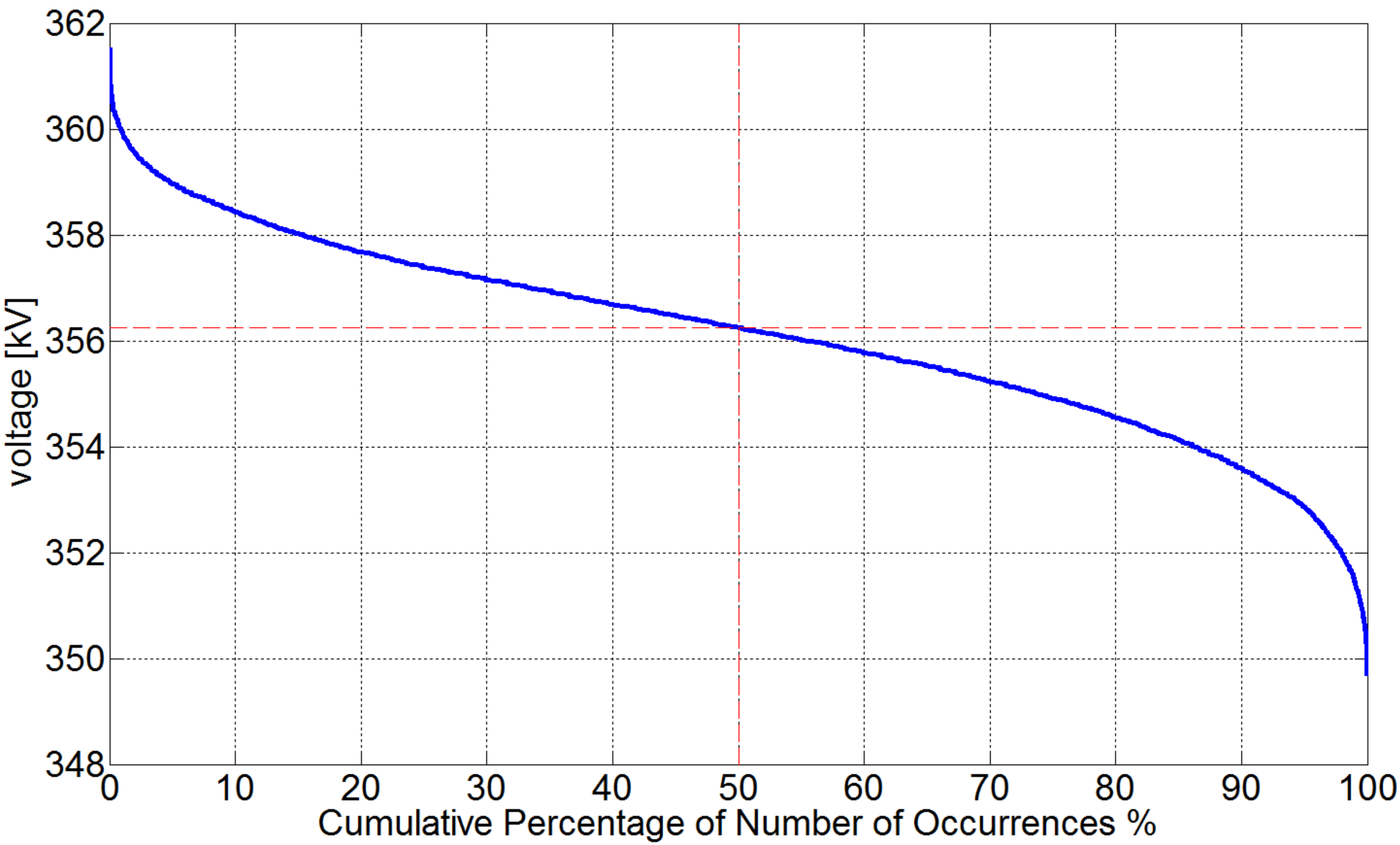
364
362
360
358
356
354
352
350
348
346
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 4*



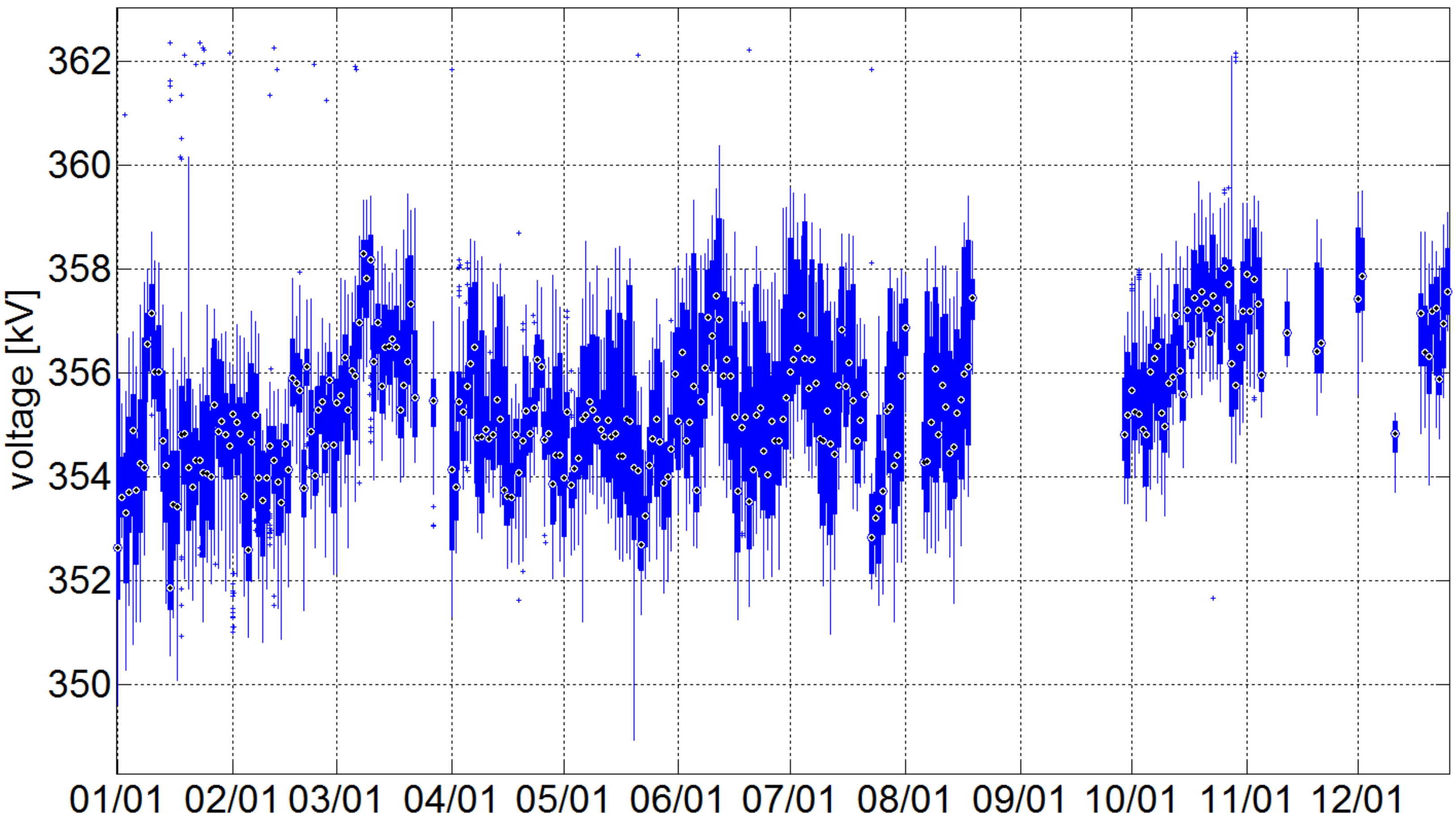
362
360
358
356
354
352
350
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

South 4*



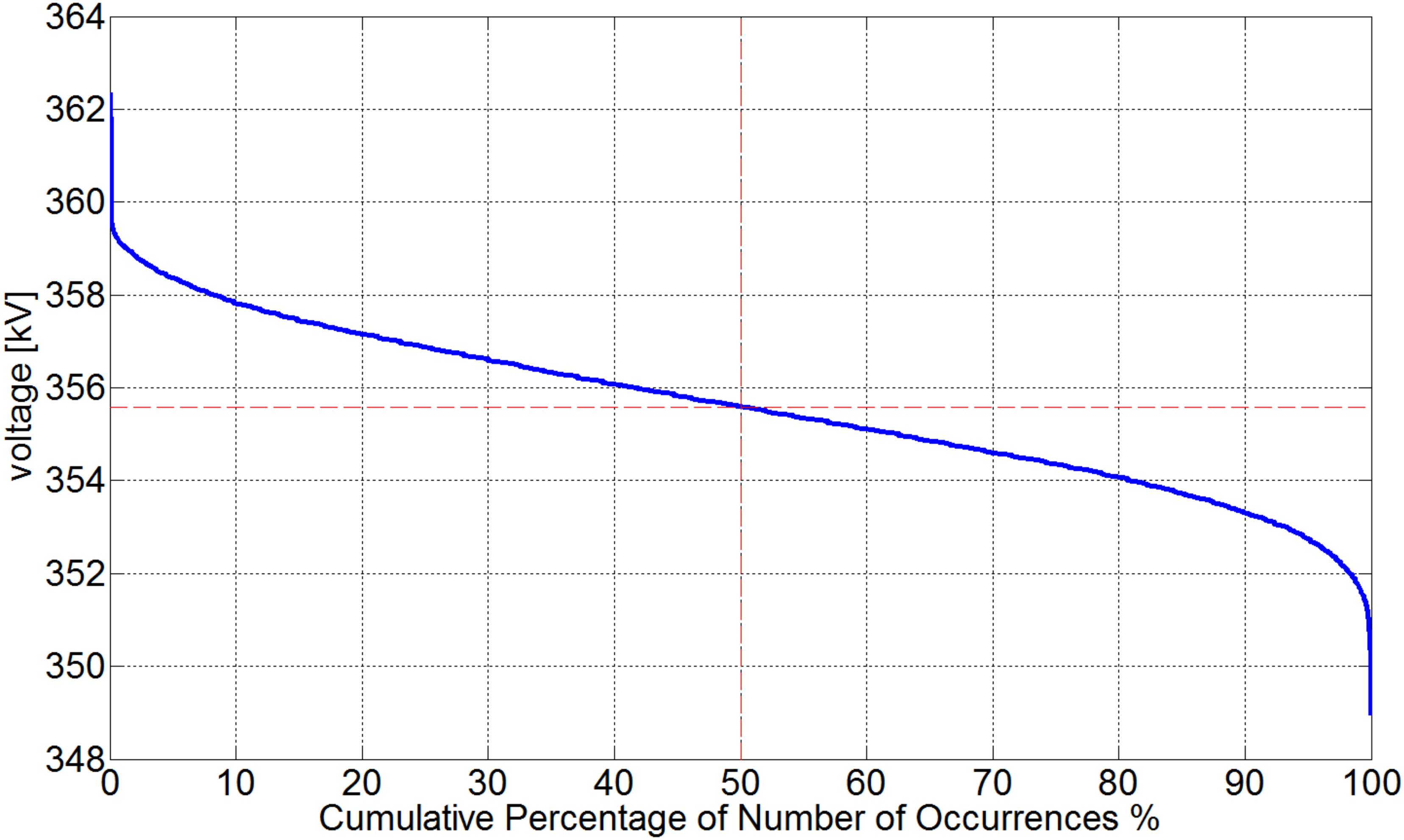
362
360
358
356
354
352
350
348
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 7*



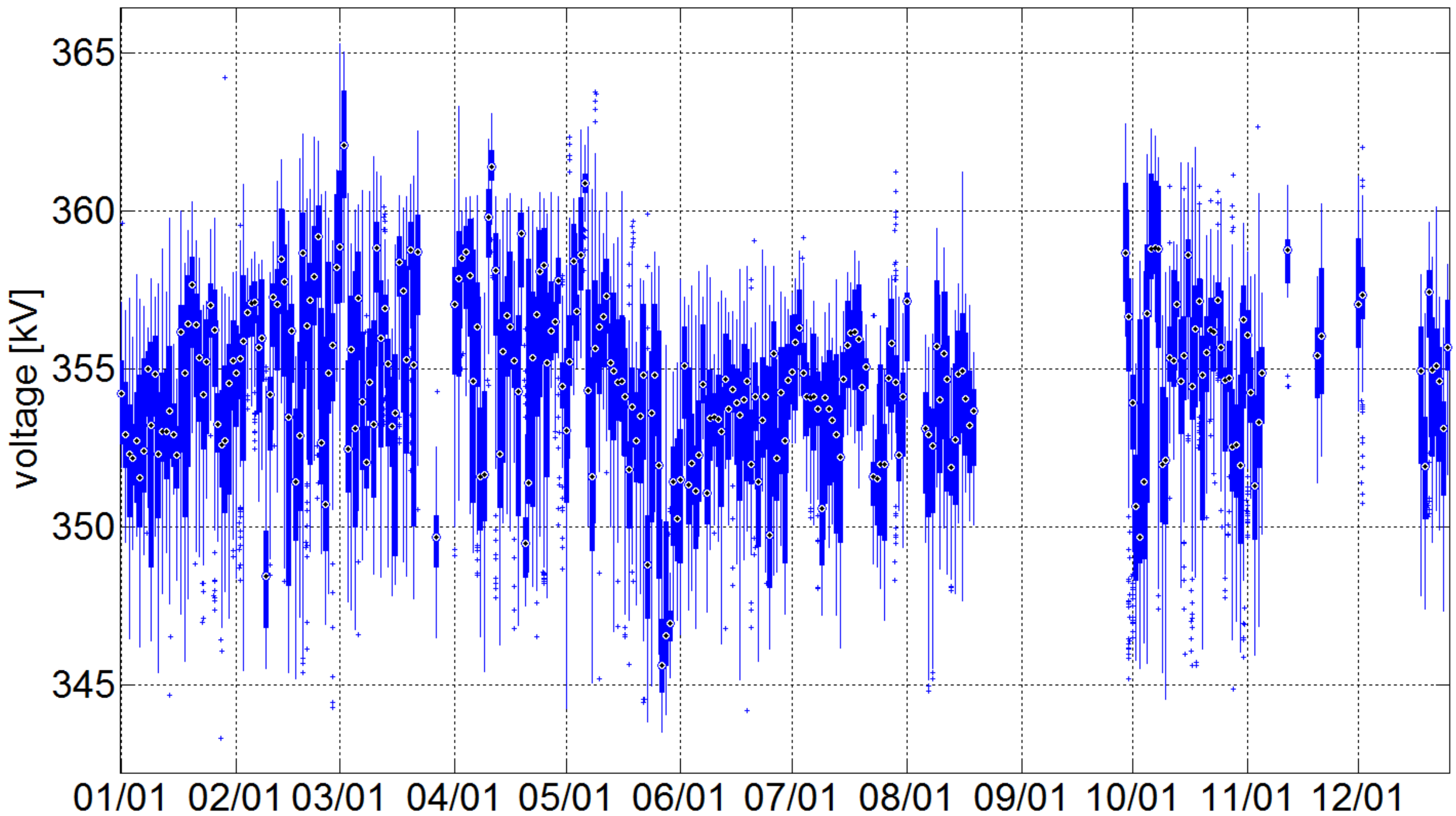
voltage [kV]
362
360
358
356
354
352
350
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

South 7*



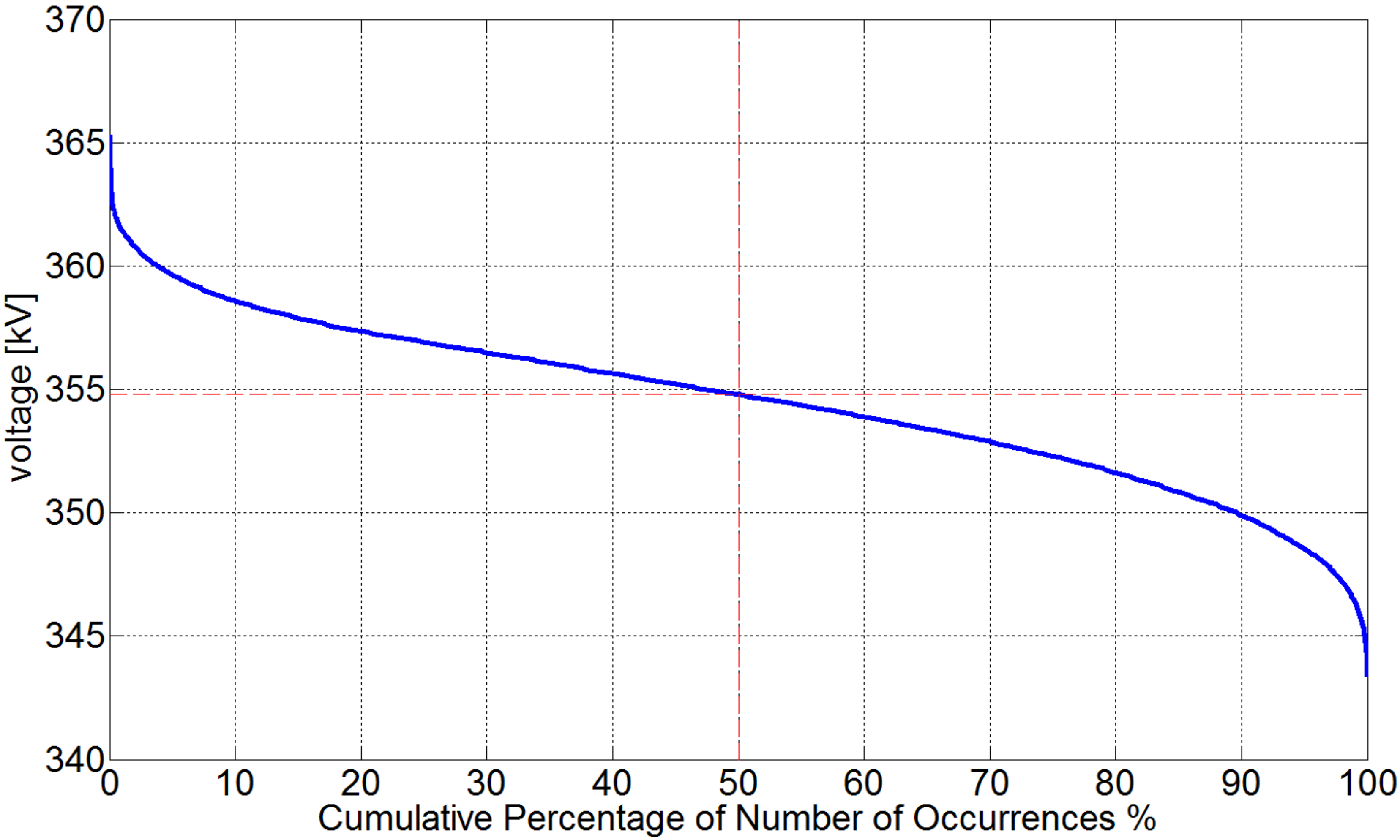
364
362
360
358
356
354
352
350
348
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 9*

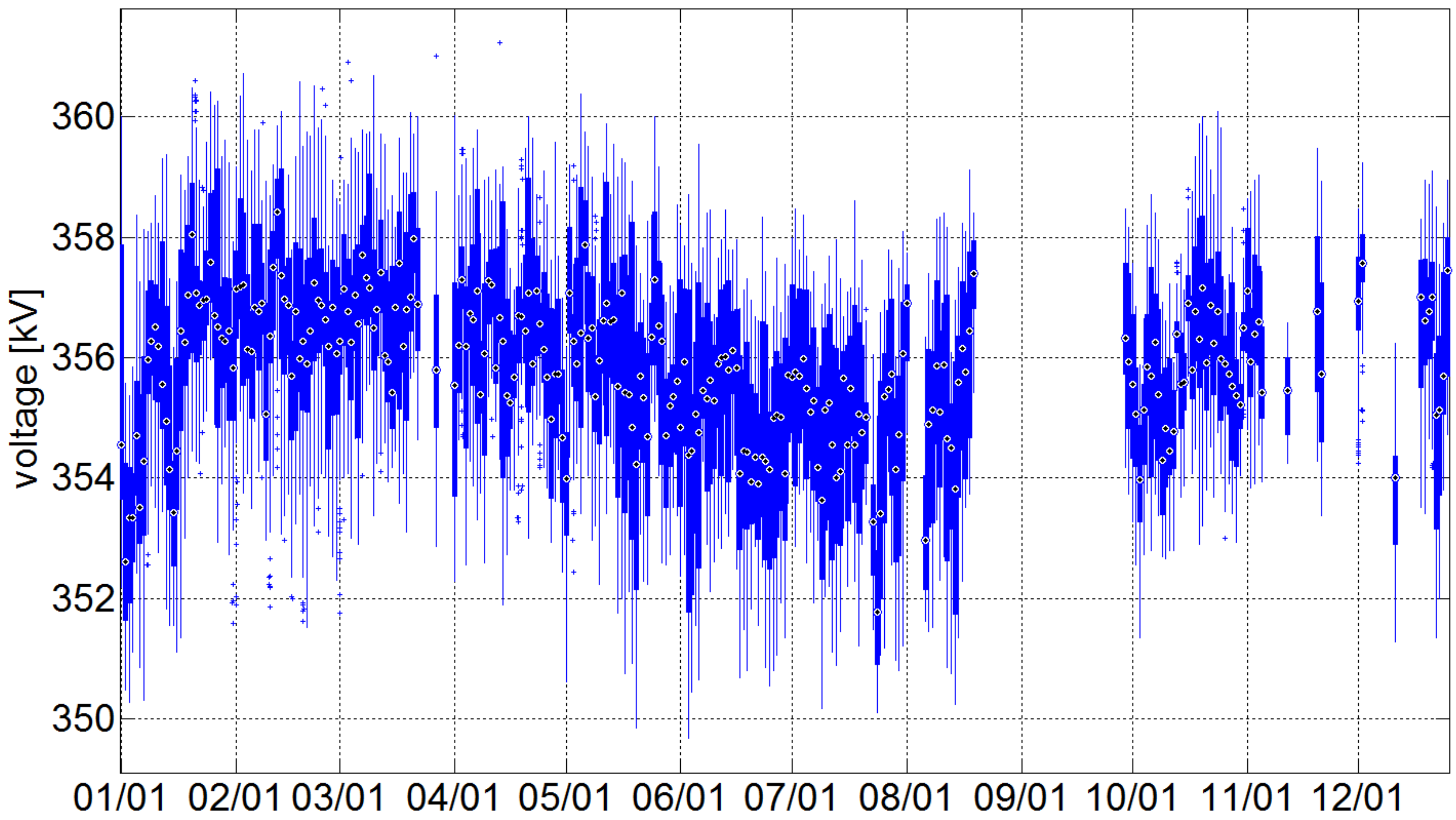


voltage [kV]
365
360
355
350
345
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

South 9*

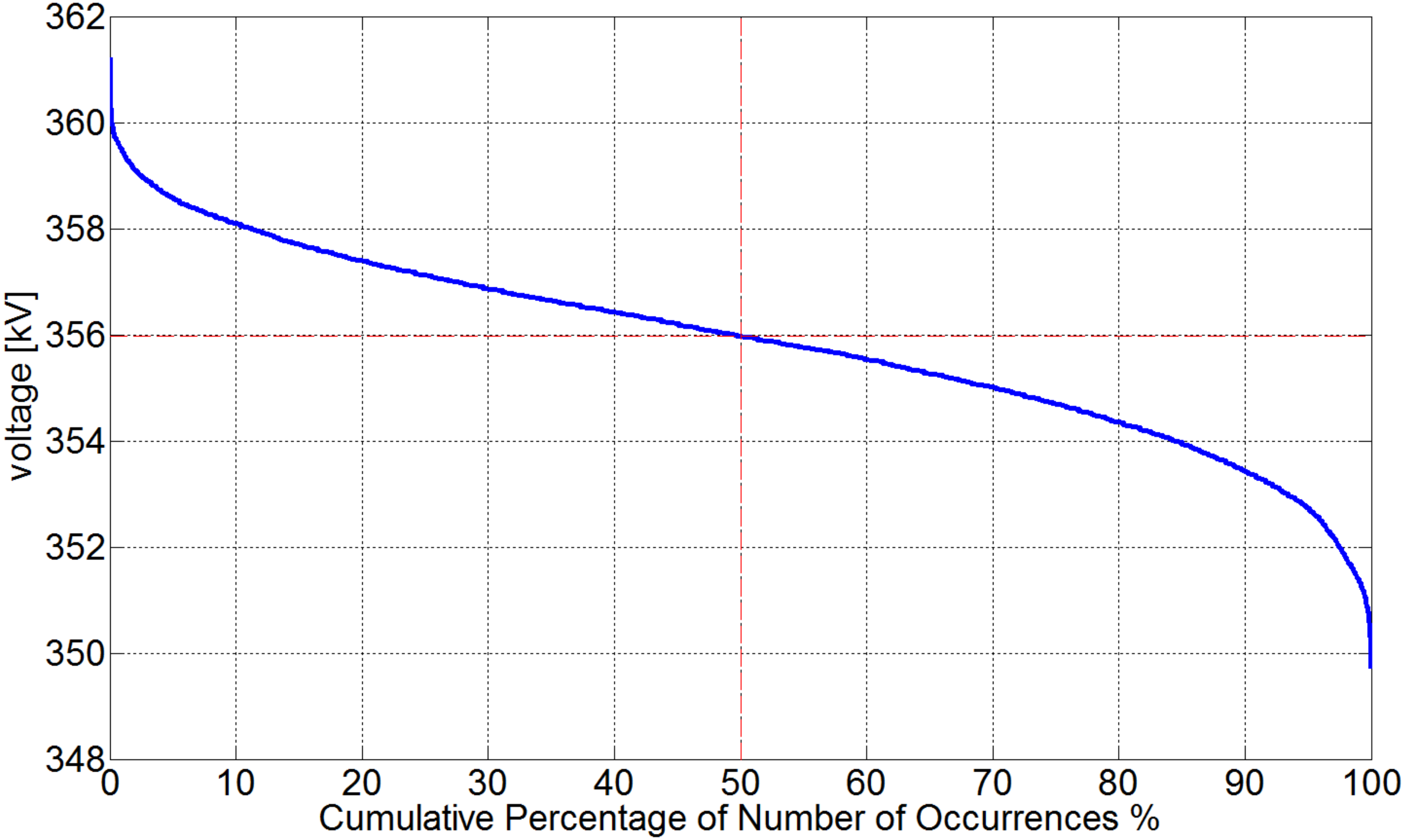

370
365
360
355
350
345
340
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

South 11*



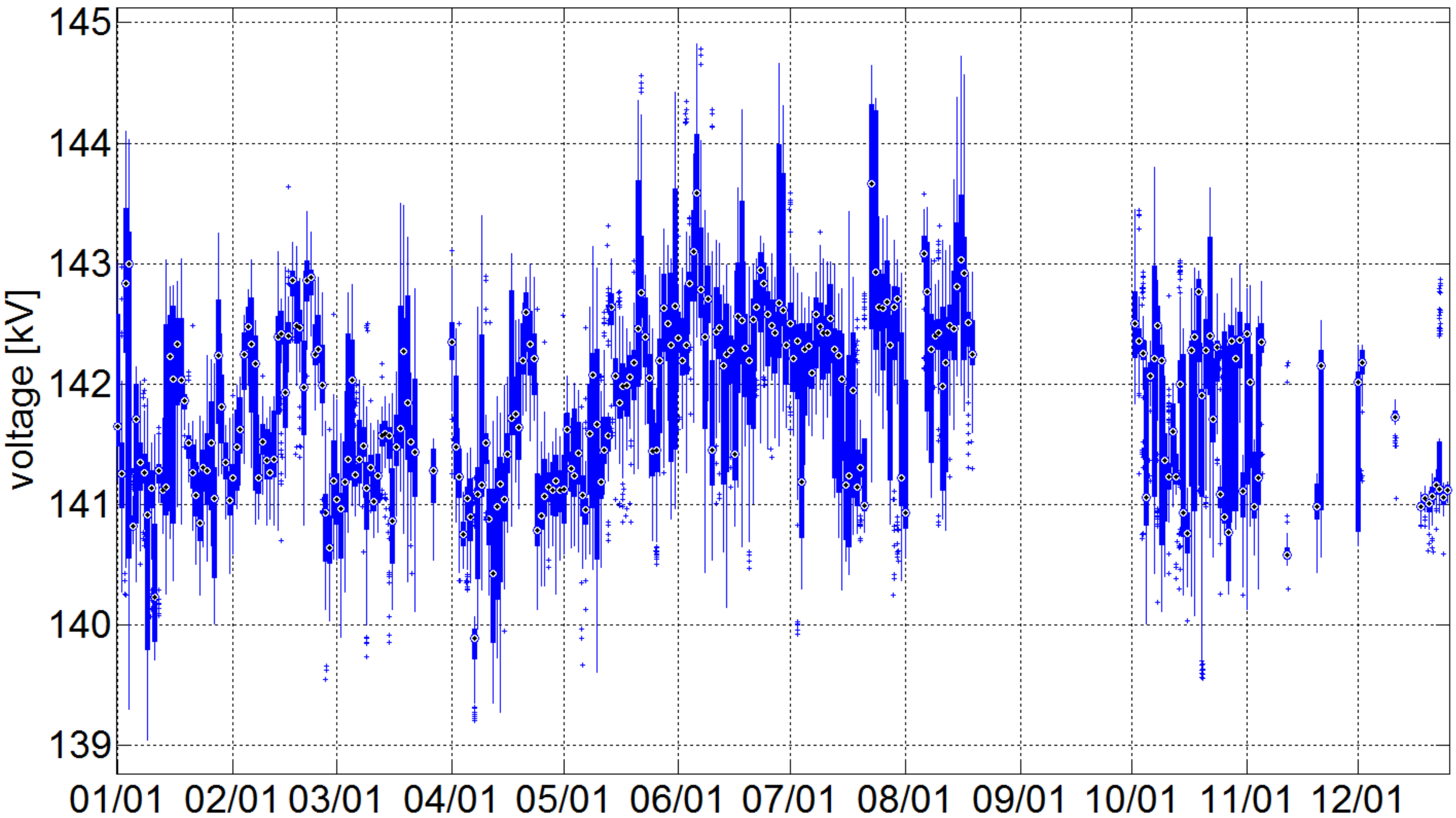
voltage [kV]
360
358
356
354
352
350
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

South 11*

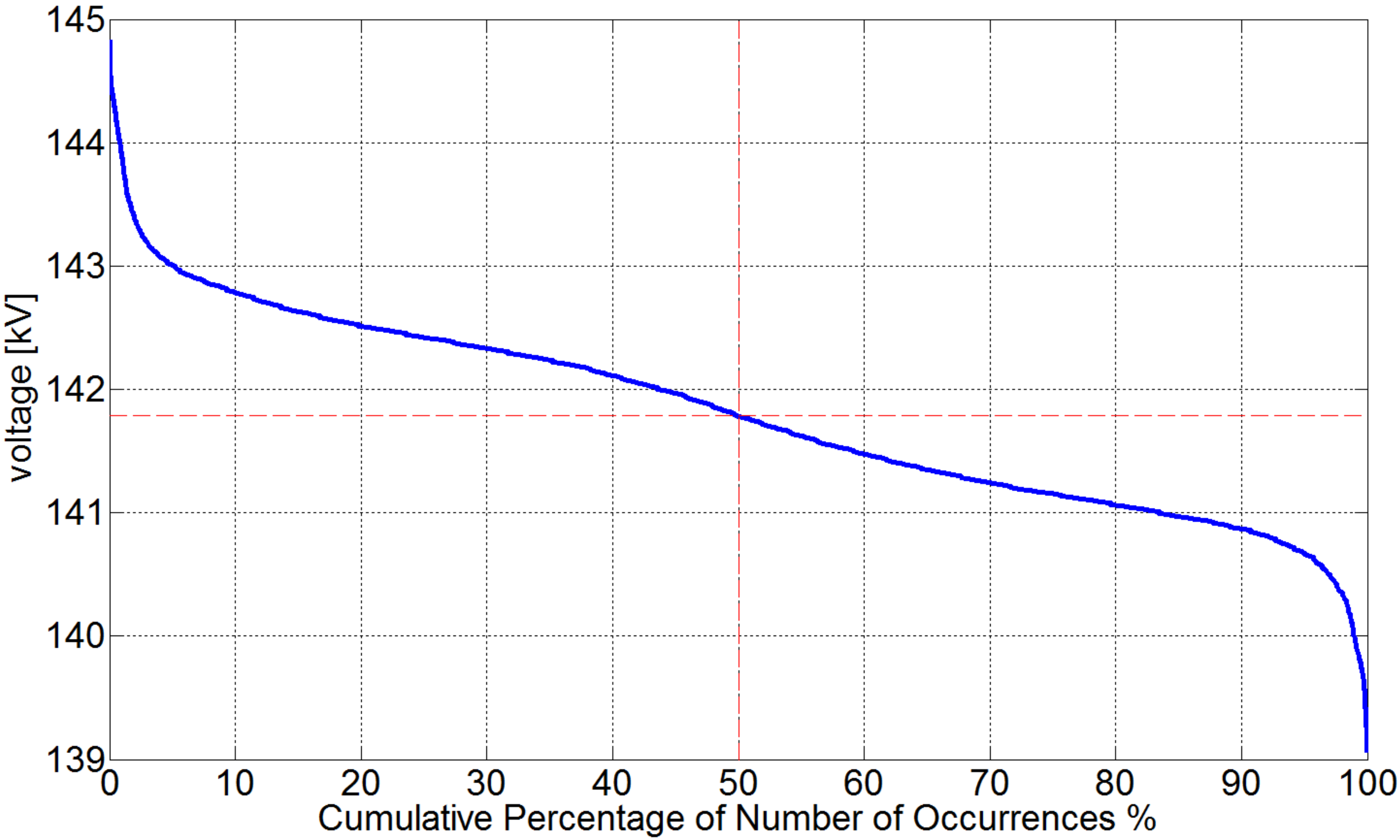


362
360
358
356
354
352
350
348
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

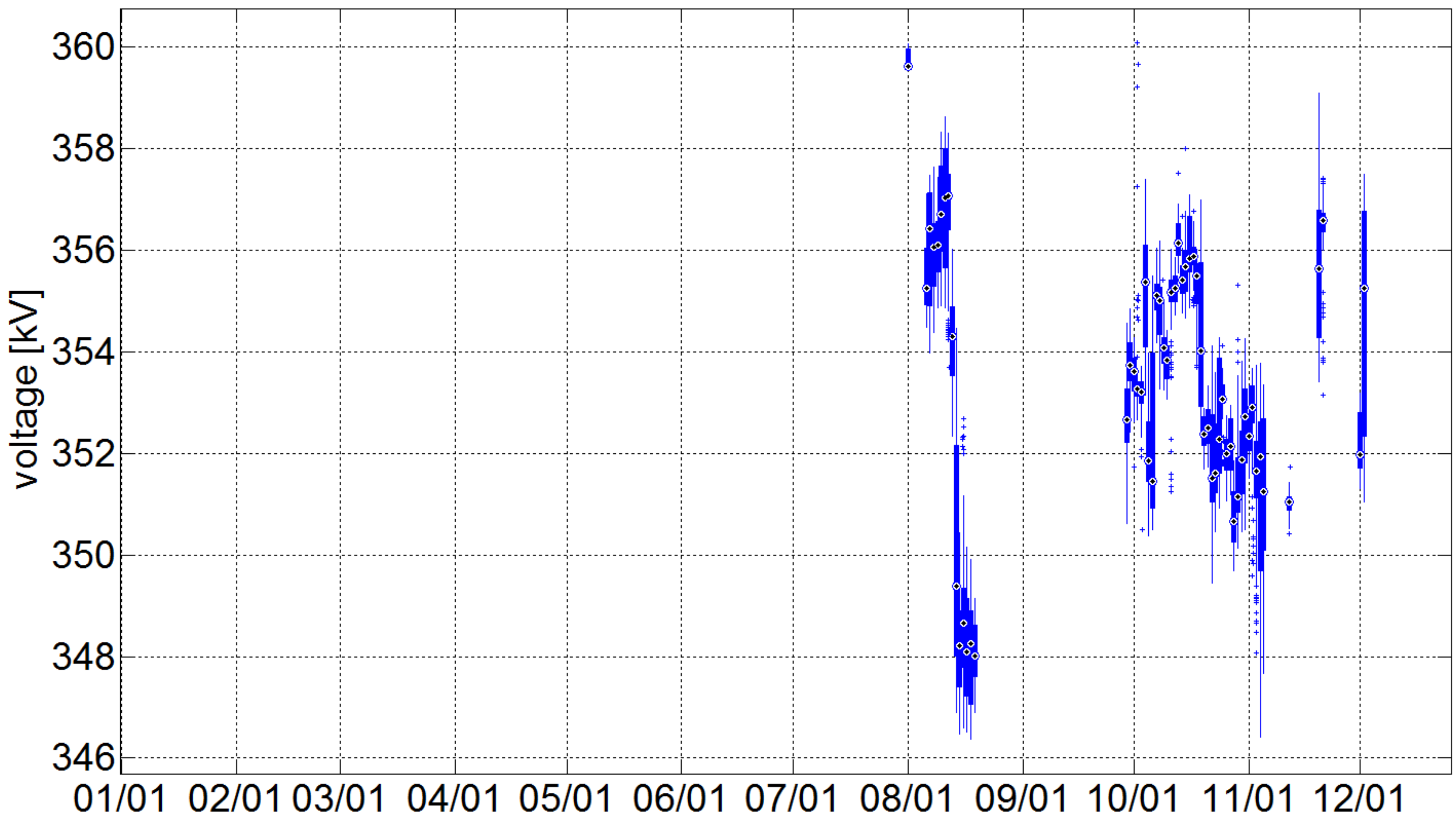
South 10*


145
144
143
142
141
140
139
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

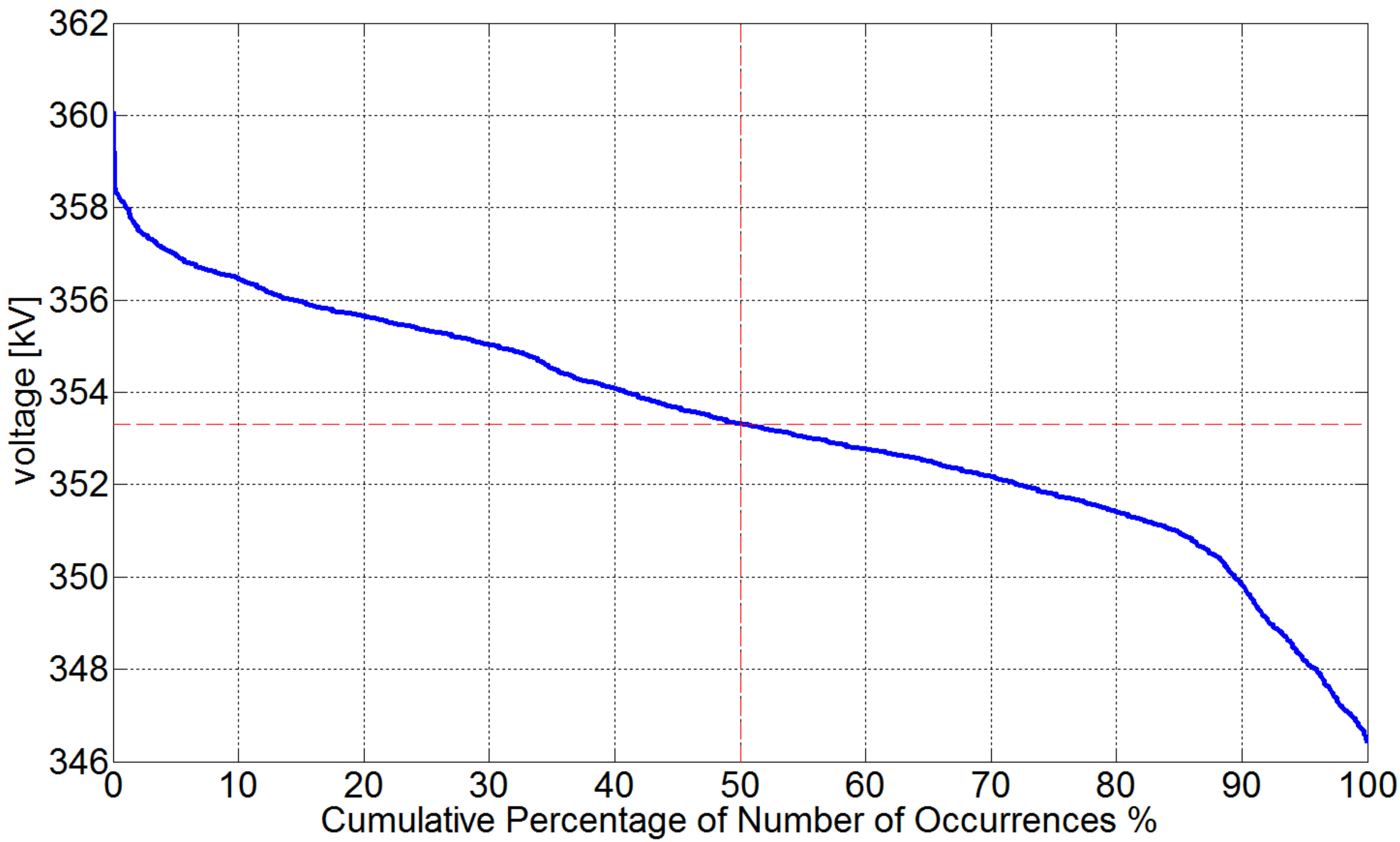
South 10*


145
144
143
142
141
140
139
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

West 16*

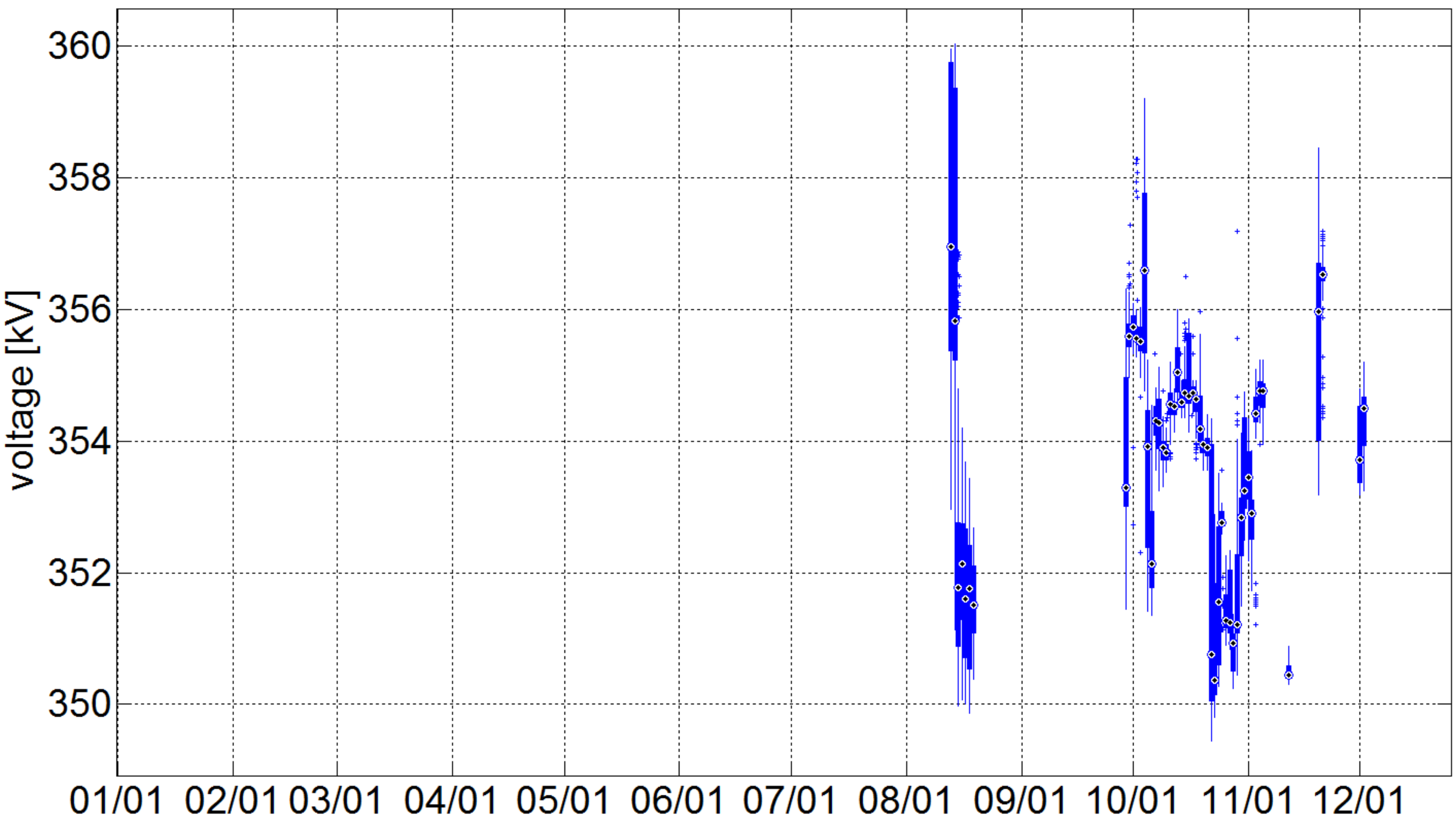

360
358
356
354
352
350
348
346
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

West 16*



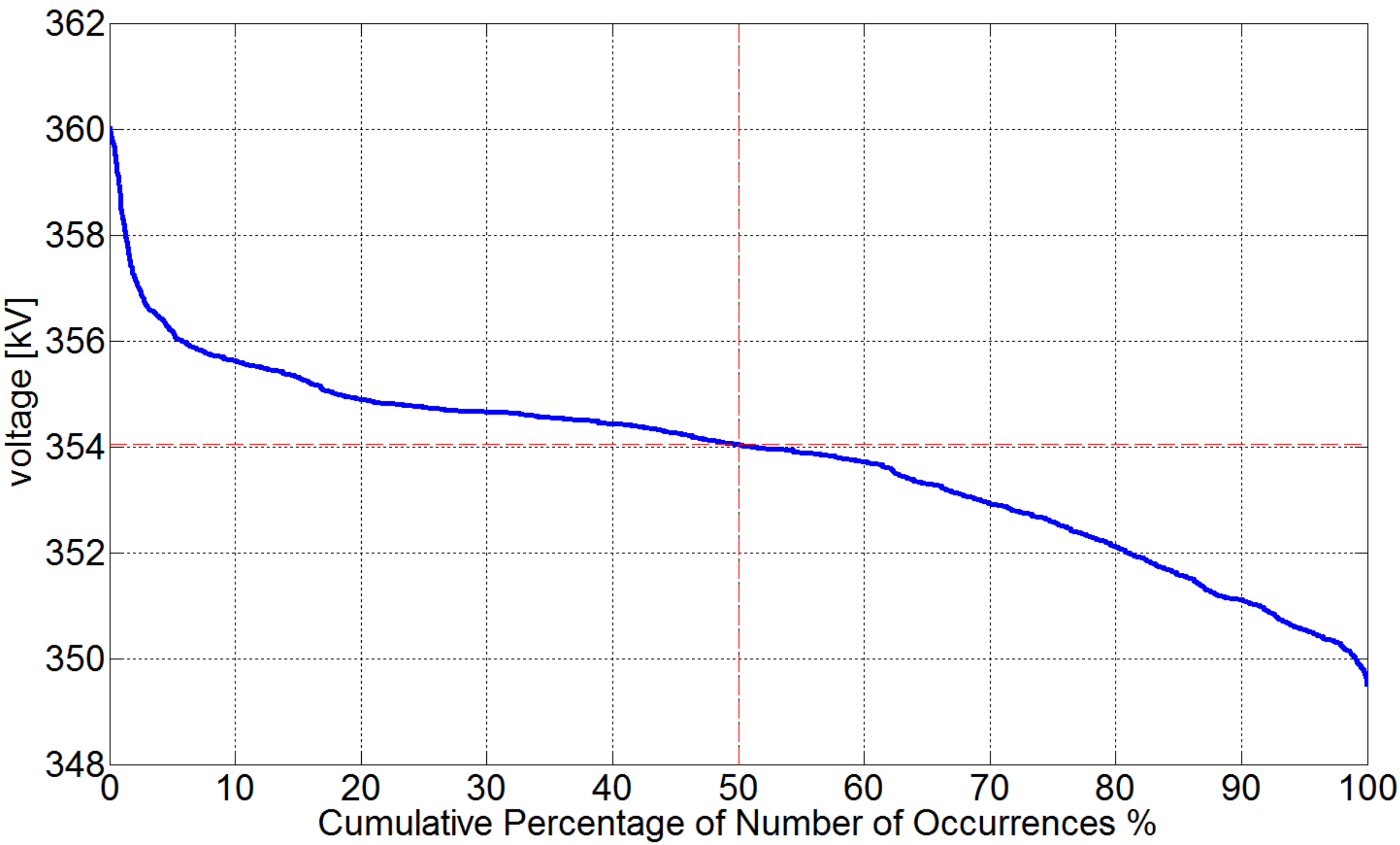
362
360
358
356
354
352
350
348
346
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

West 15*



360
358
356
354
352
350
voltage [kV]
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

West 15*



362
360
358
356
354
352
350
348
voltage [kV]
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

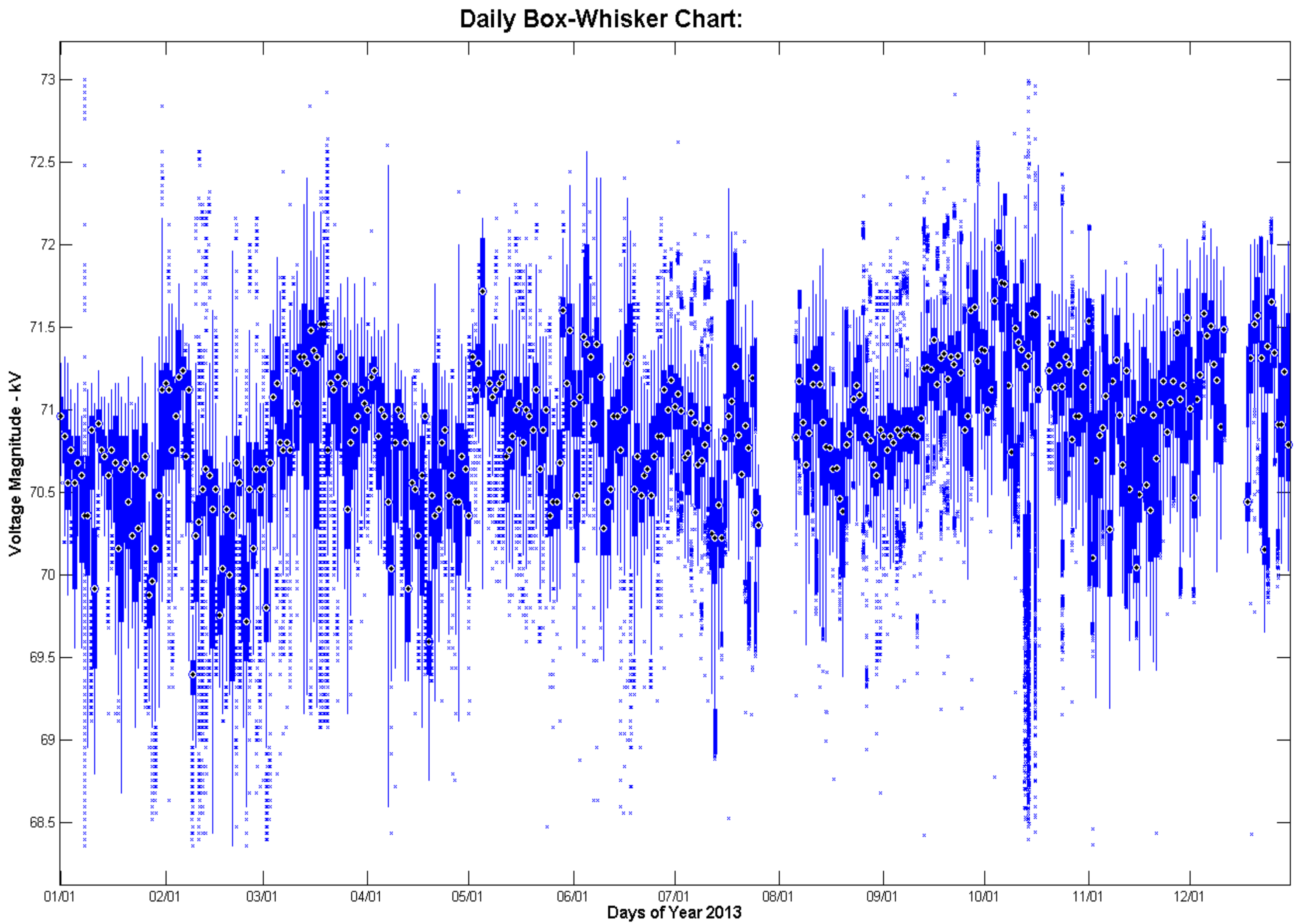
Appendix A – Part 2
CCET Discovery Across Texas project

Baseline Analysis Update #2
Voltage Magnitudes

Phasor Data: January to December 2013
Box-Whisker Plots and Time Duration Curves

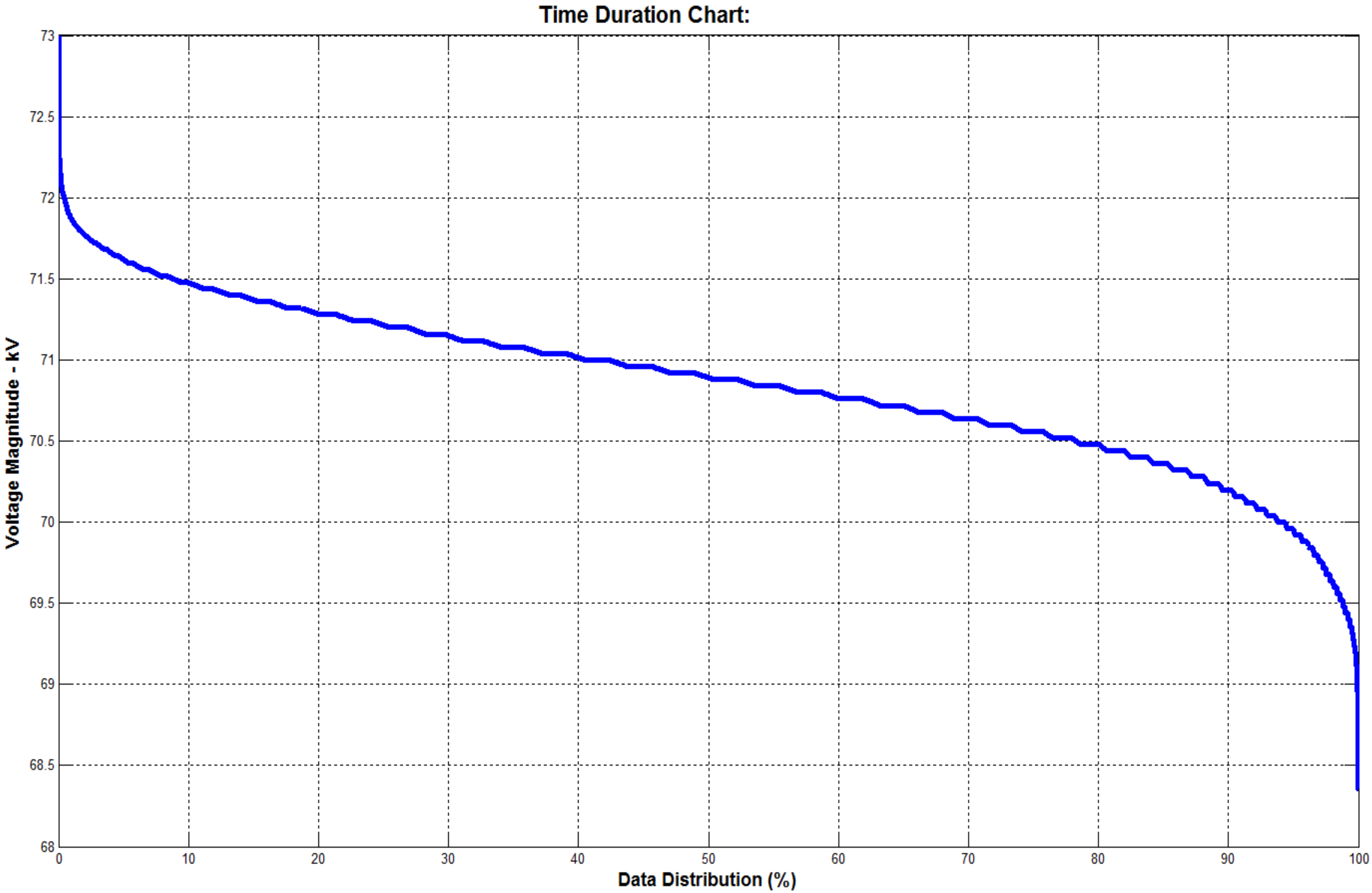
Electric Power Group   CCET   ERCOT

West 10



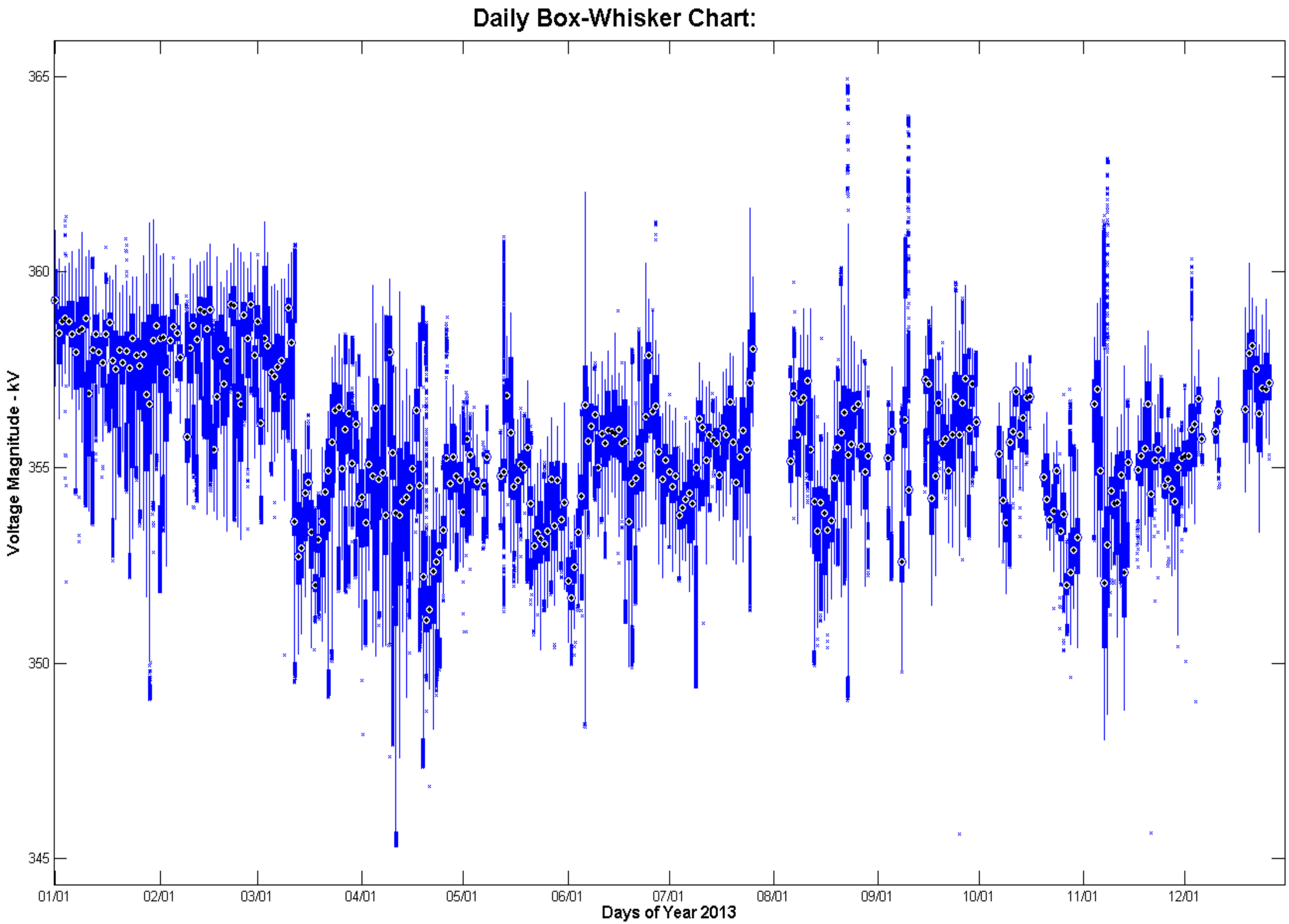
Daily Box-Whisker Chart:
Voltage Magnitude - kV
73
72.5
72
71.5
71
70.5
70
69.5
69
68.5
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 10

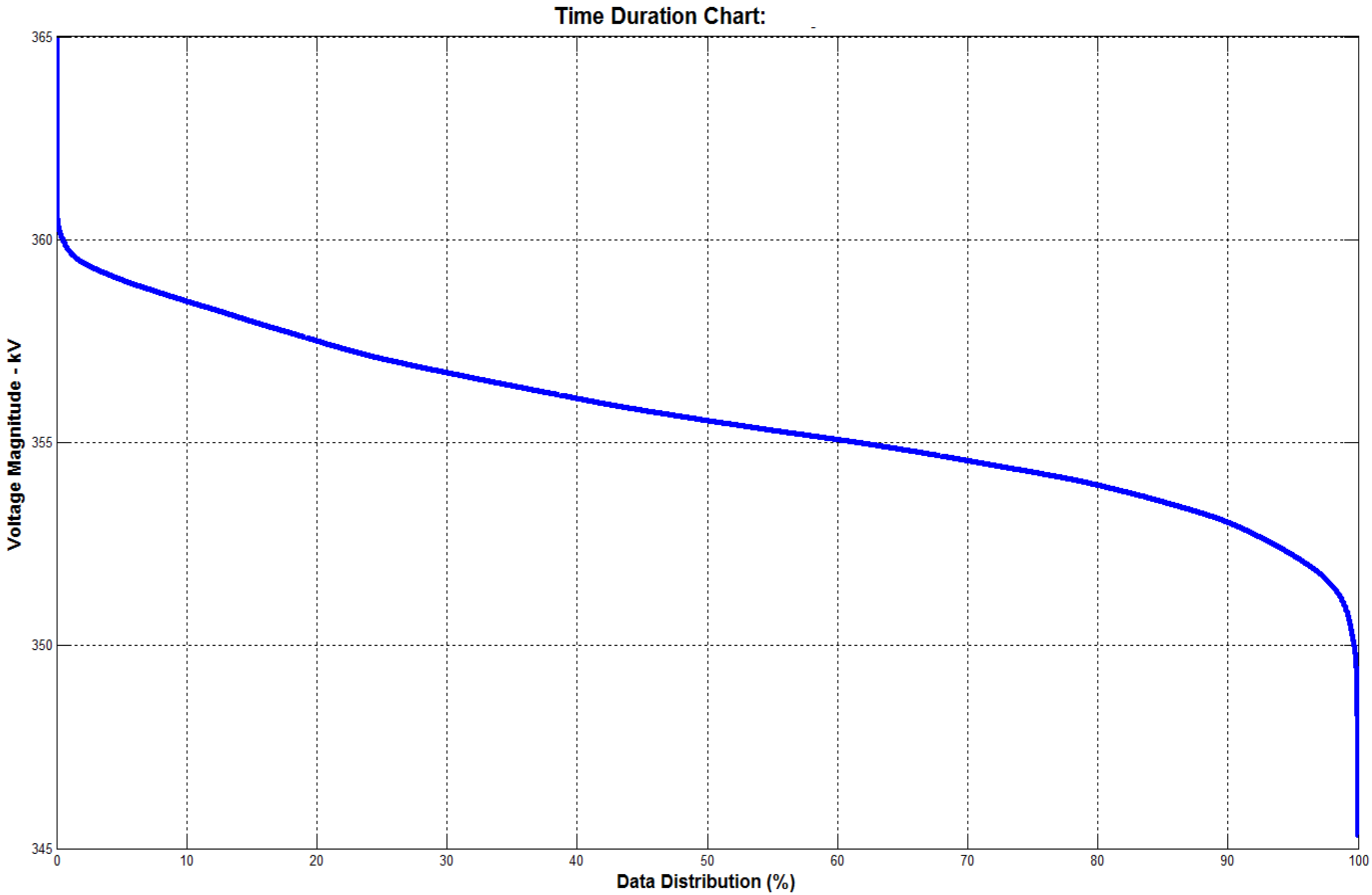


Time Duration Chart:
Voltage Magnitude - kV
73
72.5
72
71.5
71
70.5
70
69.5
69
68.5
68
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 14

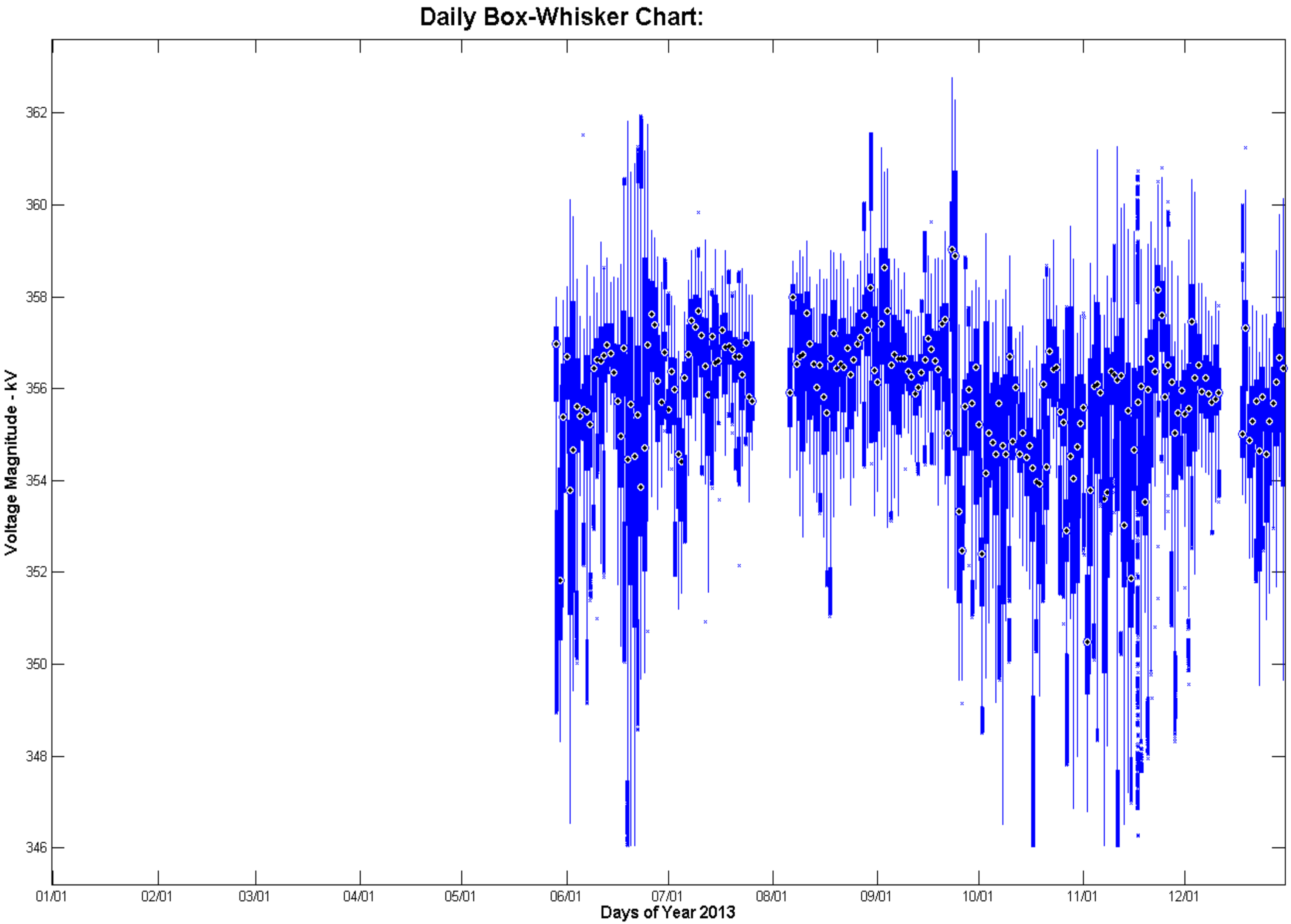

Daily Box-Whisker Chart:
Voltage Magnitude - kV
365
360
355
350
345
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 14



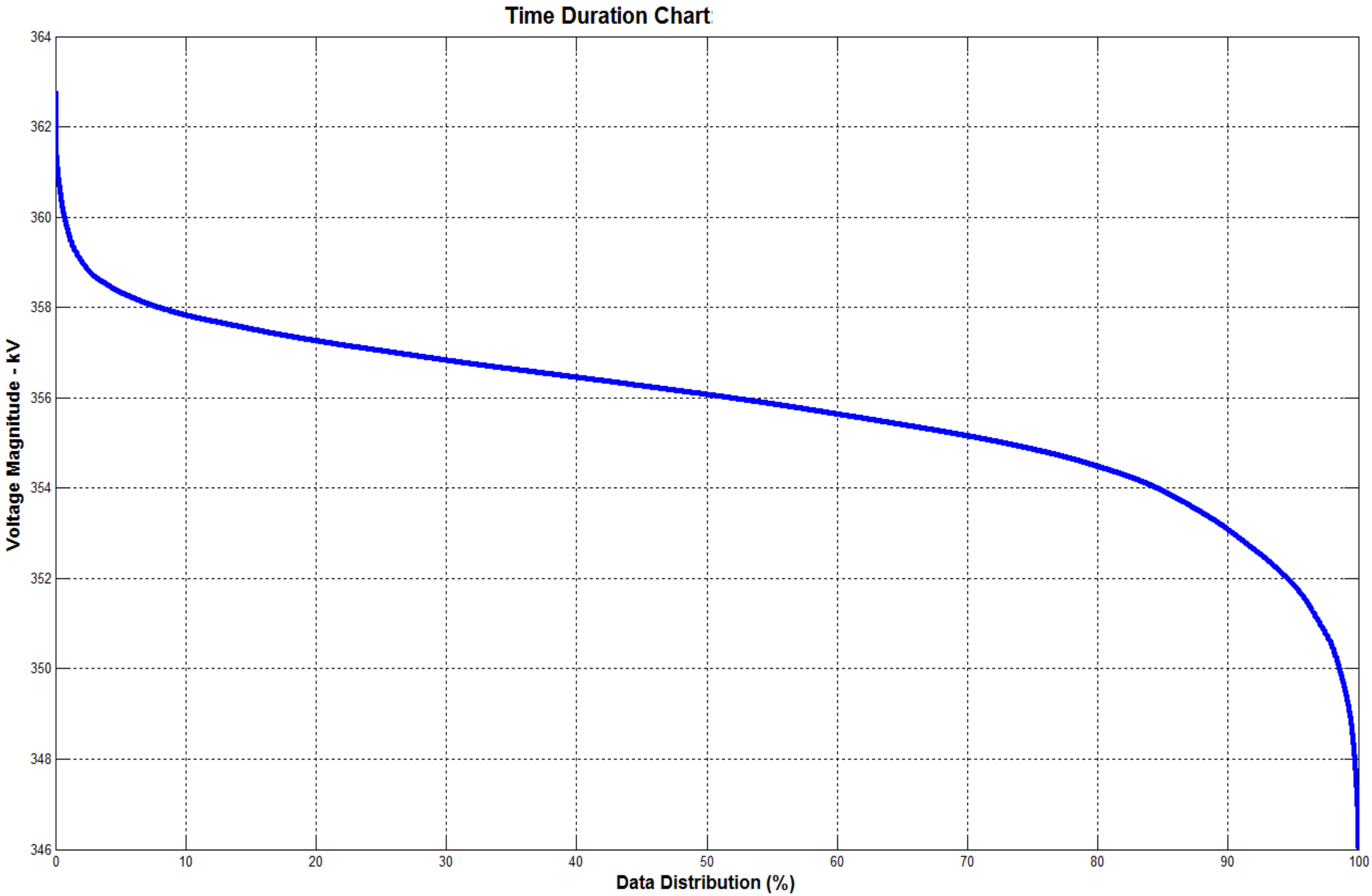
Time Duration Chart:
365
360
355
350
345
0
10
20
30
40
50
60
70
80
90
100
Voltage Magnitude - kV
Data Distribution (%)

West 1



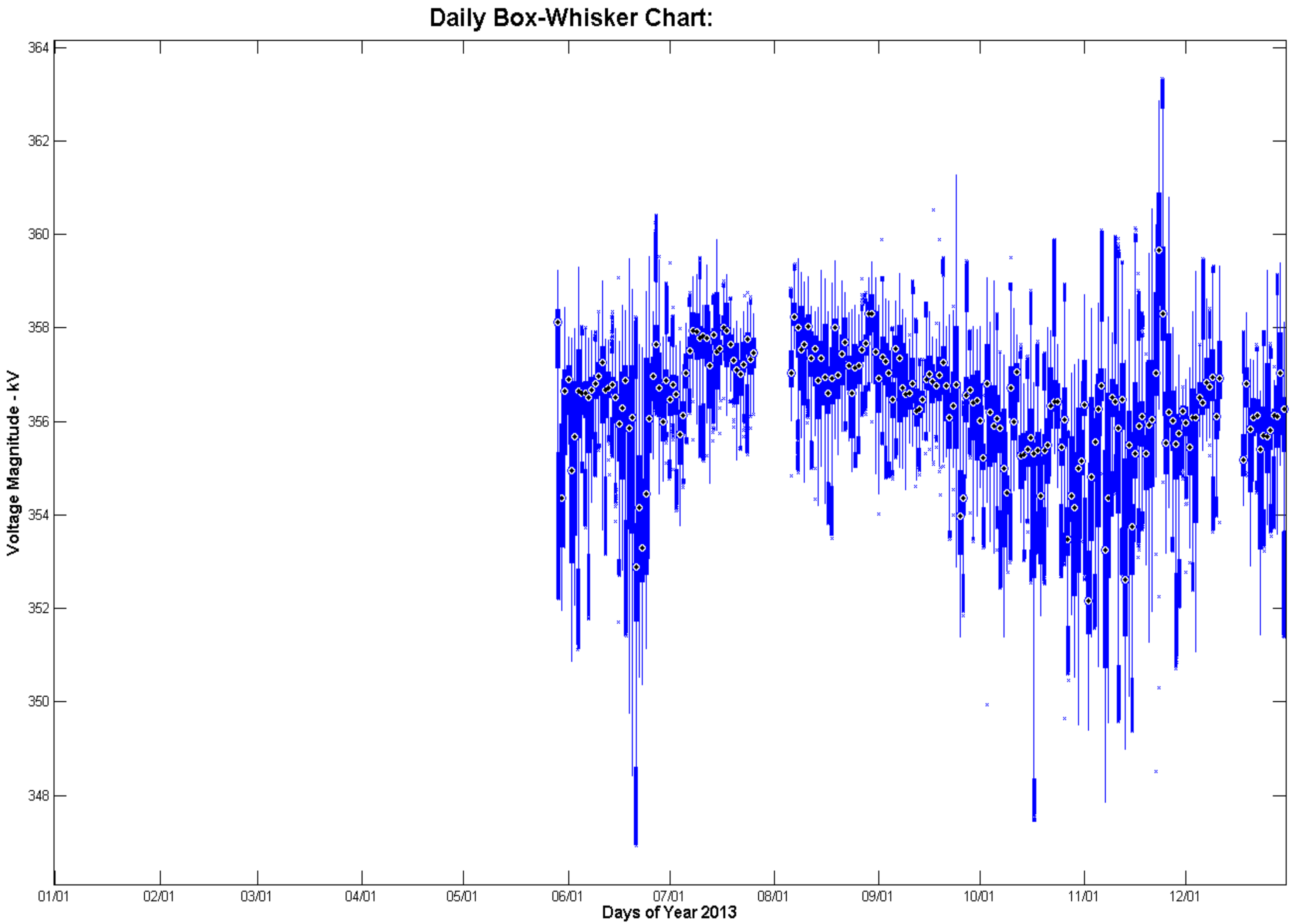
Daily Box-Whisker Chart:
Voltage Magnitude - kV
362
360
358
356
354
352
350
348
346
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 1



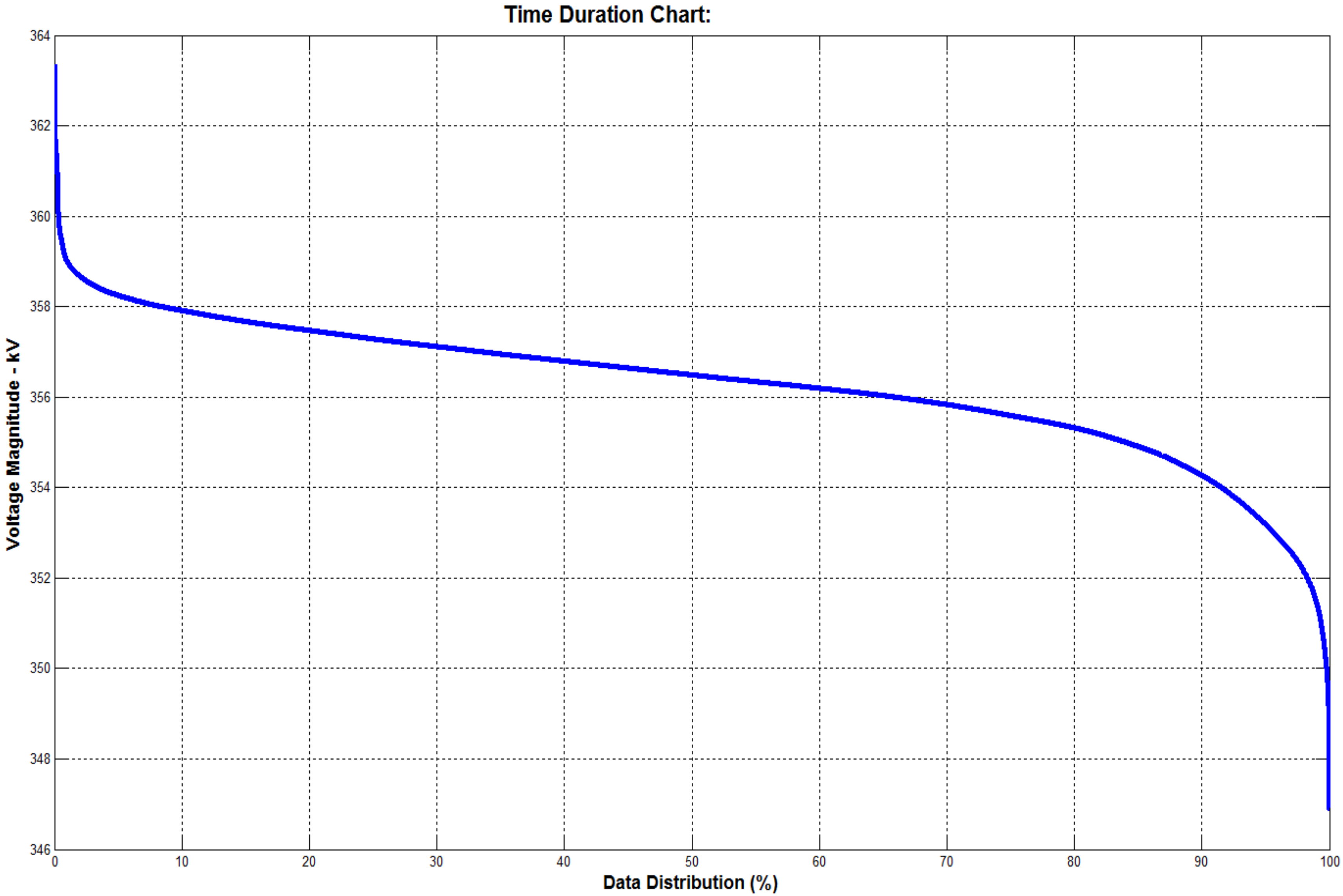
Time Duration Chart
Voltage Magnitude - kV
Data Distribution (%)
364
362
360
358
356
354
352
350
348
346
0
10
20
30
40
50
60
70
80
90
100

West 2



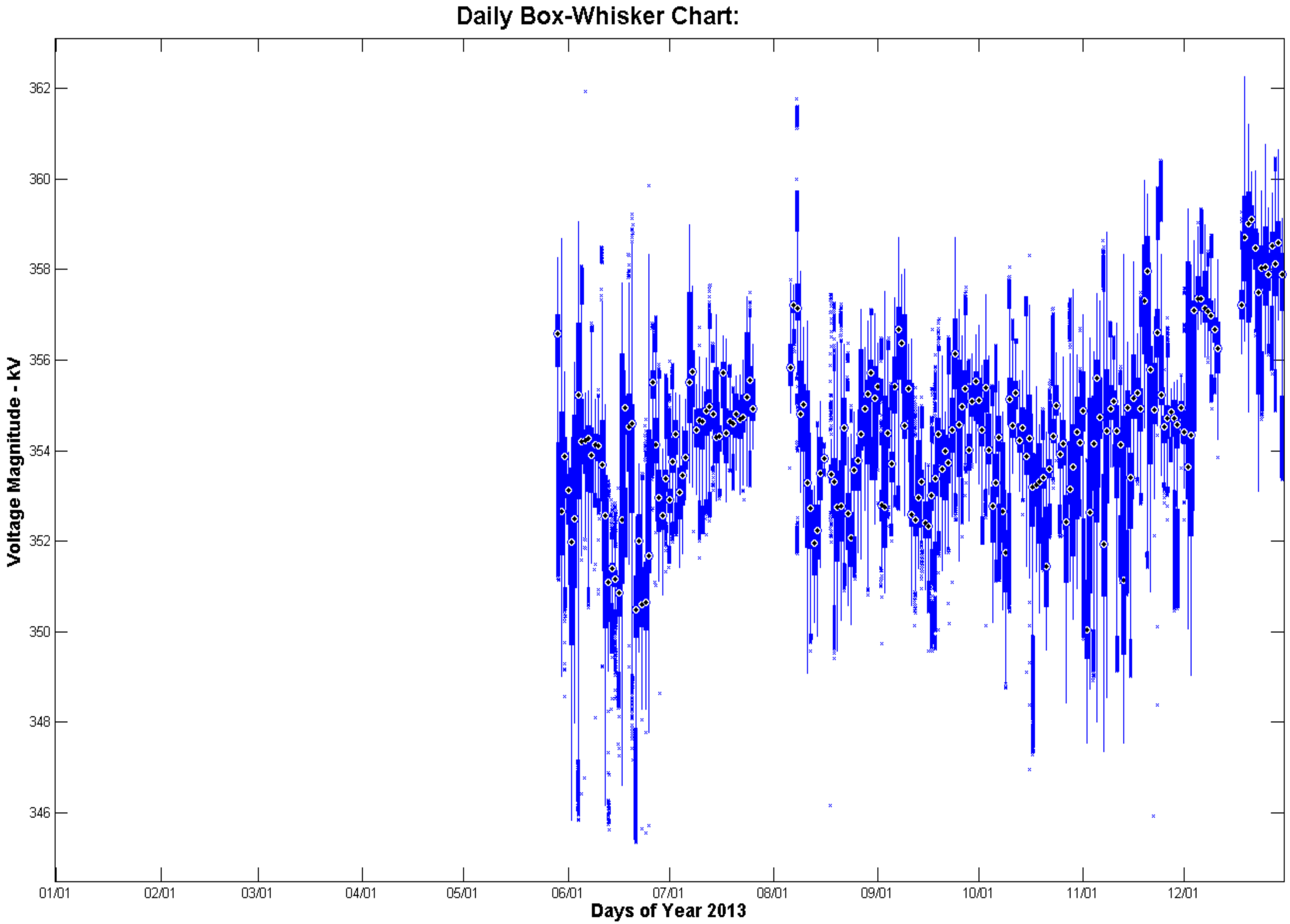
Daily Box-Whisker Chart:
364
362
360
358
356
354
352
350
348
Voltage Magnitude - kV
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 2

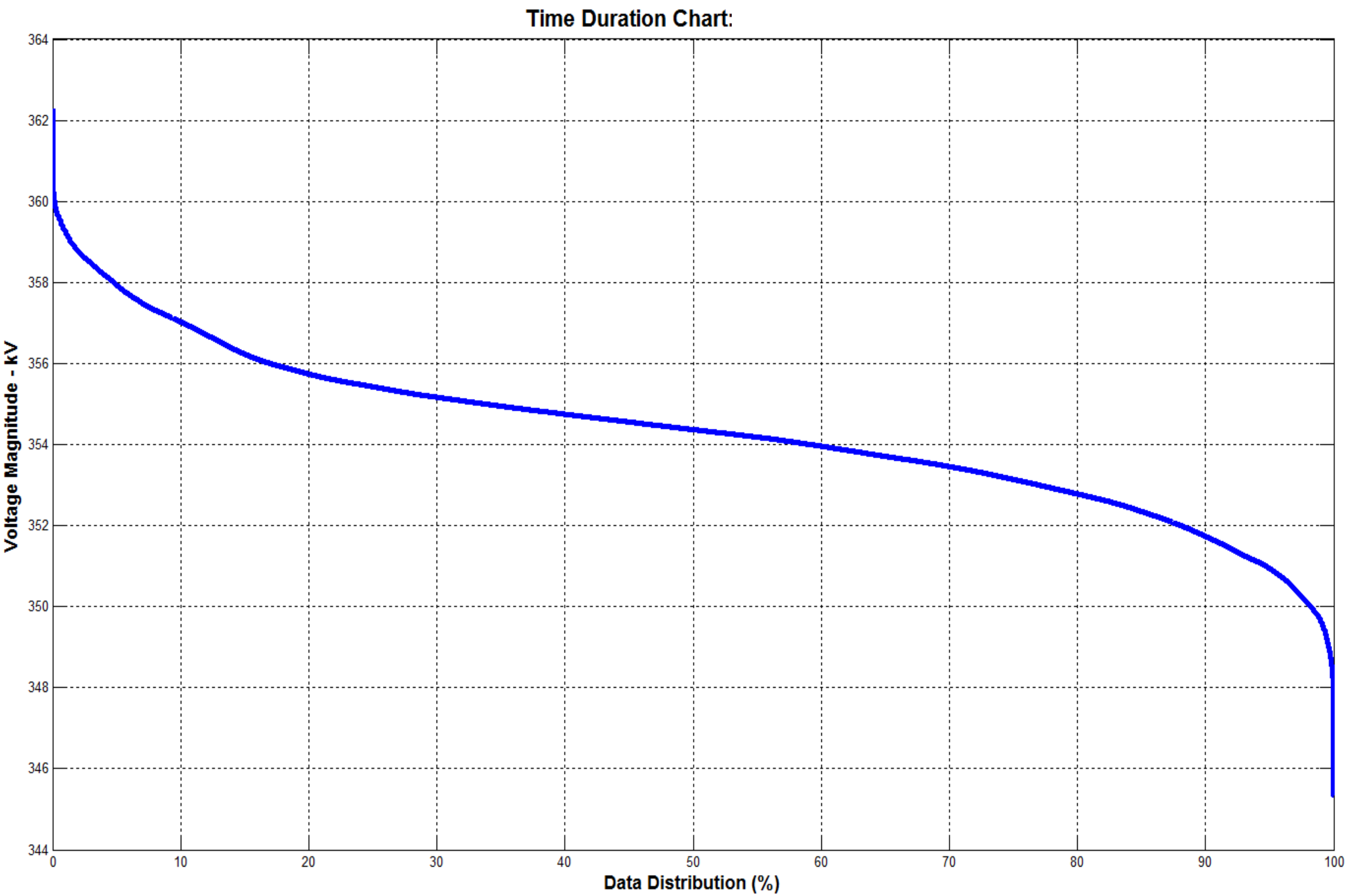


Time Duration Chart:
364
362
360
358
356
354
352
350
348
346
Voltage Magnitude - kV
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

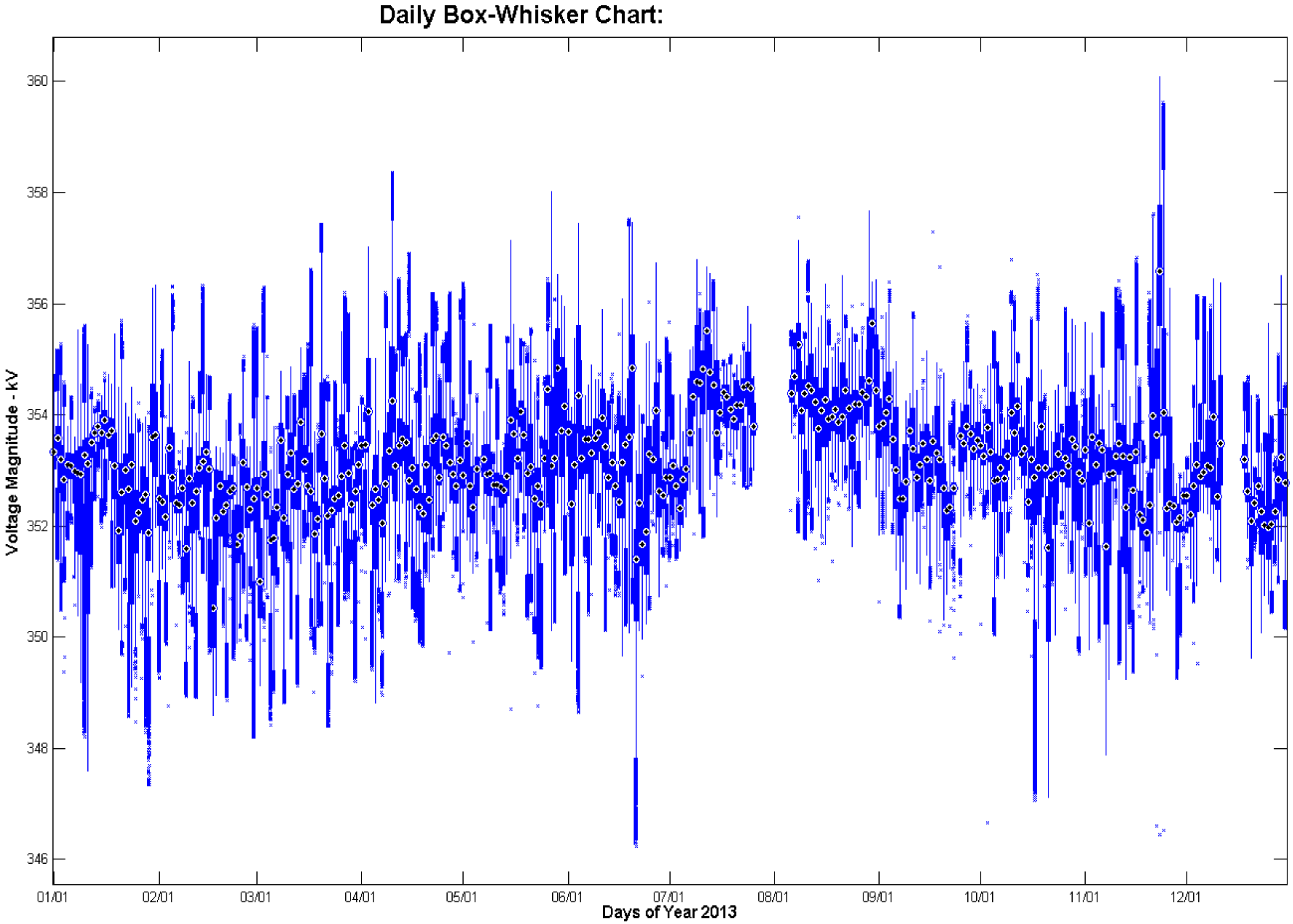
West 9


Daily Box-Whisker Chart:
Voltage Magnitude - kV
362
360
358
356
354
352
350
348
346
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 9

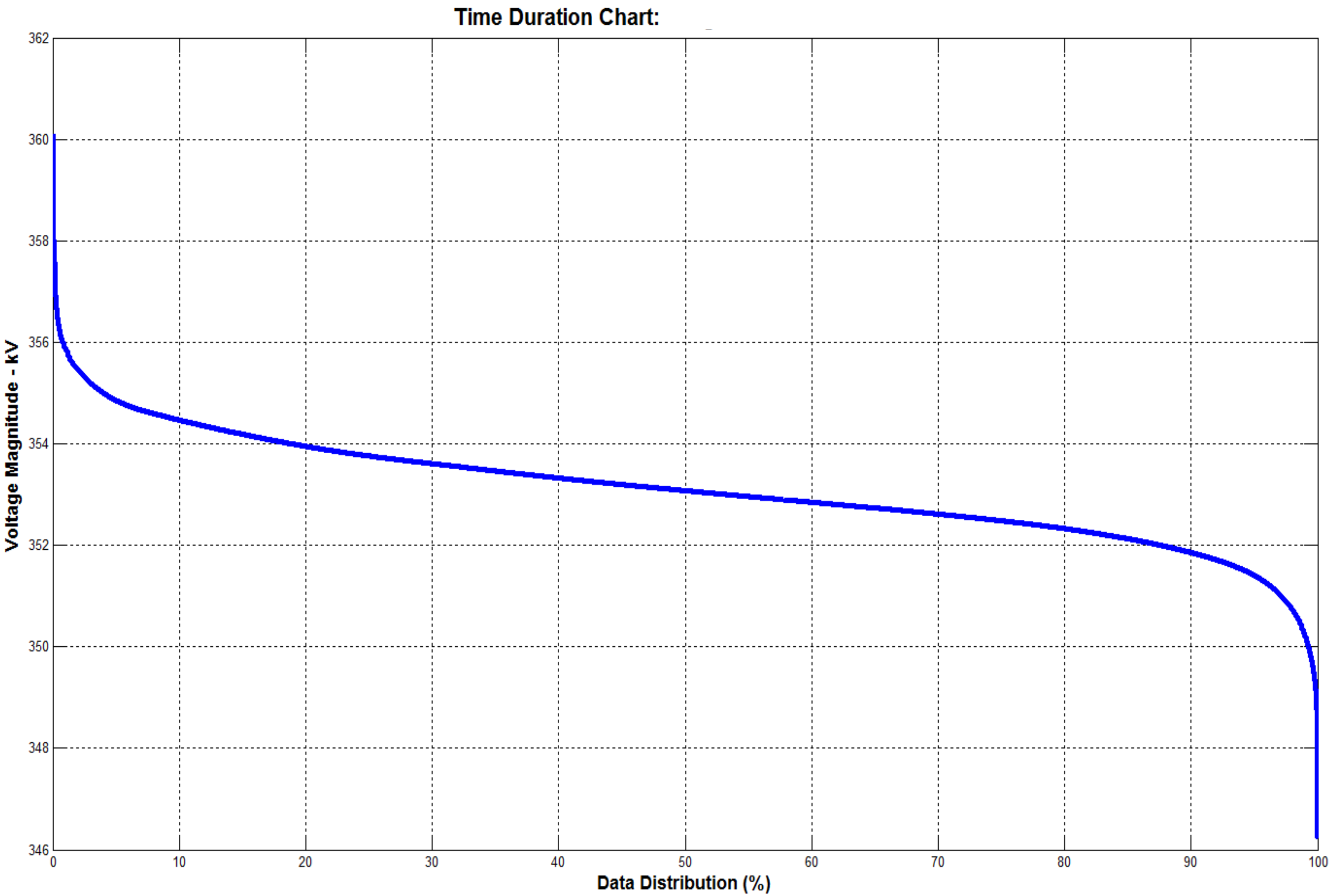

Time Duration Chart:
Voltage Magnitude - kV
Data Distribution (%)
364
362
360
358
356
354
352
350
348
346
344
0
10
20
30
40
50
60
70
80
90
100

West 11



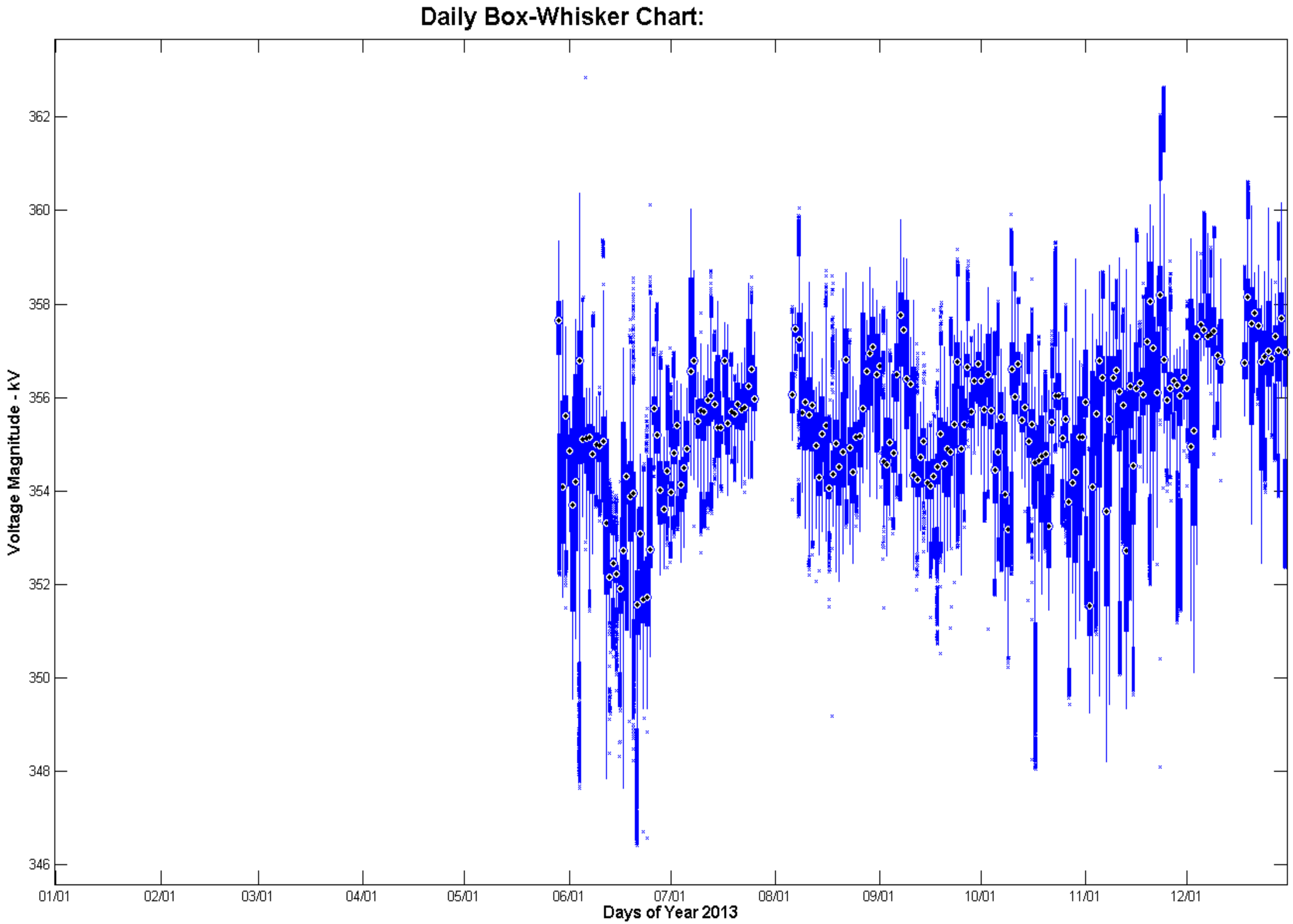
Daily Box-Whisker Chart:
Voltage Magnitude - kV
360
358
356
354
352
350
348
346
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 11

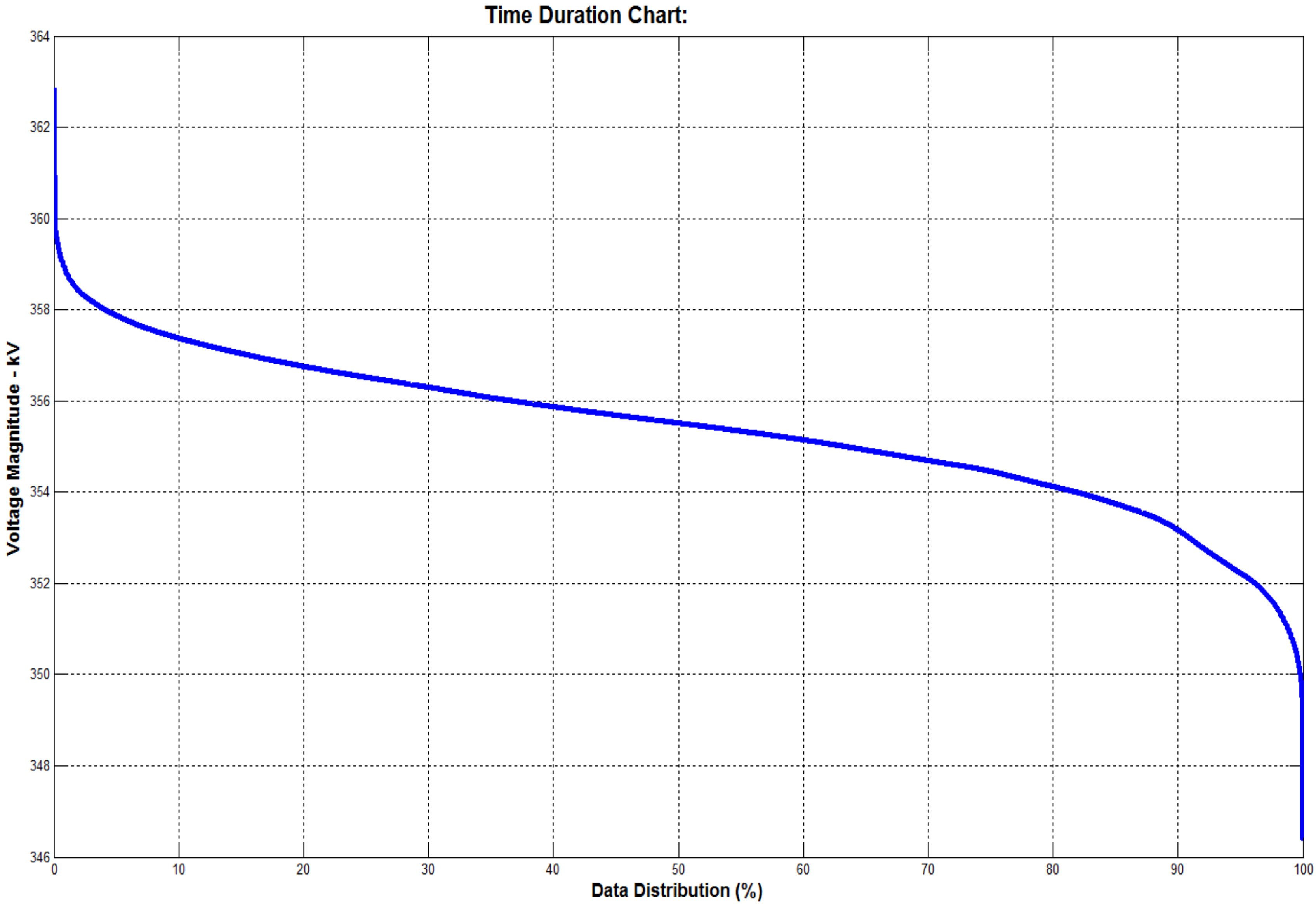


Time Duration Chart:
Voltage Magnitude - kV
362
360
358
356
354
352
350
348
346
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 12

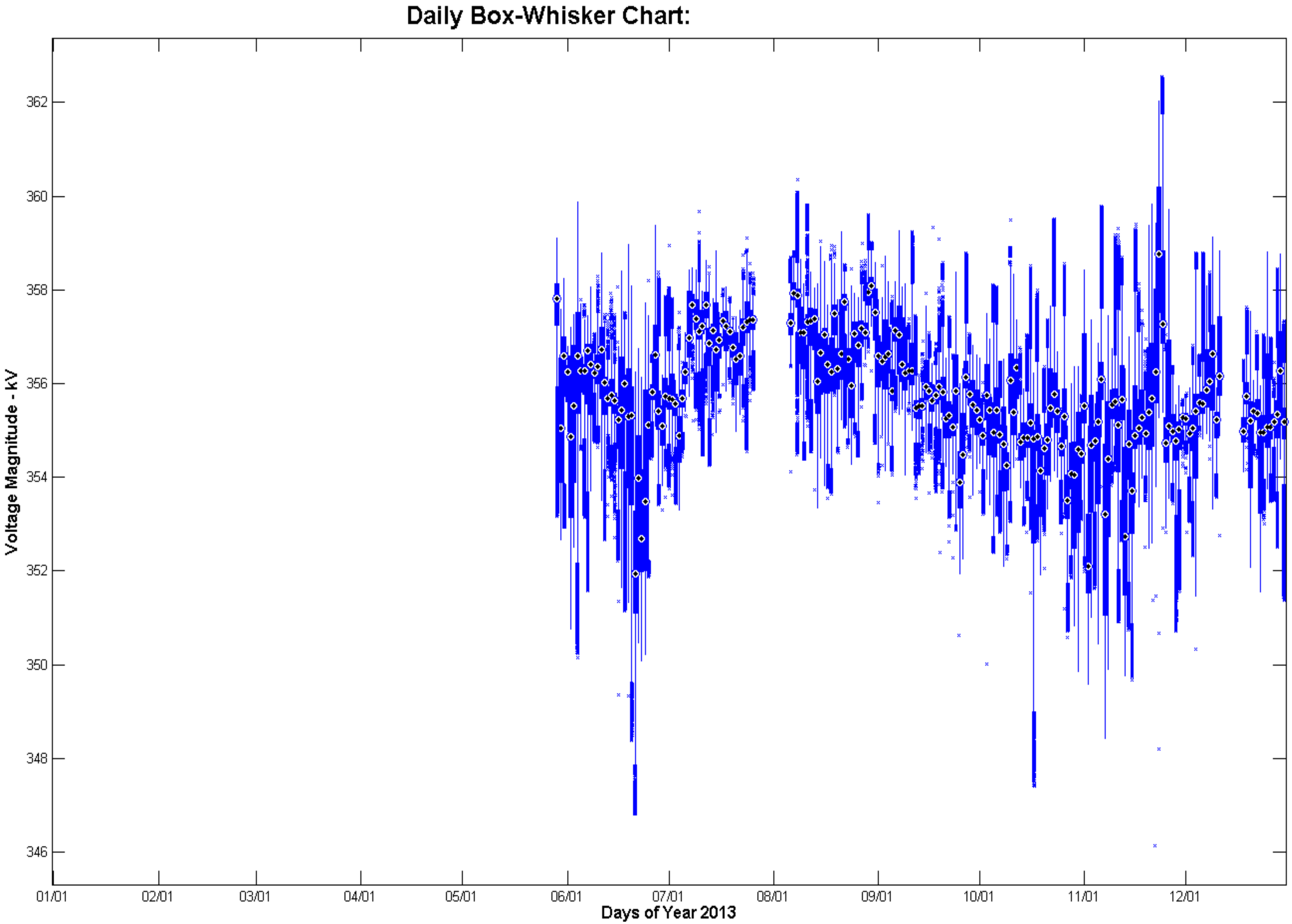

Daily Box-Whisker Chart:
Voltage Magnitude - kV
346
348
350
352
354
356
358
360
362
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 12



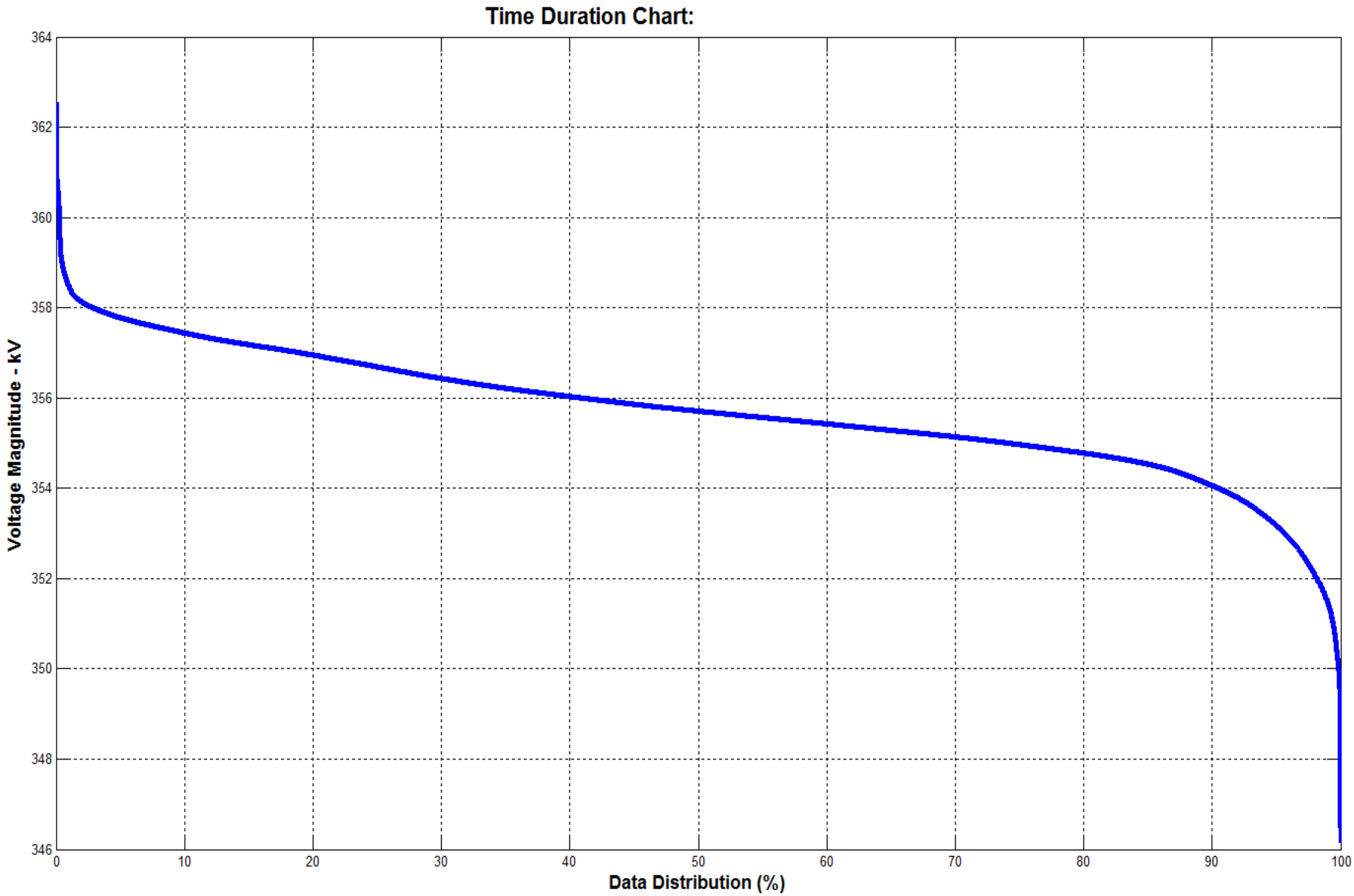
Time Duration Chart:
364
362
360
358
356
354
352
350
348
346
Voltage Magnitude - kV
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 5

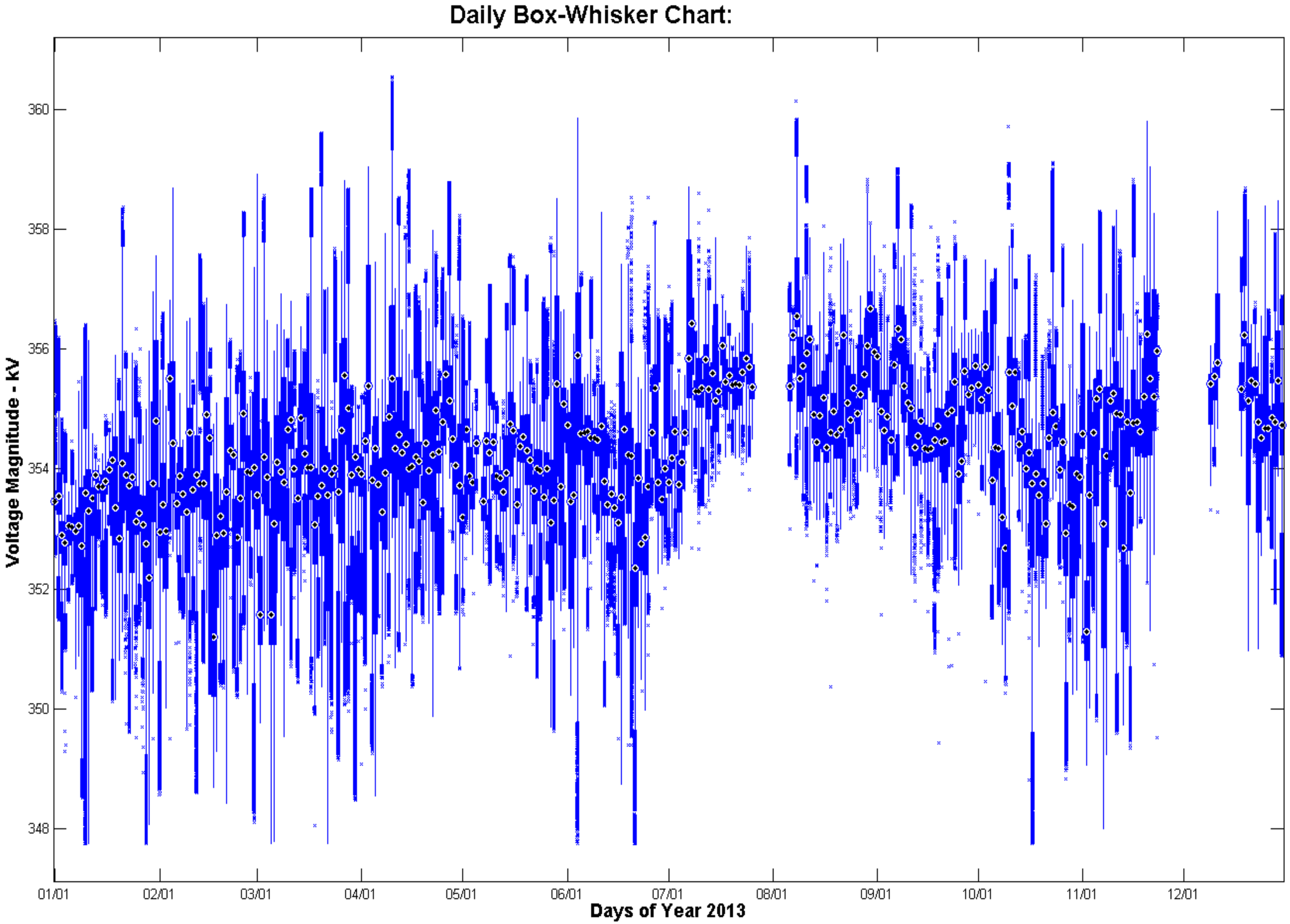


Daily Box-Whisker Chart:
Voltage Magnitude - kV
362
360
358
356
354
352
350
348
346
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 5

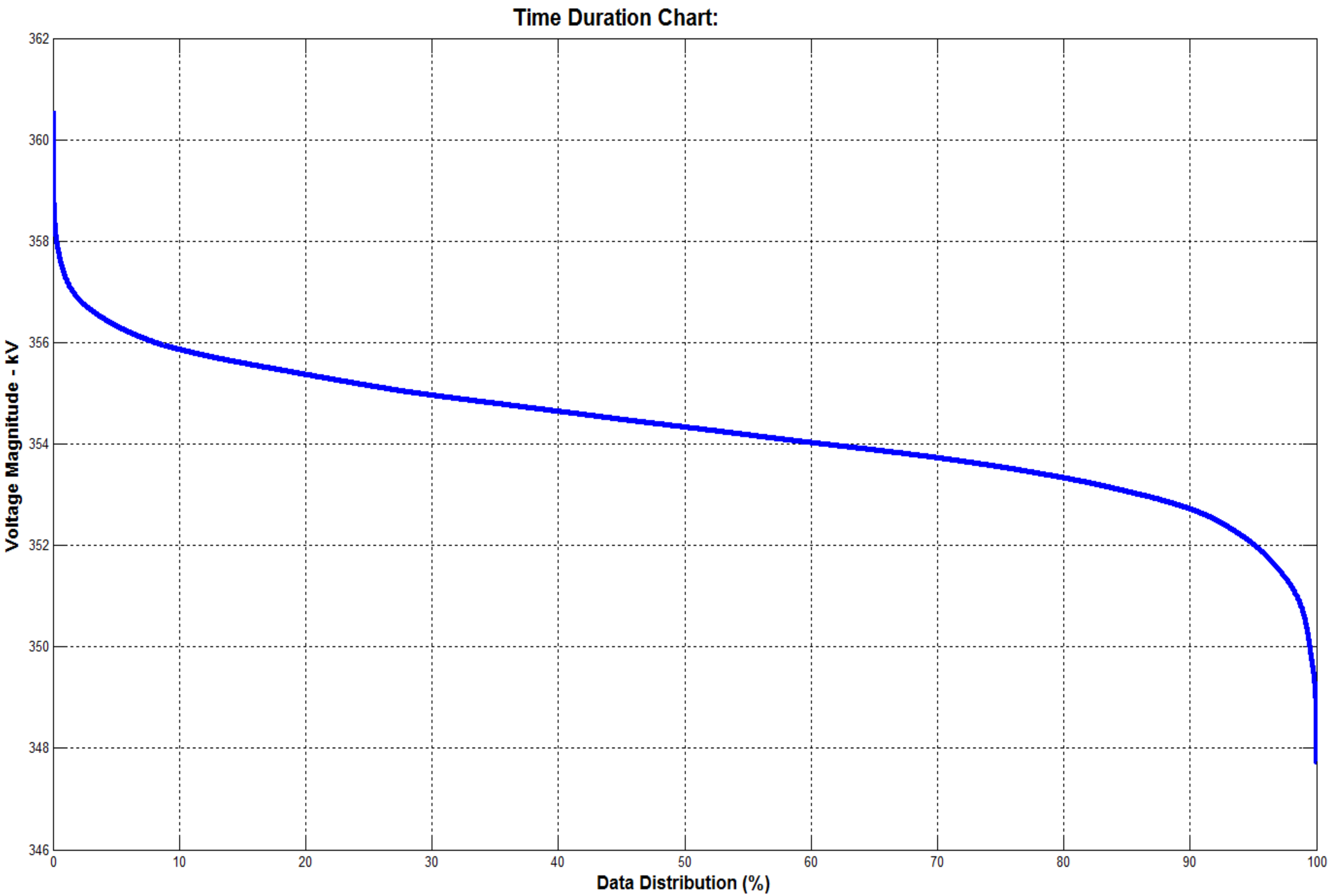

Time Duration Chart:
Voltage Magnitude - kV
364
362
360
358
356
354
352
350
348
346
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 6



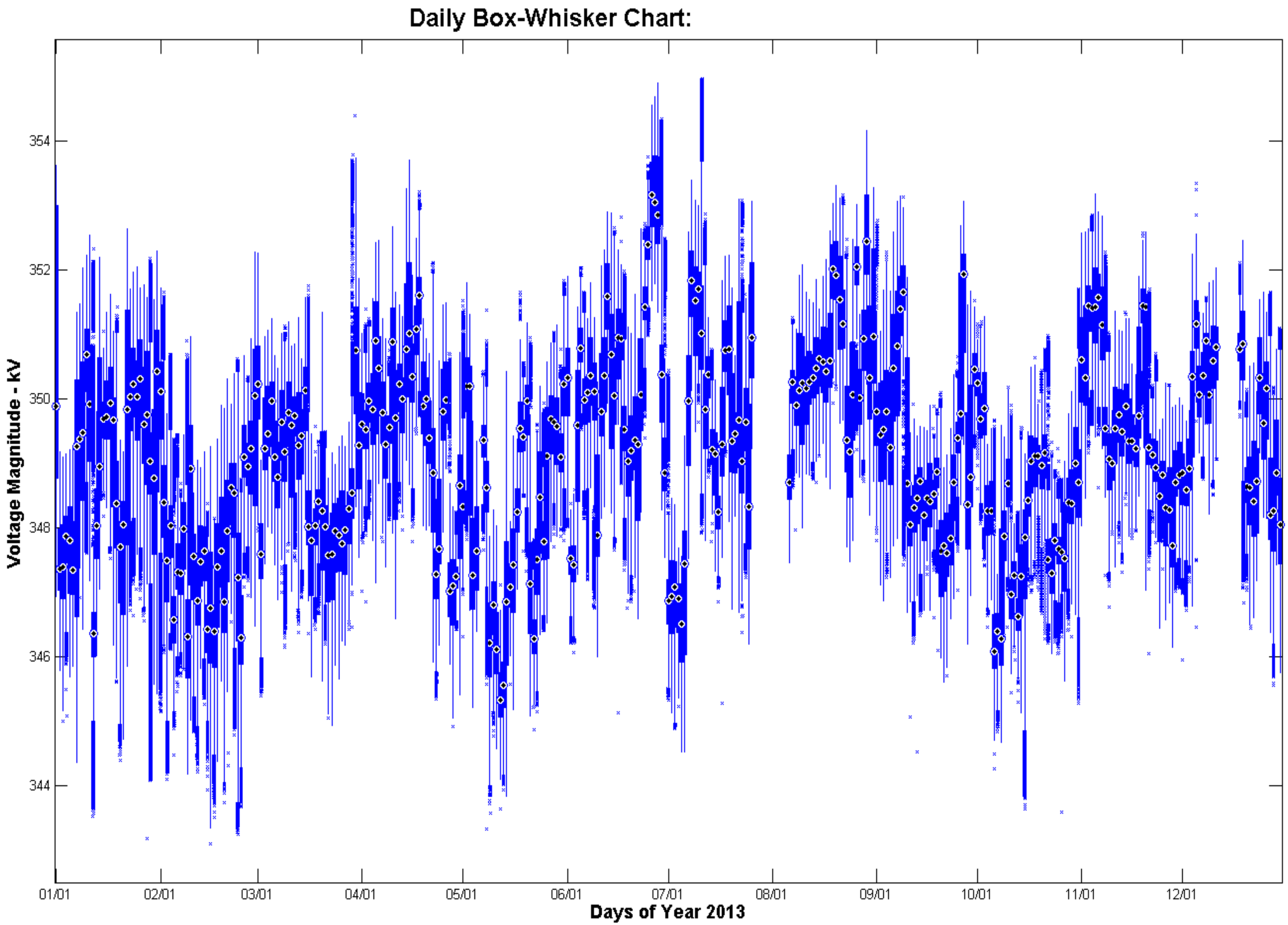
Daily Box-Whisker Chart:
Voltage Magnitude - kV
360
358
356
354
352
350
348
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 6



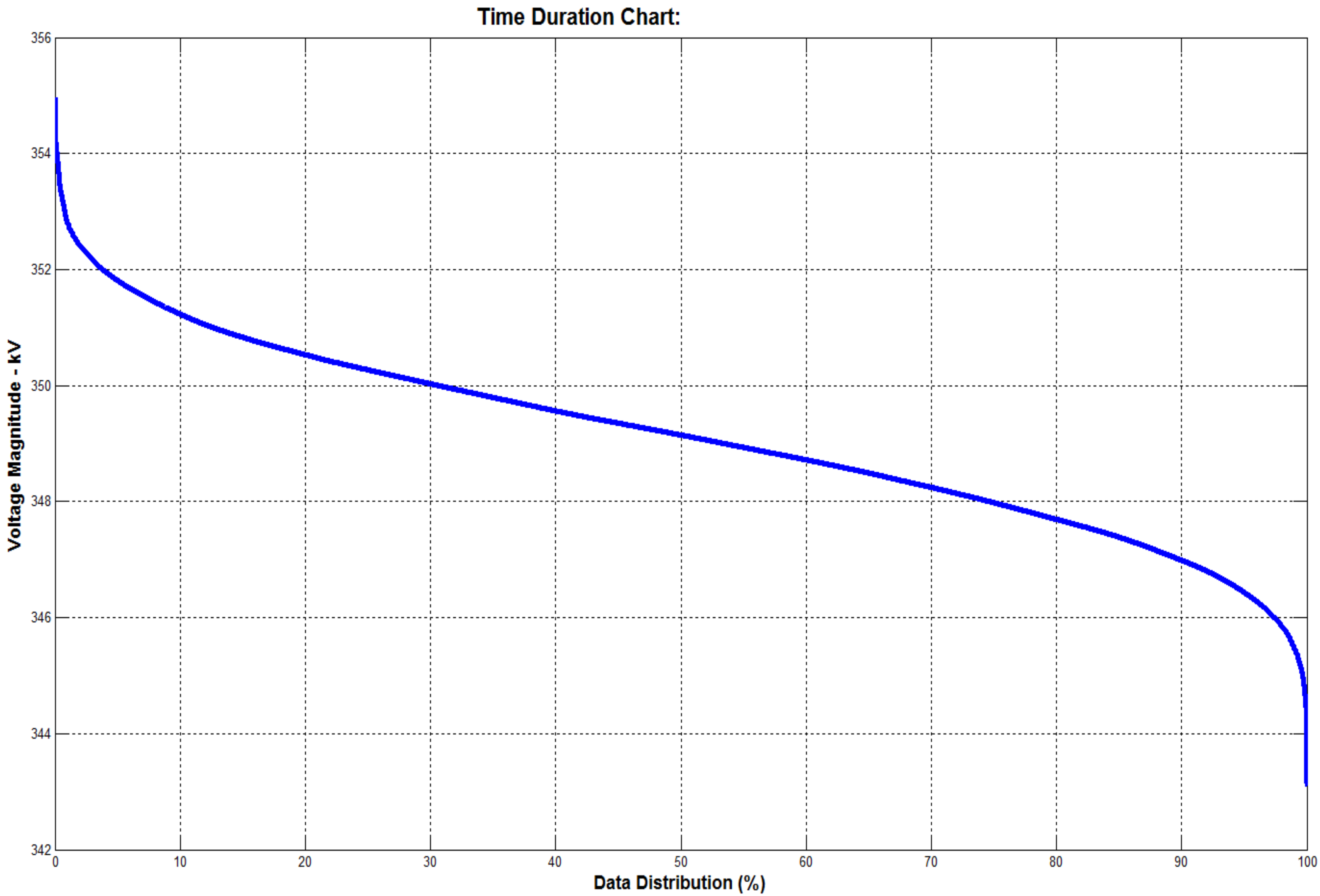
Time Duration Chart:
Voltage Magnitude - kV
362
360
358
356
354
352
350
348
346
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

North 1

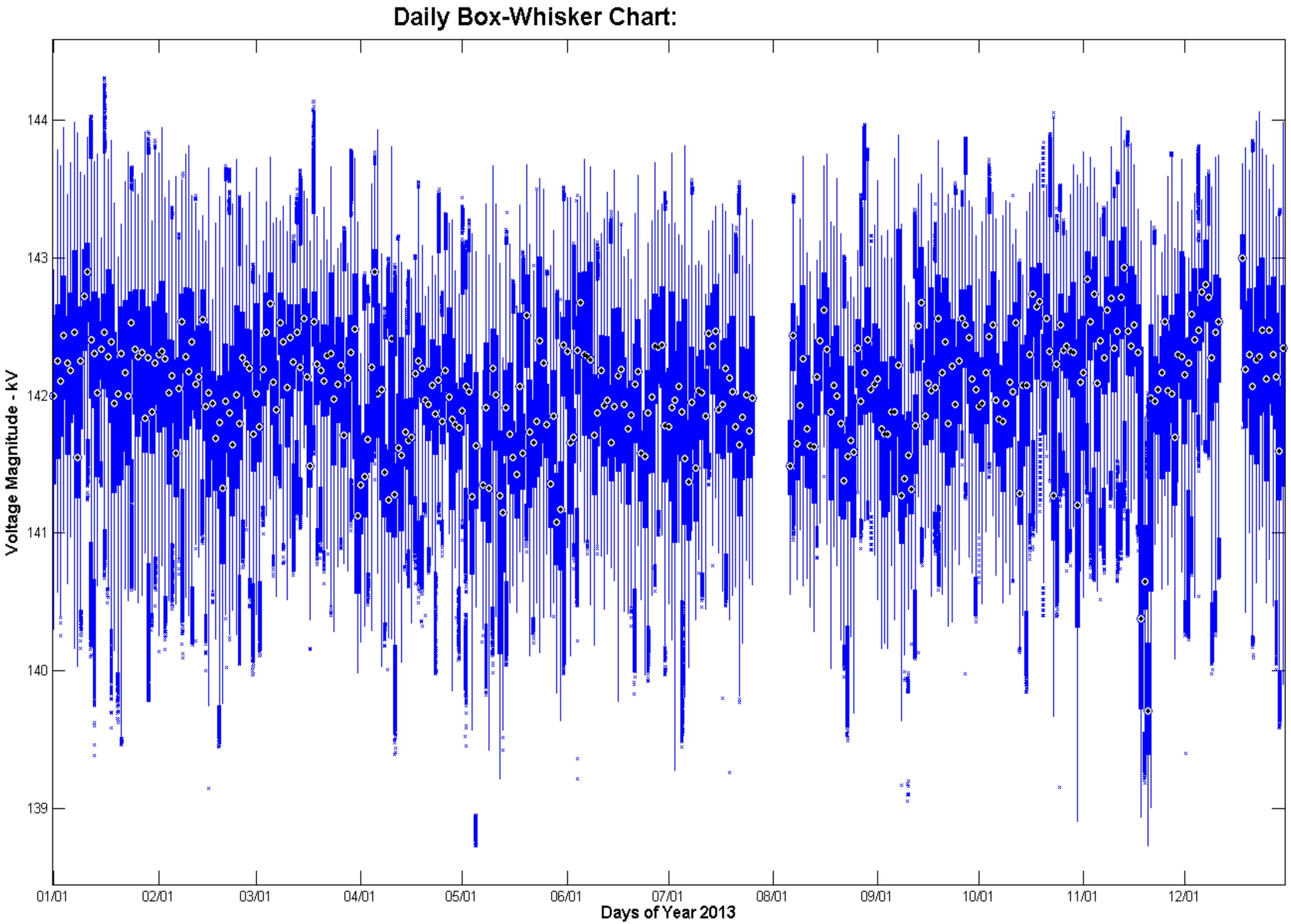


Daily Box-Whisker Chart:
Voltage Magnitude - kV
354
352
350
348
346
344
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

North 1

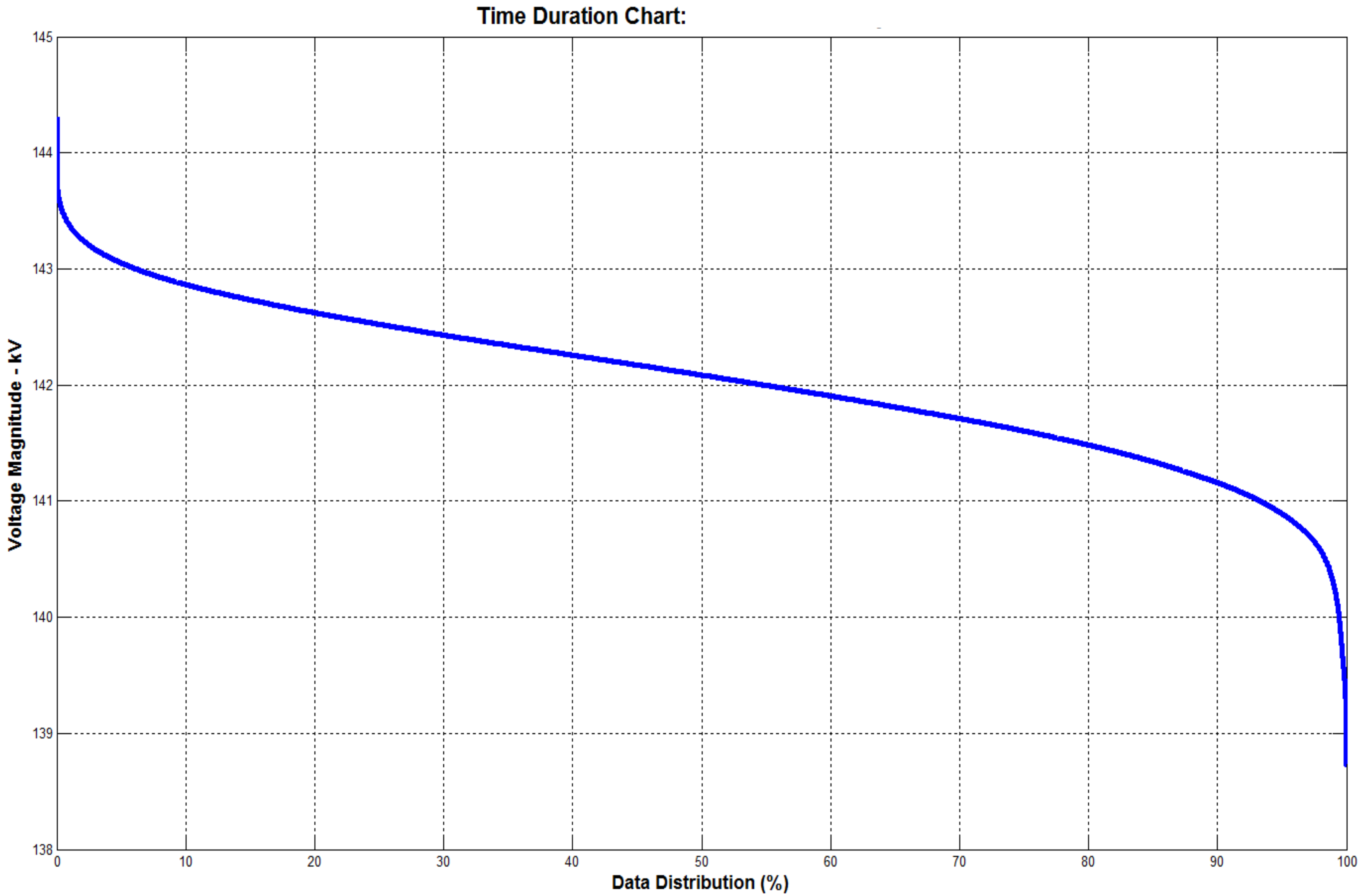

Time Duration Chart:
Voltage Magnitude - kV
356
354
352
350
348
346
344
342
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

North 4



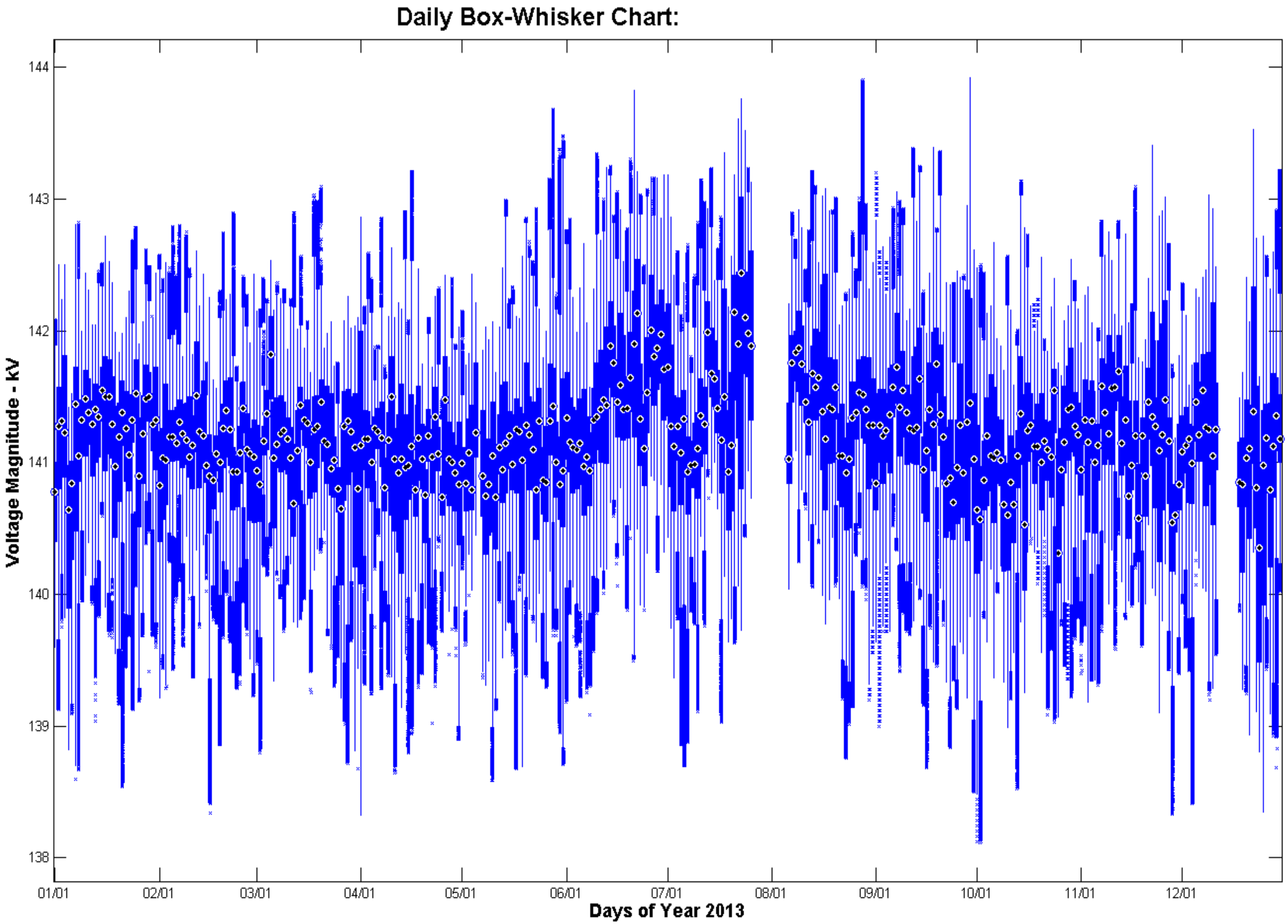
Daily Box-Whisker Chart:
Voltage Magnitude - kV
144
143
142
141
140
139
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

North 4



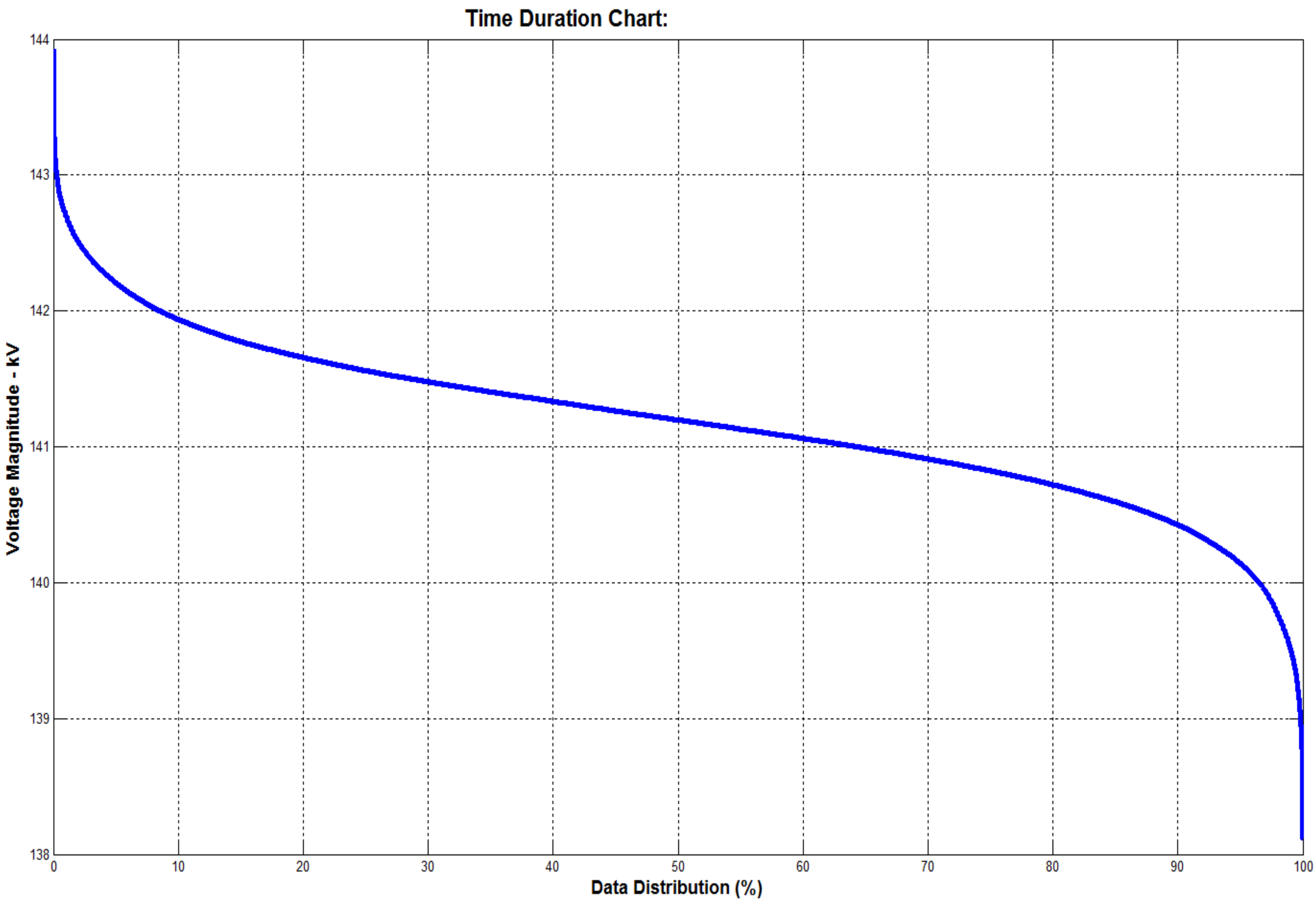
Time Duration Chart:
Voltage Magnitude - kV
145
144
143
142
141
140
139
138
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

North 5

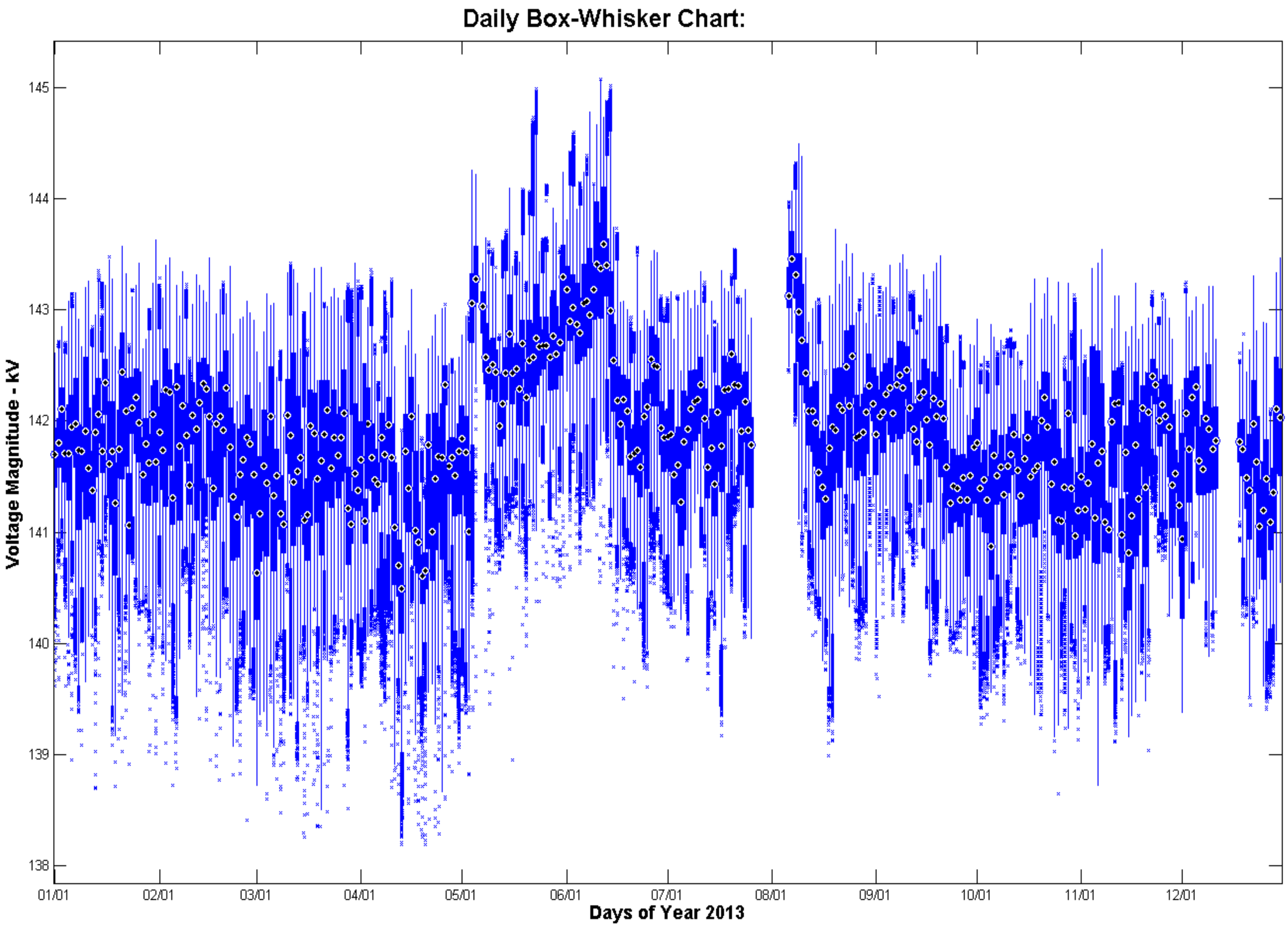


Daily Box-Whisker Chart:
144
143
142
141
140
139
138
Voltage Magnitude - kV
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

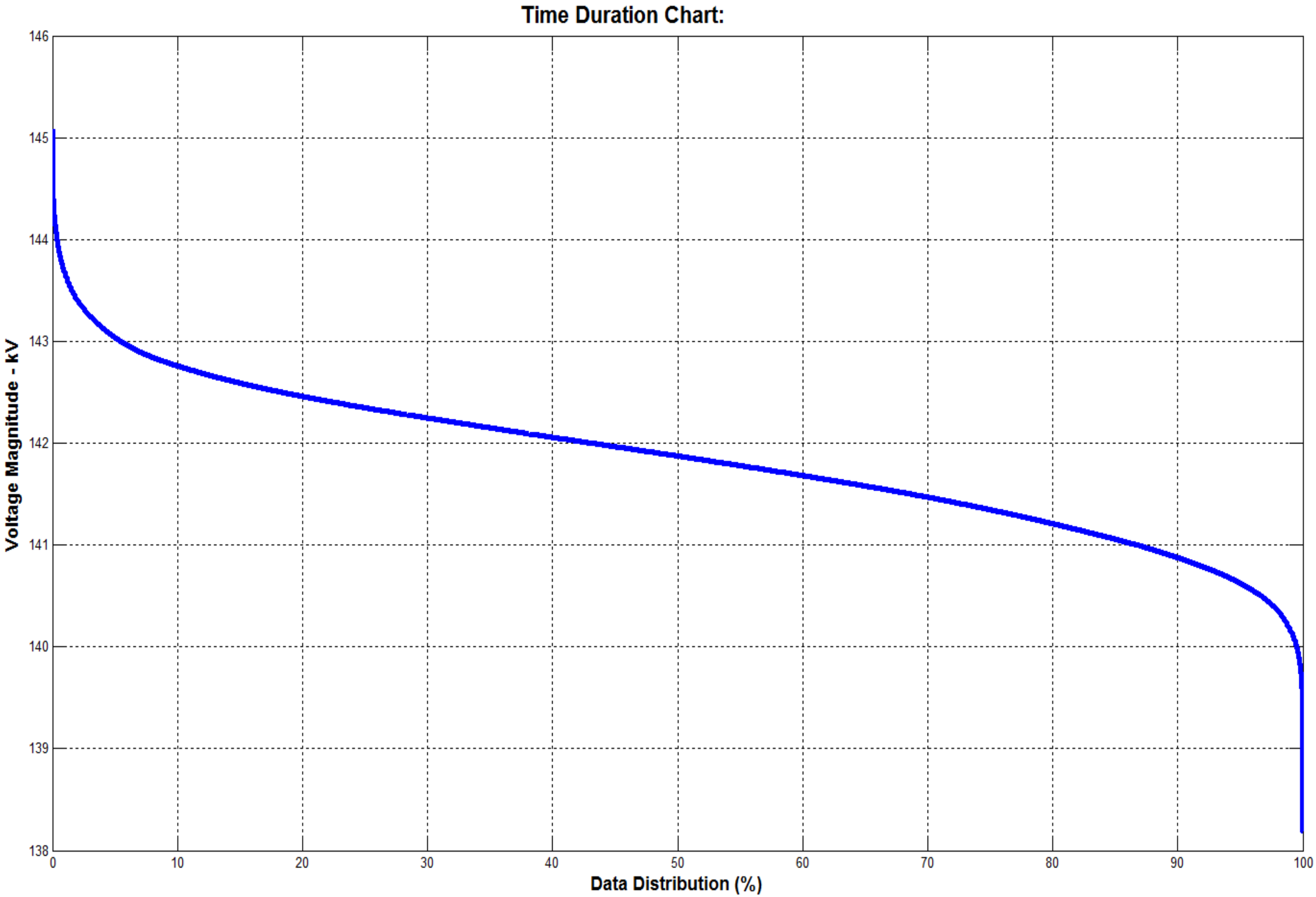
North 5


Time Duration Chart:
Voltage Magnitude - kV
144
143
142
141
140
139
138
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

North 6

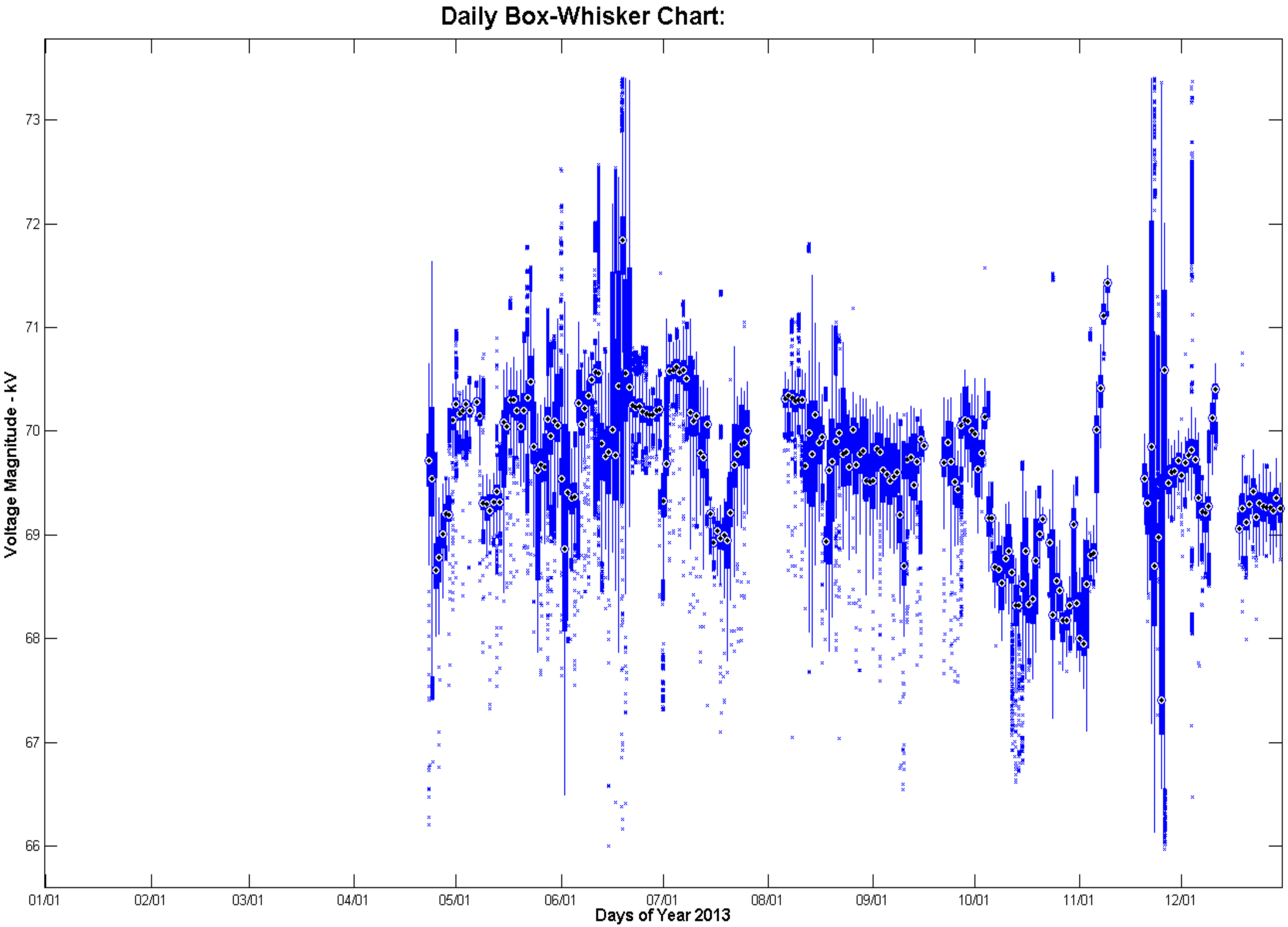

Daily Box-Whisker Chart:
Voltage Magnitude - kV
145
144
143
142
141
140
139
138
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

North 6



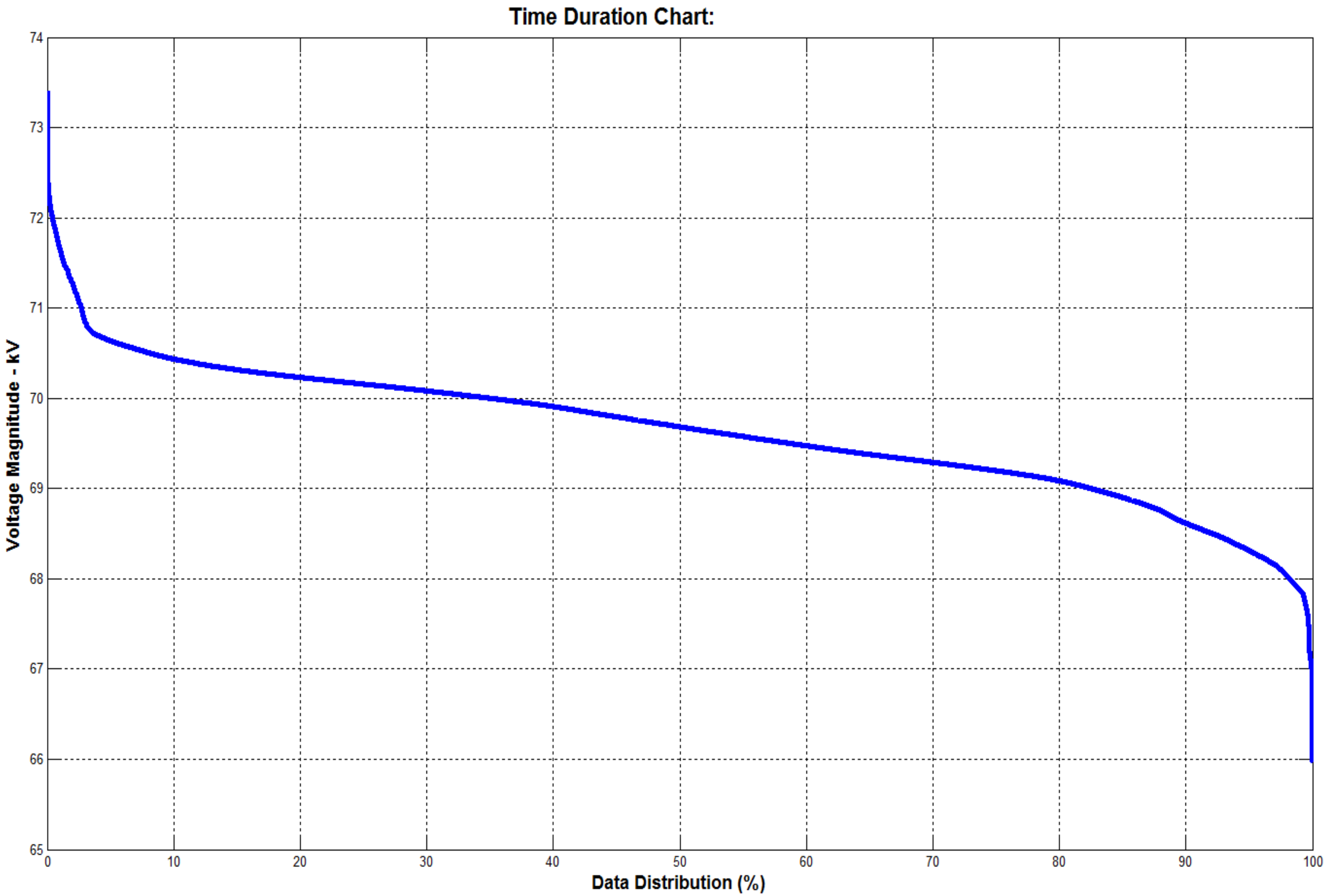
Time Duration Chart:
146
145
144
143
142
141
140
139
138
Voltage Magnitude - kV
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

FarWest 2



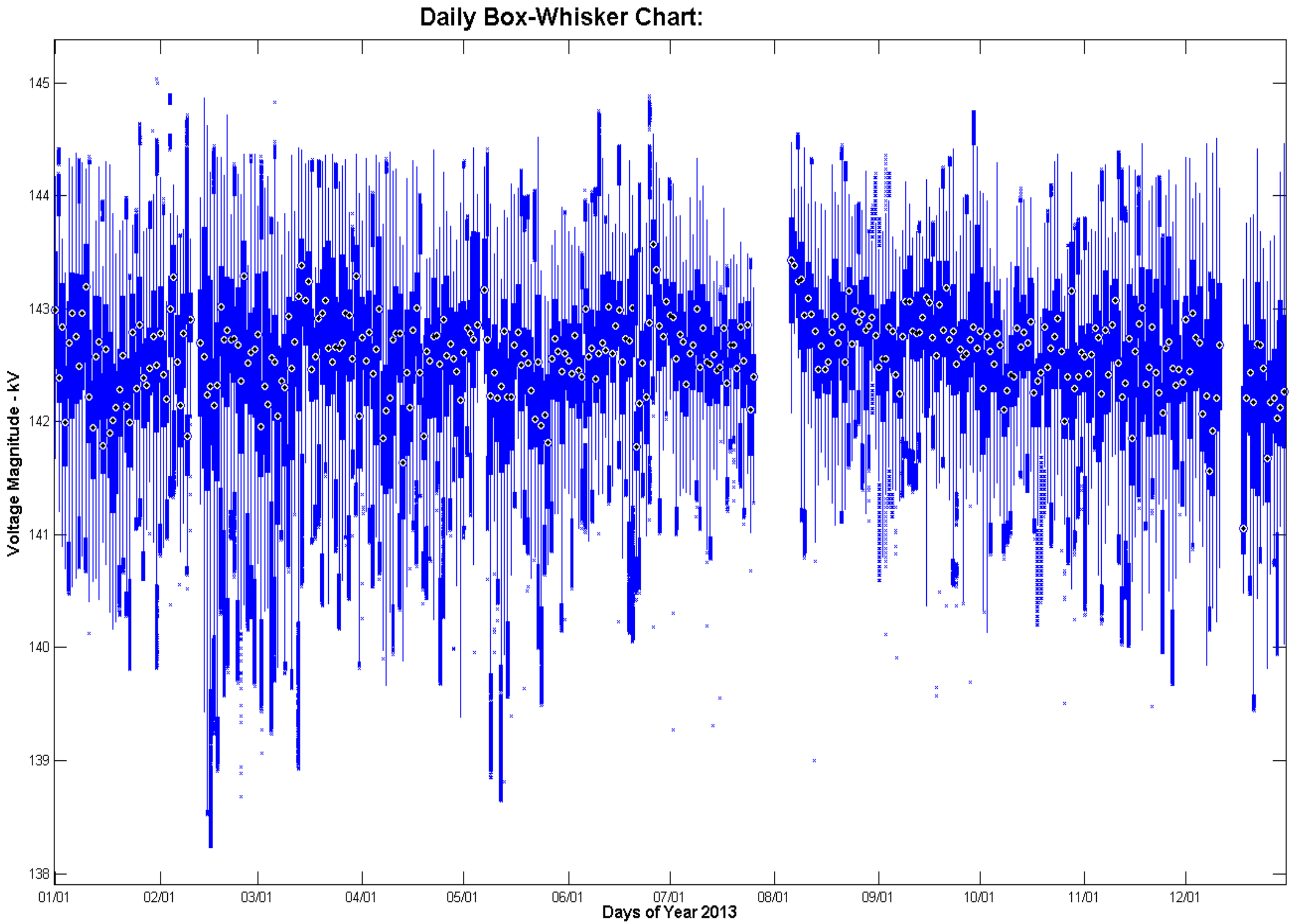
Daily Box-Whisker Chart:
Voltage Magnitude - kV
73
72
71
70
69
68
67
66
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

FarWest 2

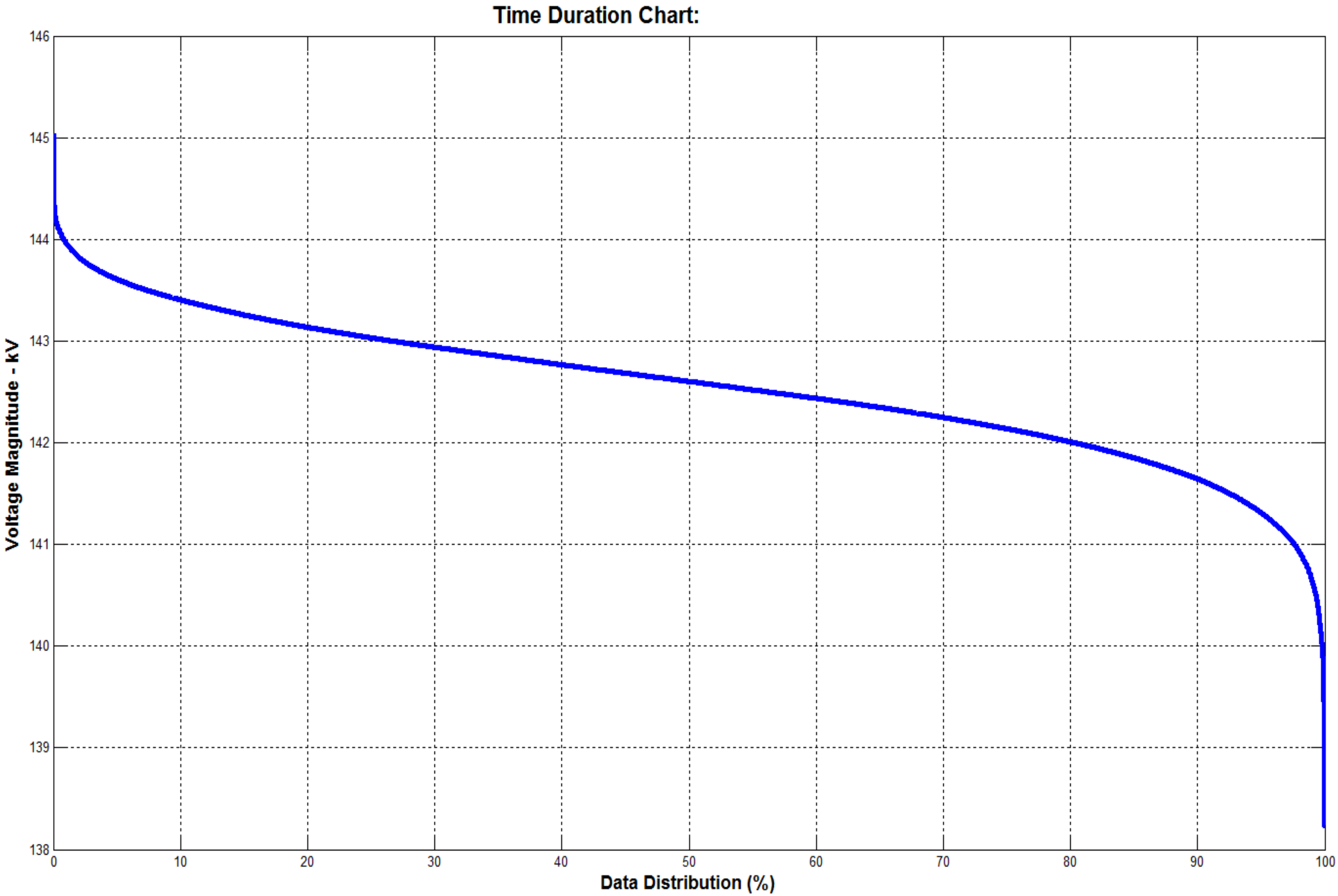


Time Duration Chart:
74
73
72
71
70
69
68
67
66
65
Voltage Magnitude - kV
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

North 7

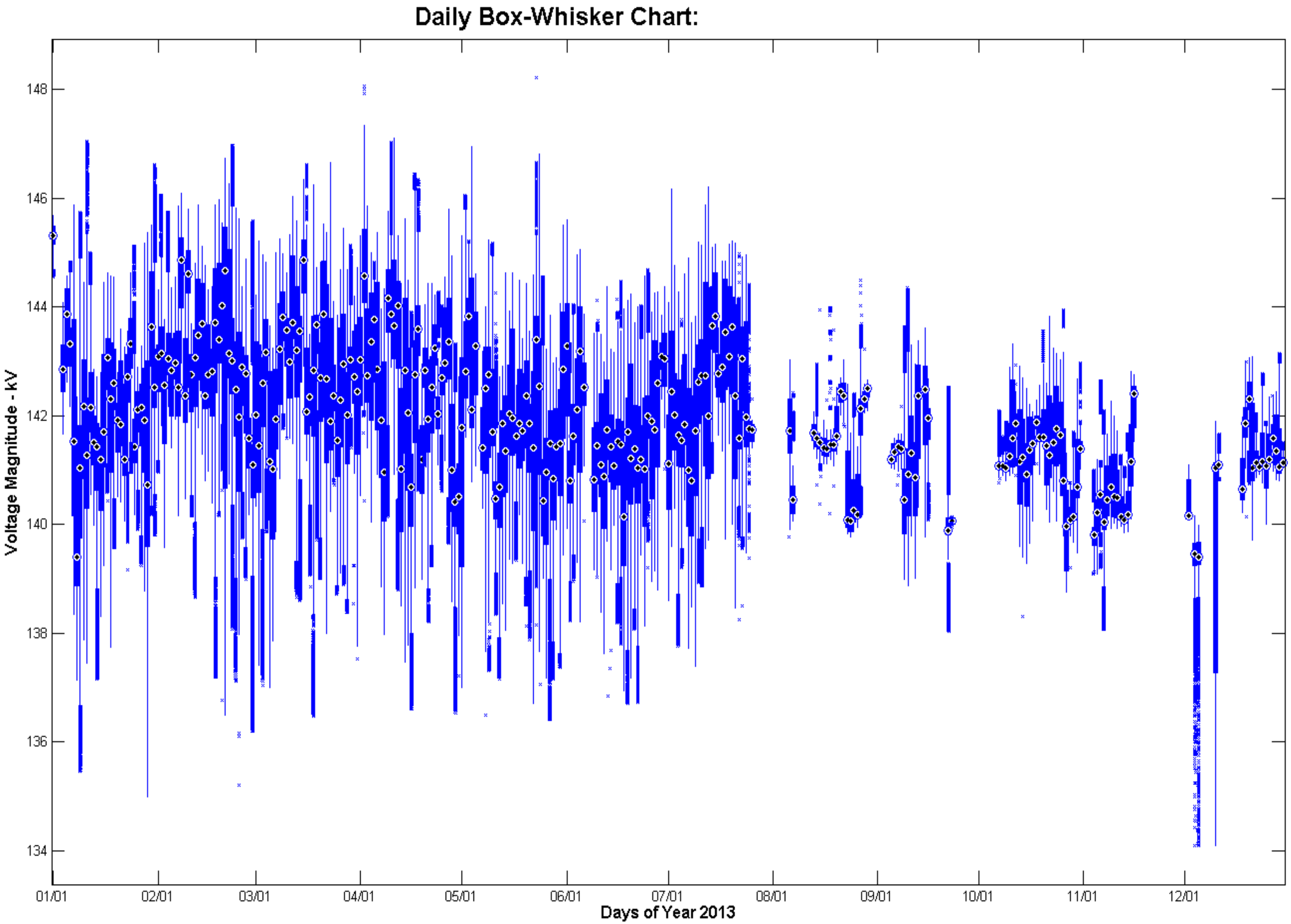

Daily Box-Whisker Chart:
145
144
143
142
141
140
139
138
Voltage Magnitude - kV
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

North 7

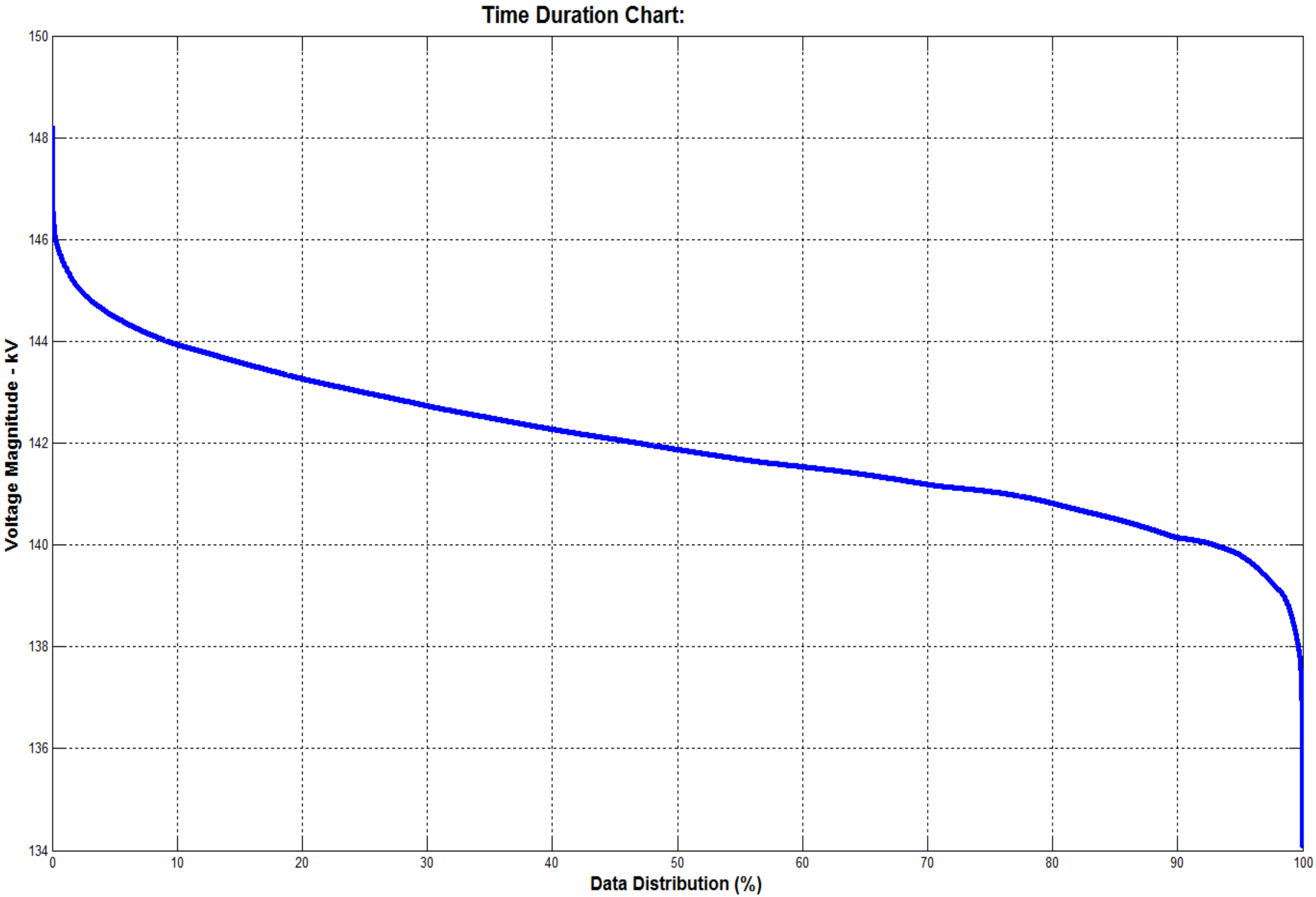


Time Duration Chart:
Voltage Magnitude - kV
146
145
144
143
142
141
140
139
138
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 4

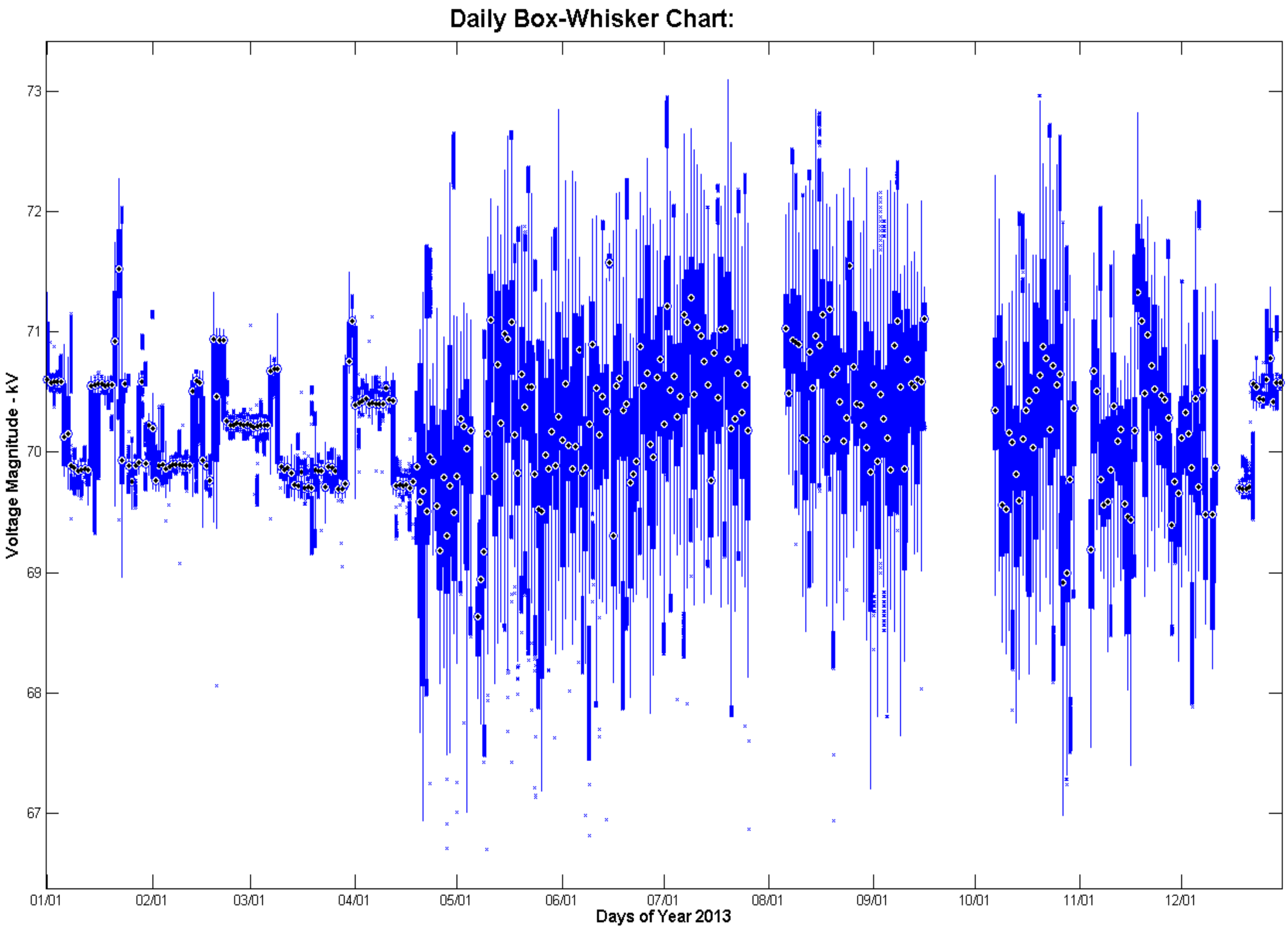

Daily Box-Whisker Chart:
Voltage Magnitude - kV
148
146
144
142
140
138
136
134
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 4



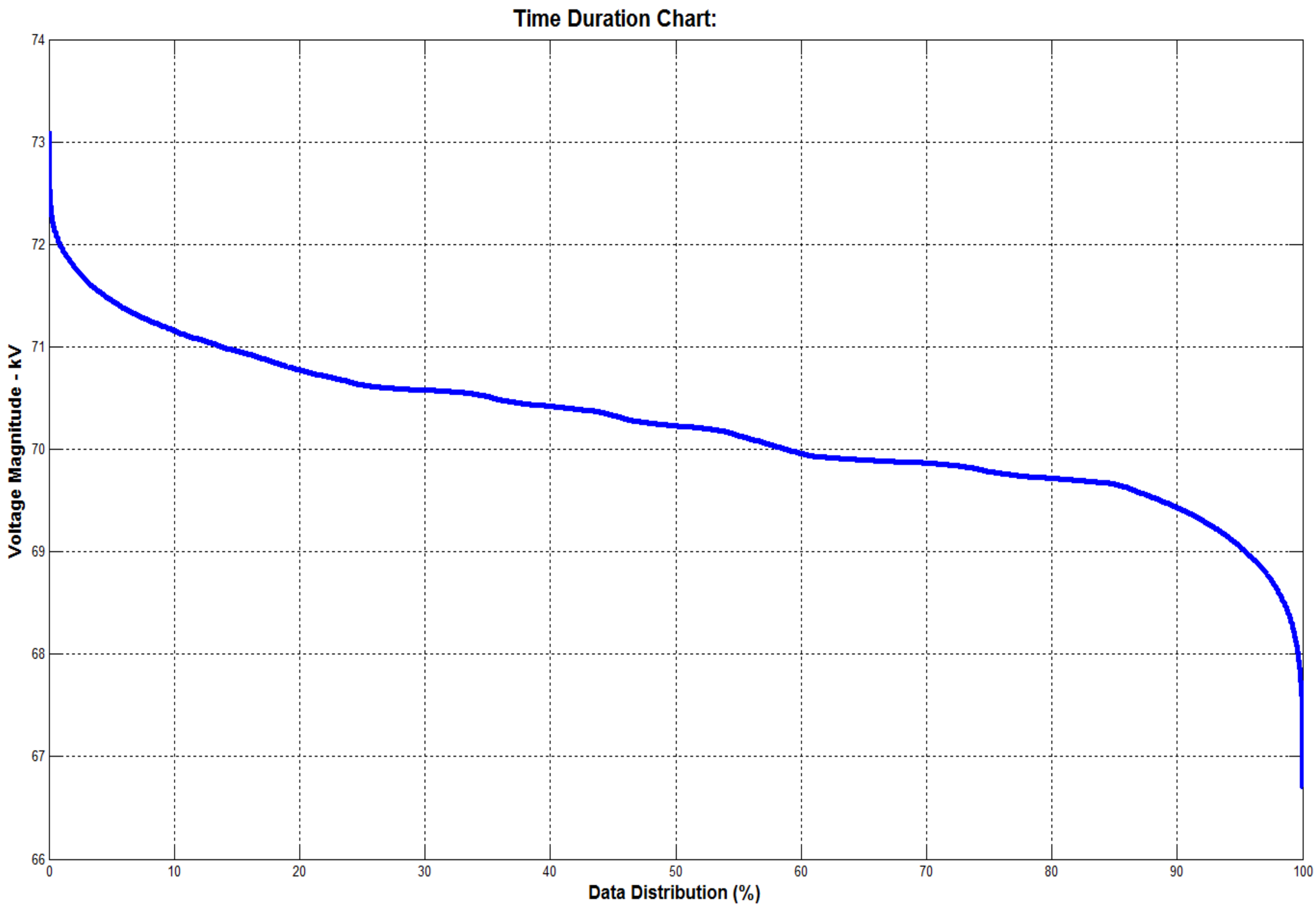
Time Duration Chart:
Voltage Magnitude - kV
150
148
146
144
142
140
138
136
134
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

Coast 2



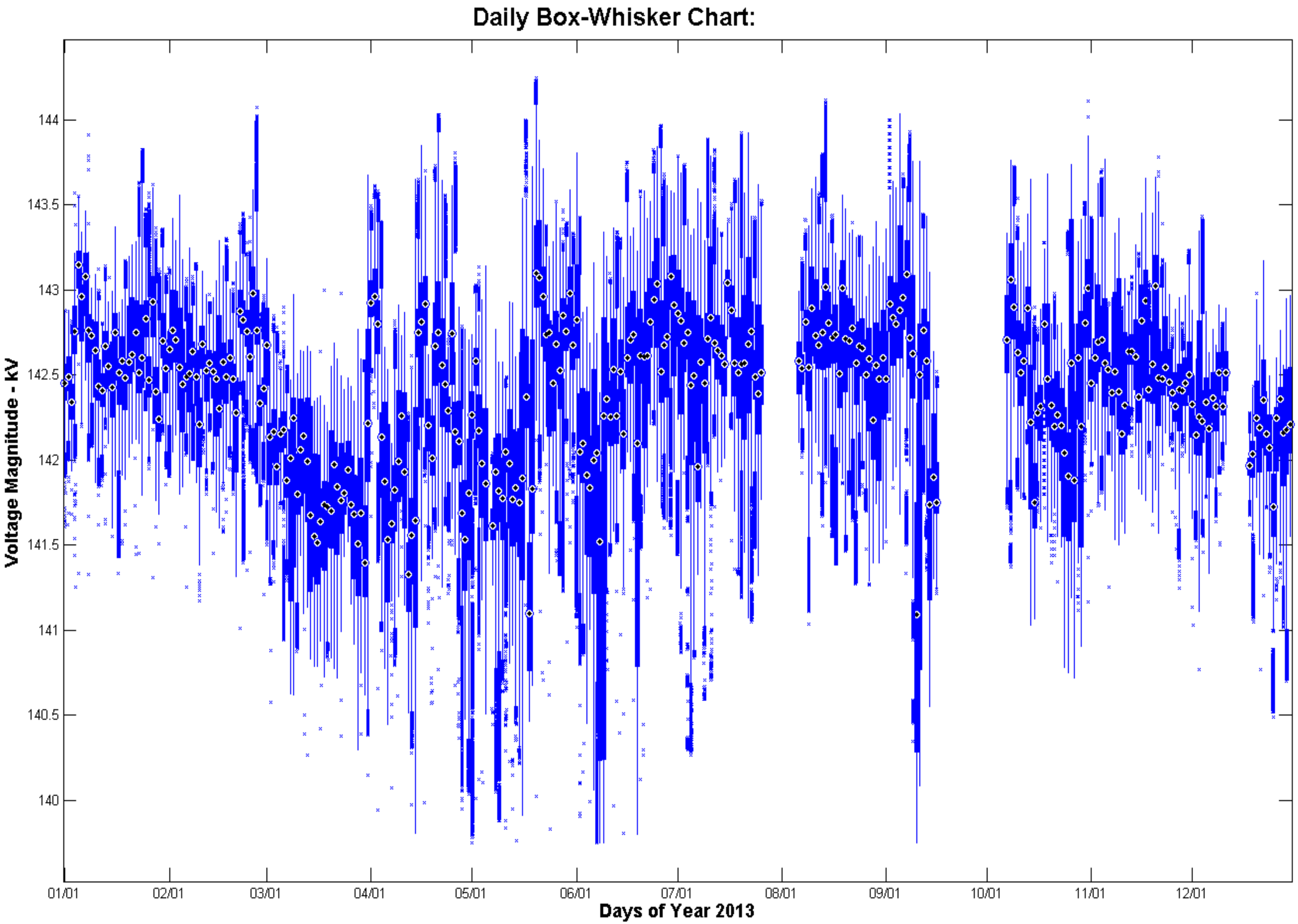
Daily Box-Whisker Chart:
Voltage Magnitude - kV
73
72
71
70
69
68
67
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

Coast 2



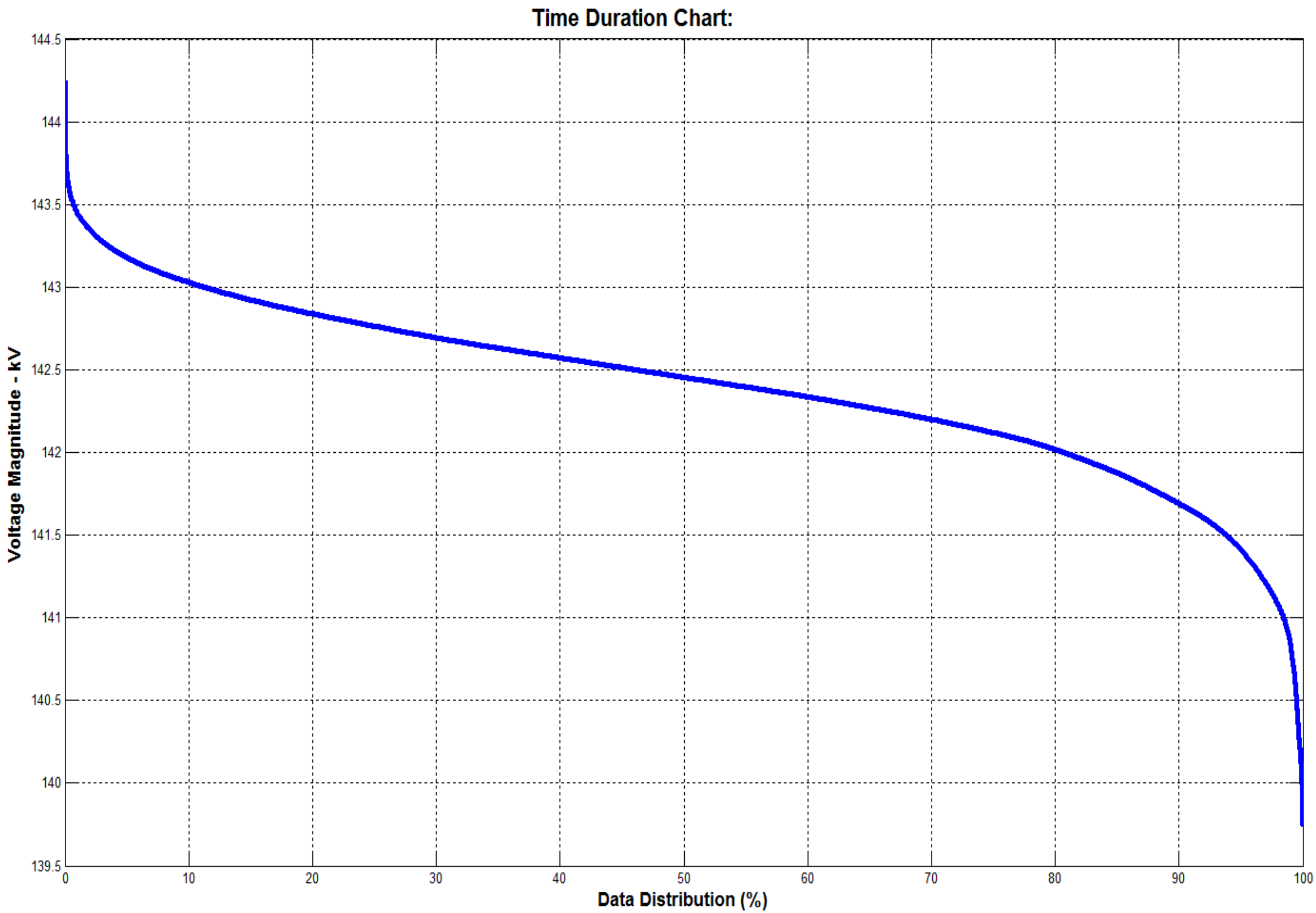
Time Duration Chart:
74
73
72
71
70
69
68
67
66
Voltage Magnitude - kV
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

Coast 1



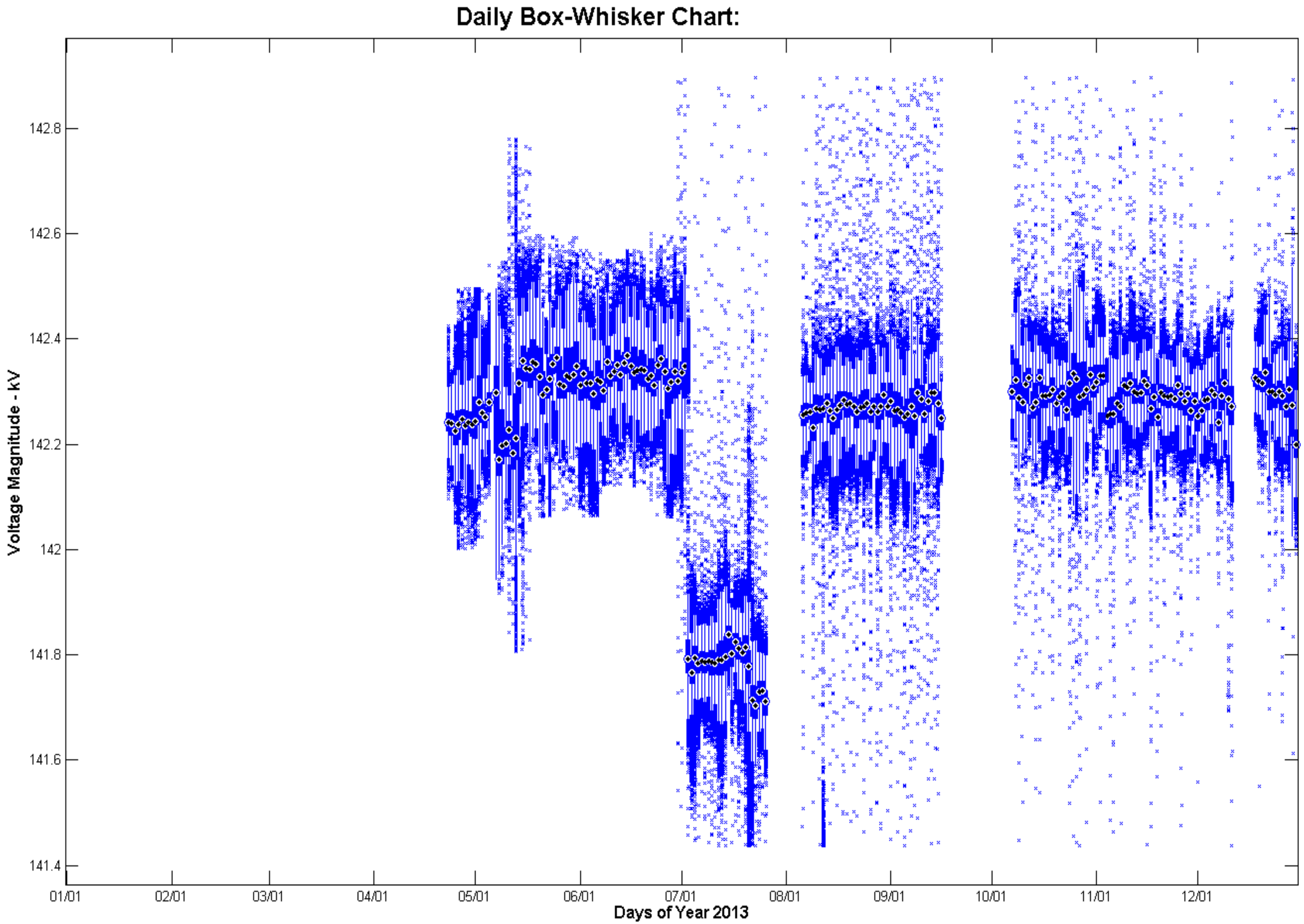
Daily Box-Whisker Chart:
Voltage Magnitude - kV
144
143.5
143
142.5
142
141.5
141
140.5
140
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

Coast 1



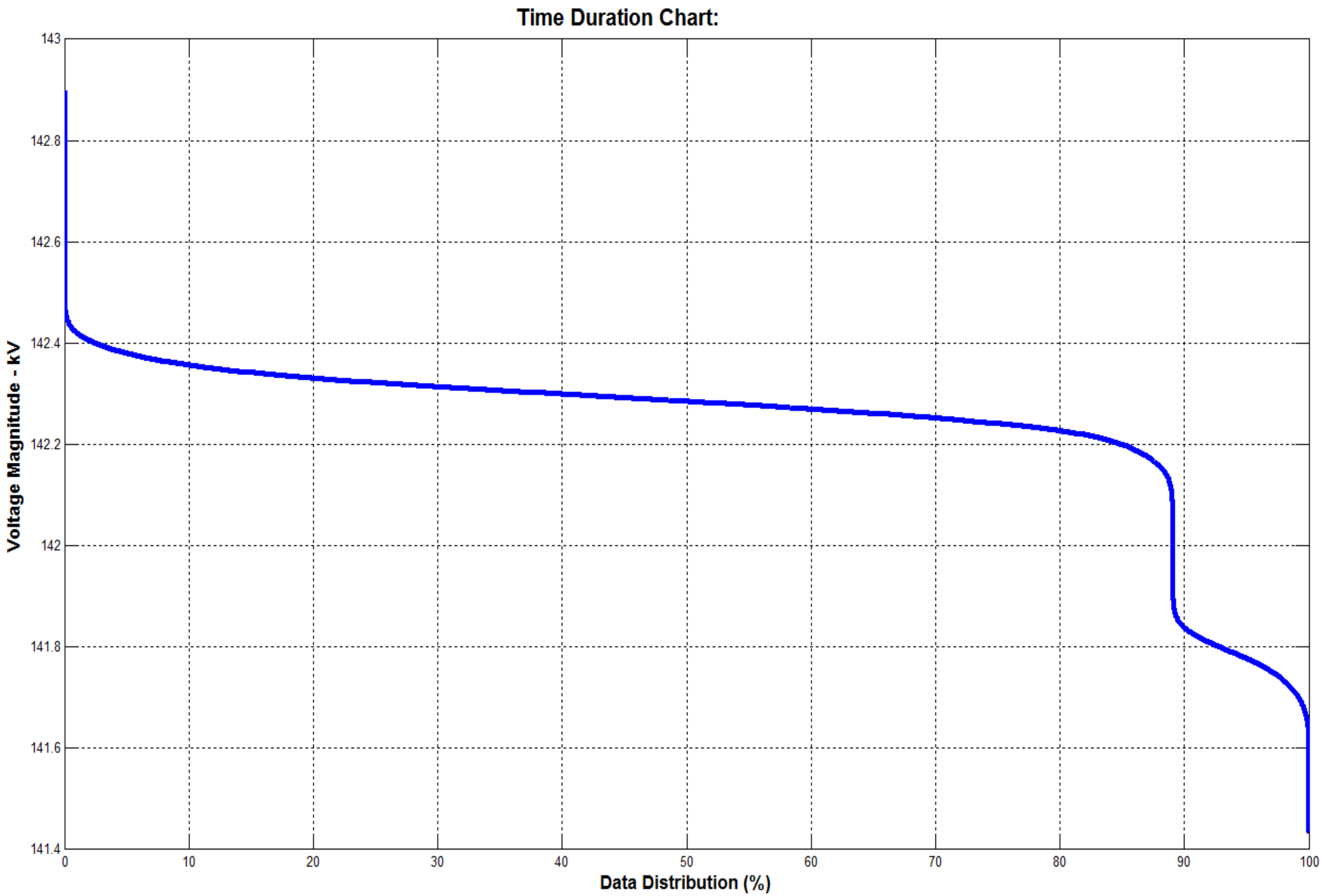
Time Duration Chart:
Voltage Magnitude - kV
144.5
144
143.5
143
142.5
142
141.5
141
140.5
140
139.5
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

South 3



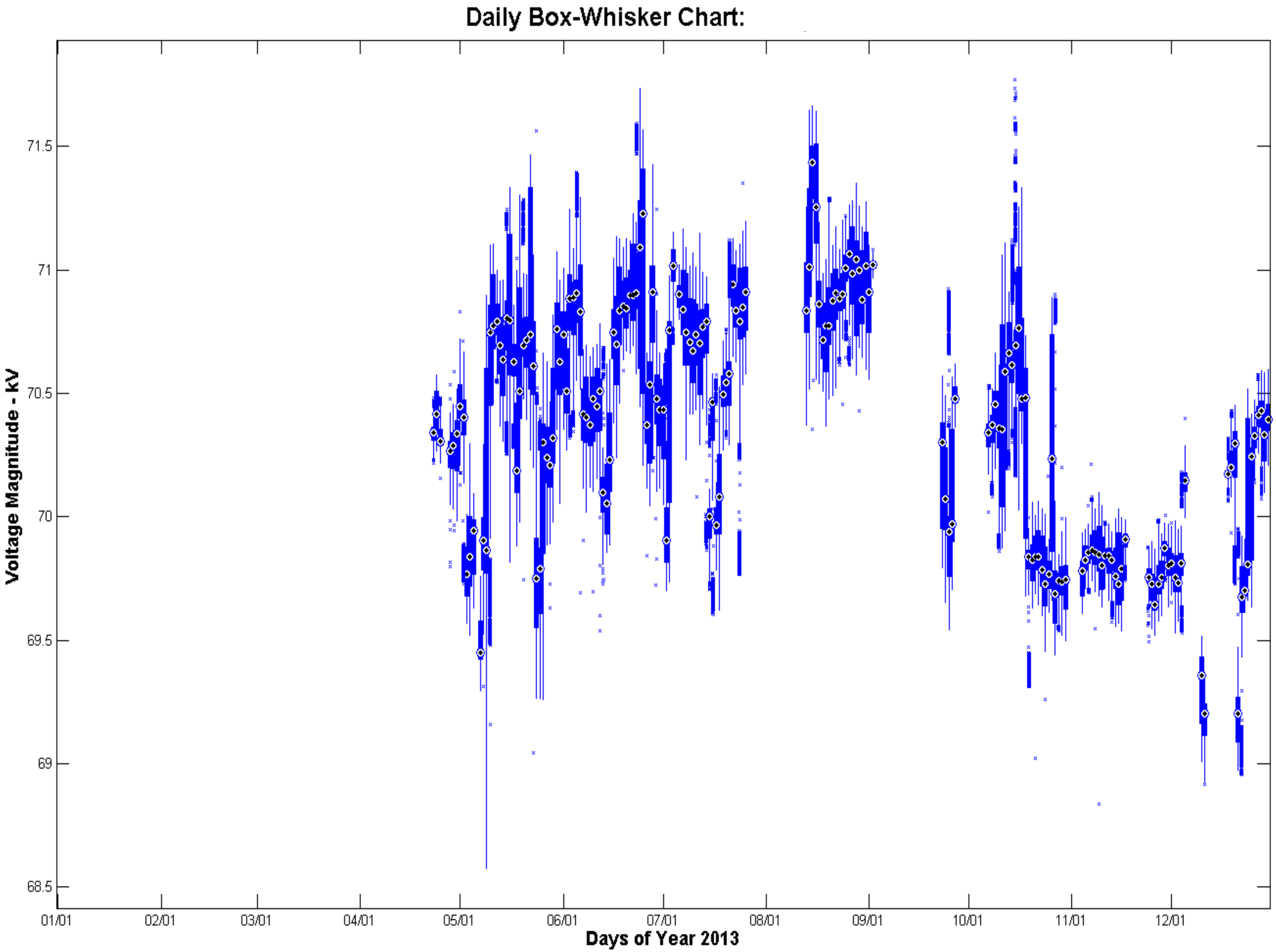
Daily Box-Whisker Chart:
Voltage Magnitude - kV
142.8
142.6
142.4
142.2
142
141.8
141.6
141.4
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

South 3

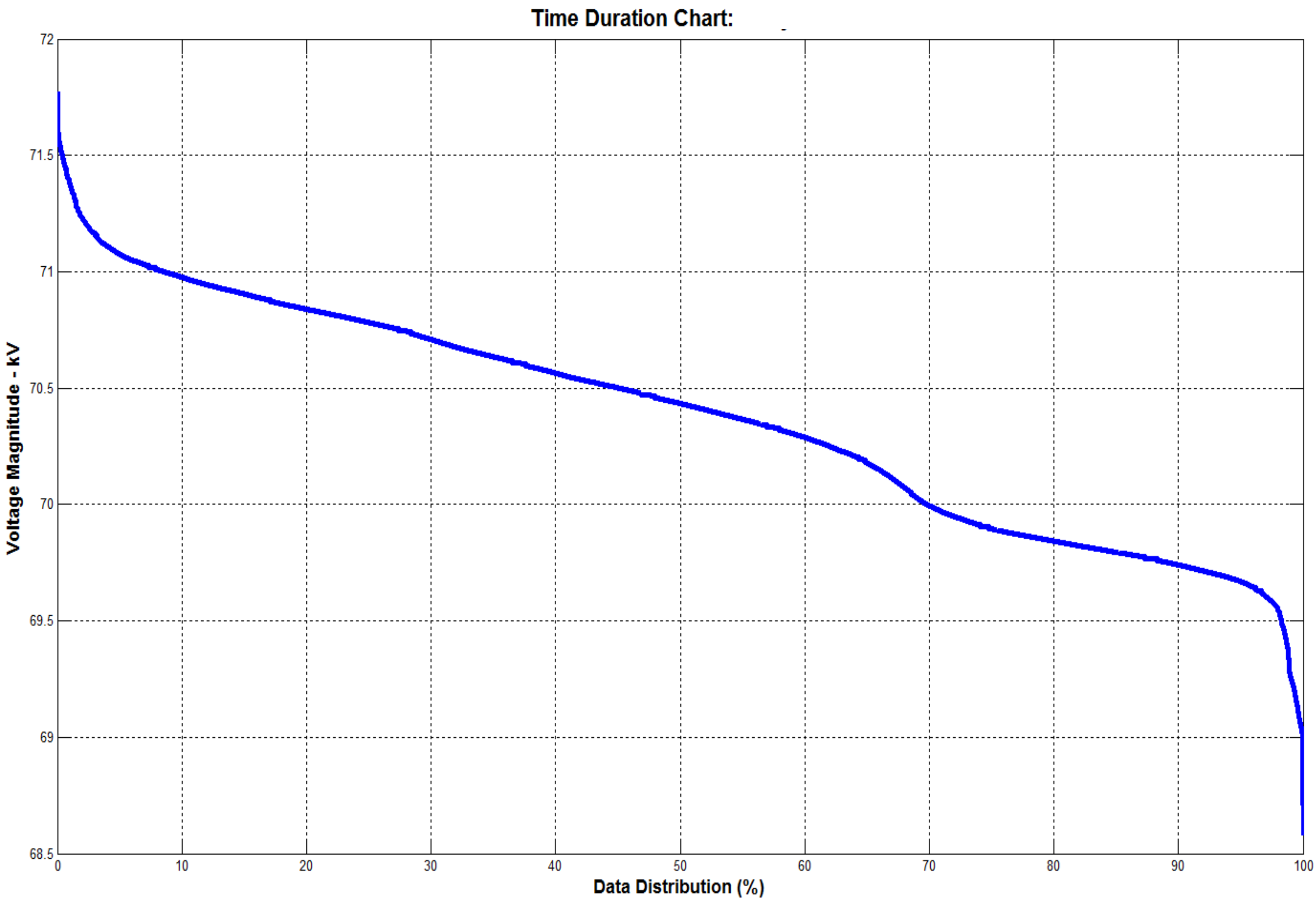


Time Duration Chart:
143
142.8
142.6
142.4
142.2
142
141.8
141.6
141.4
Voltage Magnitude - kV
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

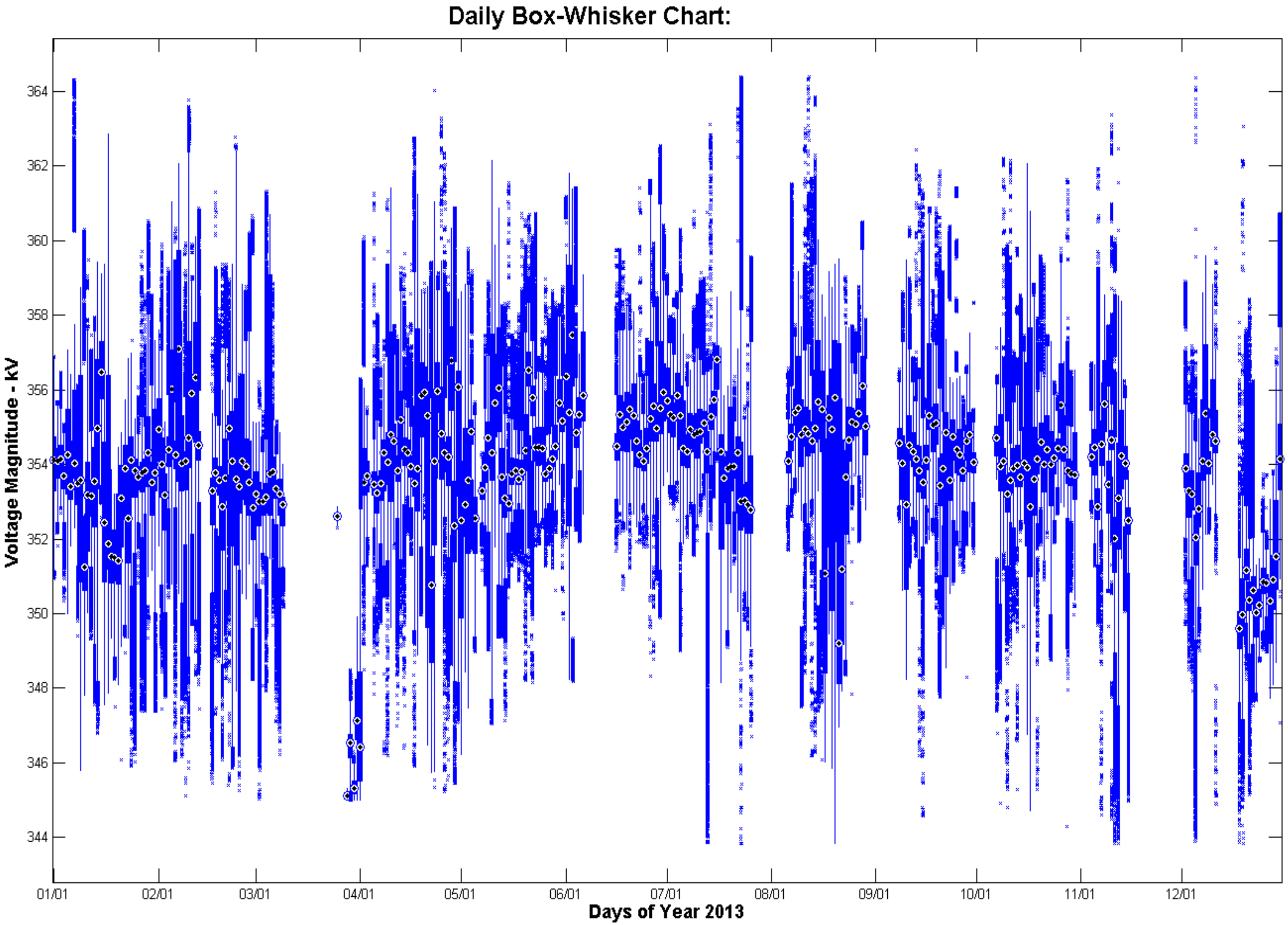
South 5


Daily Box-Whisker Chart:
71.5
71
70.5
70
69.5
69
68.5
Voltage Magnitude - kV
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

South 5

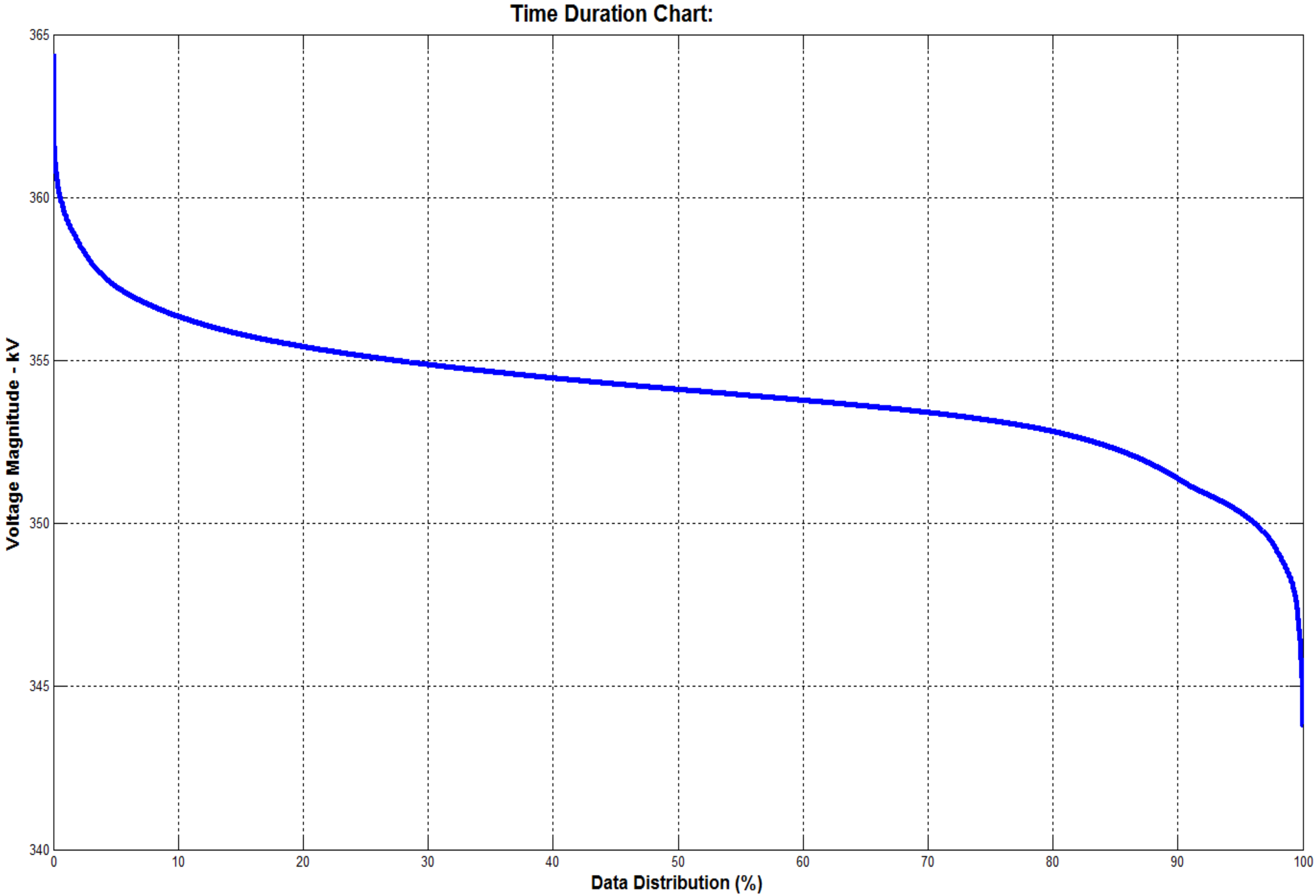

Time Duration Chart:
Voltage Magnitude - kV
Data Distribution (%)
72
71.5
71
70.5
70
69.5
69
68.5
0
10
20
30
40
50
60
70
80
90
100

Coast 4



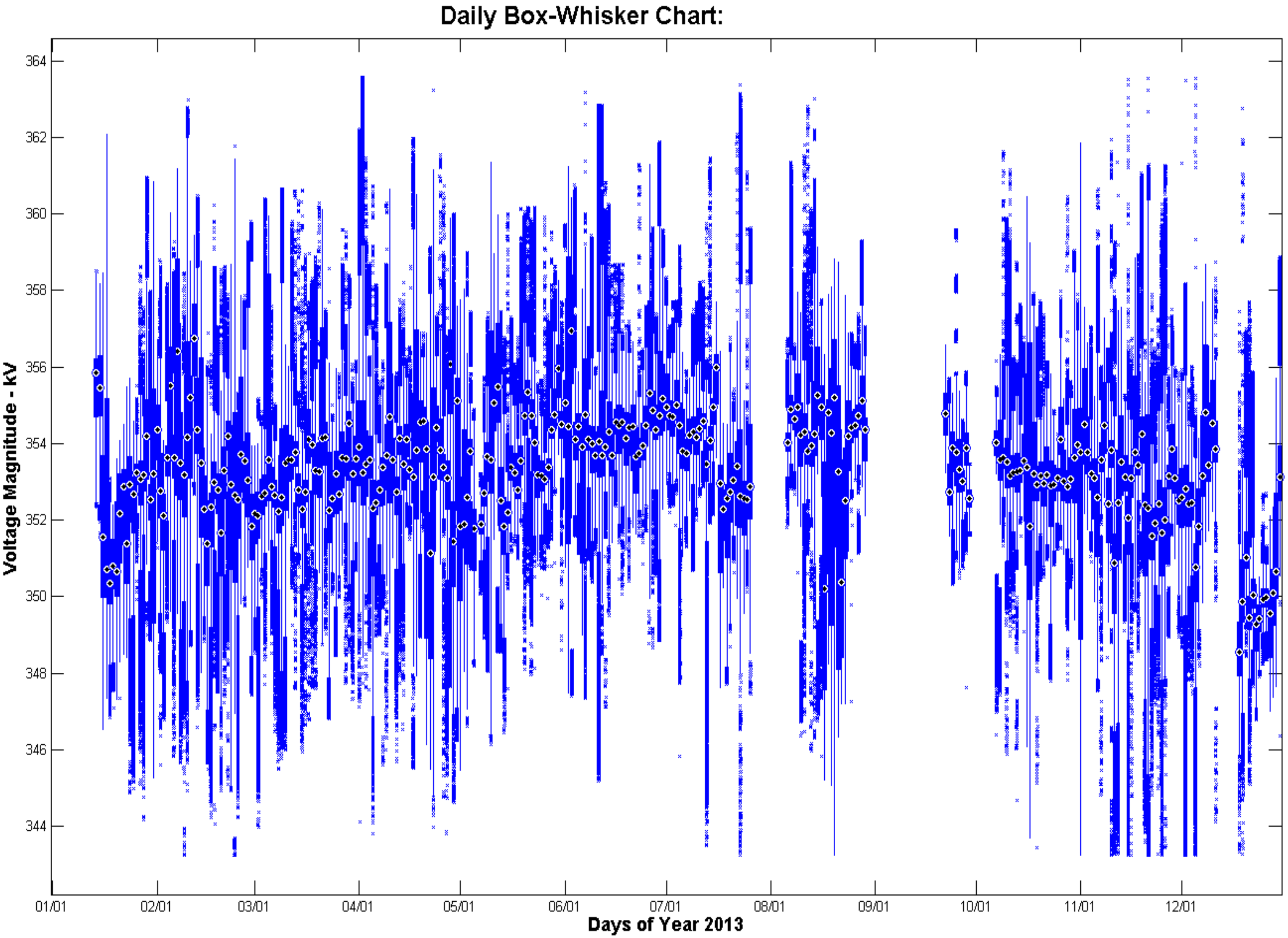
Daily Box-Whisker Chart:
Voltage Magnitude - kV
364
362
360
358
356
354
352
350
348
346
344
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

Coast 4



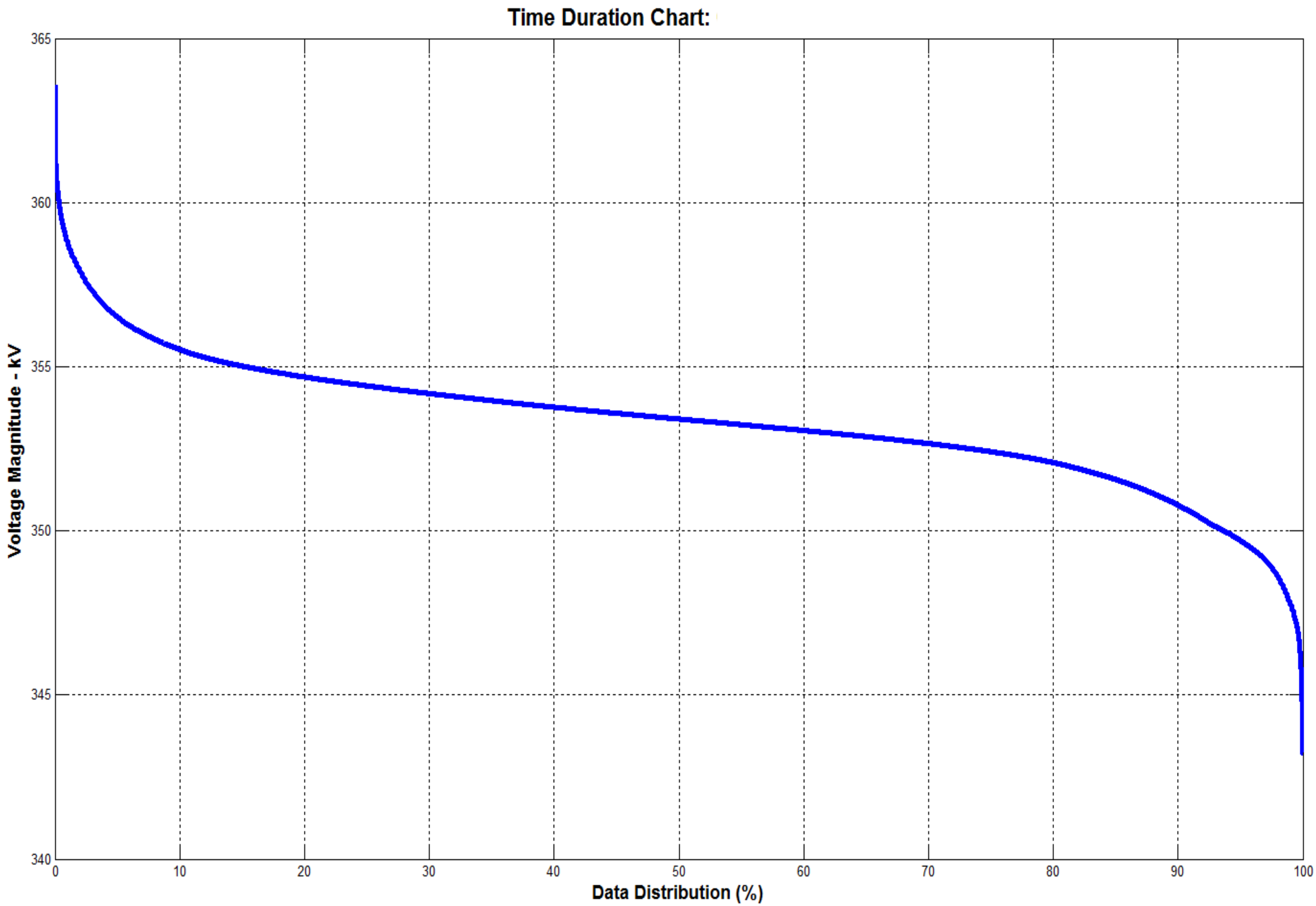
Time Duration Chart:
Voltage Magnitude - kV
365
360
355
350
345
340
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

Coast 3



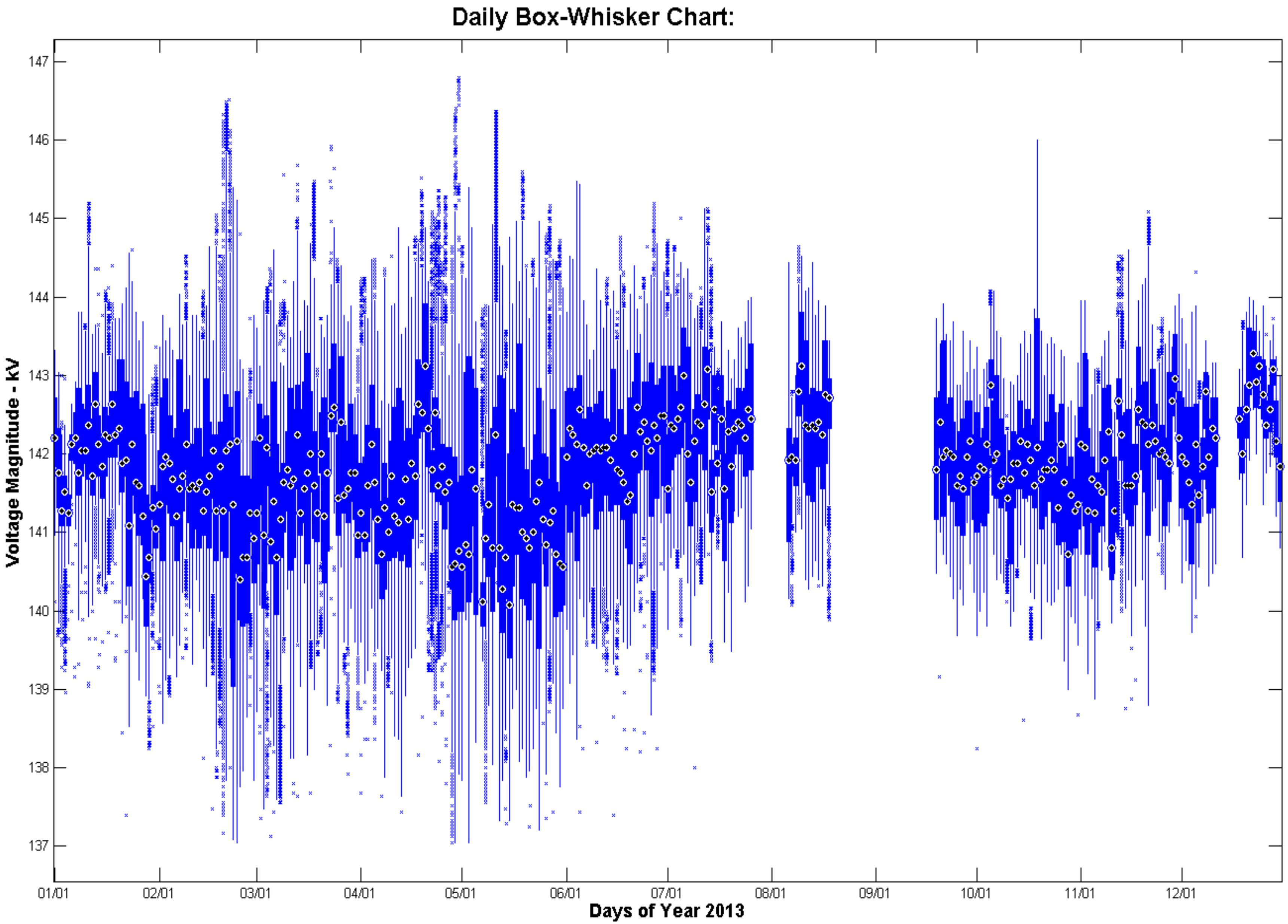
Daily Box-Whisker Chart:
Voltage Magnitude - kV
364
362
360
358
356
354
352
350
348
346
344
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

Coast 3



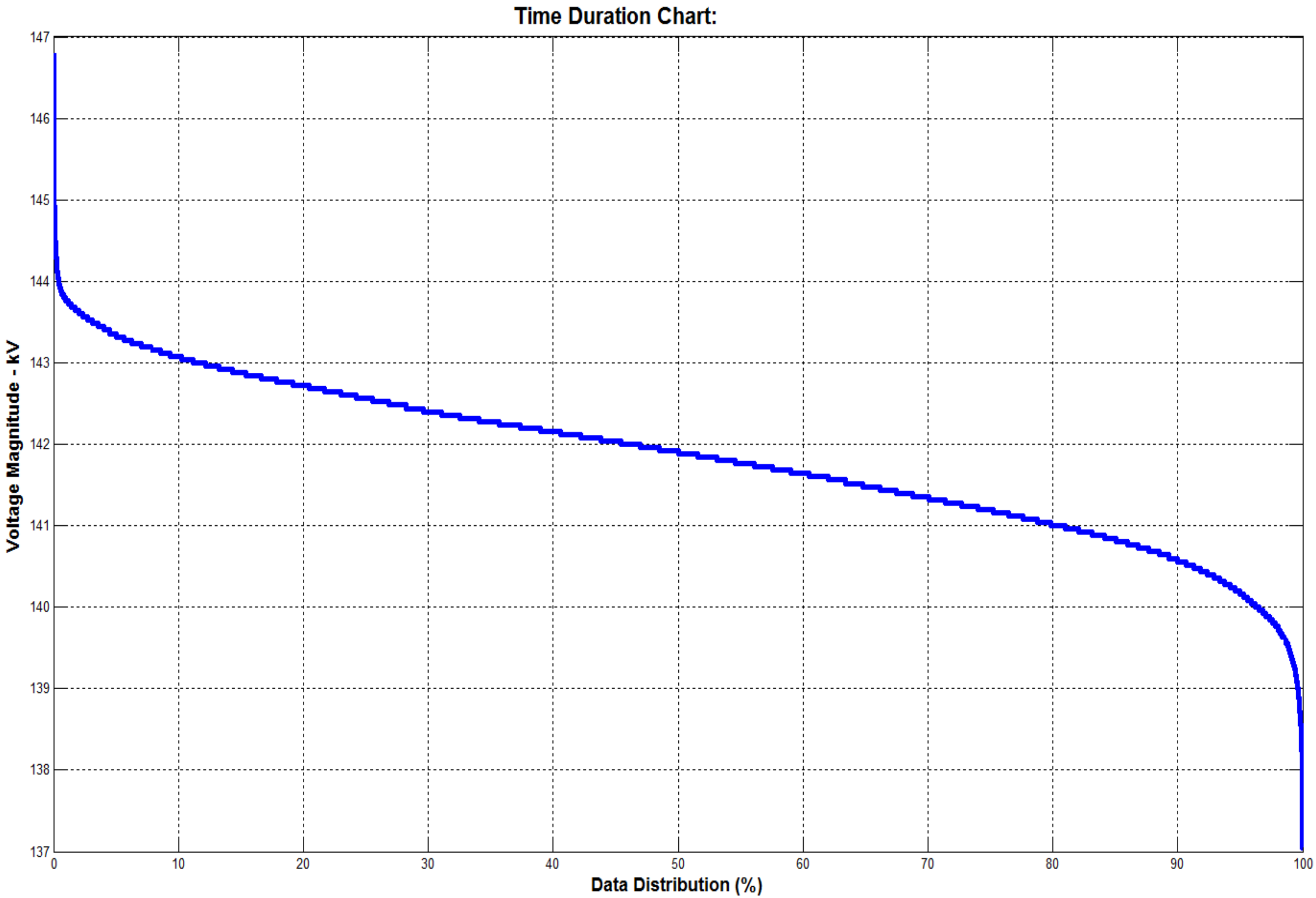
Time Duration Chart:
365
360
355
350
345
340
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)
Voltage Magnitude - kV

South 13

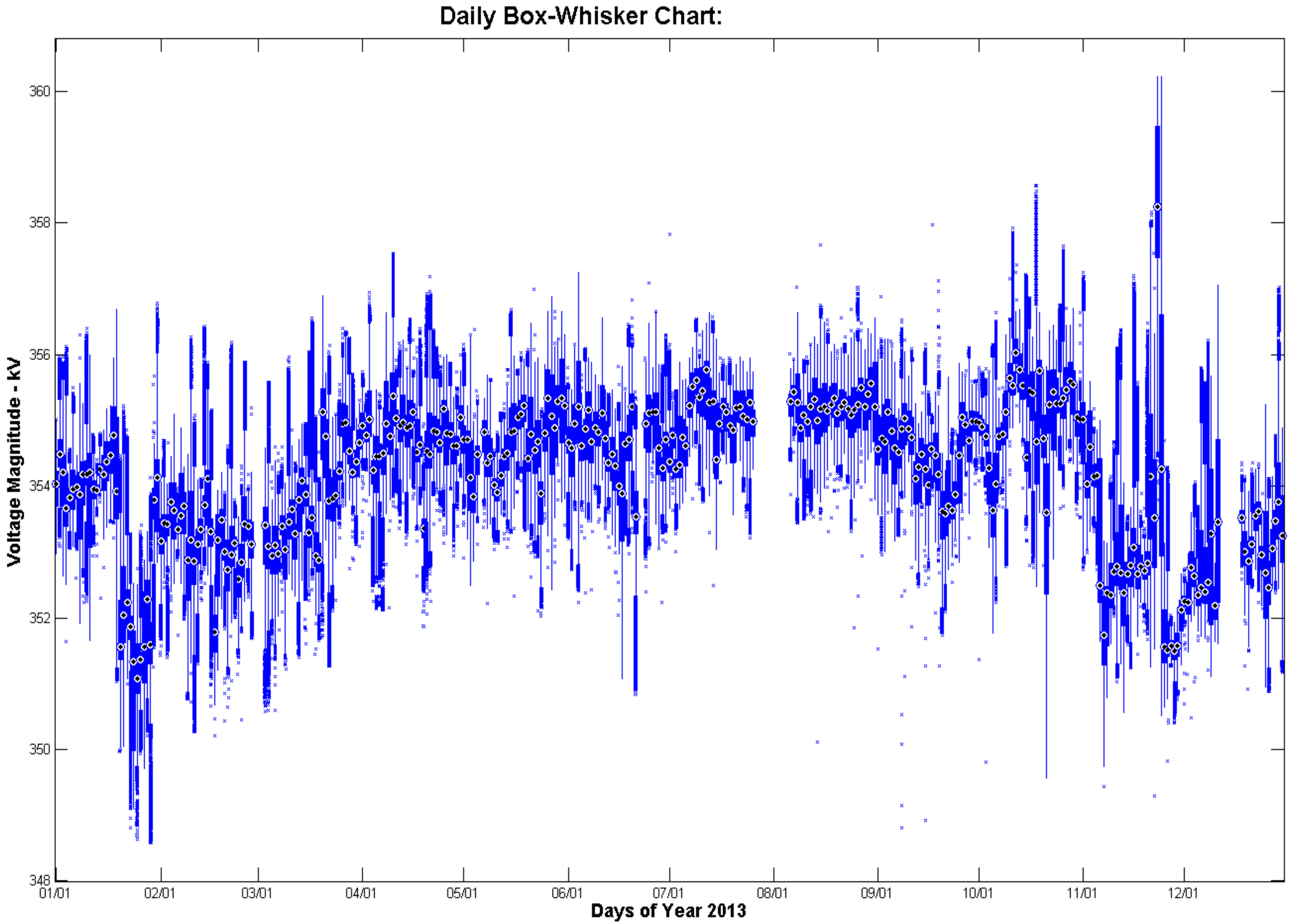


Daily Box-Whisker Chart:
Voltage Magnitude - kV
147
146
145
144
143
142
141
140
139
138
137
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

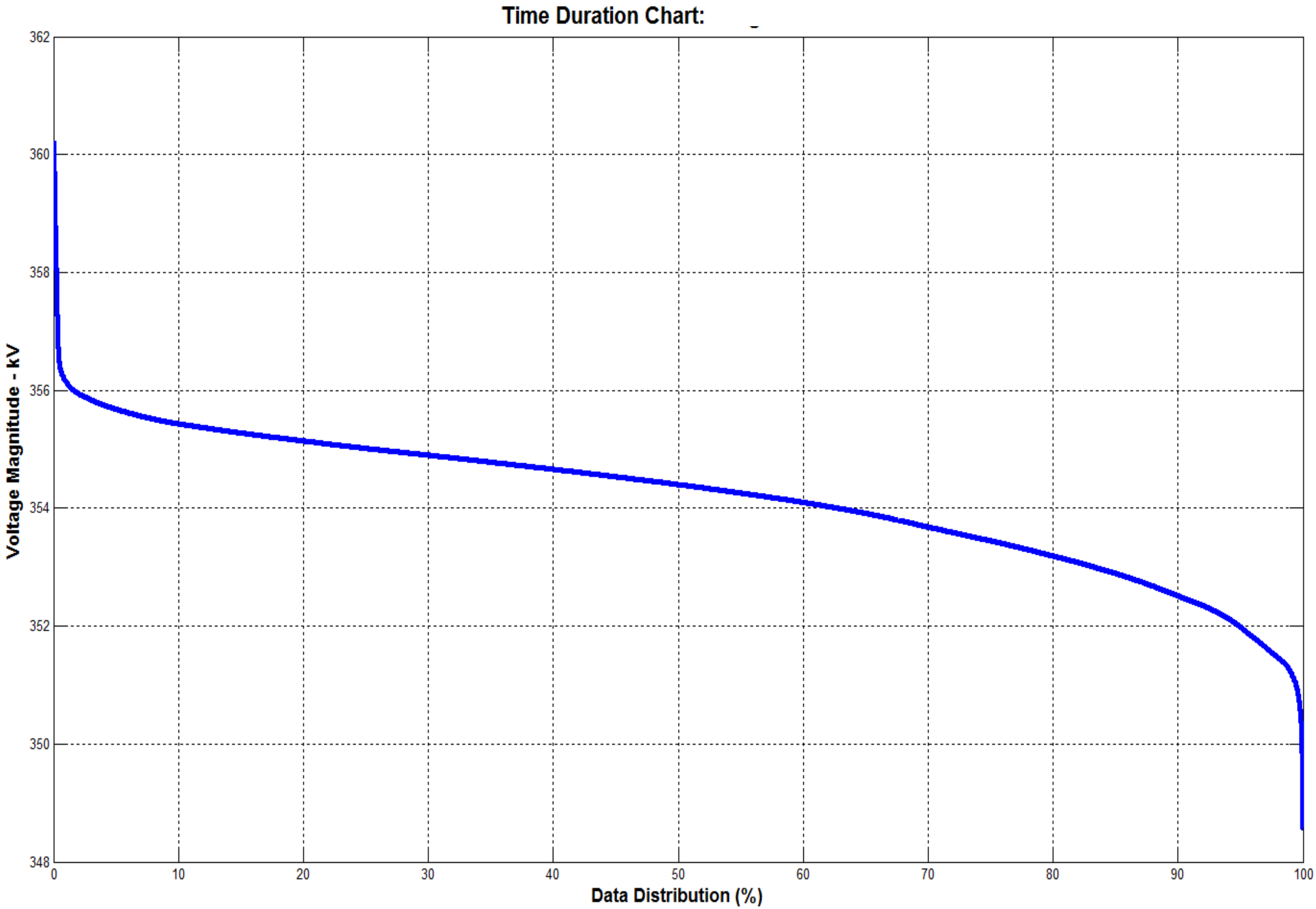
South 13


Time Duration Chart:
Voltage Magnitude - kV
147
146
145
144
143
142
141
140
139
138
137
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

FarWest 4

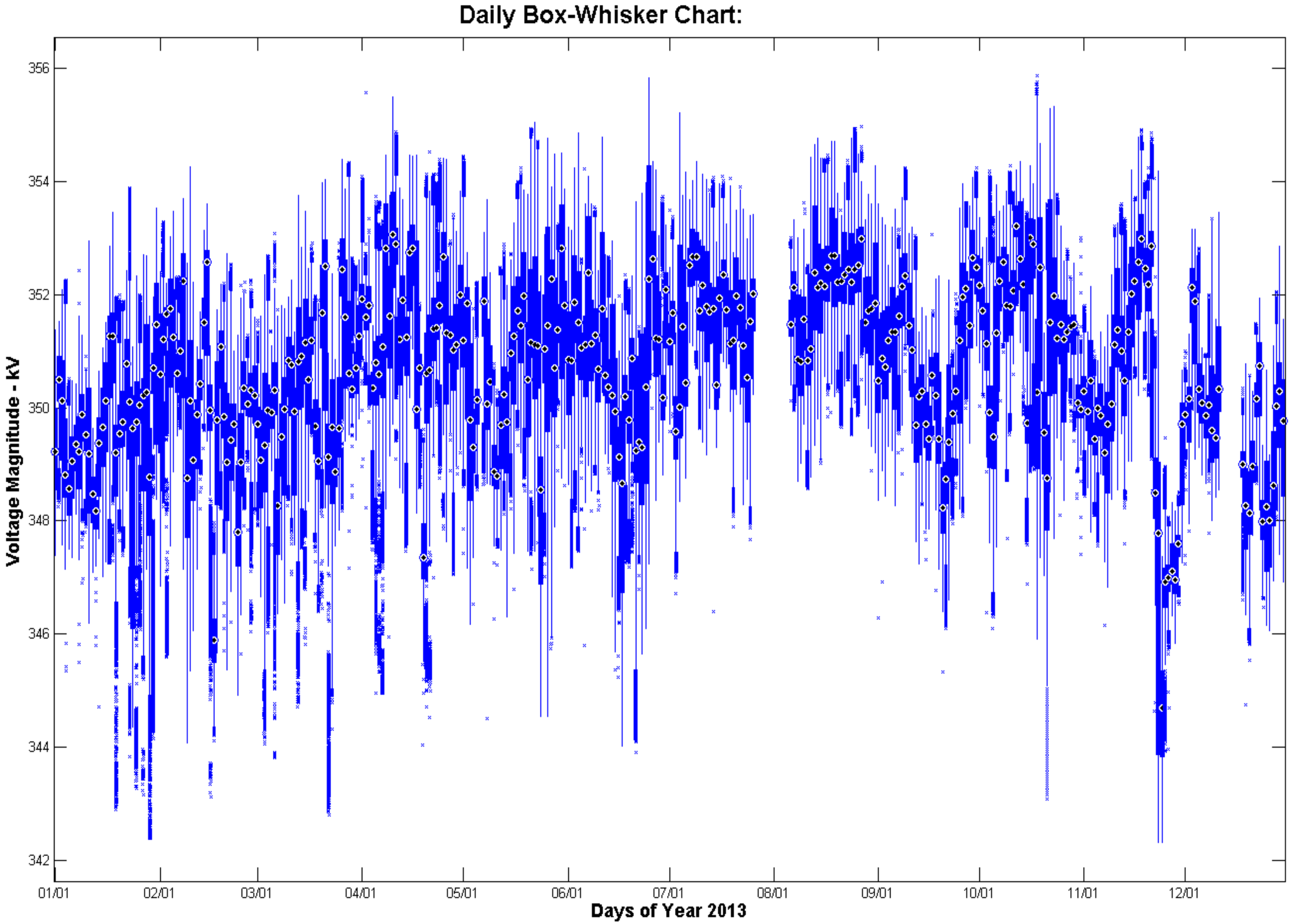

Daily Box-Whisker Chart:
Voltage Magnitude - kV
360
358
356
354
352
350
348
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

FarWest 4



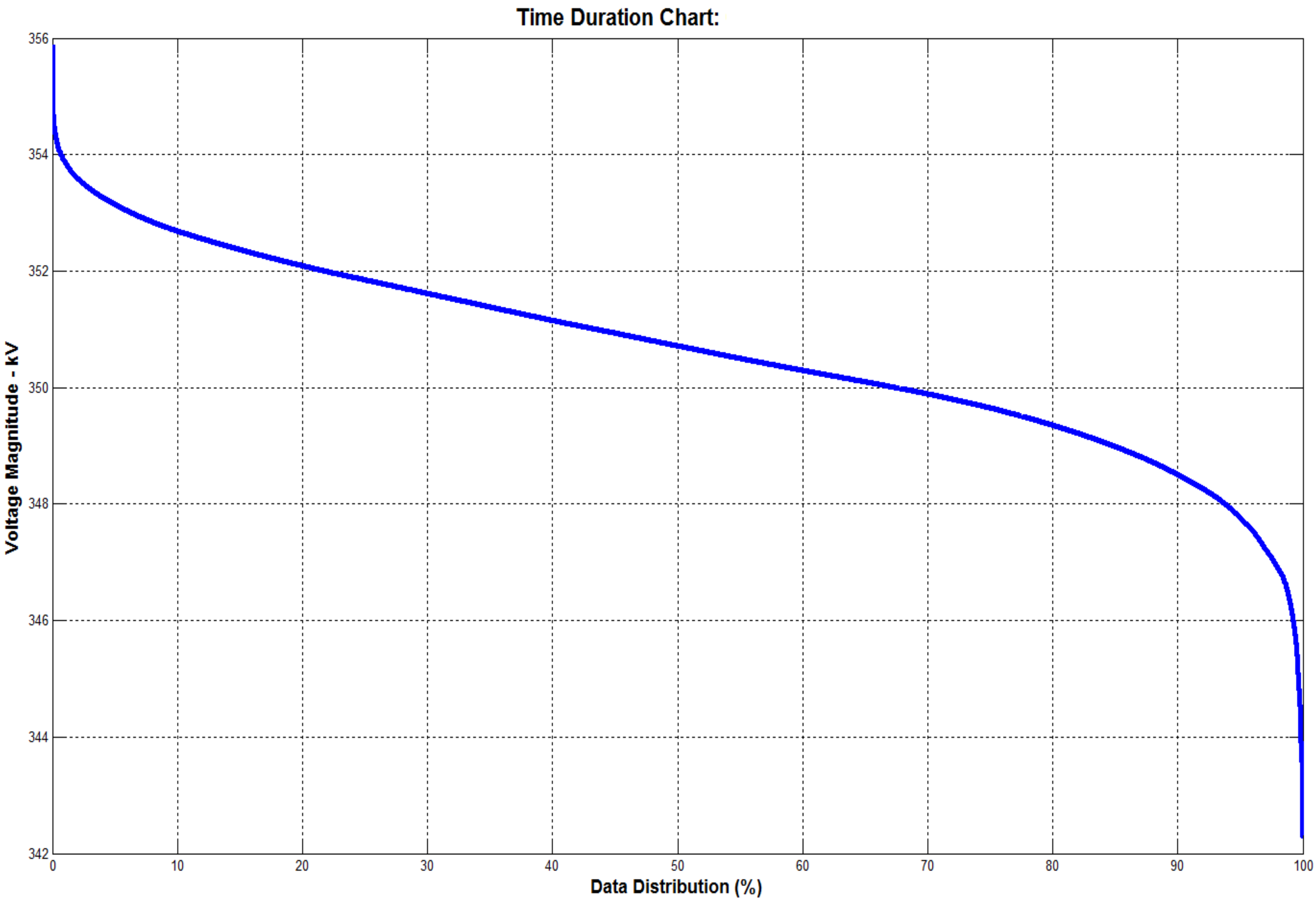
Time Duration Chart:
362
360
358
356
354
352
350
348
Voltage Magnitude - kV
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

FarWest 7

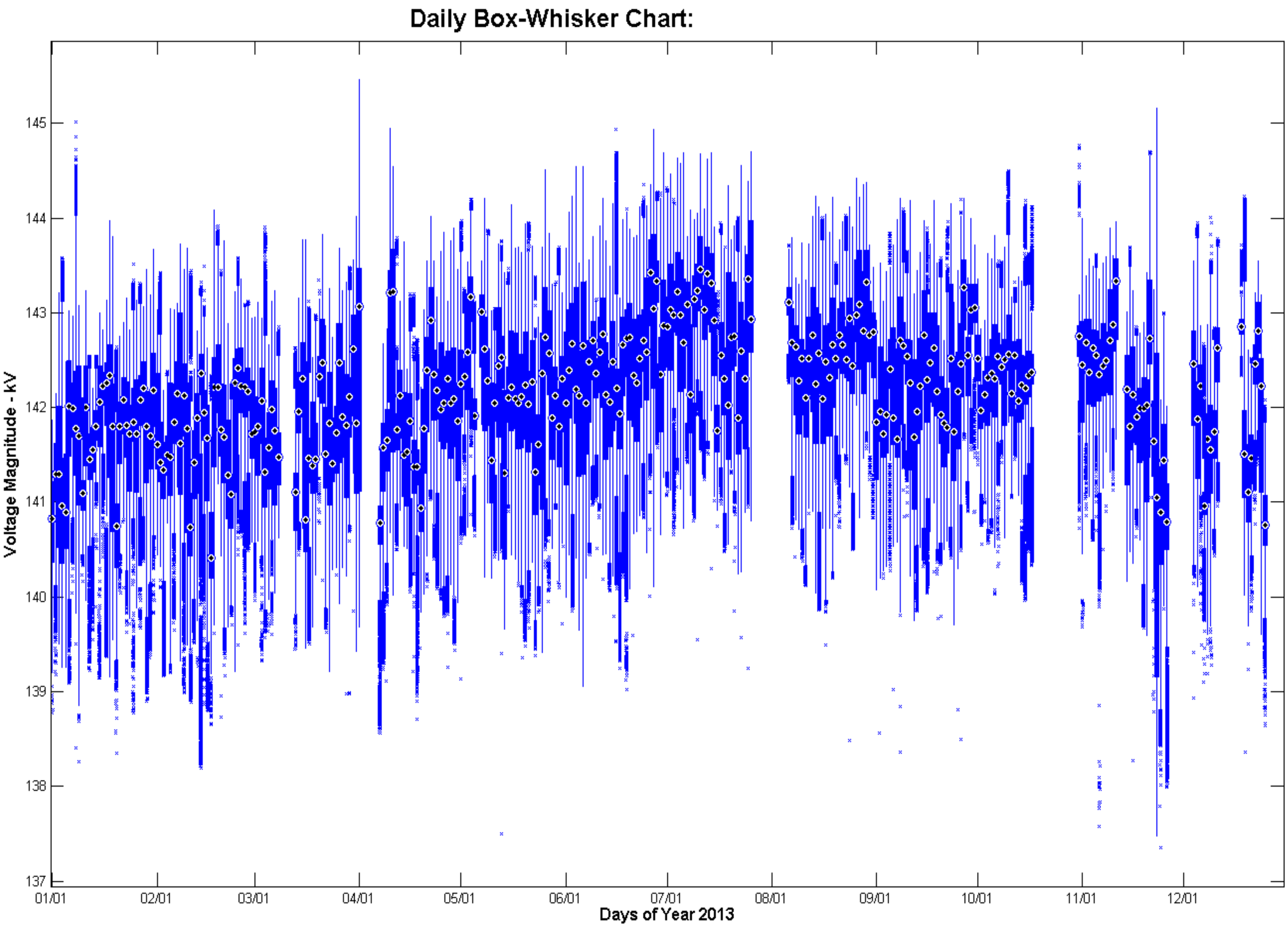


Daily Box-Whisker Chart:
Voltage Magnitude - kV
356
354
352
350
348
346
344
342
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

FarWest 7

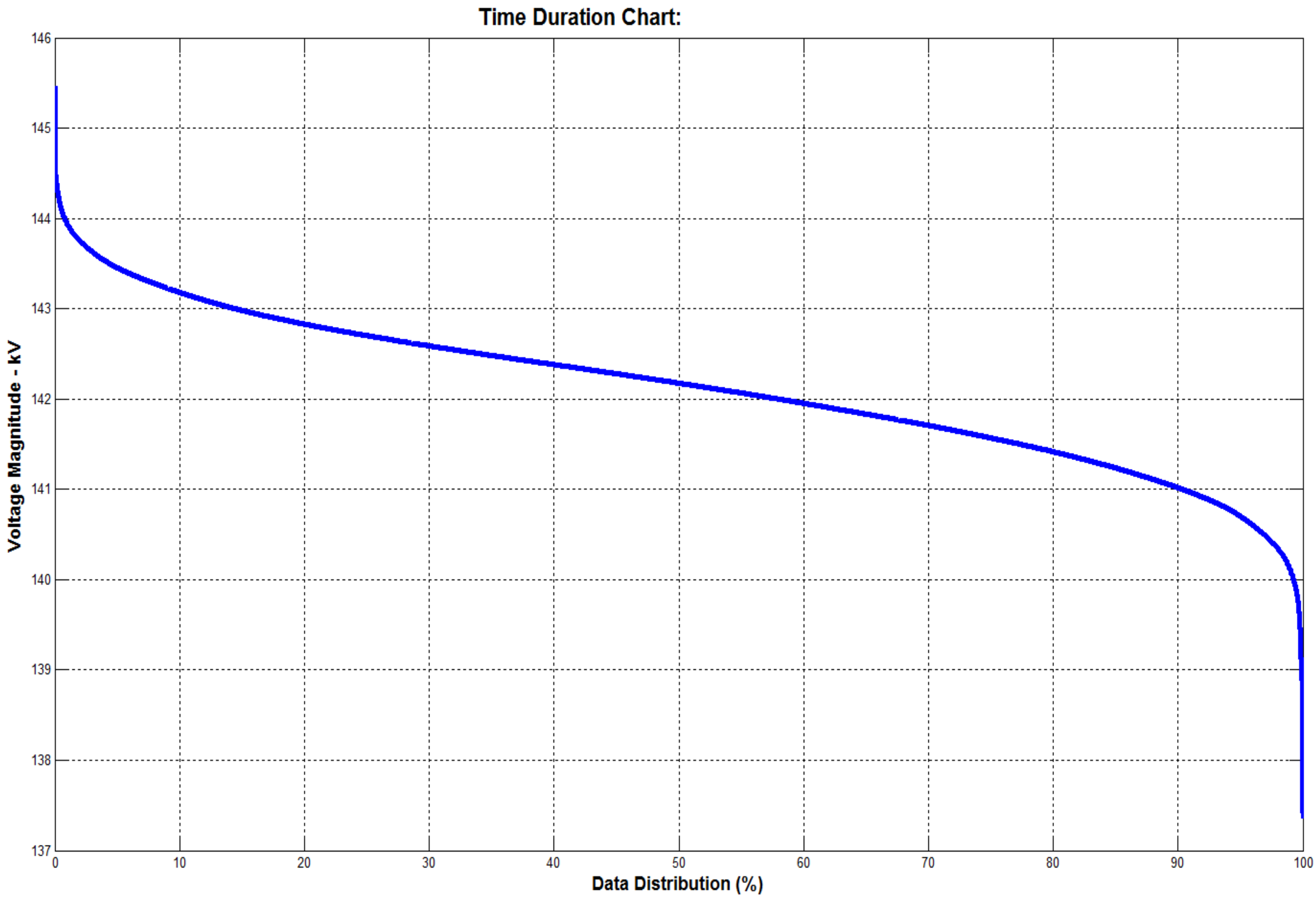

Time Duration Chart:
Voltage Magnitude - kV
356
354
352
350
348
346
344
342
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

FarWest 8



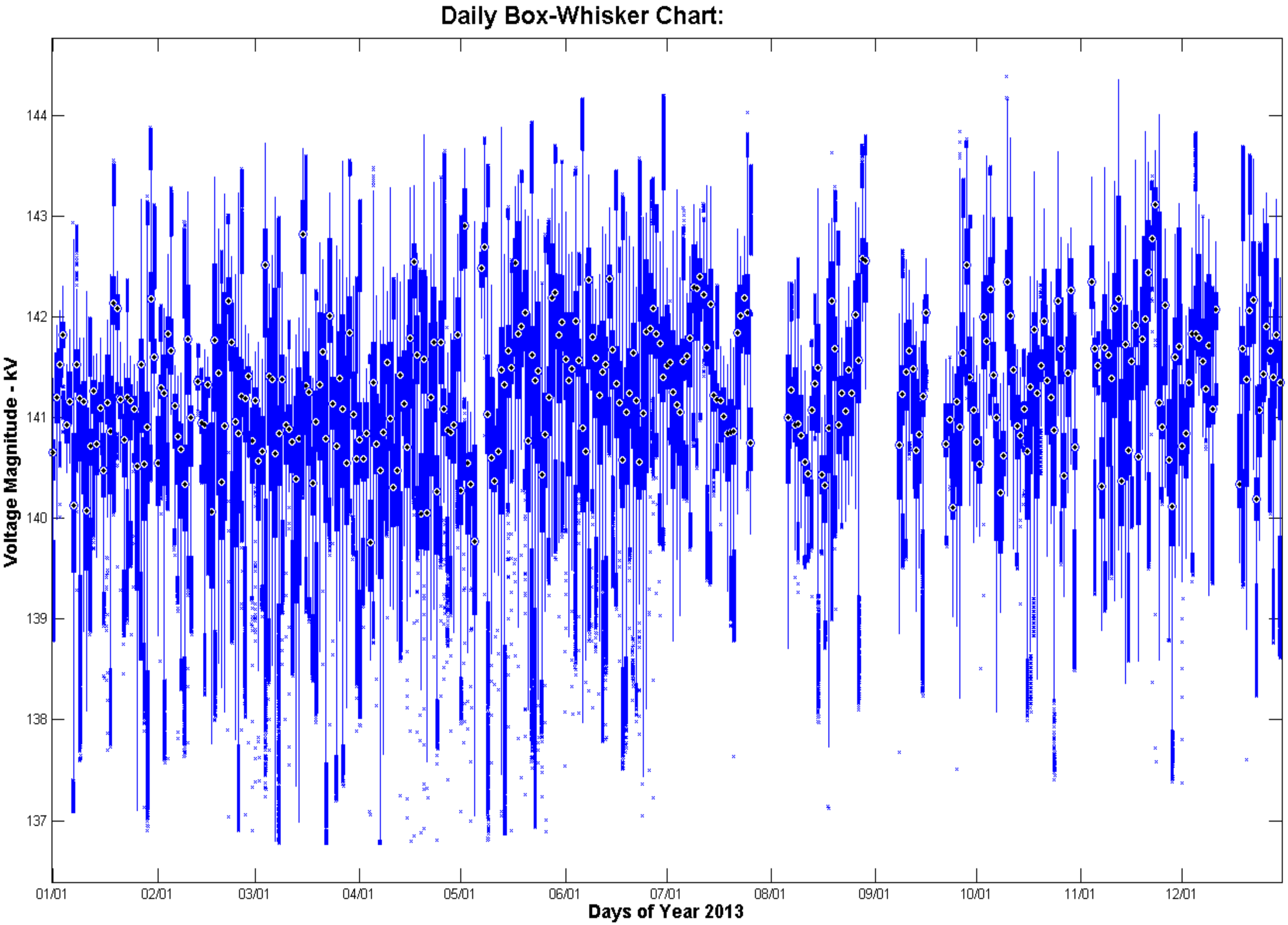
Daily Box-Whisker Chart:
Voltage Magnitude - kV
145
144
143
142
141
140
139
138
137
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

FarWest 8



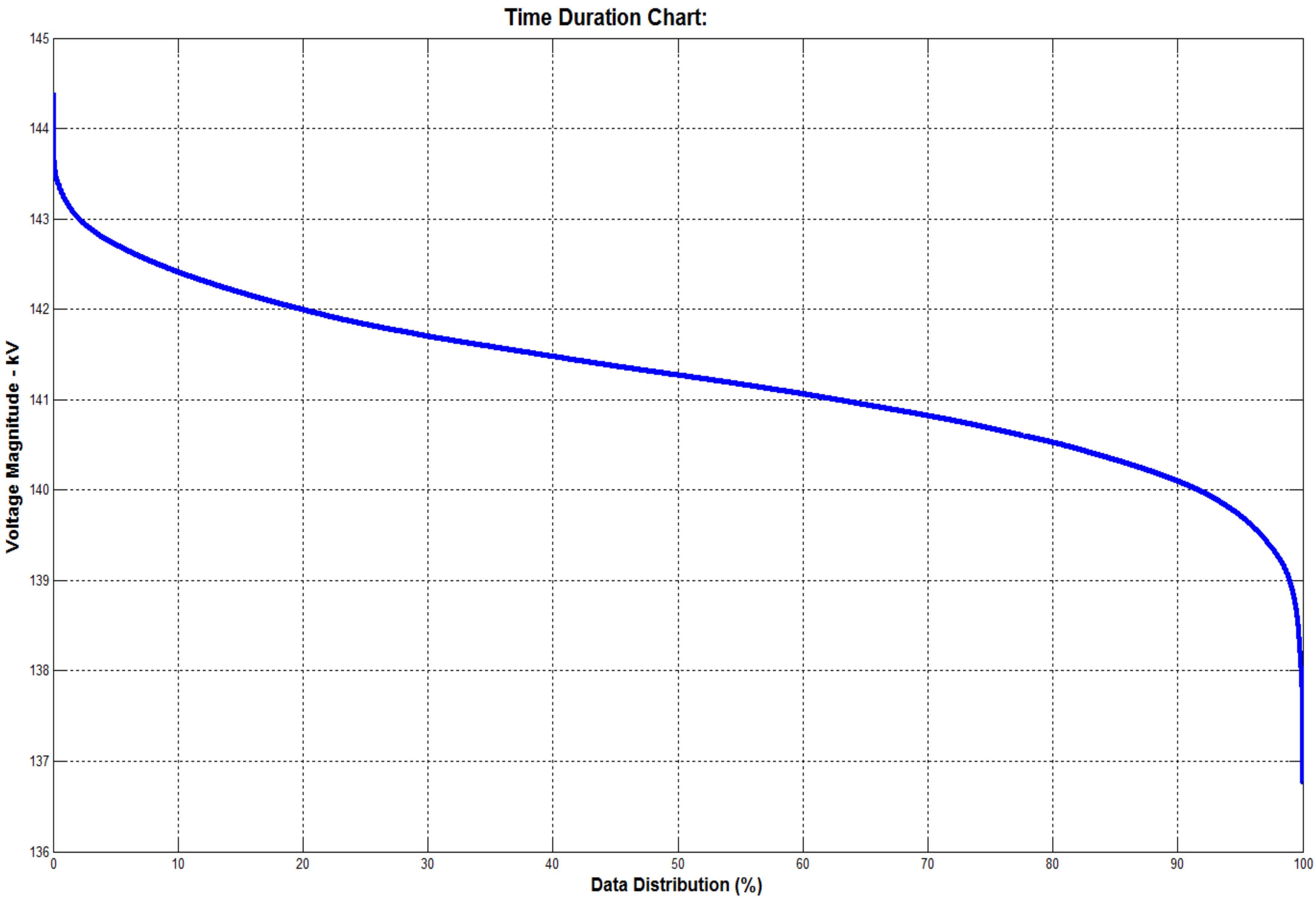
Time Duration Chart:
Voltage Magnitude - kV
Data Distribution (%)
146
145
144
143
142
141
140
139
138
137
0
10
20
30
40
50
60
70
80
90
100

FarWest 9



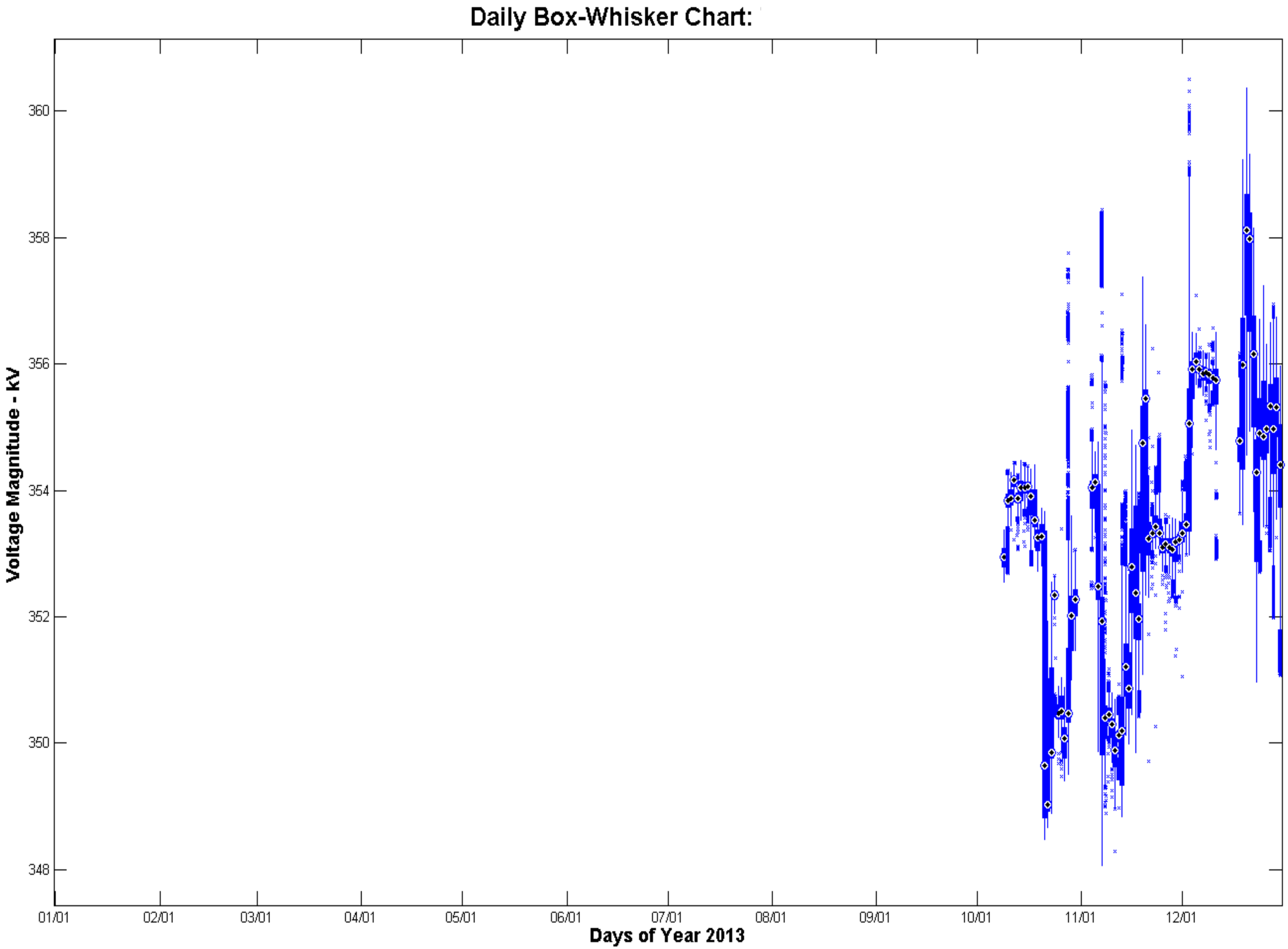
Daily Box-Whisker Chart:
Voltage Magnitude - kV
144
143
142
141
140
139
138
137
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

FarWest 9

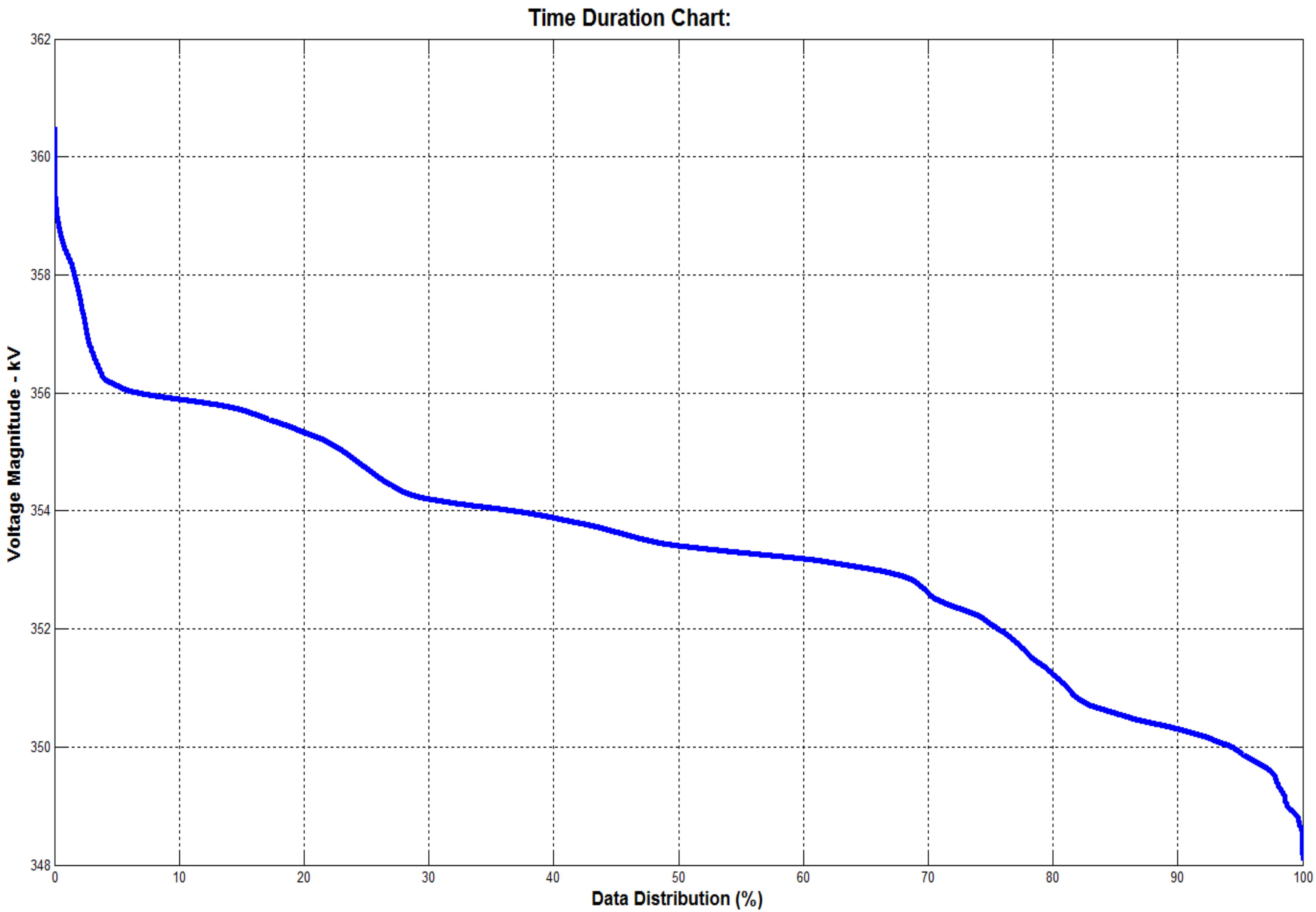


Time Duration Chart:
145
144
143
142
141
140
139
138
137
136
Voltage Magnitude - kV
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 15


Daily Box-Whisker Chart:
Voltage Magnitude - kV
360
358
356
354
352
350
348
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 15



Time Duration Chart:
Voltage Magnitude - kV
362
360
358
356
354
352
350
348
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

Appendix B – Part 1

CCET Discovery Across Texas project

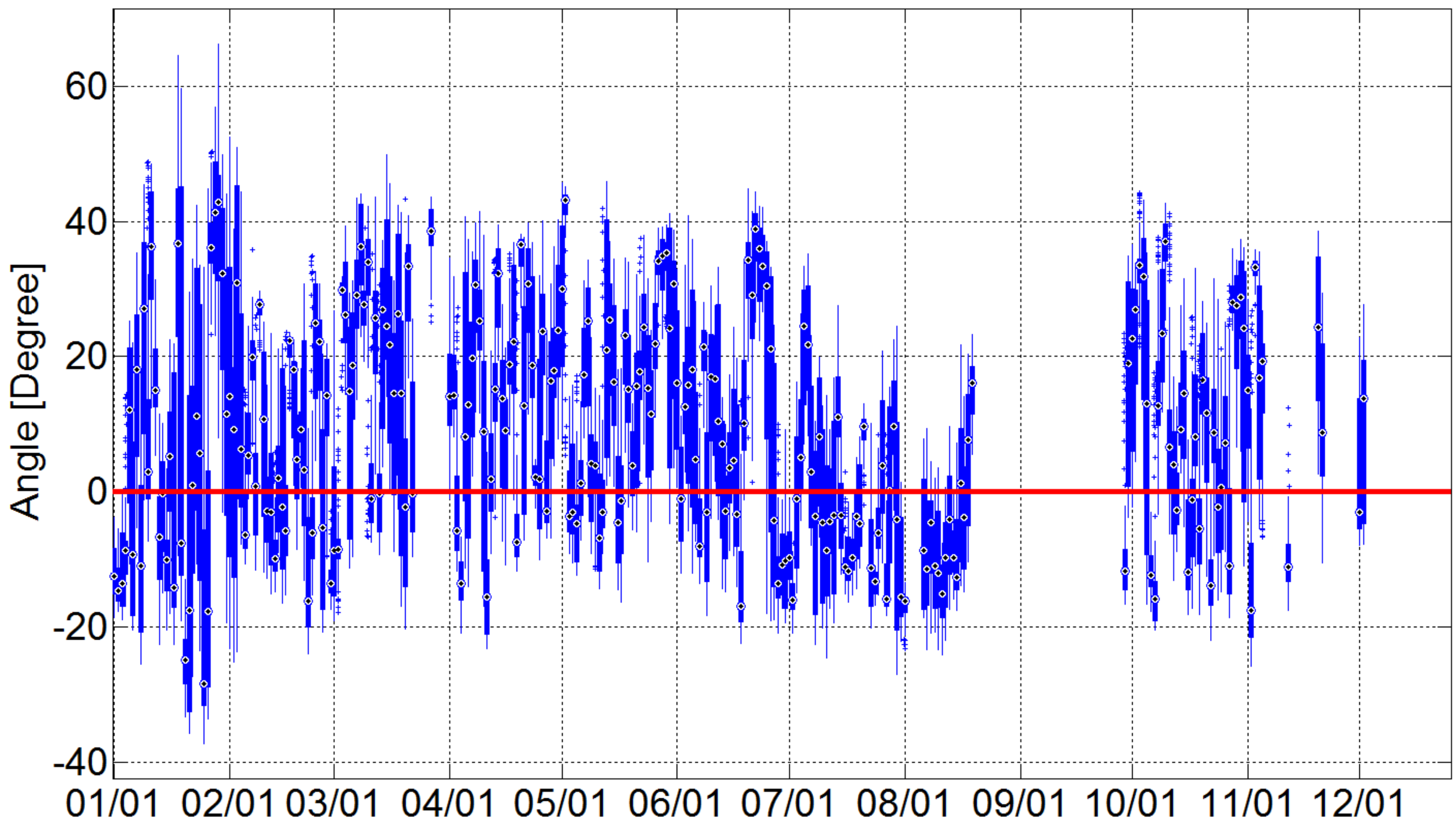
Baseline Analysis Update - Voltage Angles (Reference: North 7)

State Estimator Data: January to December 2013

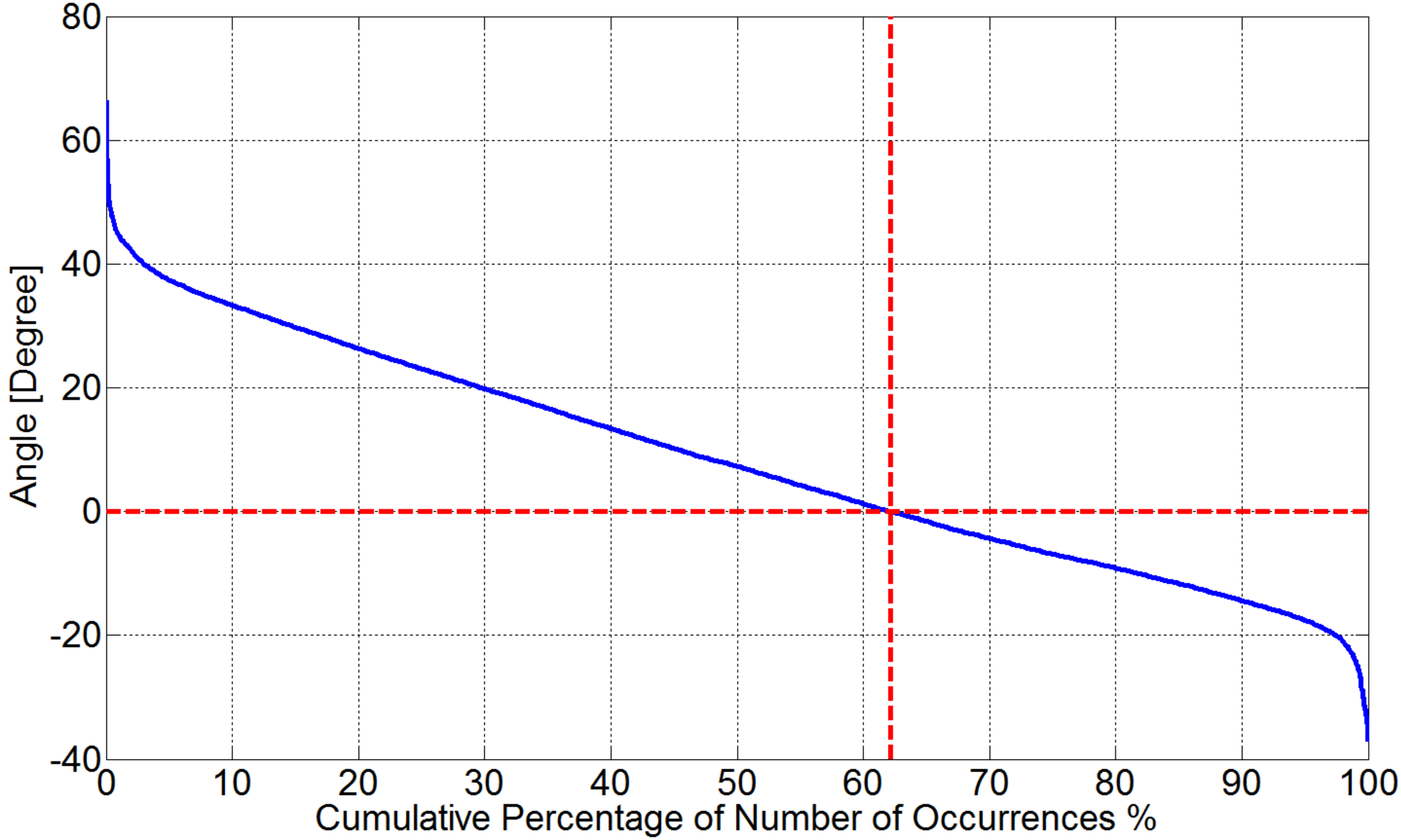
Box-Whisker Plots and Time Duration Curves

Electric Power Group CCET ERCOT

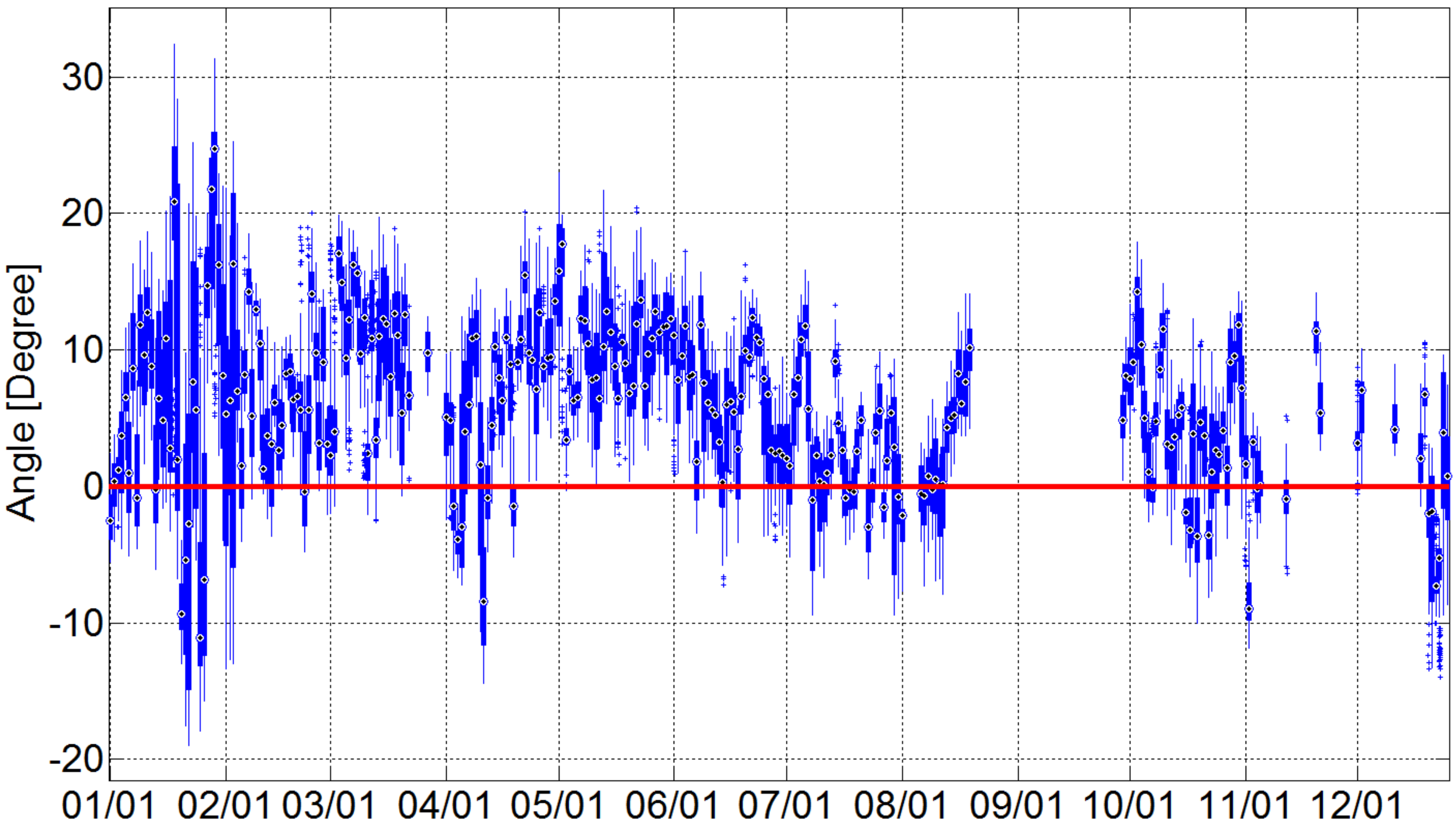
West 10-North 7



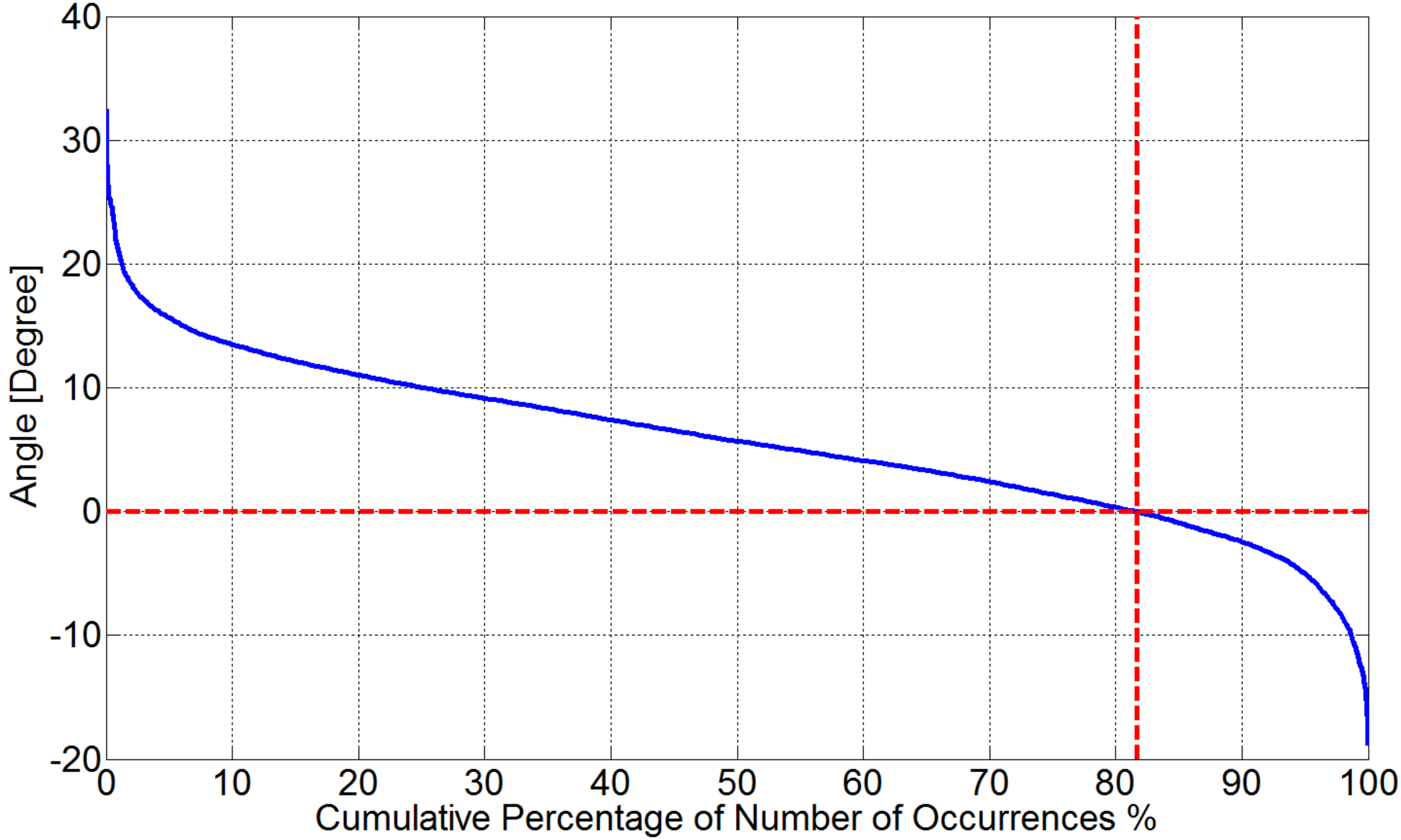
West 10-North 7



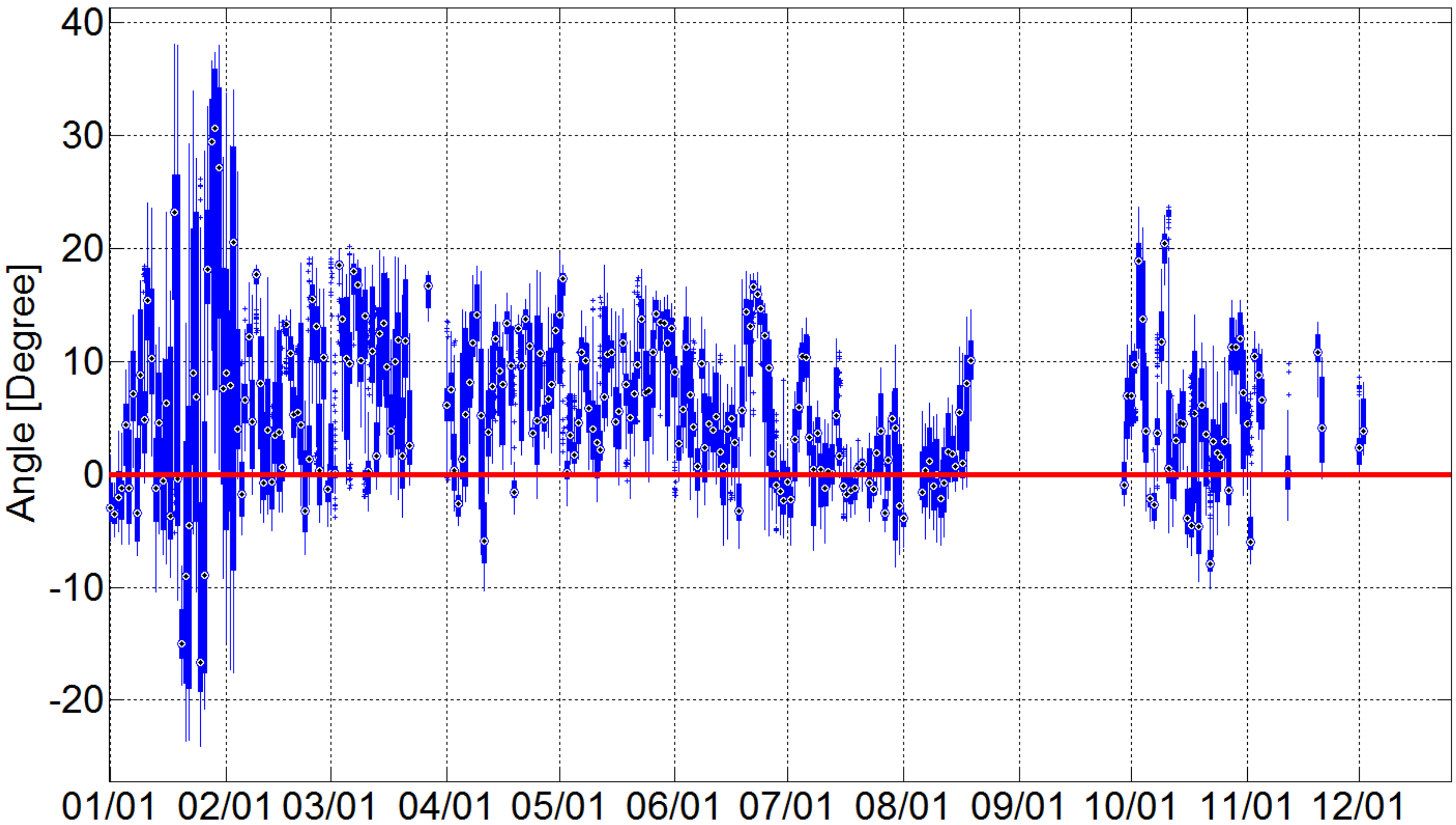
West 14-North 7



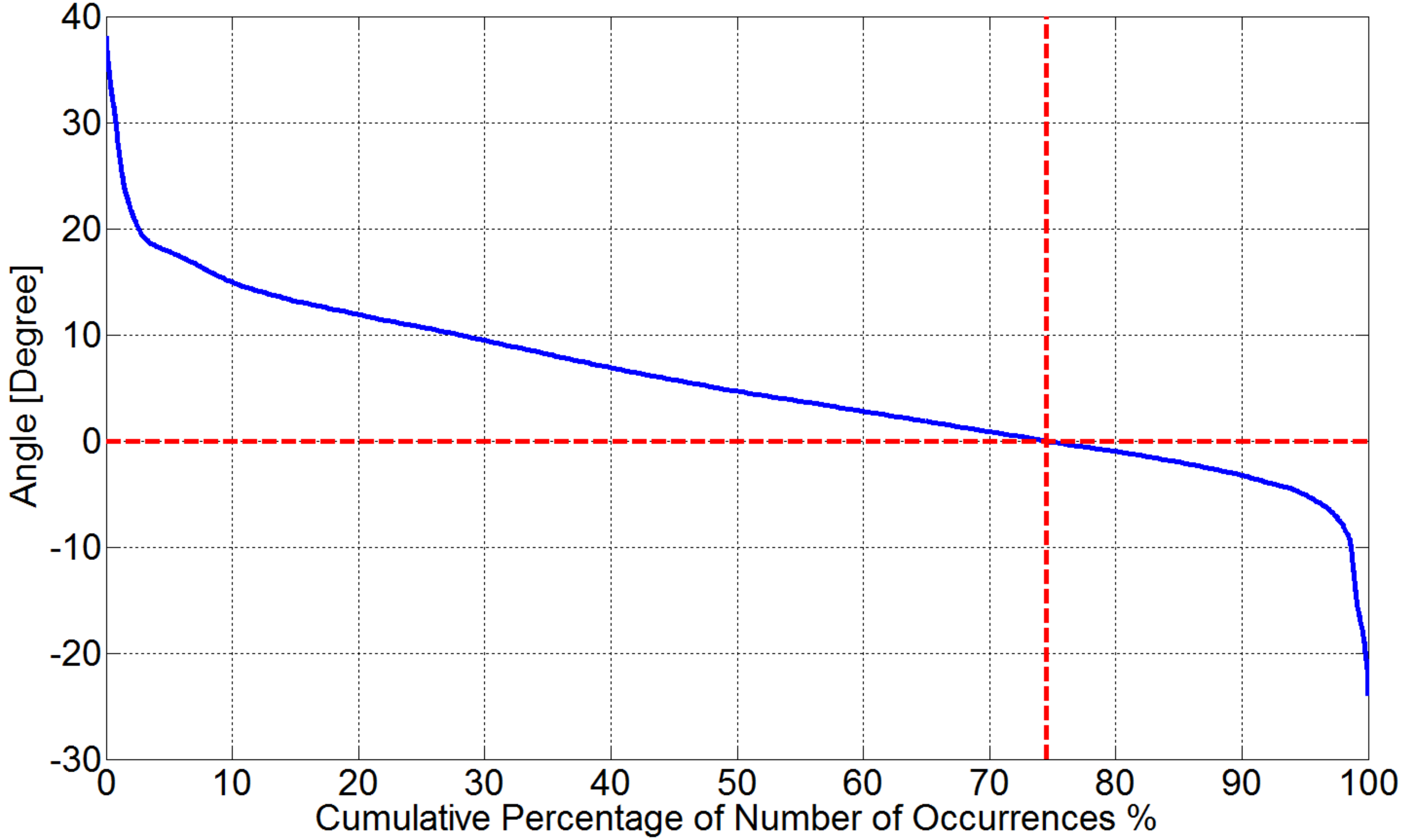
West 14-North 7



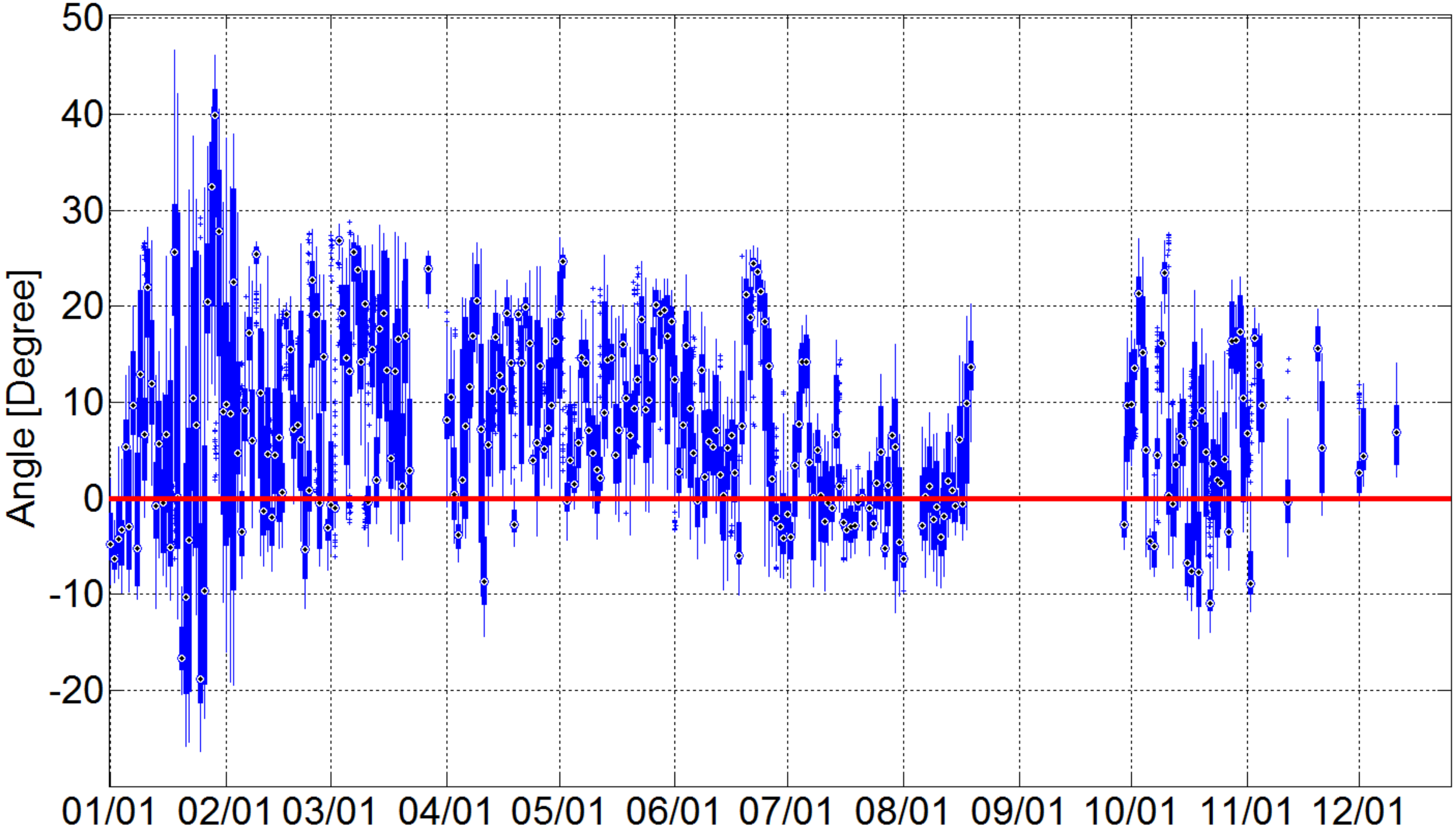
West 1-North 7



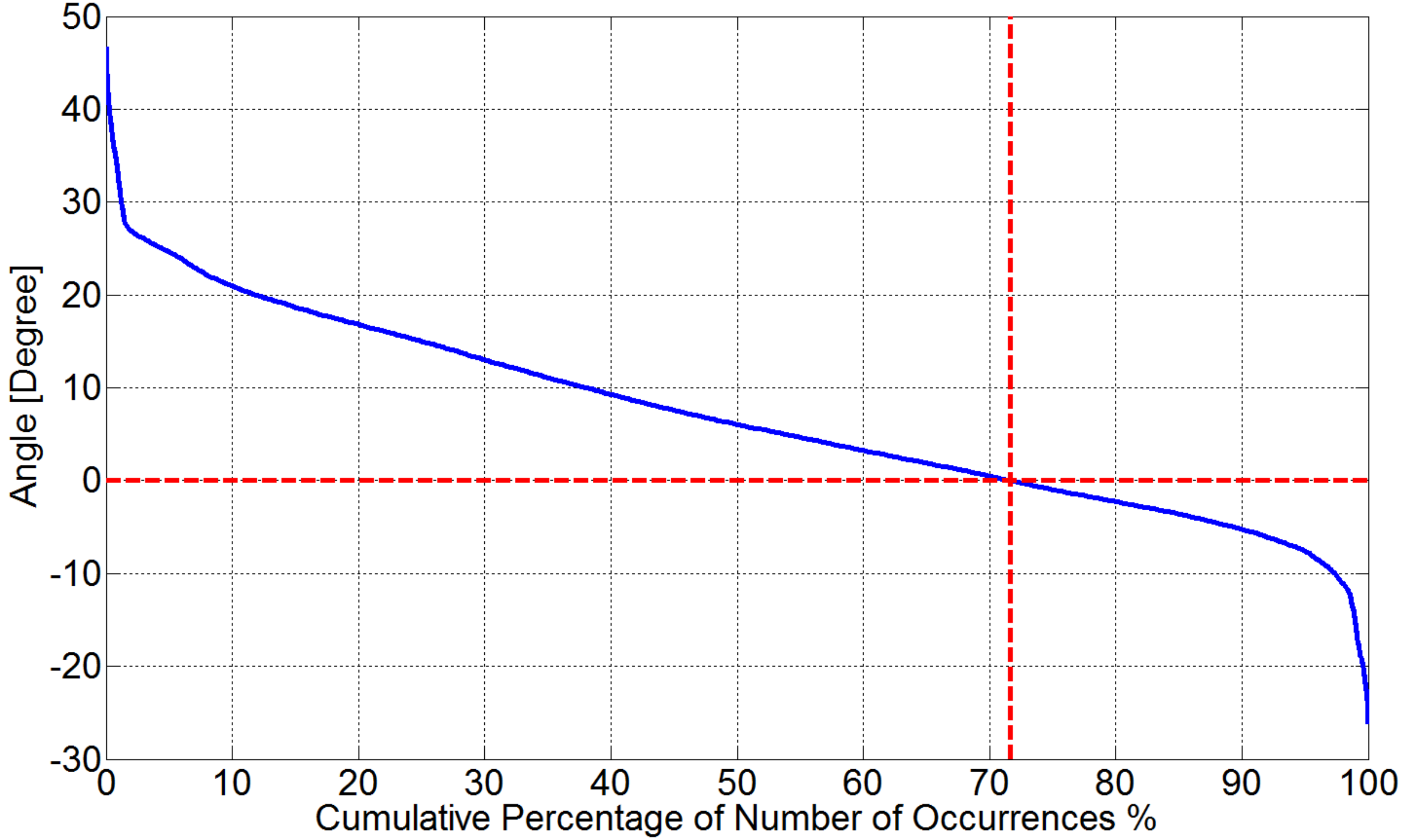
West 1-North 7



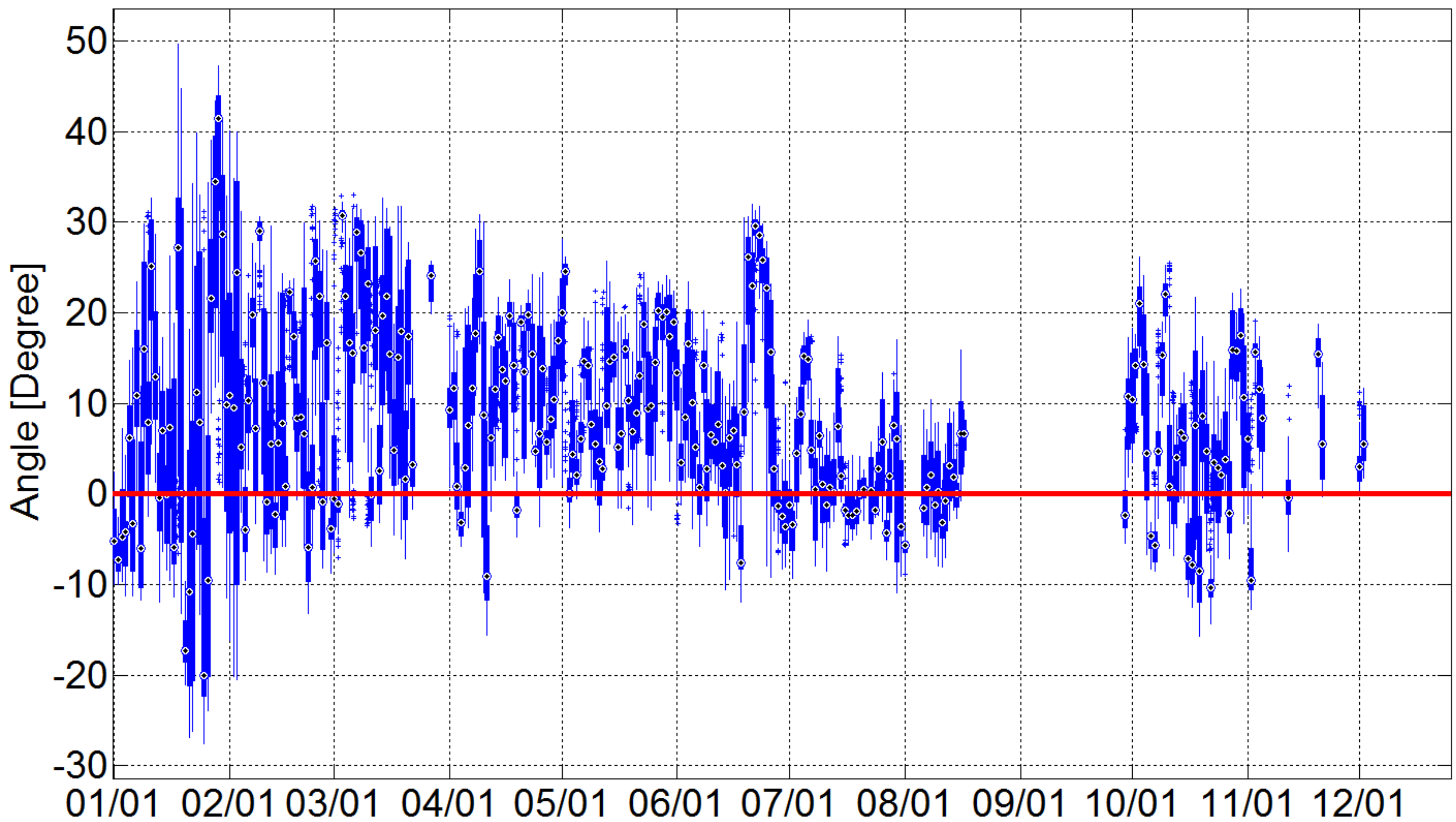
West 2-North 7



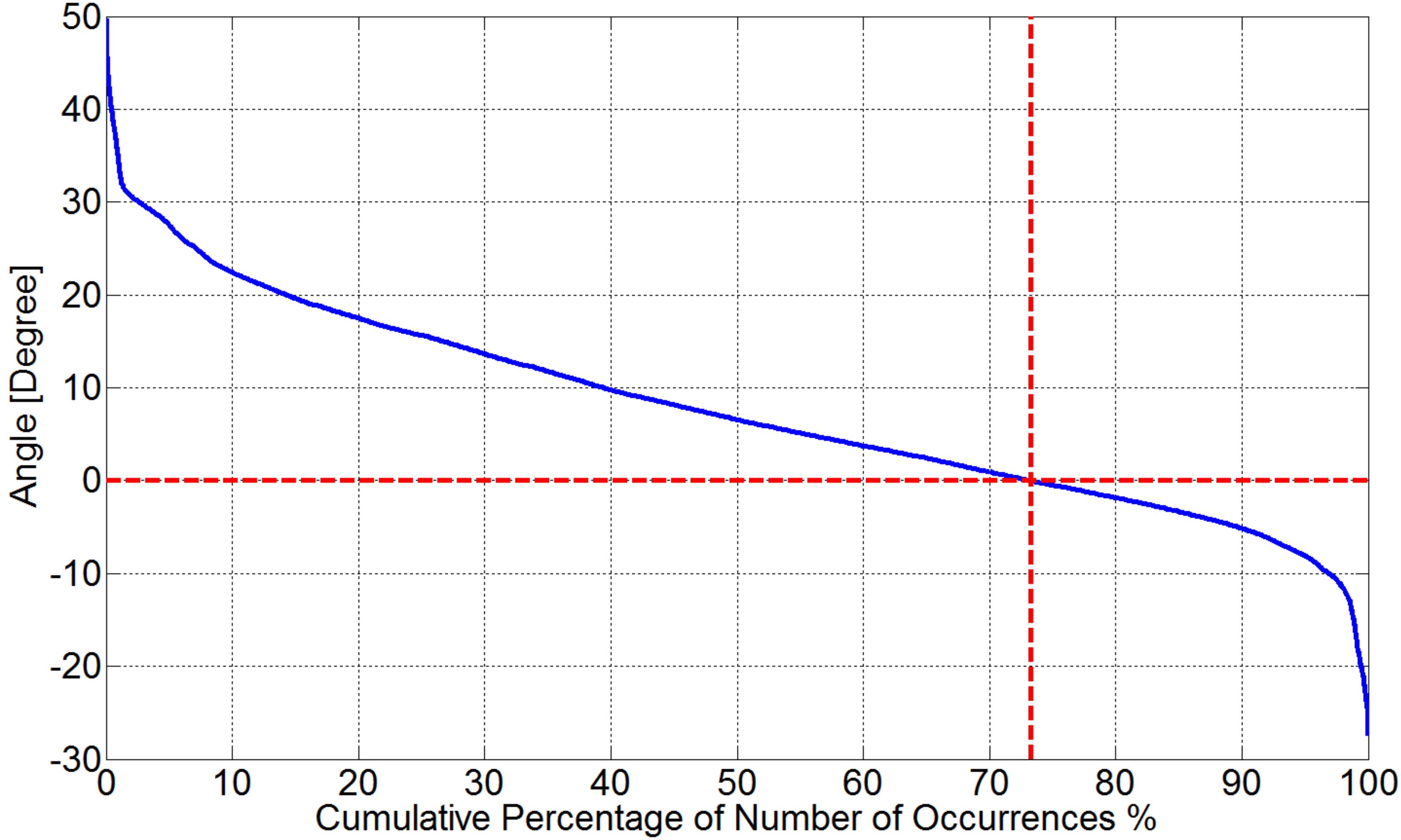
West 2-North 7



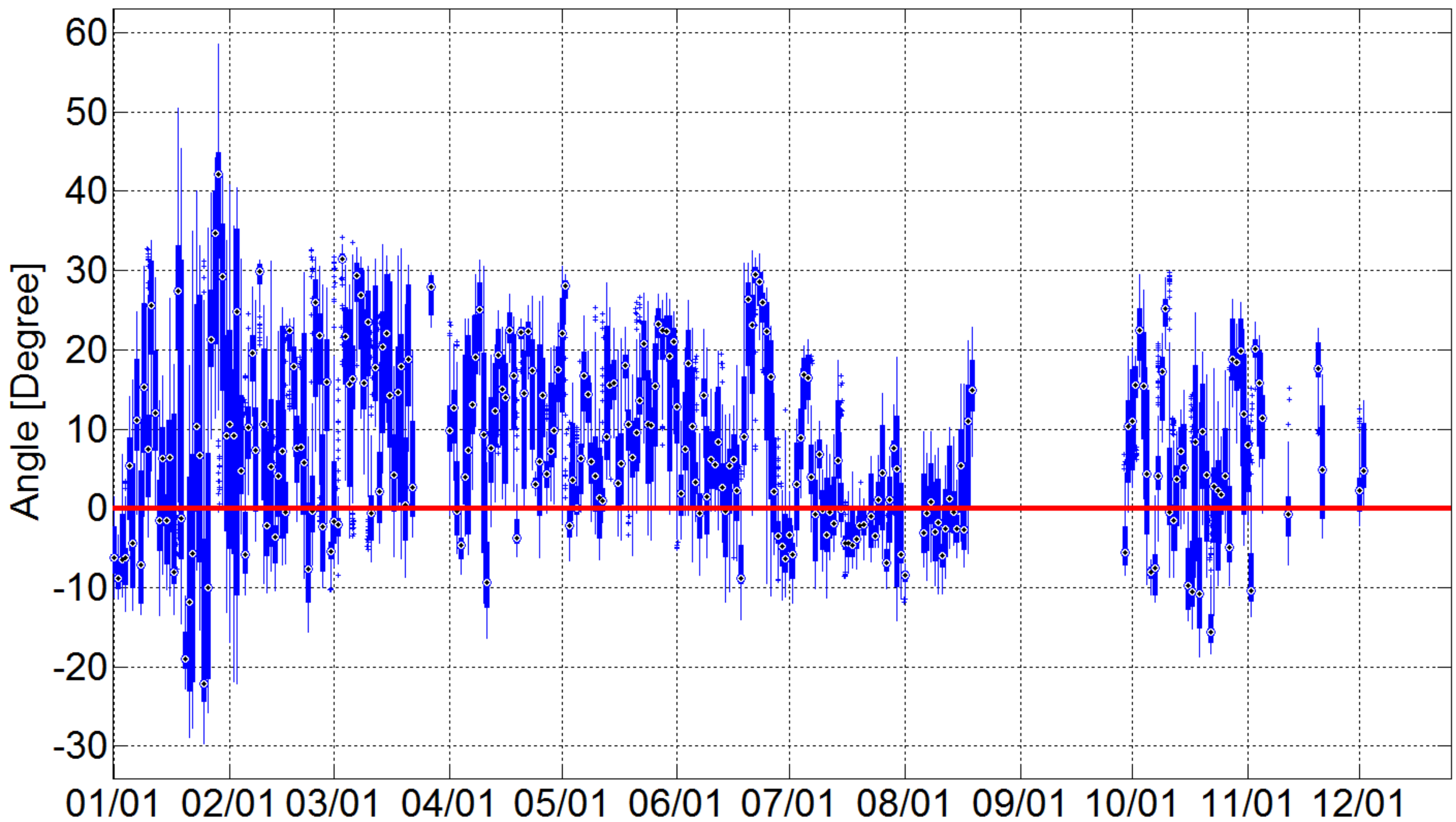
West 9-North 7



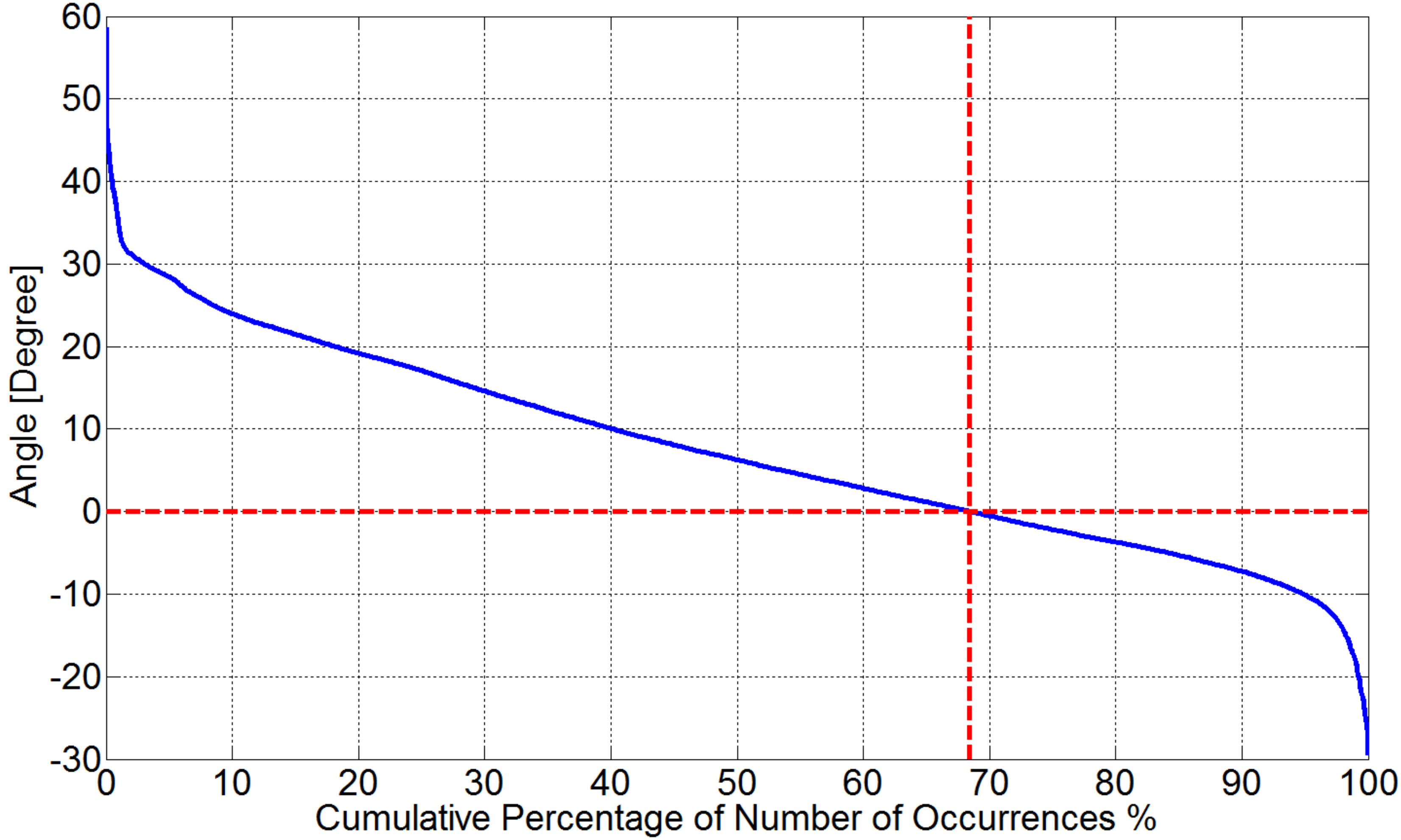
West 9-North 7



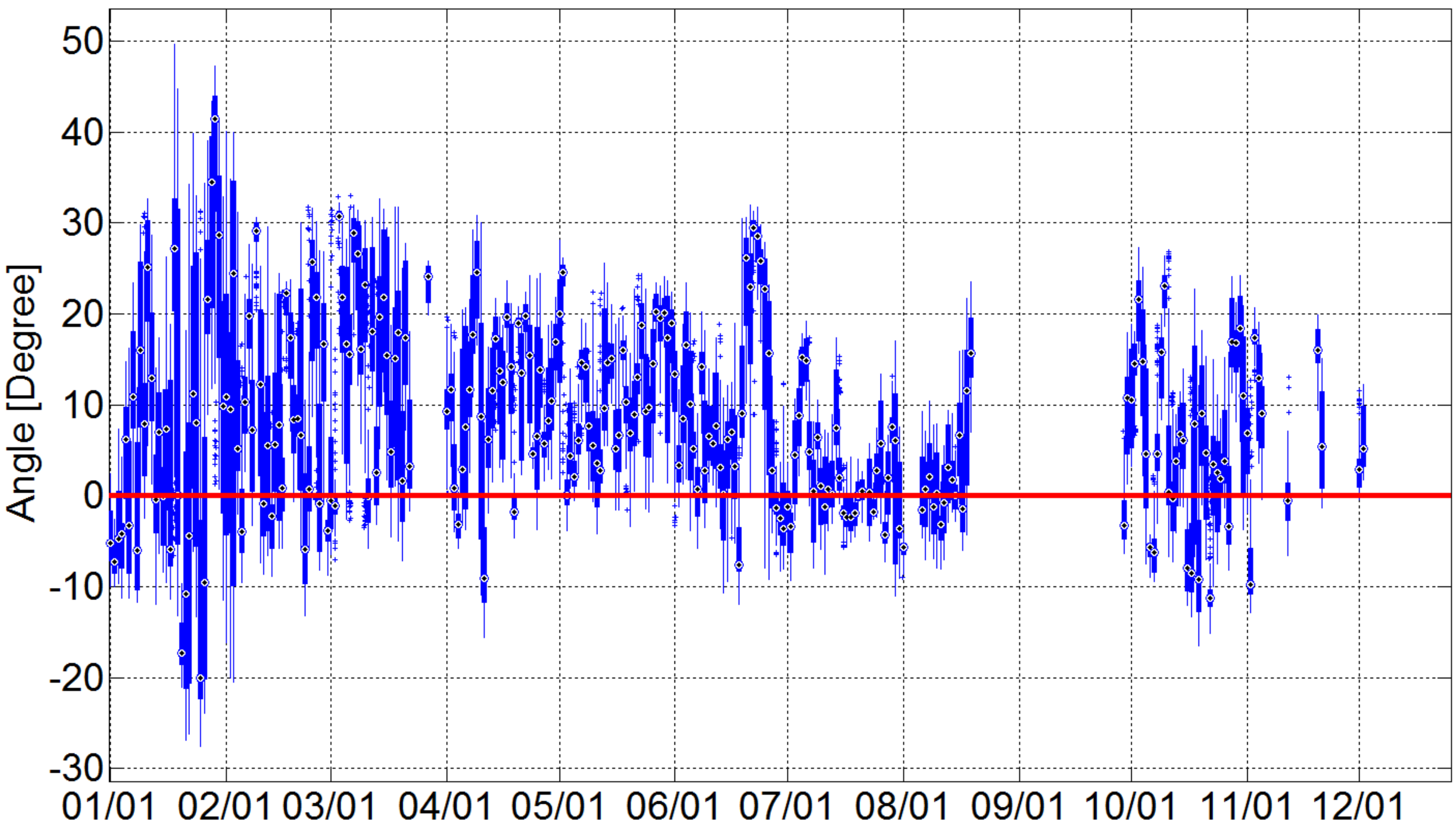
West 11-North 7



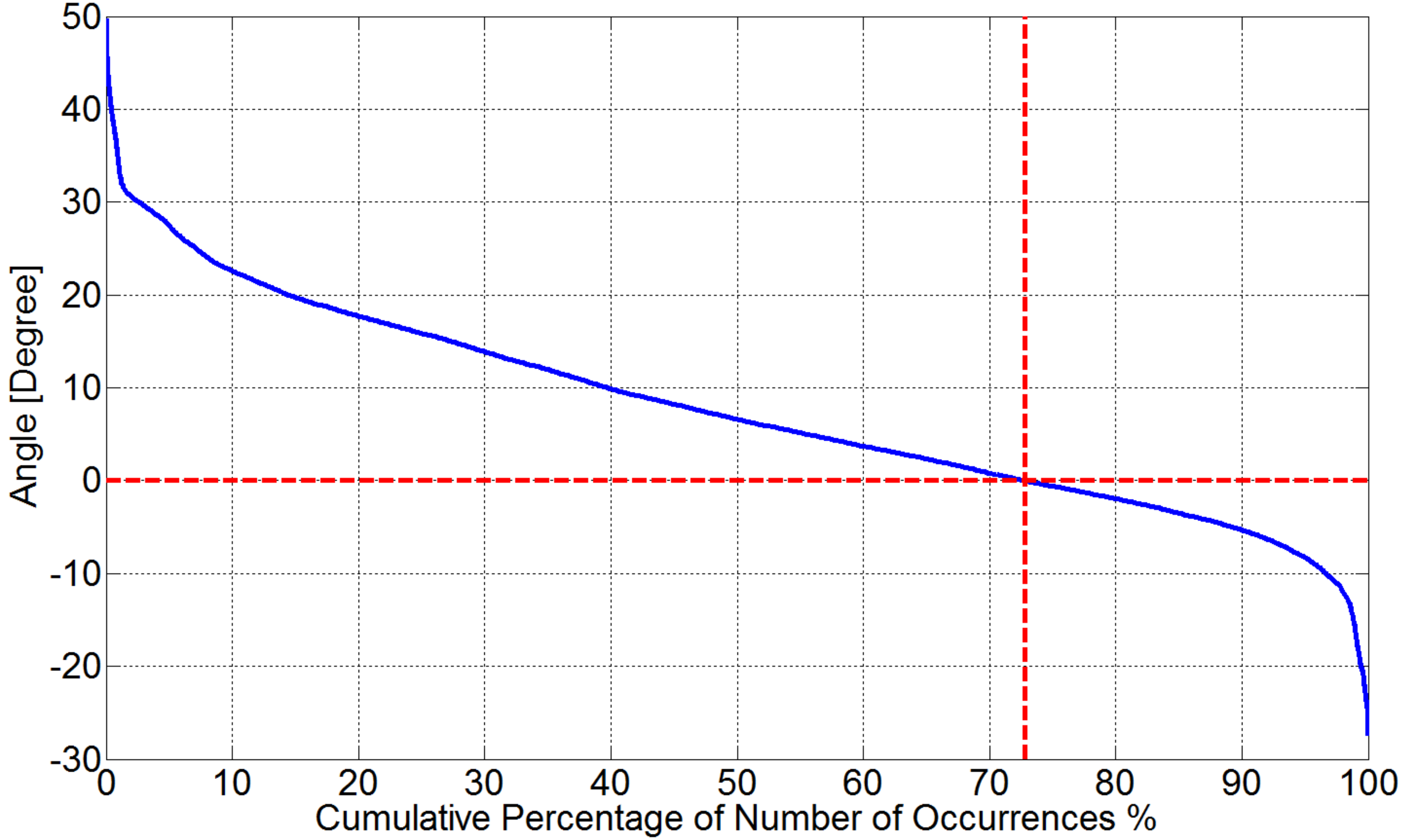
West 11-North 7



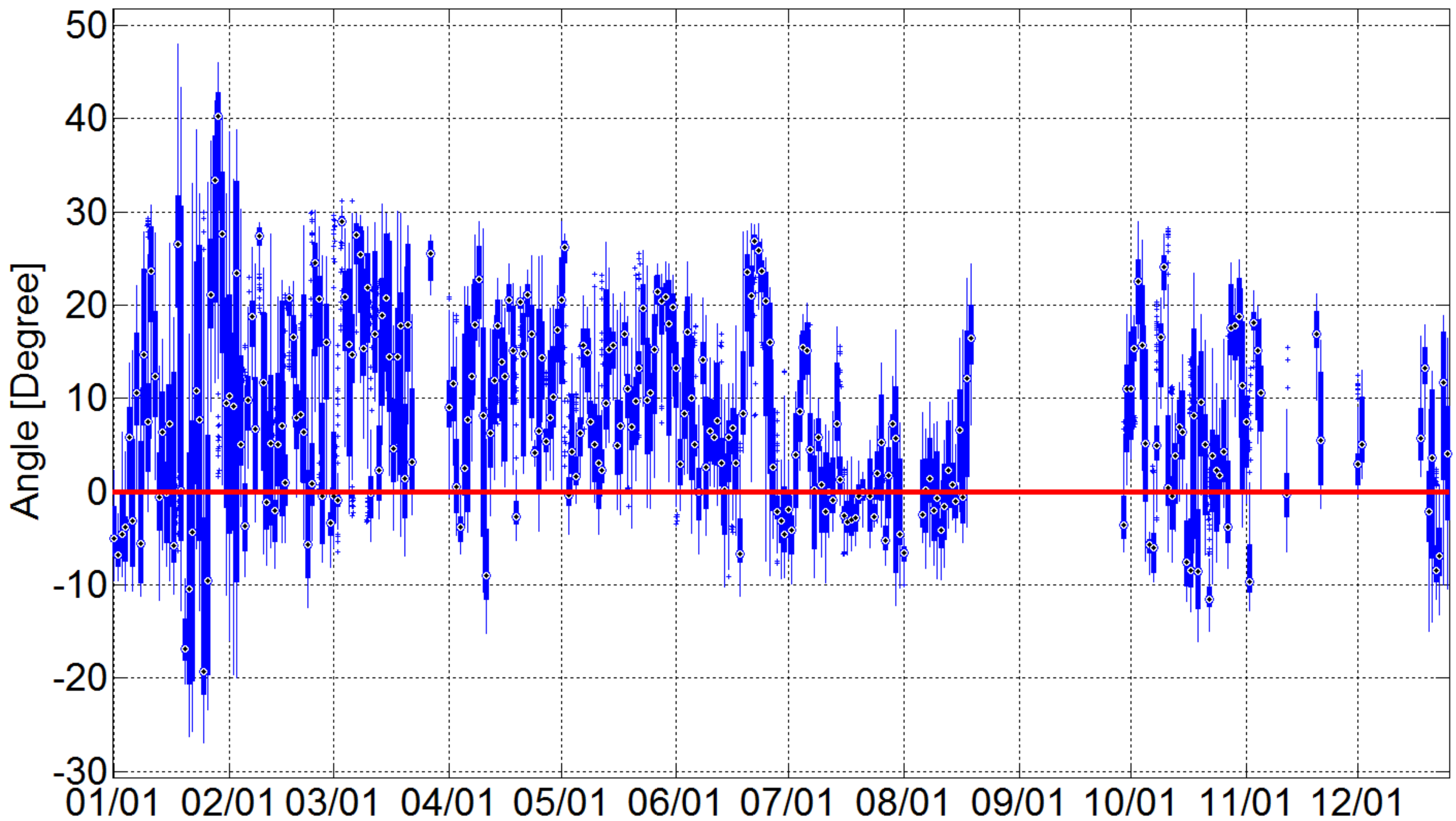
West 12-North 7



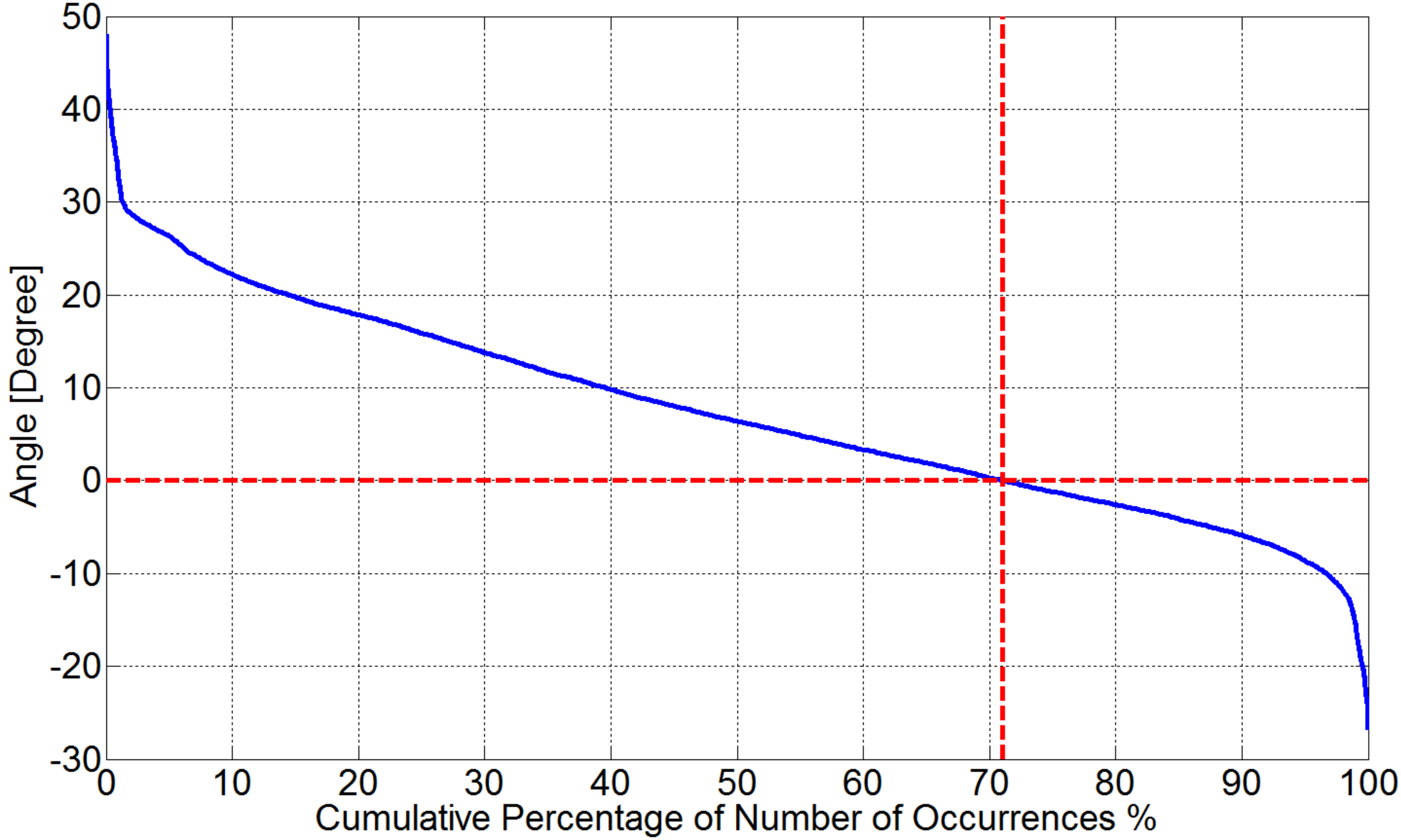
West 12-North 7



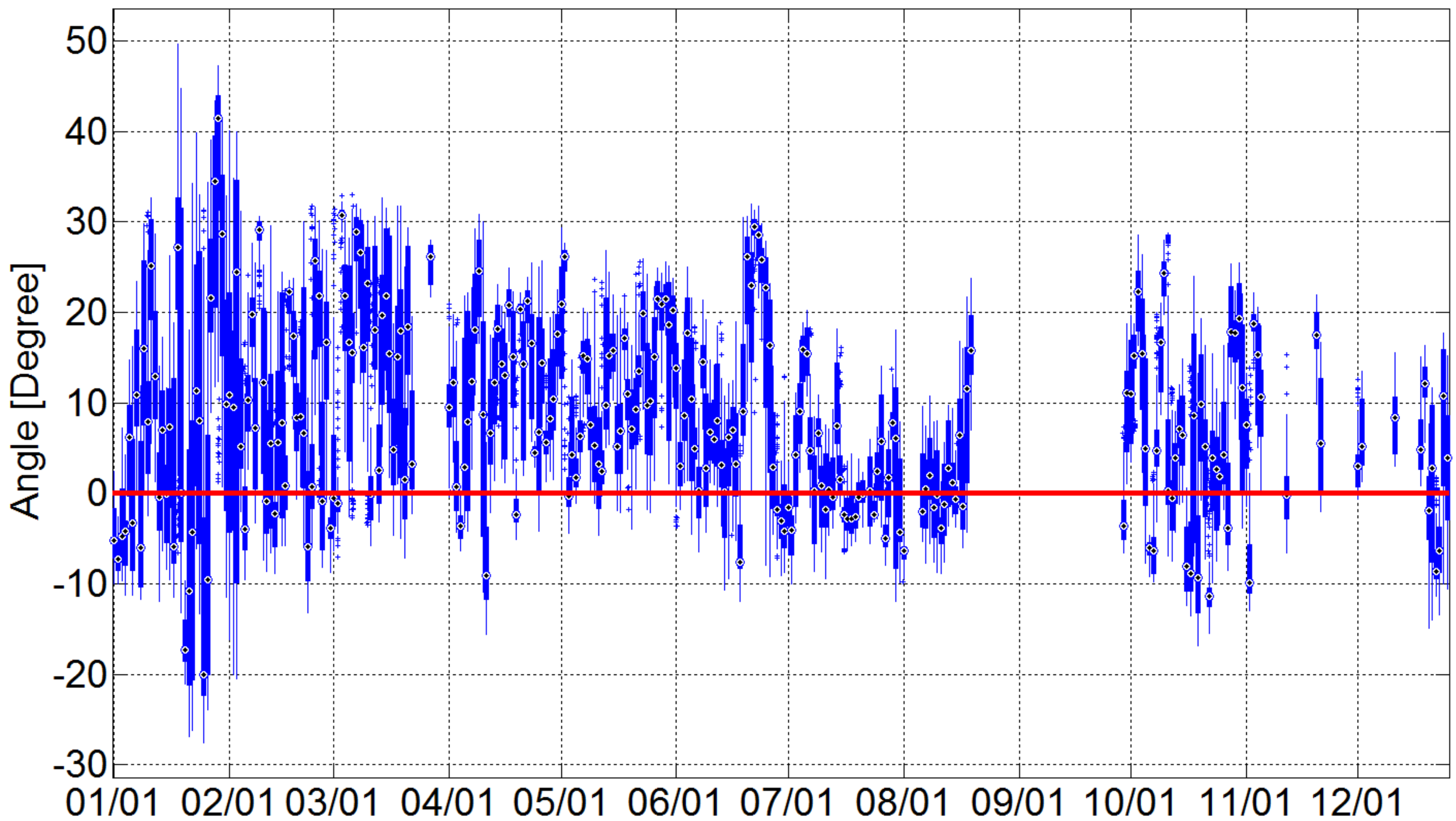
West 5-North 7



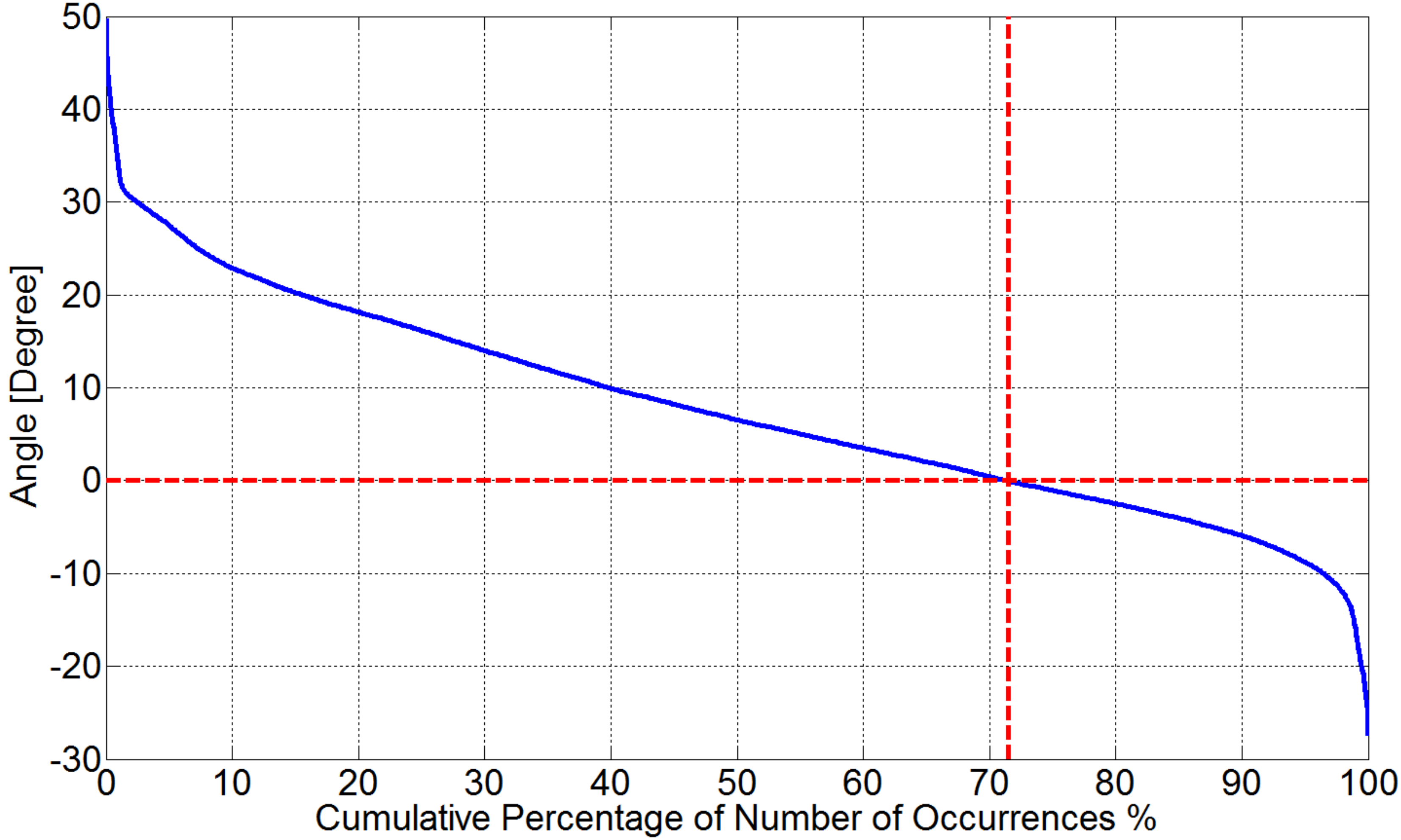
West 5-North 7



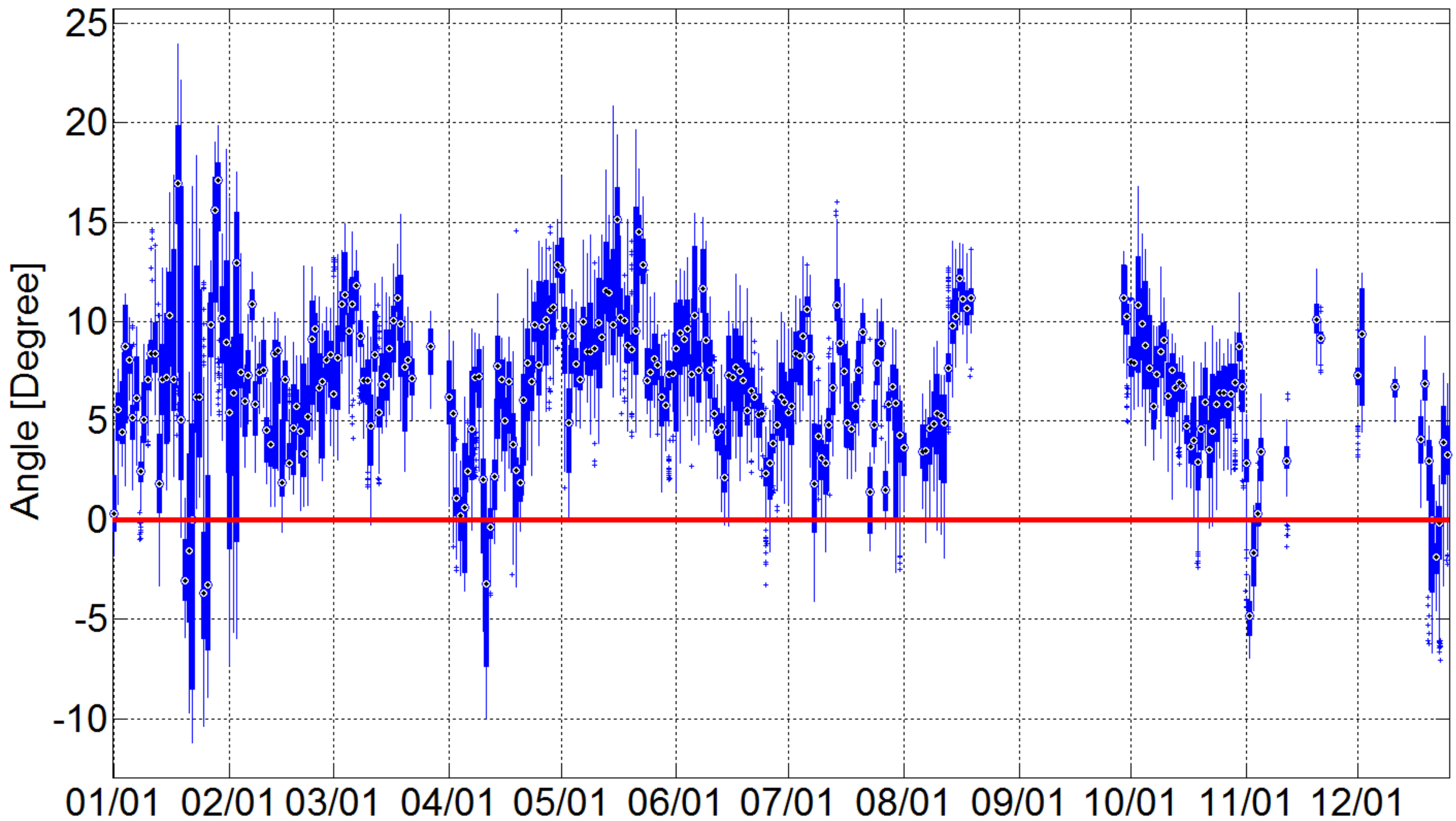
West 6-North 7



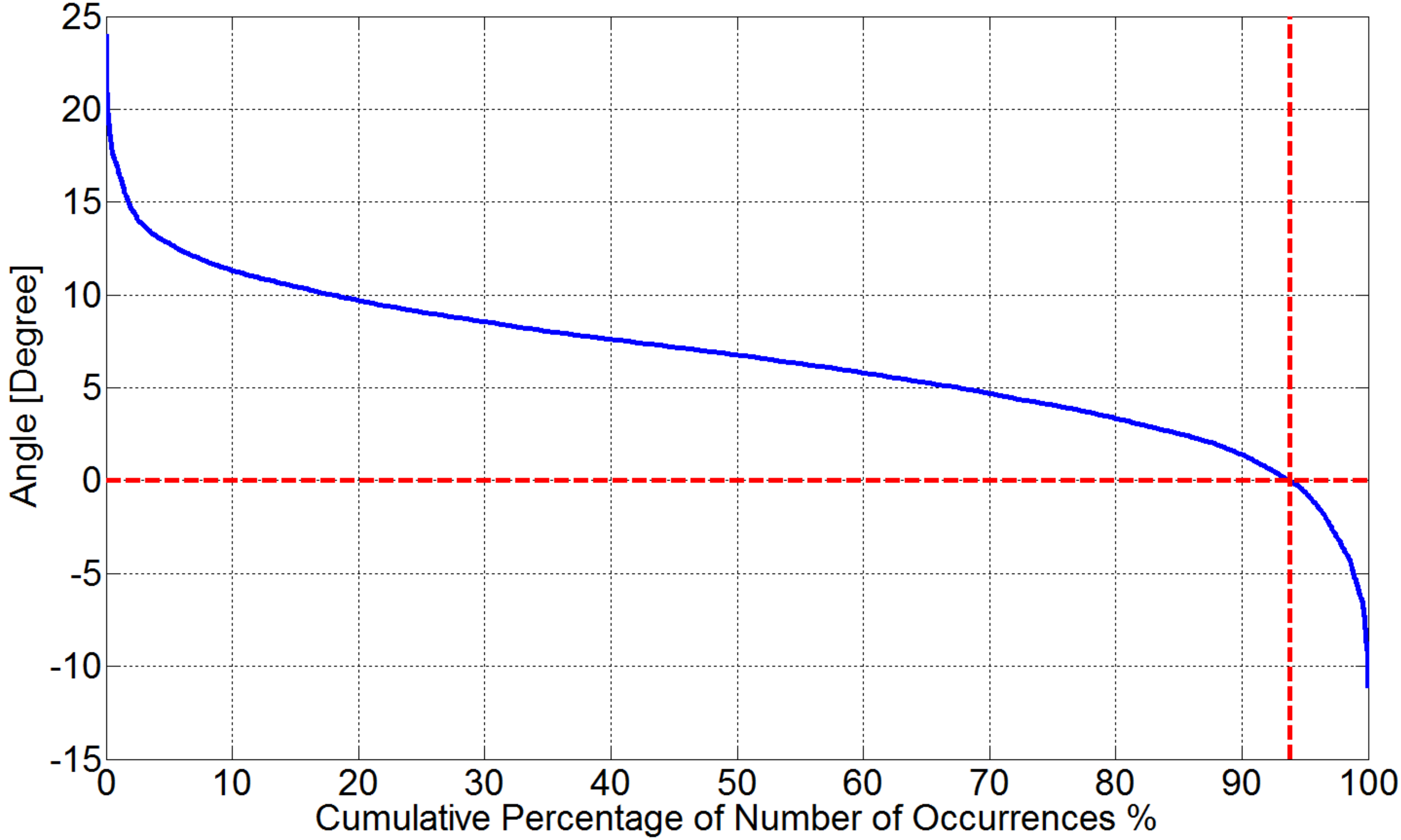
West 6-North 7



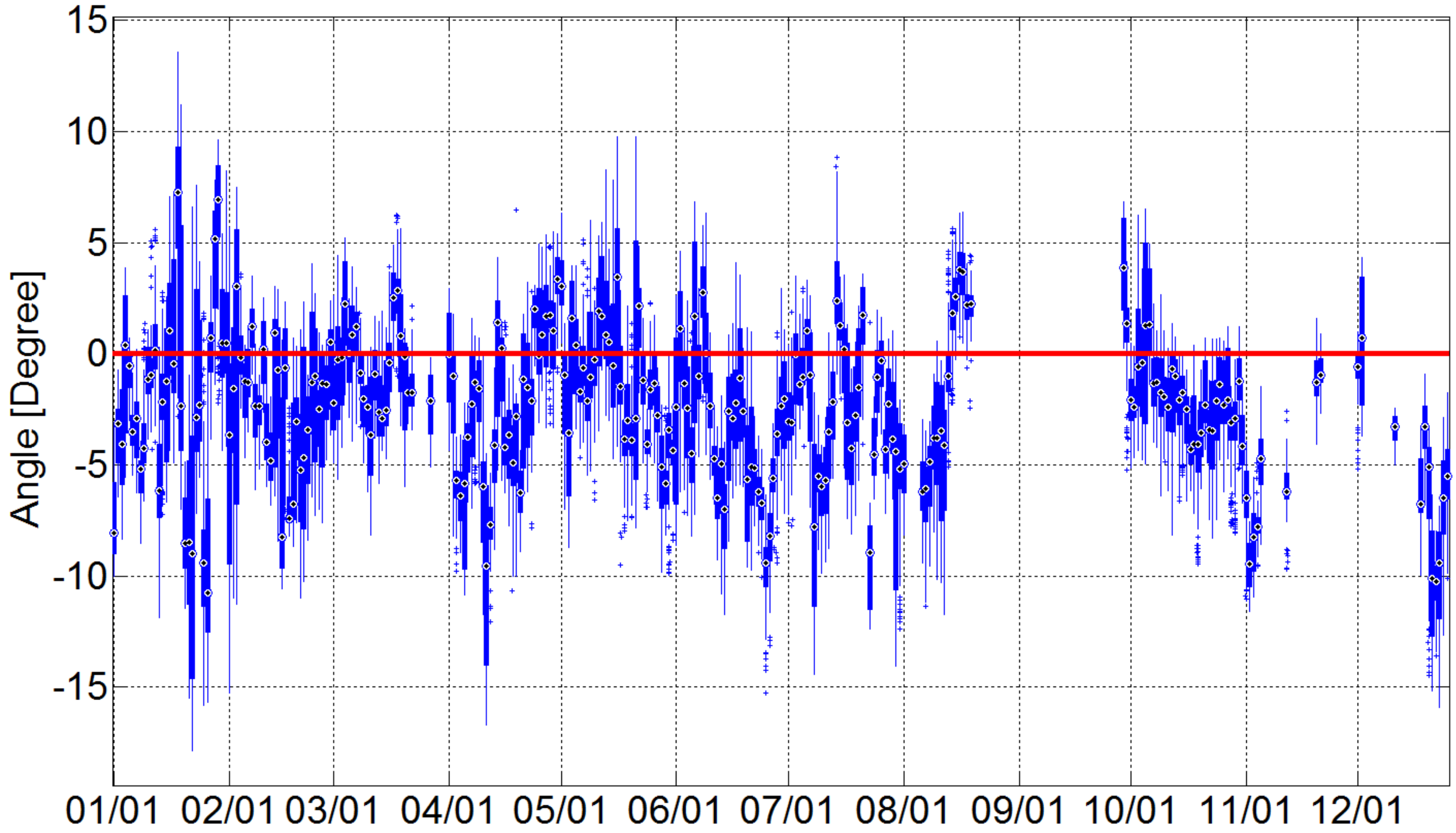
North 1-North 7



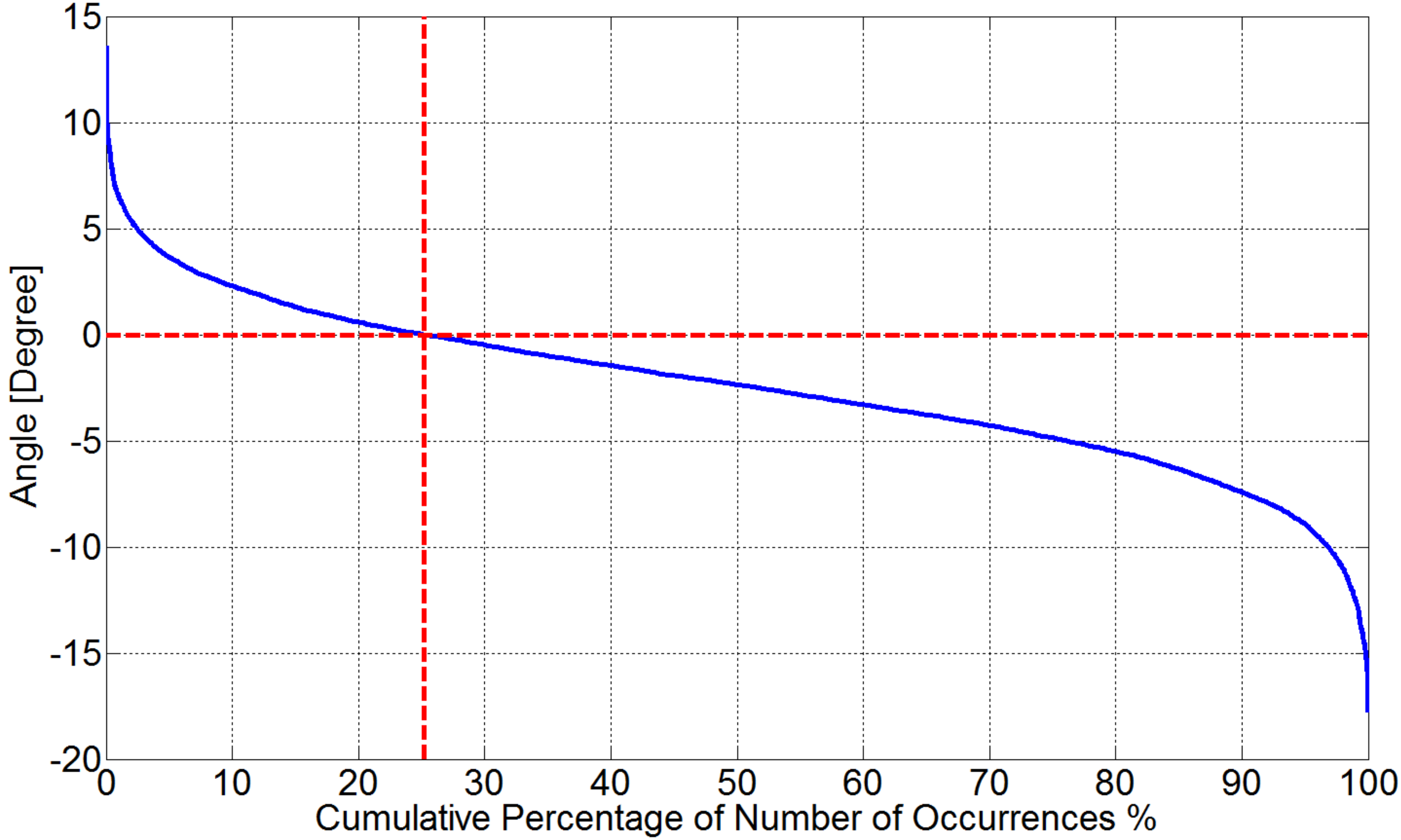
North 1-North 7



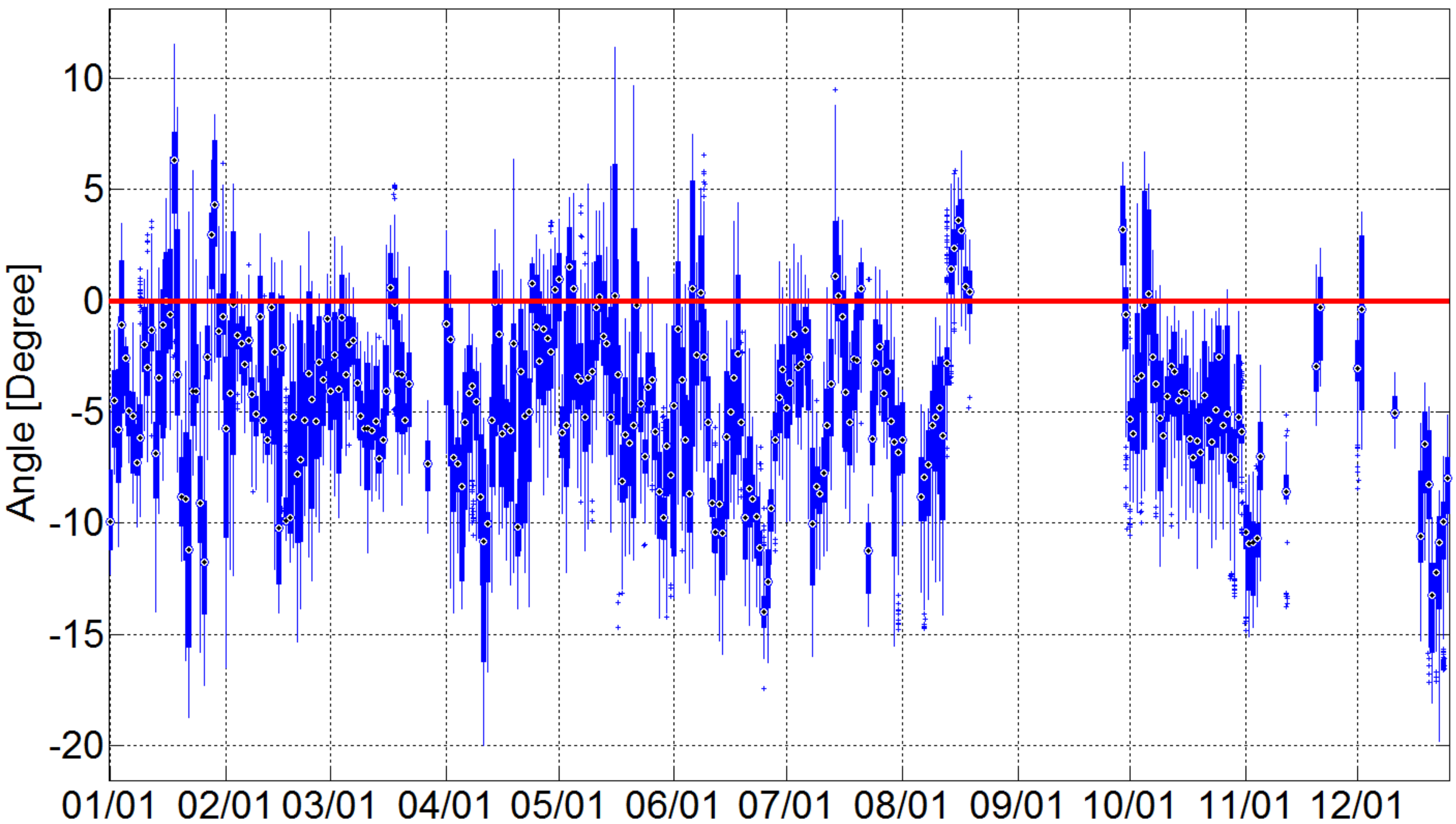
North 4-North 7



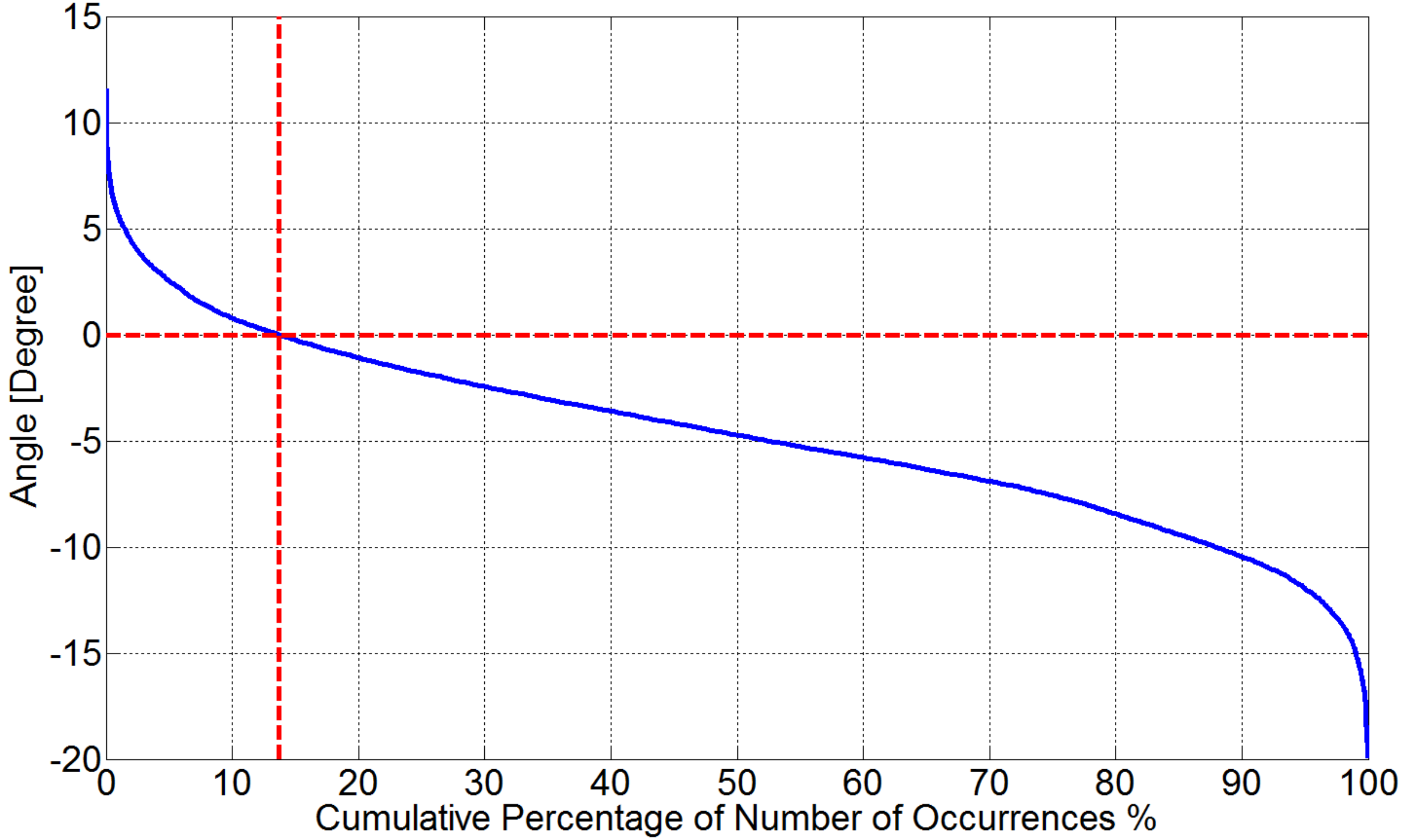
North 4-North 7



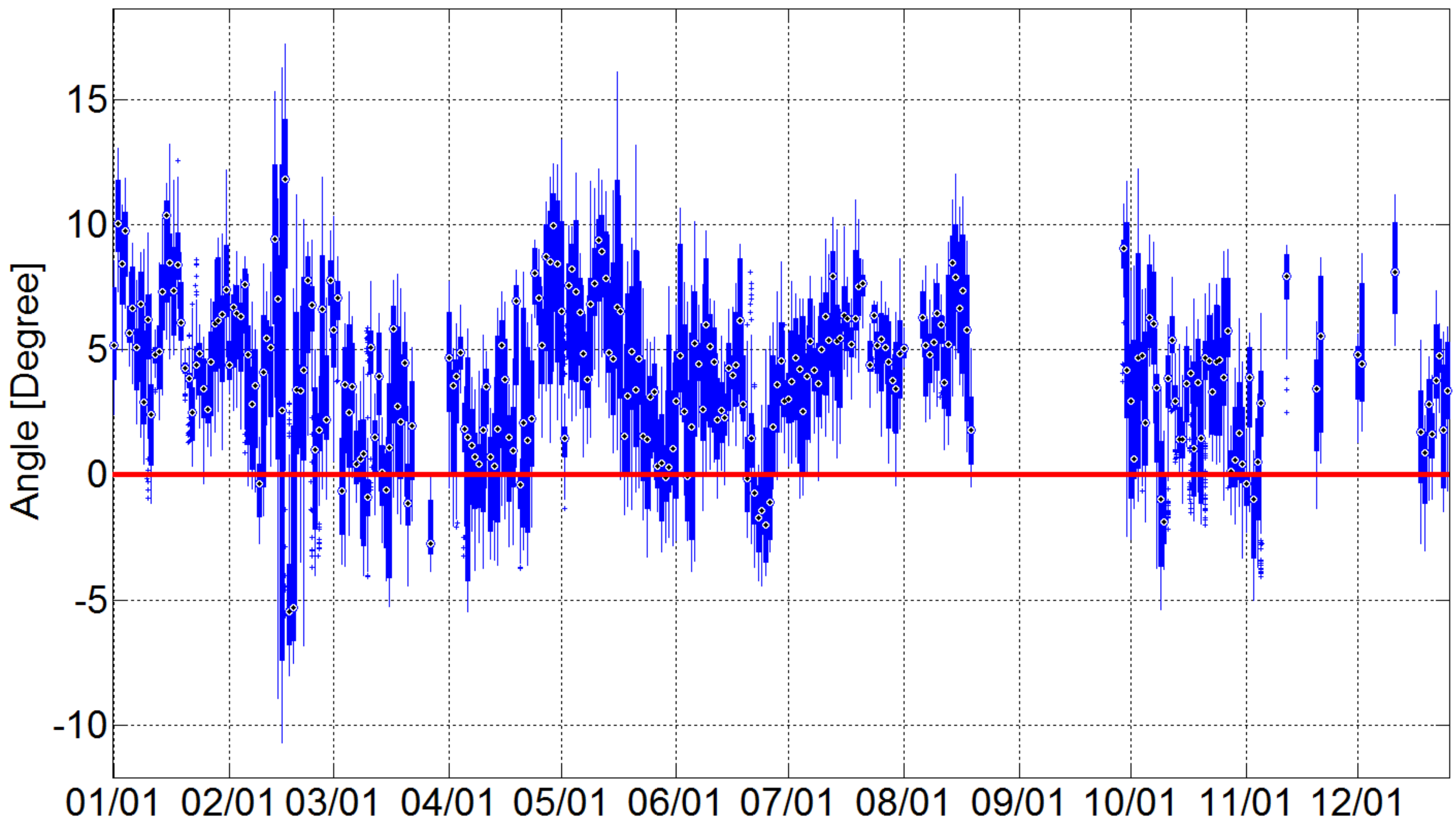
North 5-North 7



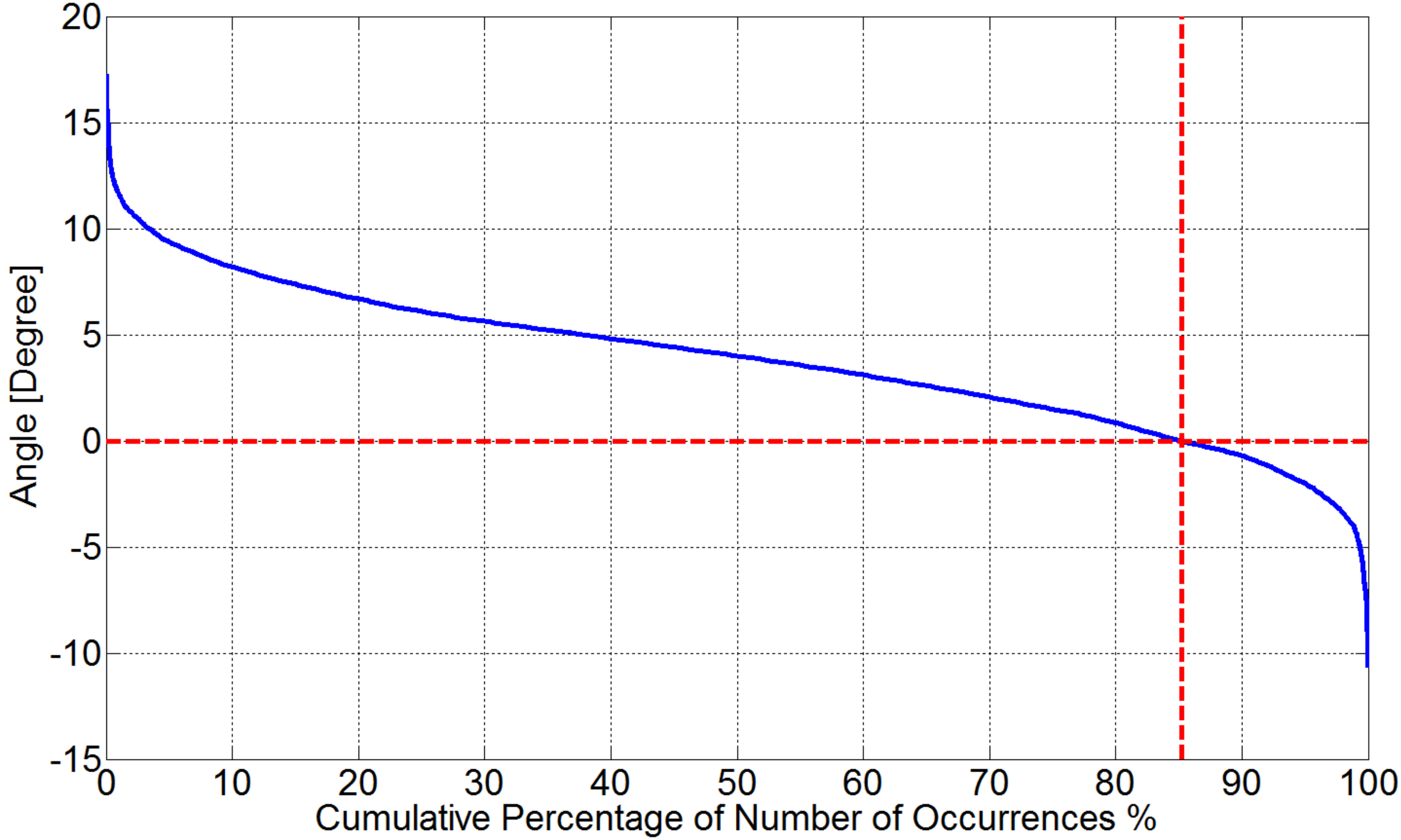
North 5-North 7



North 6-North 7



North 6-North 7



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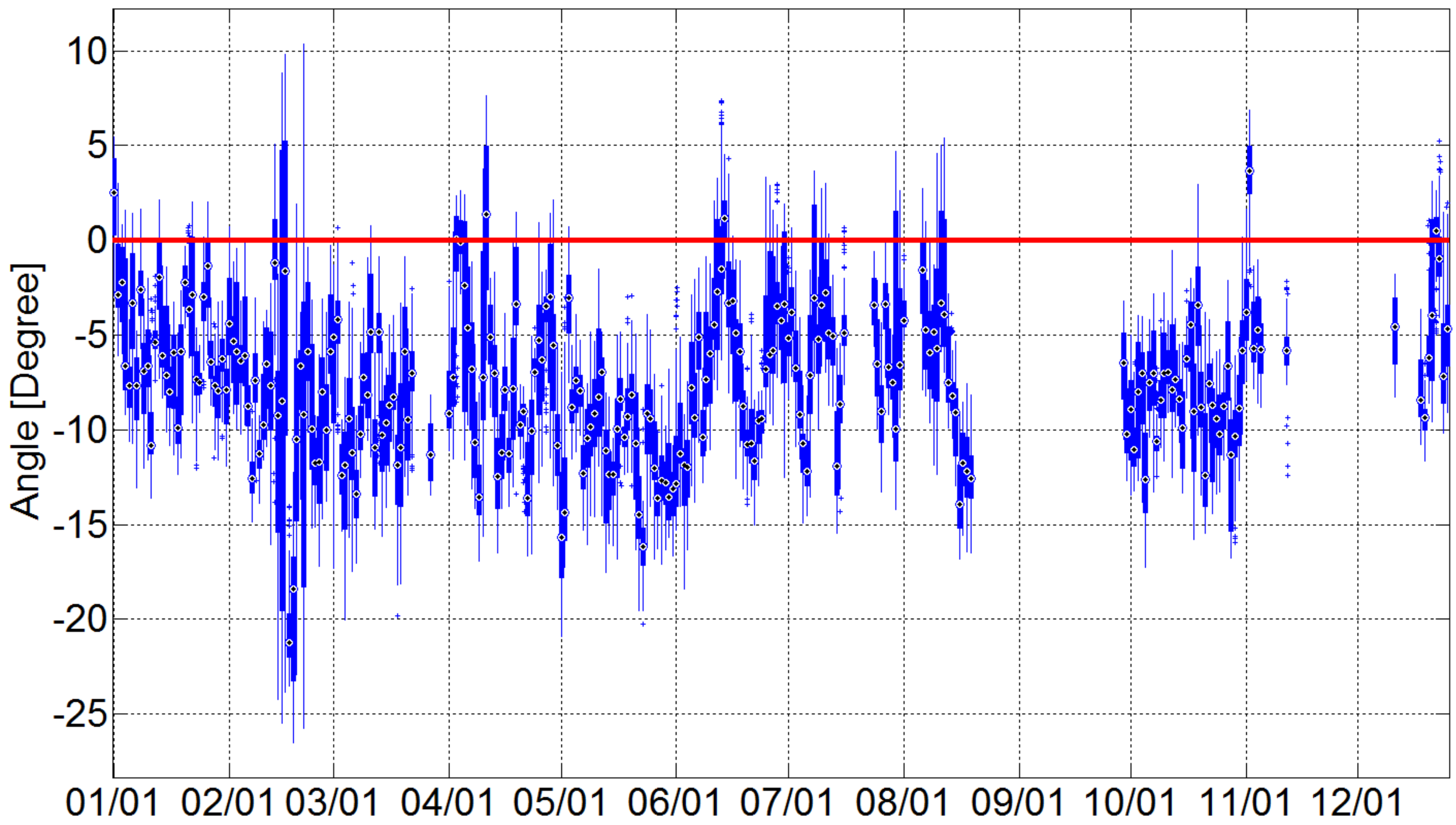
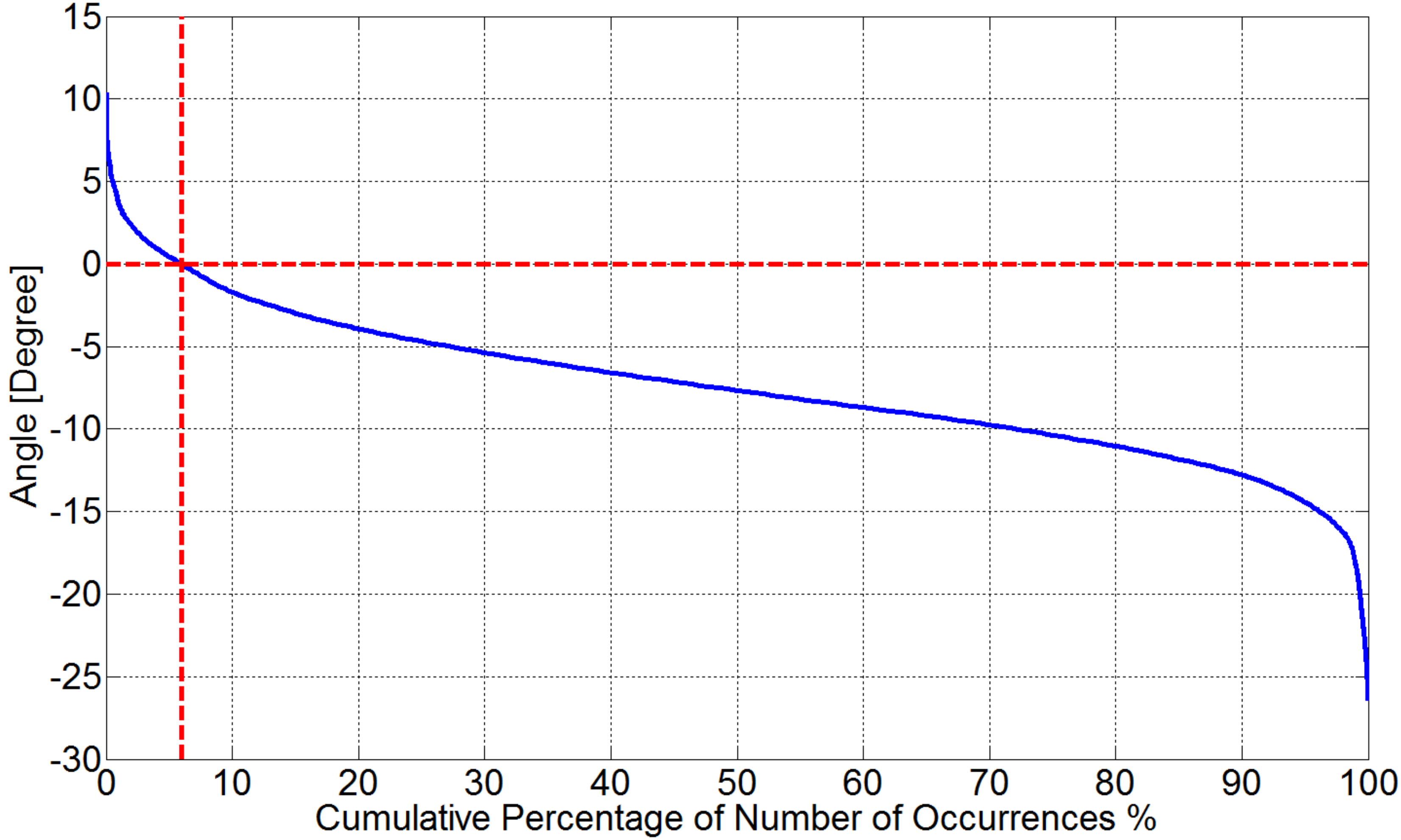
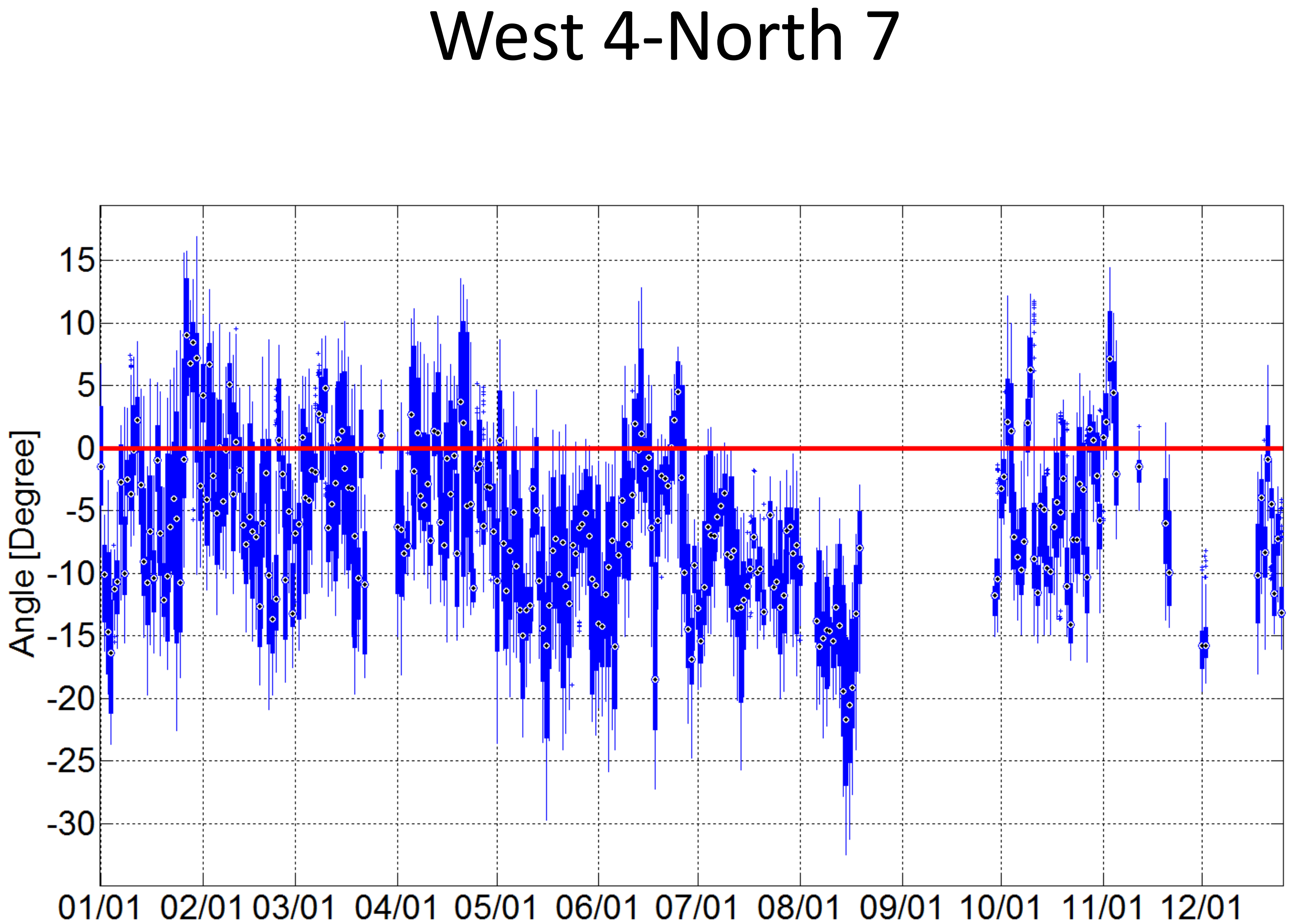


FarWest 2-North 7




West 4-North 7
Angle [Degree]
15
10
5
0
-5
-10
-15
-20
-25
-30
01/01
02/01
03/01
04/01
05/01
06/01
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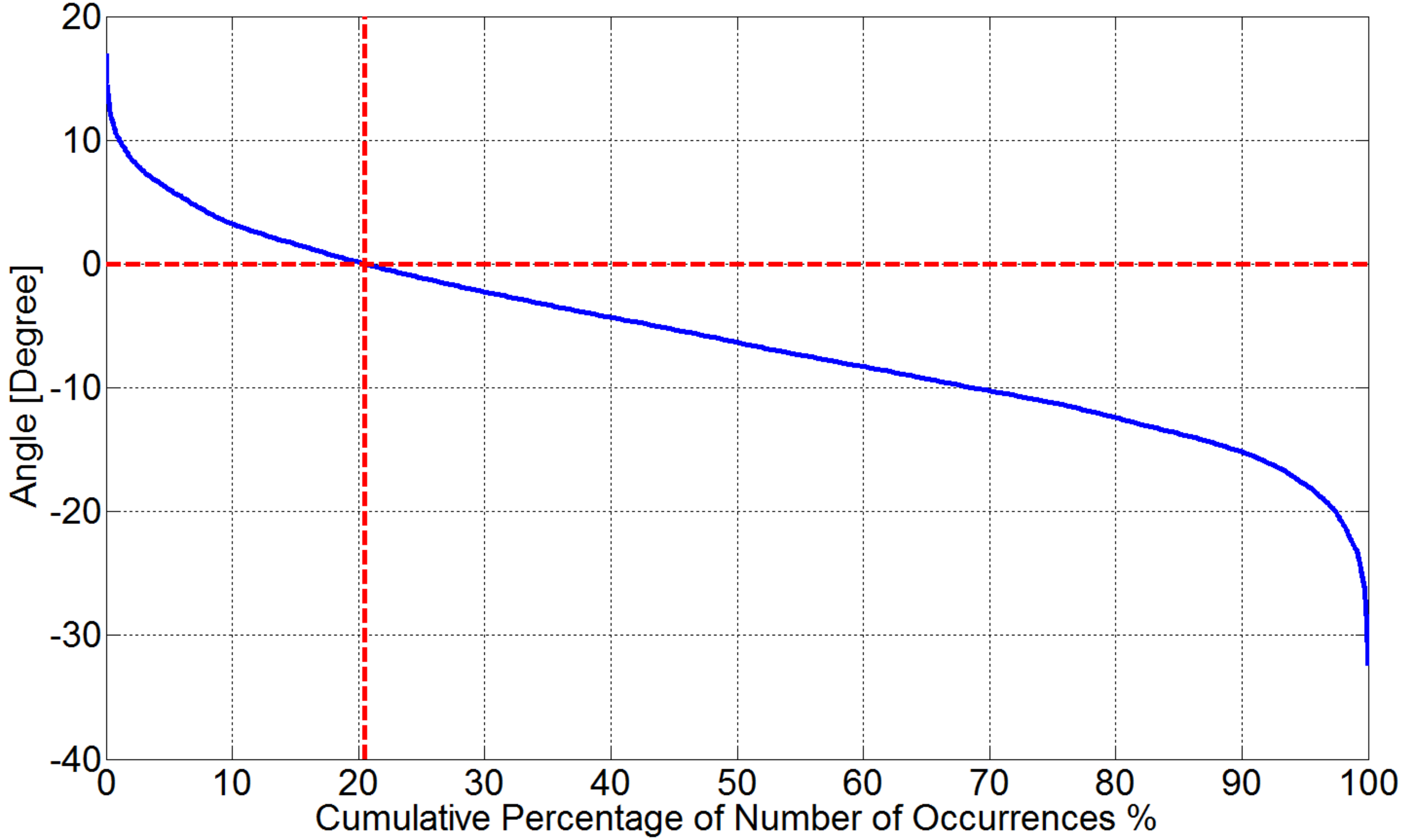
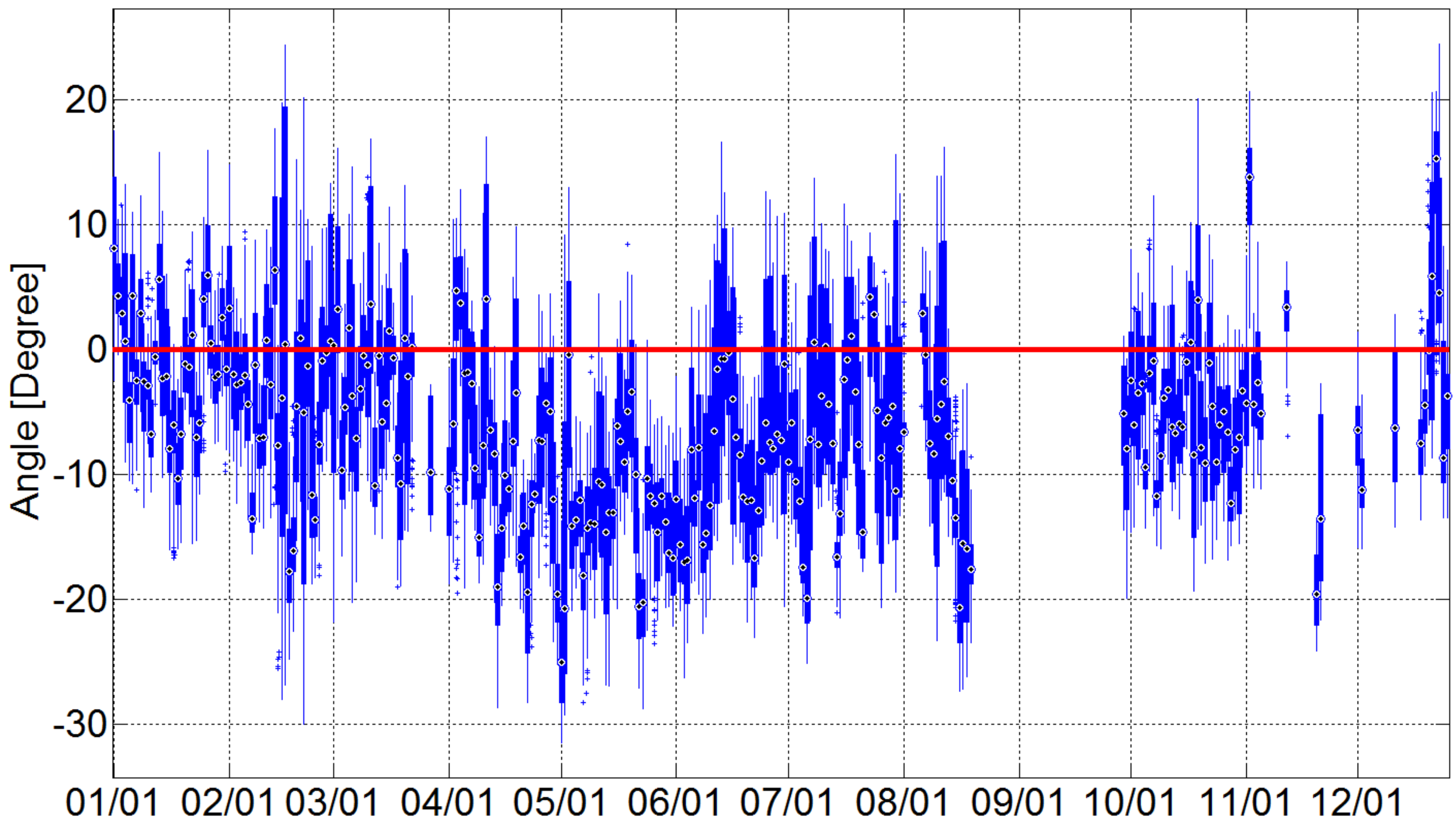
11/01
12/01

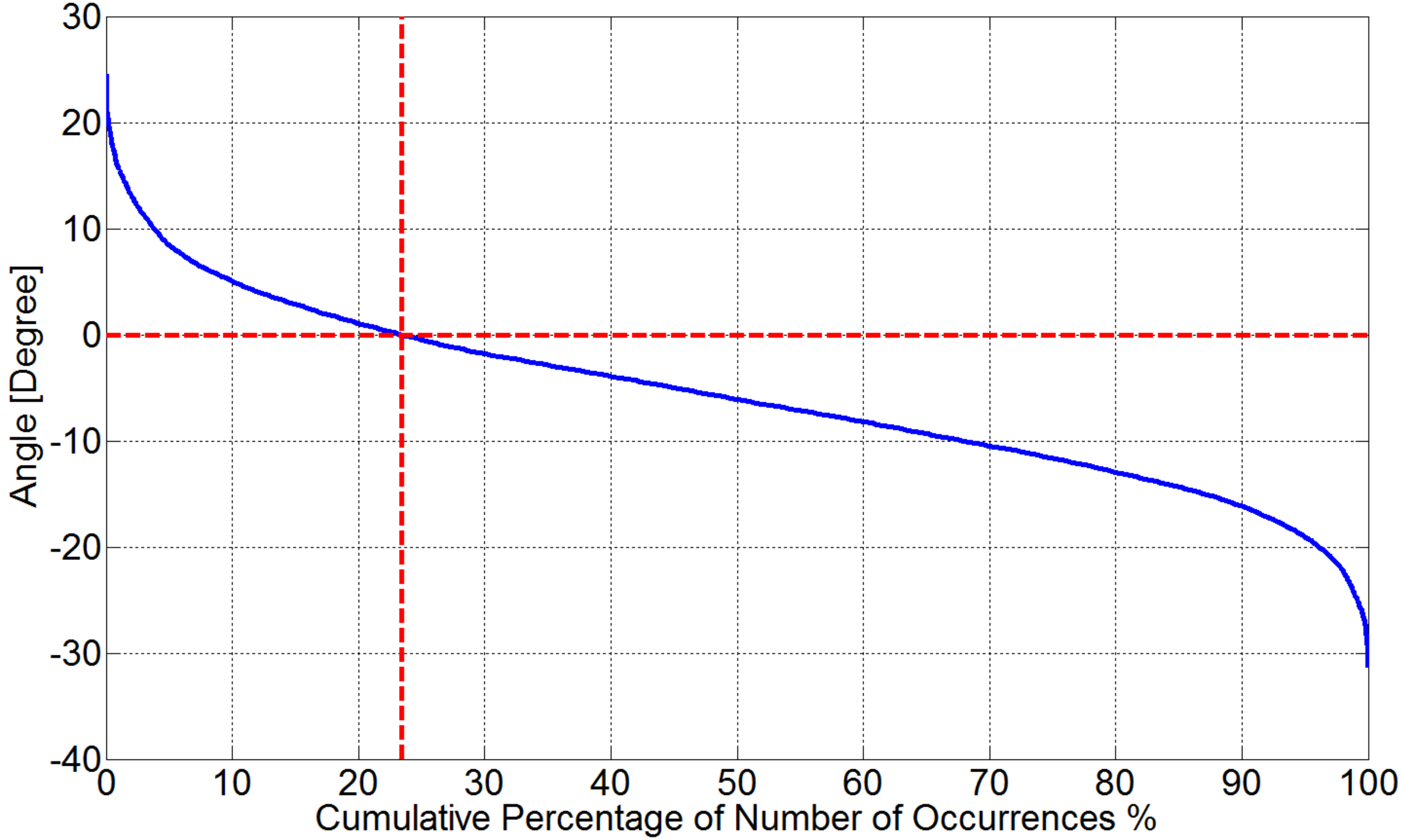
West 4-North 7



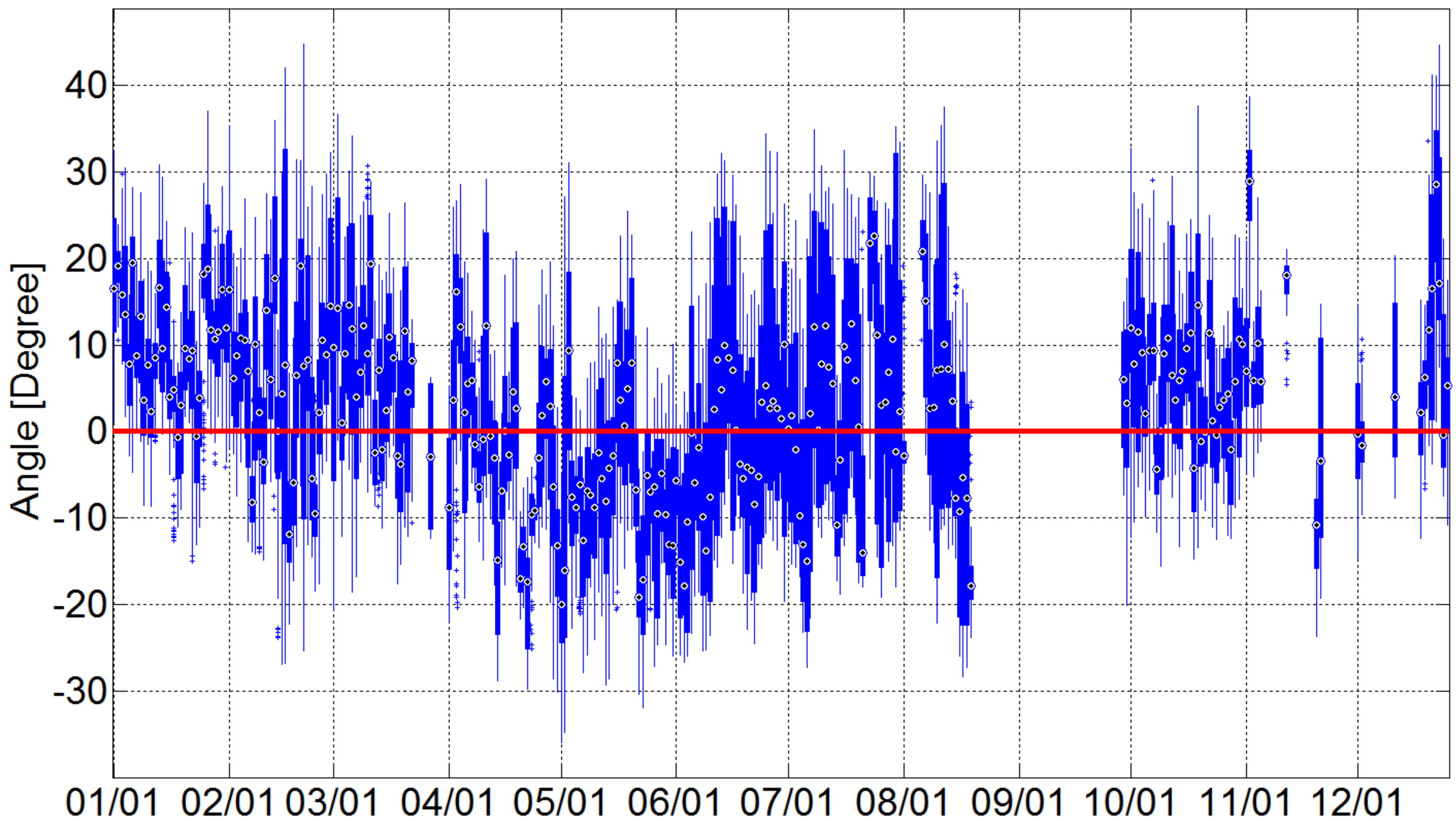
Coast 2-North 7



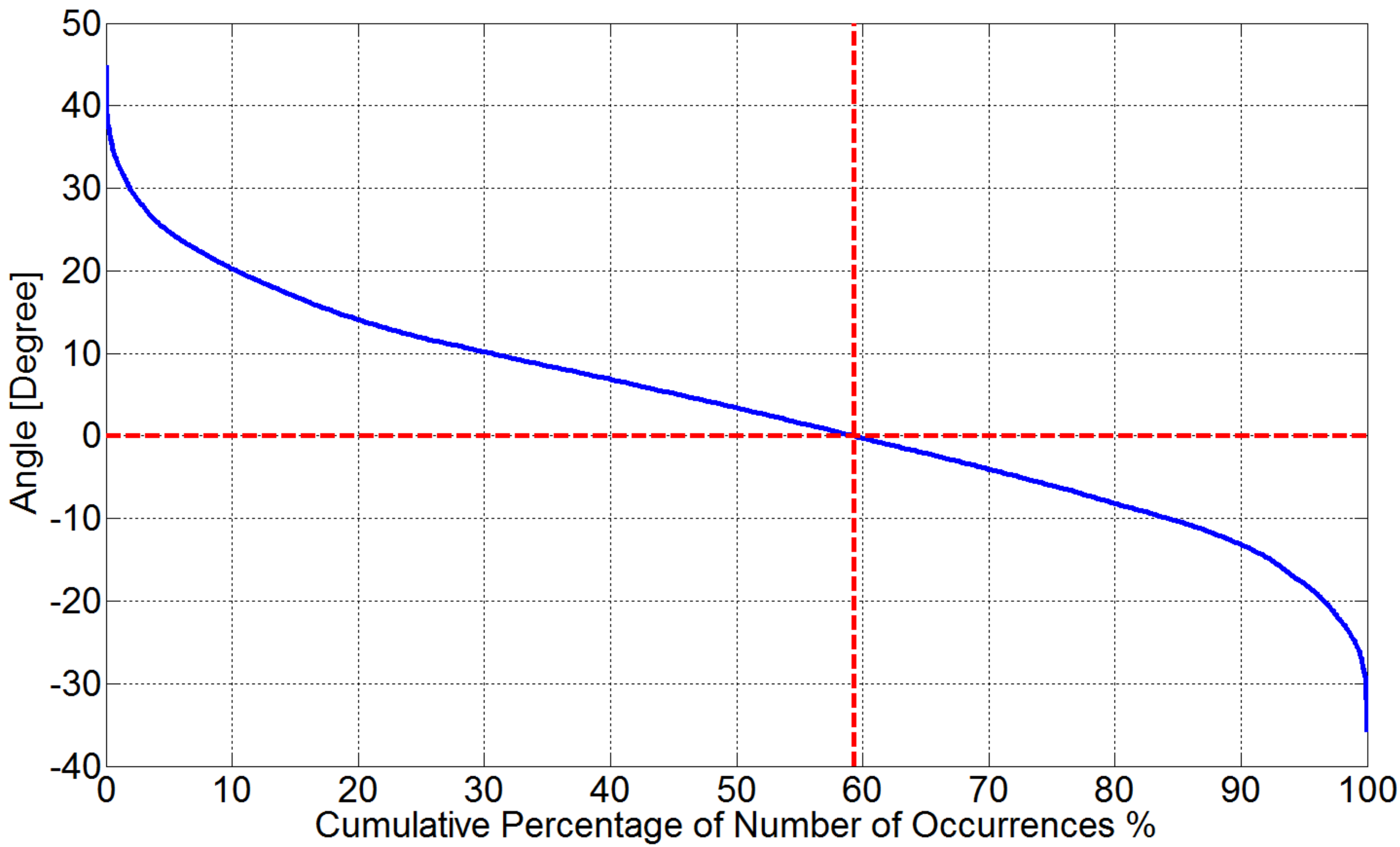
Coast 2-North 7



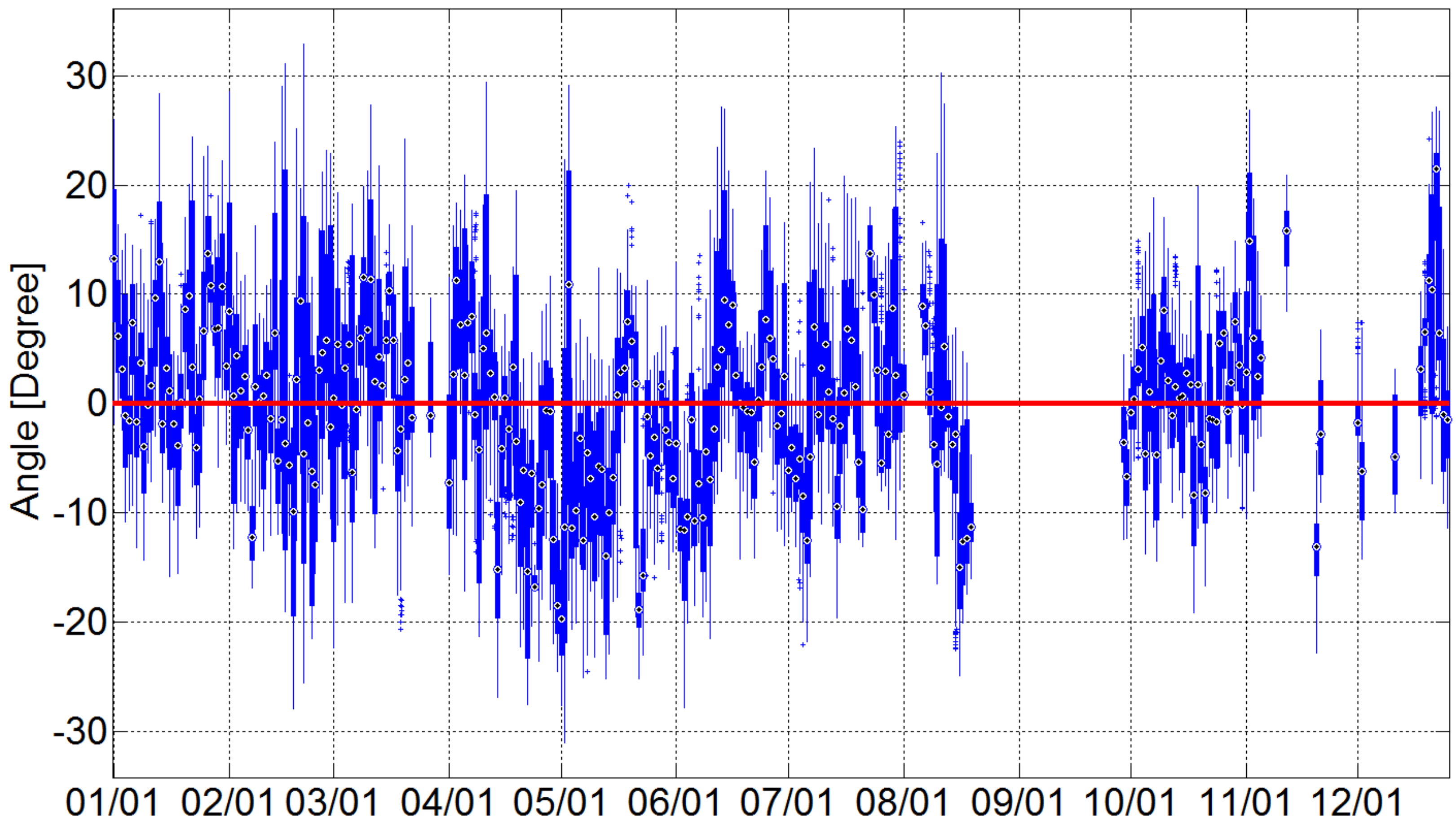
Coast 1-North 7



Coast 1-North 7



South 3-North 7



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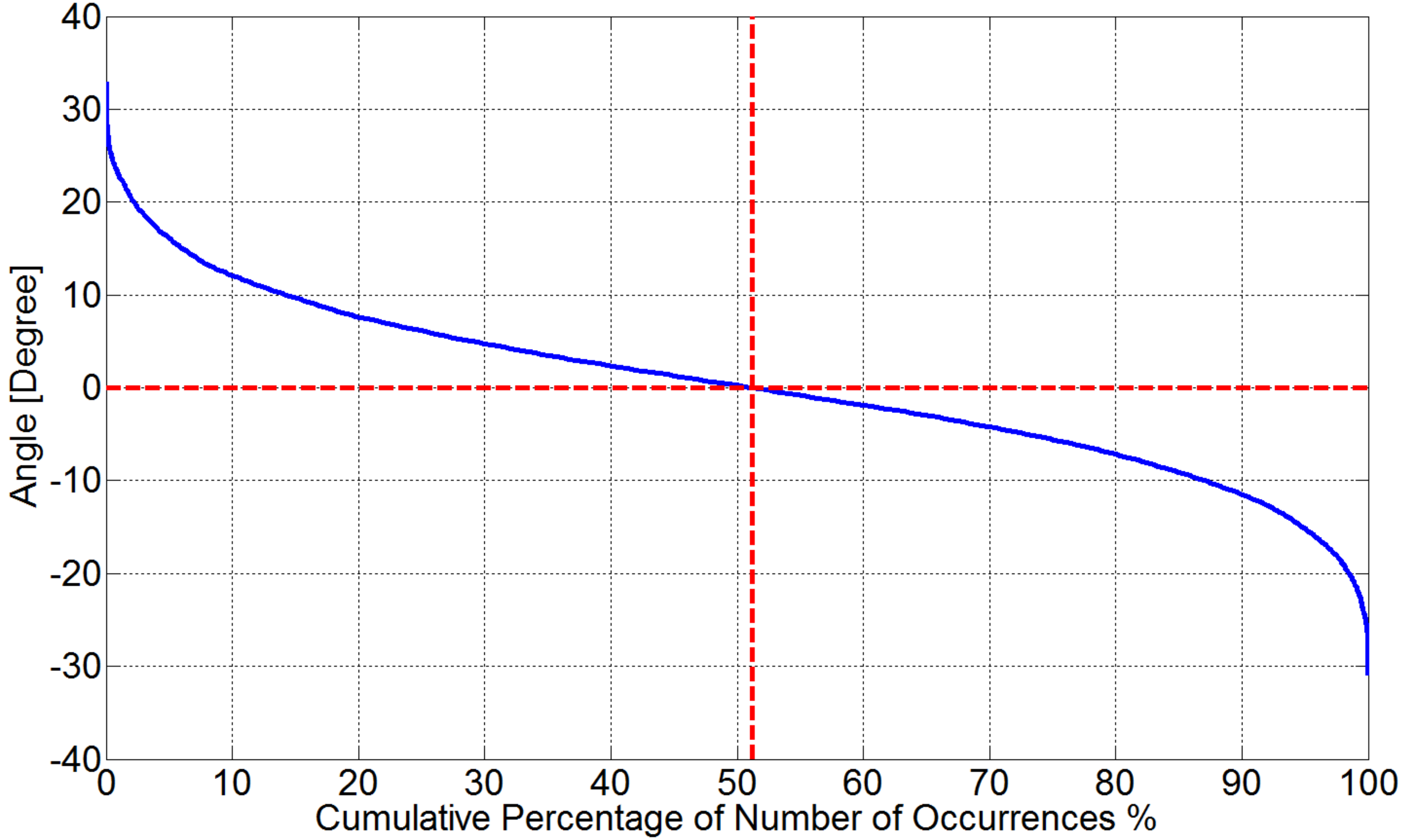
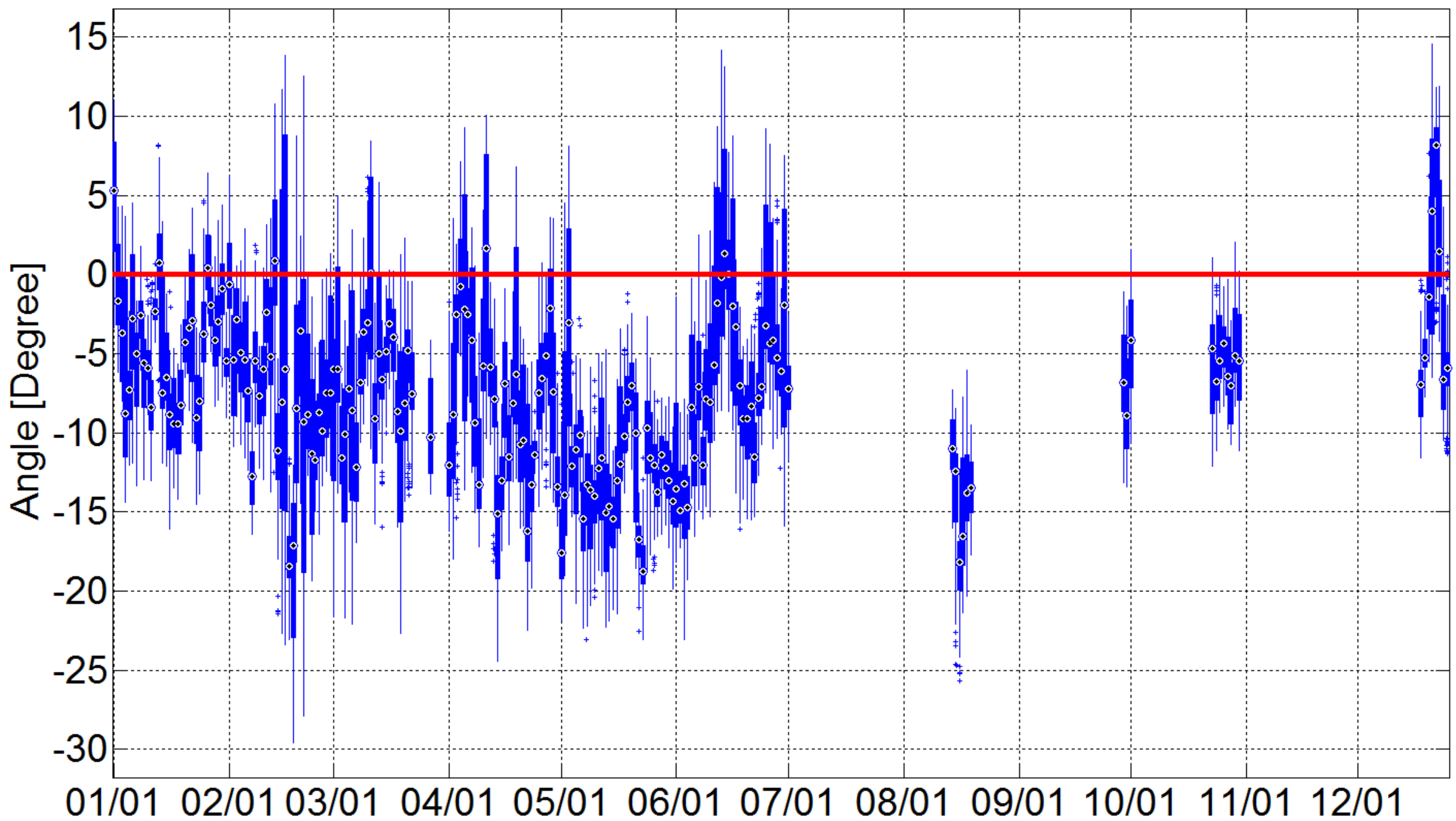
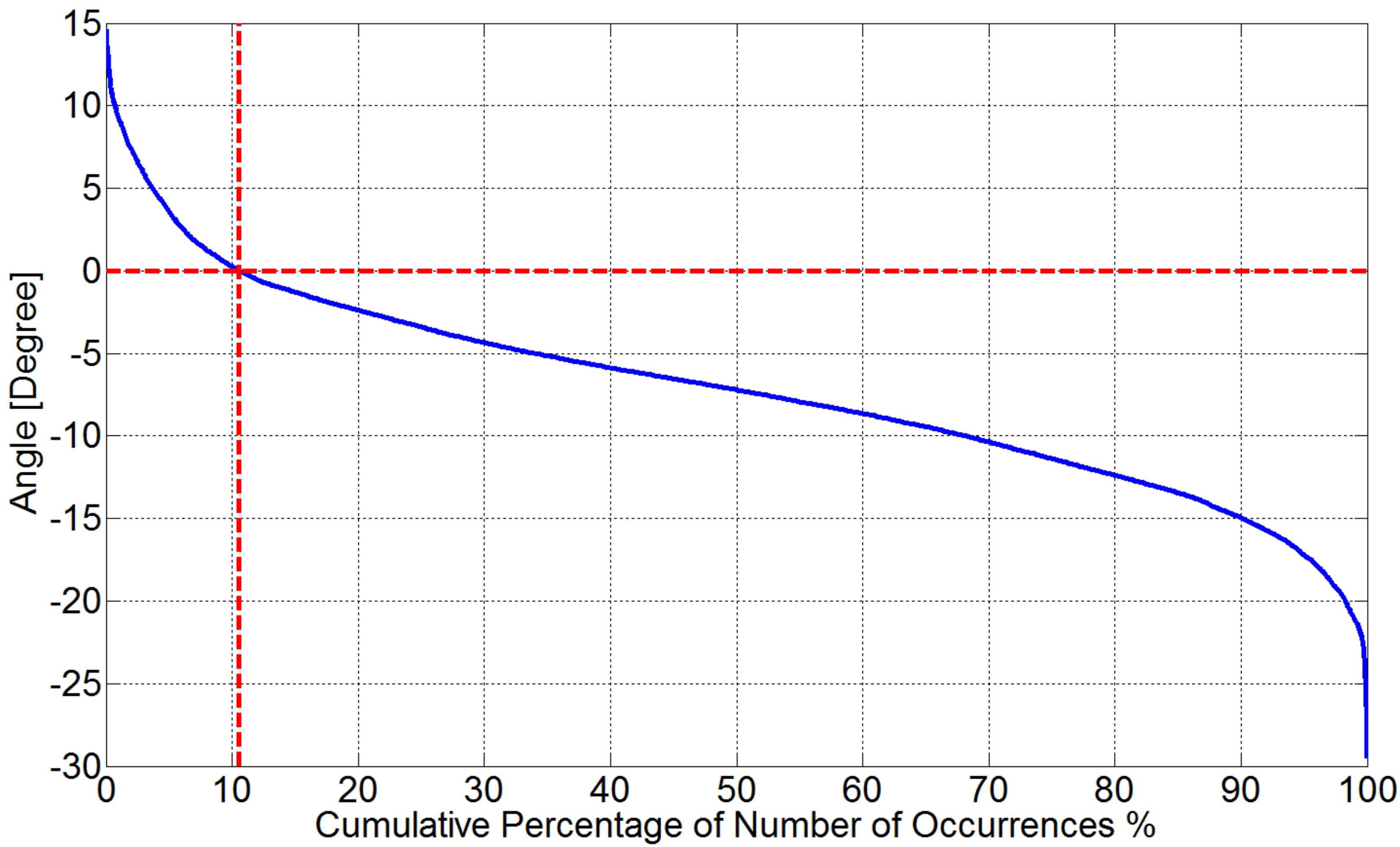


South 5-North 7



South 5-North 7



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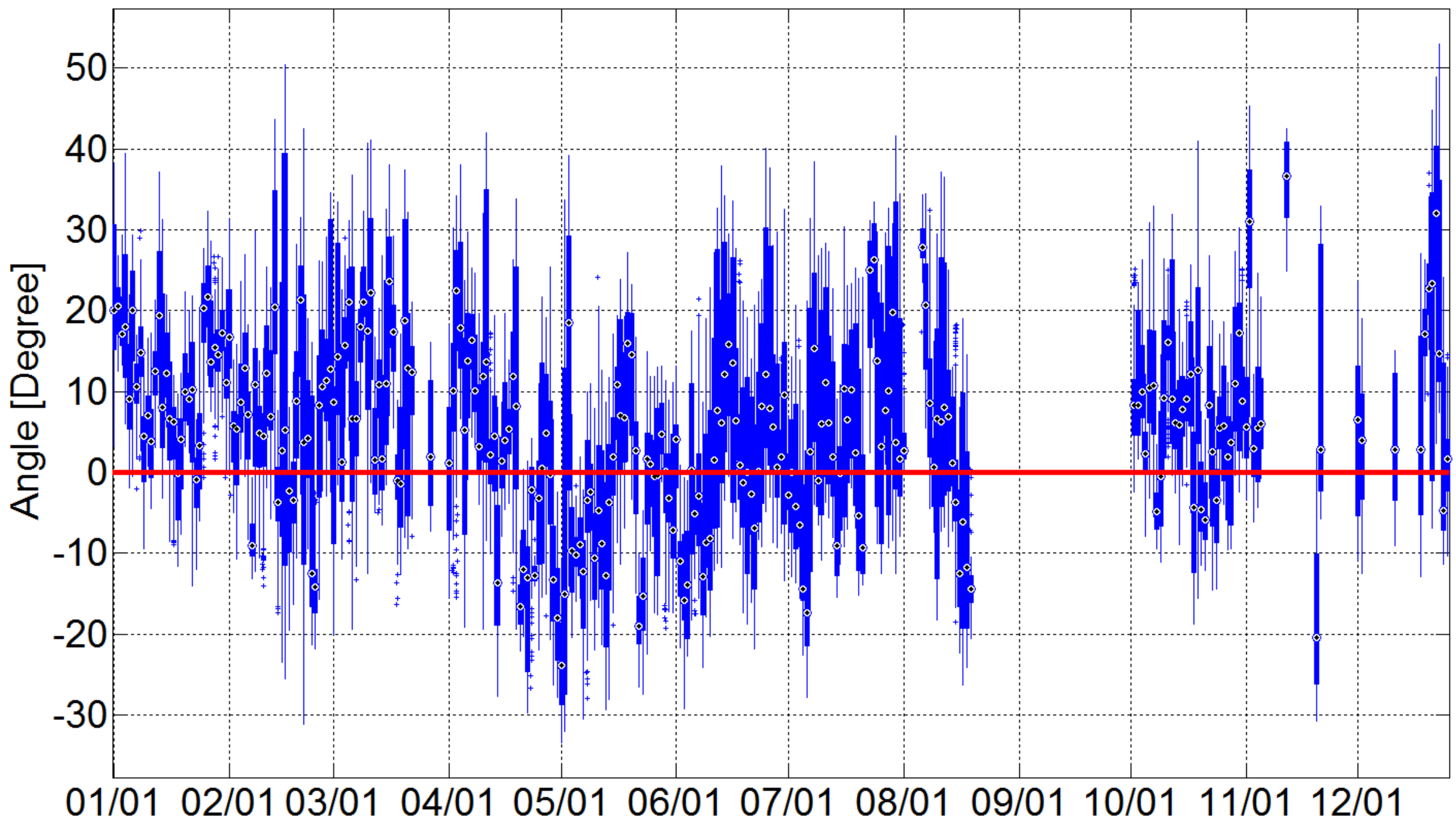
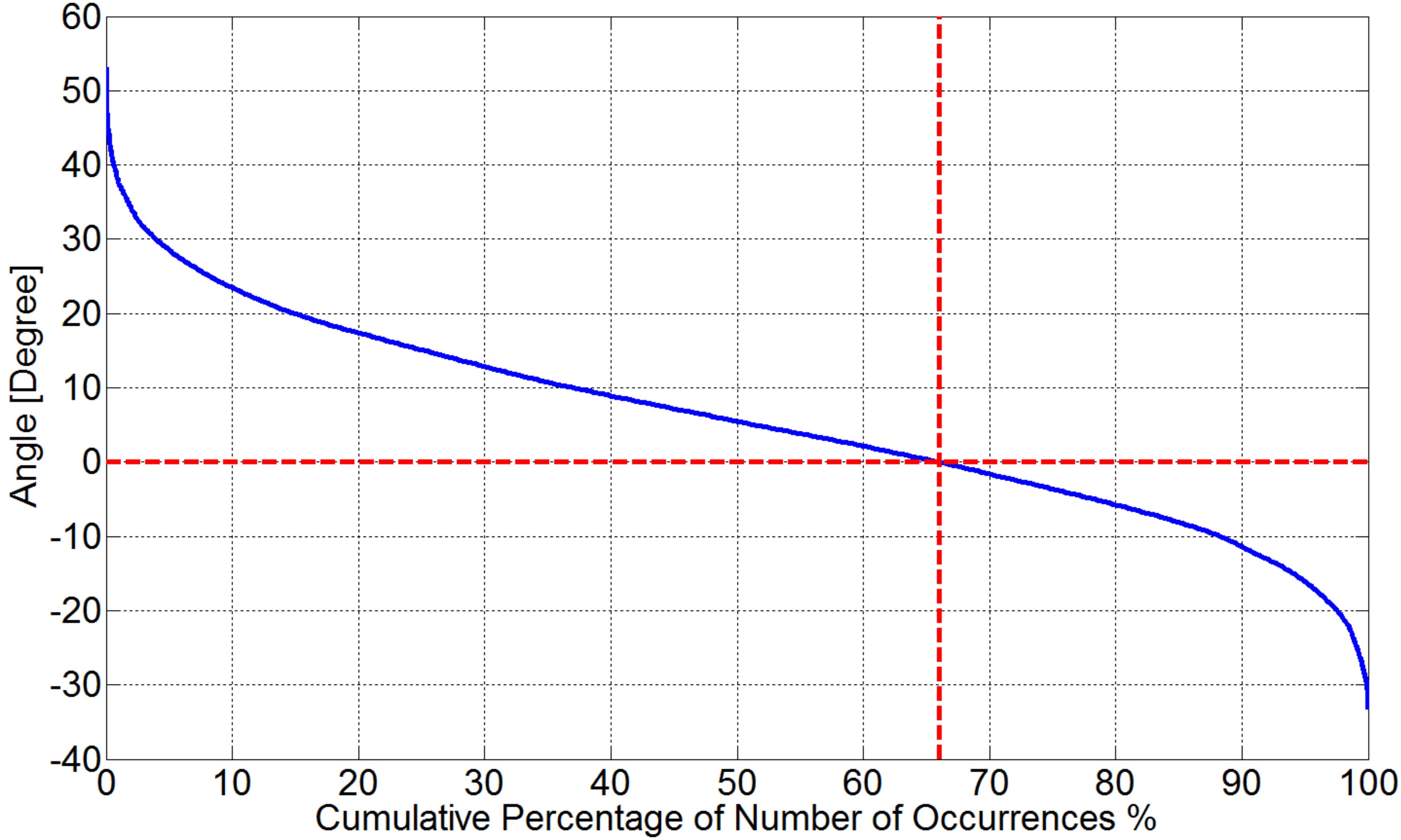
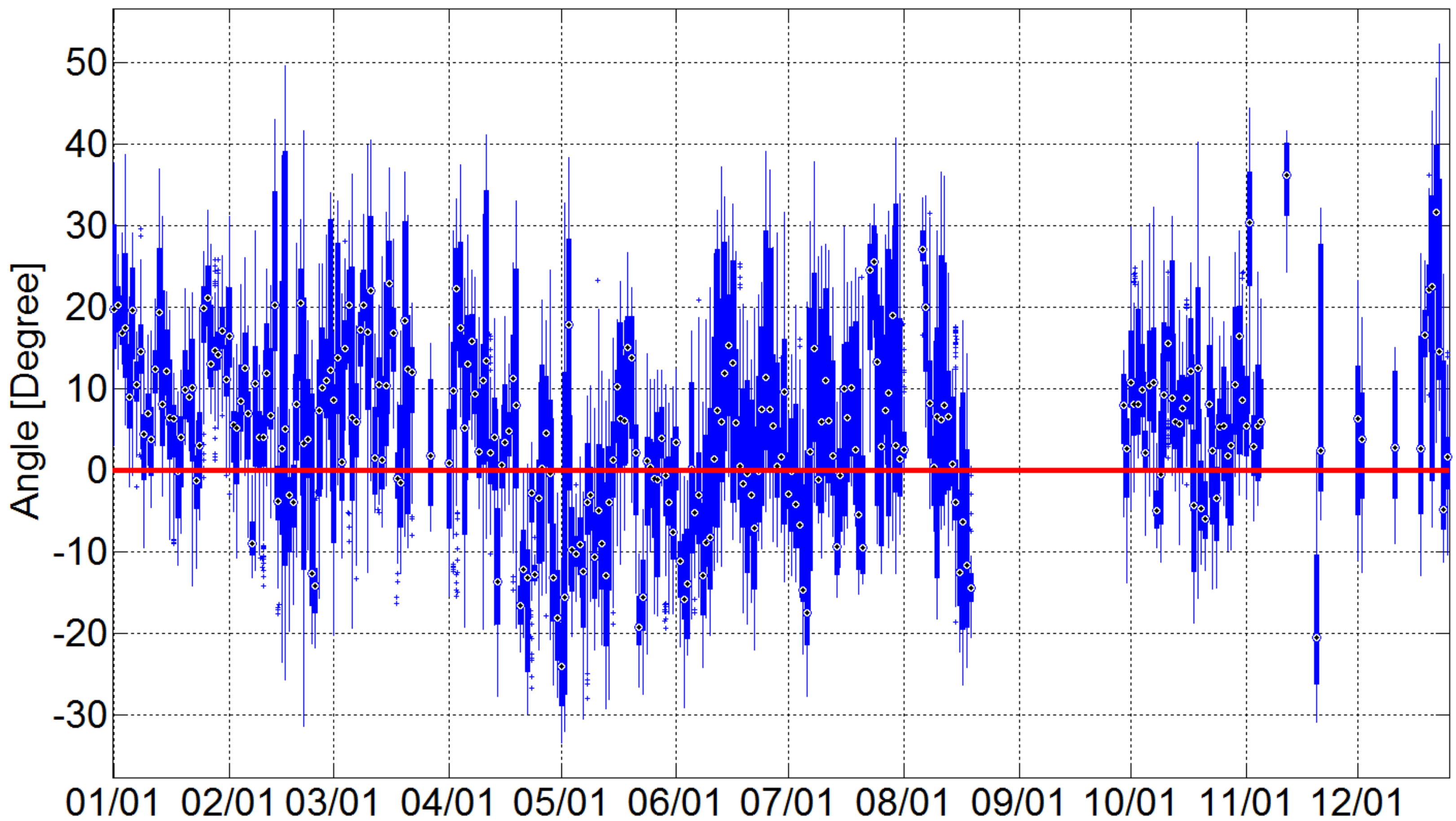


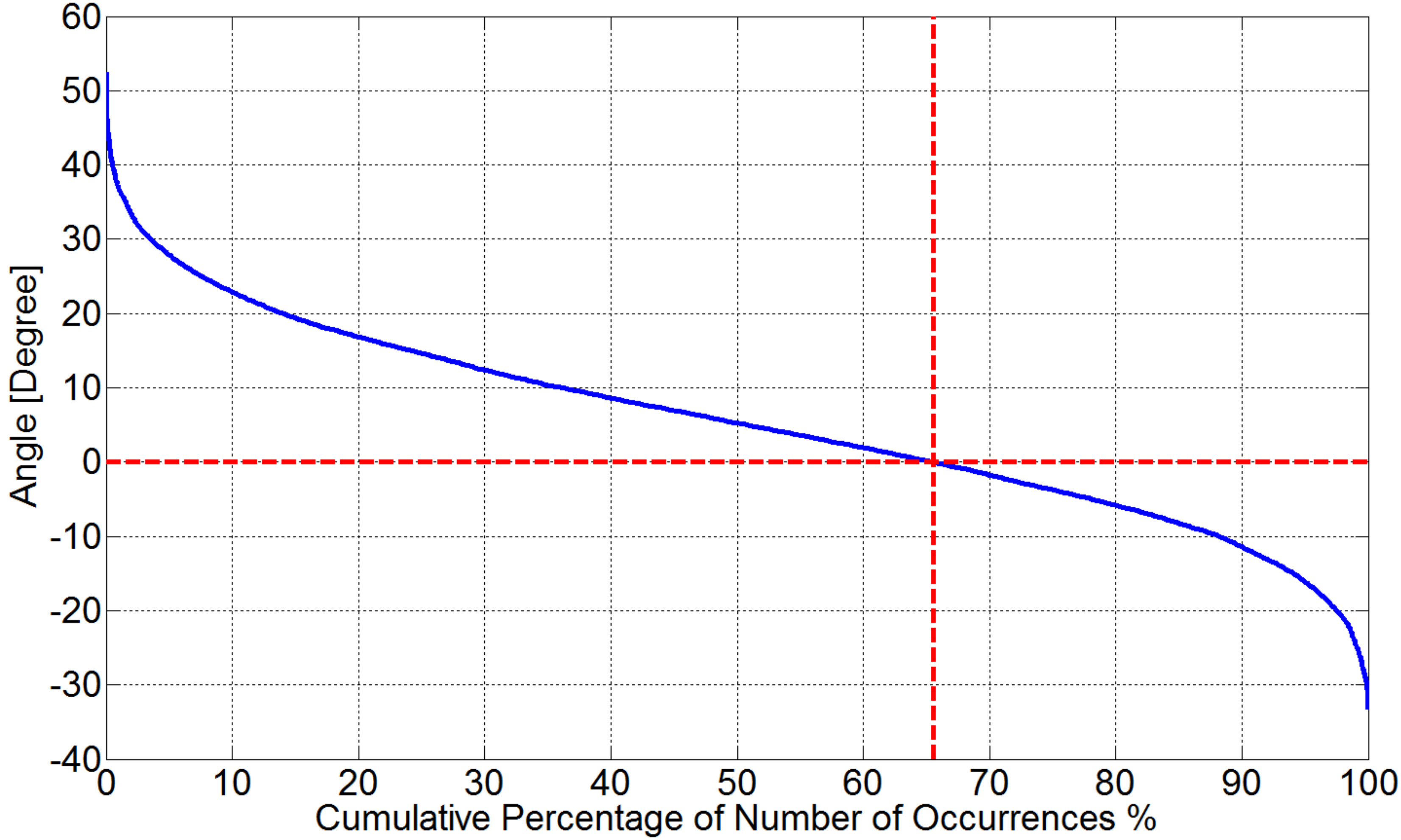
Coast 4-North 7



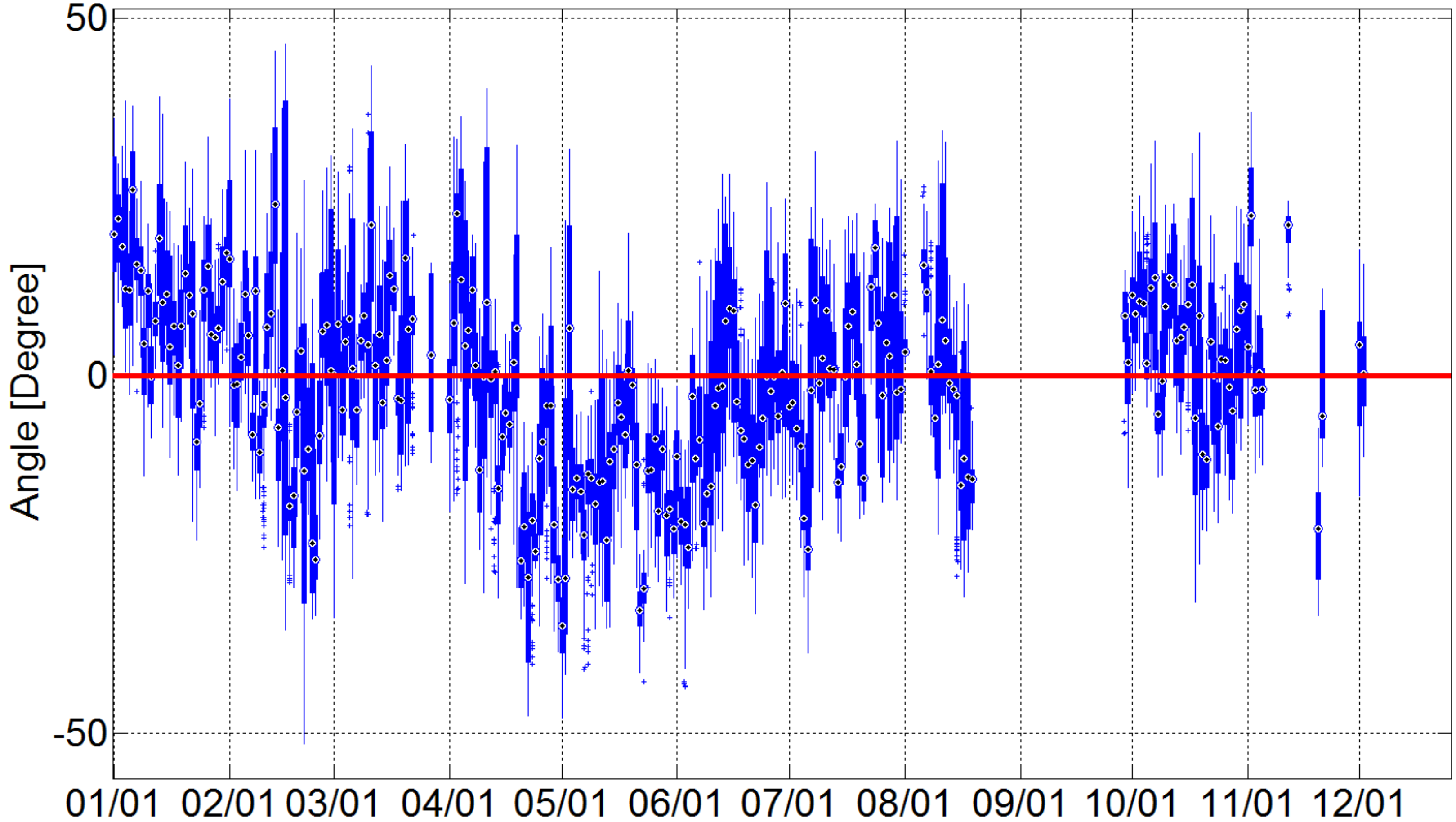
Coast 3-North 7



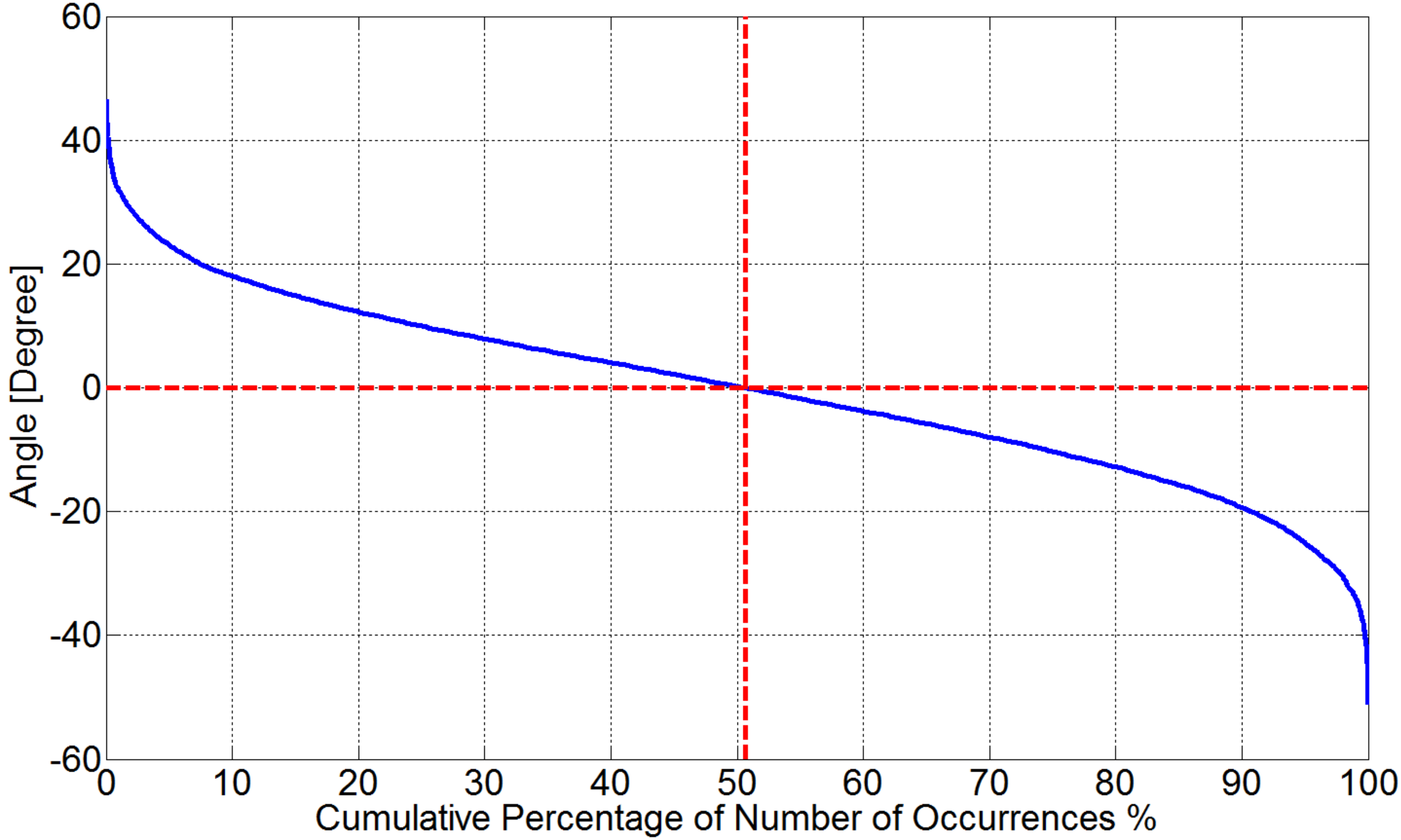
Coast 3-North 7



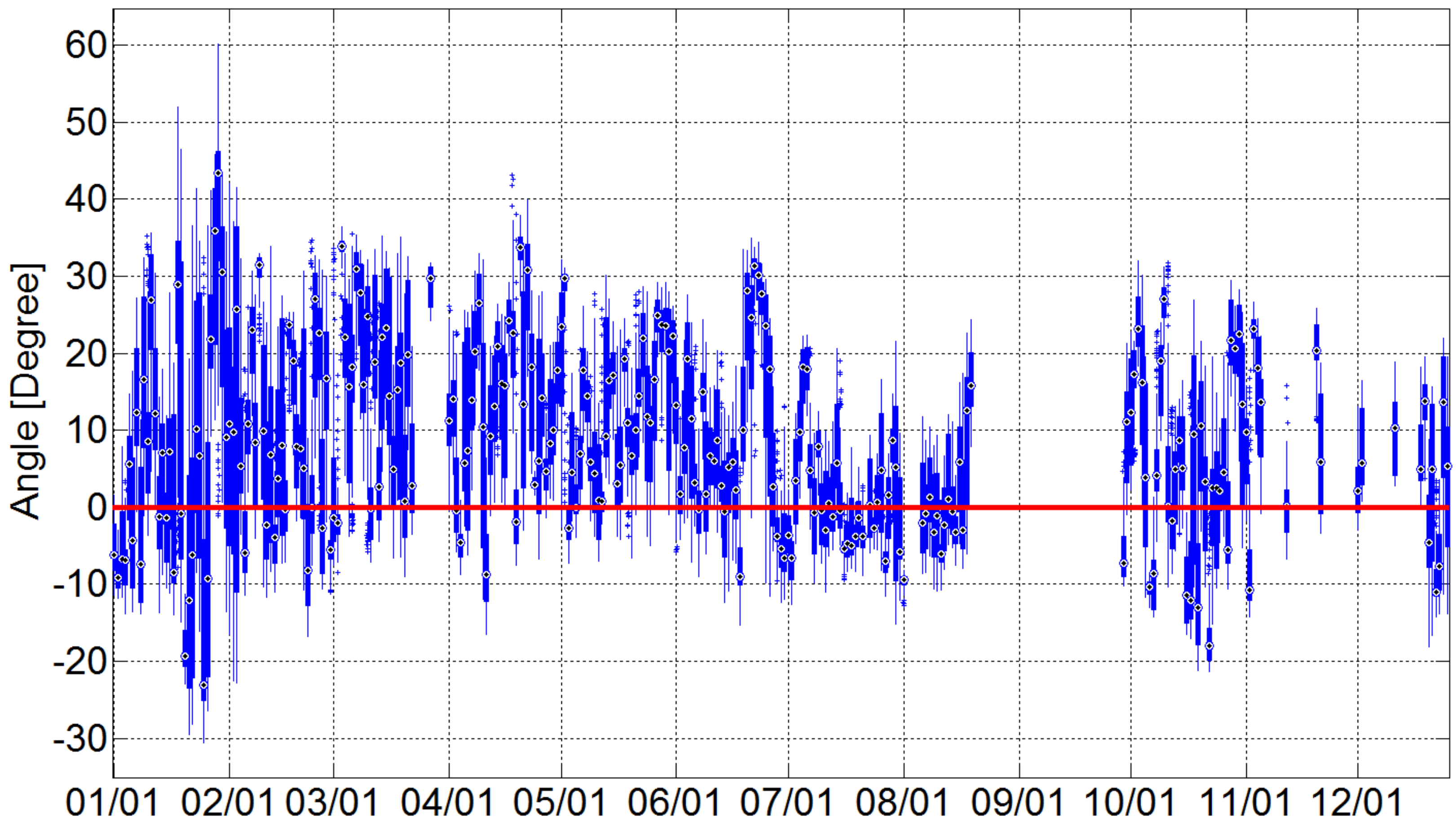
South 13-North 7



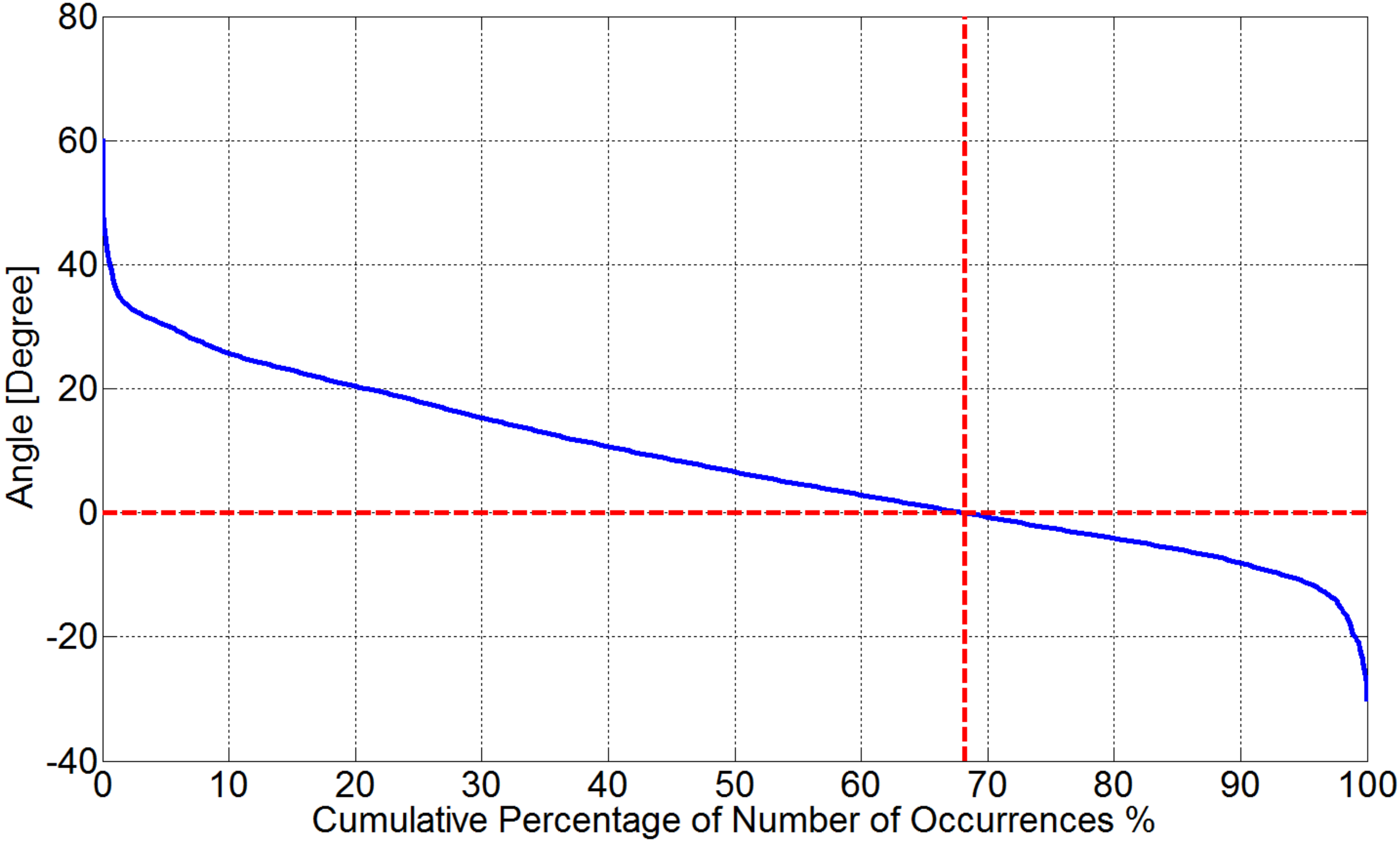
South 13-North 7



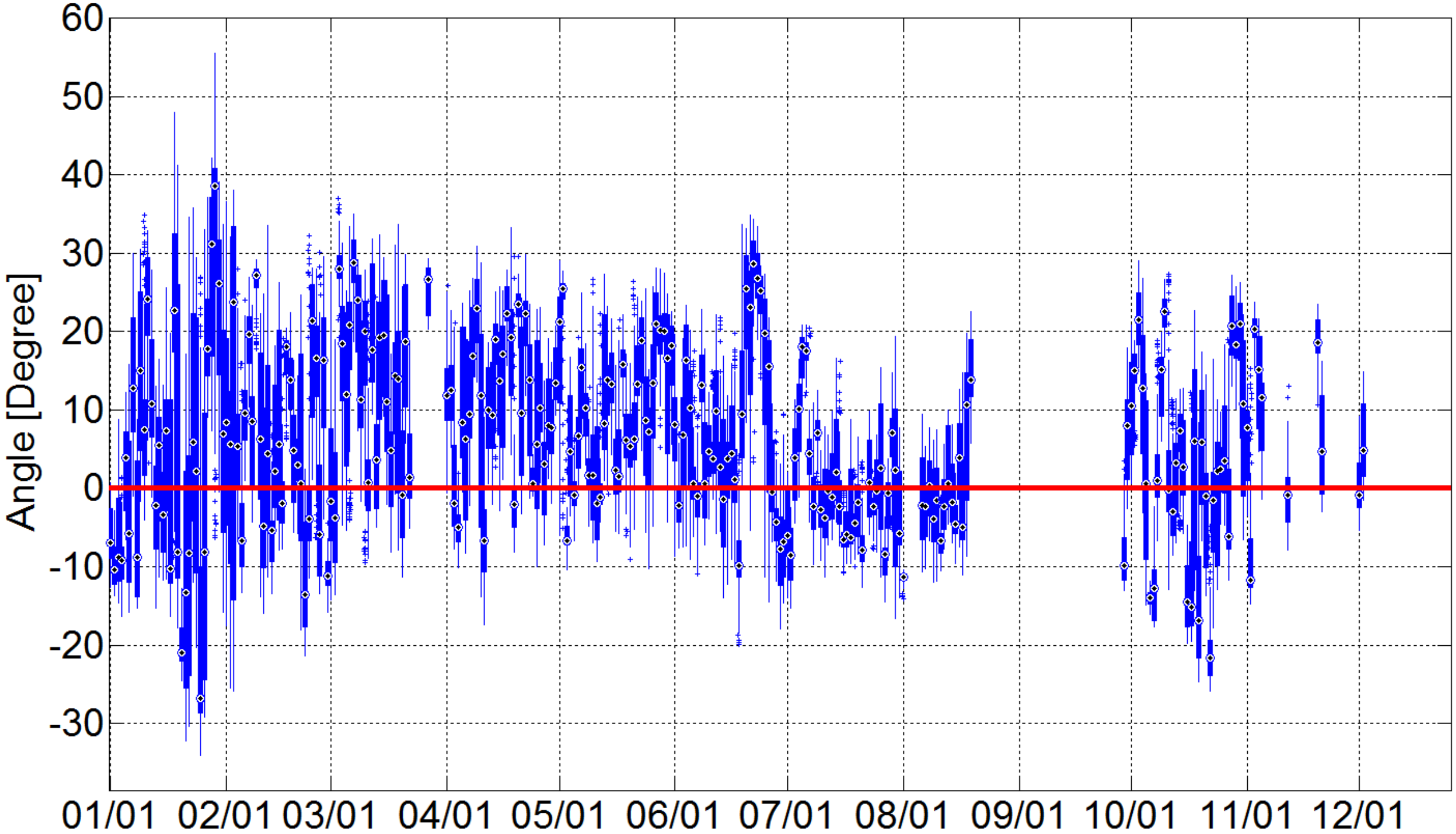
FarWest 4-North 7



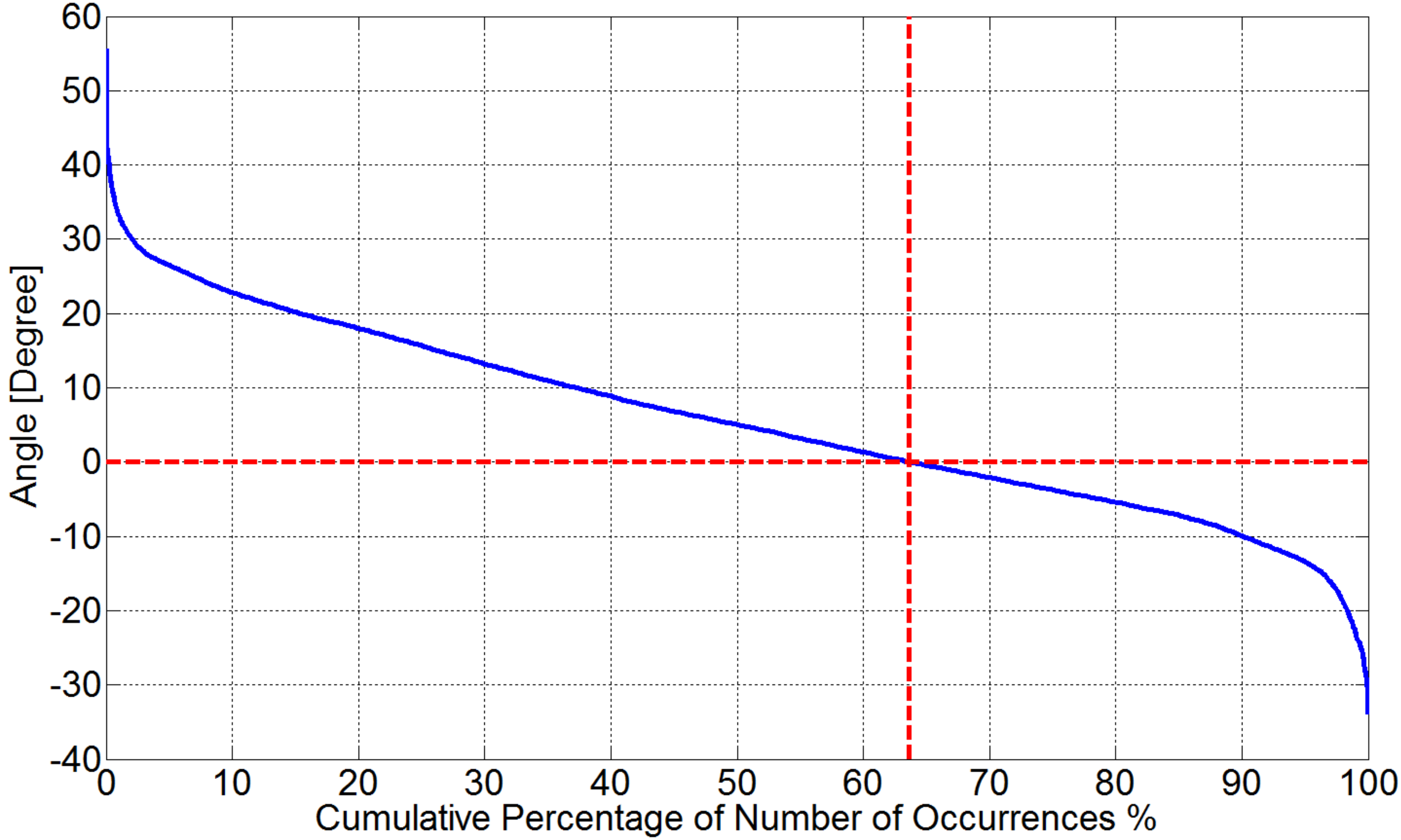
FarWest 4-North 7



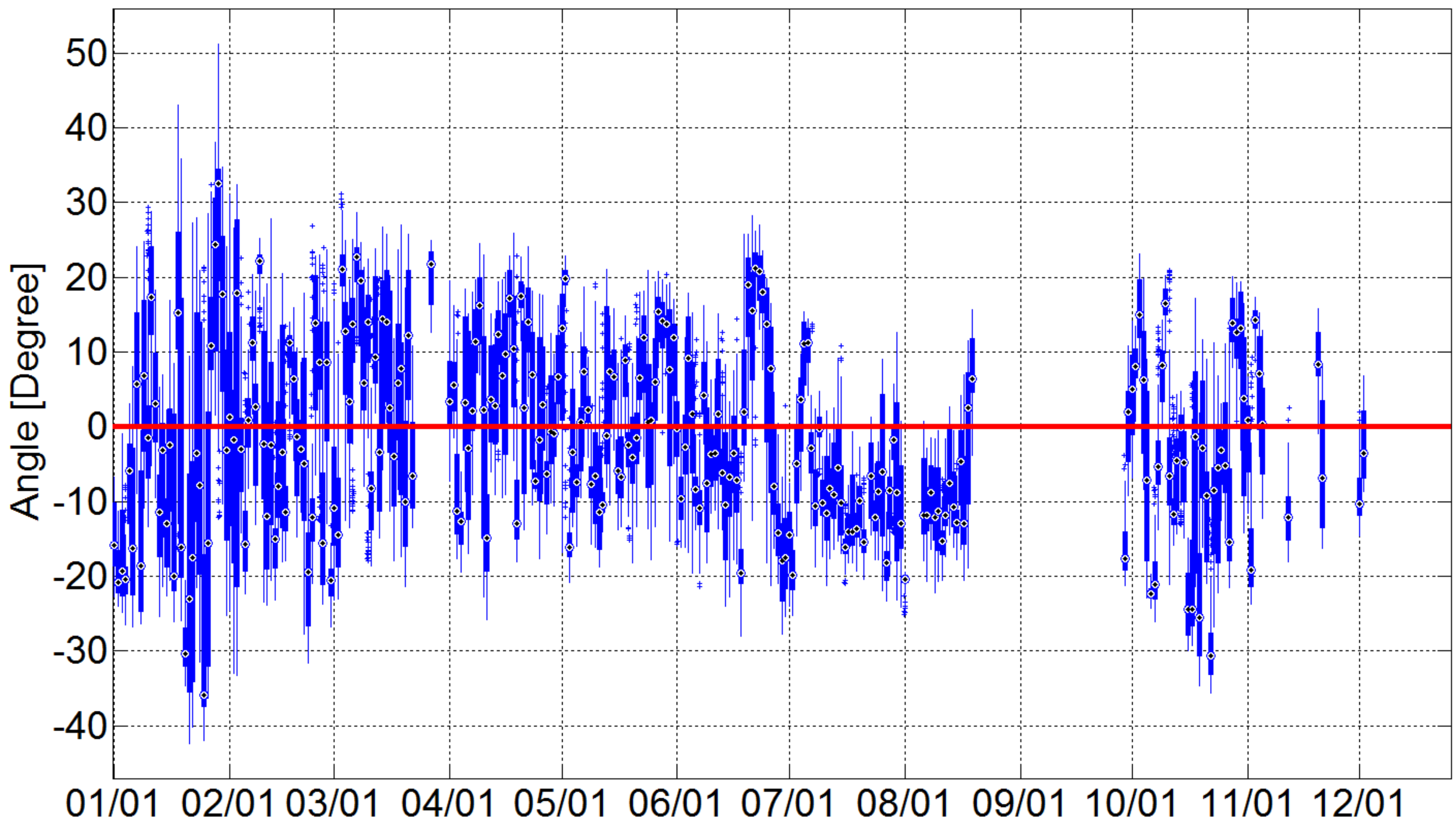
FarWest 7-North 7



FarWest 7-North 7



FarWest 8-North 7



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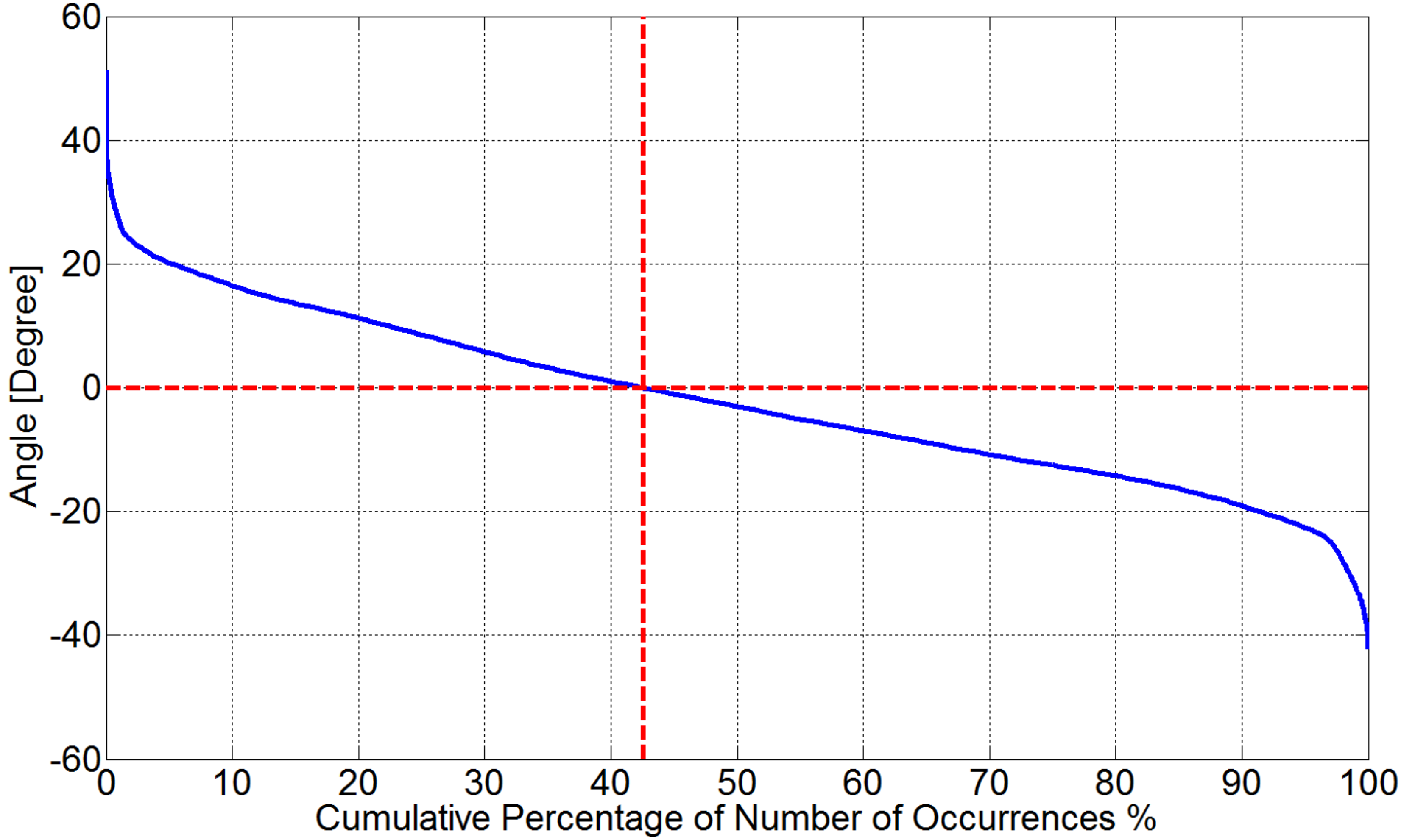
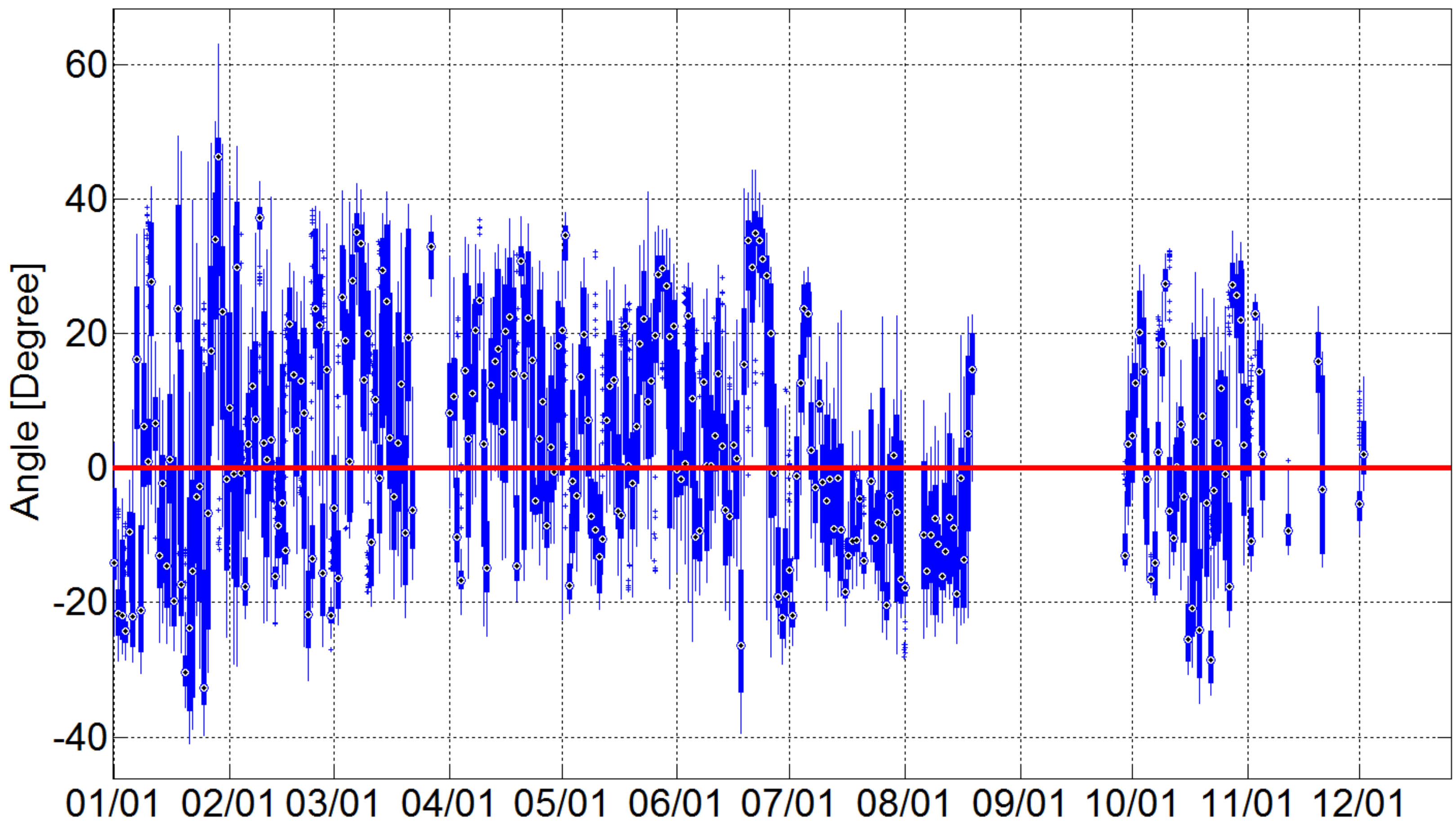
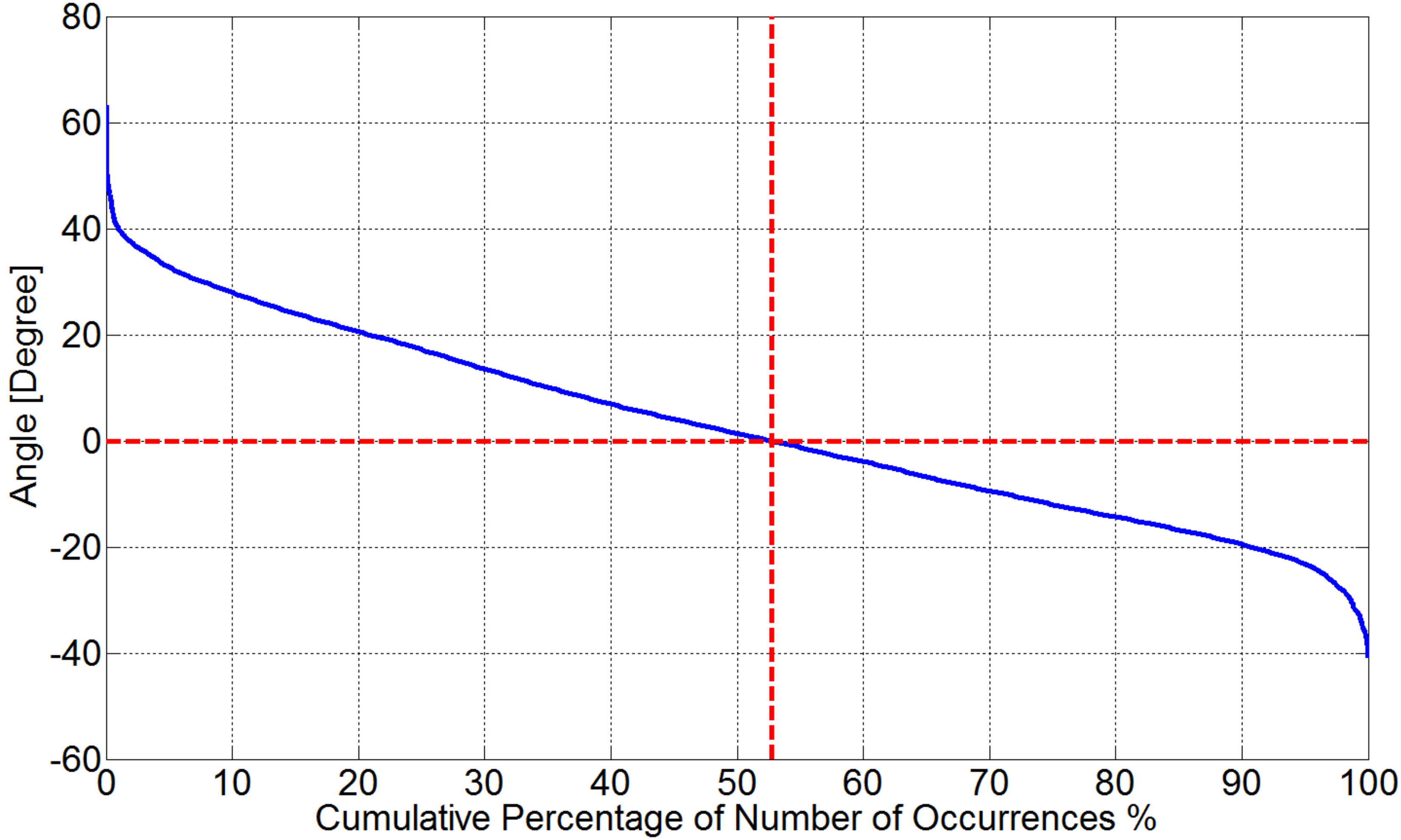


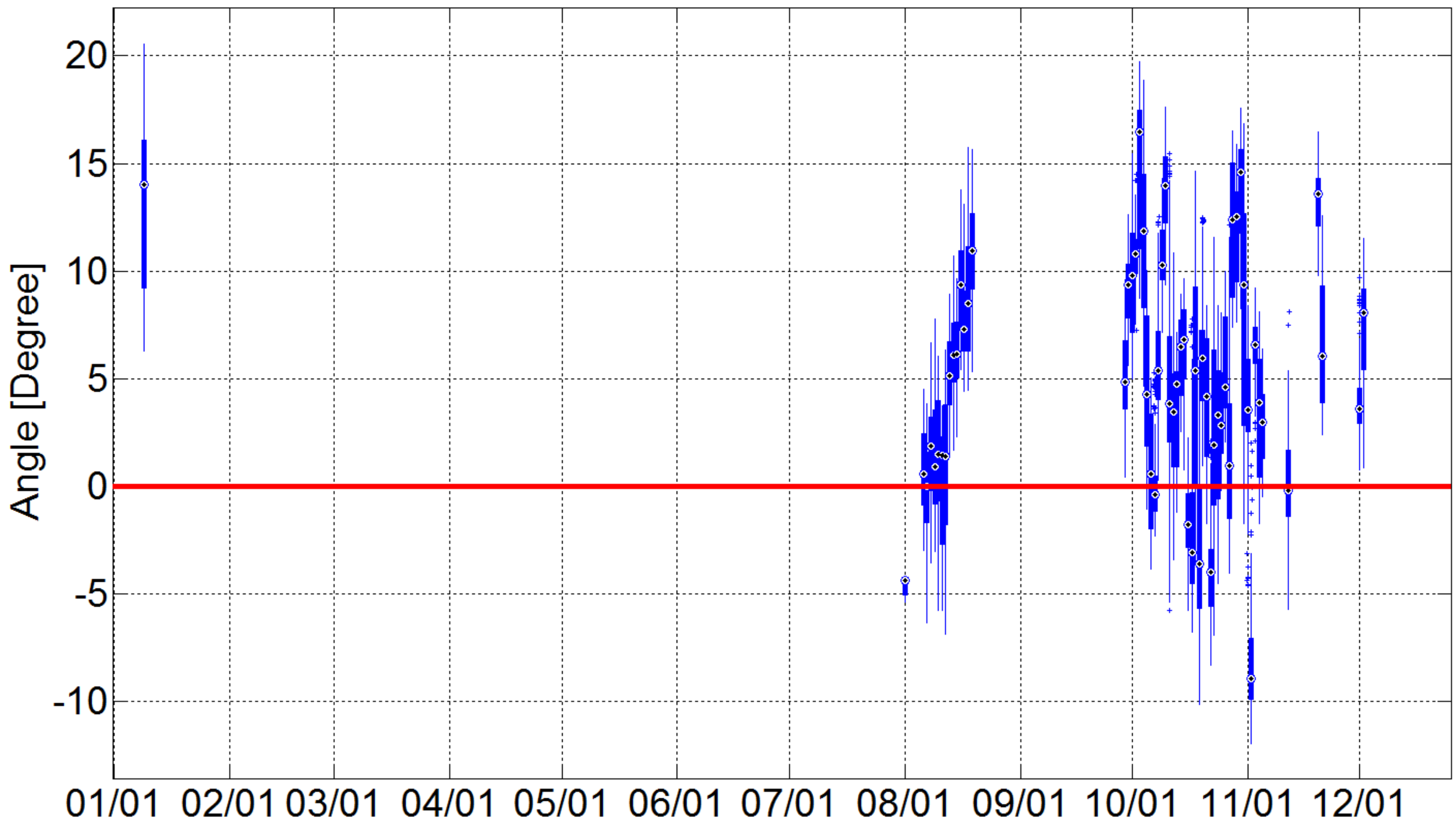
FarWest 9-North 7



FarWest 9-North 7



West 16-North 7



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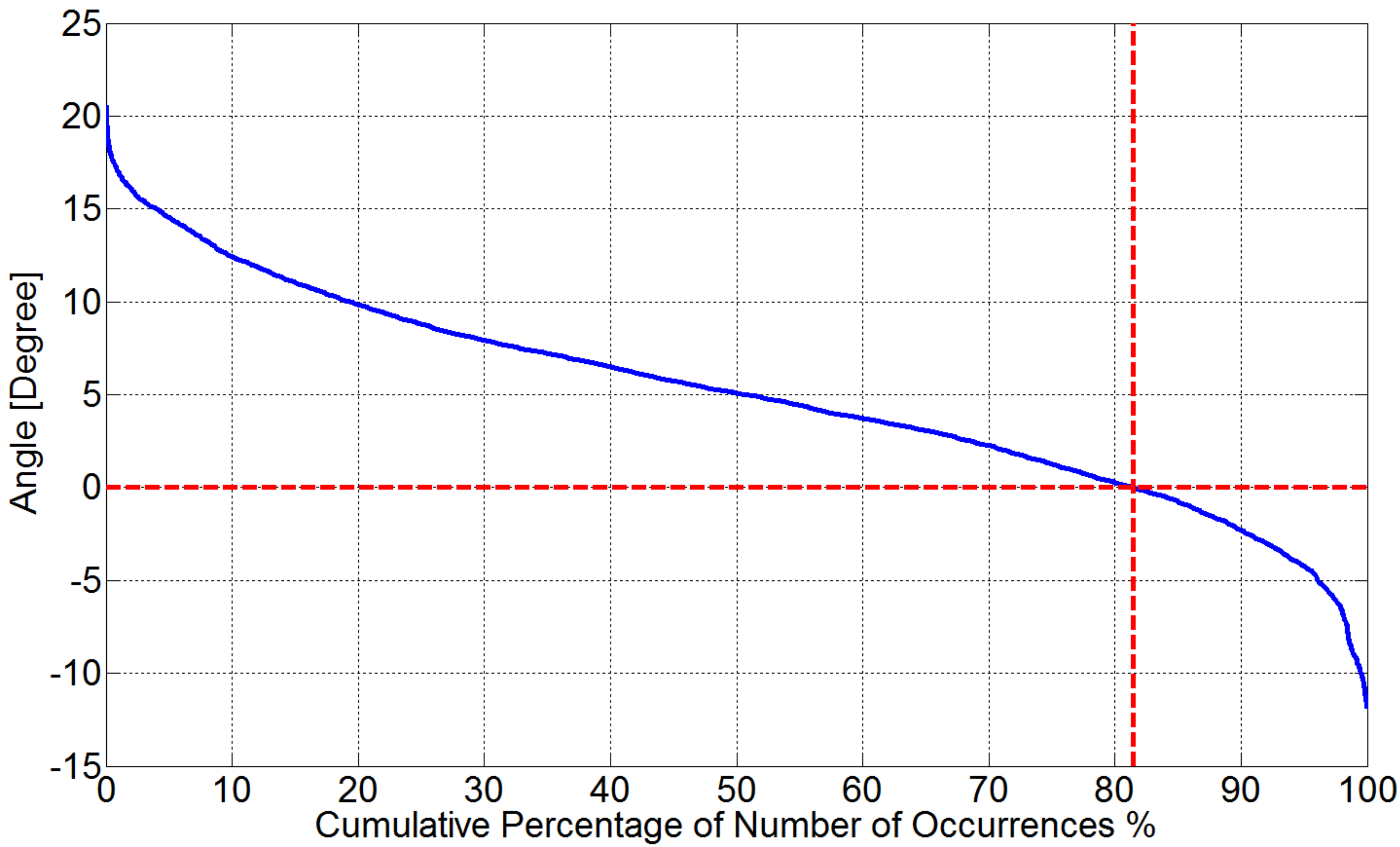

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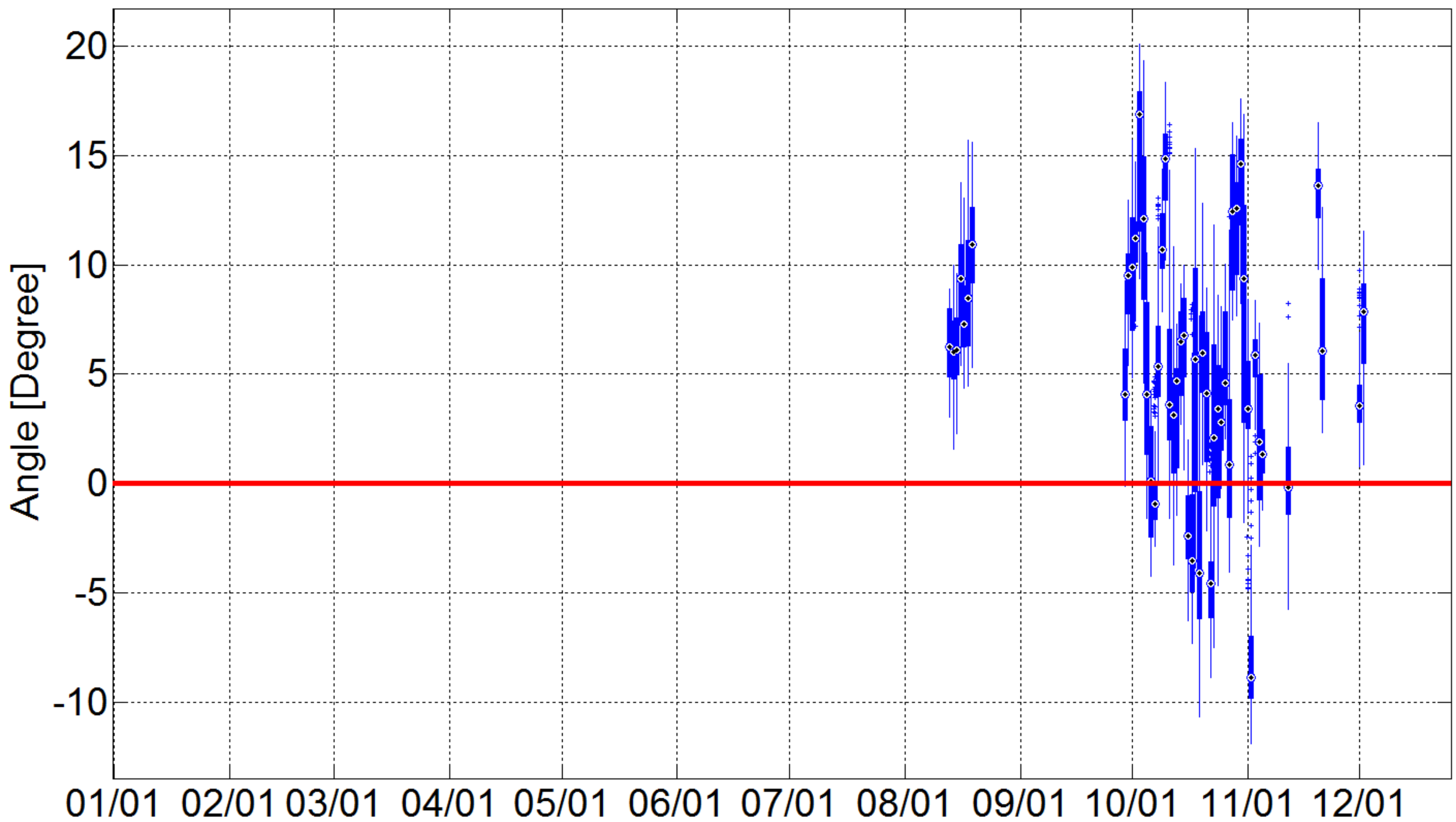

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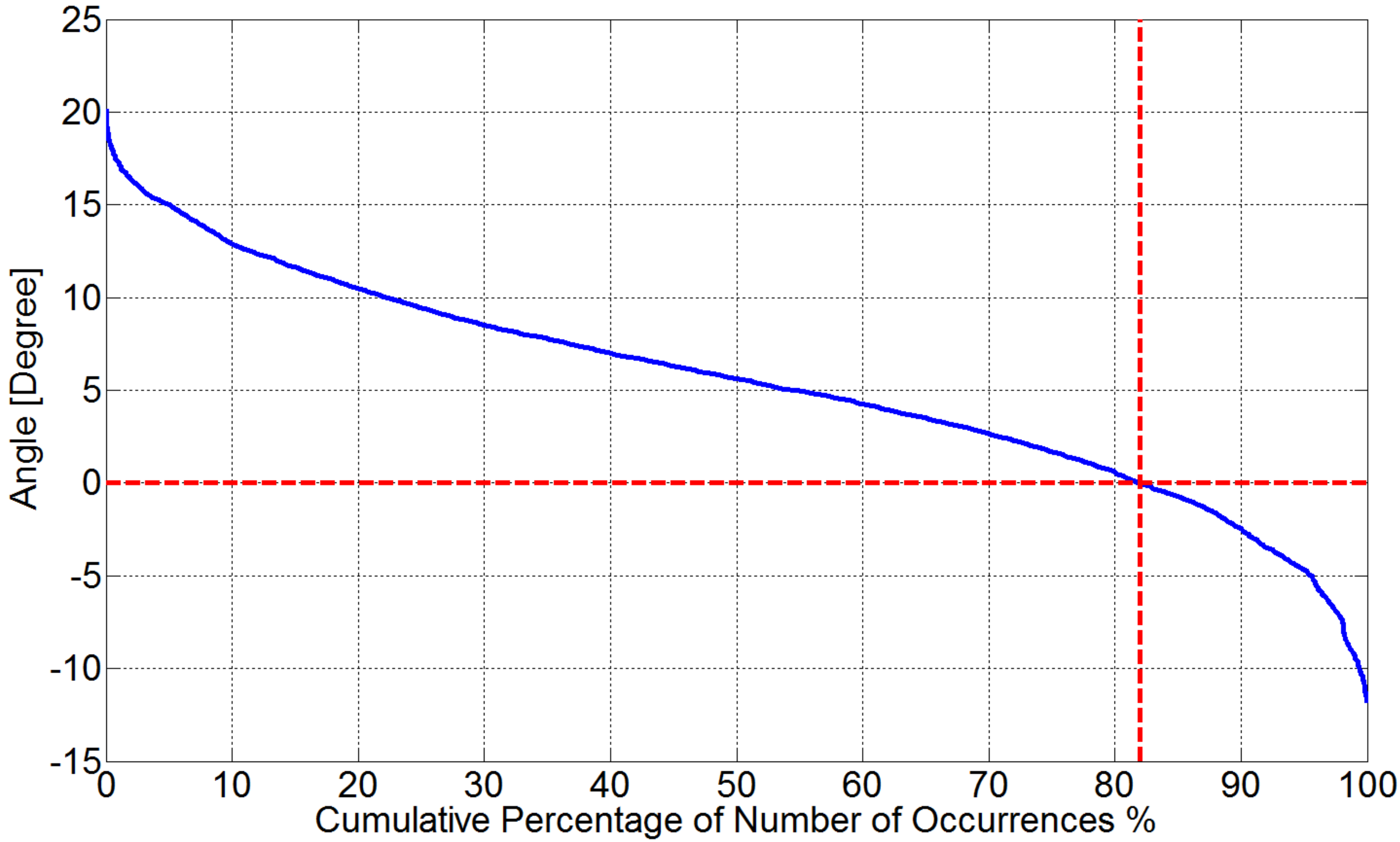

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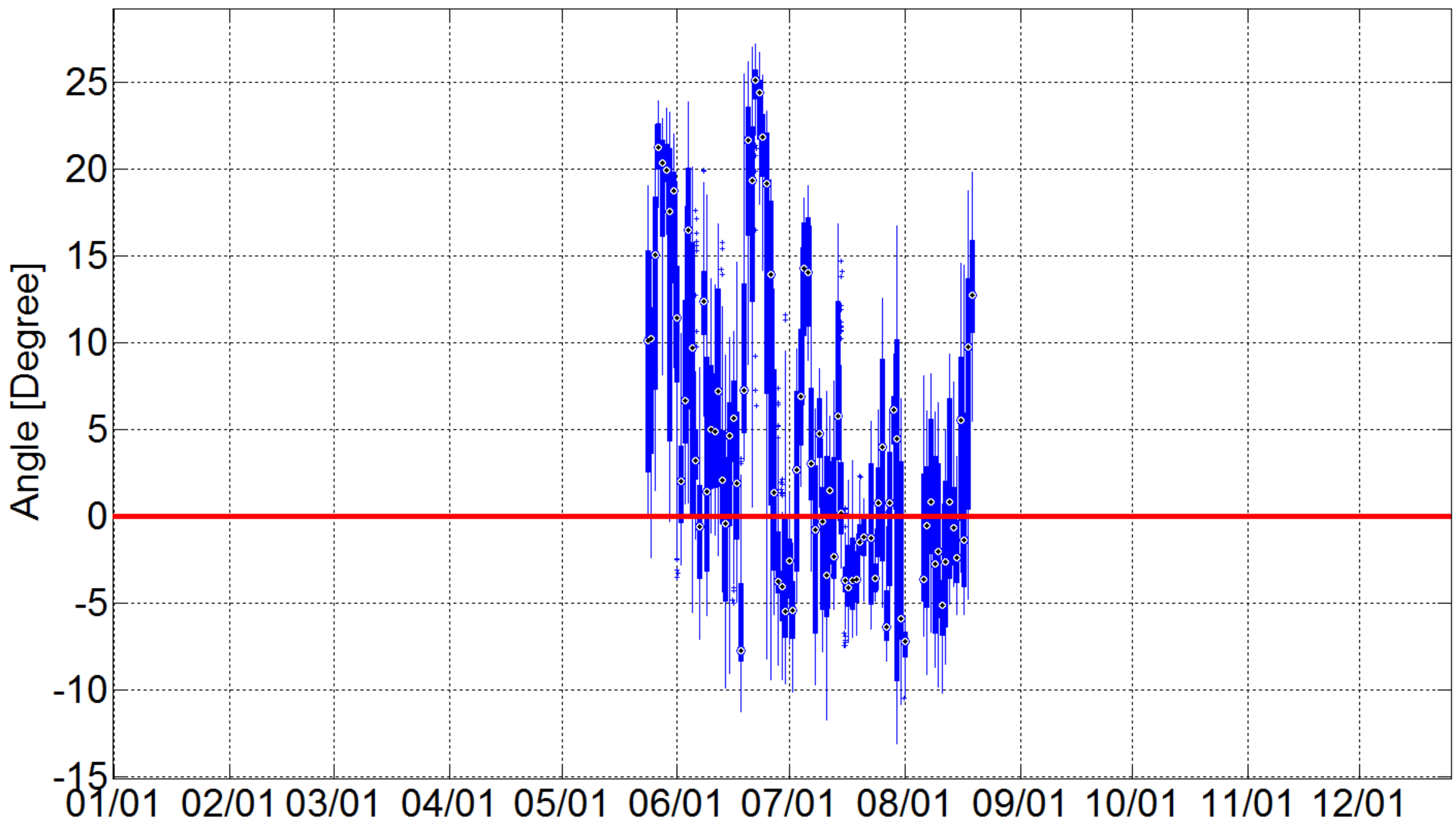

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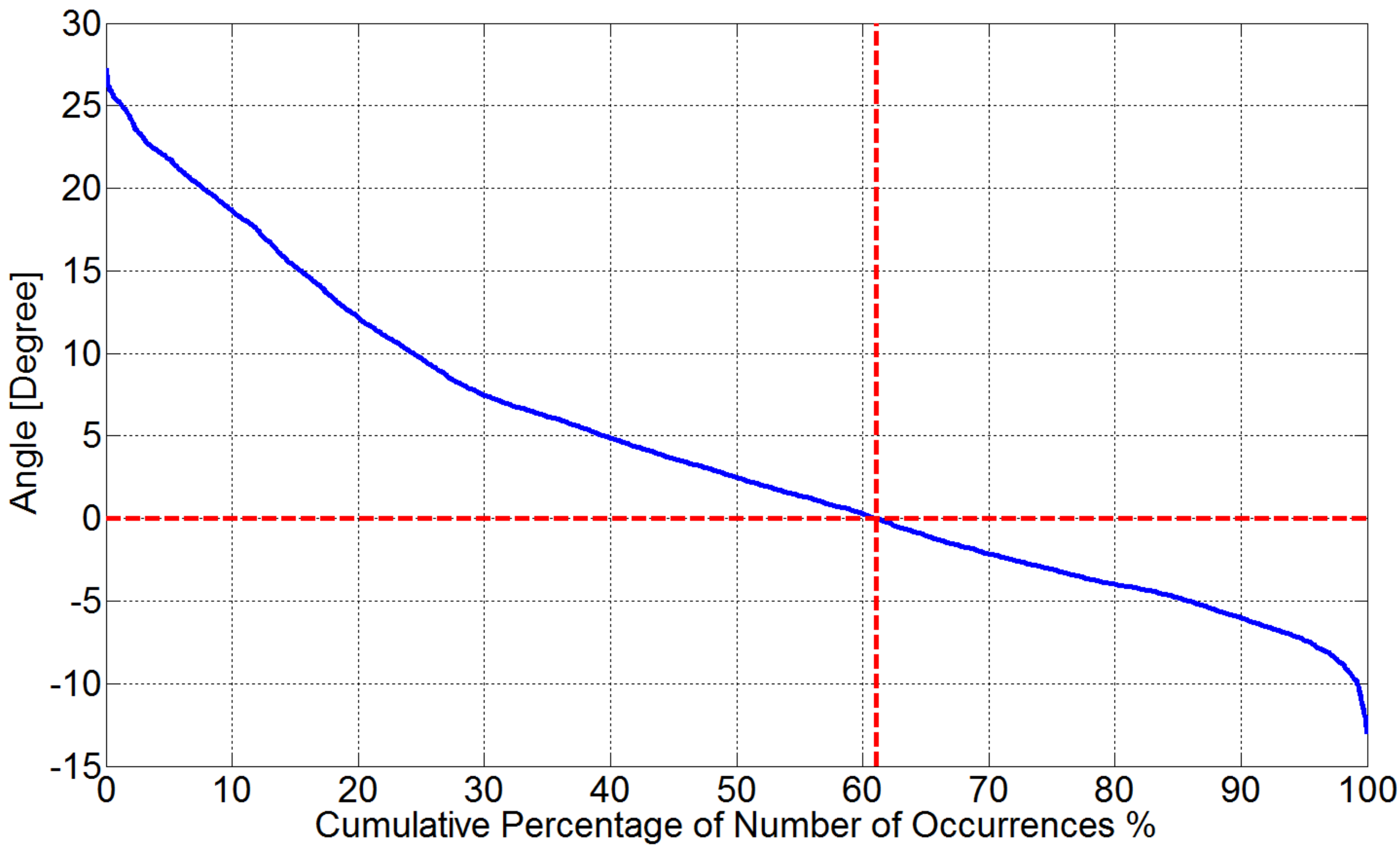

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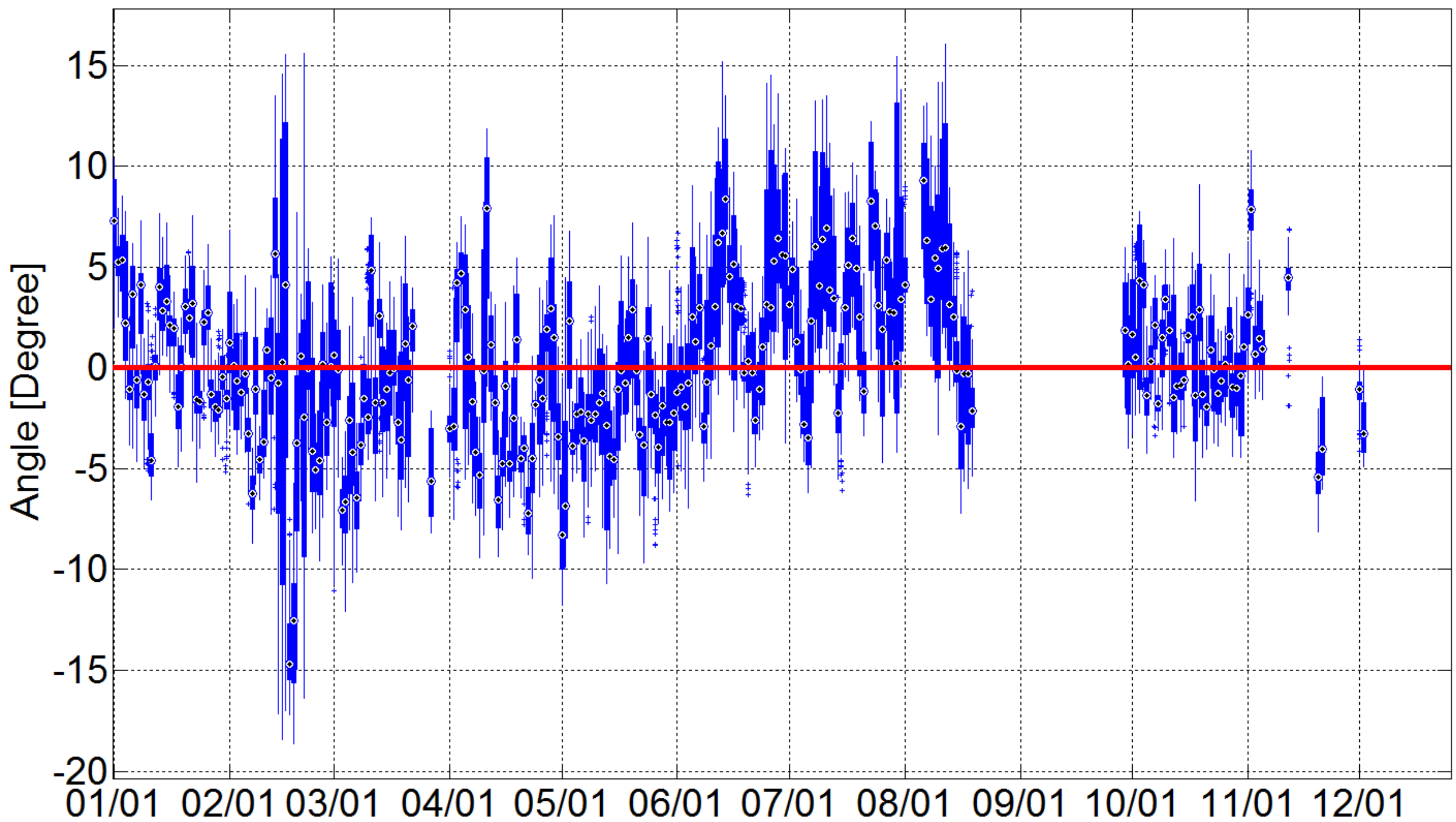

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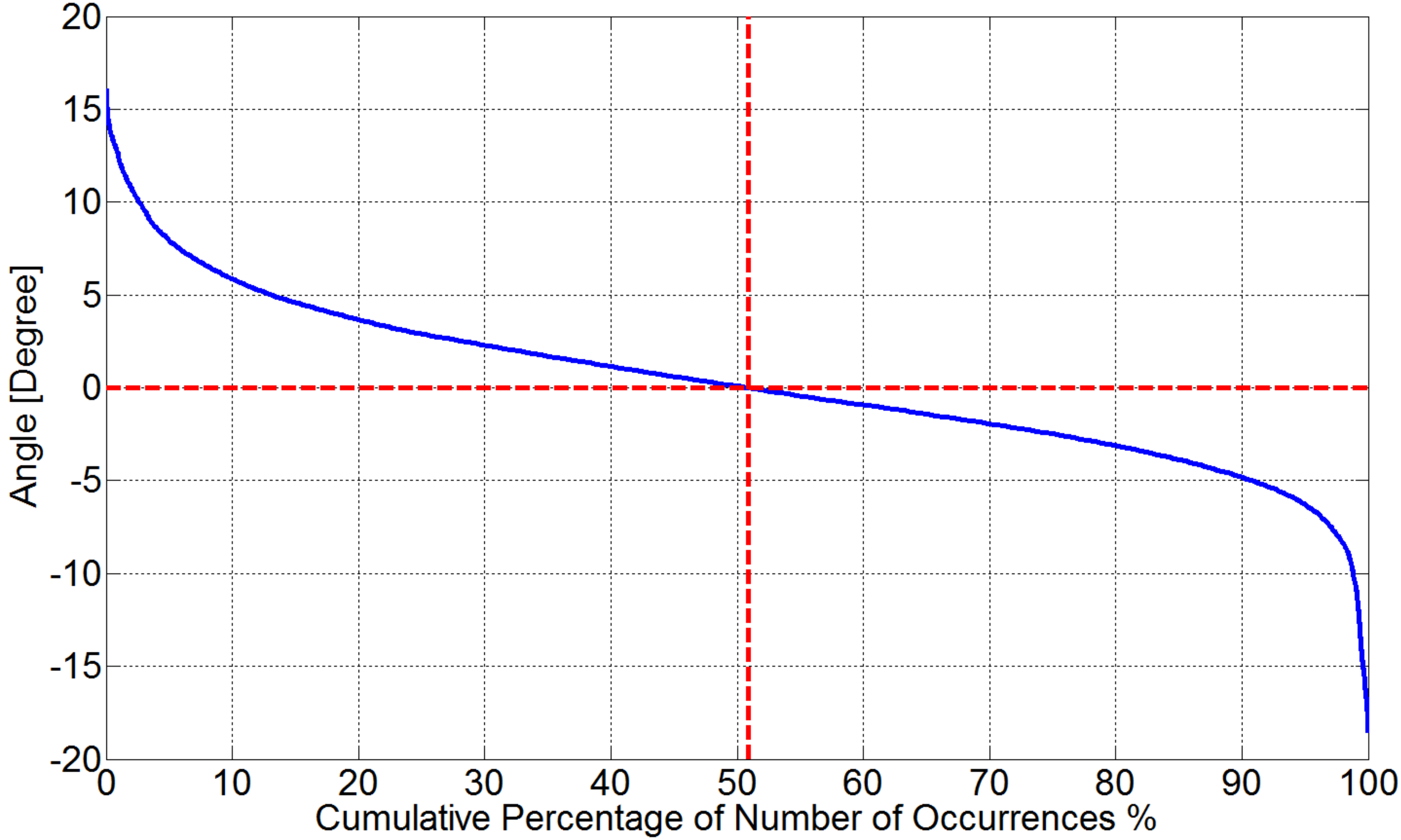

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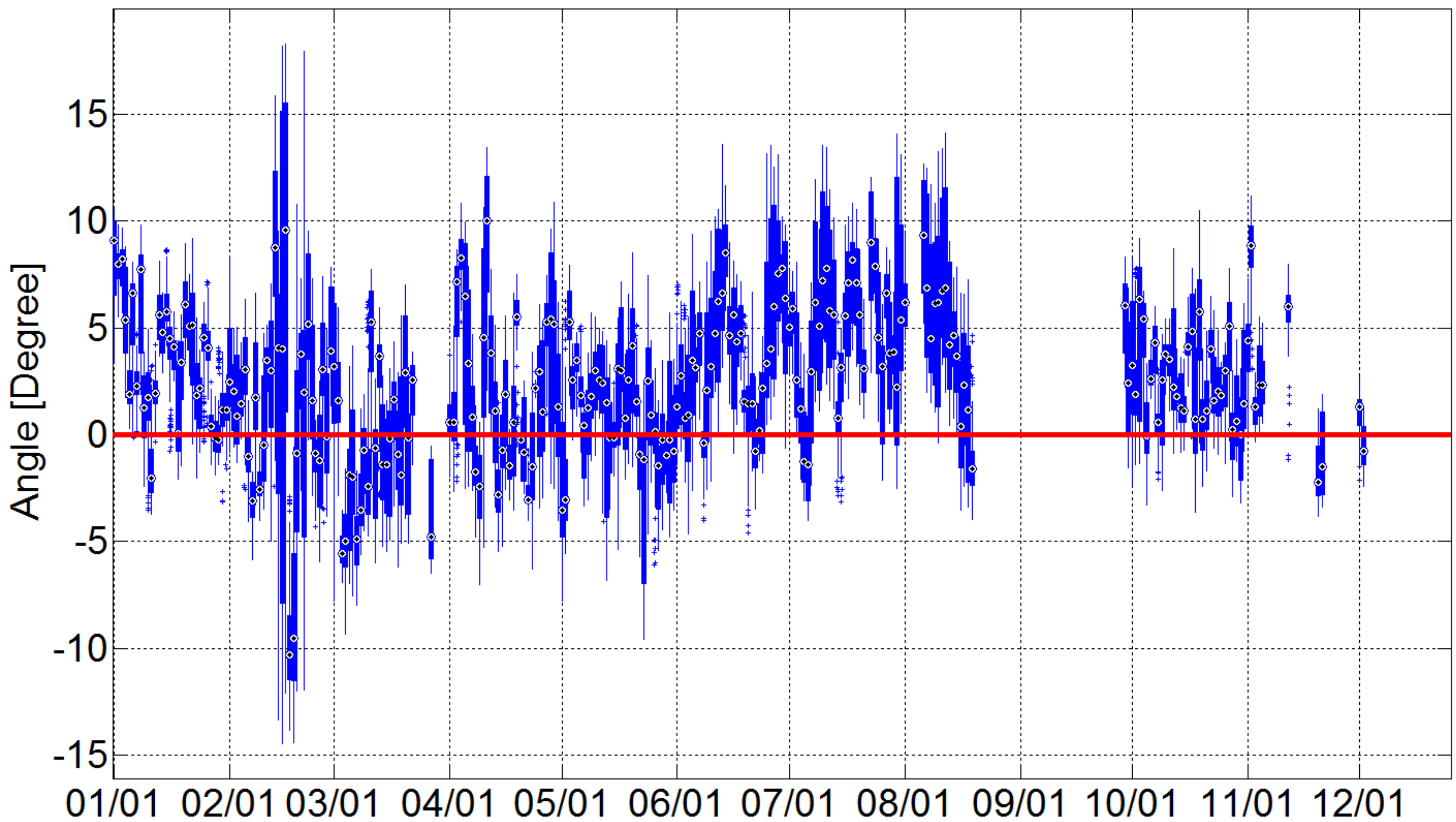

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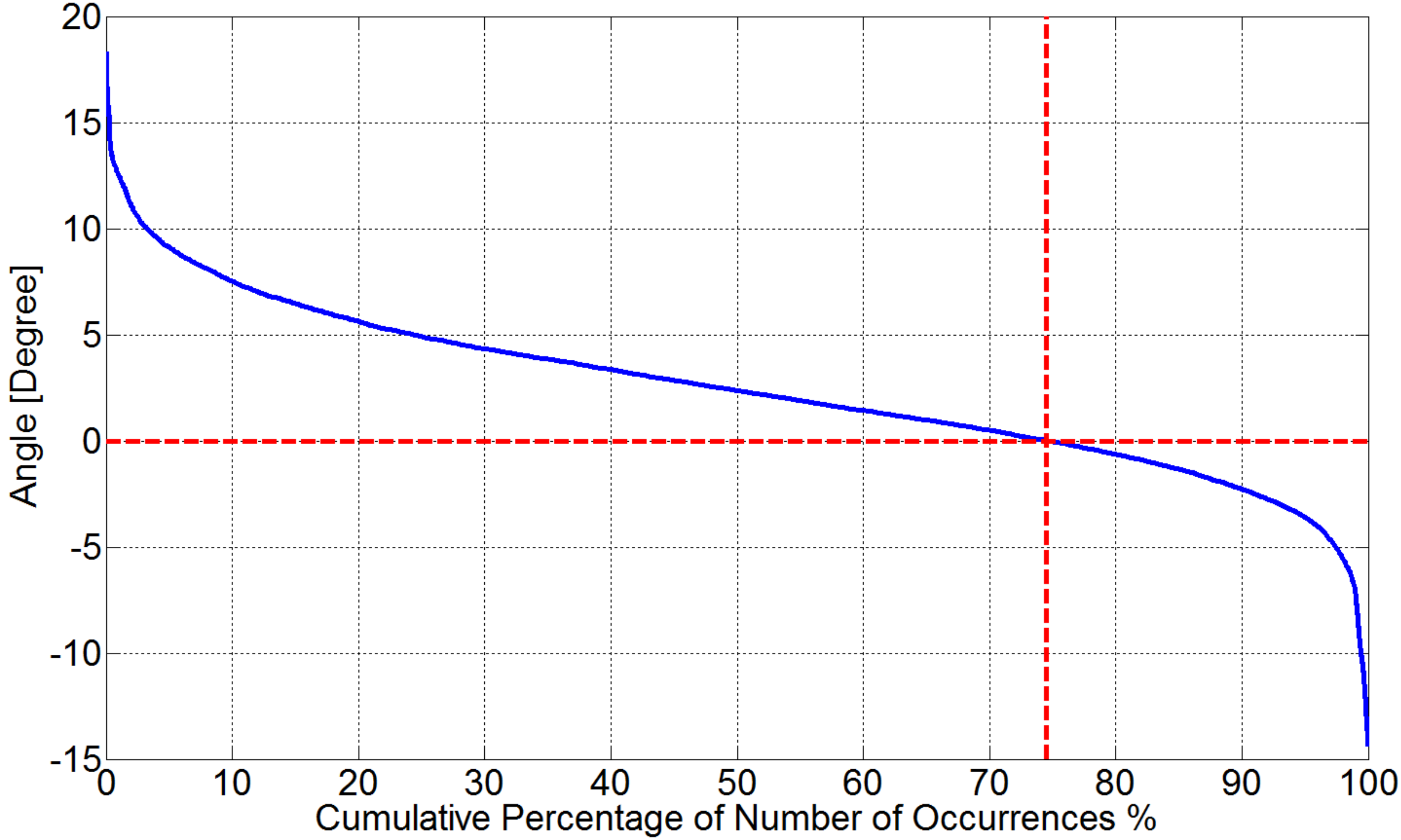

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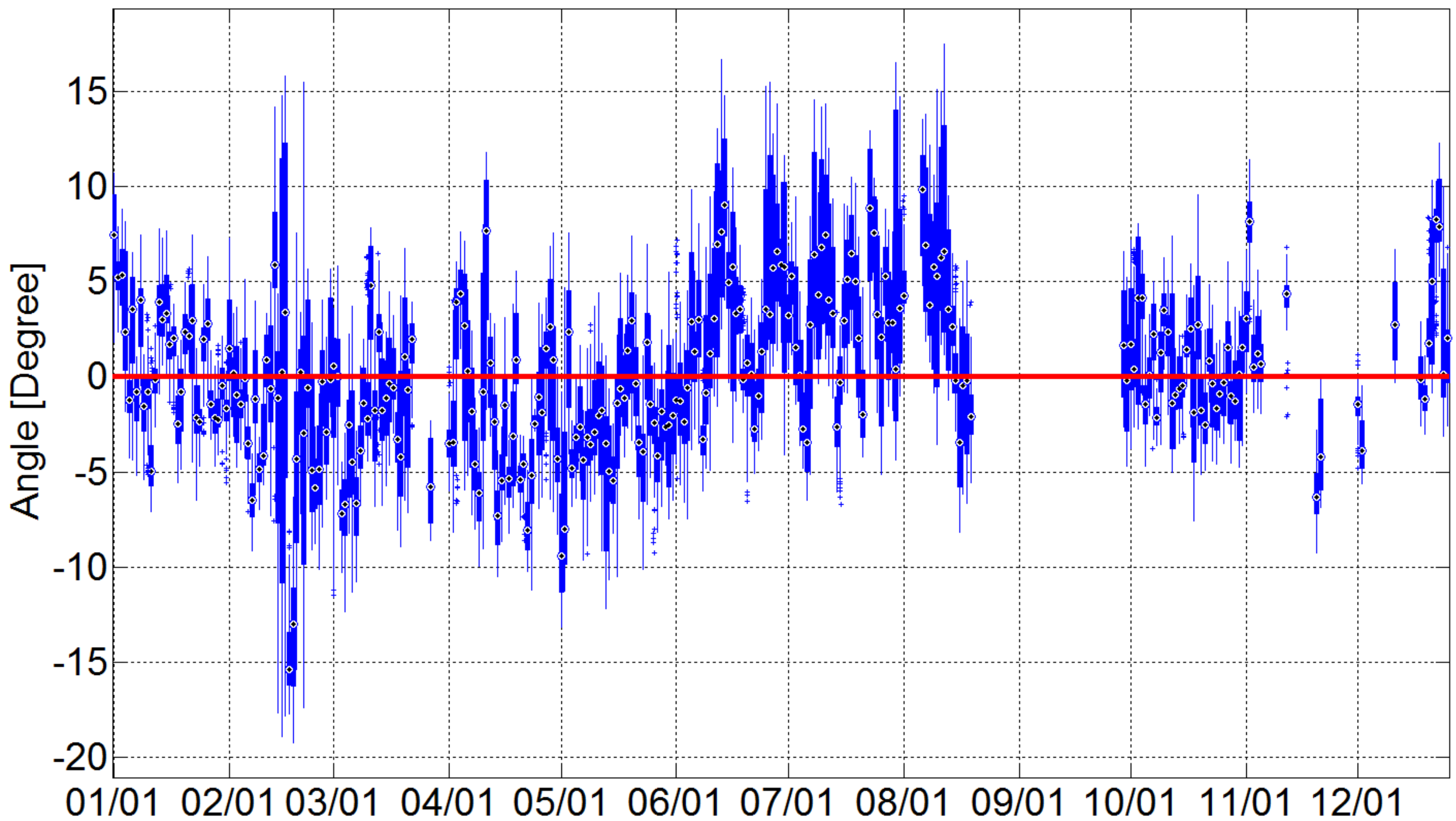
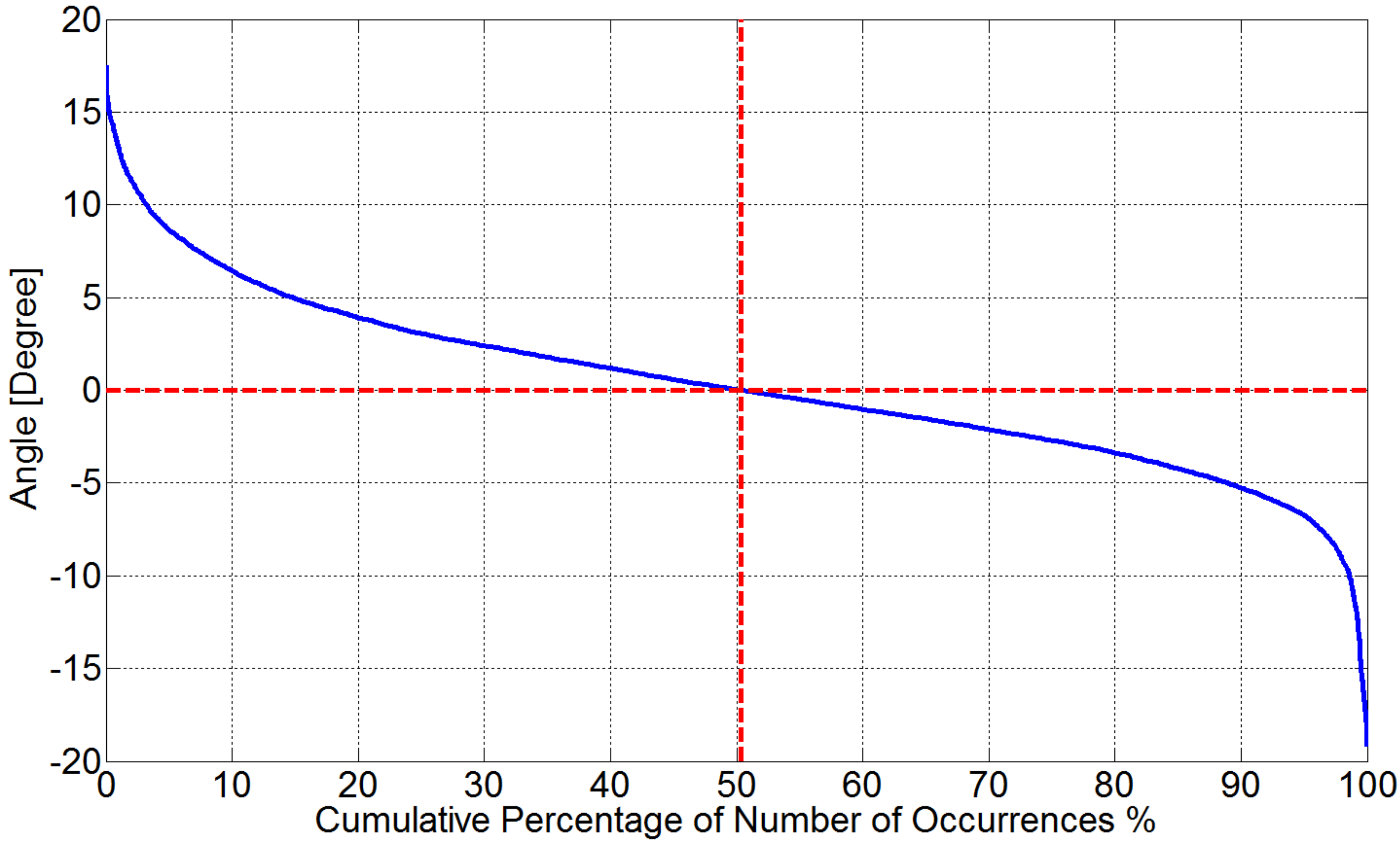
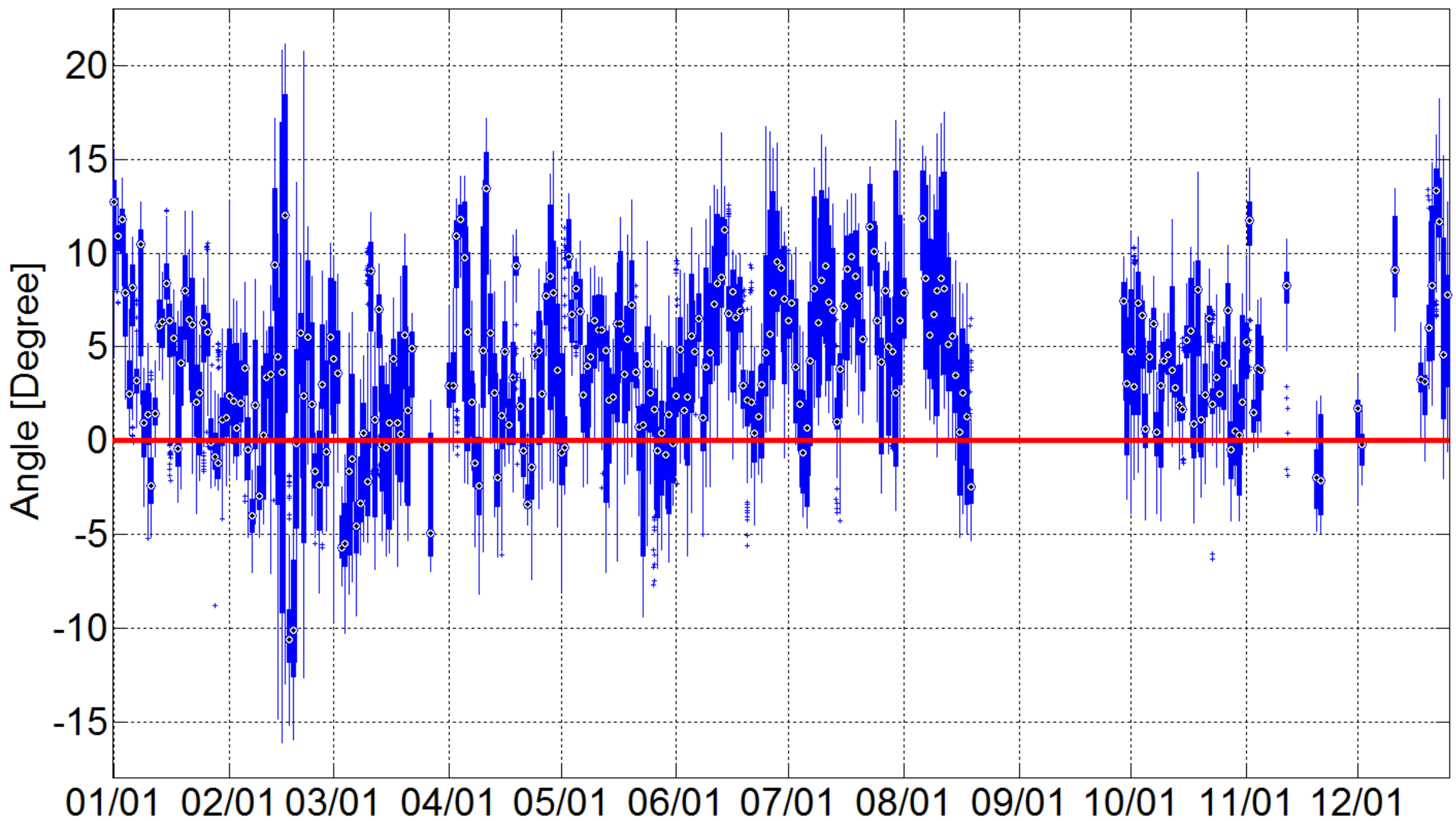


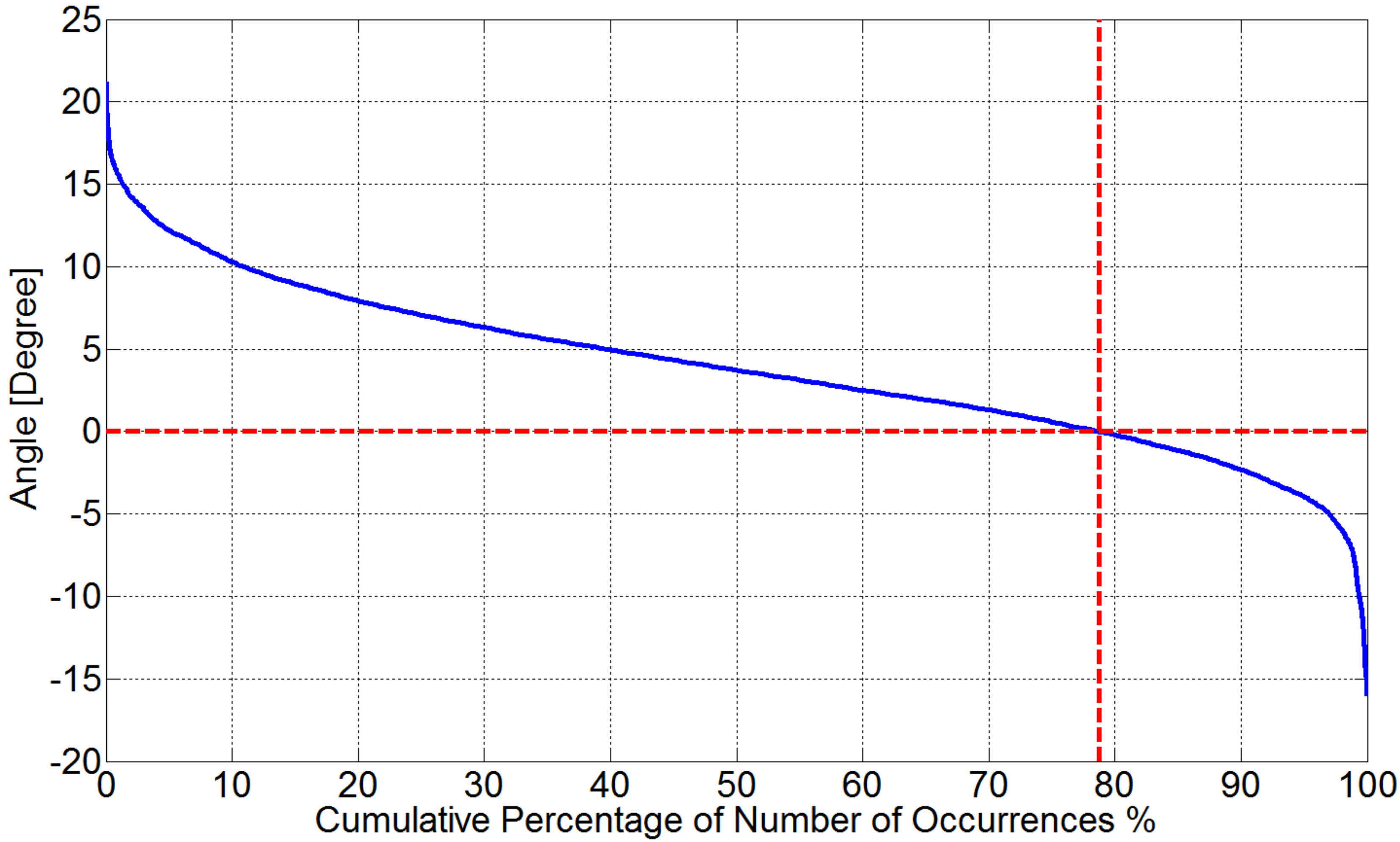
South 4-North 7



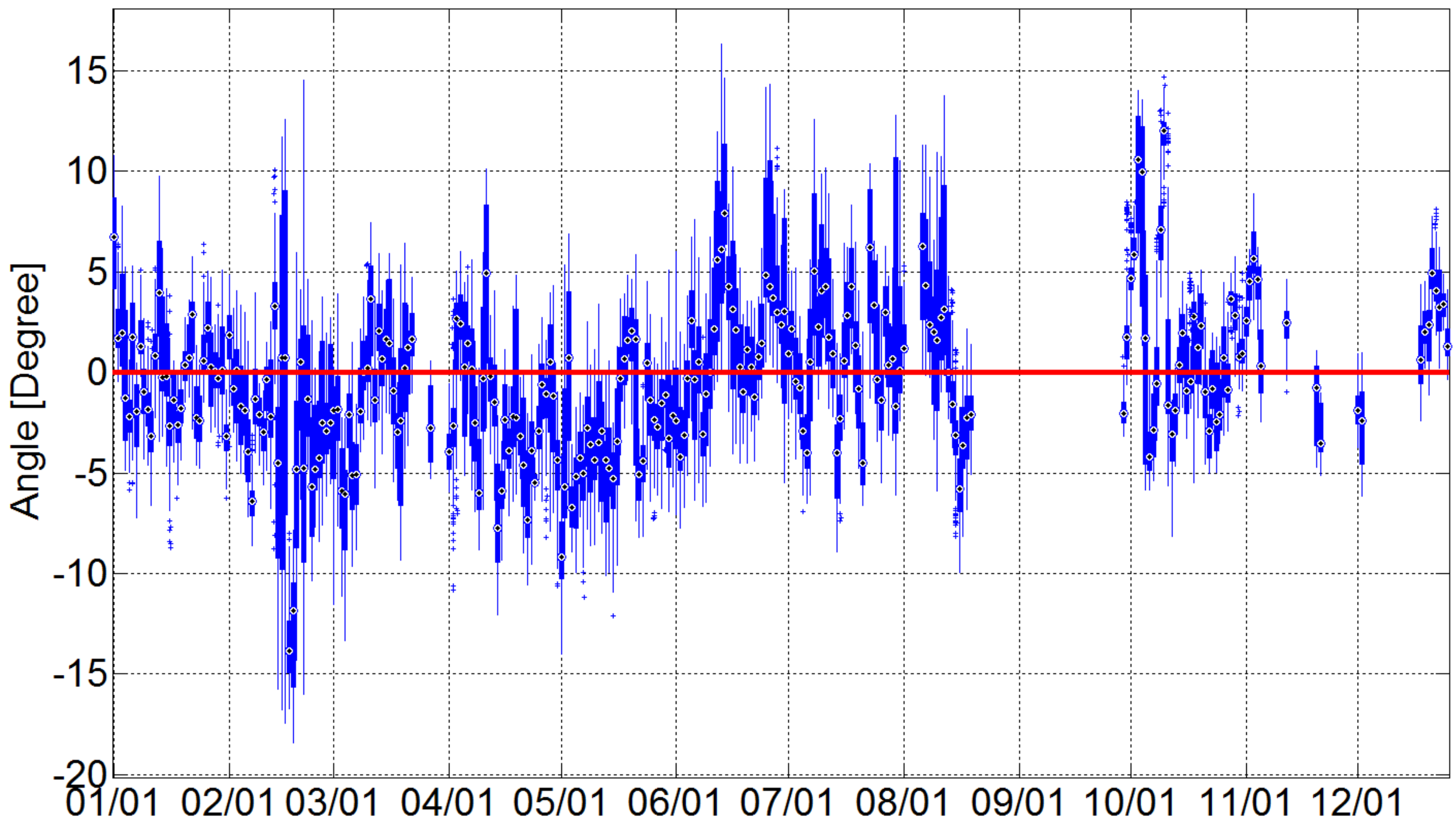
South 7-North 7



South 7-North 7



South 9-North 7



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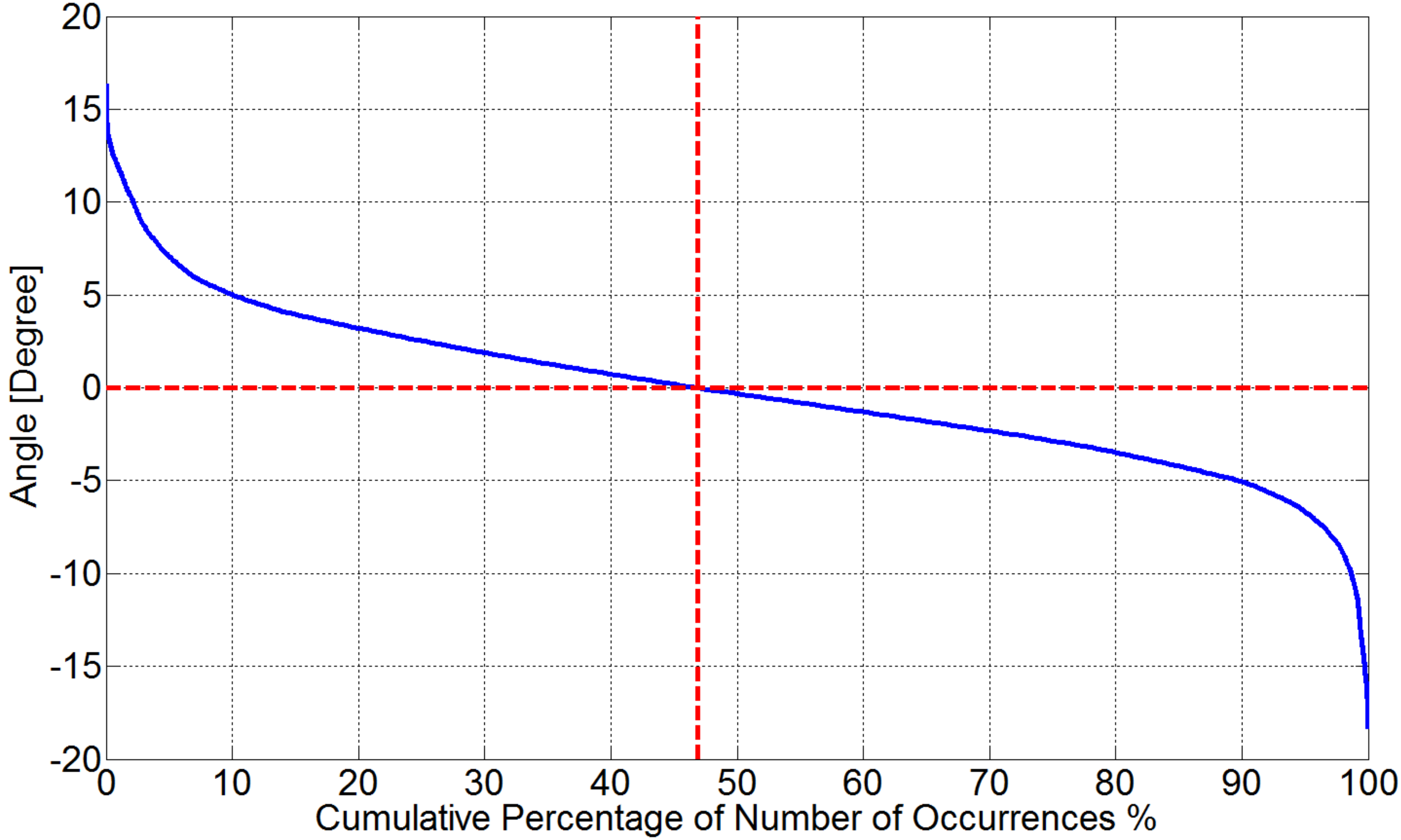
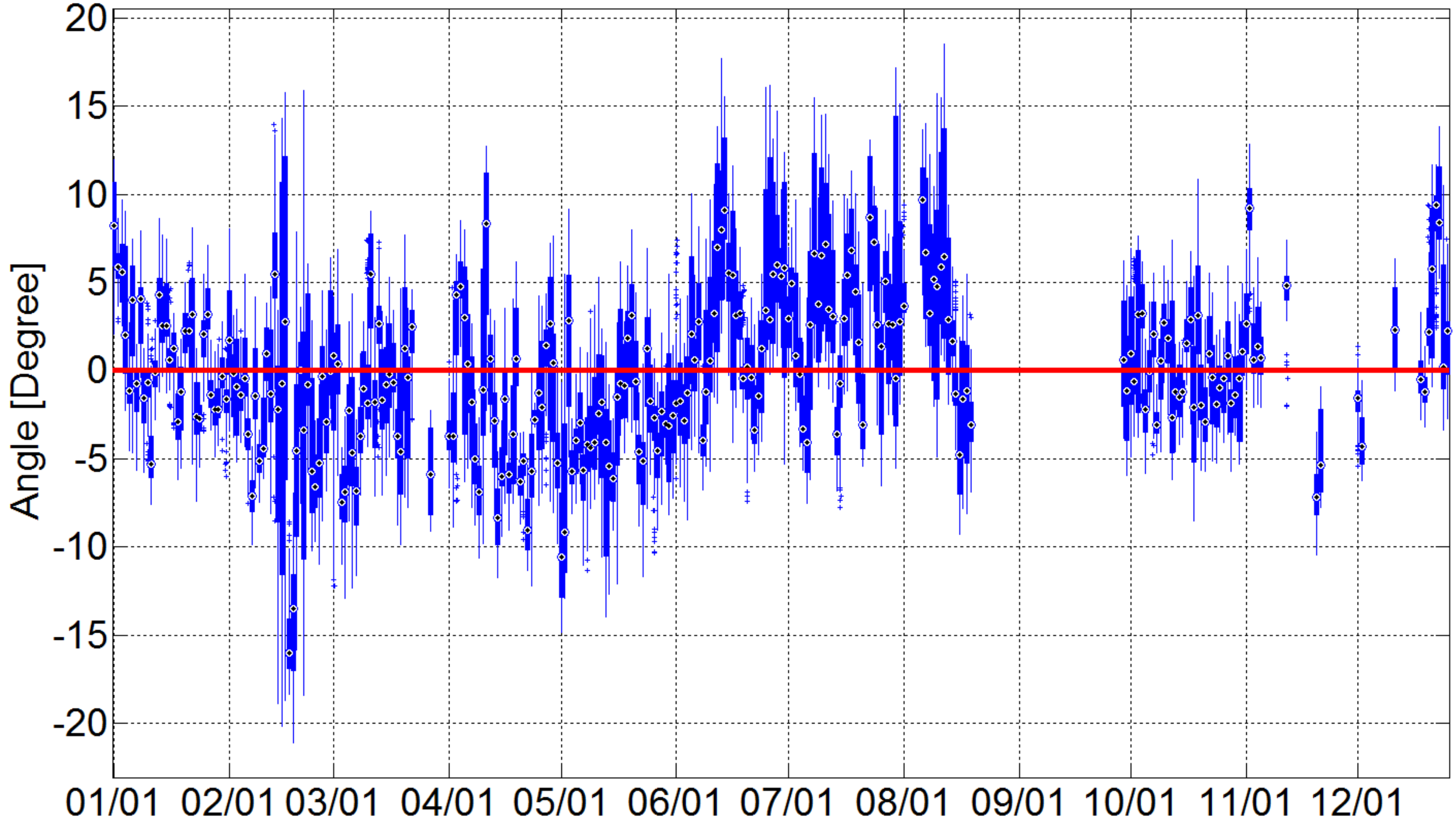
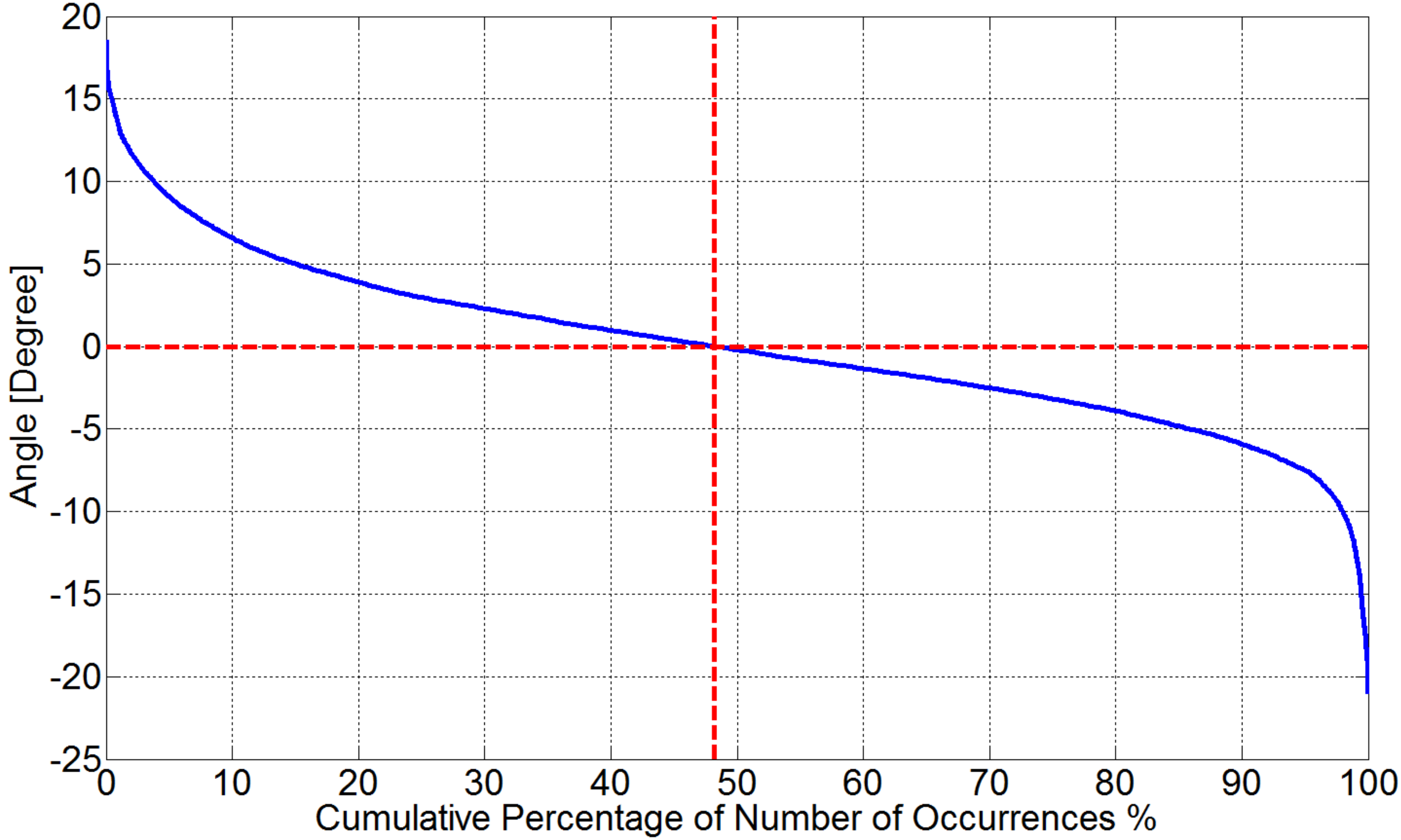


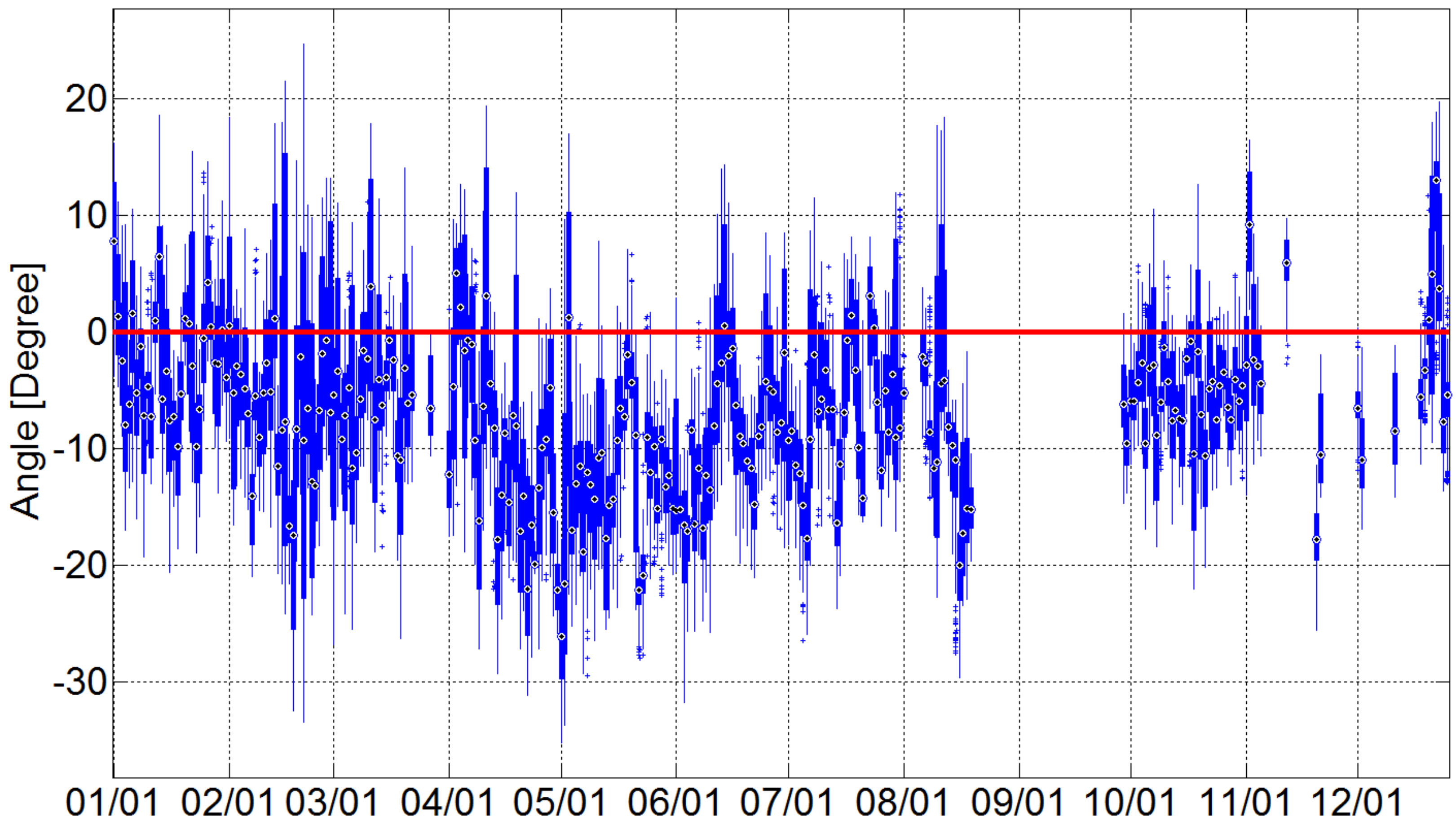
South 11-North 7



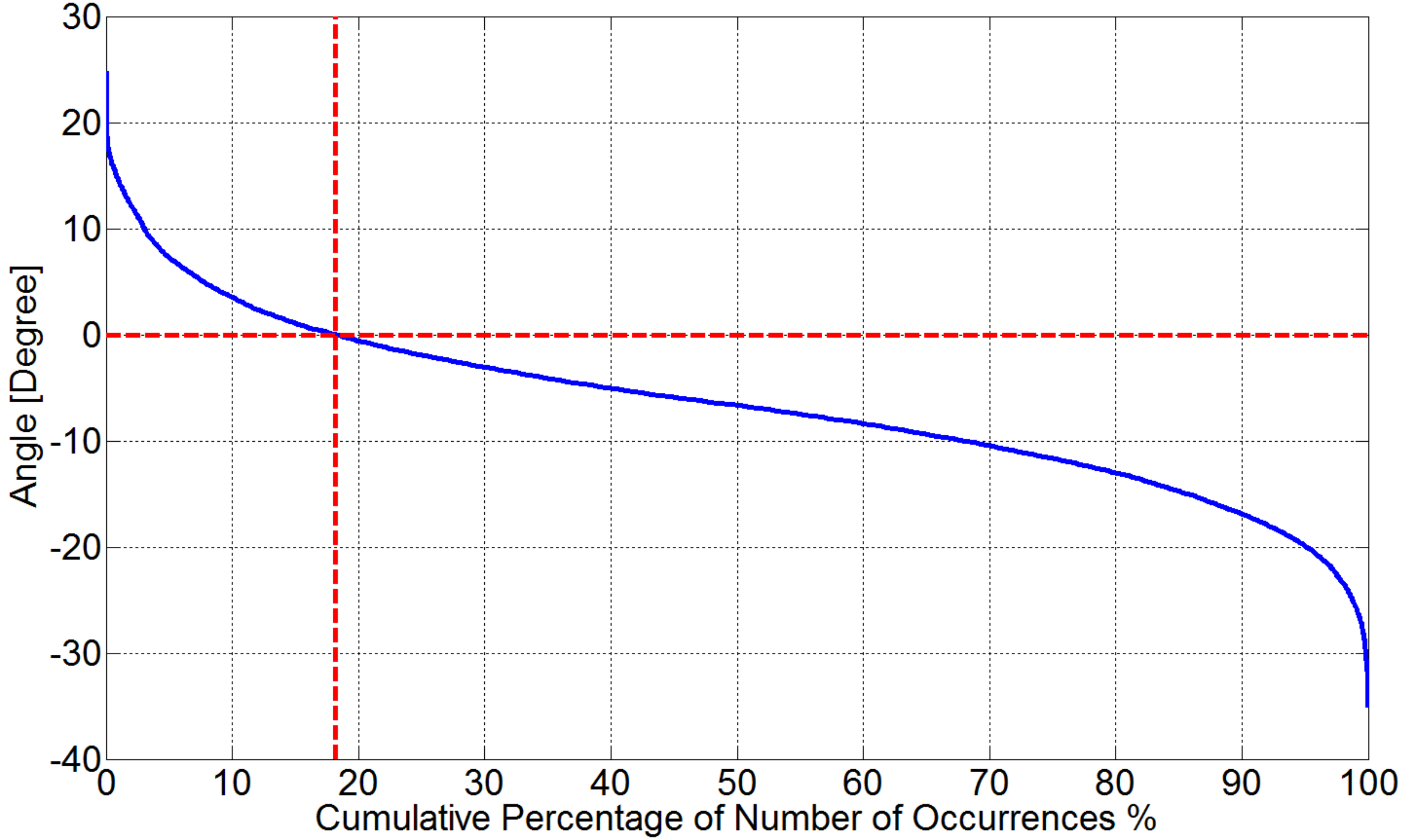
South 11-North 7



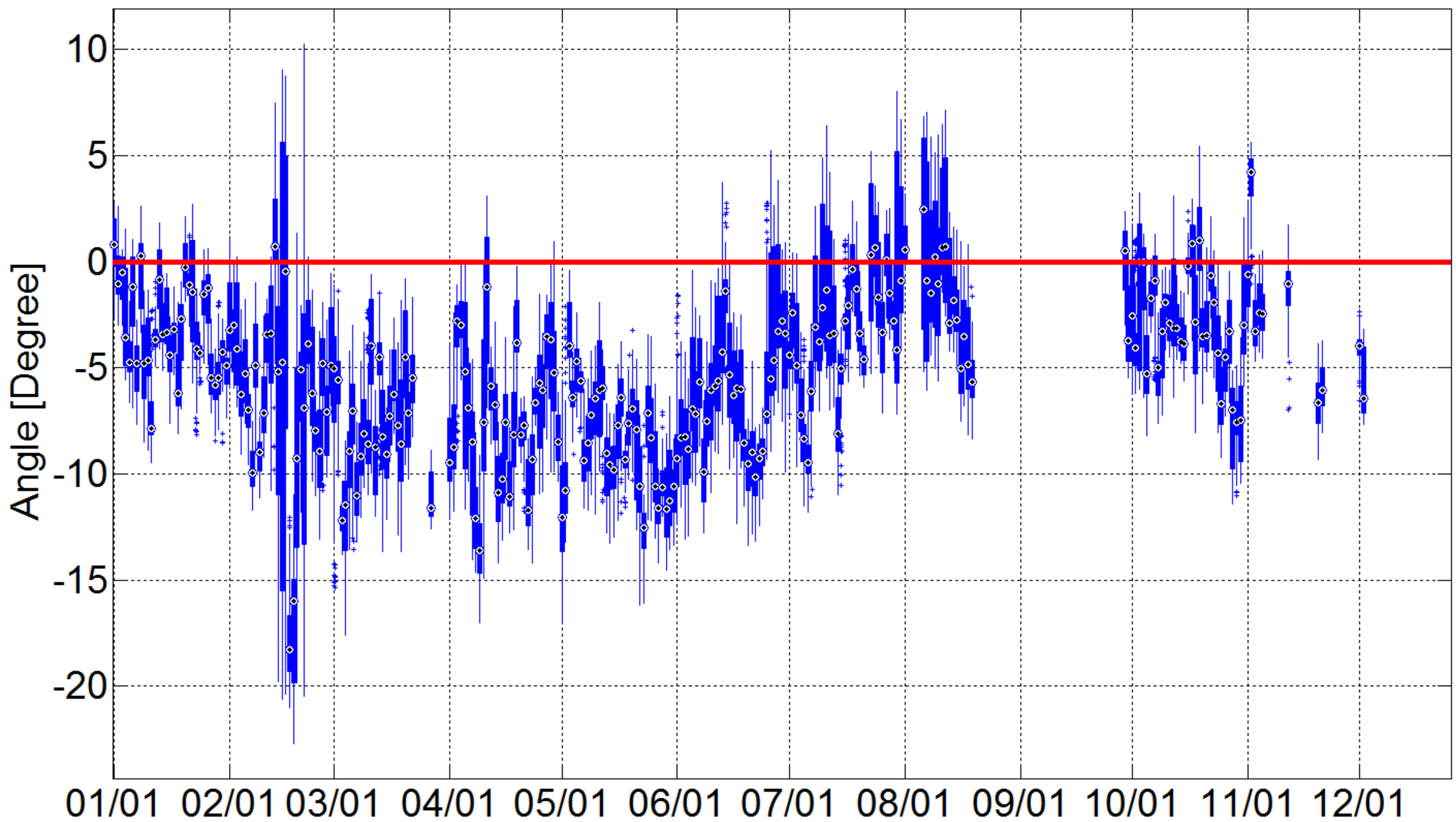
South 10-North 7



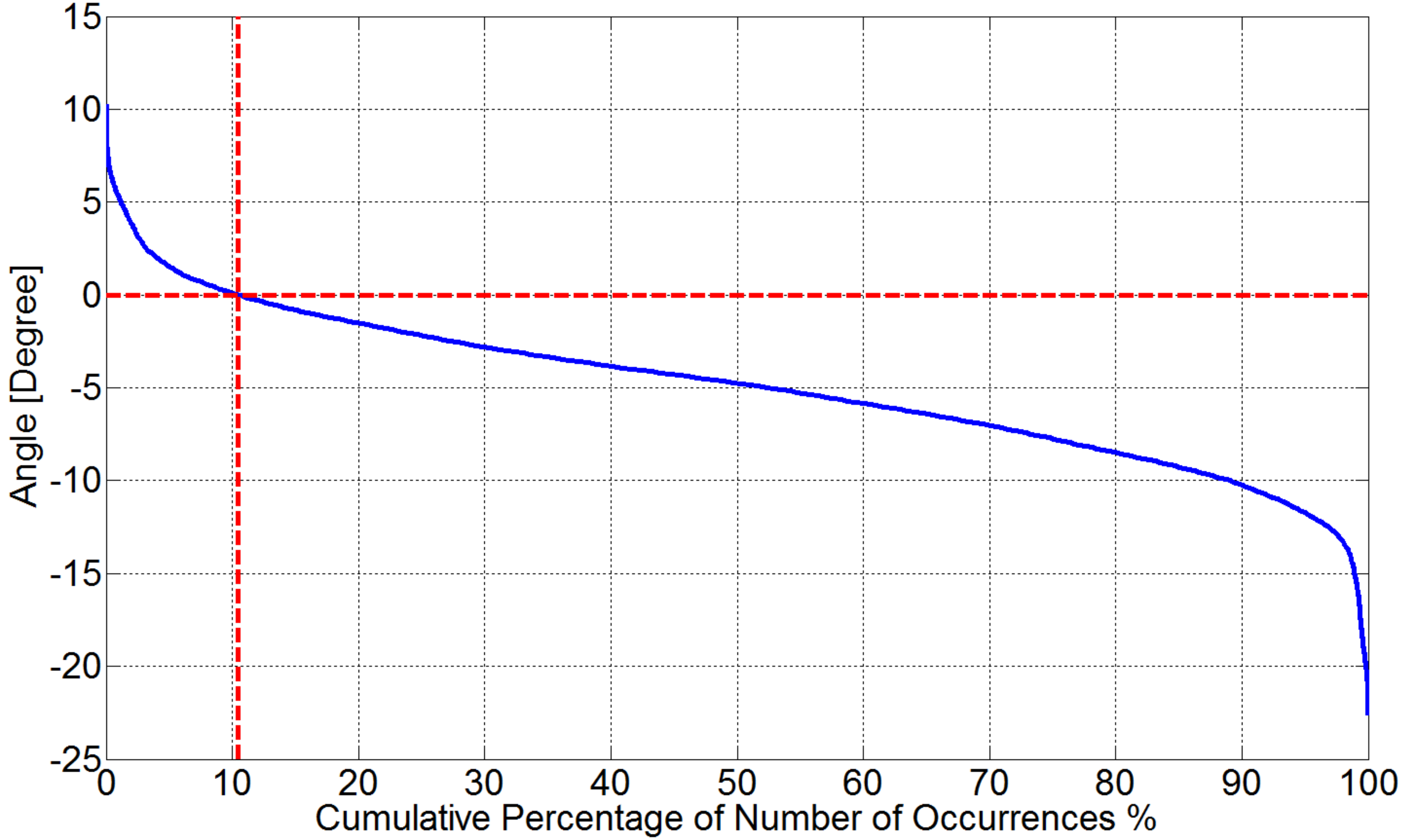
South 10-North 7



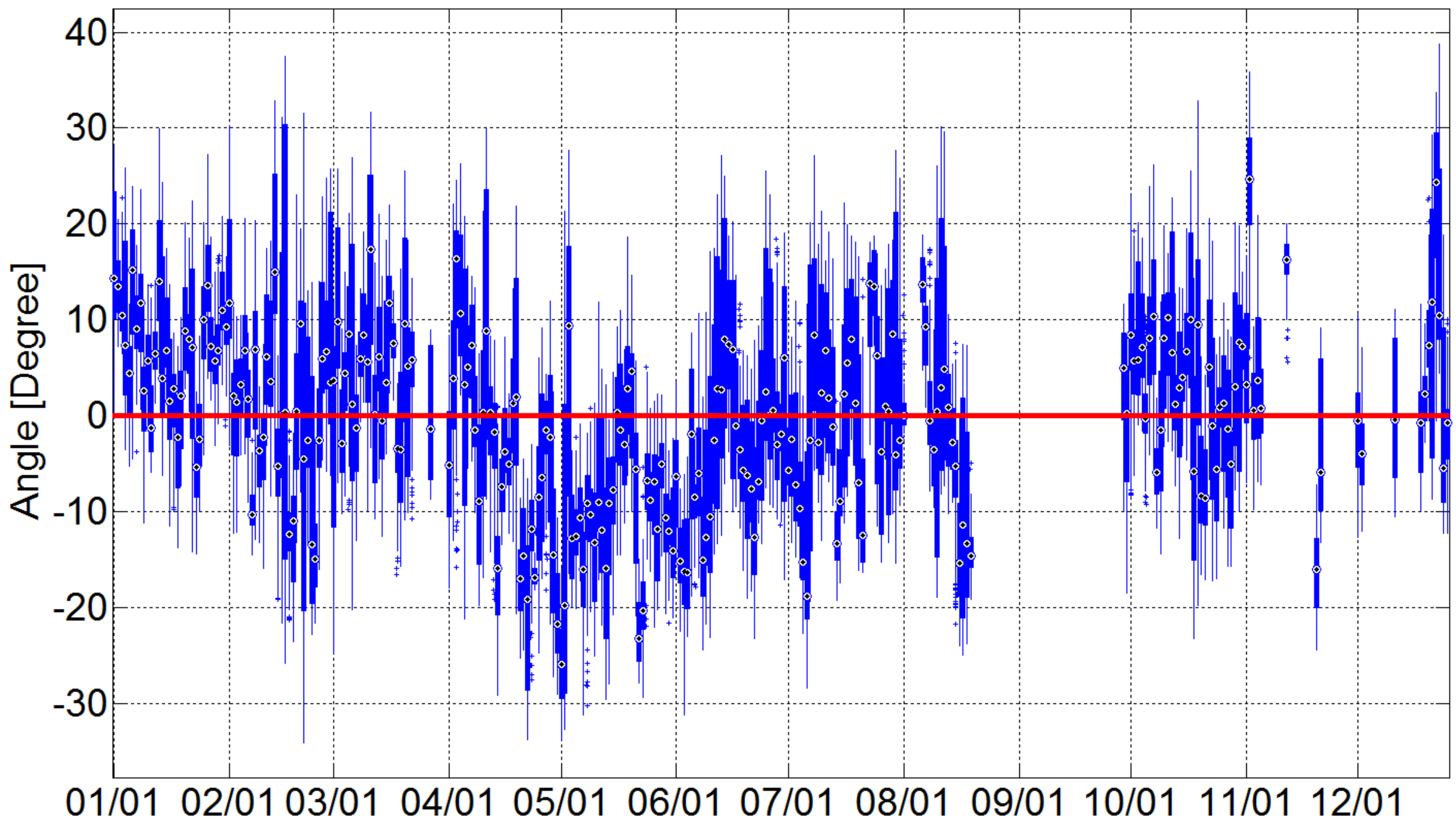
North 2-North 7



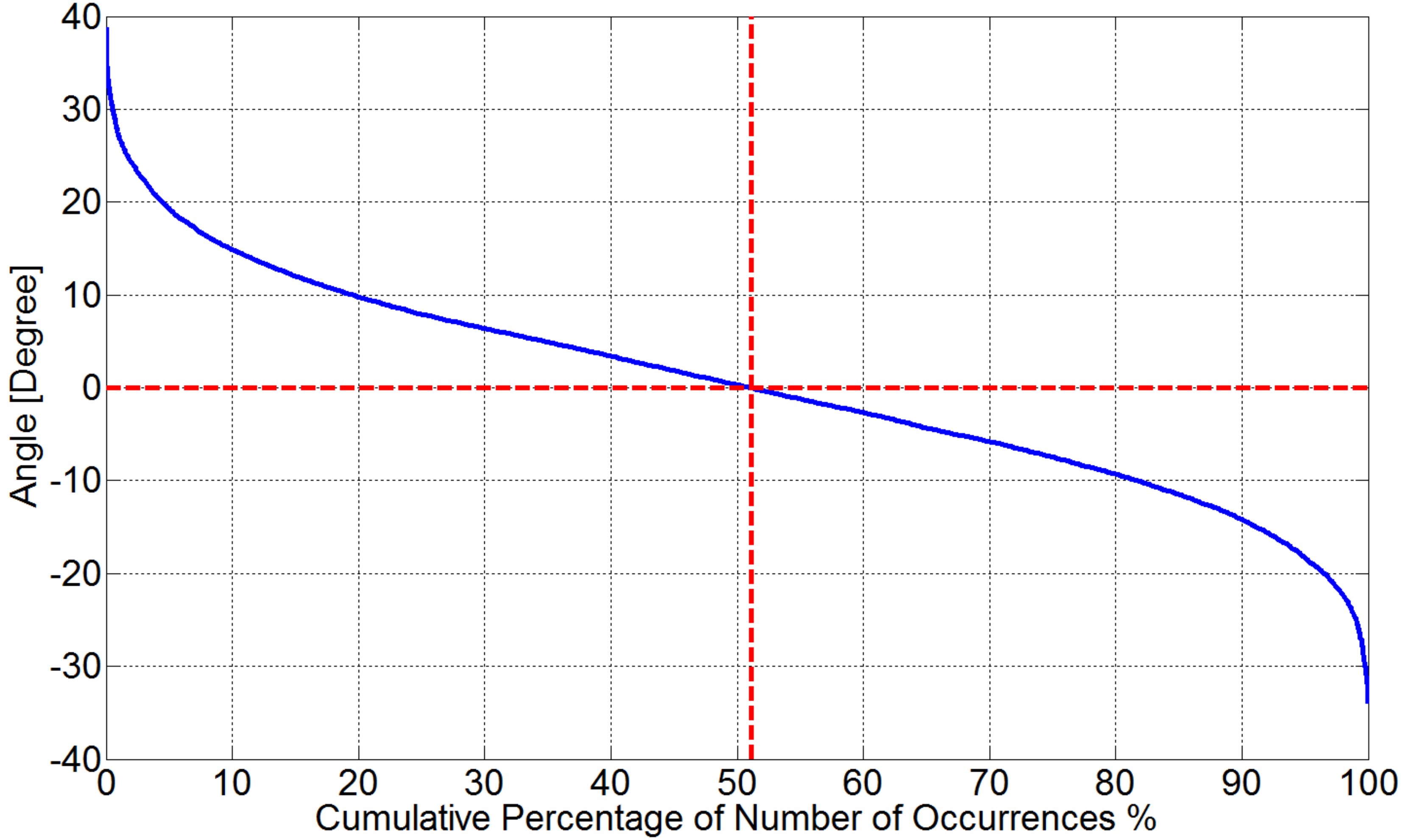
North 2-North 7



South 6-North 7



South 6-North 7



Appendix B – Part 2
CCET Discovery Across Texas project

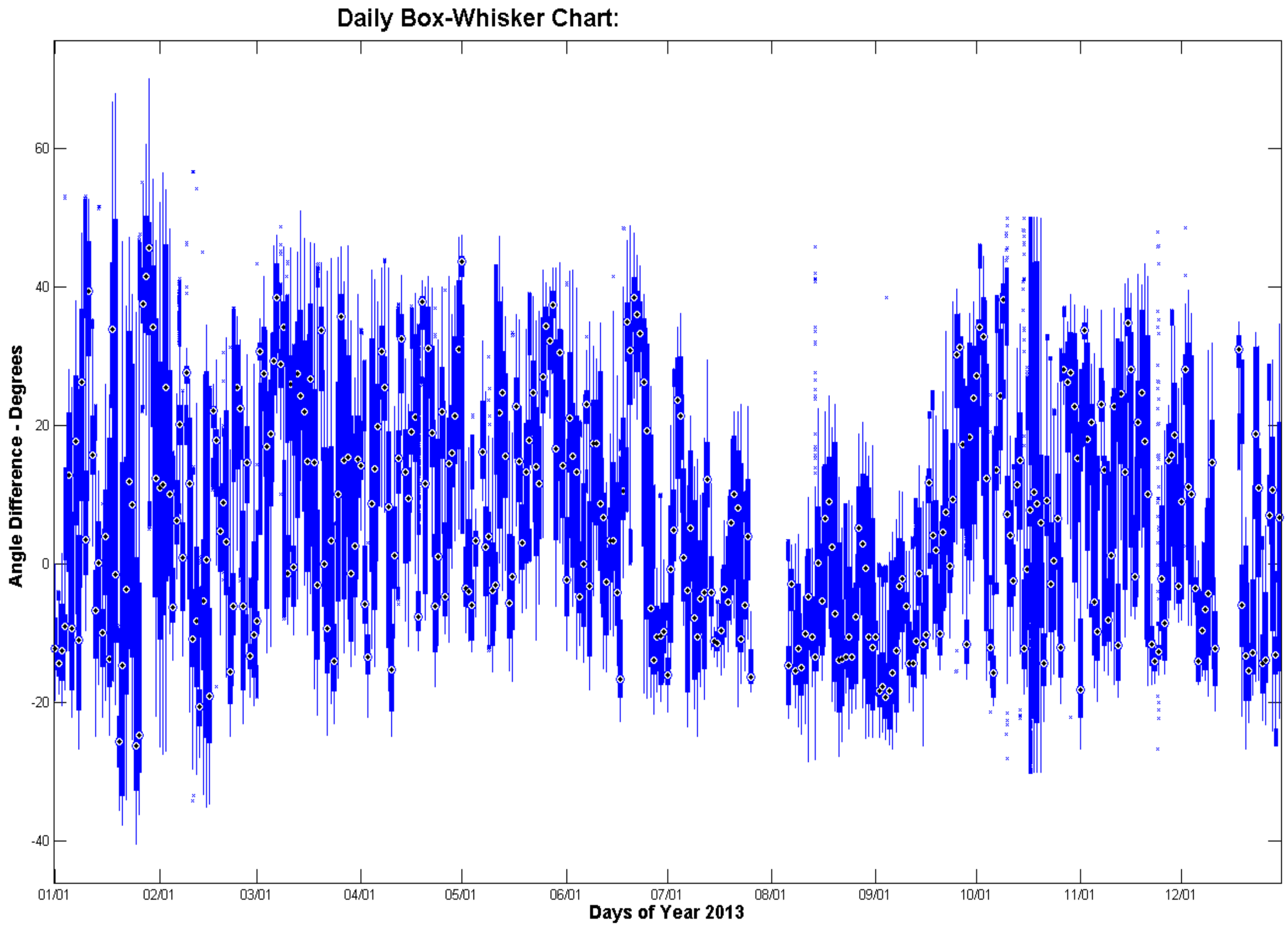
Baseline Analysis Update - Voltage Angles (Reference: North 7)

Phasor Data: January to December 2013

Box-Whisker Plots and Time Duration Curves

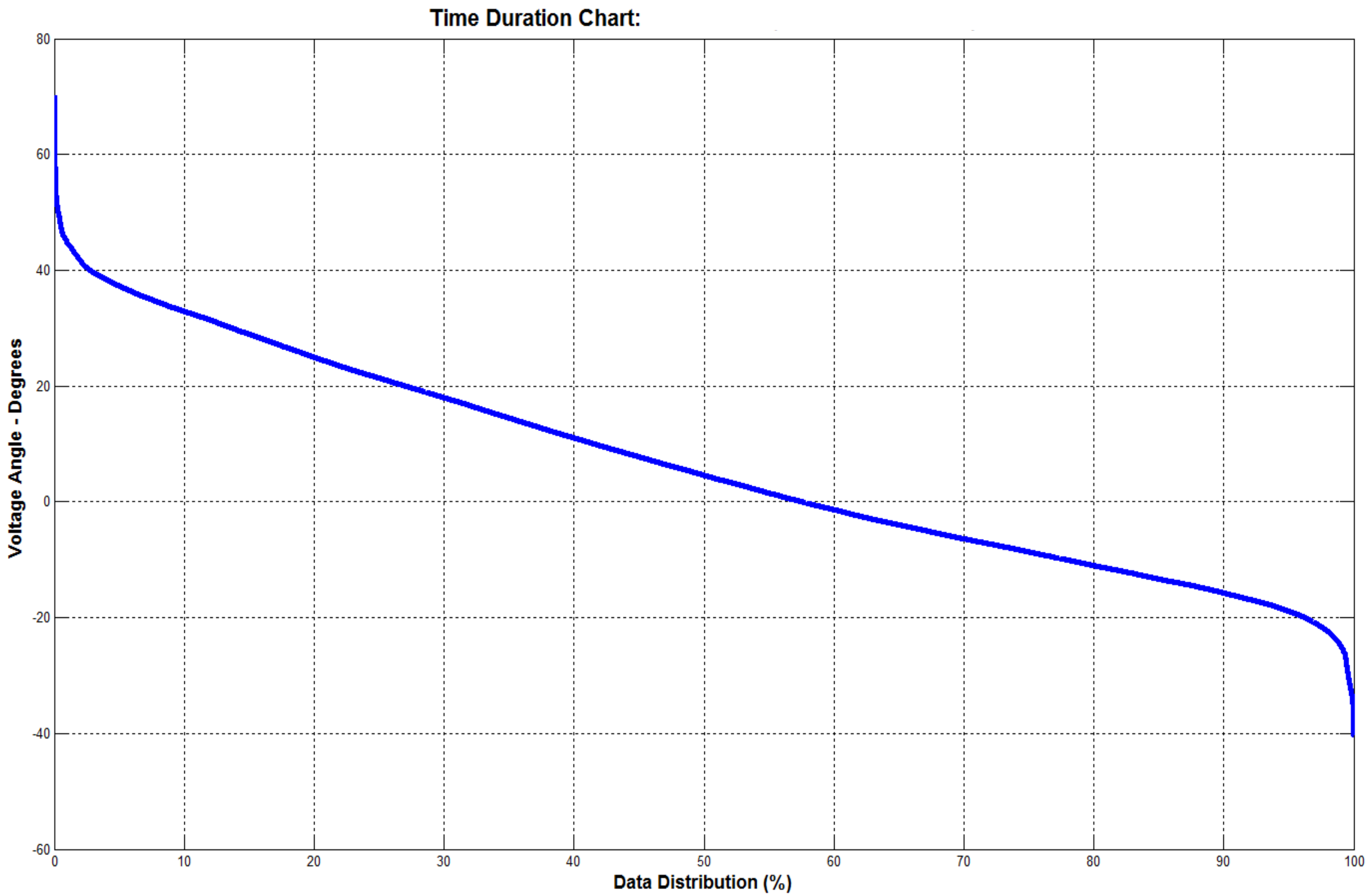
Electric Power Group CCET ERCOT

West 10

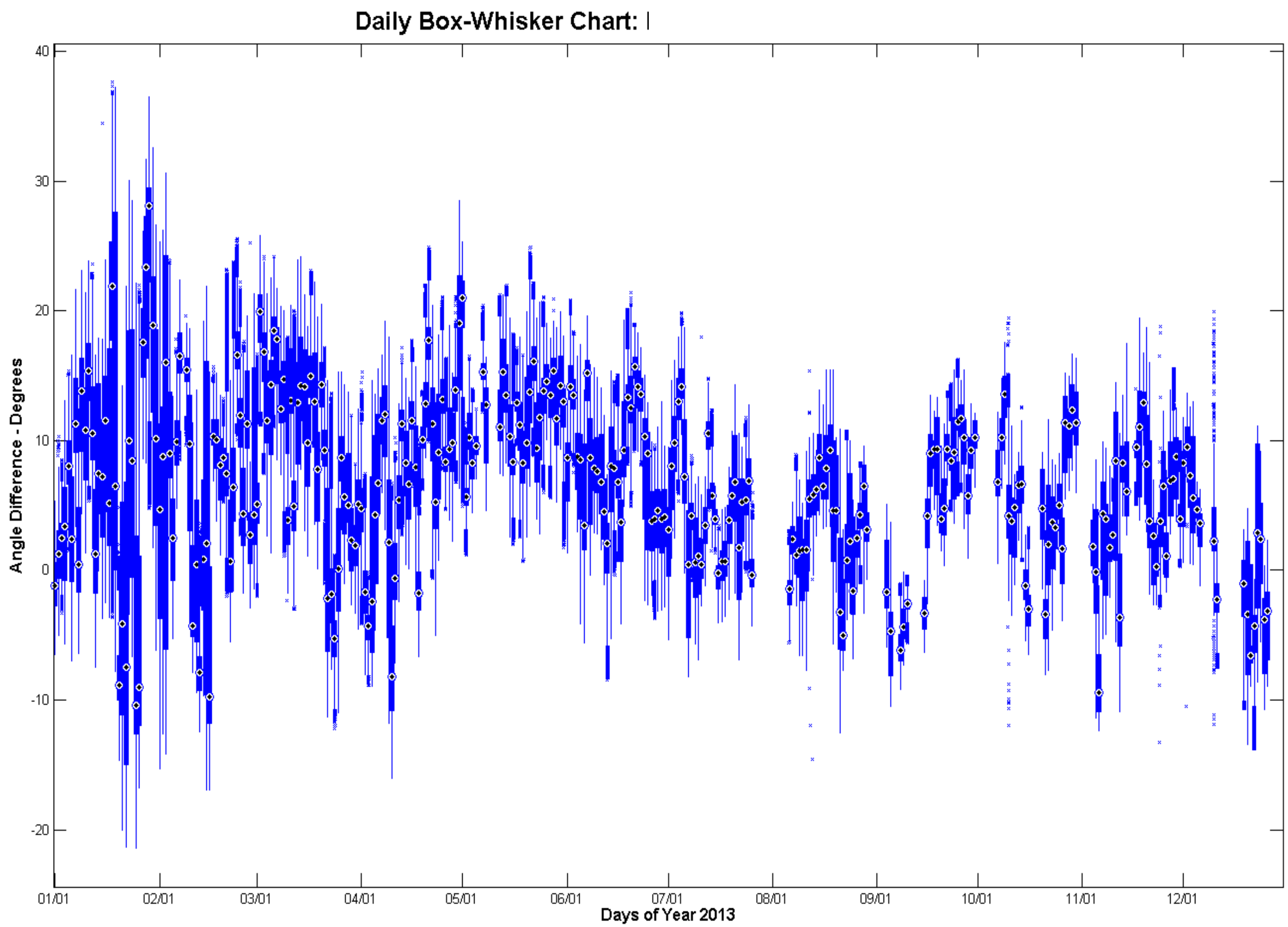


Daily Box-Whisker Chart:
Angle Difference - Degrees
60
40
20
0
-20
-40
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 10

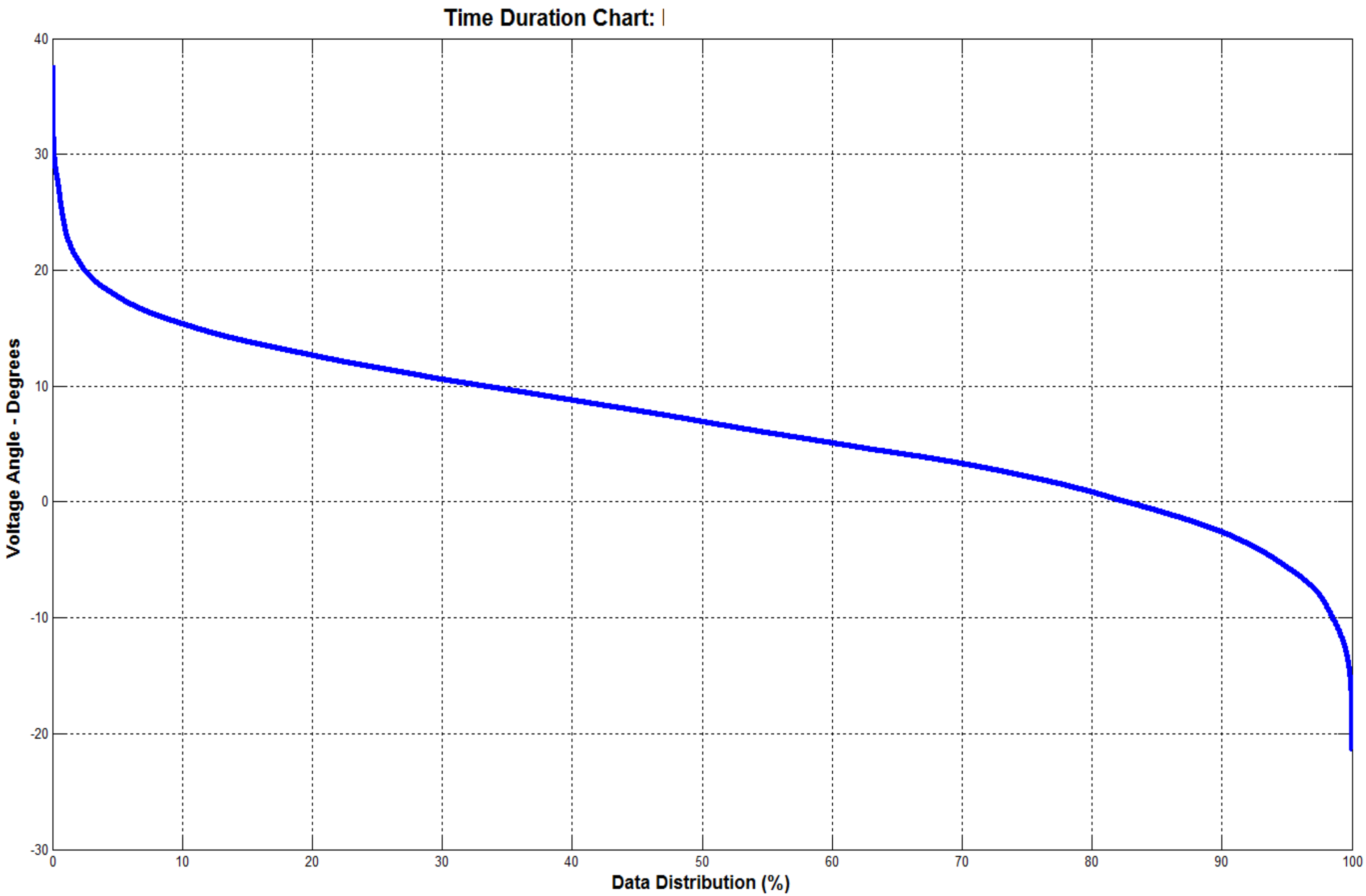

Time Duration Chart:
Voltage Angle - Degrees
Data Distribution (%)
80
60
40
20
0
-20
-40
-60
0
10
20
30
40
50
60
70
80
90
100

West 14



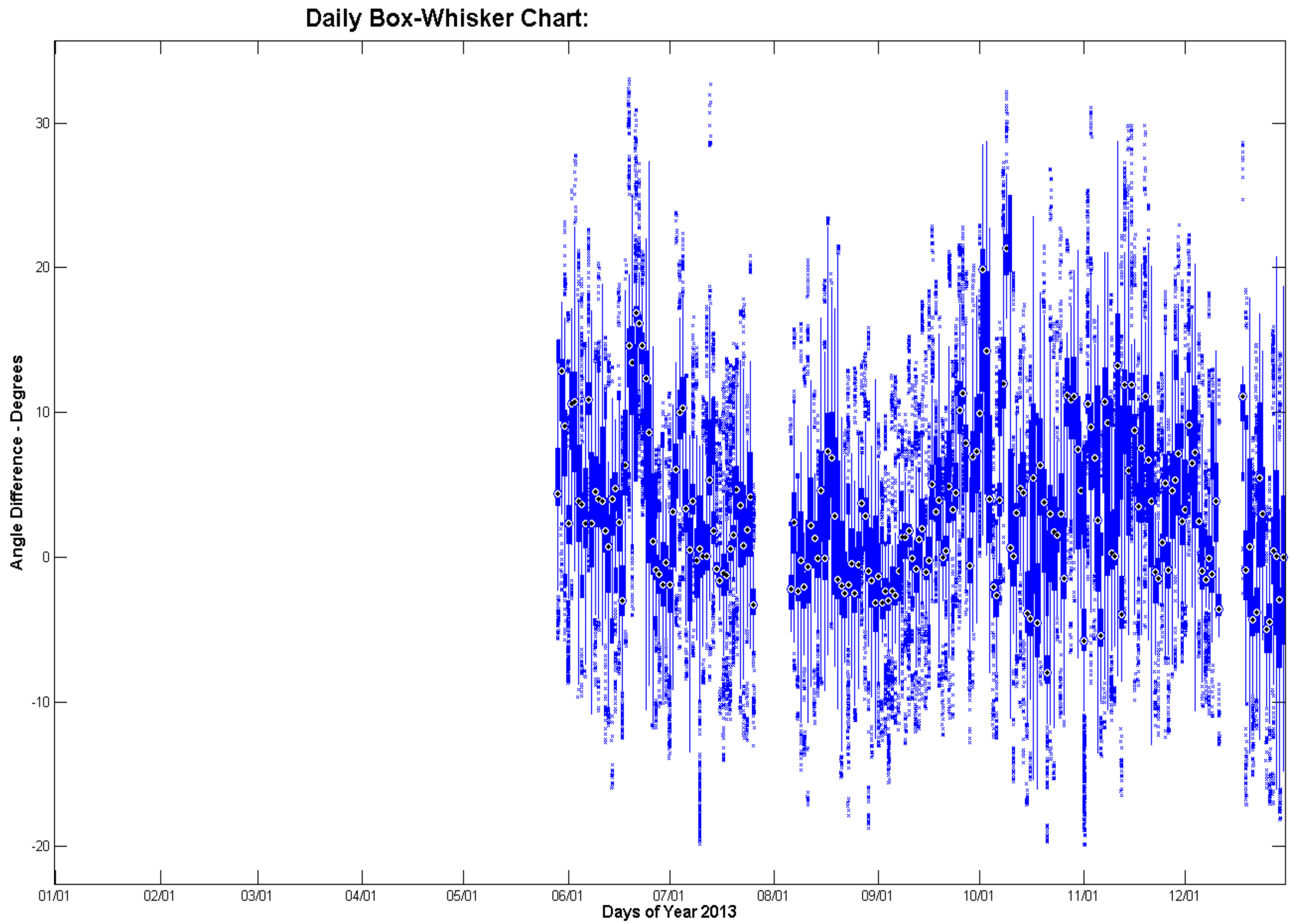
Daily Box-Whisker Chart: I
Angle Difference - Degrees
40
30
20
10
0
-10
-20
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 14



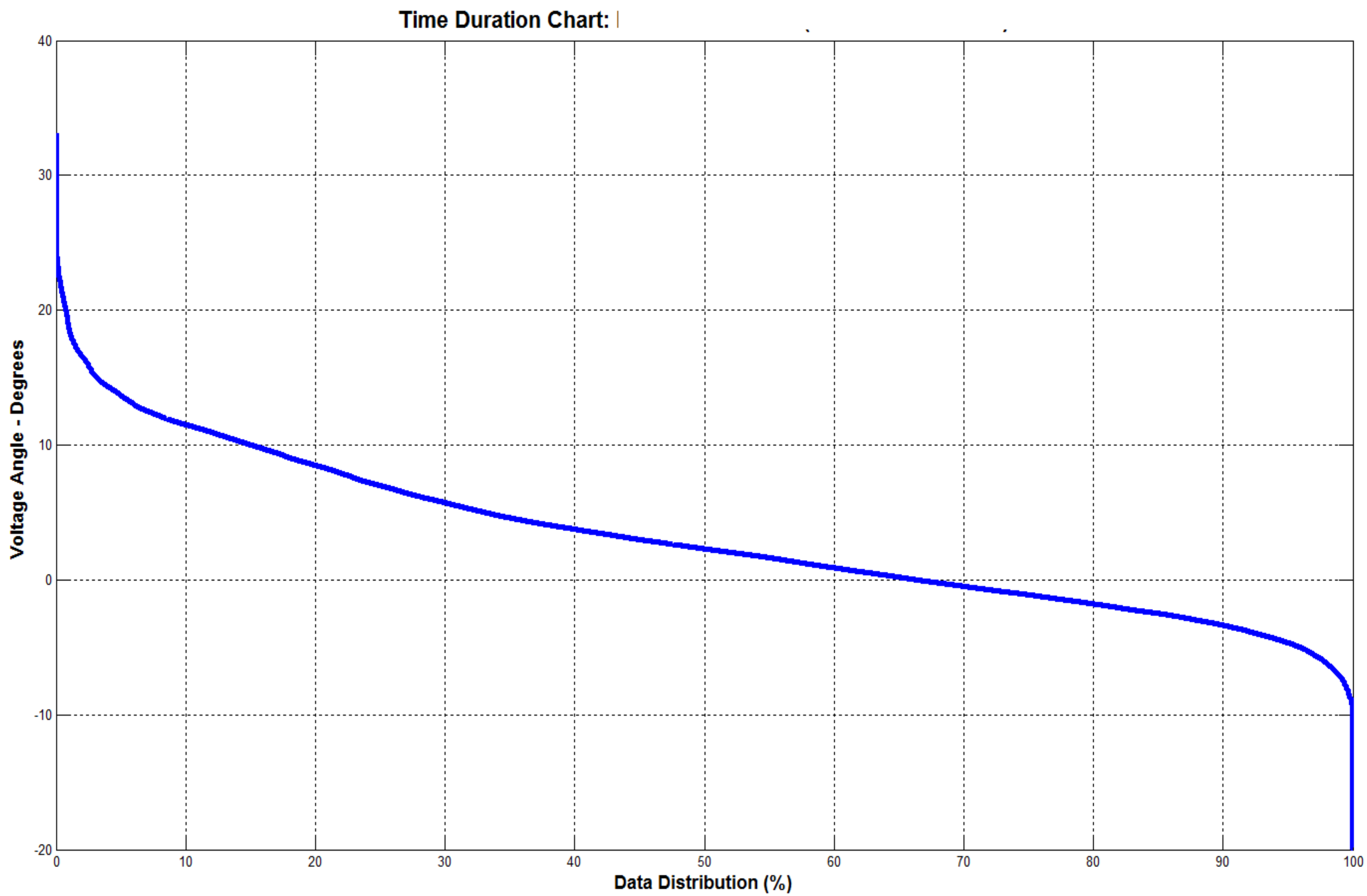
Time Duration Chart: I
Voltage Angle - Degrees
40
30
20
10
0
-10
-20
-30
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 1



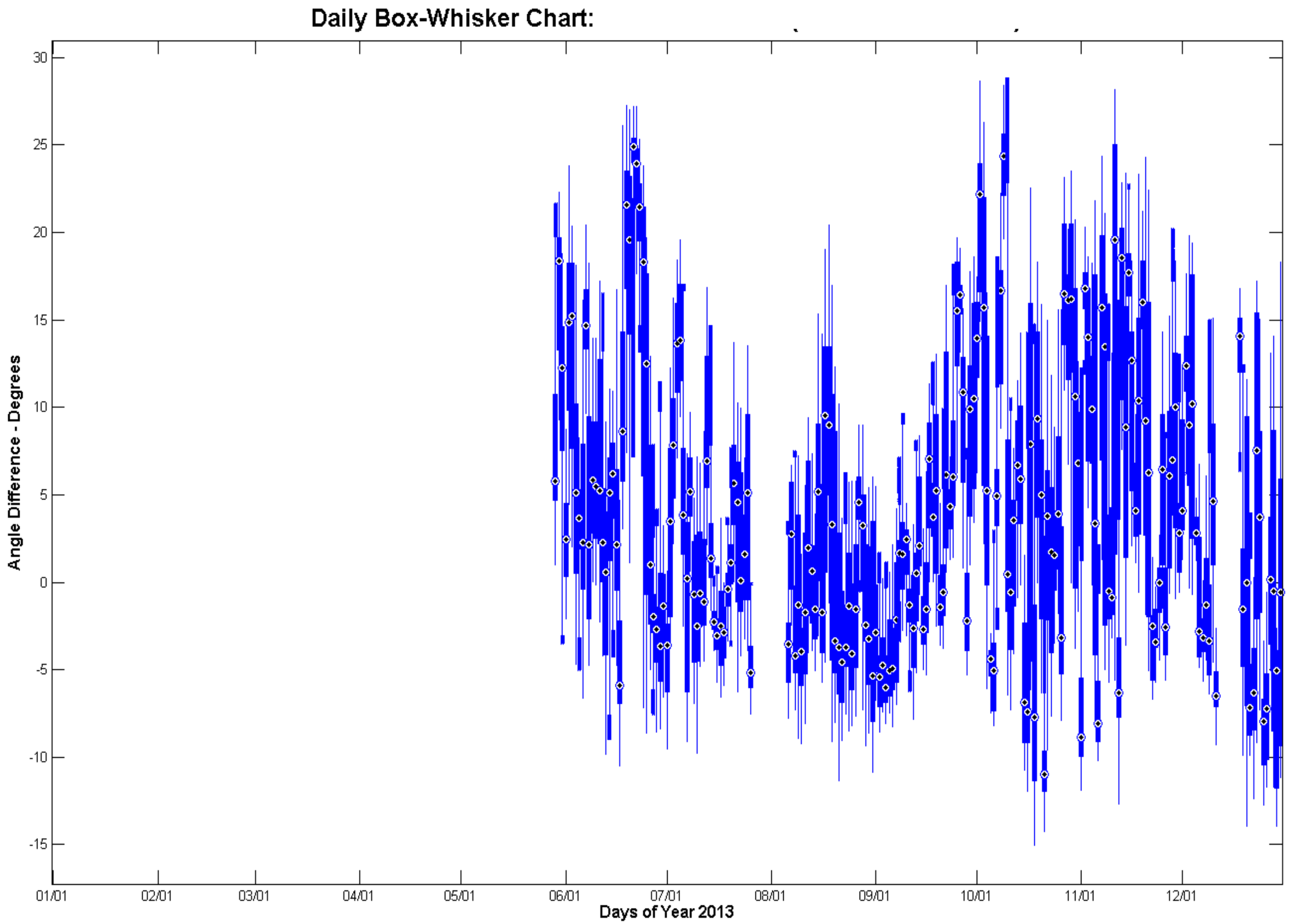
Daily Box-Whisker Chart:
Angle Difference - Degrees
30
20
10
0
-10
-20
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 1



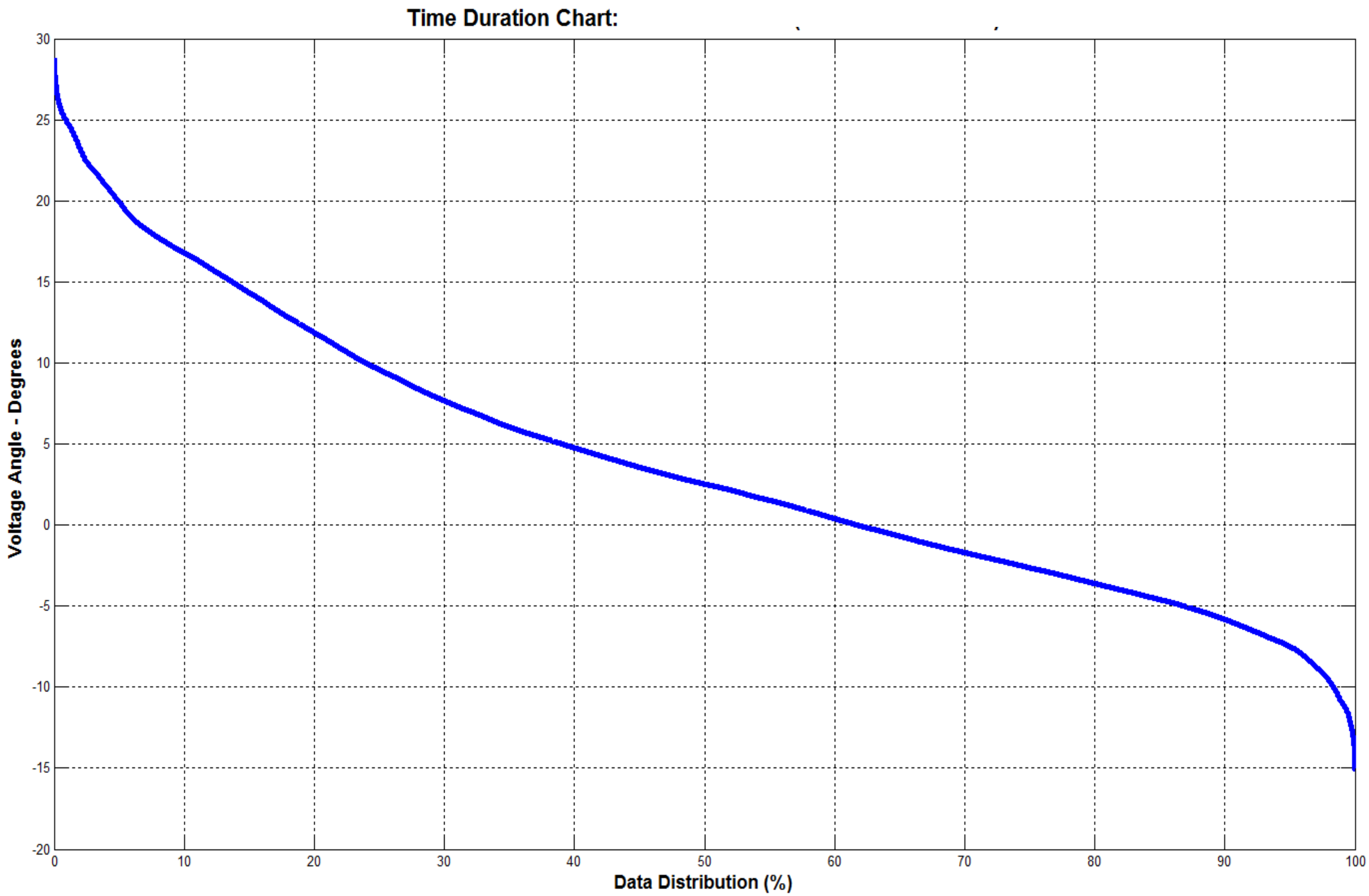
Time Duration Chart:
40
30
20
10
0
-10
-20
Voltage Angle - Degrees
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 2



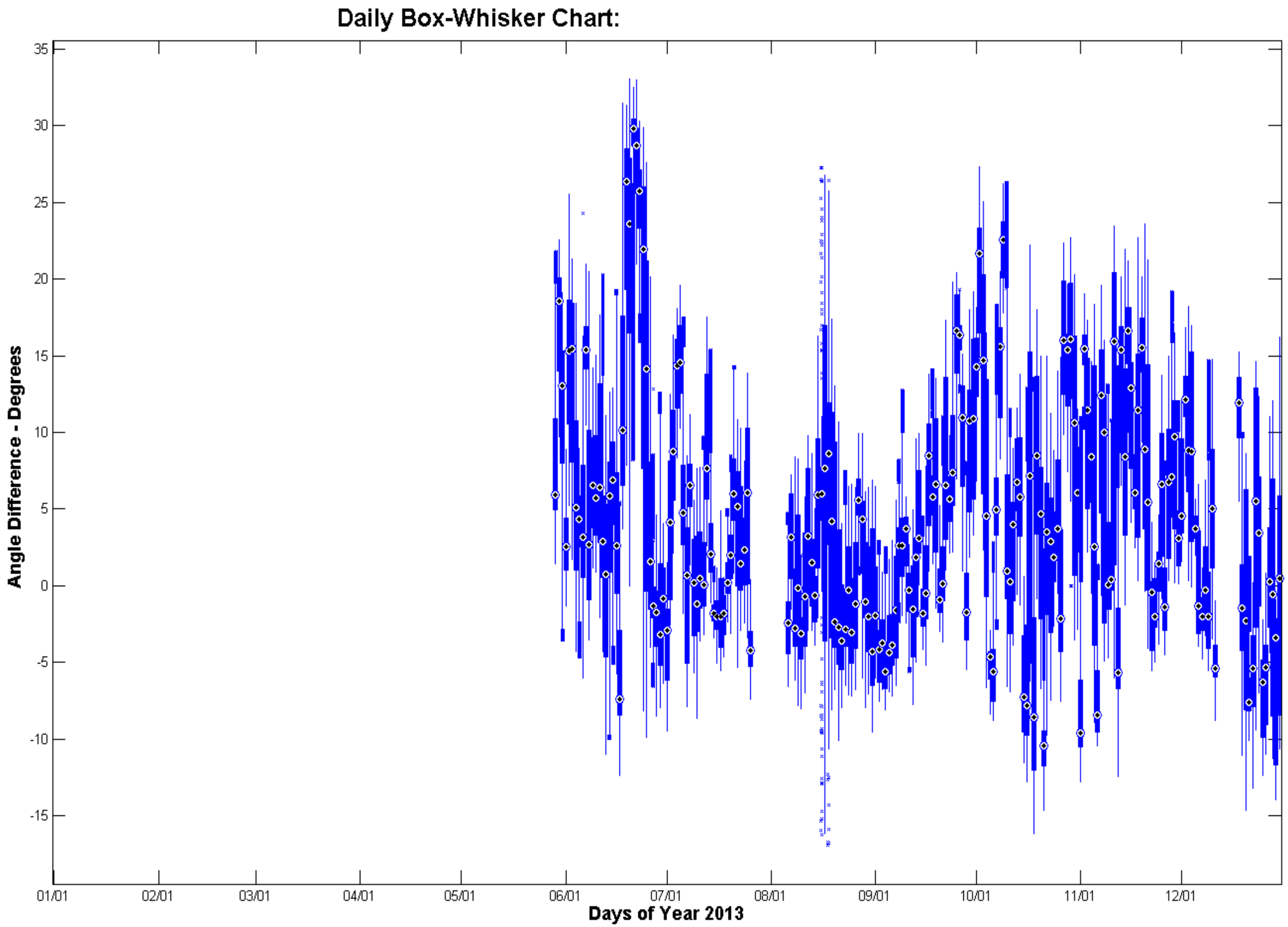
Daily Box-Whisker Chart:
Angle Difference - Degrees
30
25
20
15
10
5
0
-5
-10
-15
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 2



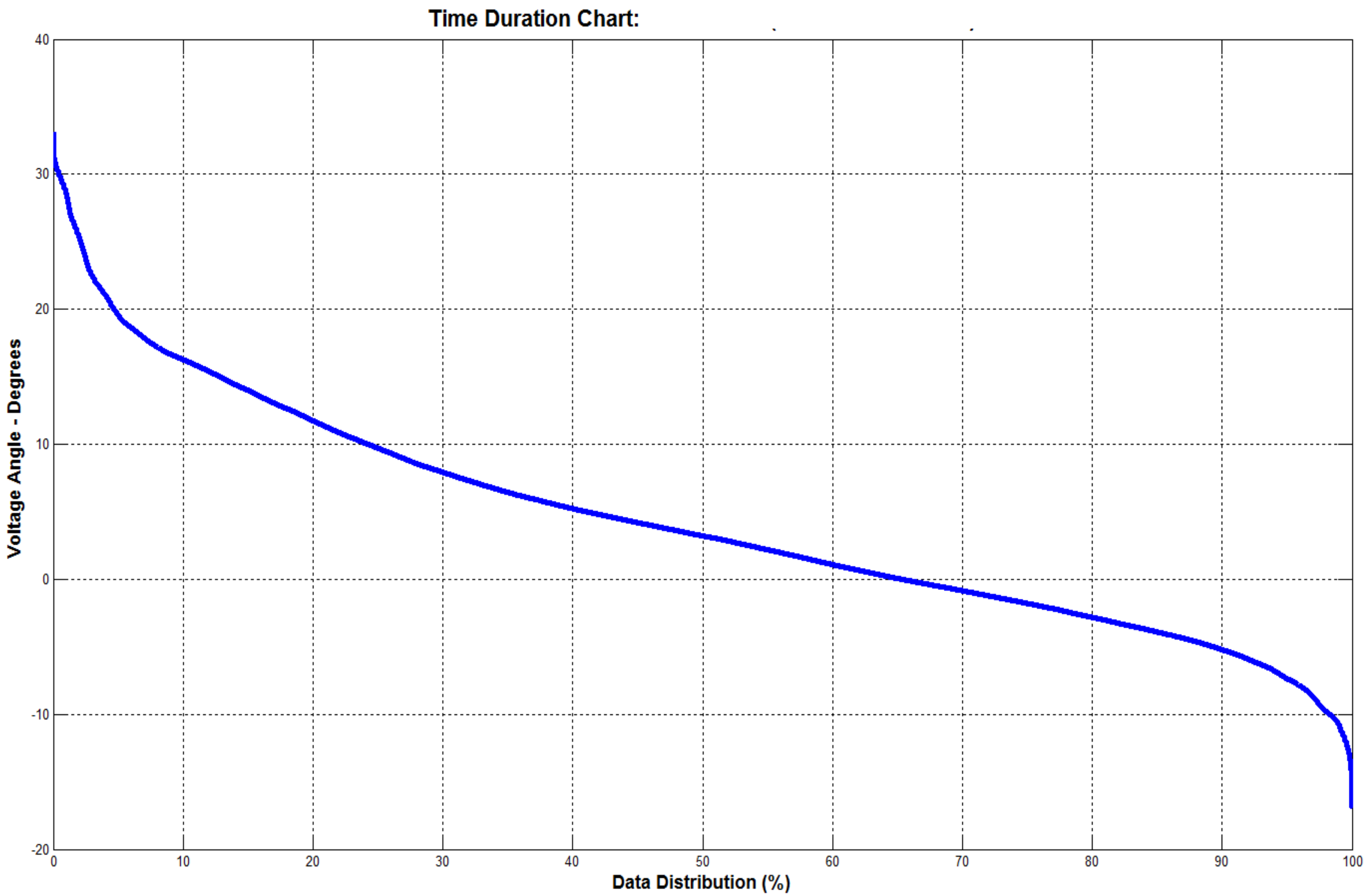
Time Duration Chart:
30
25
20
15
10
5
0
-5
-10
-15
-20
Voltage Angle - Degrees
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 9



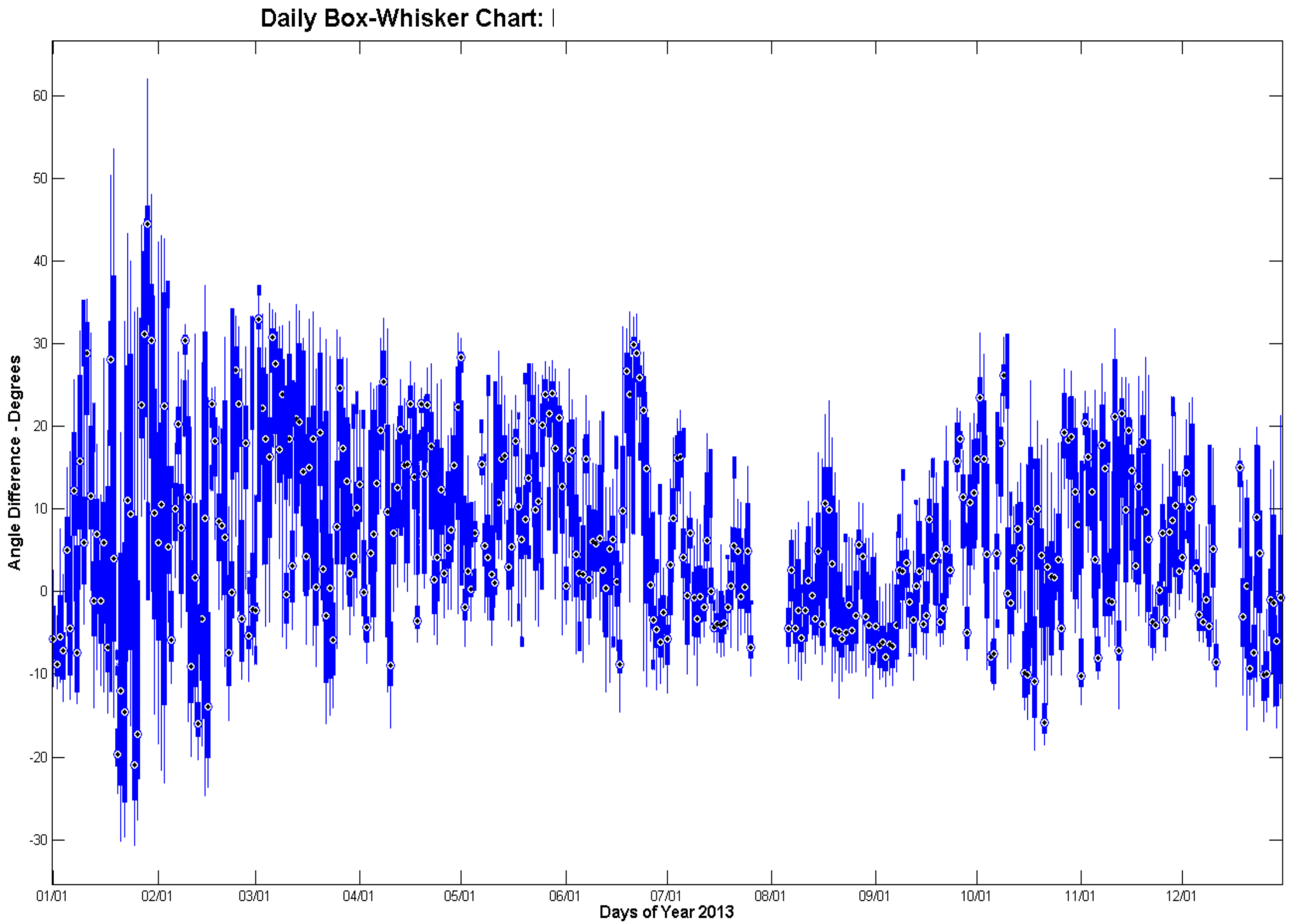
Daily Box-Whisker Chart:
Angle Difference - Degrees
35
30
25
20
15
10
5
0
-5
-10
-15
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 9



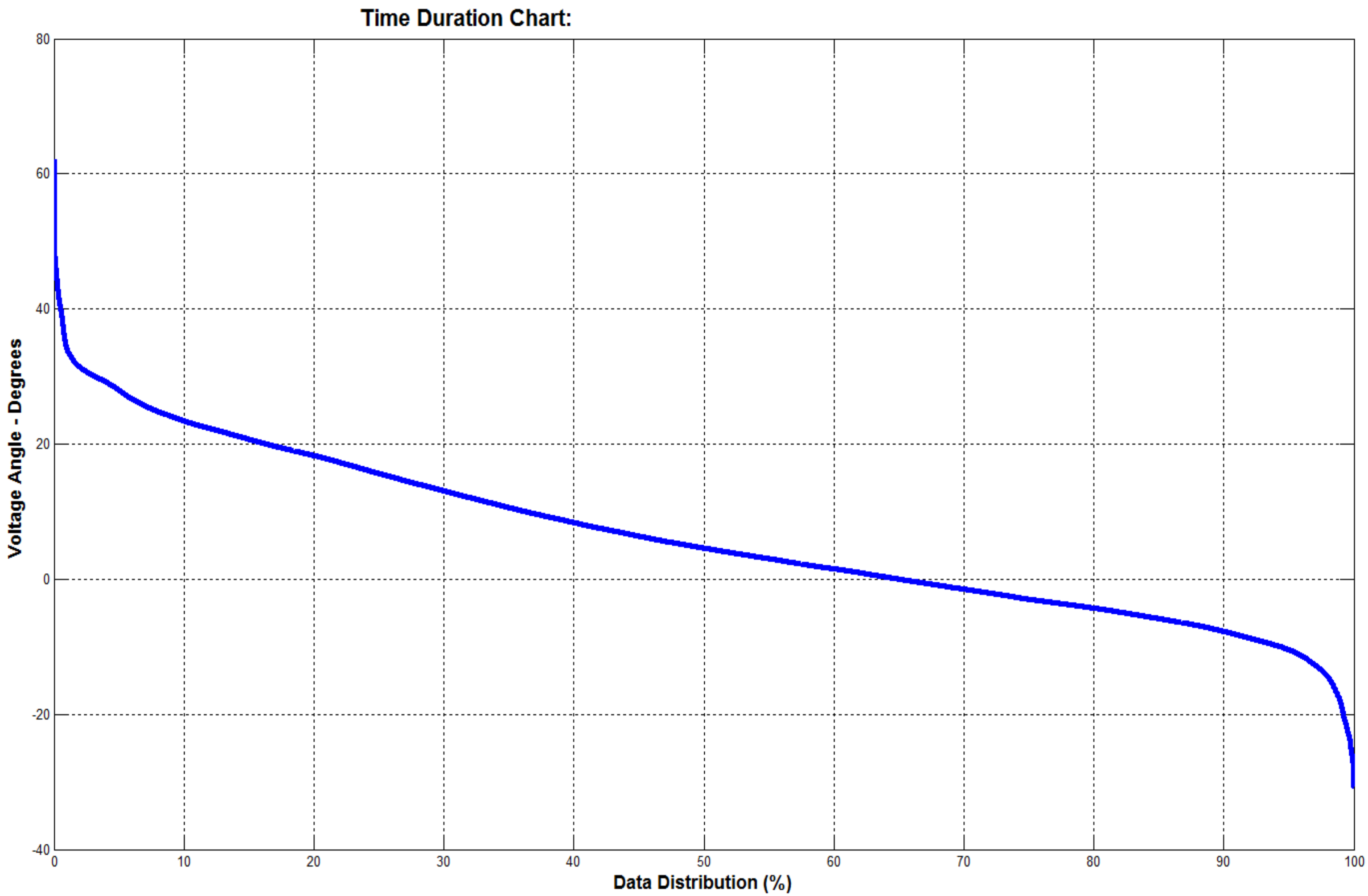
Time Duration Chart:
Voltage Angle - Degrees
40
30
20
10
0
-10
-20
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 11

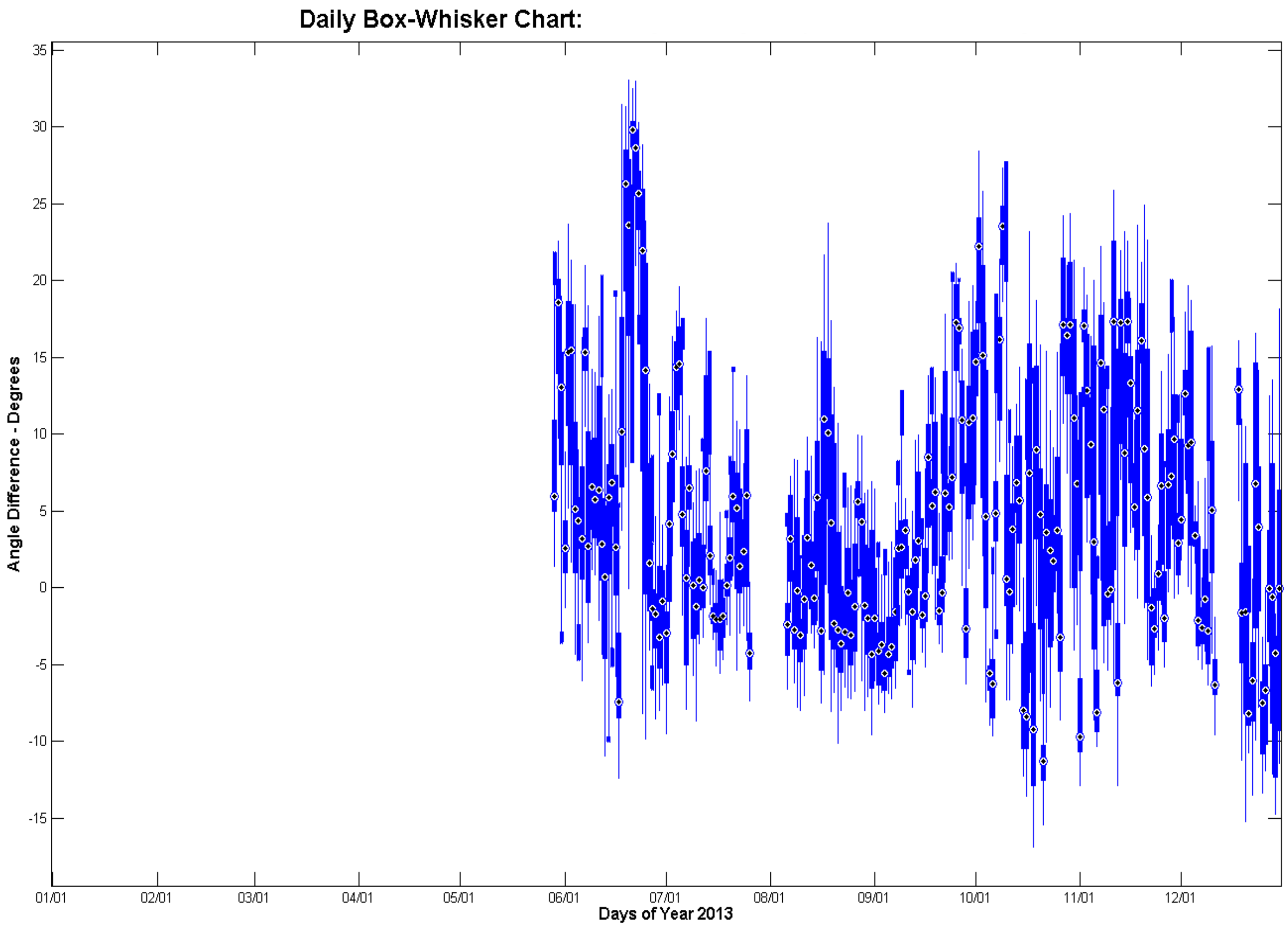


Daily Box-Whisker Chart:
Angle Difference - Degrees
60
50
40
30
20
10
0
-10
-20
-30
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 11

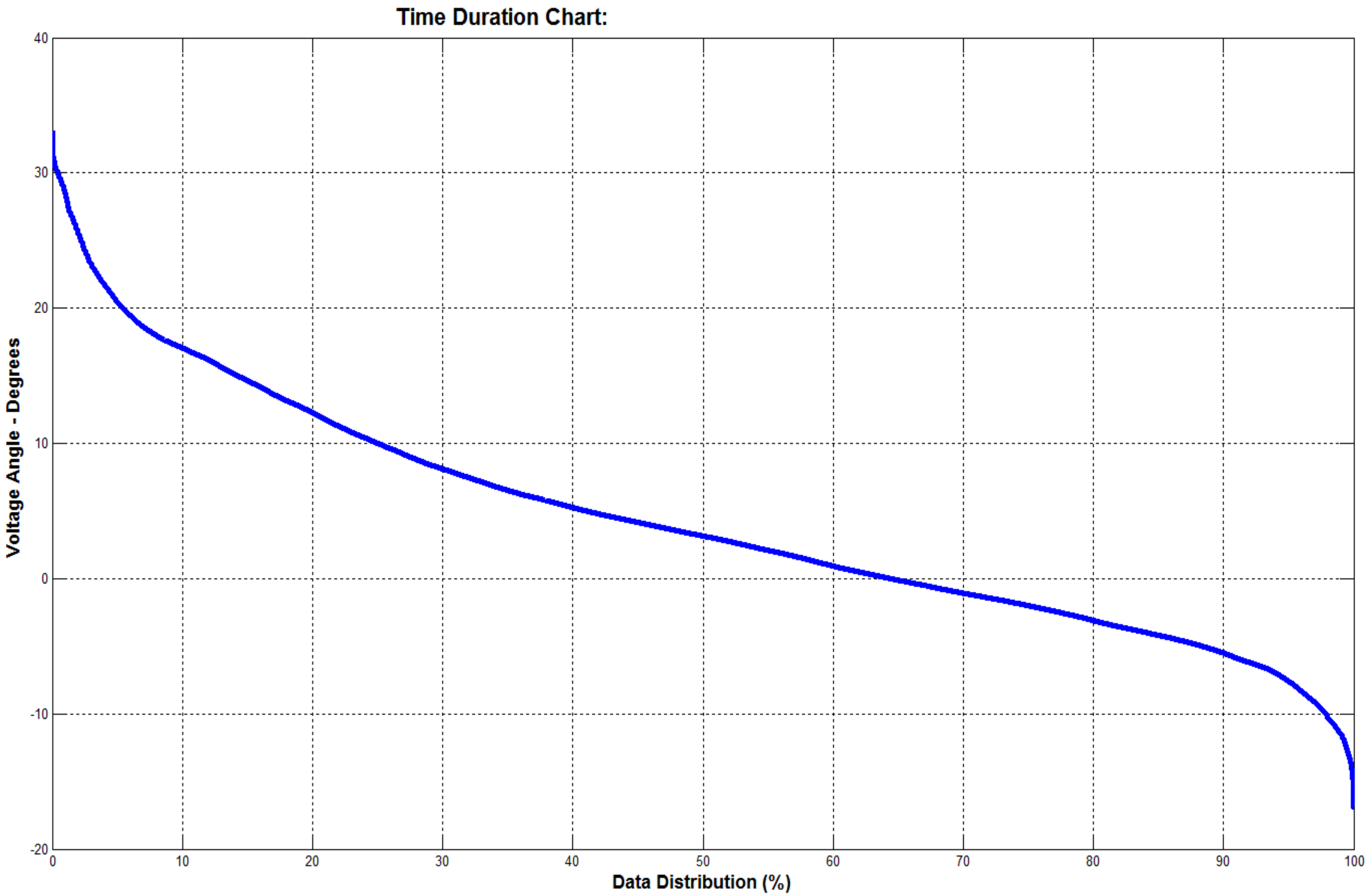

Time Duration Chart:
Voltage Angle - Degrees
80
60
40
20
0
-20
-40
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 12



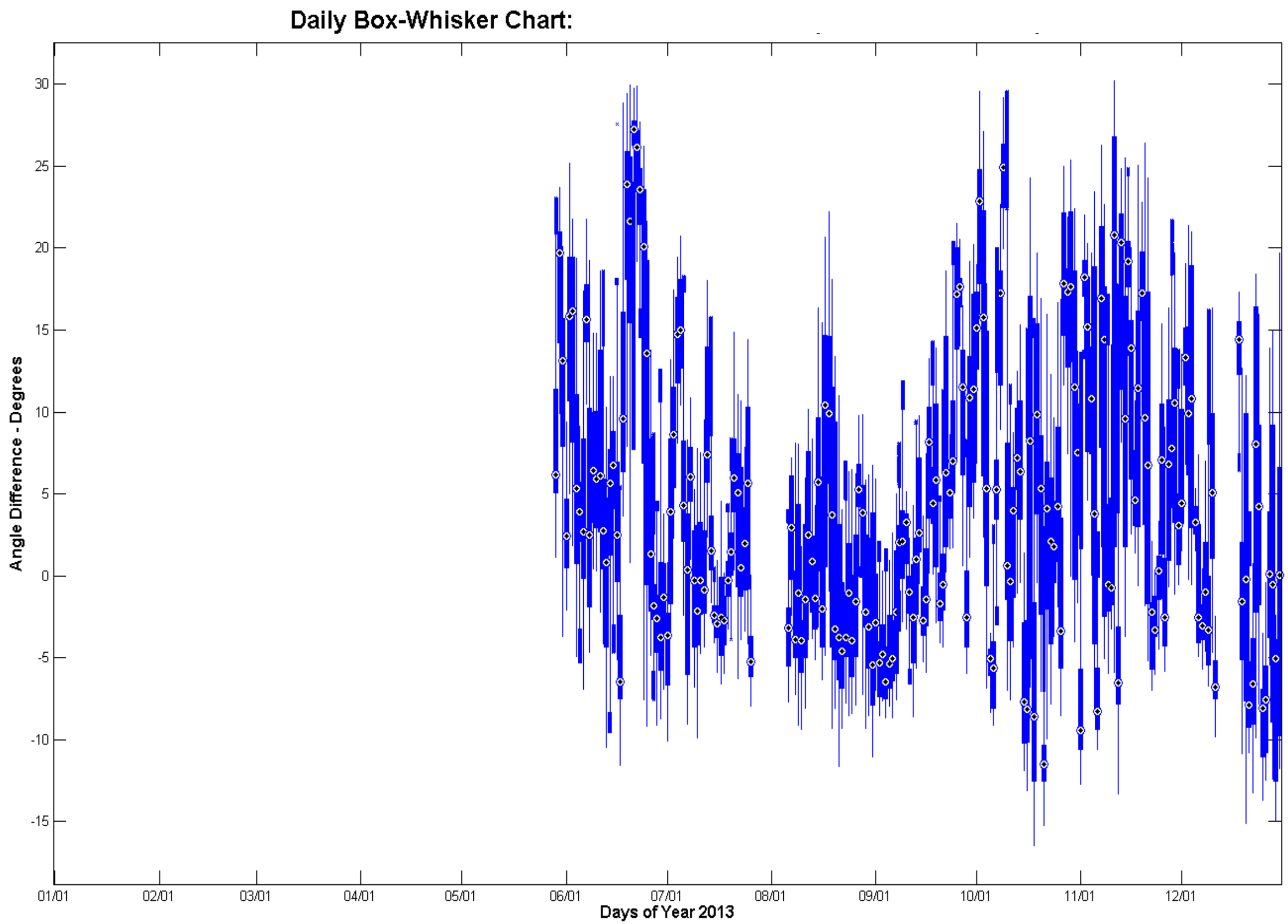
Daily Box-Whisker Chart:
Angle Difference - Degrees
Days of Year 2013
35
30
25
20
15
10
5
0
-5
-10
-15
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

West 12



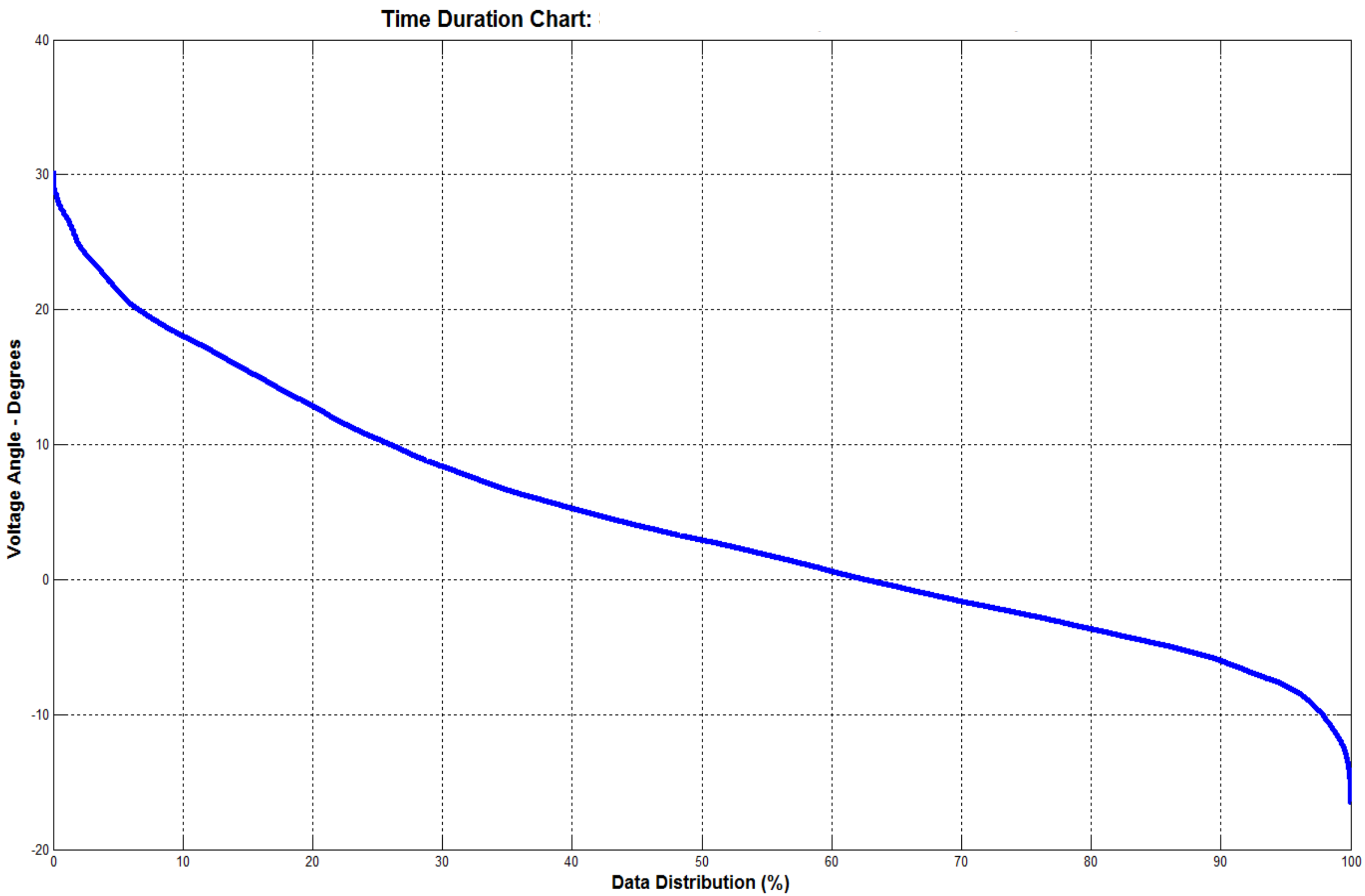
Time Duration Chart:
40
30
20
10
0
-10
-20
0
10
20
30
40
50
60
70
80
90
100
Voltage Angle - Degrees
Data Distribution (%)

West 5



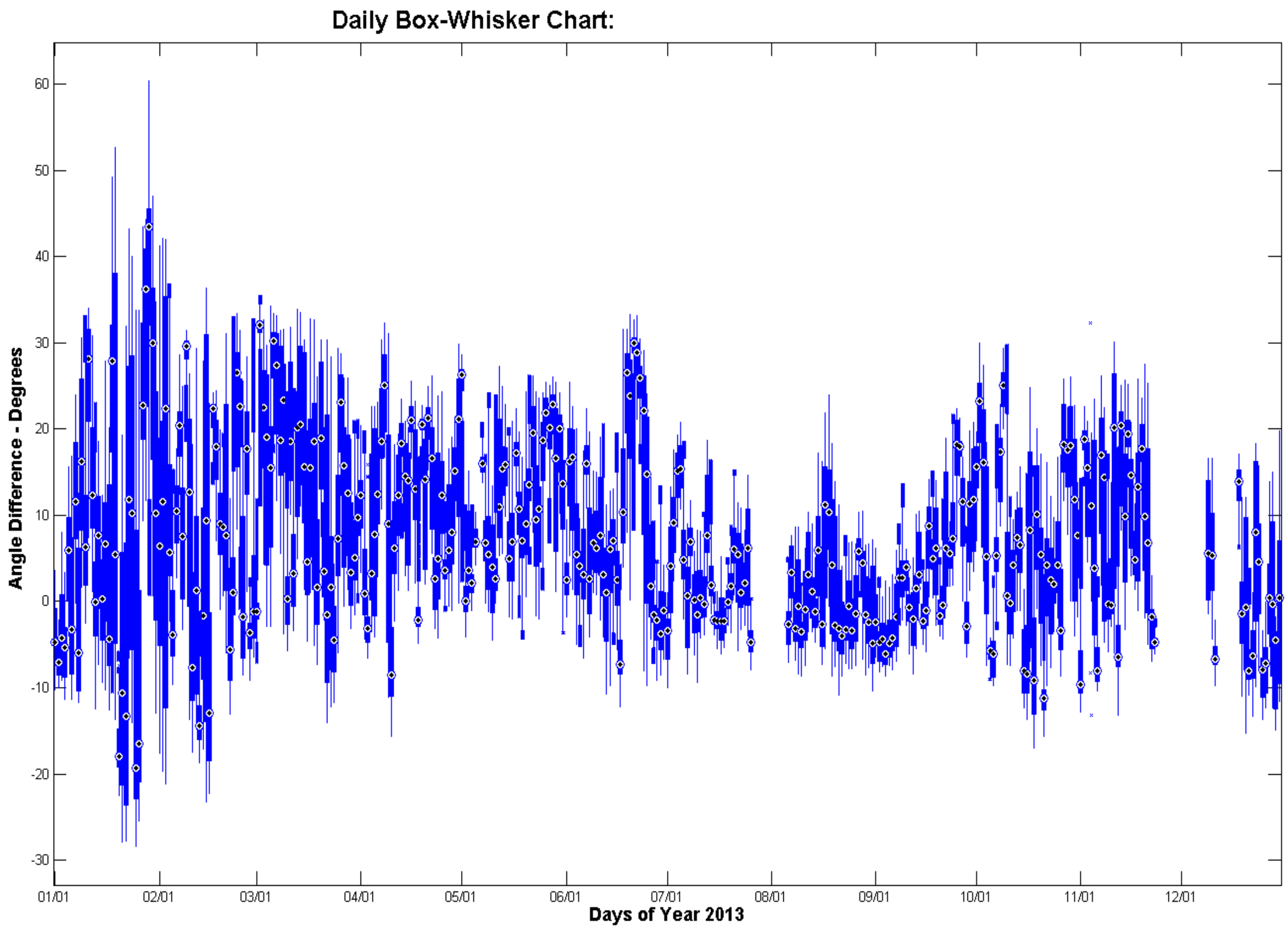
Daily Box-Whisker Chart:
Angle Difference - Degrees
30
25
20
15
10
5
0
-5
-10
-15
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 5



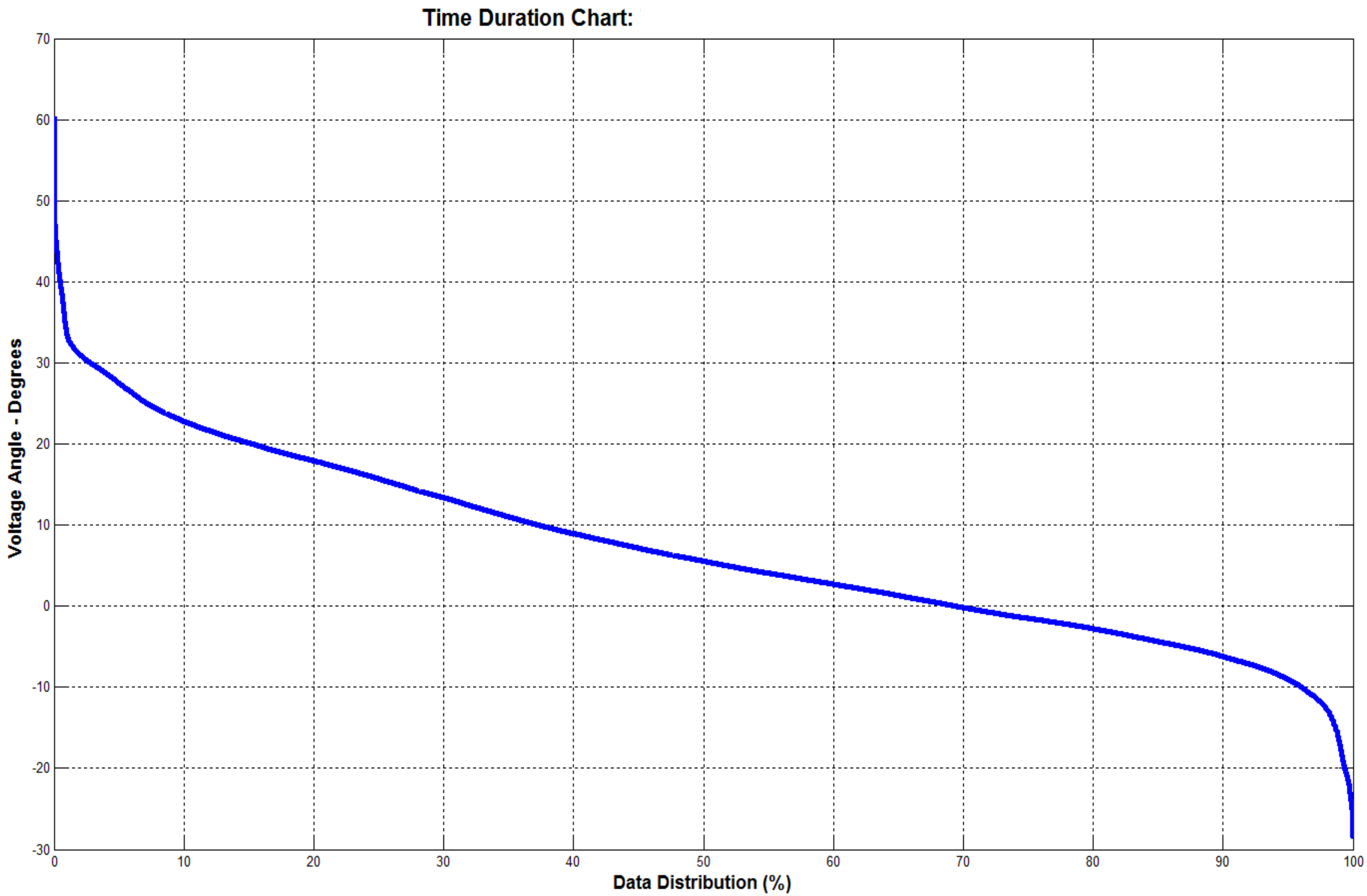
Time Duration Chart:
40
30
20
10
0
-10
-20
Voltage Angle - Degrees
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 6

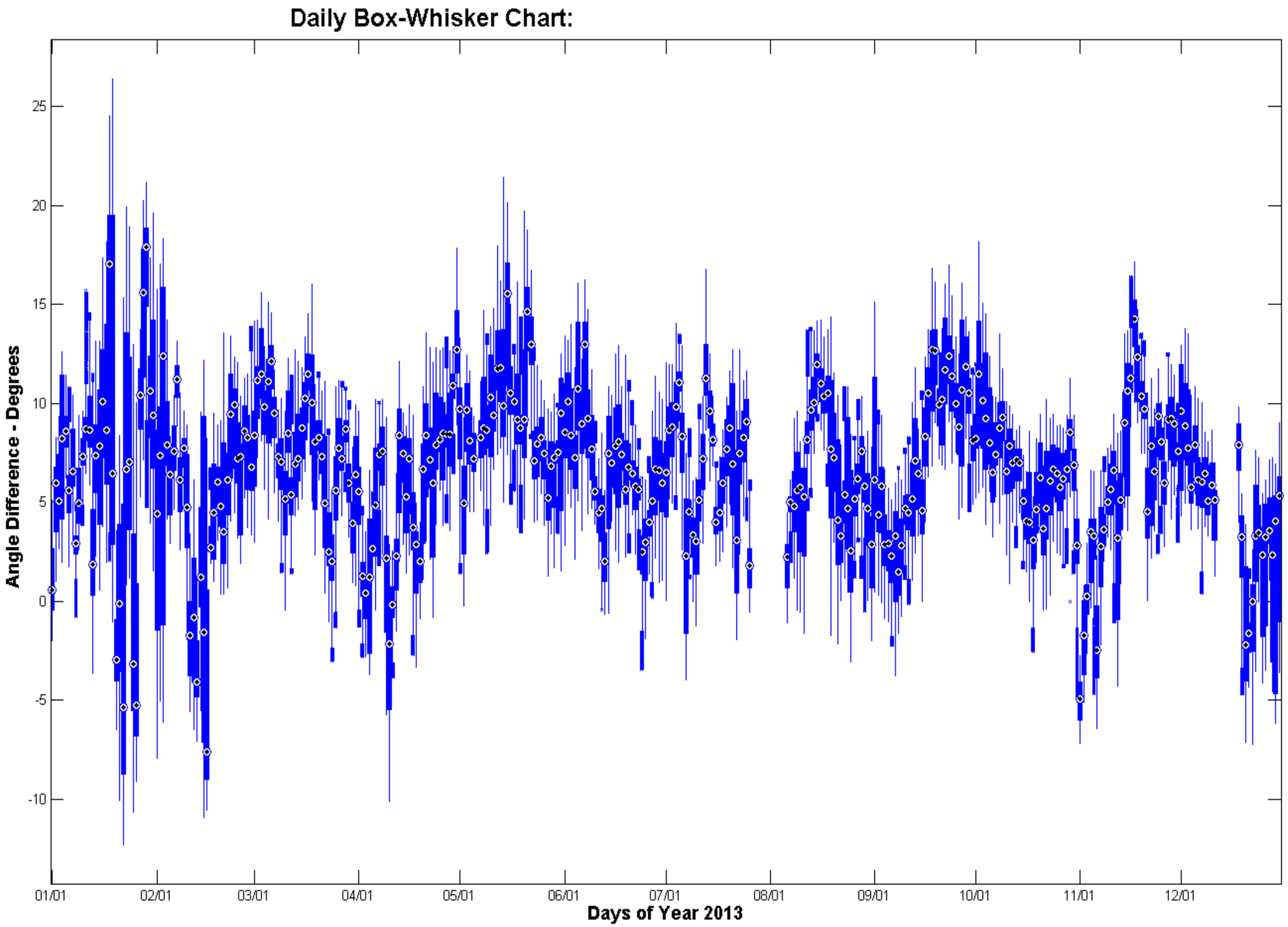


Daily Box-Whisker Chart:
Angle Difference - Degrees
60
50
40
30
20
10
0
-10
-20
-30
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 6

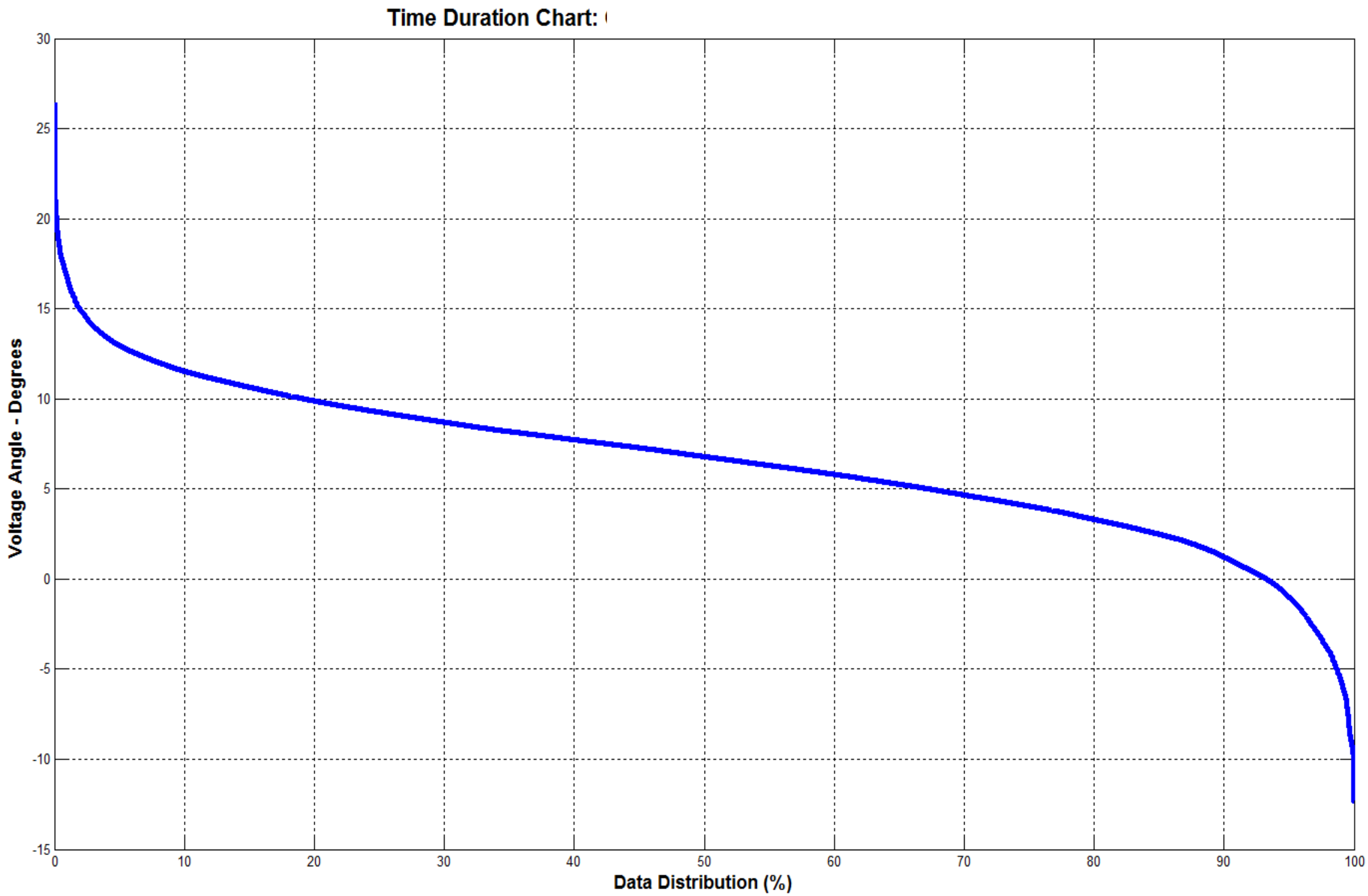

Time Duration Chart:
Voltage Angle - Degrees
Data Distribution (%)
70
60
50
40
30
20
10
0
-10
-20
-30
0
10
20
30
40
50
60
70
80
90
100

North 1

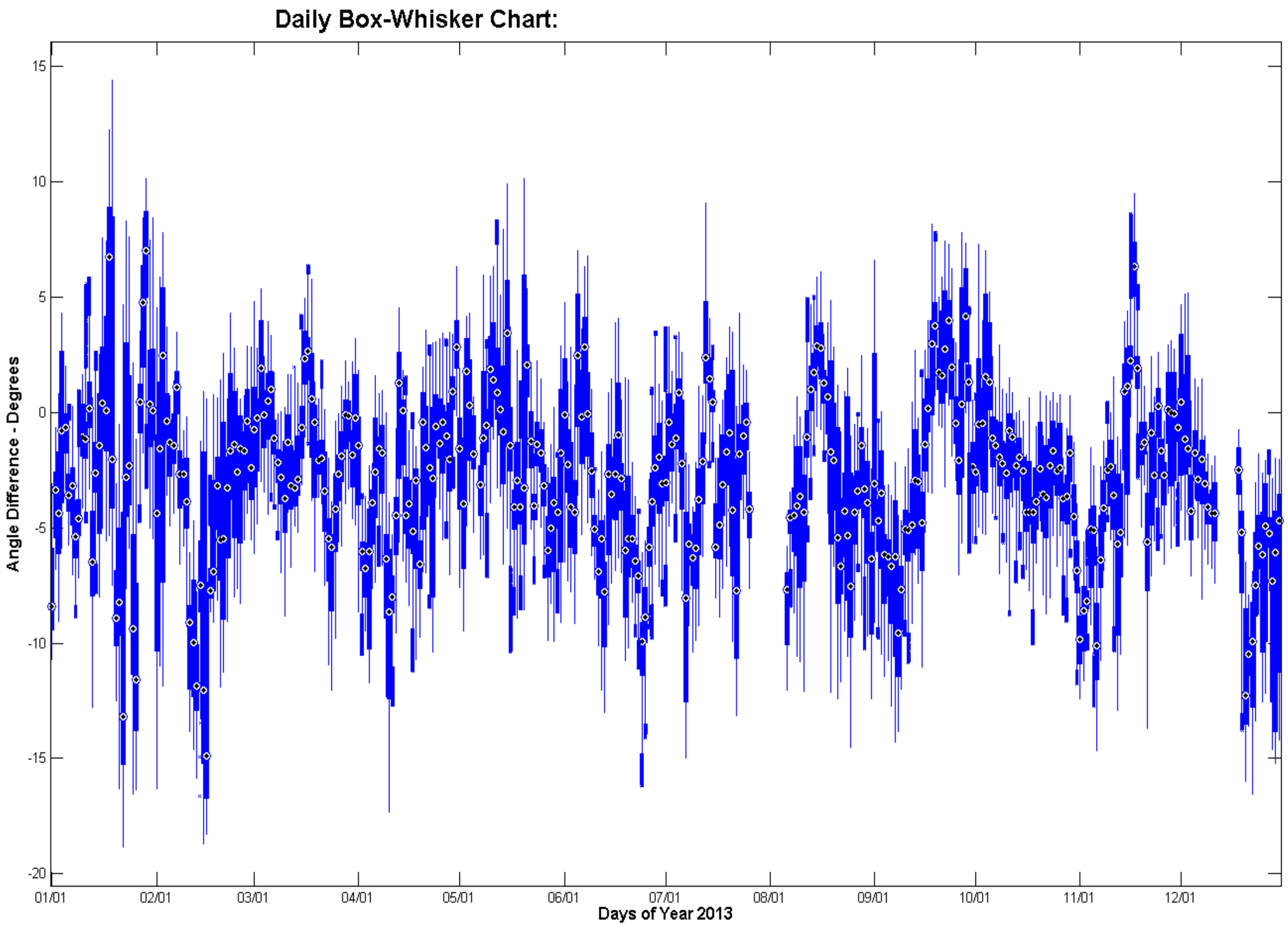


Daily Box-Whisker Chart:
Angle Difference - Degrees
25
20
15
10
5
0
-5
-10
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

North 1

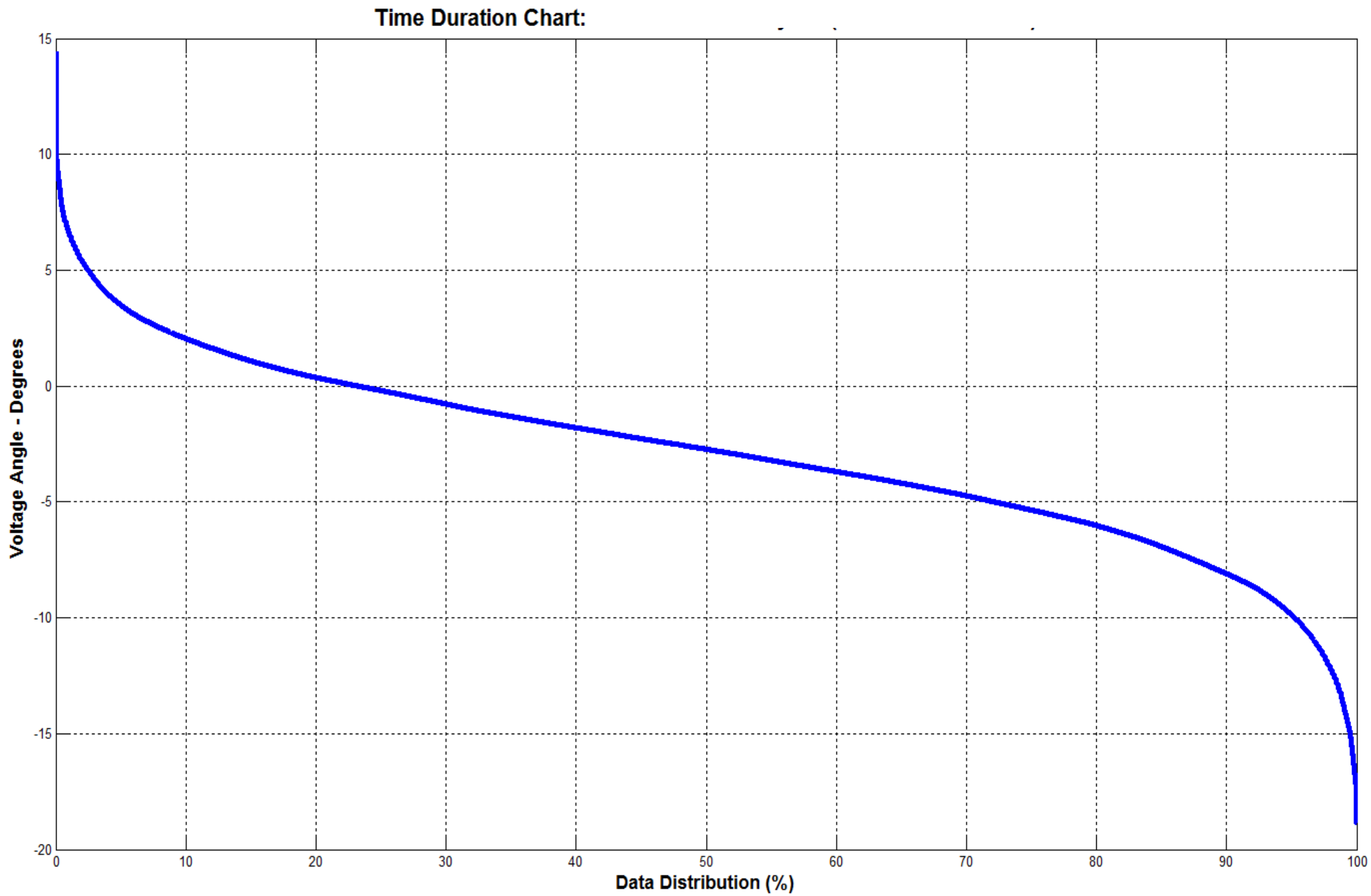

Time Duration Chart: (
Voltage Angle - Degrees
Data Distribution (%)
30
25
20
15
10
5
0
-5
-10
-15
0
10
20
30
40
50
60
70
80
90
100

North 4



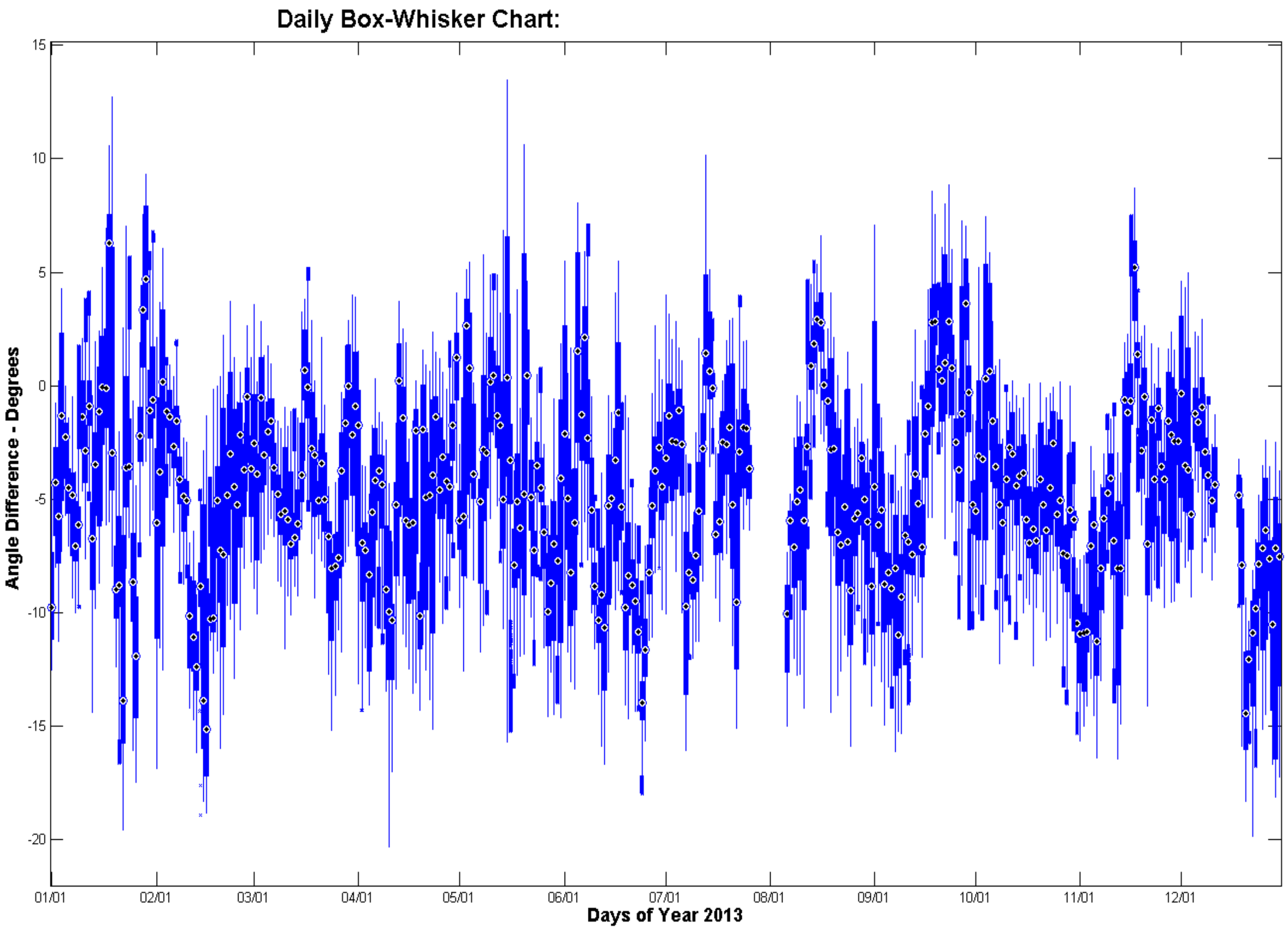
Daily Box-Whisker Chart:
15
10
5
0
-5
-10
-15
-20
Angle Difference - Degrees
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

North 4



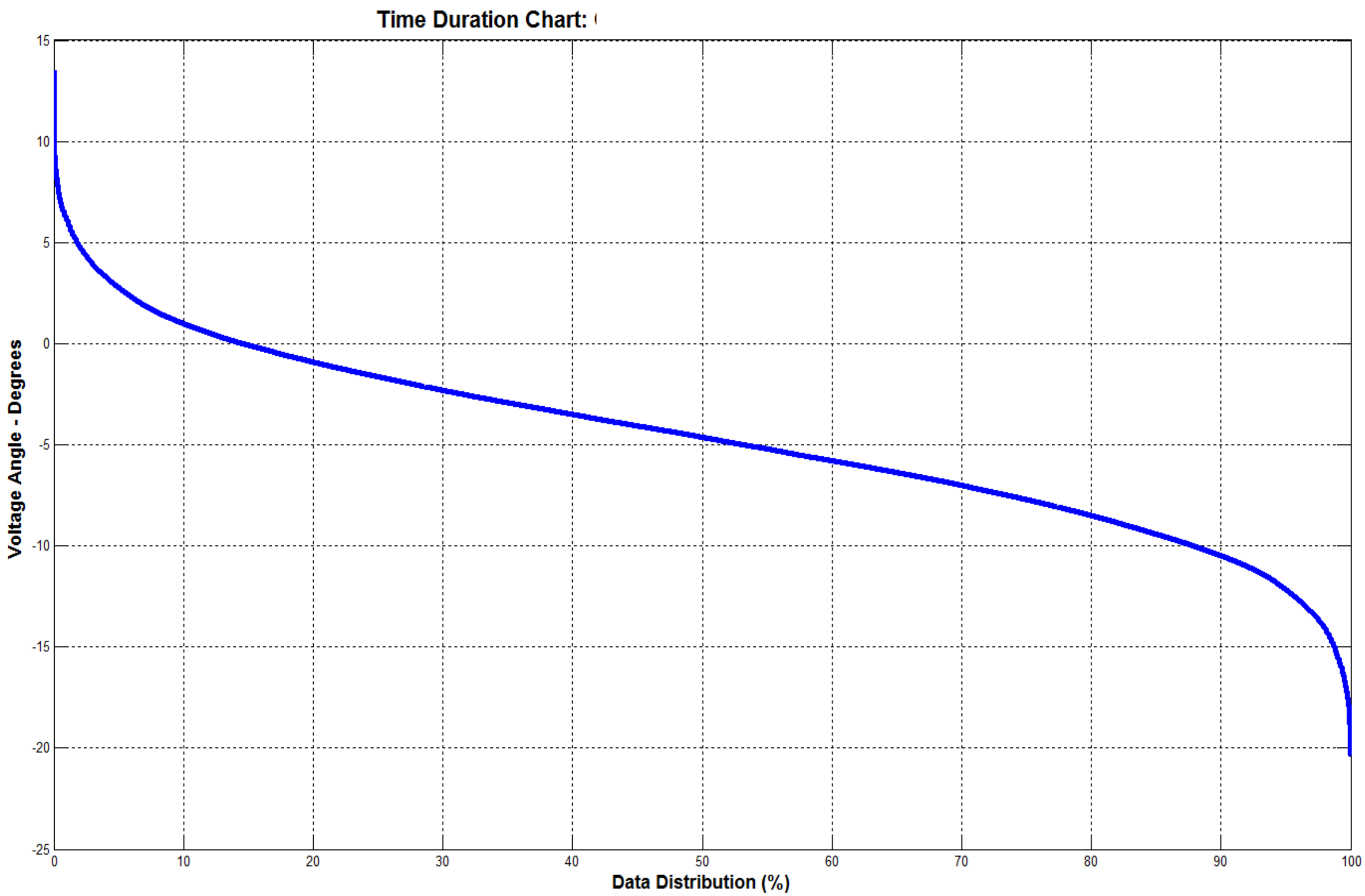
Time Duration Chart:
Voltage Angle - Degrees
Data Distribution (%)
15
10
5
0
-5
-10
-15
-20
0
10
20
30
40
50
60
70
80
90
100

North 5

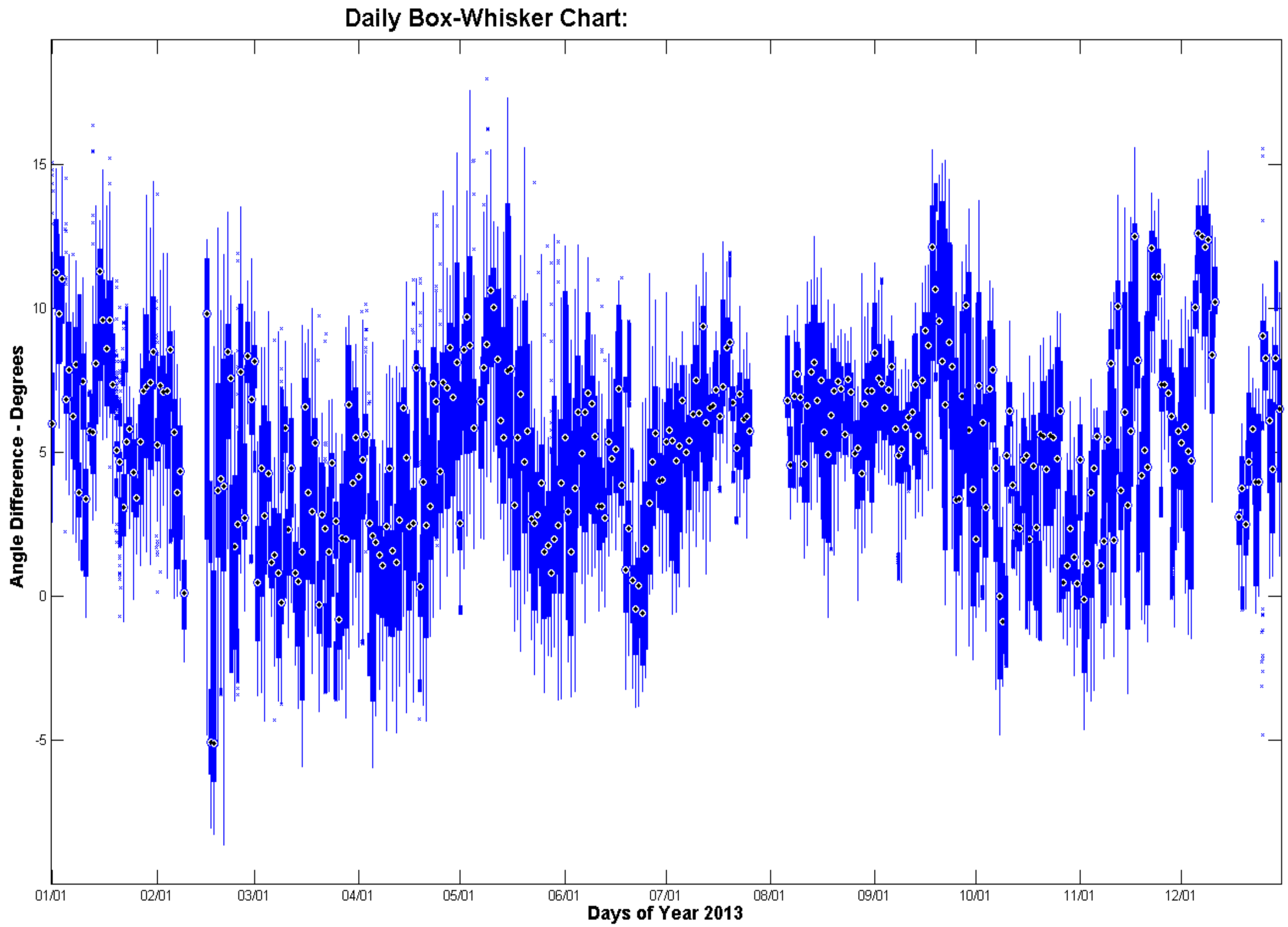


Daily Box-Whisker Chart:
15
10
5
0
-5
-10
-15
-20
Angle Difference - Degrees
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

North 5

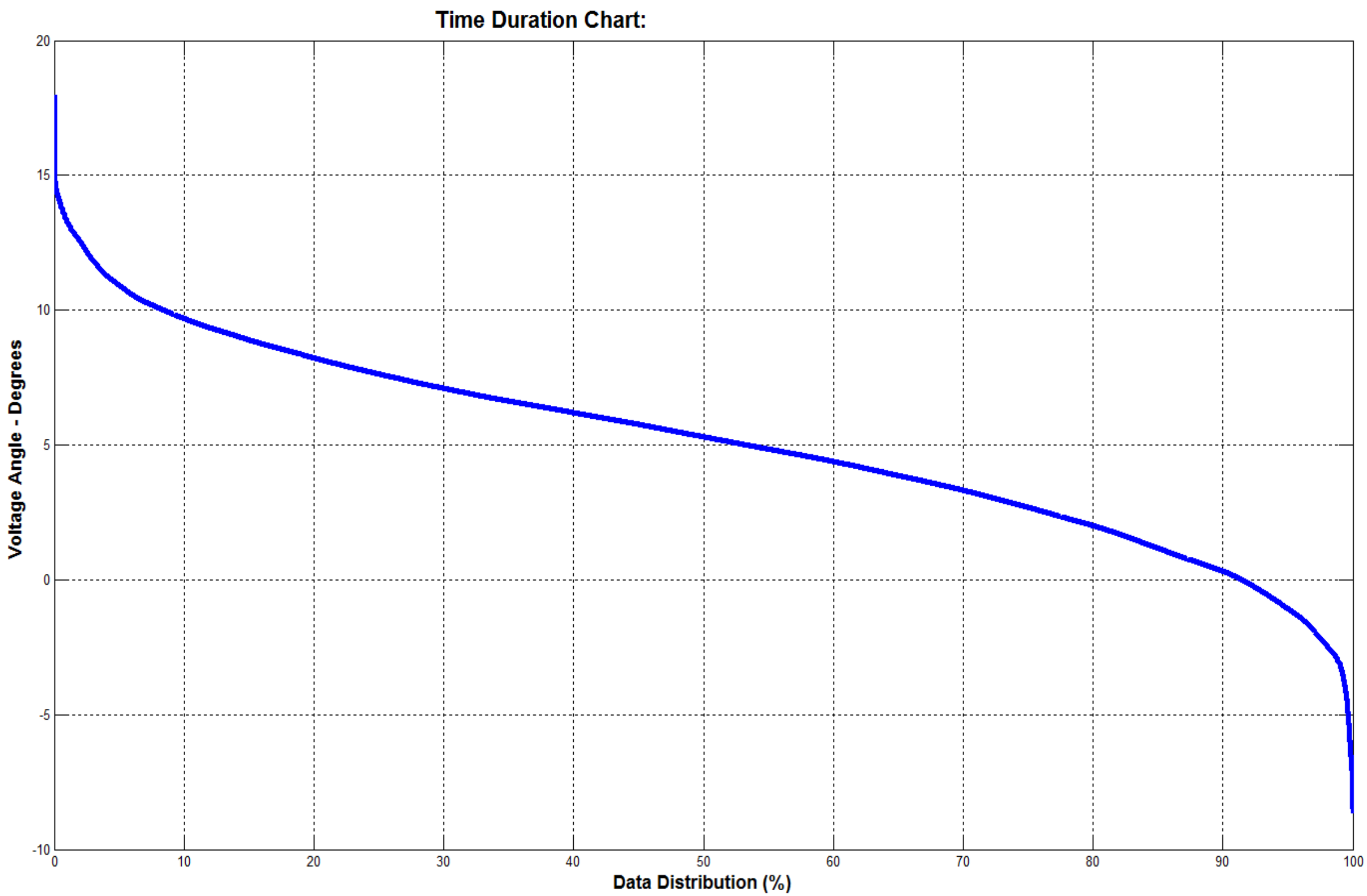

Time Duration Chart: (
Voltage Angle - Degrees
Data Distribution (%)
15
10
5
0
-5
-10
-15
-20
-25
0
10
20
30
40
50
60
70
80
90
100

North 6

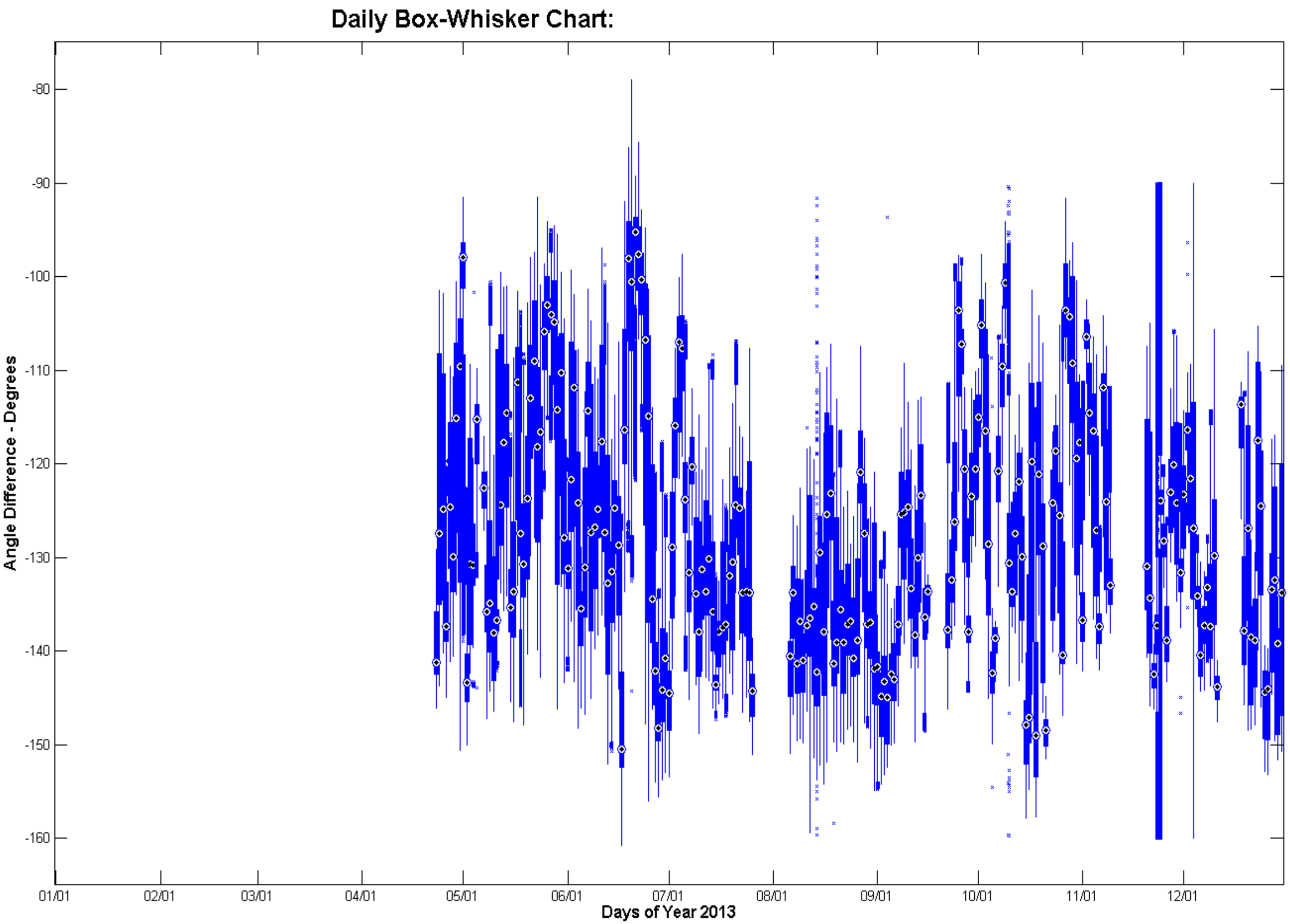


Daily Box-Whisker Chart:
Angle Difference - Degrees
15
10
5
0
-5
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

North 6

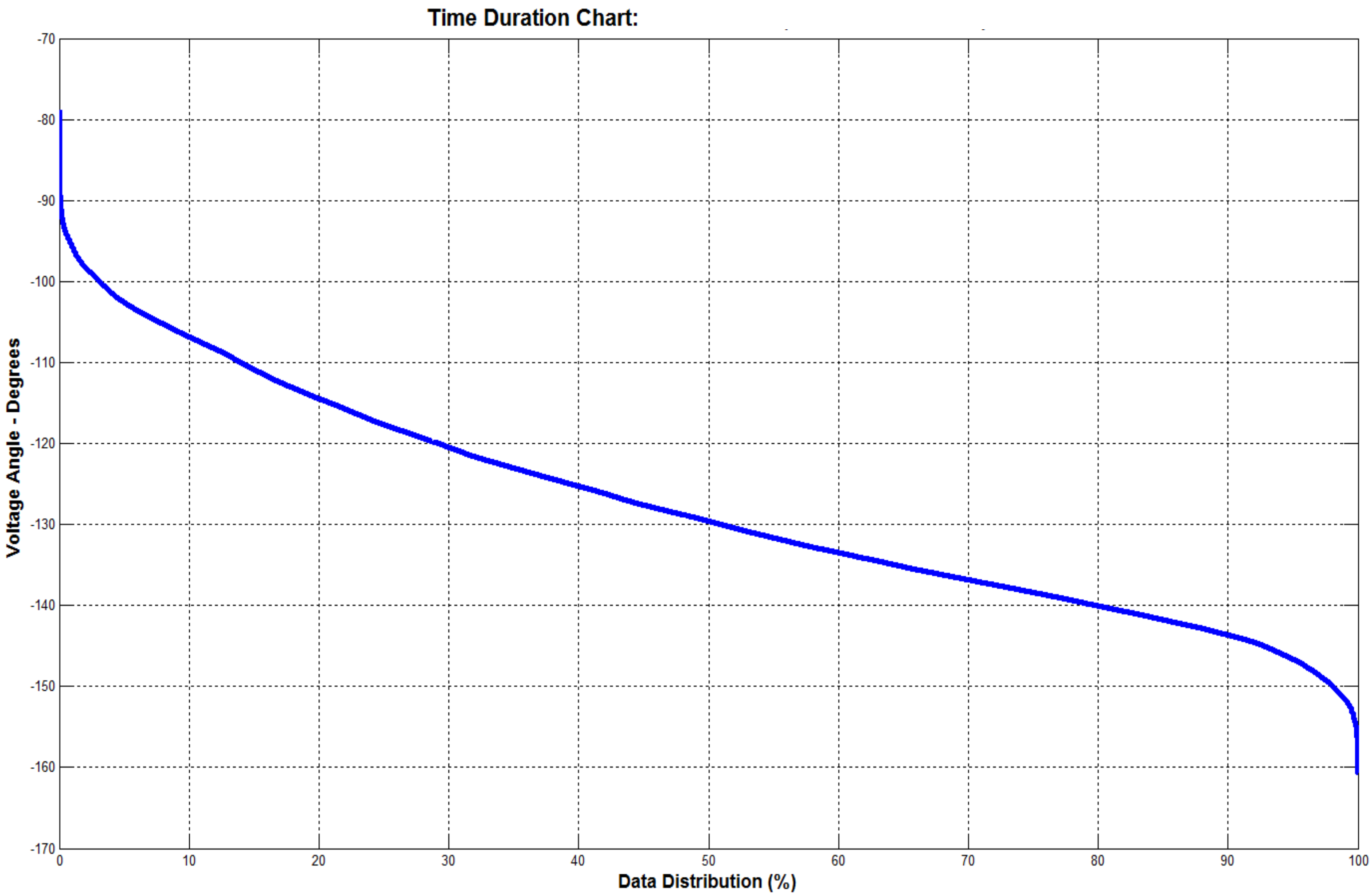

Time Duration Chart:
Voltage Angle - Degrees
Data Distribution (%)
20
15
10
5
0
-5
-10
0
10
20
30
40
50
60
70
80
90
100

FarWest 2



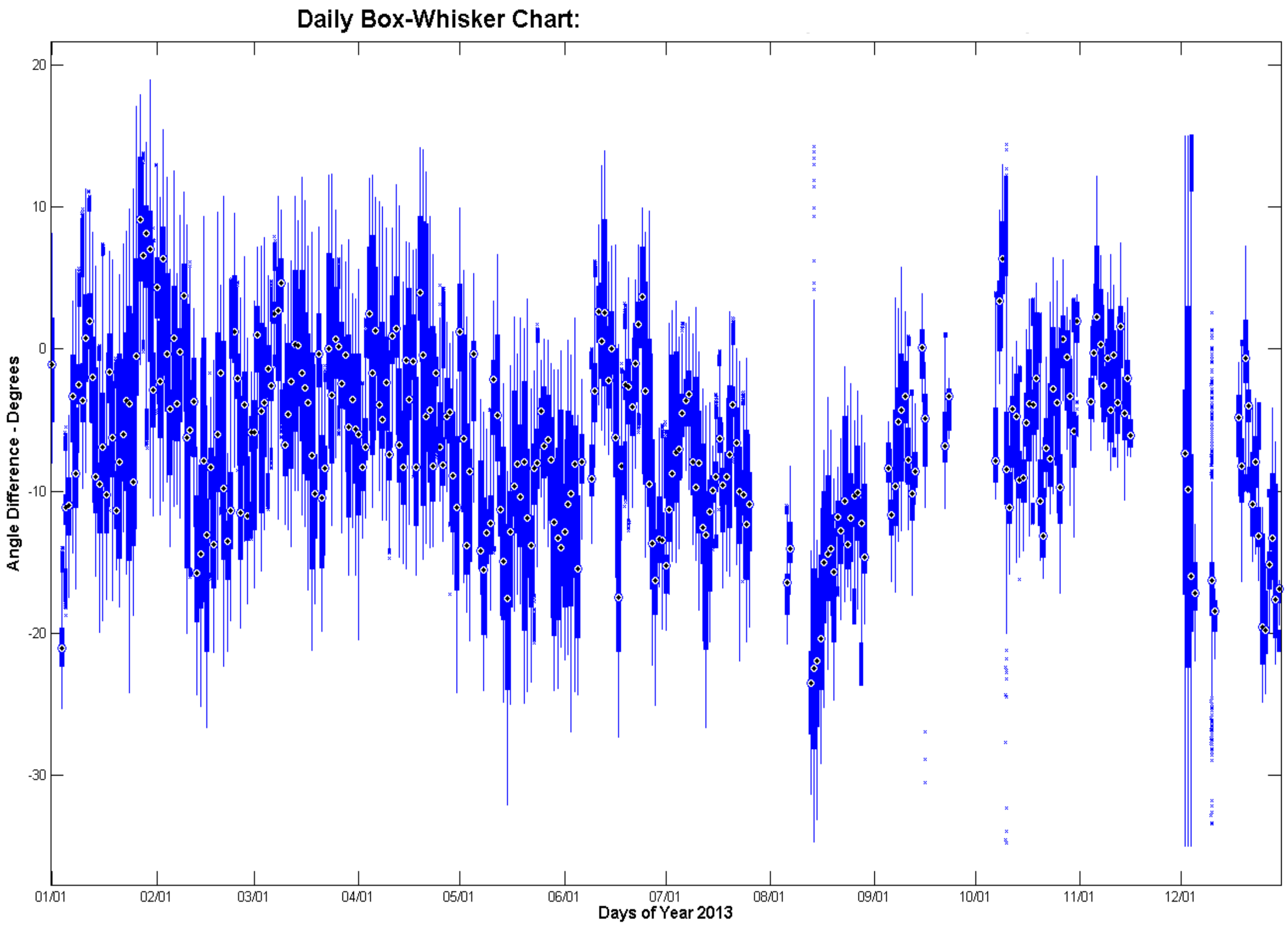
Daily Box-Whisker Chart:
Angle Difference - Degrees
-80
-90
-100
-110
-120
-130
-140
-150
-160
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

FarWest 2



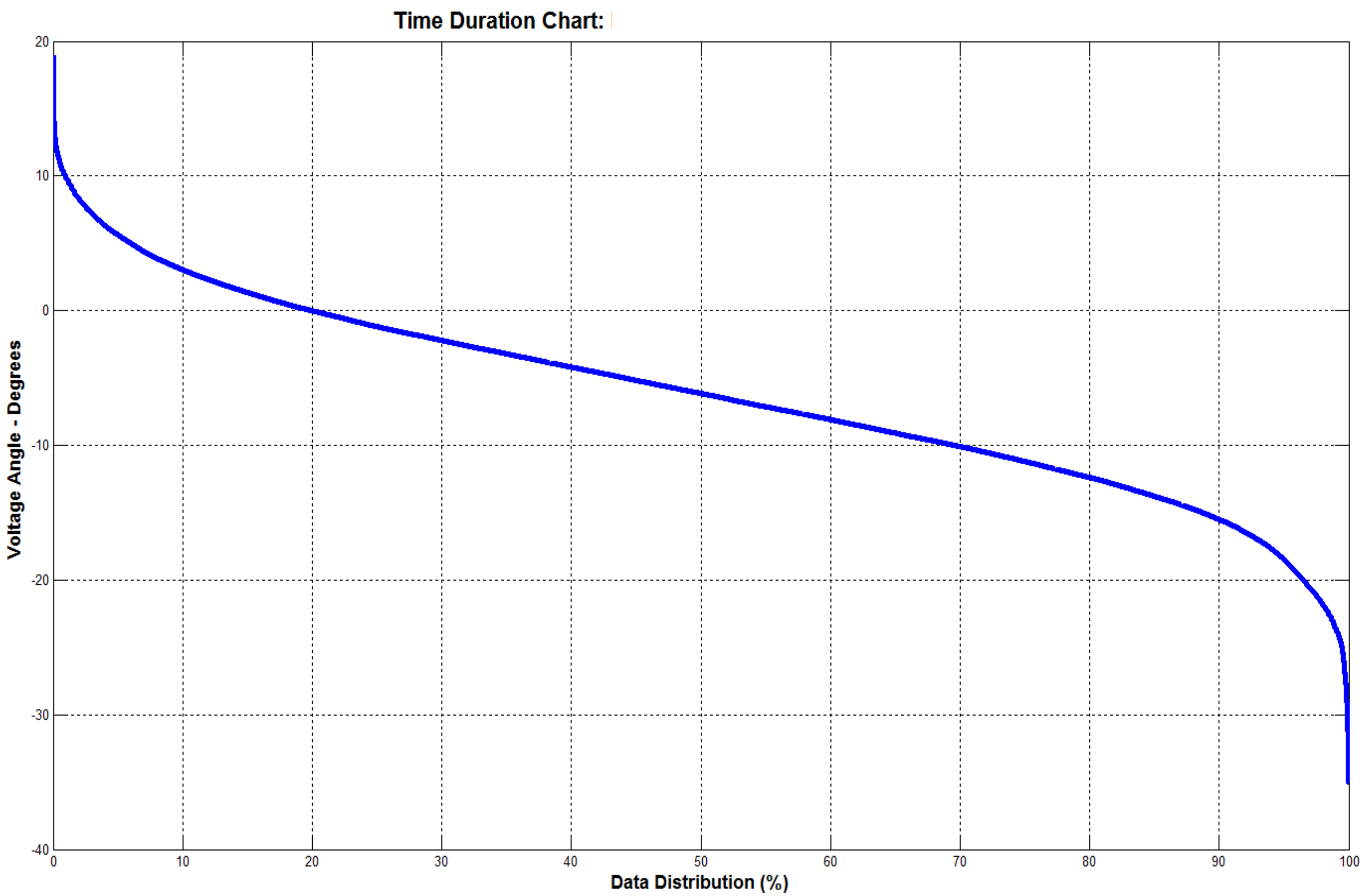
Time Duration Chart:
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
Voltage Angle - Degrees
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 4



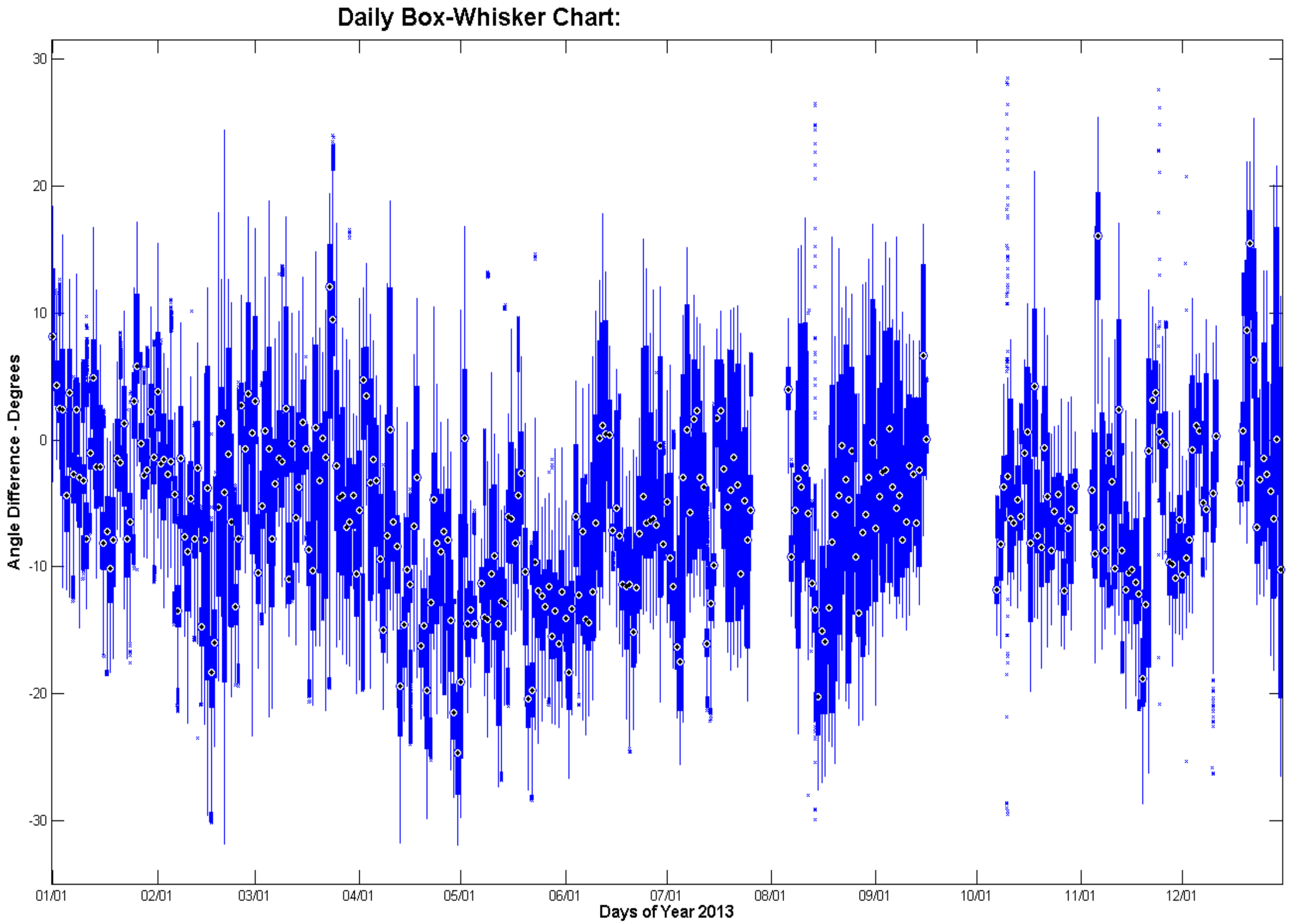
Daily Box-Whisker Chart:
20
10
0
-10
-20
-30
Angle Difference - Degrees
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 4

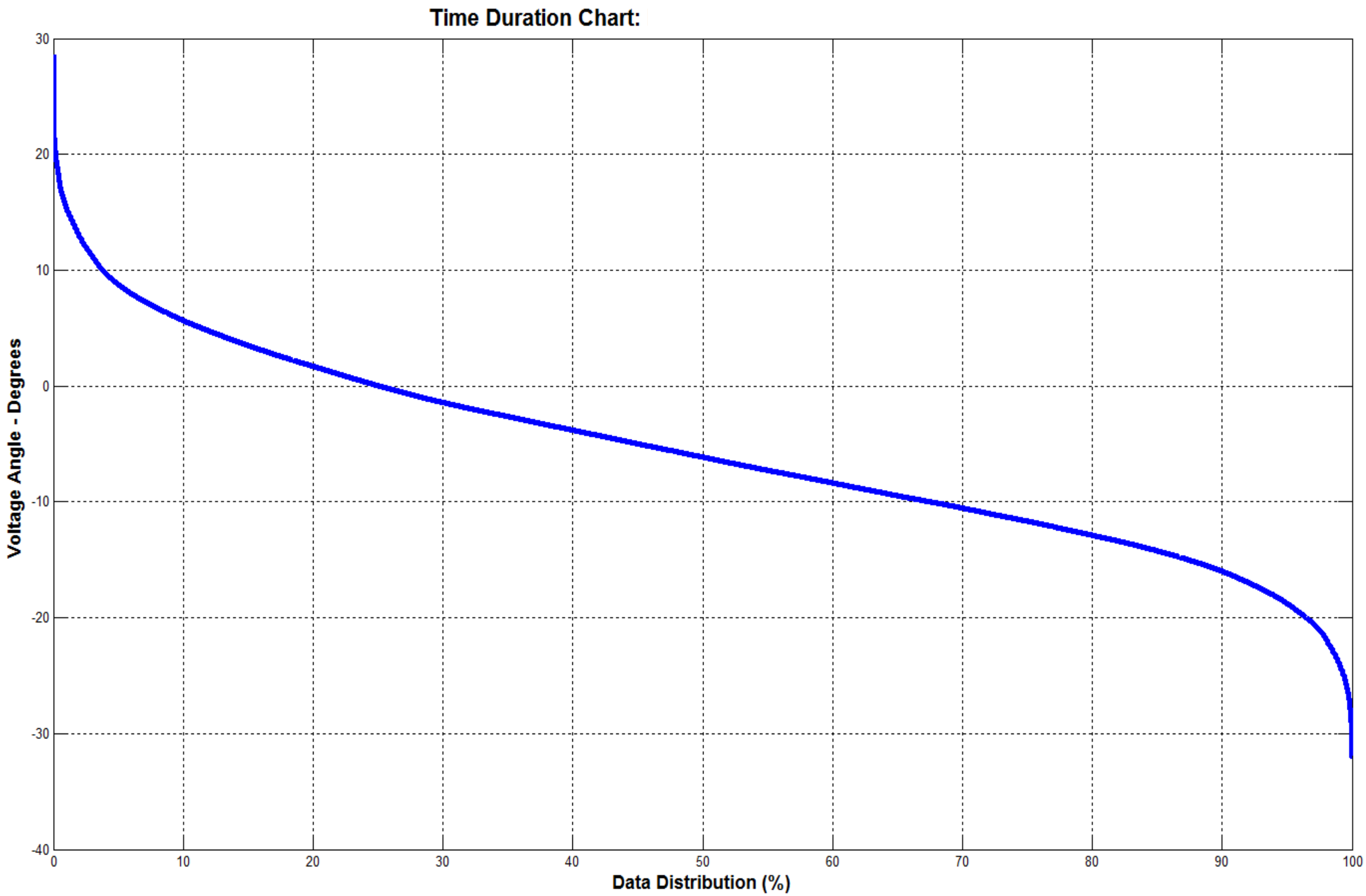


Time Duration Chart:
Voltage Angle - Degrees
Data Distribution (%)
20
10
0
-10
-20
-30
-40
0
10
20
30
40
50
60
70
80
90
100

Coast 2

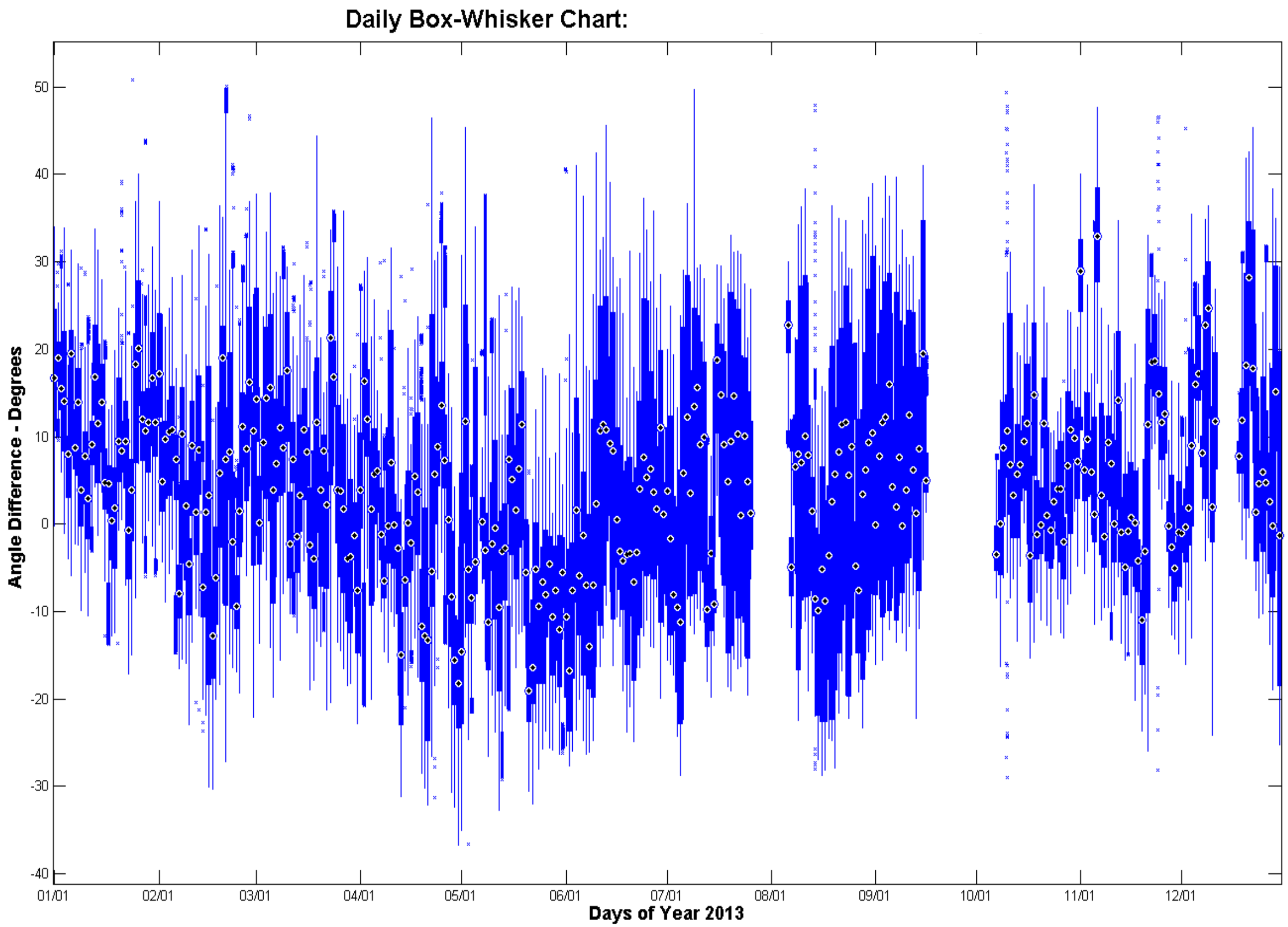

Daily Box-Whisker Chart:
Angle Difference - Degrees
30
20
10
0
-10
-20
-30
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

Coast 2

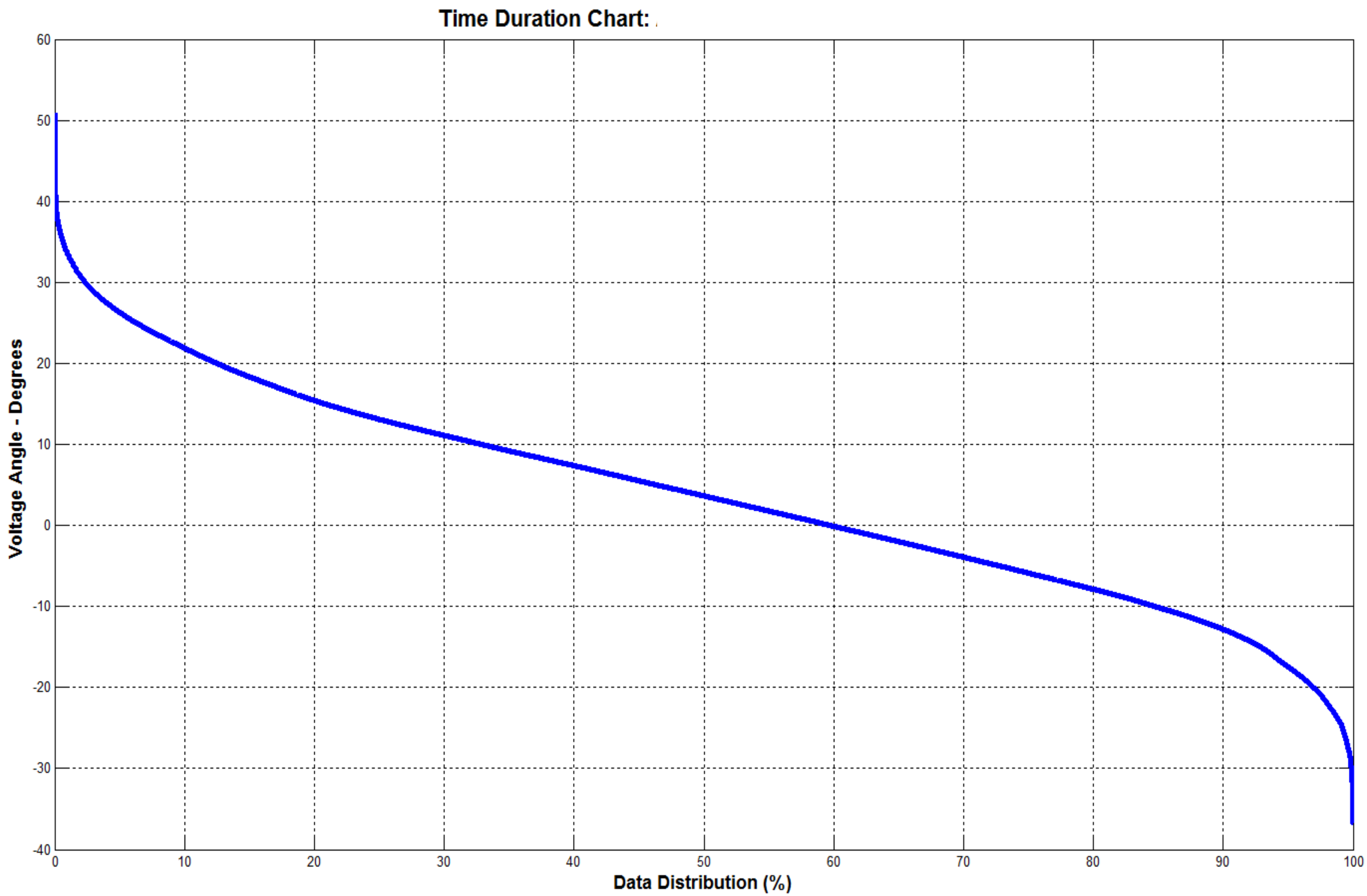


Time Duration Chart:
30
20
10
0
-10
-20
-30
-40
Voltage Angle - Degrees
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

Coast 1

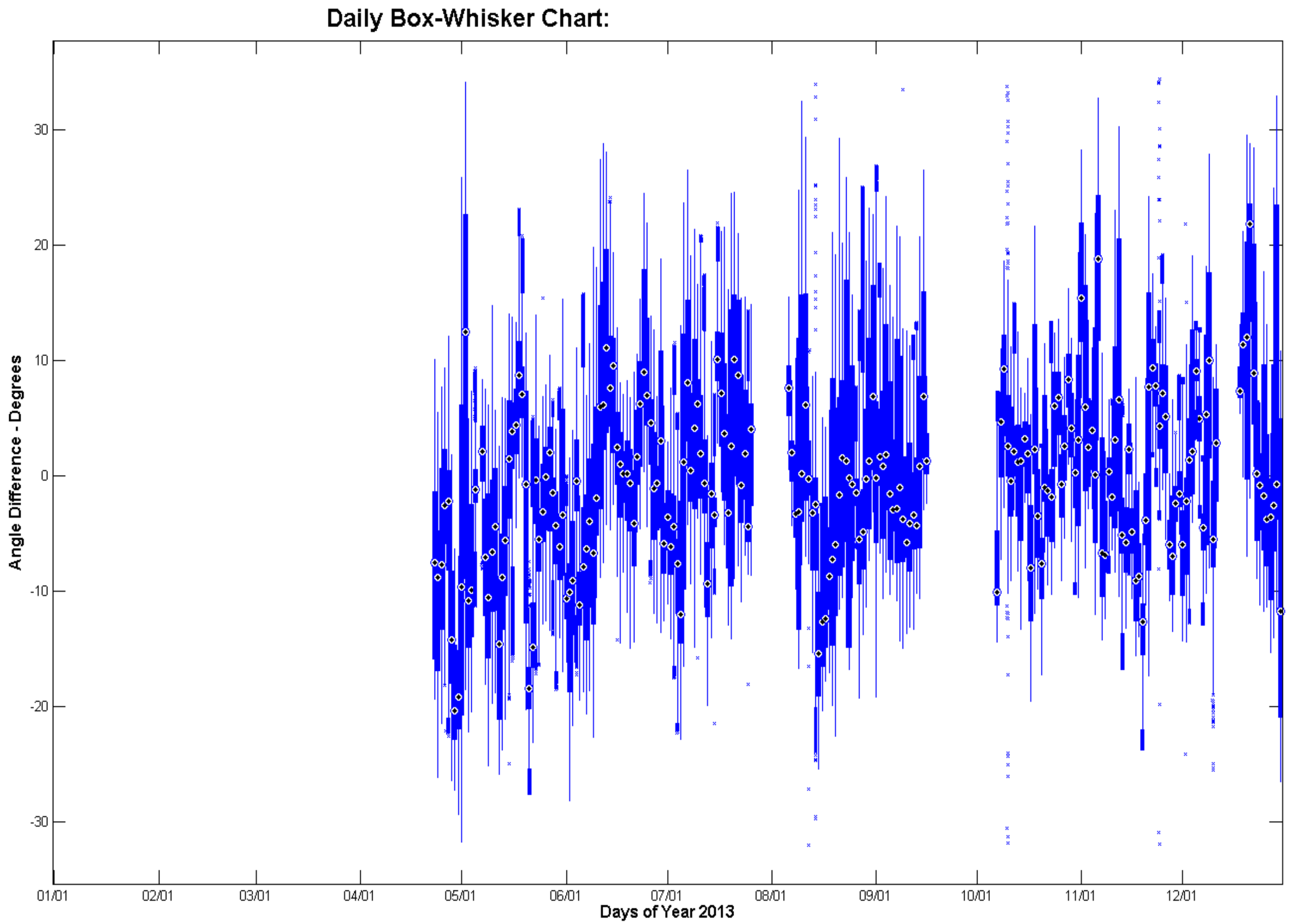

Daily Box-Whisker Chart:
Angle Difference - Degrees
50
40
30
20
10
0
-10
-20
-30
-40
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

Coast 1



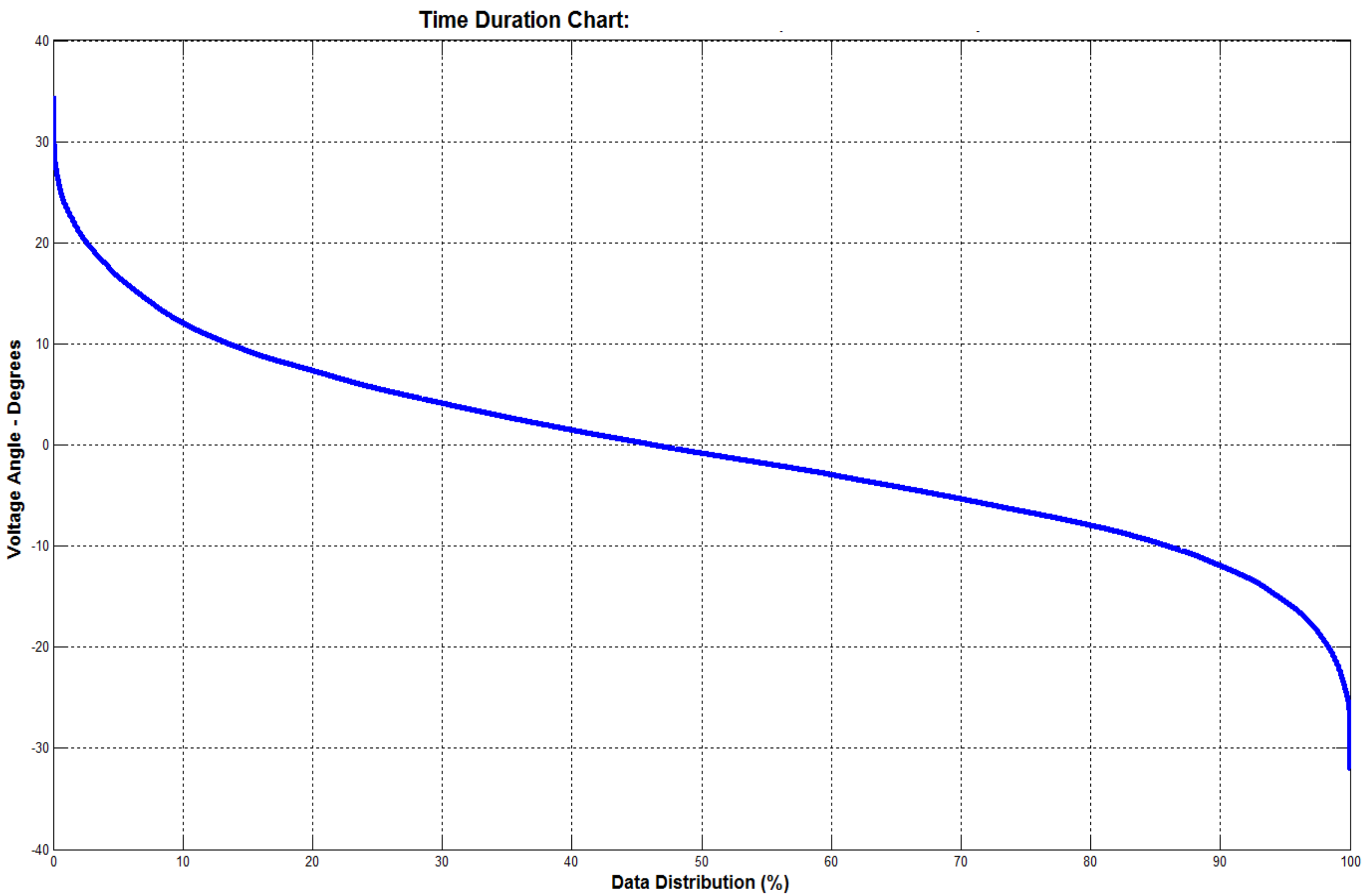
Time Duration Chart:
Voltage Angle - Degrees
Data Distribution (%)
60
50
40
30
20
10
0
-10
-20
-30
-40
0
10
20
30
40
50
60
70
80
90
100

South 3



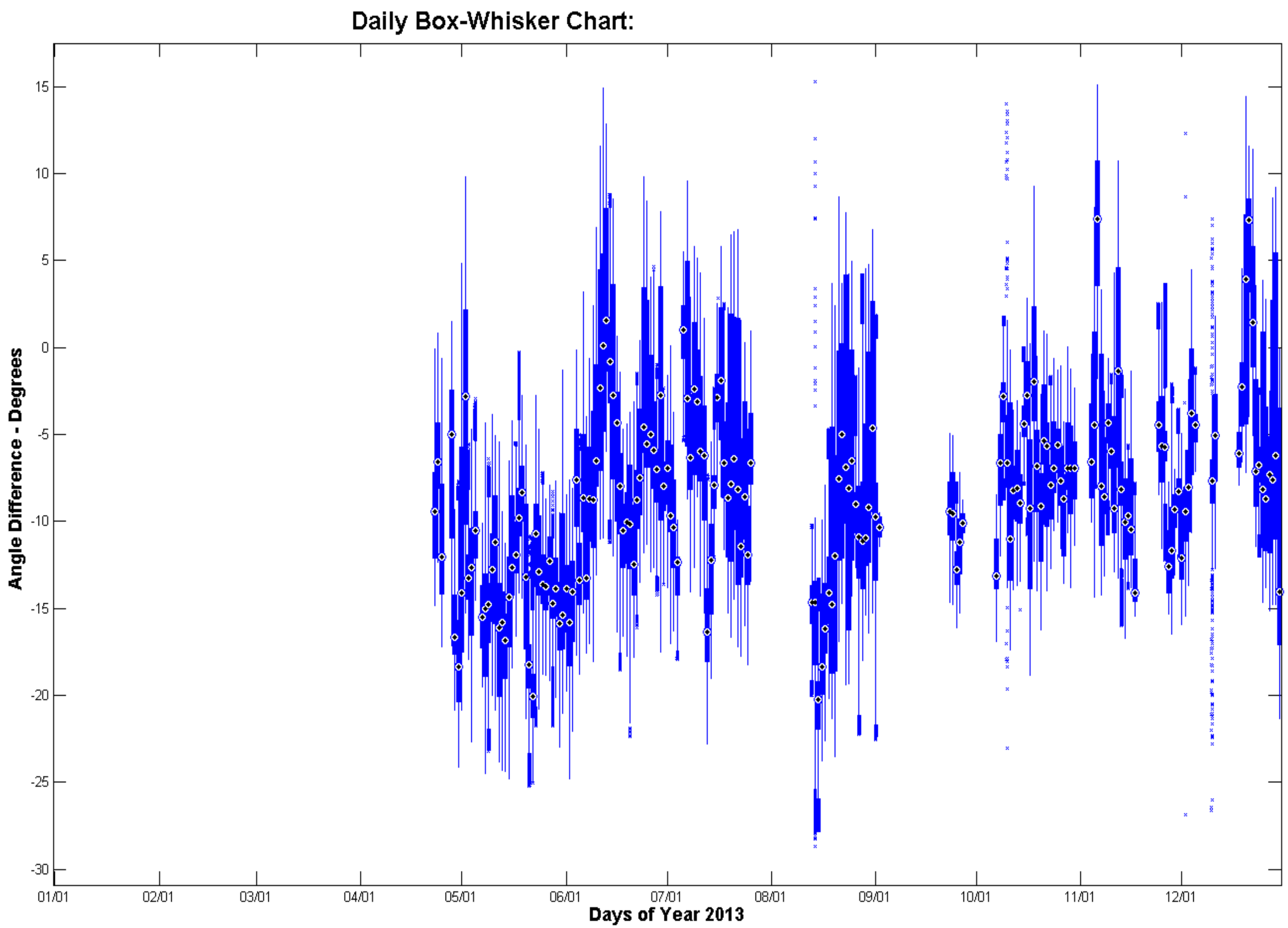
Daily Box-Whisker Chart:
Angle Difference - Degrees
30
20
10
0
-10
-20
-30
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

South 3



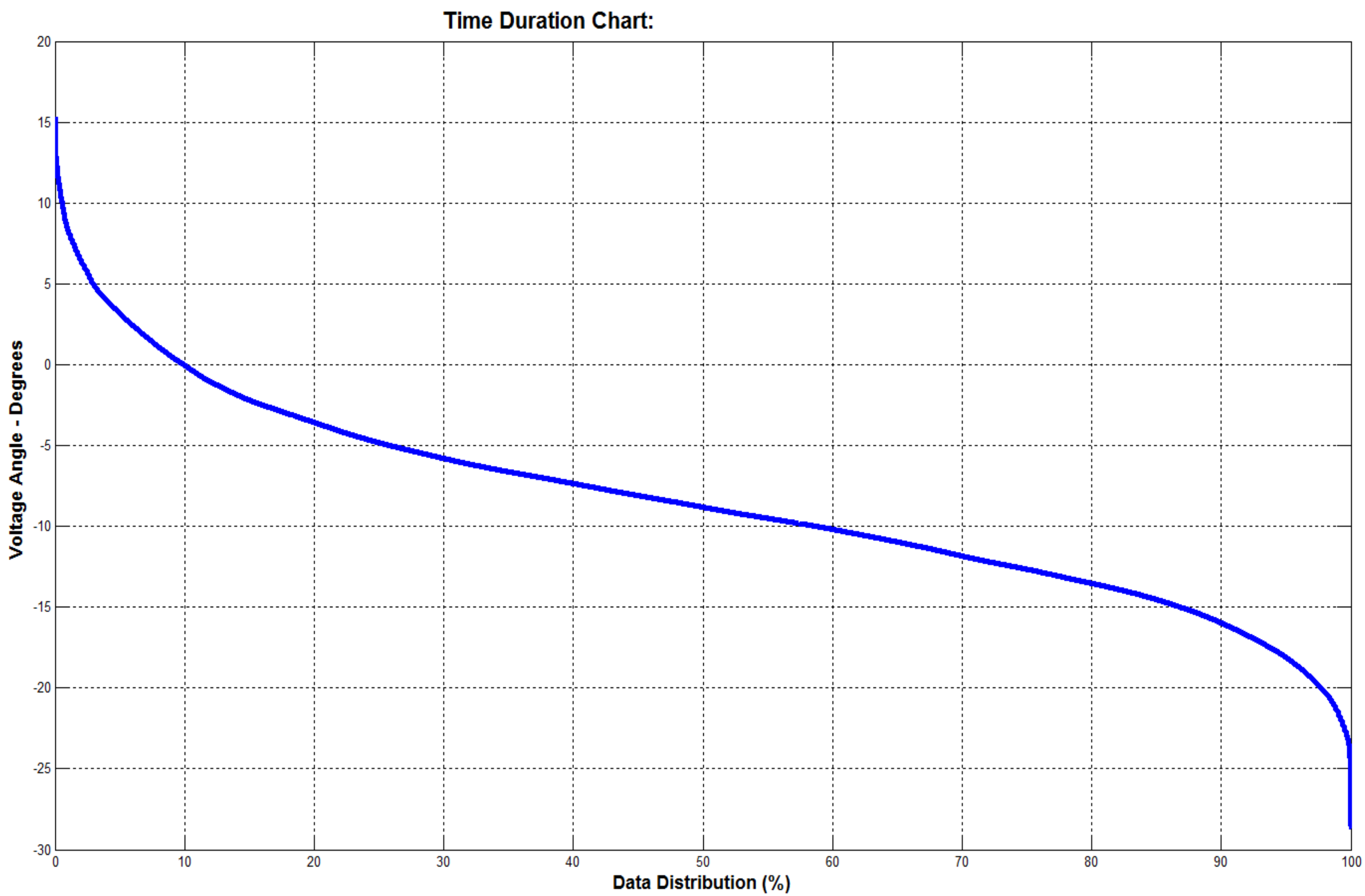
Time Duration Chart:
40
30
20
10
0
-10
-20
-30
-40
0
10
20
30
40
50
60
70
80
90
100
Voltage Angle - Degrees
Data Distribution (%)

South 5



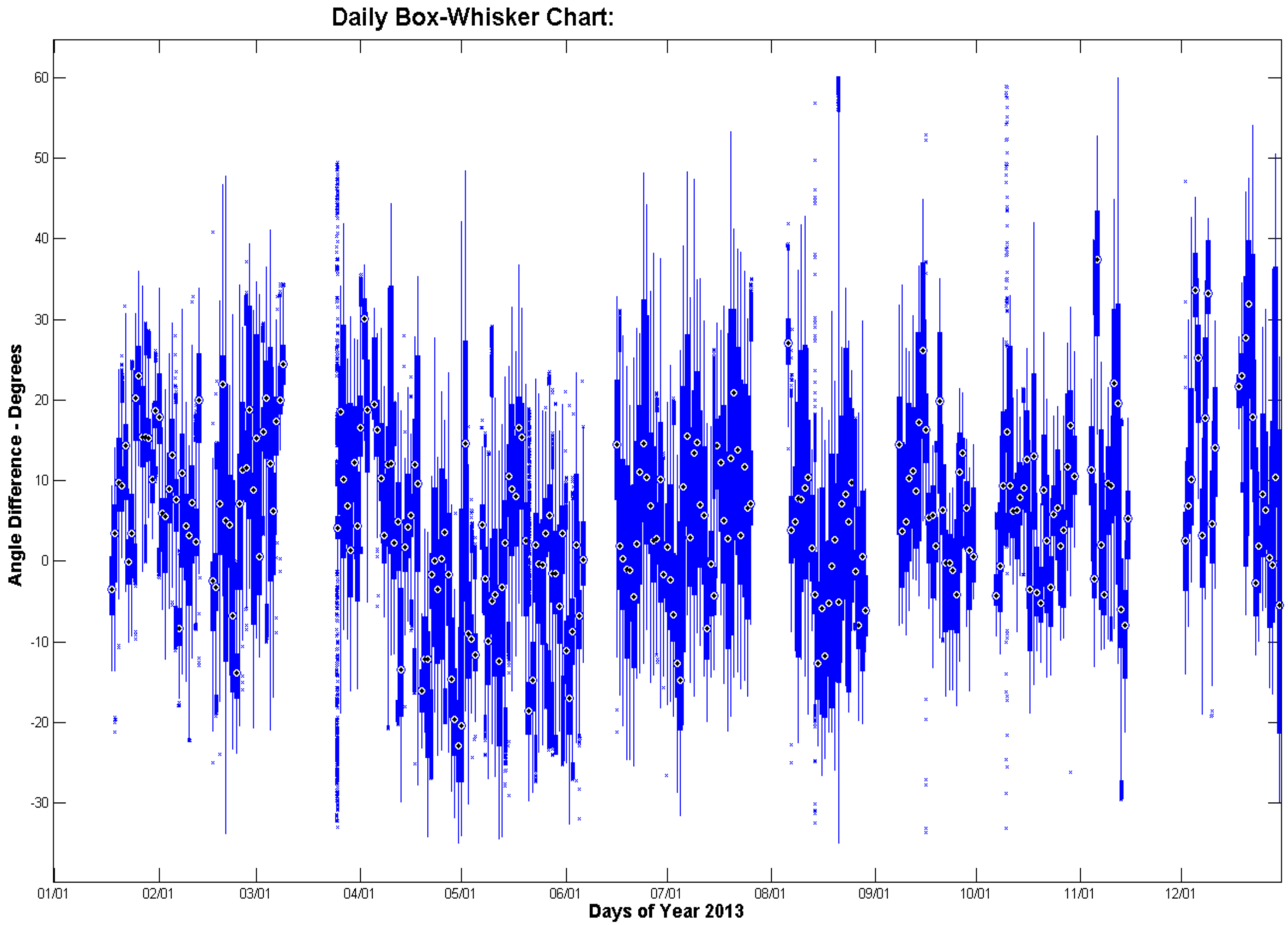
Daily Box-Whisker Chart:
Angle Difference - Degrees
15
10
5
0
-5
-10
-15
-20
-25
-30
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

South 5

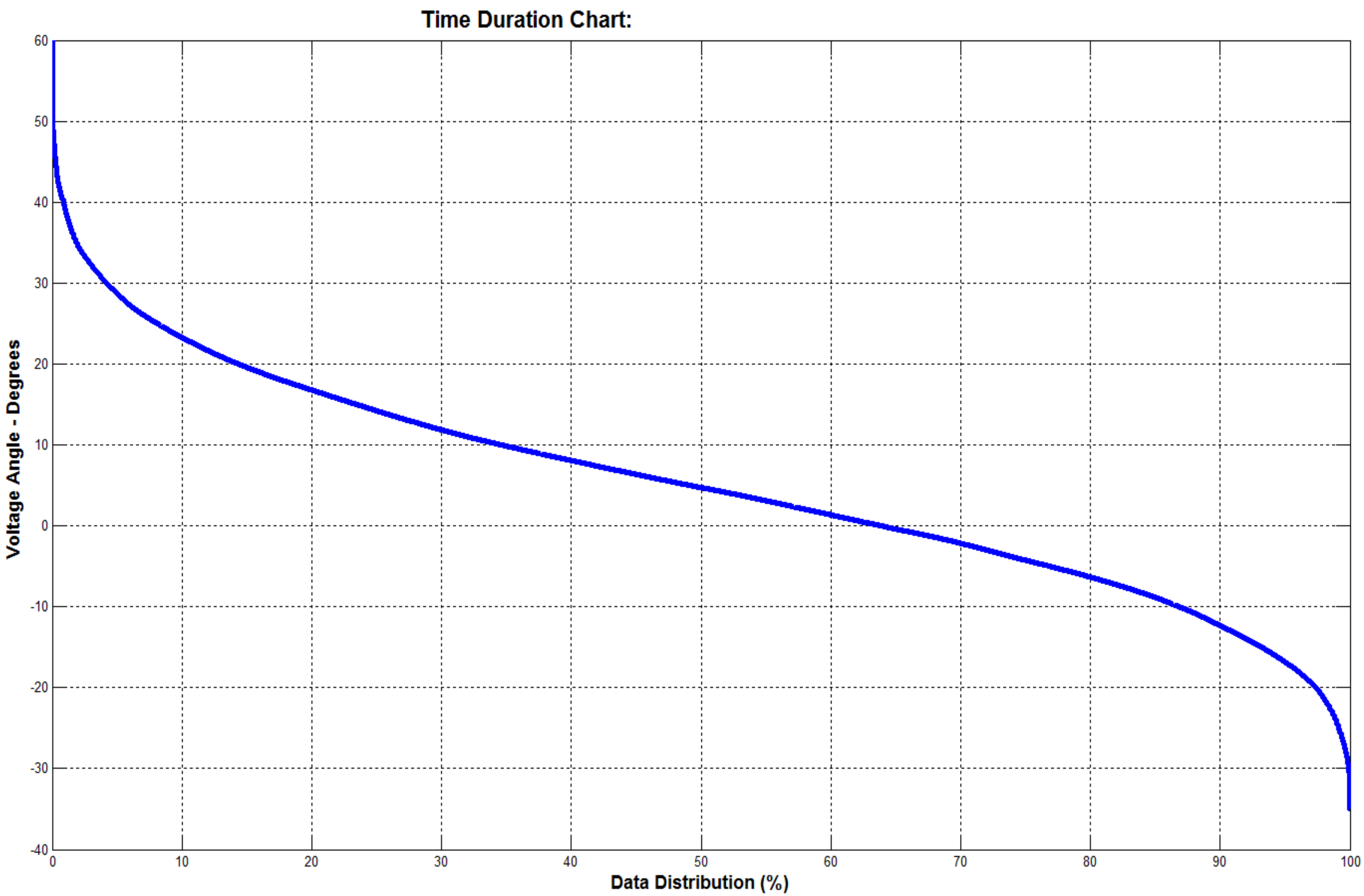


Time Duration Chart:
Voltage Angle - Degrees
Data Distribution (%)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
0
10
20
30
40
50
60
70
80
90
100

Coast 4

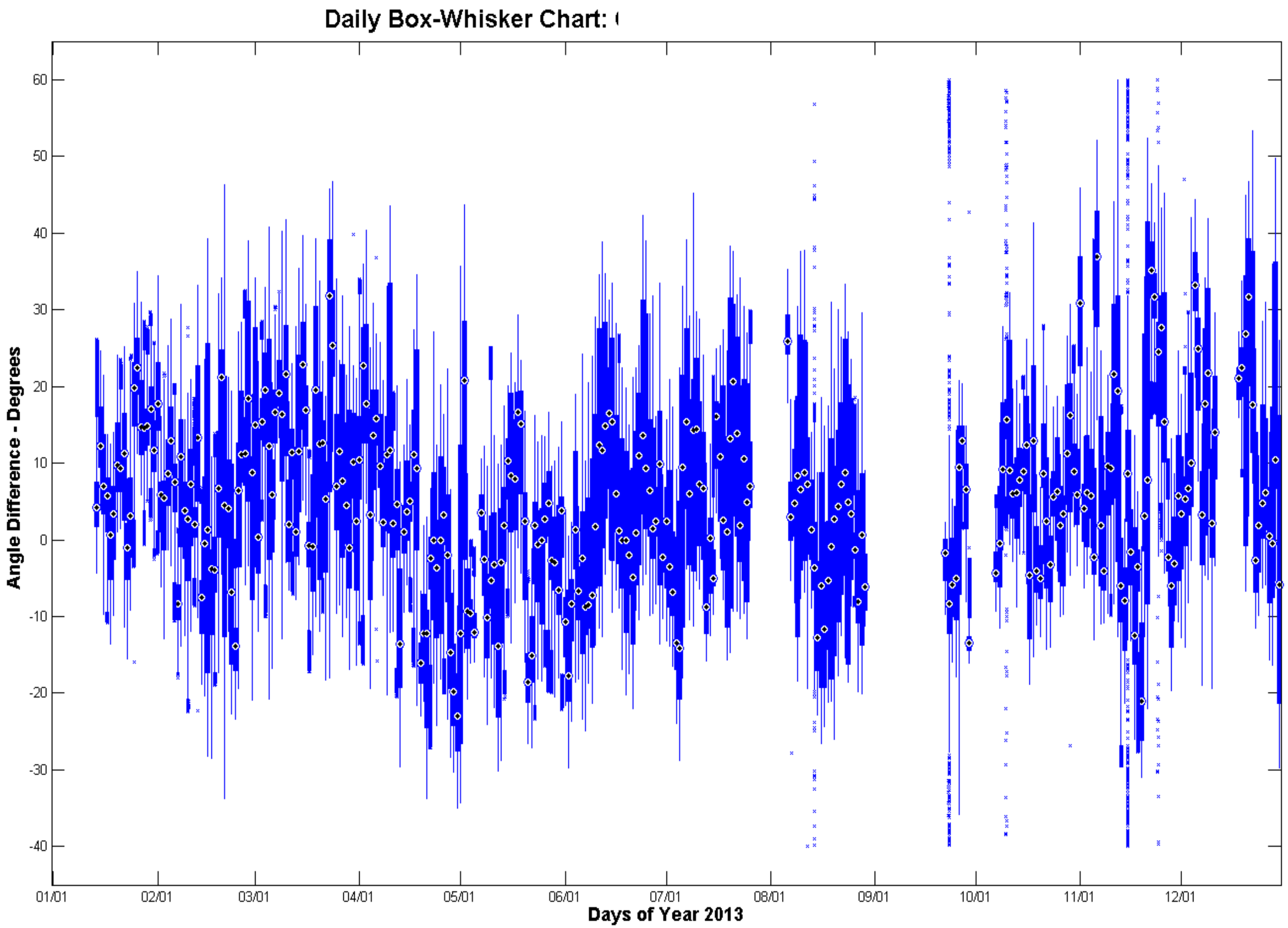

Daily Box-Whisker Chart:
Angle Difference - Degrees
60
50
40
30
20
10
0
-10
-20
-30
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

Coast 4



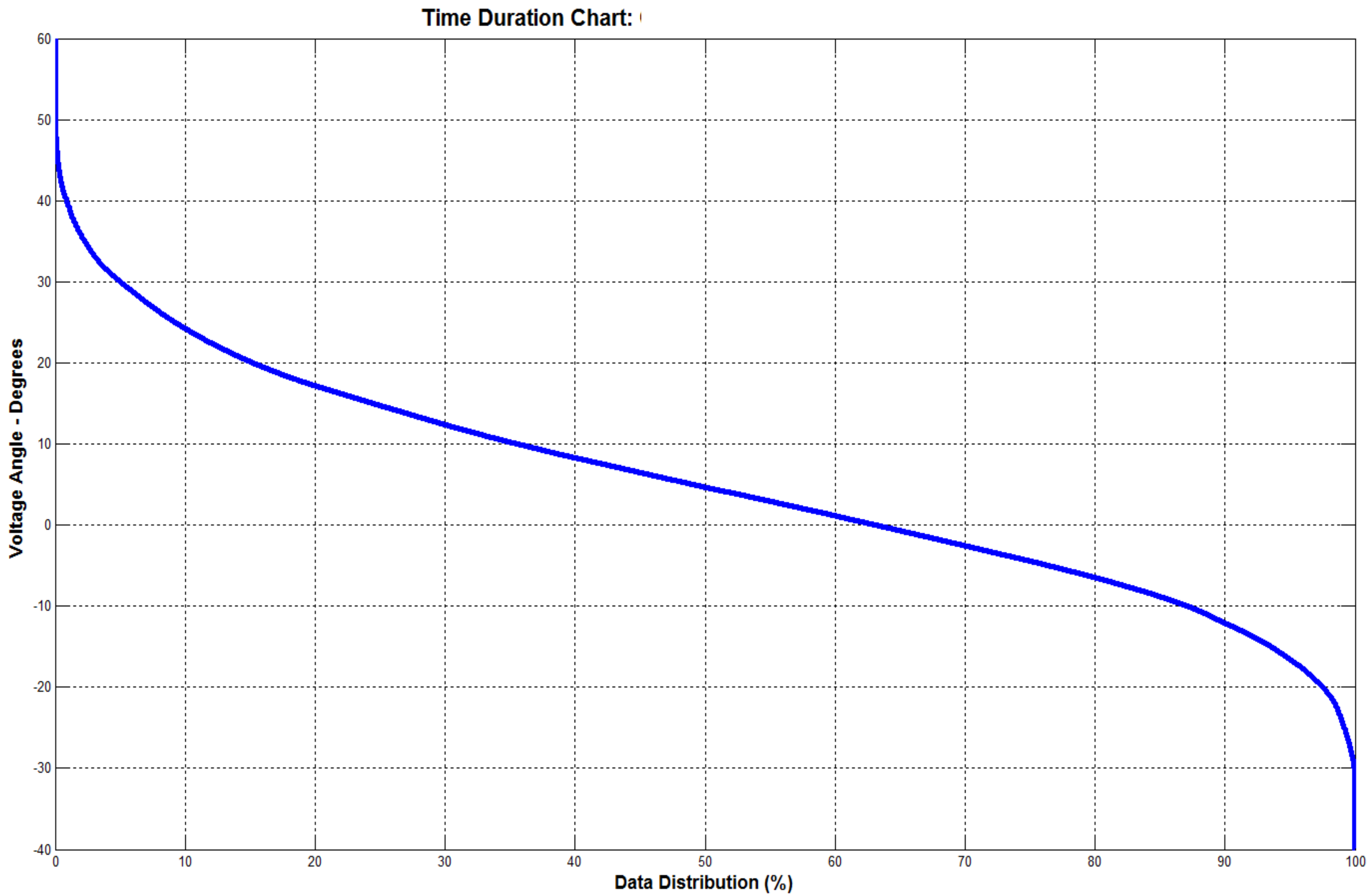
Time Duration Chart:
60
50
40
30
20
10
0
-10
-20
-30
-40
Voltage Angle - Degrees
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

Coast 3



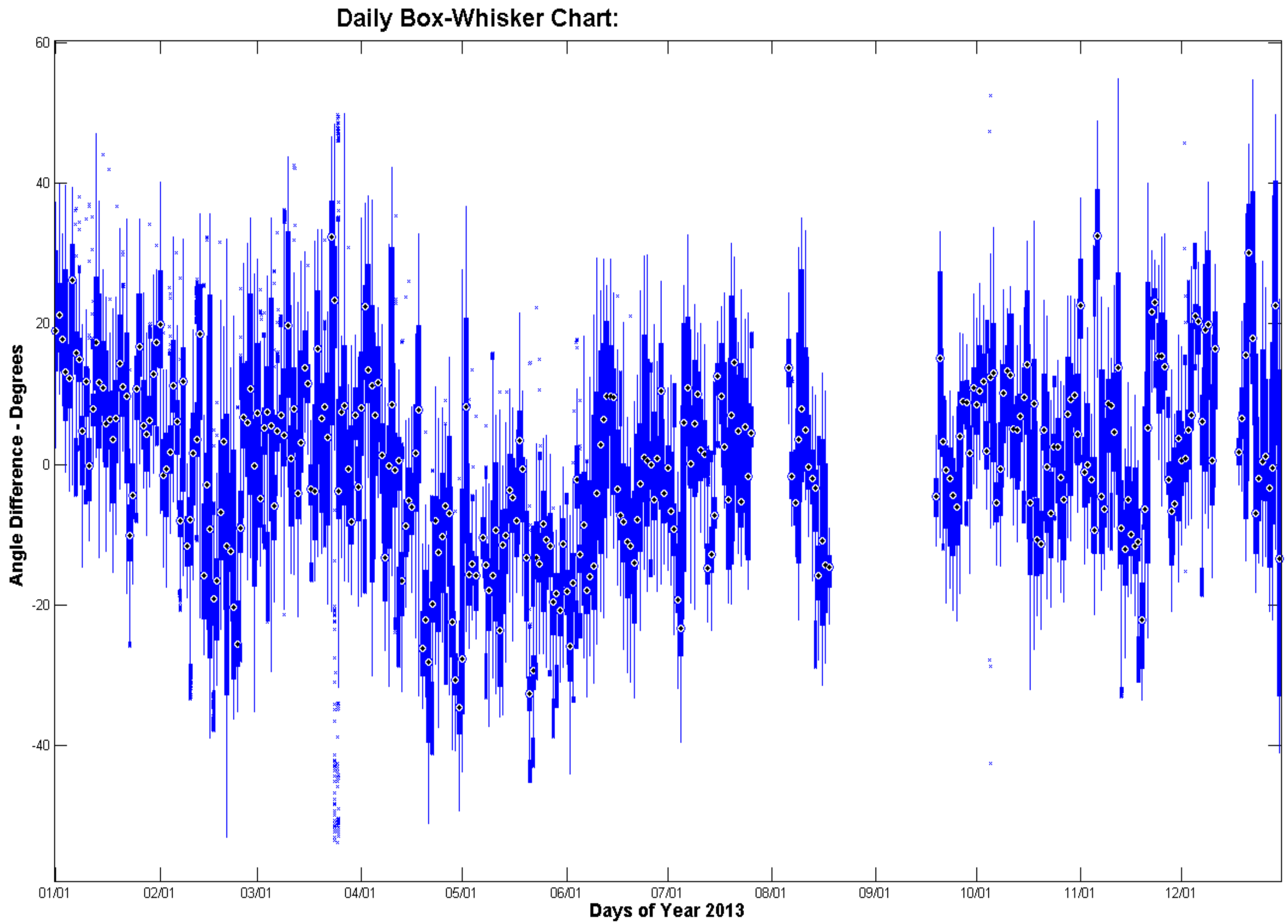
Daily Box-Whisker Chart: (
Angle Difference - Degrees
60
50
40
30
20
10
0
-10
-20
-30
-40
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

Coast 3



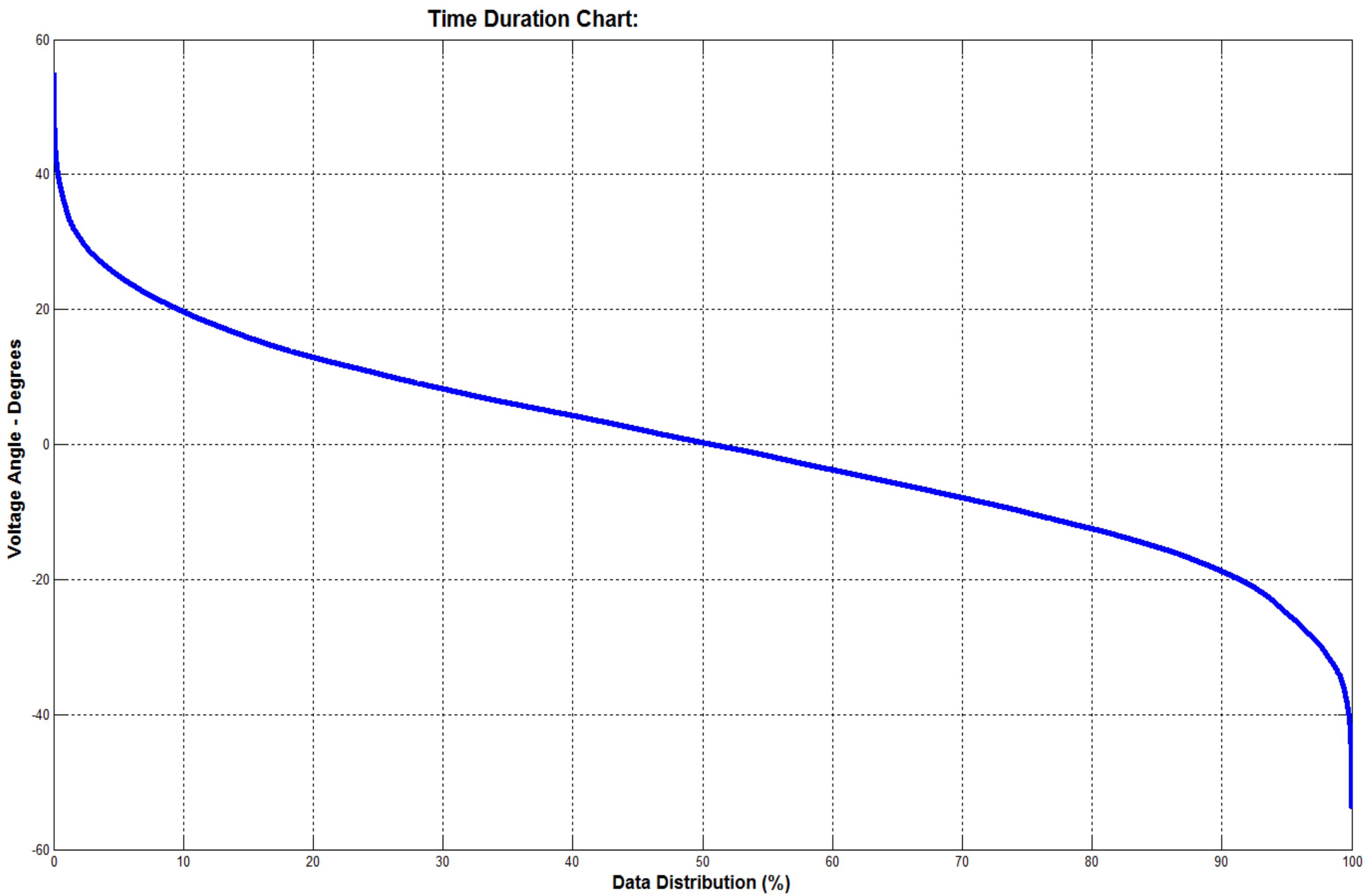
Time Duration Chart:
Voltage Angle - Degrees
60
50
40
30
20
10
0
-10
-20
-30
-40
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

South 13



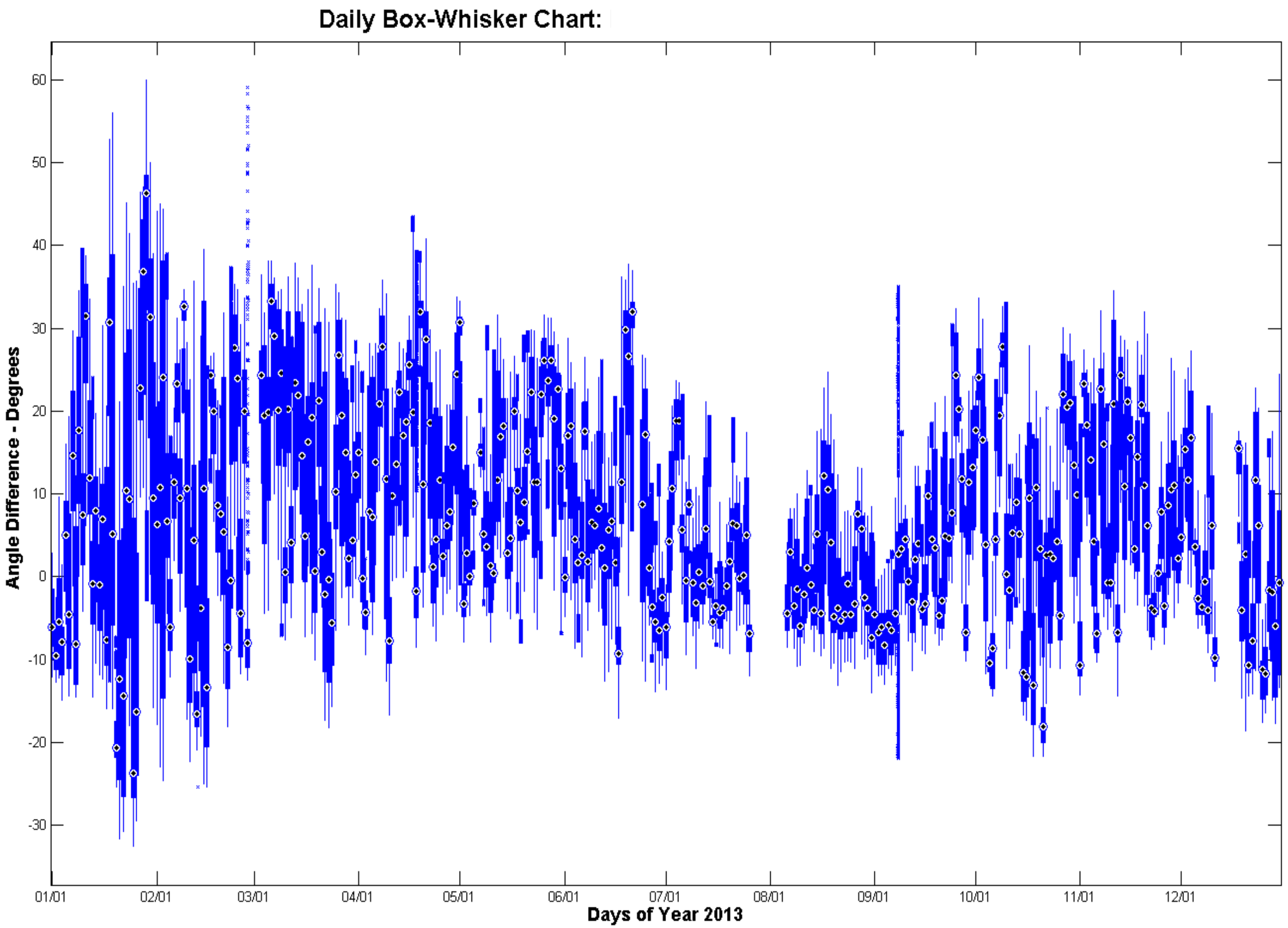
Daily Box-Whisker Chart:
60
40
20
0
-20
-40
Angle Difference - Degrees
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

South 13



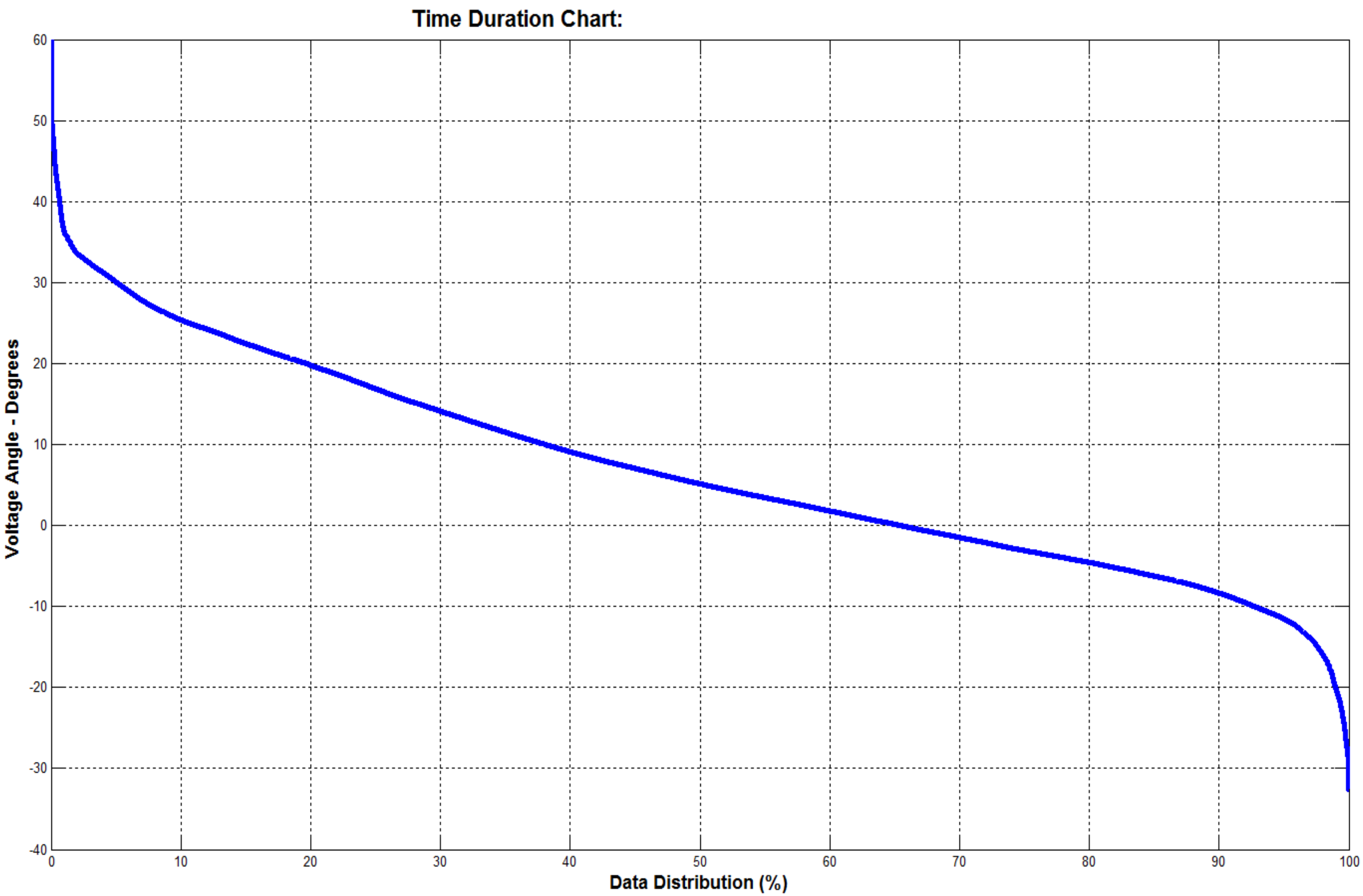
Time Duration Chart:
60
40
20
0
-20
-40
-60
0
10
20
30
40
50
60
70
80
90
100
Voltage Angle - Degrees
Data Distribution (%)

FarWest 4



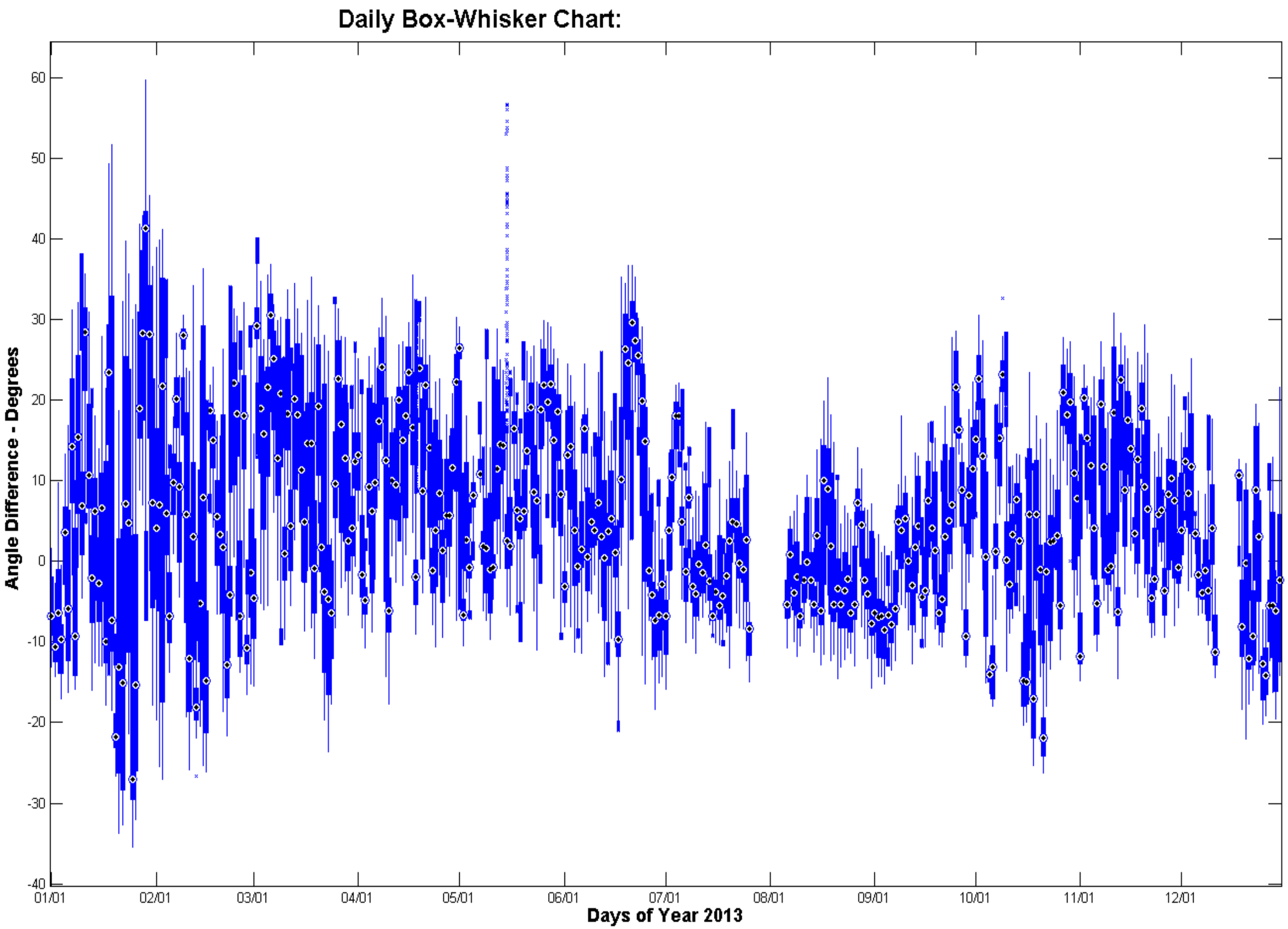
Daily Box-Whisker Chart:
Angle Difference - Degrees
60
50
40
30
20
10
0
-10
-20
-30
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

FarWest 4



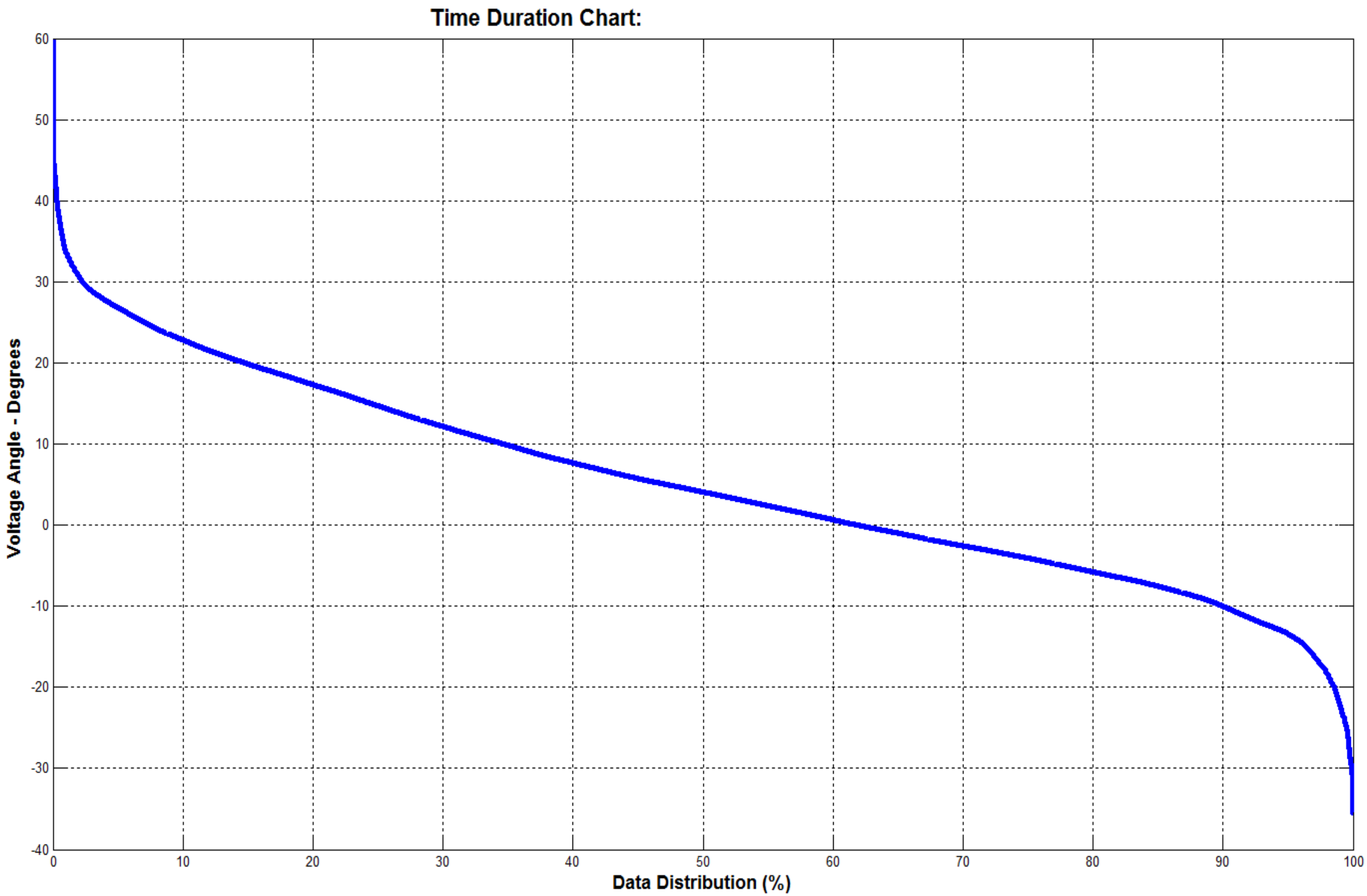
Time Duration Chart:
Voltage Angle - Degrees
Data Distribution (%)
60
50
40
30
20
10
0
-10
-20
-30
-40
0
10
20
30
40
50
60
70
80
90
100

FarWest 7



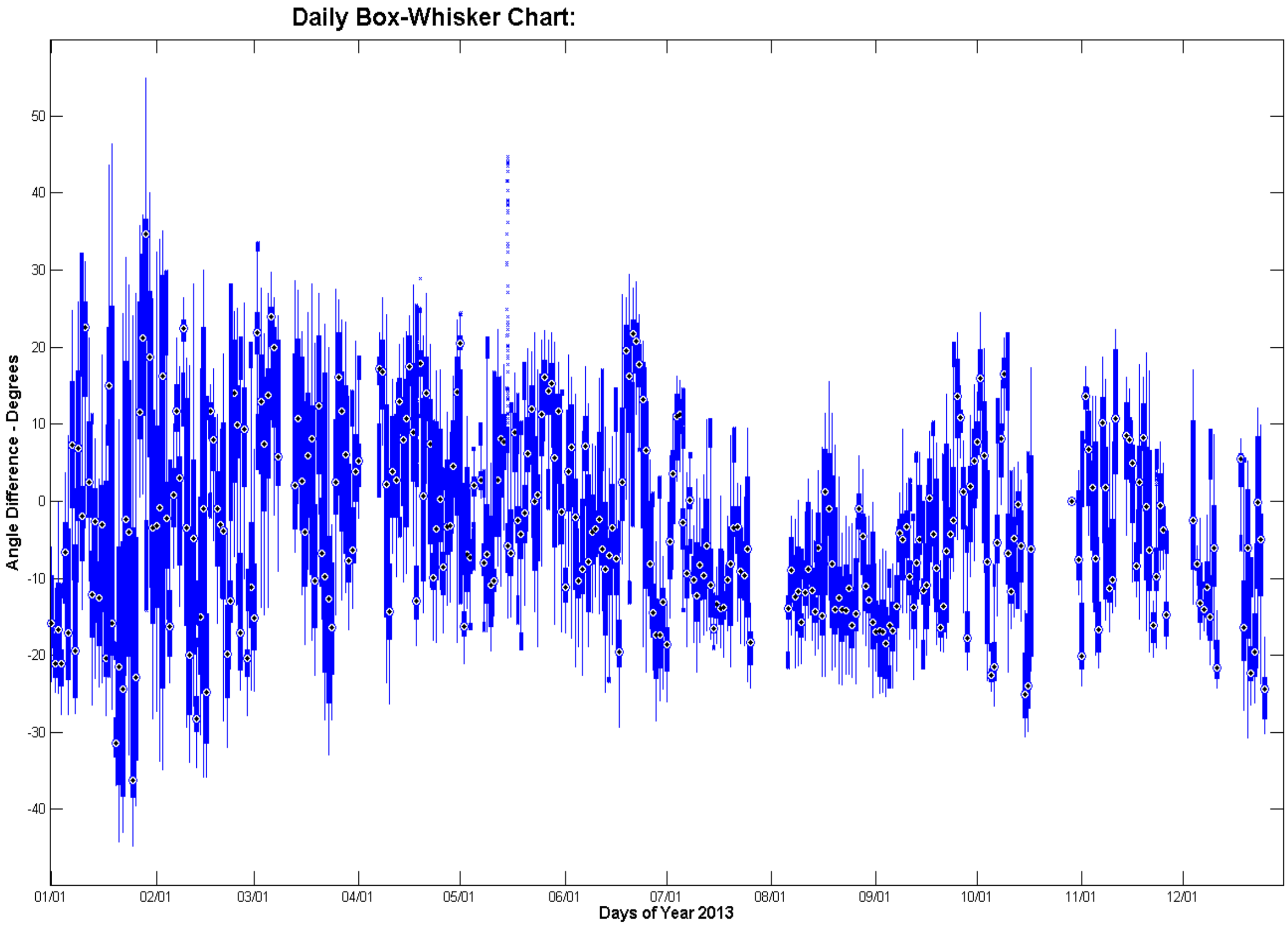
Daily Box-Whisker Chart:
Angle Difference - Degrees
60
50
40
30
20
10
0
-10
-20
-30
-40
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

FarWest 7



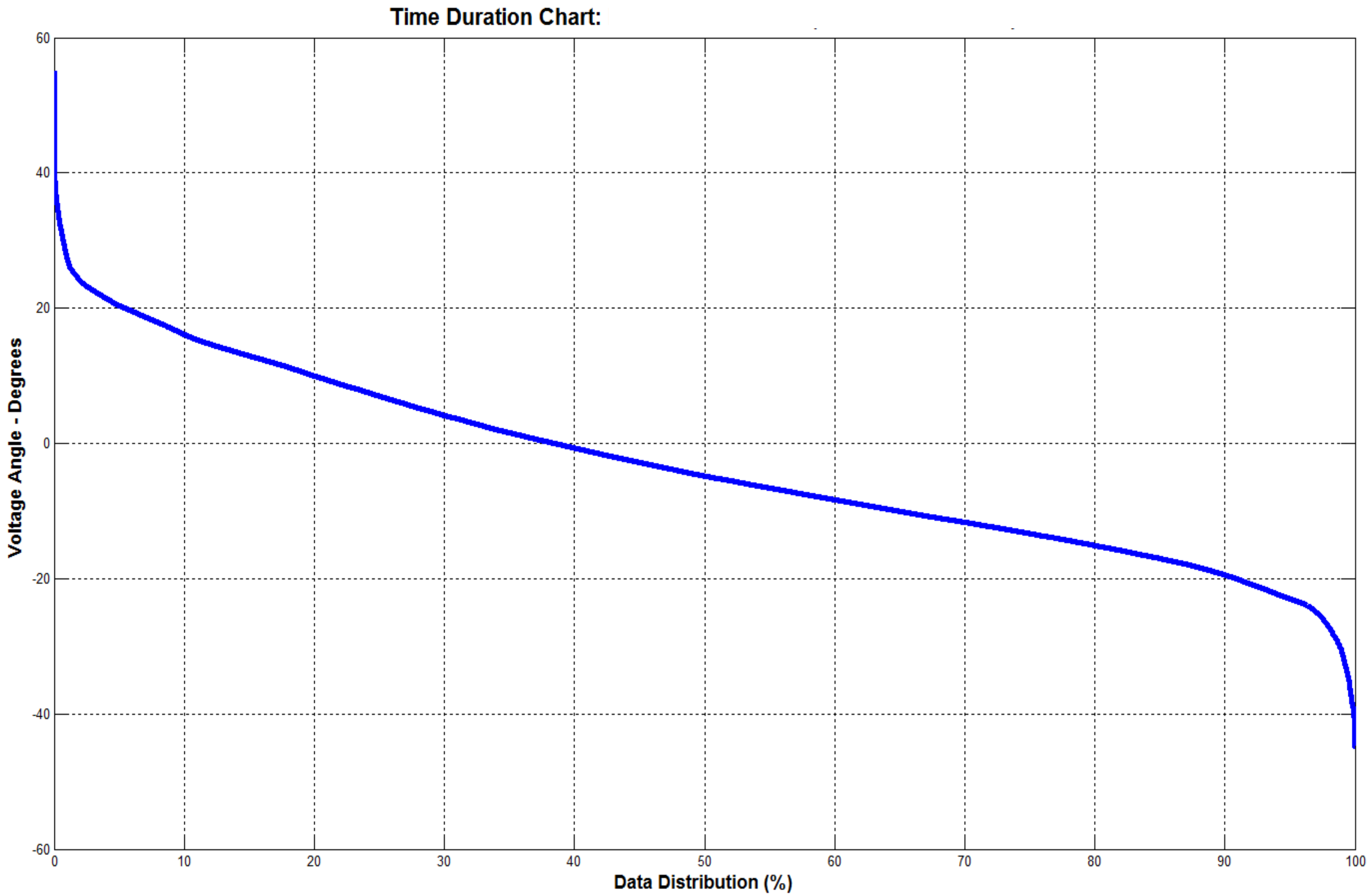
Time Duration Chart:
Voltage Angle - Degrees
Data Distribution (%)
60
50
40
30
20
10
0
-10
-20
-30
-40
0
10
20
30
40
50
60
70
80
90
100

FarWest 8

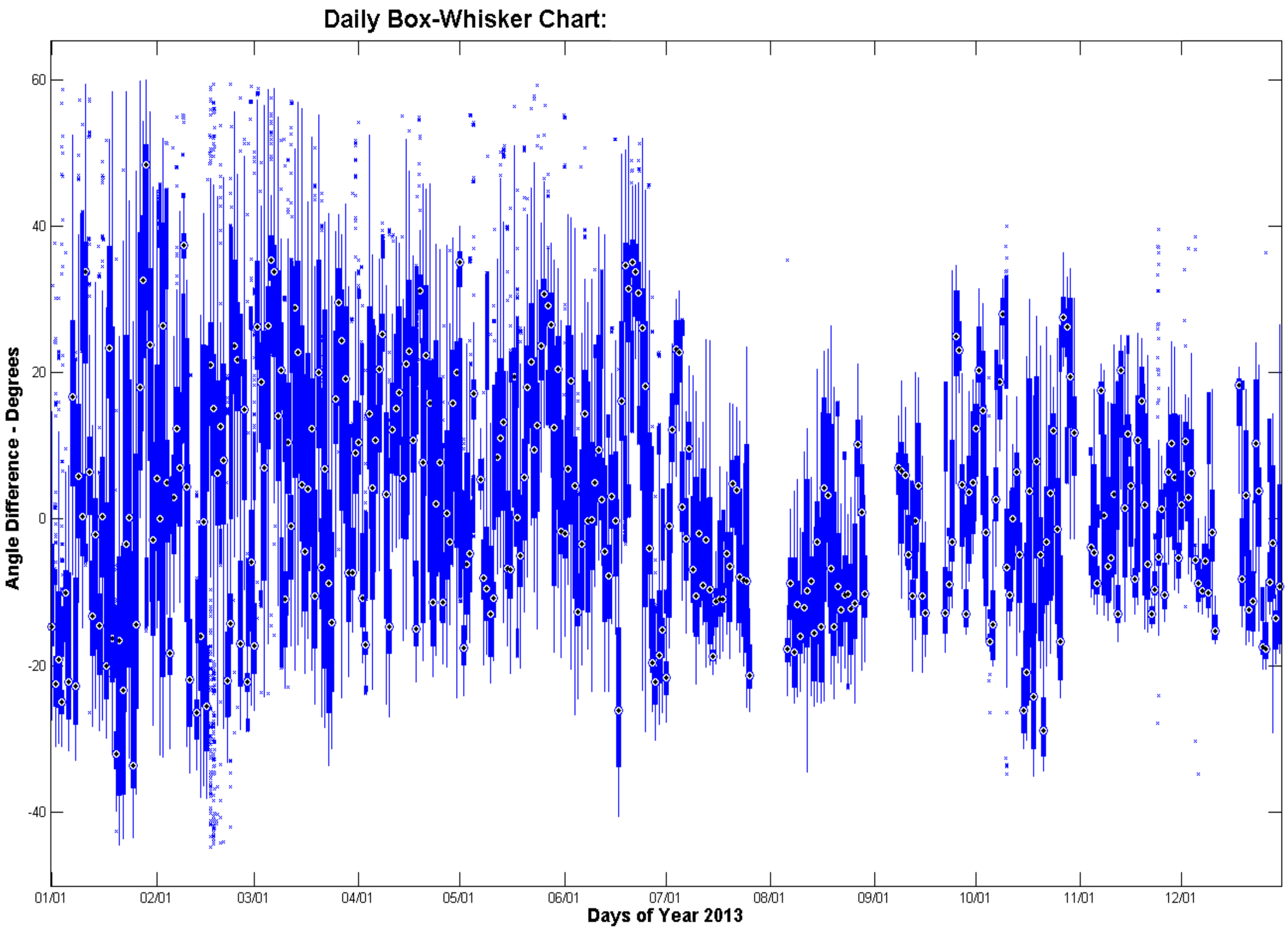


Daily Box-Whisker Chart:
Angle Difference - Degrees
50
40
30
20
10
0
-10
-20
-30
-40
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

FarWest 8

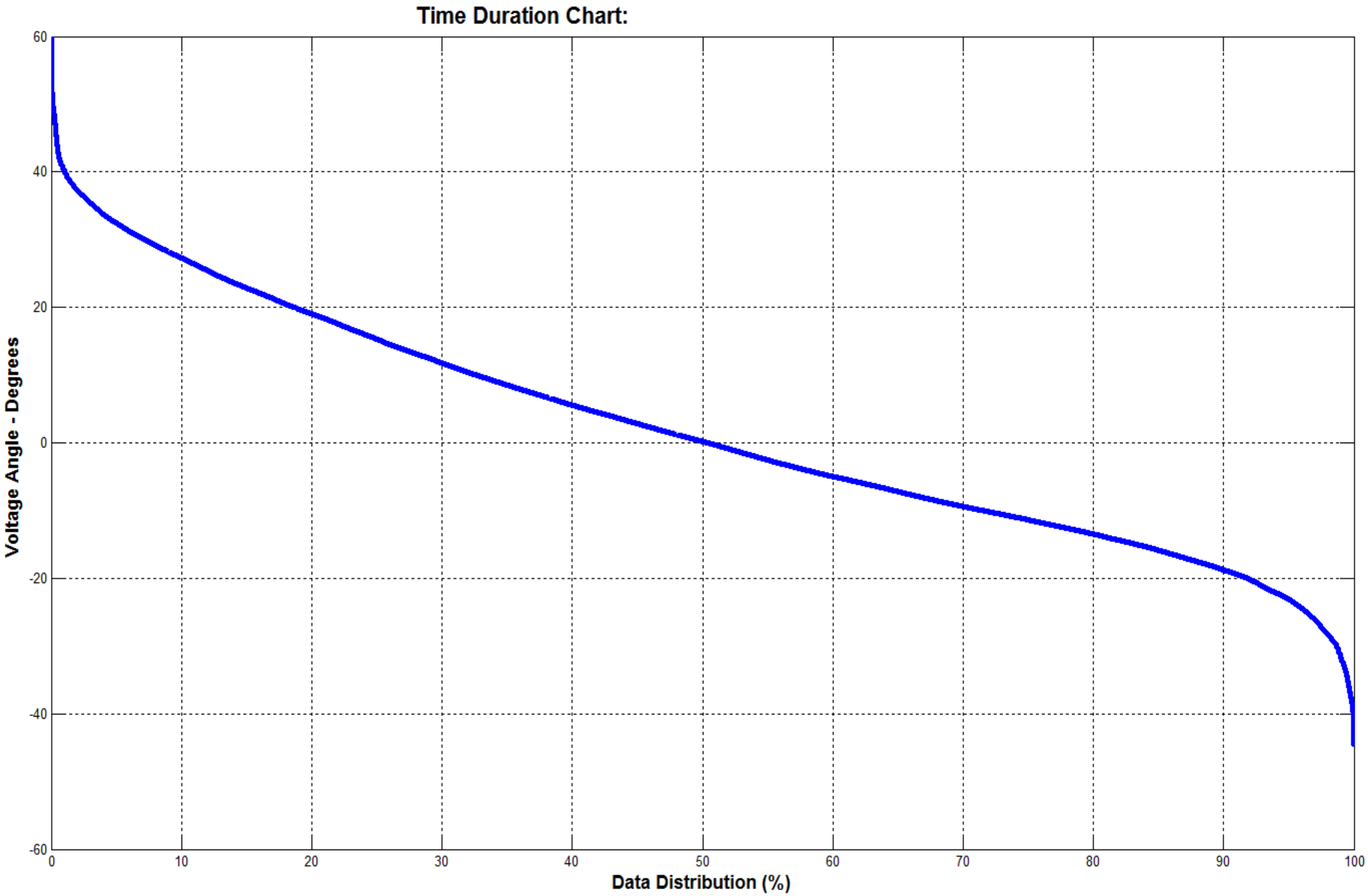

Time Duration Chart:
Voltage Angle - Degrees
Data Distribution (%)
60
40
20
0
-20
-40
-60
0
10
20
30
40
50
60
70
80
90
100

FarWest 9



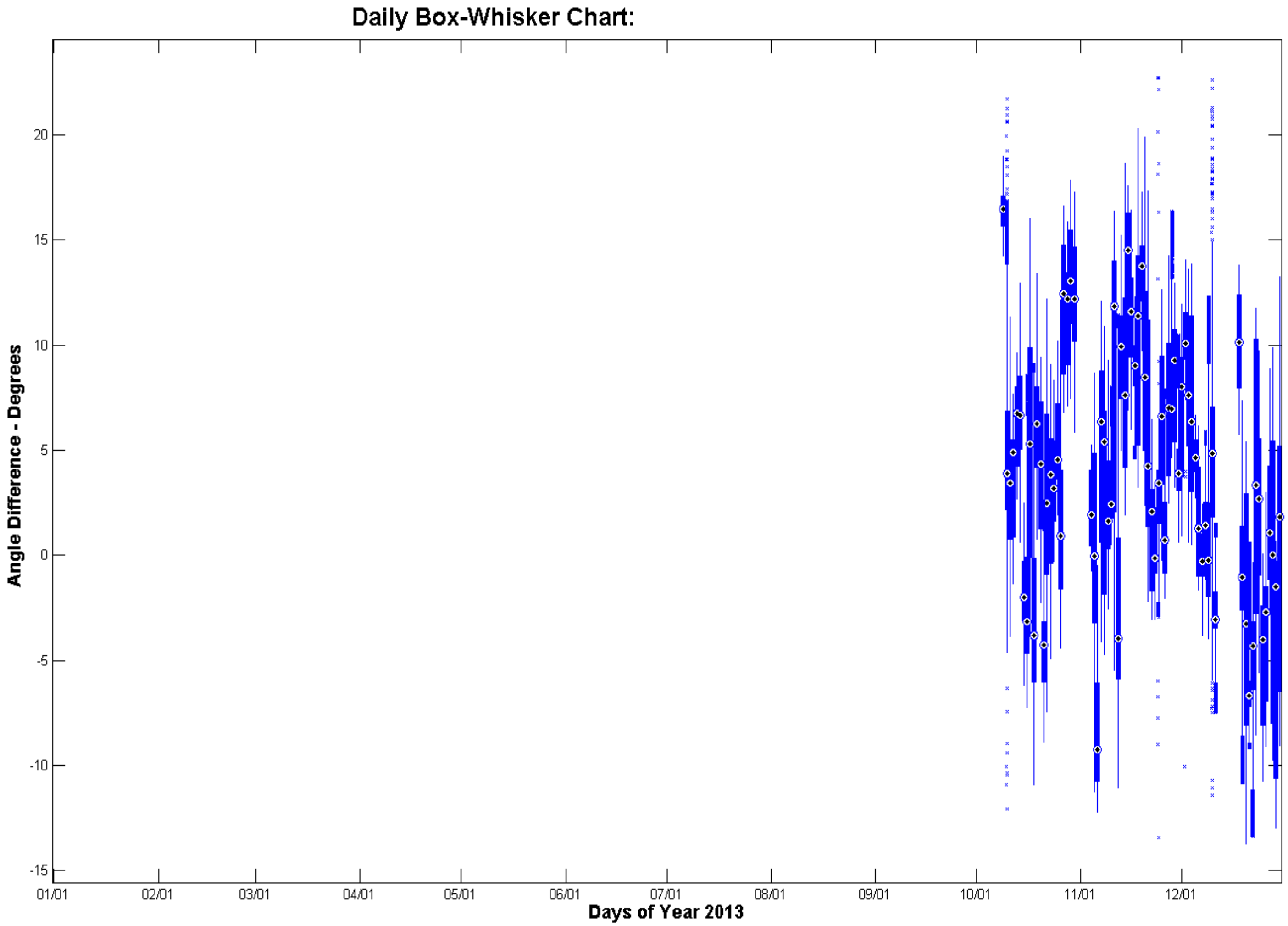
Daily Box-Whisker Chart:
60
40
20
0
-20
-40
Angle Difference - Degrees
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

FarWest 9



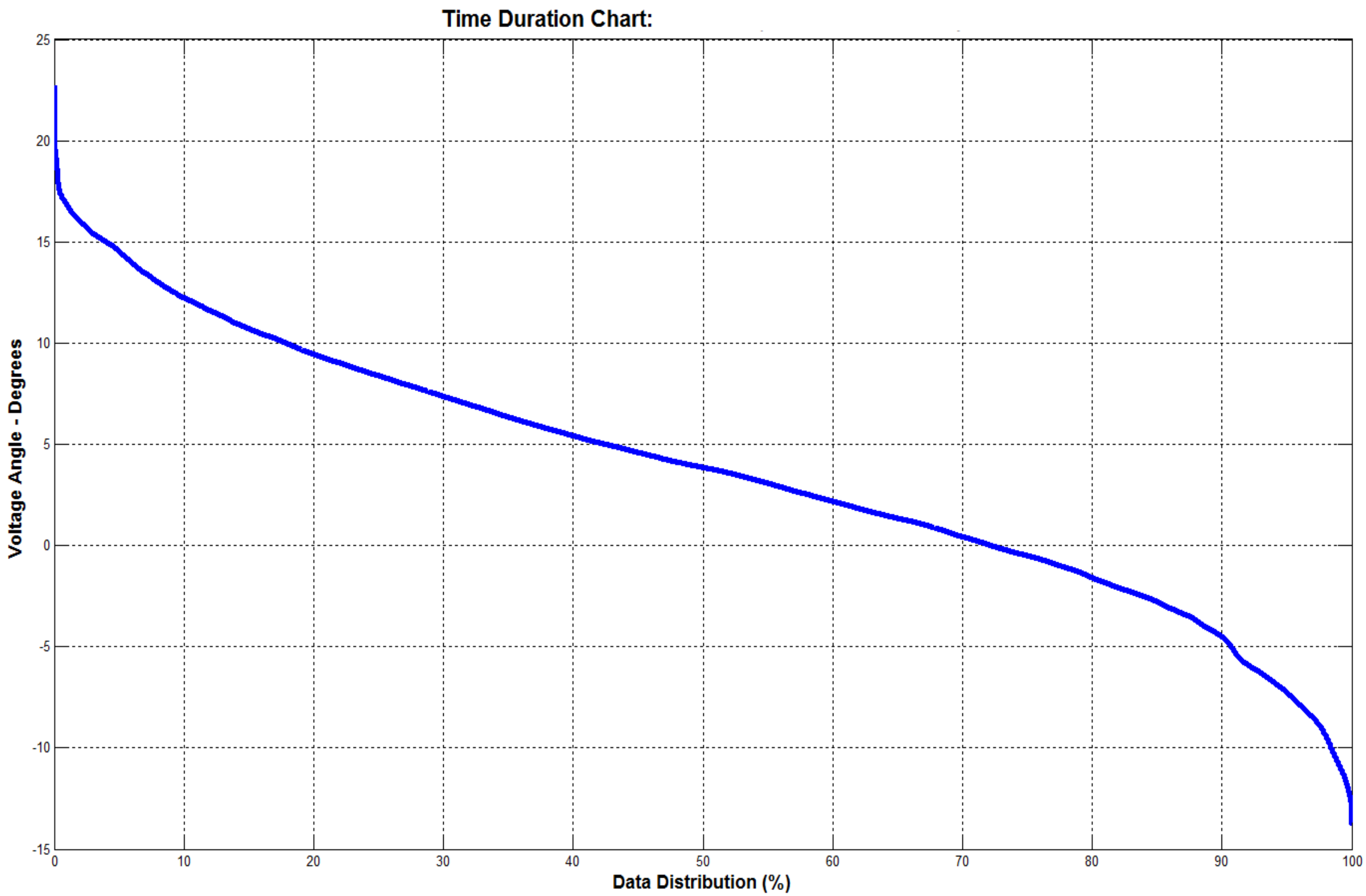
Time Duration Chart:
60
40
20
0
-20
-40
-60
Voltage Angle - Degrees
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

West 15



Daily Box-Whisker Chart:
Angle Difference - Degrees
20
15
10
5
0
-5
-10
-15
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Days of Year 2013

West 15



Time Duration Chart:
25
20
15
10
5
0
-5
-10
-15
Voltage Angle - Degrees
0
10
20
30
40
50
60
70
80
90
100
Data Distribution (%)

Appendix C – Part 1

CCET Discovery Across Texas project

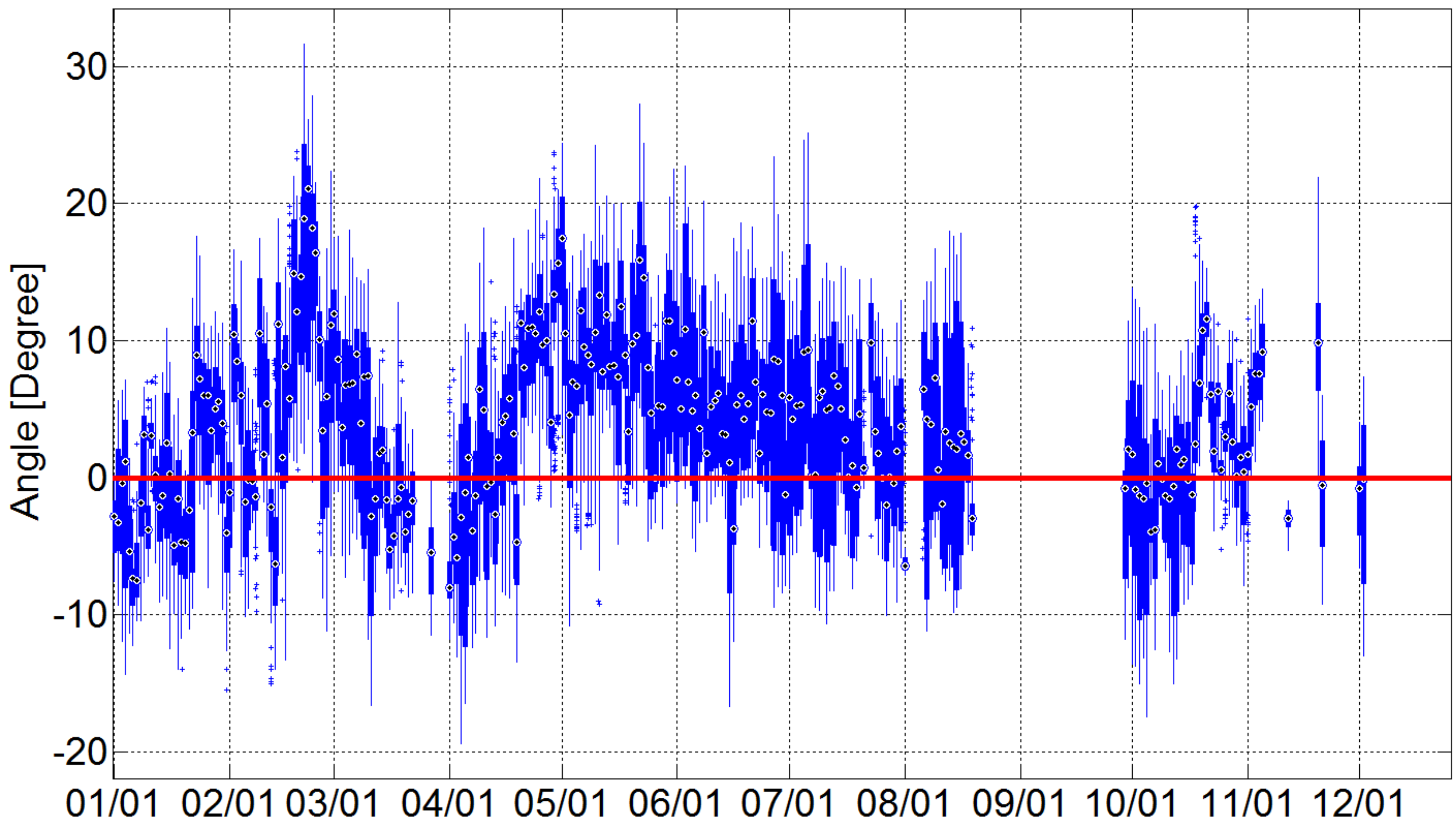
Baseline Analysis Update – Angle Differences

State Estimator Data: January to December 2013

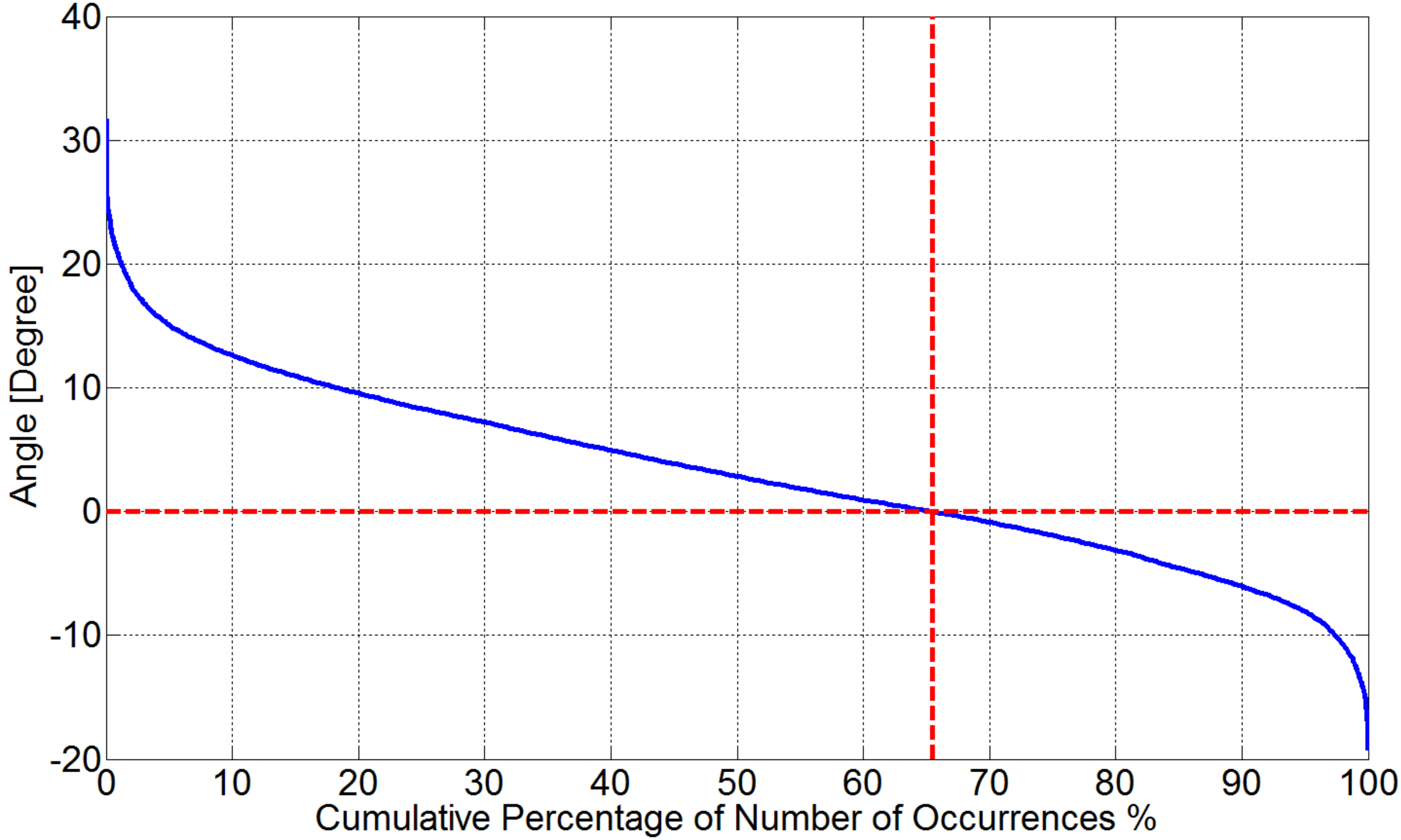
Box-Whisker Plots and Time Duration Curves

Electric Power Group CCET ERCOT

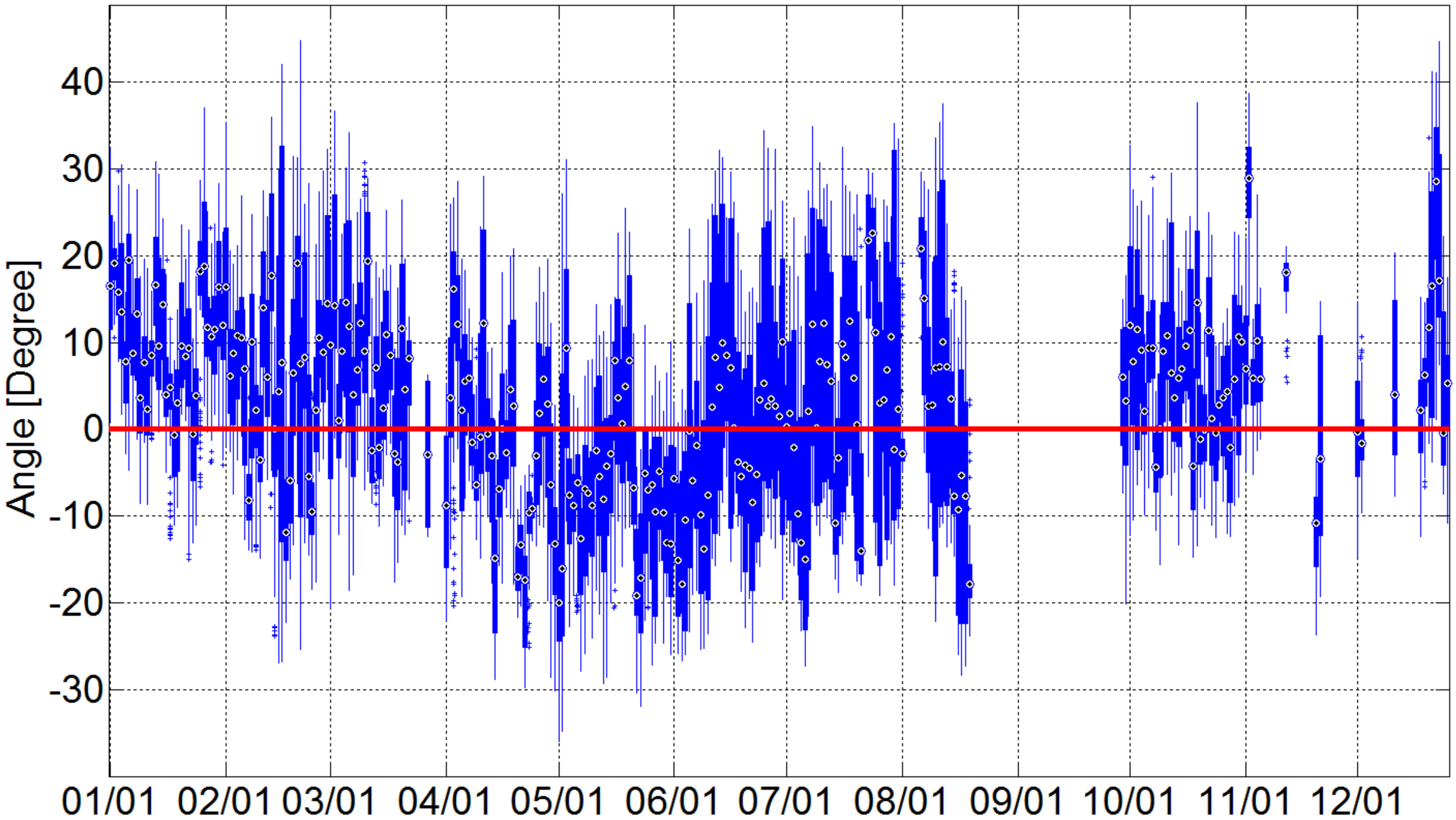
Coast 1-South 13



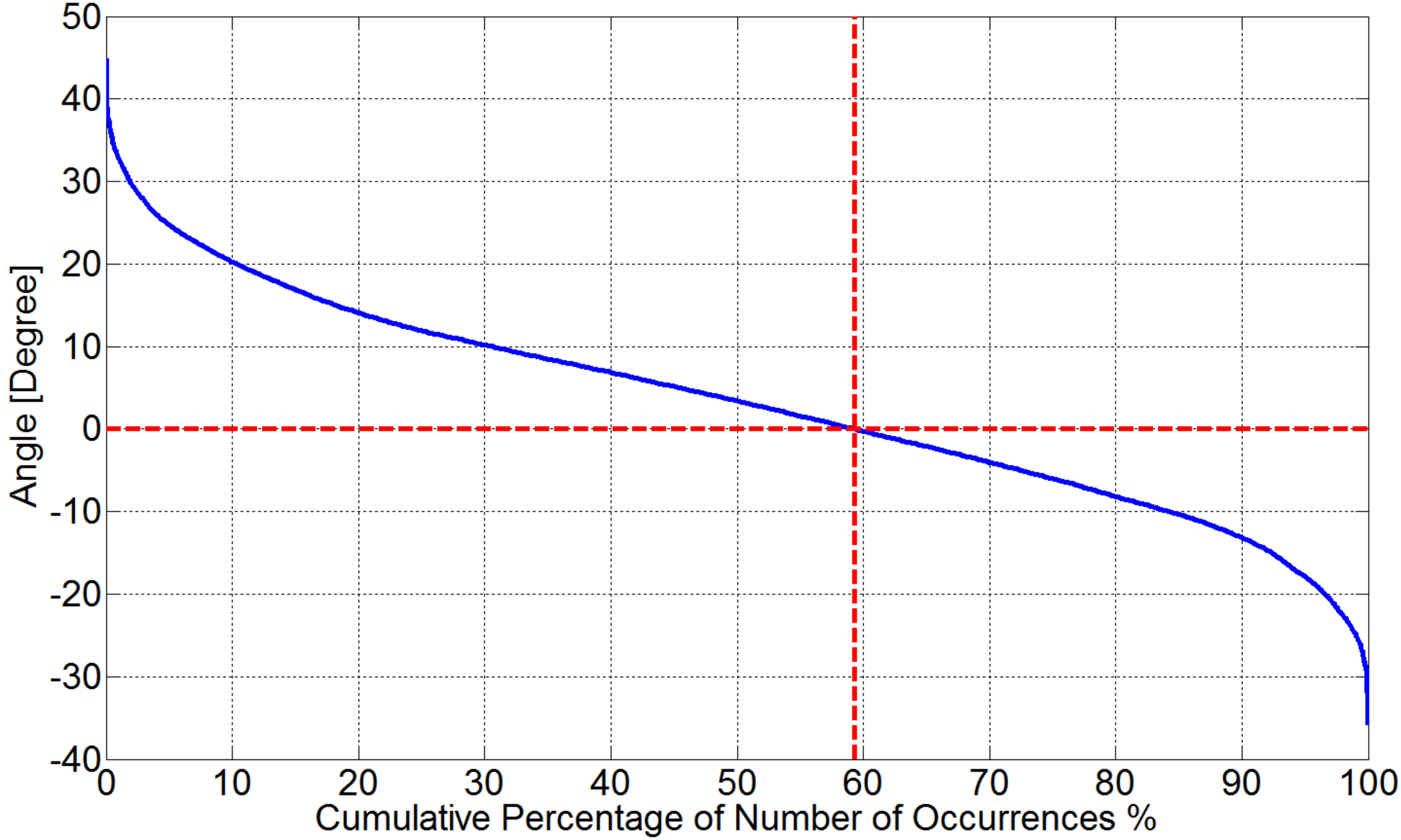
Coast 1-South 13



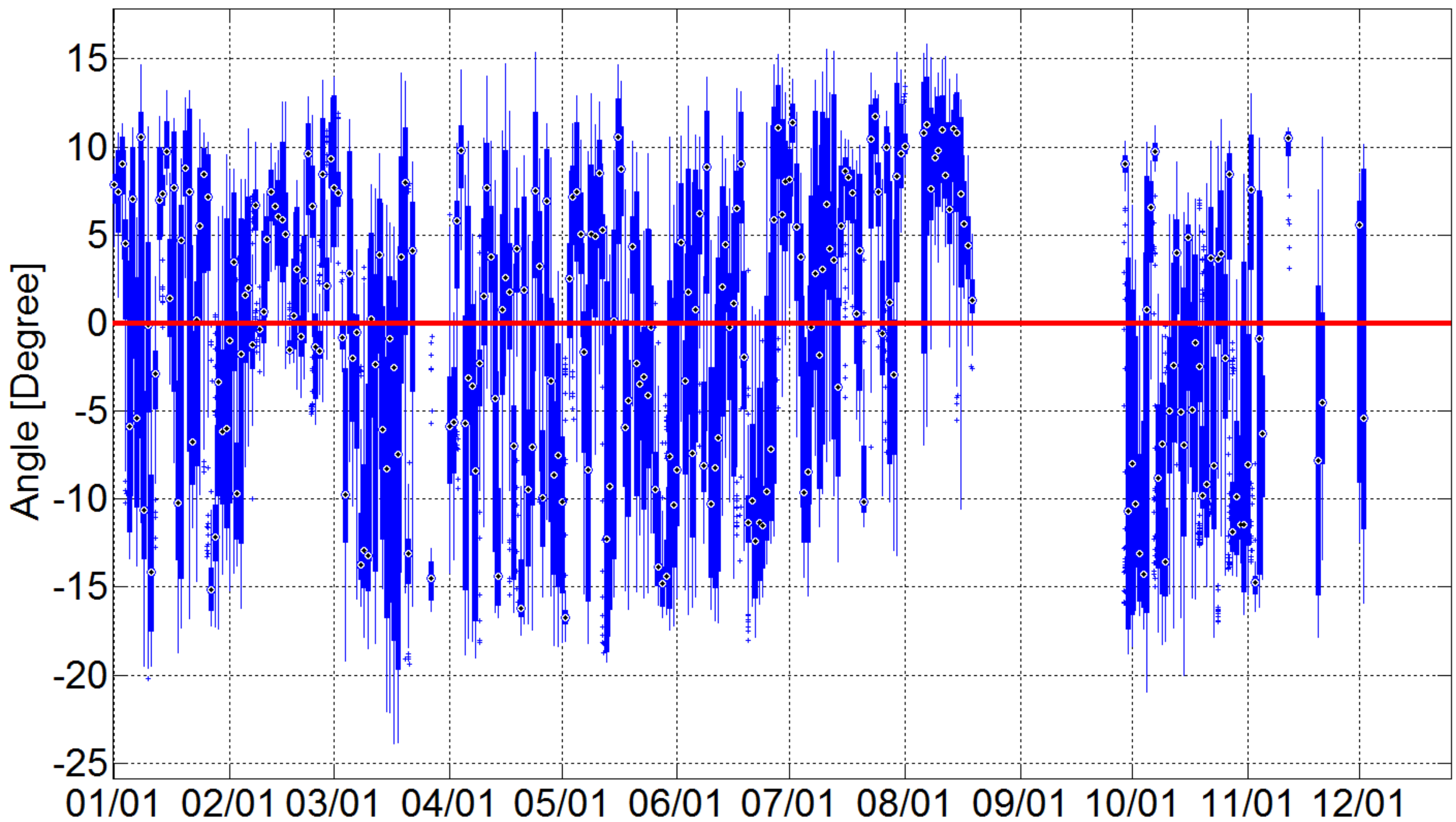
Coast 1-North 7



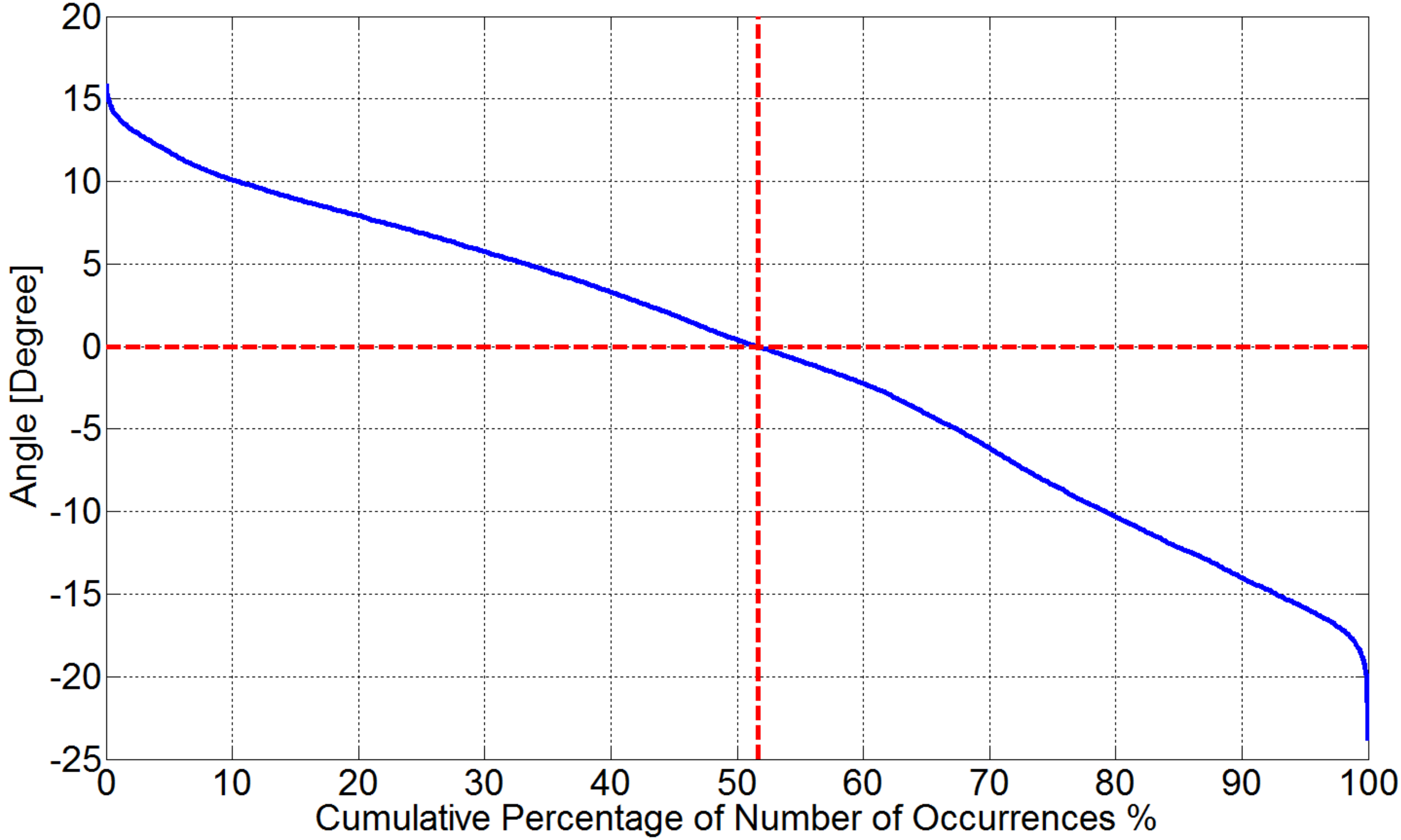
Coast 1-North 7



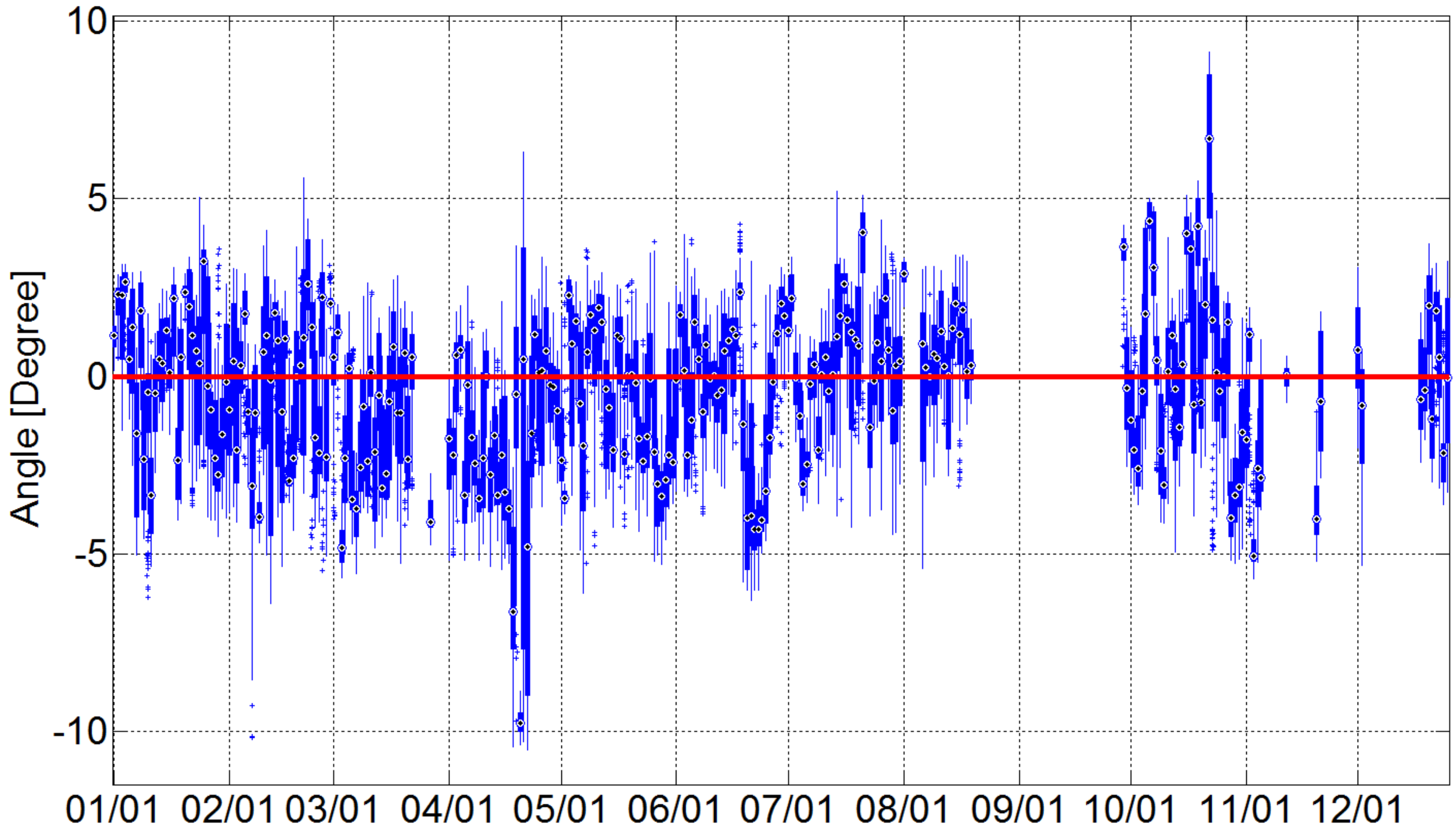
West 5-West 10



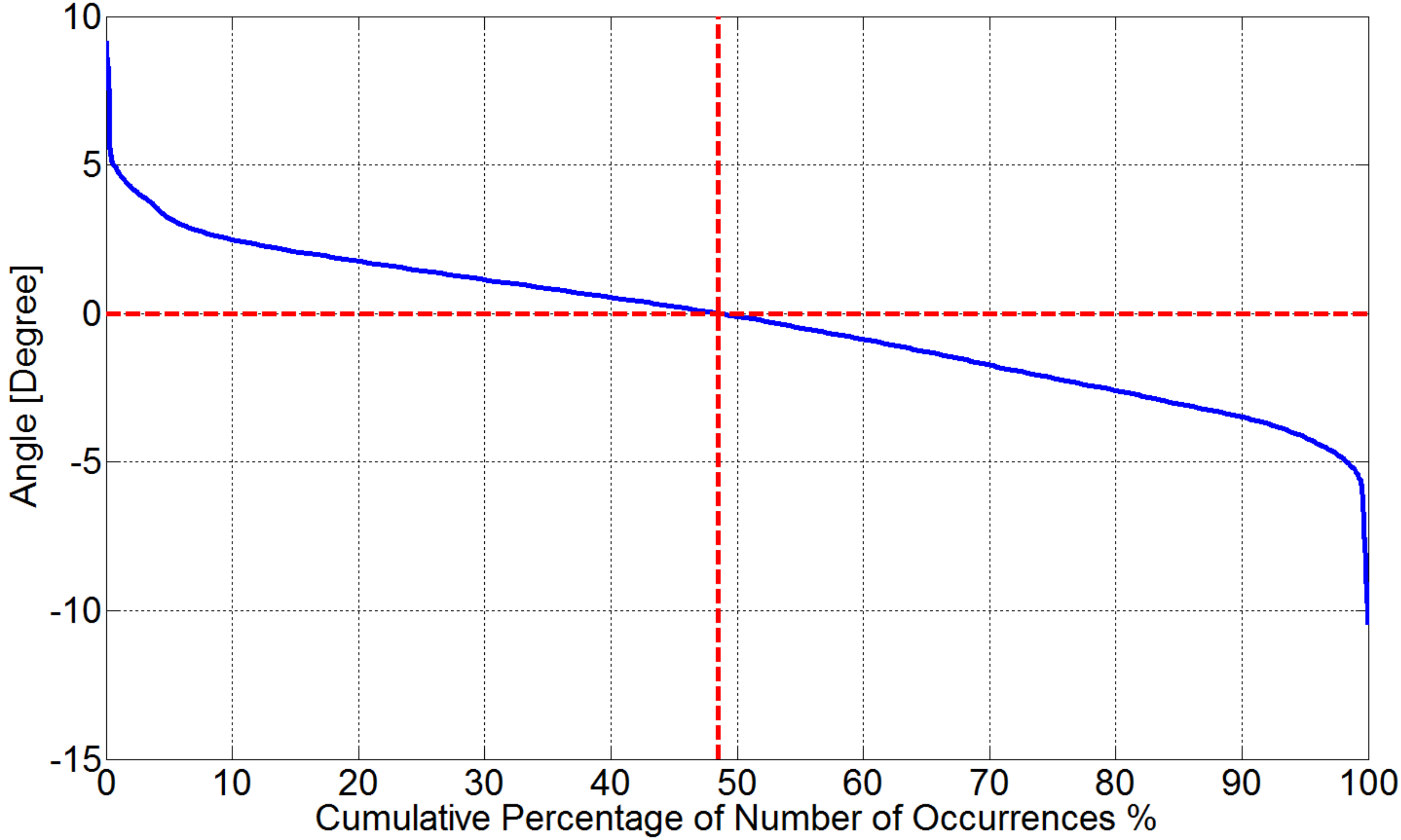
West 5-West 10



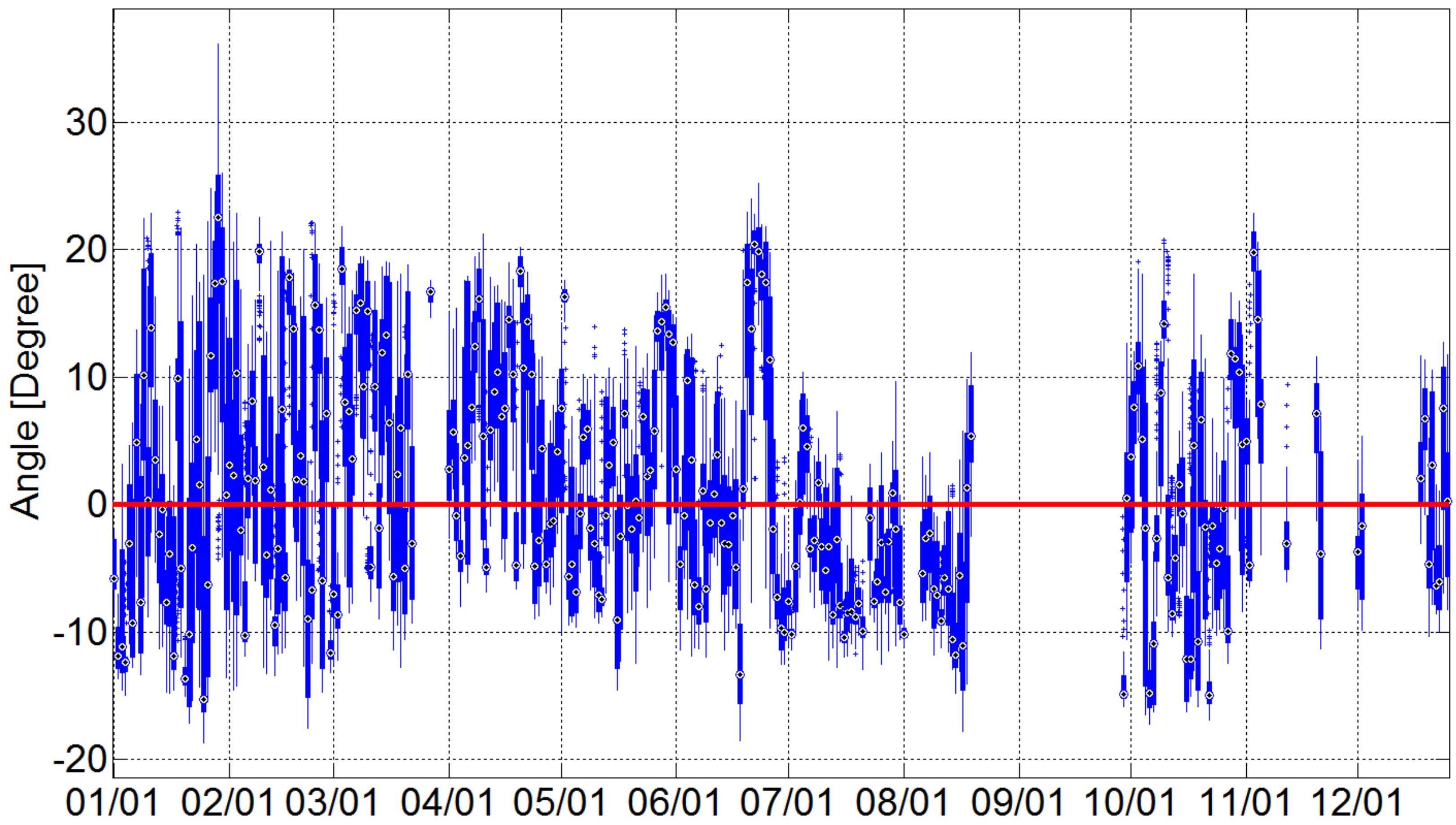
West 5-FarWest 4



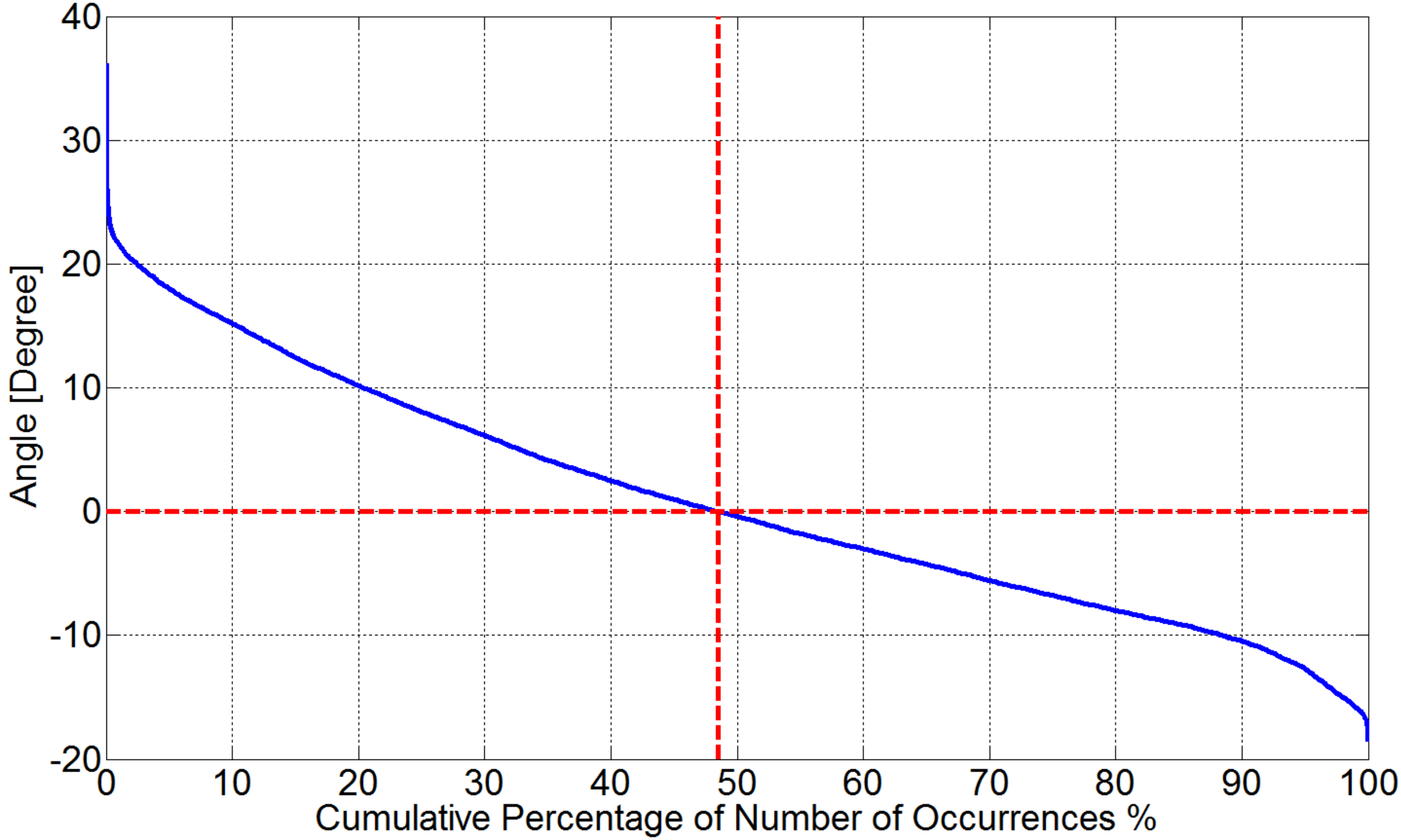
West 5-FarWest 4



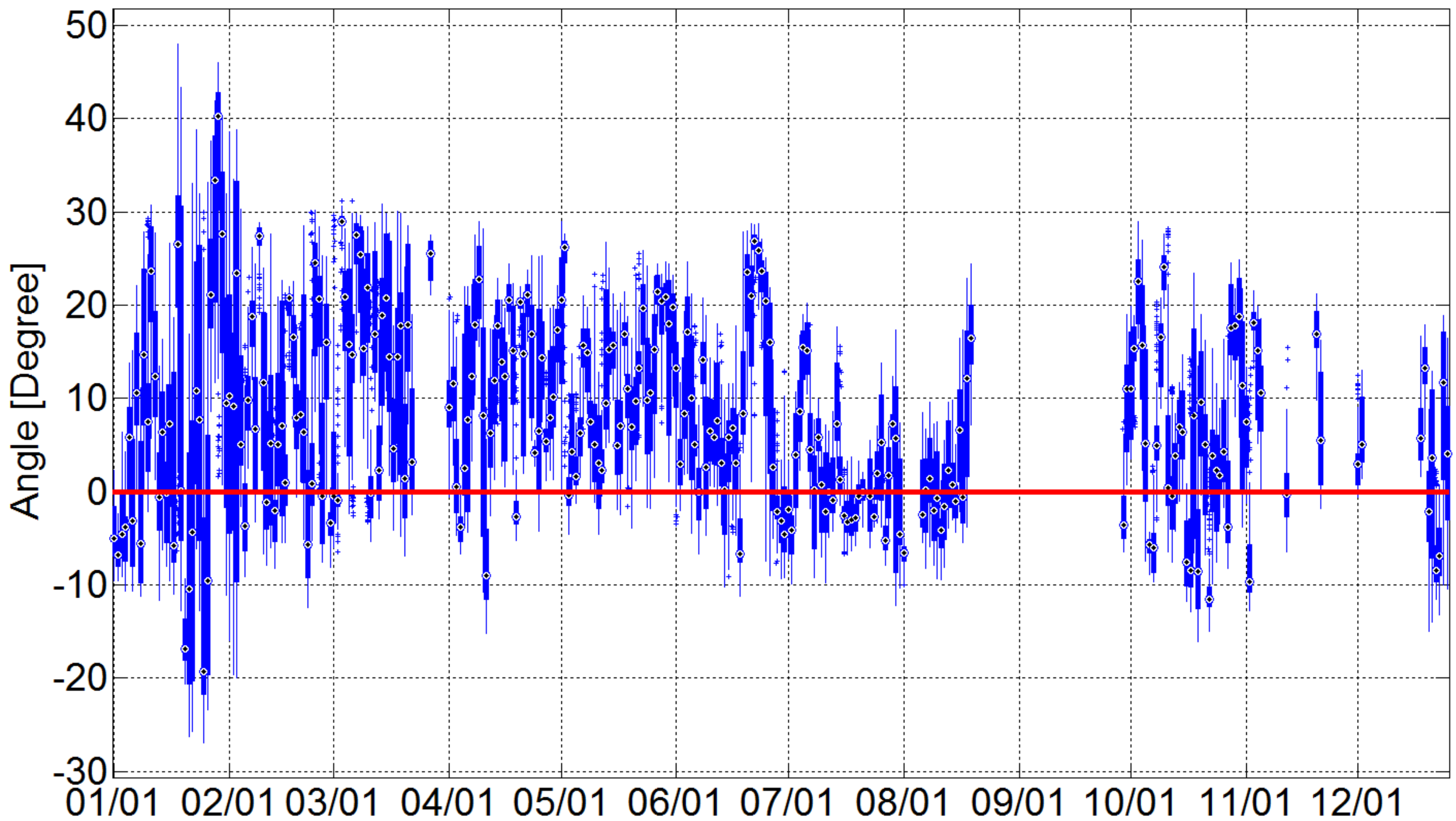
West 5-North 1



West 5-North 1



West 5-North 7



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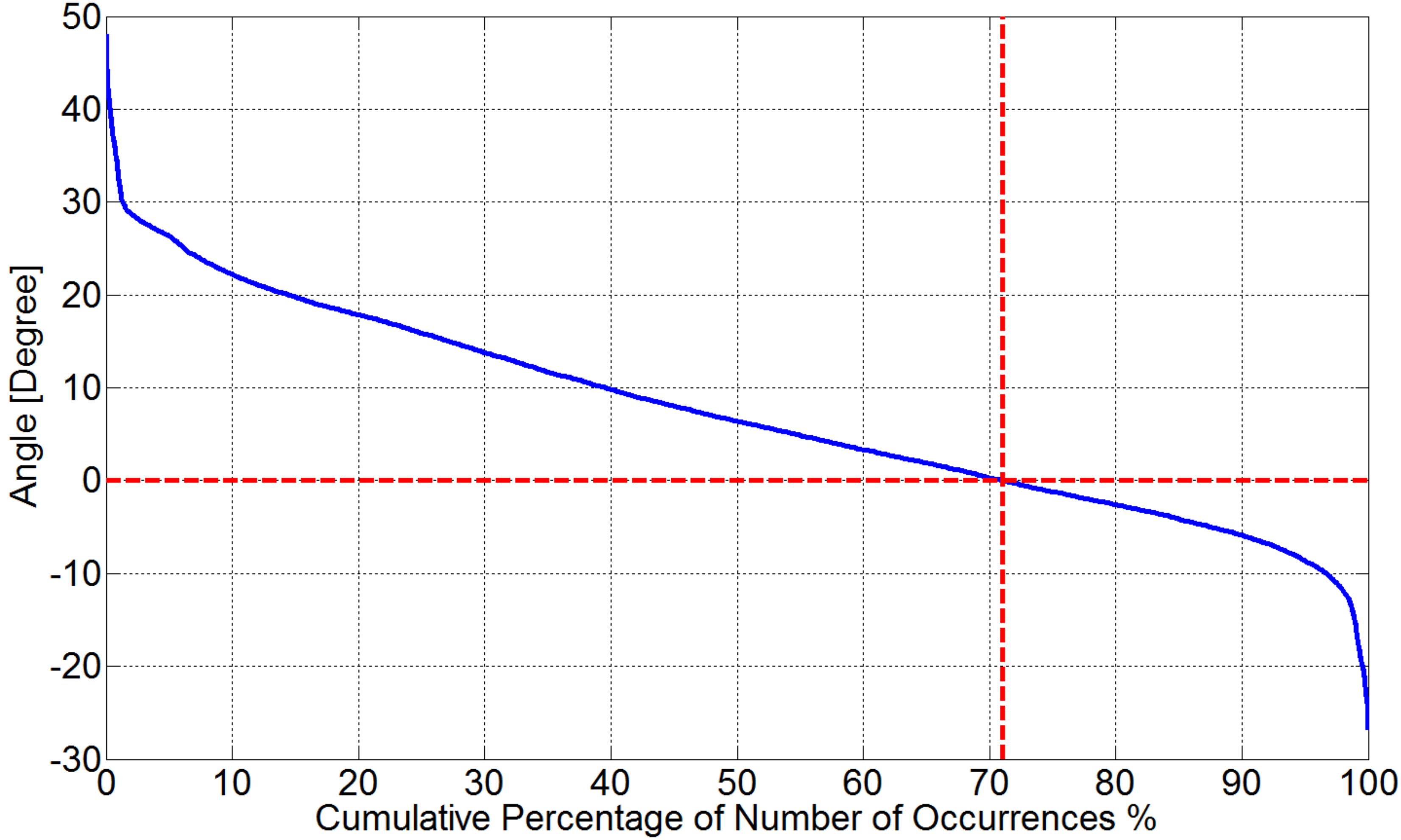
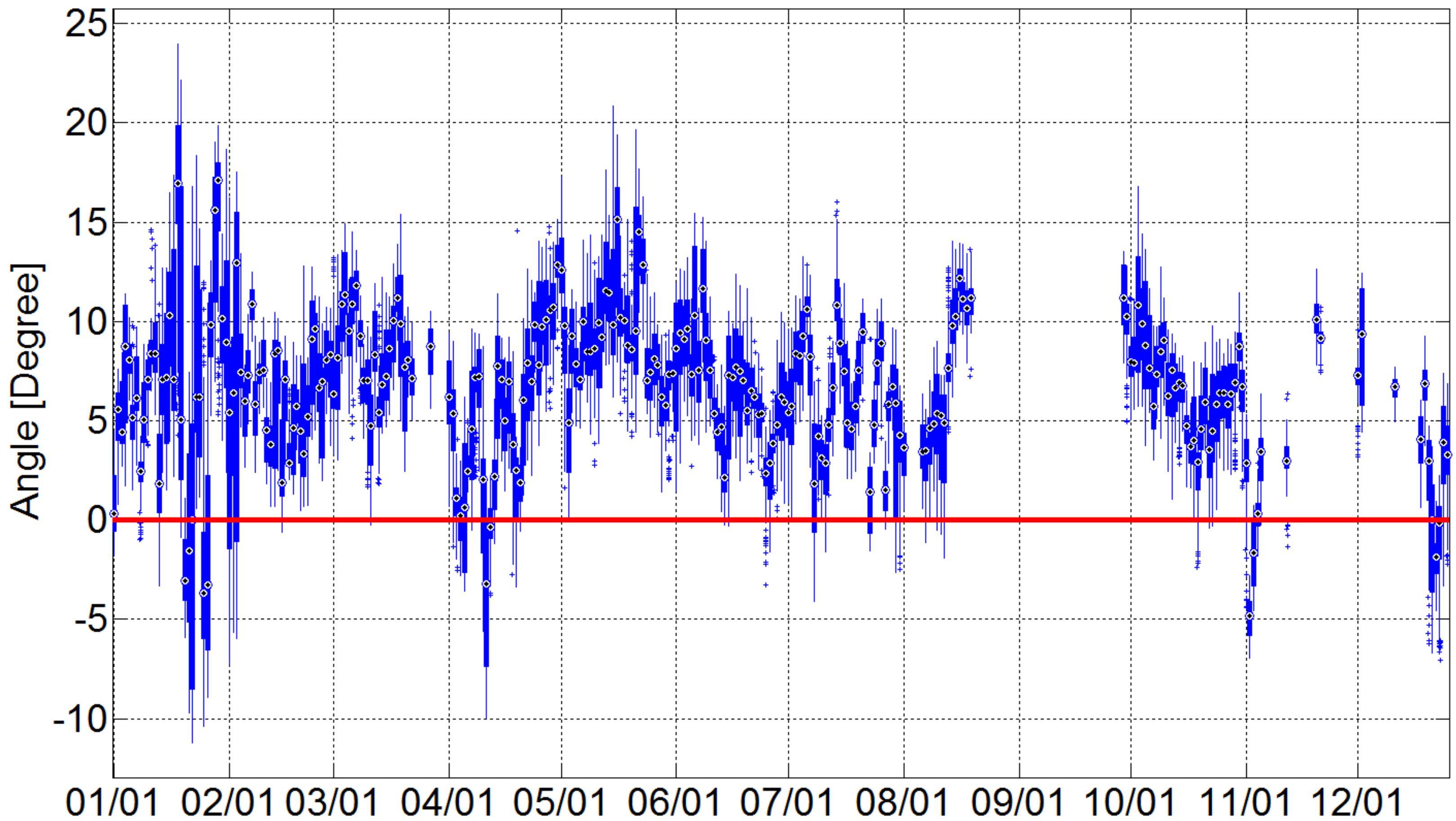


North 1-North 7



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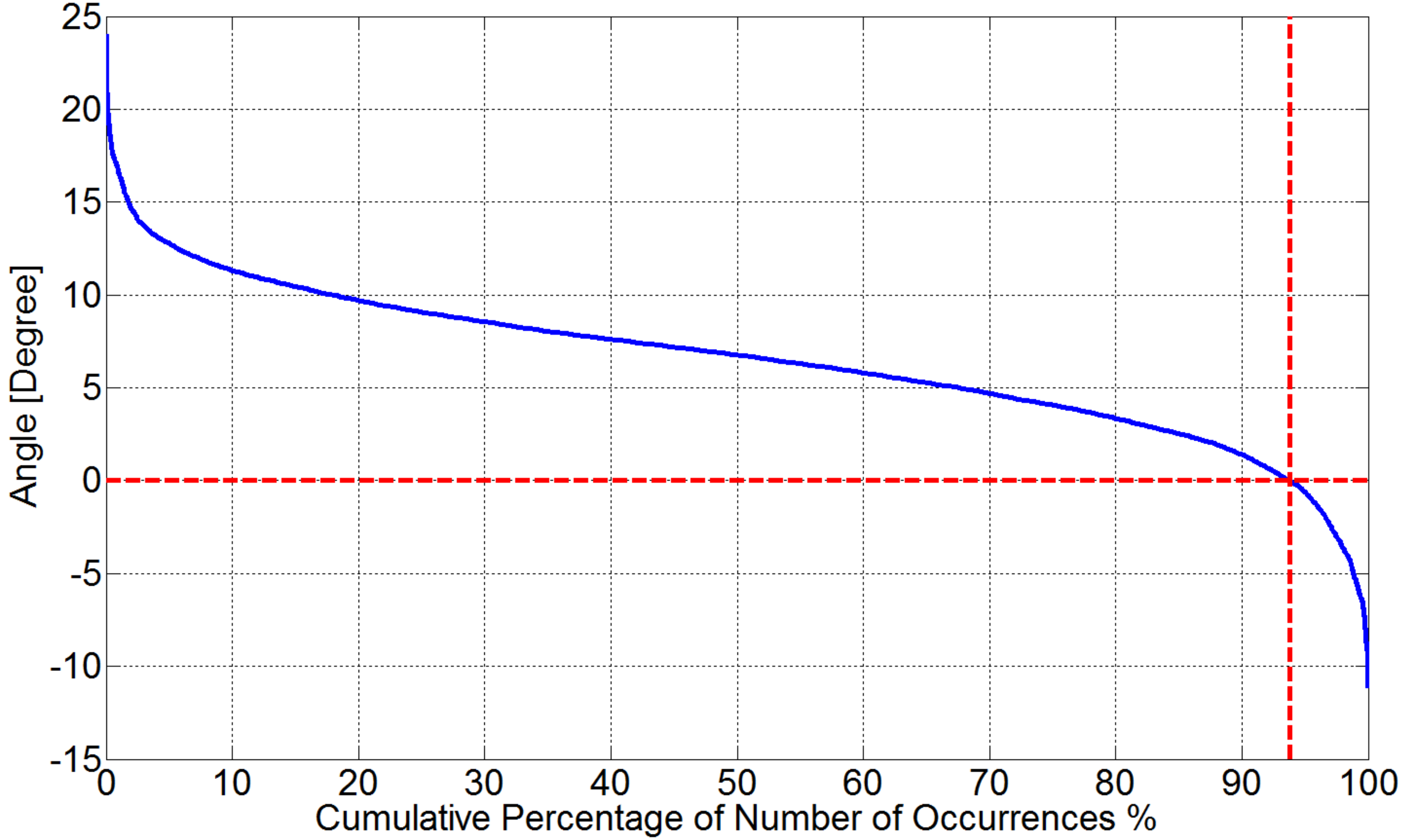
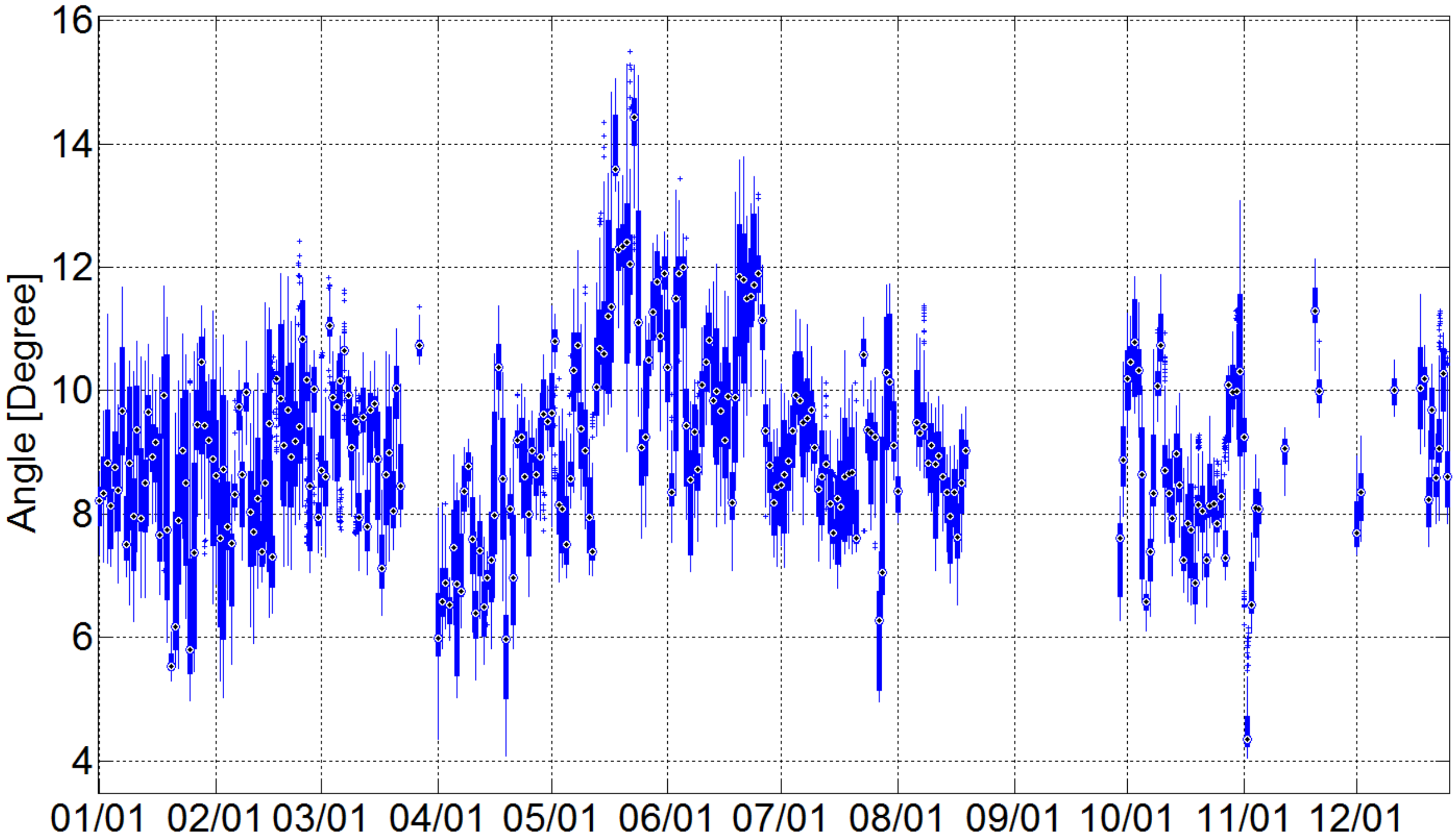


North 1-North 4



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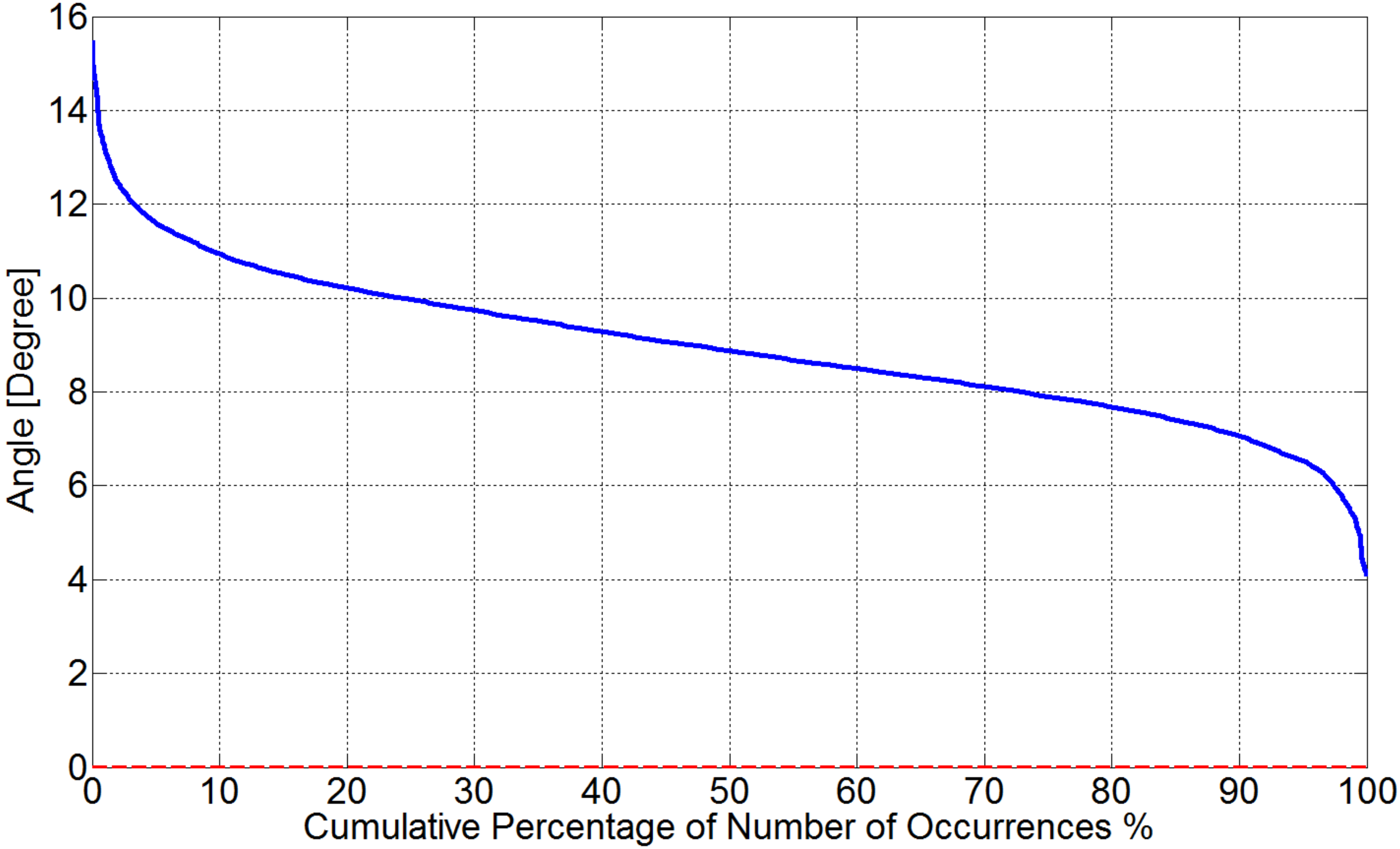
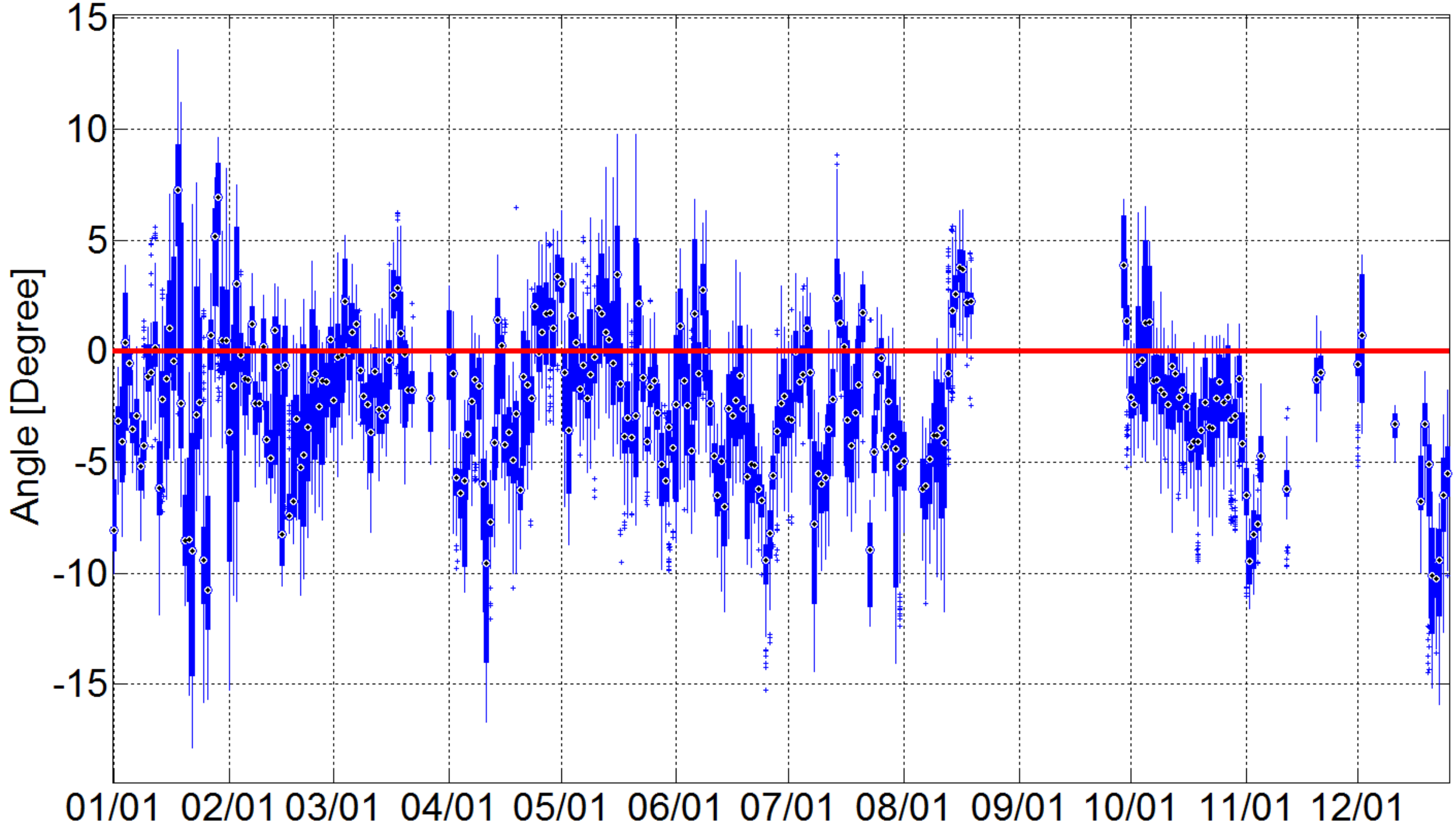


North 4-North 7



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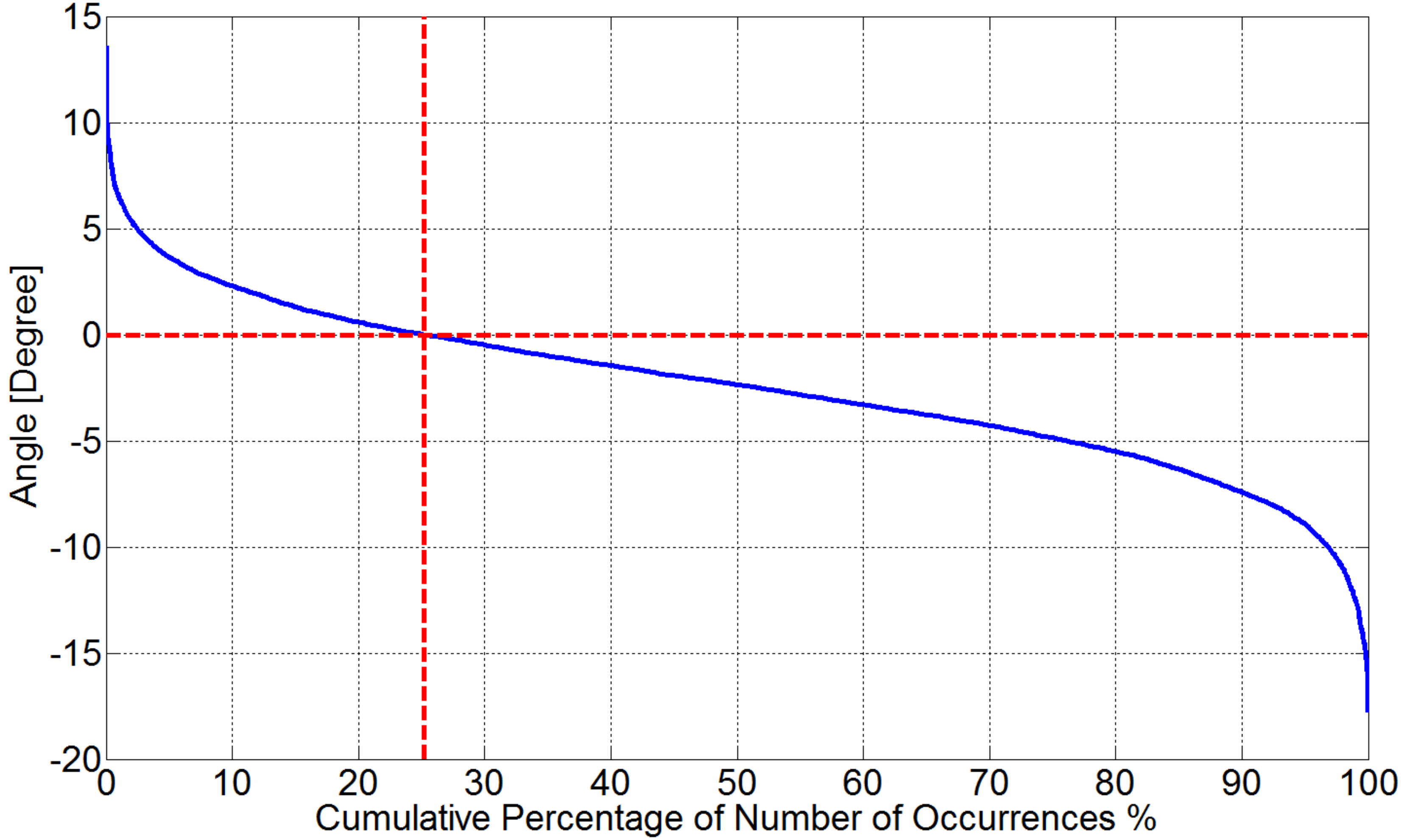
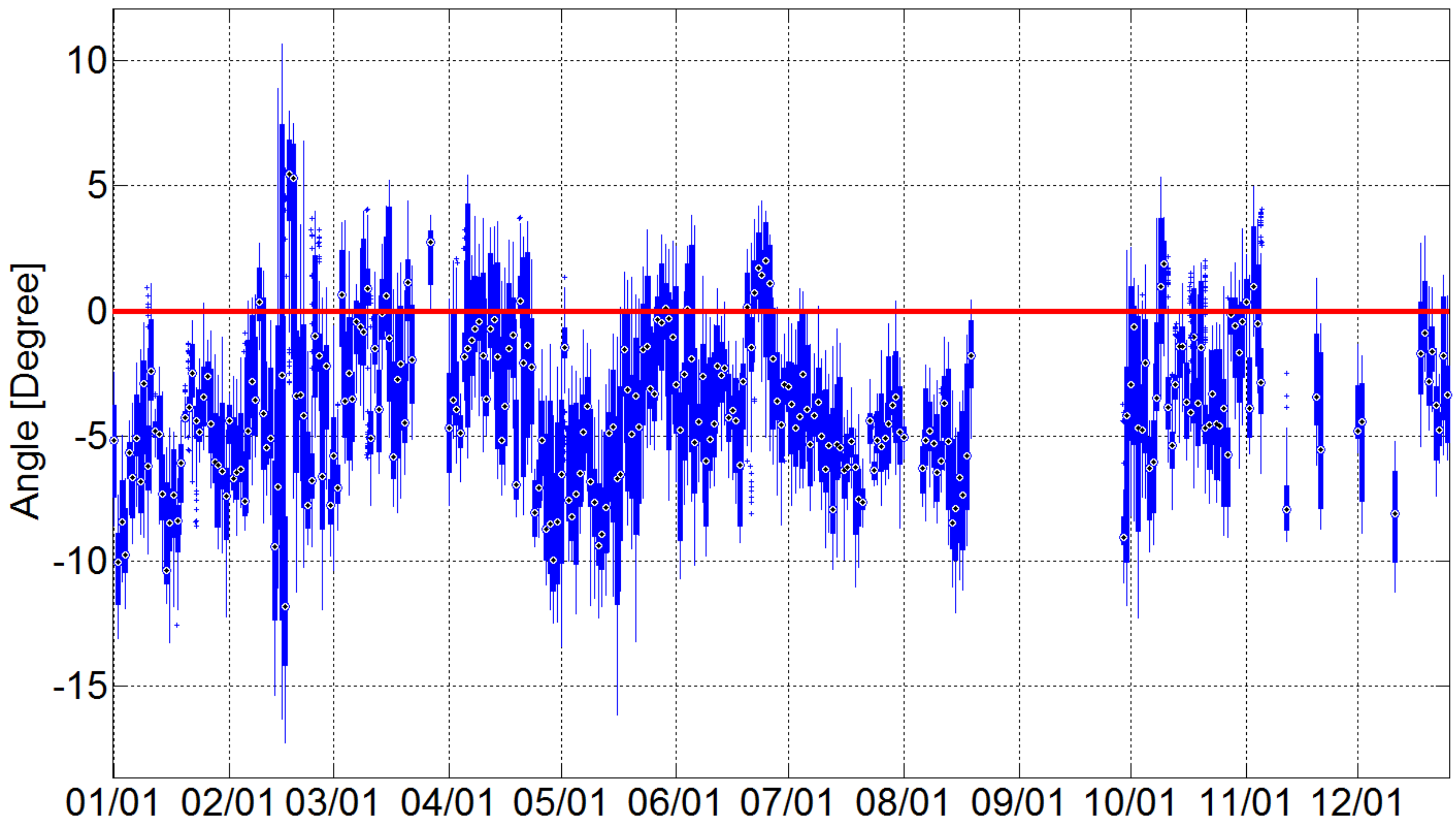
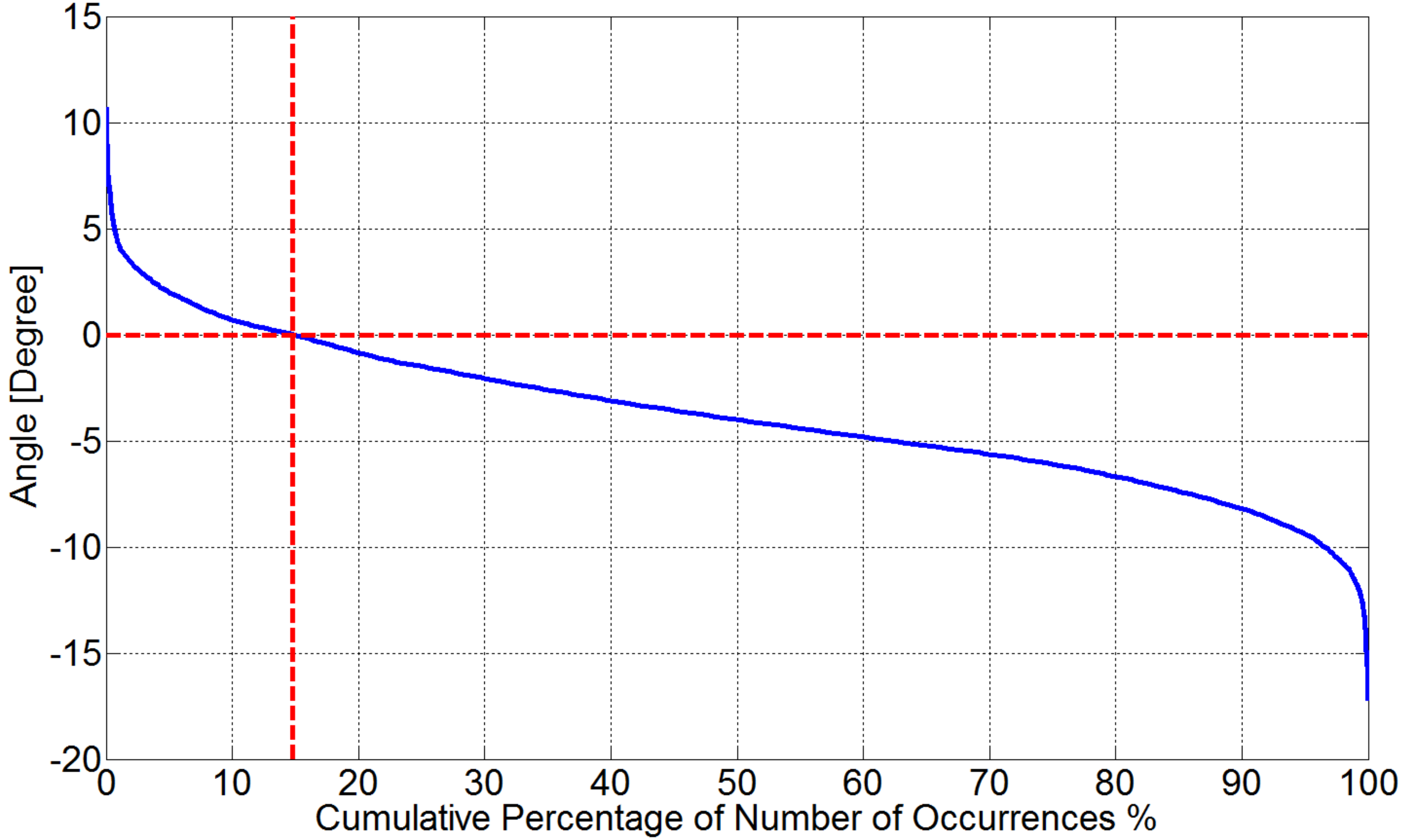


North 7-North 6



North 7-North 6



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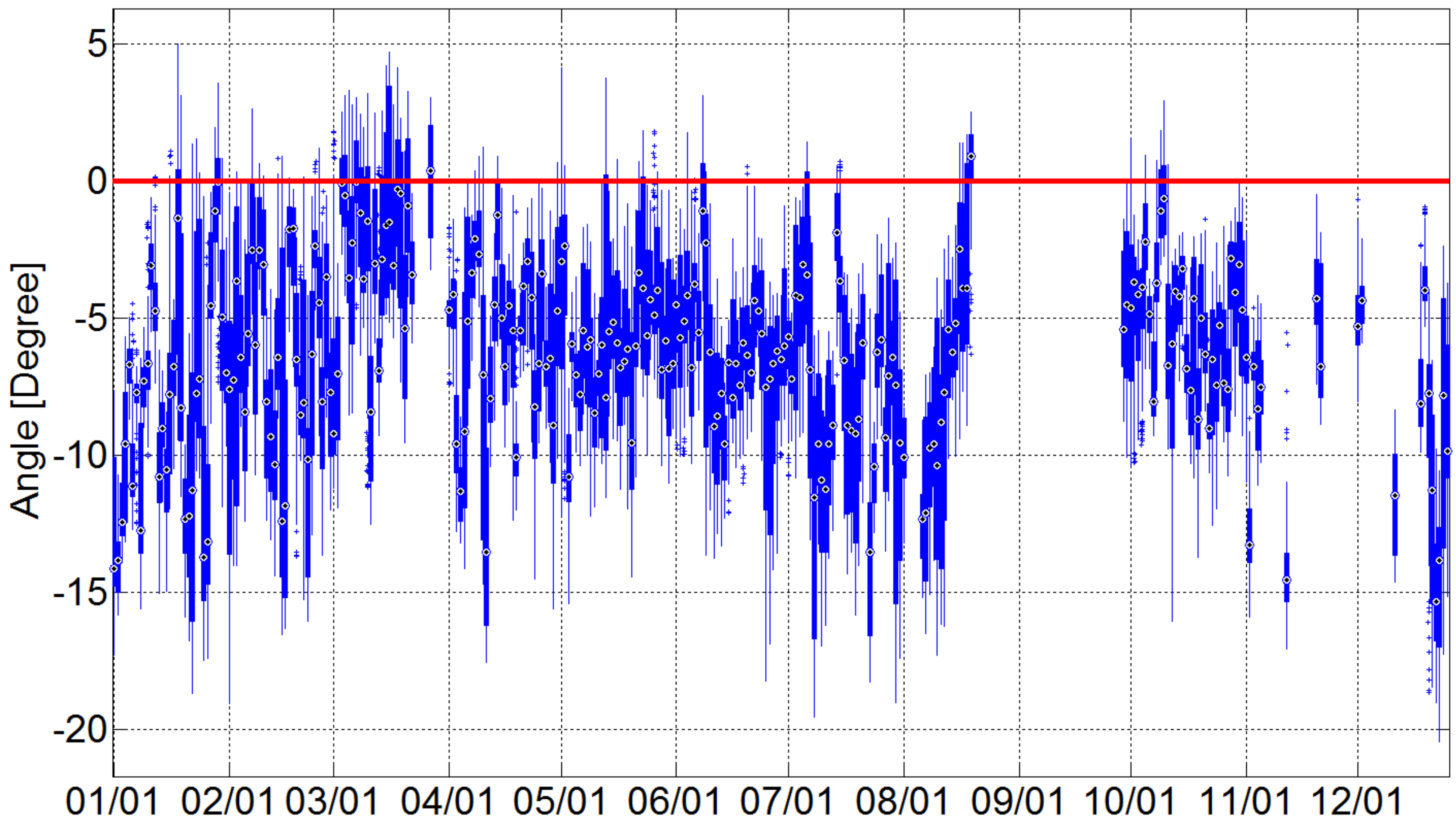
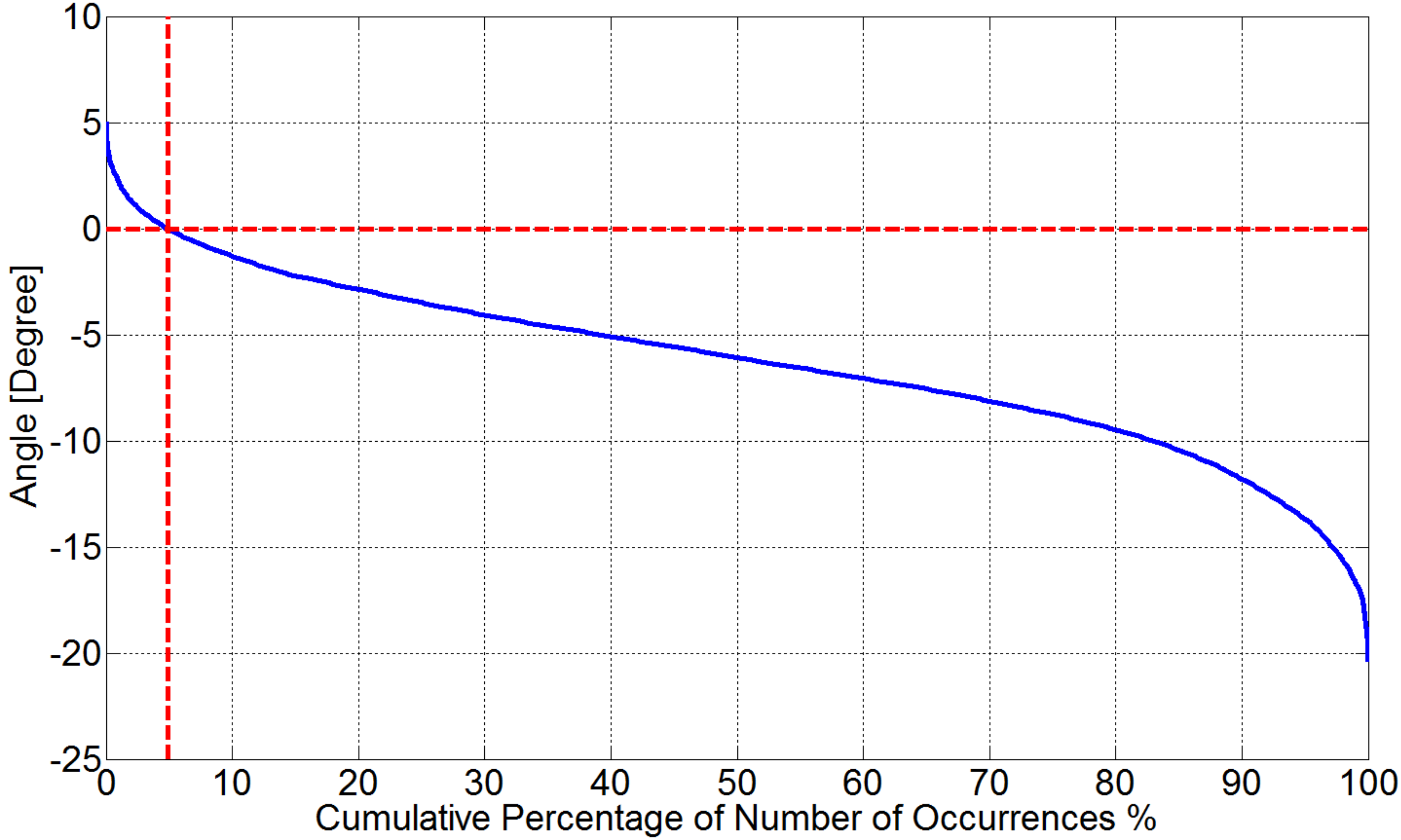
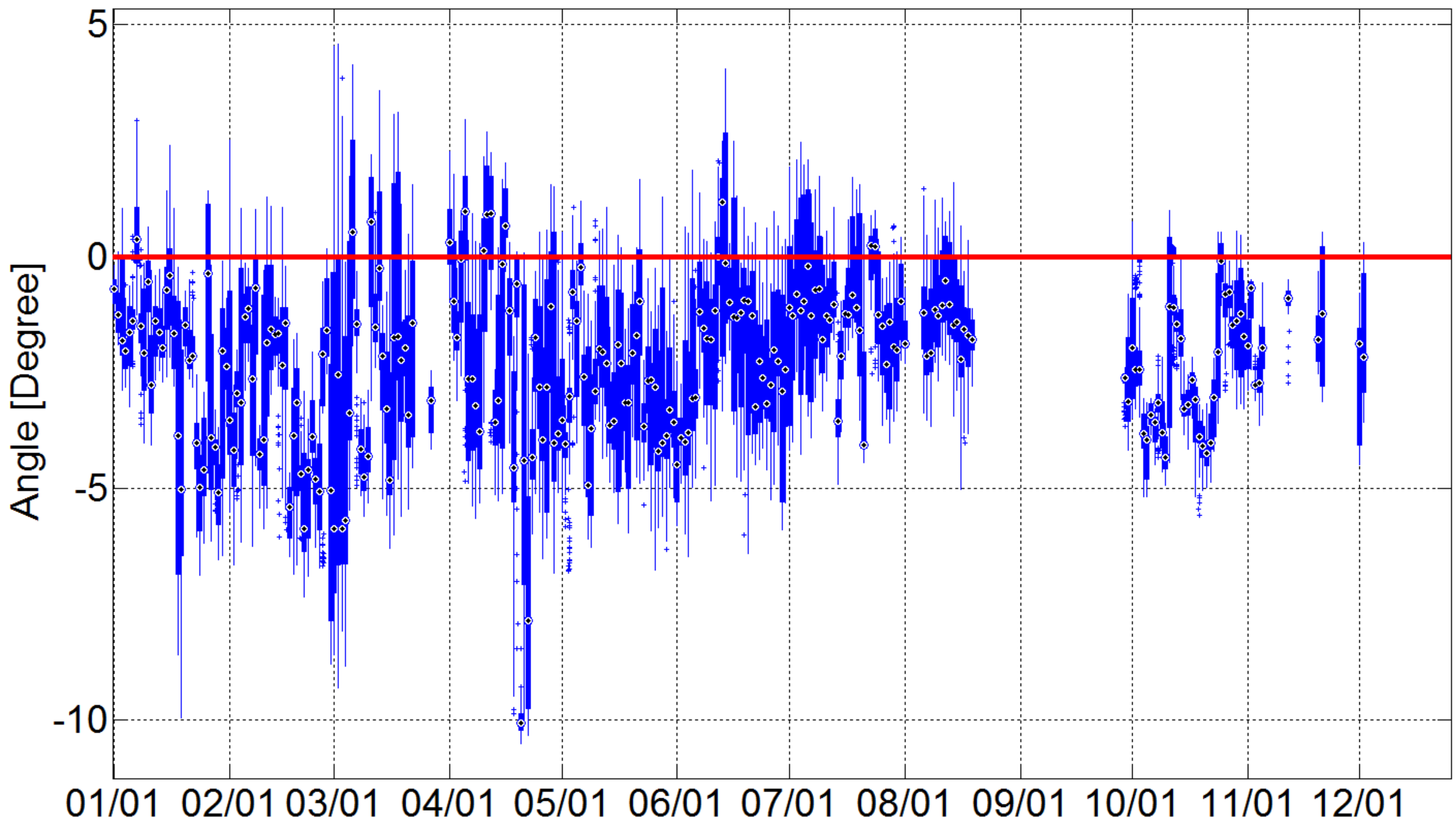


North 4-North 6



FarWest 7-FarWest 4



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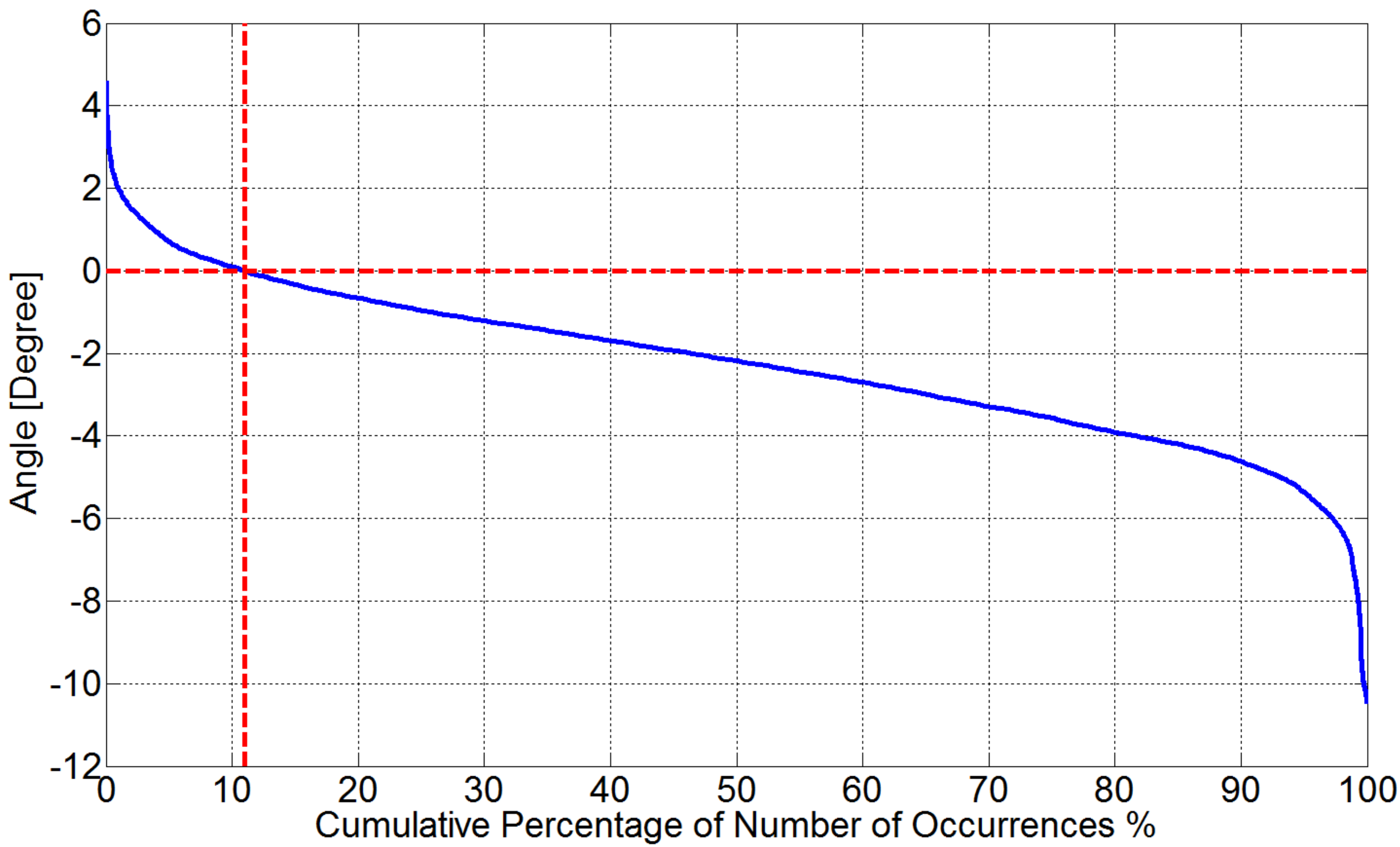
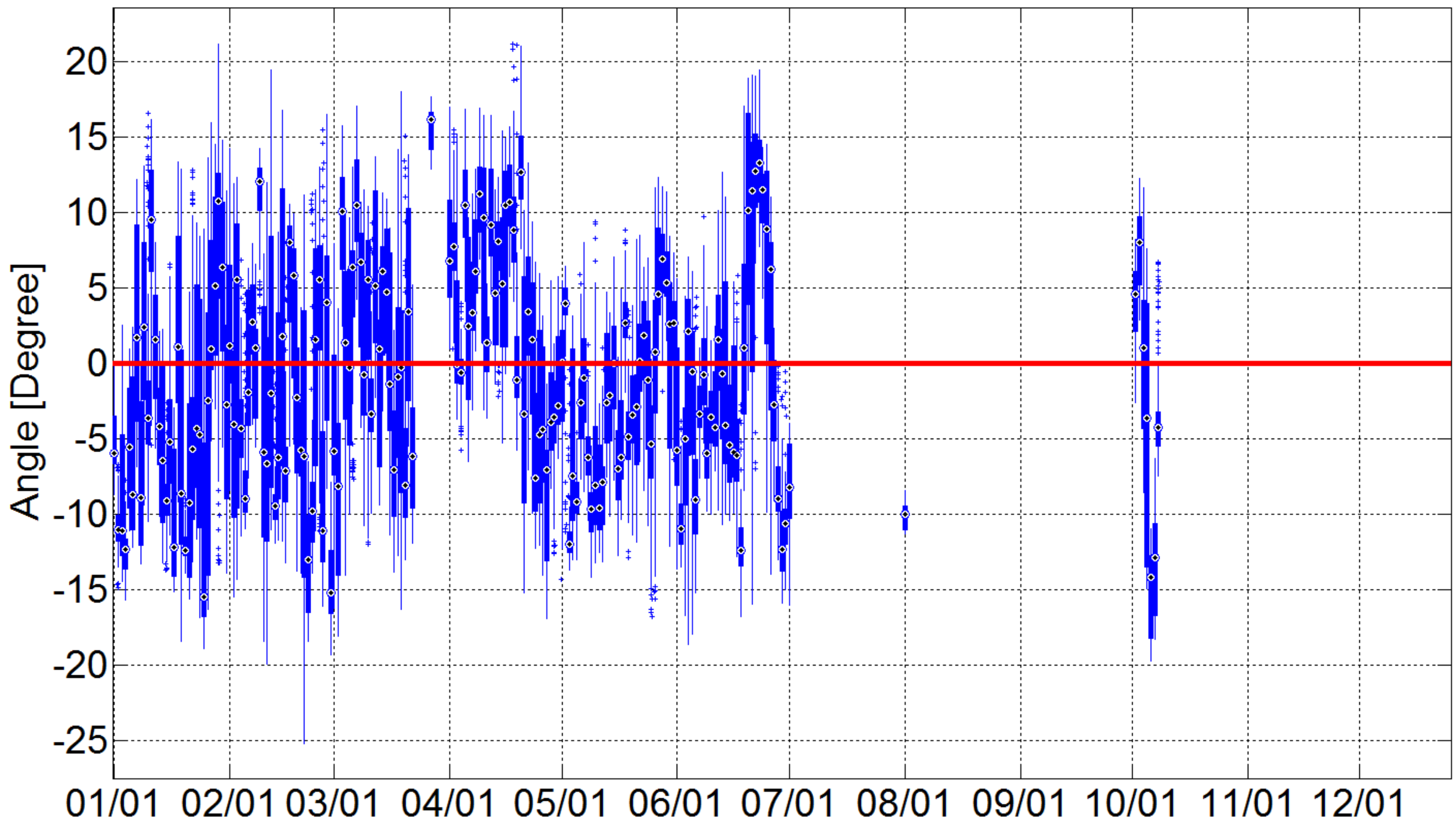


FarWest 7-West 14



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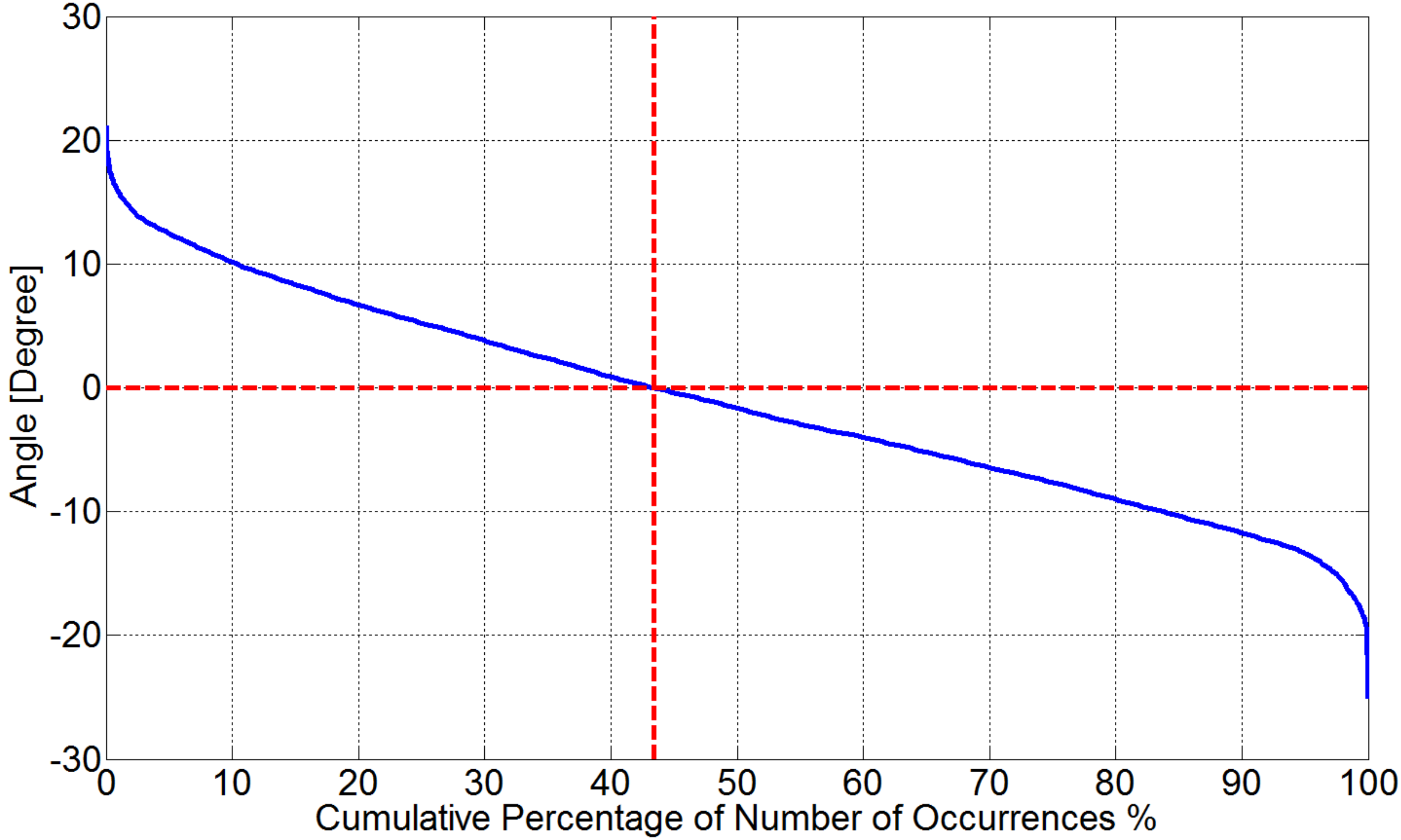

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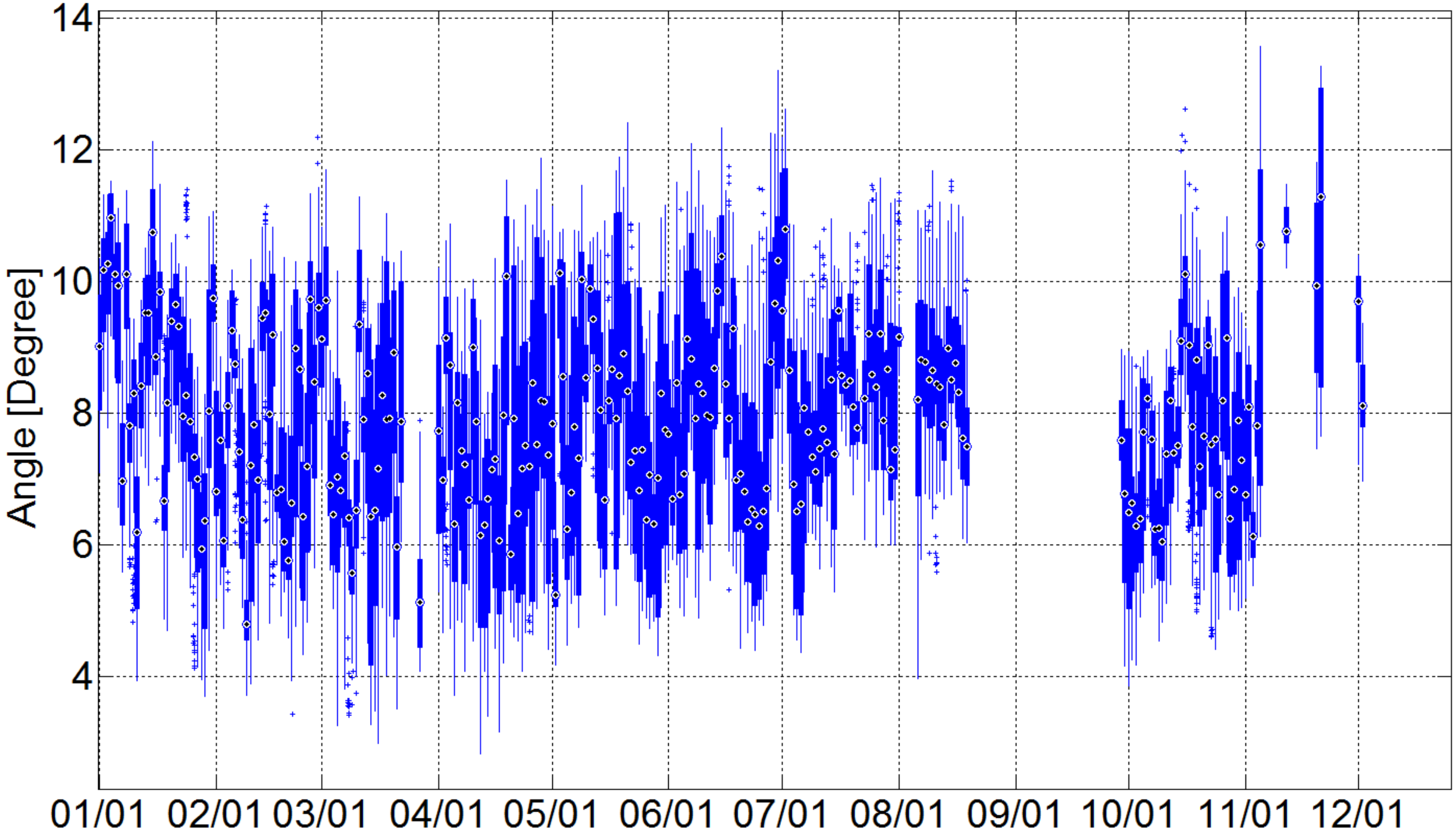

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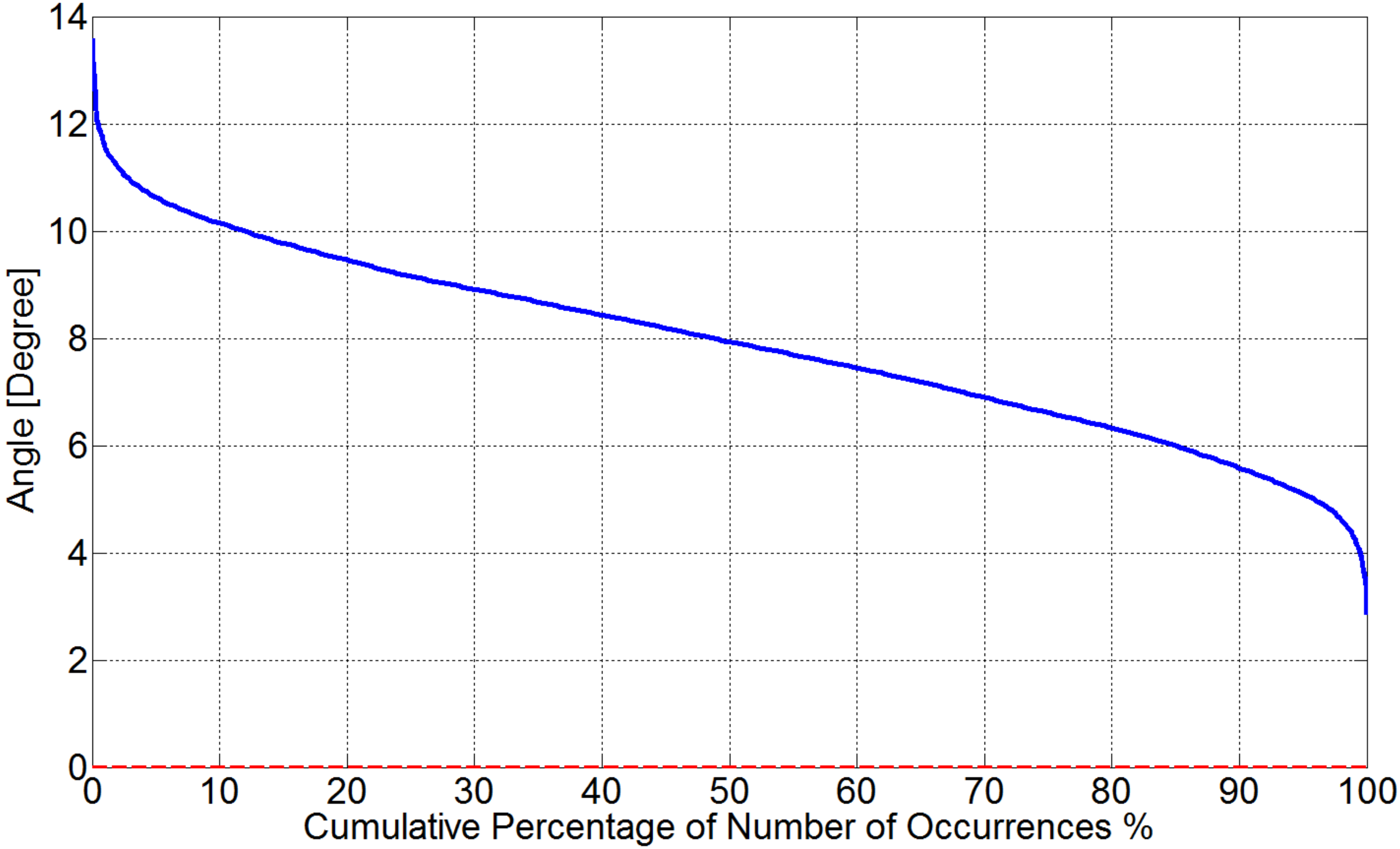

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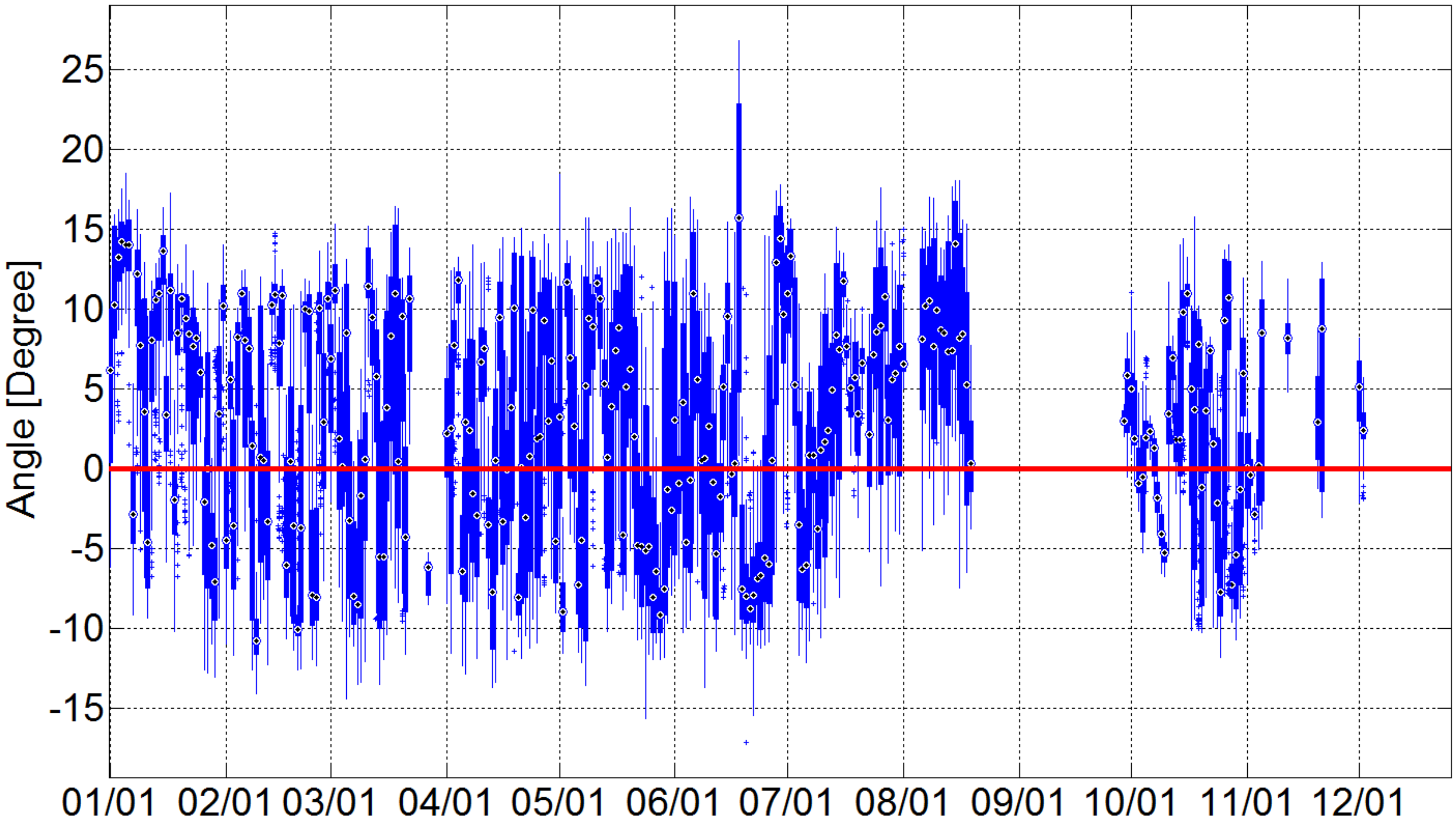

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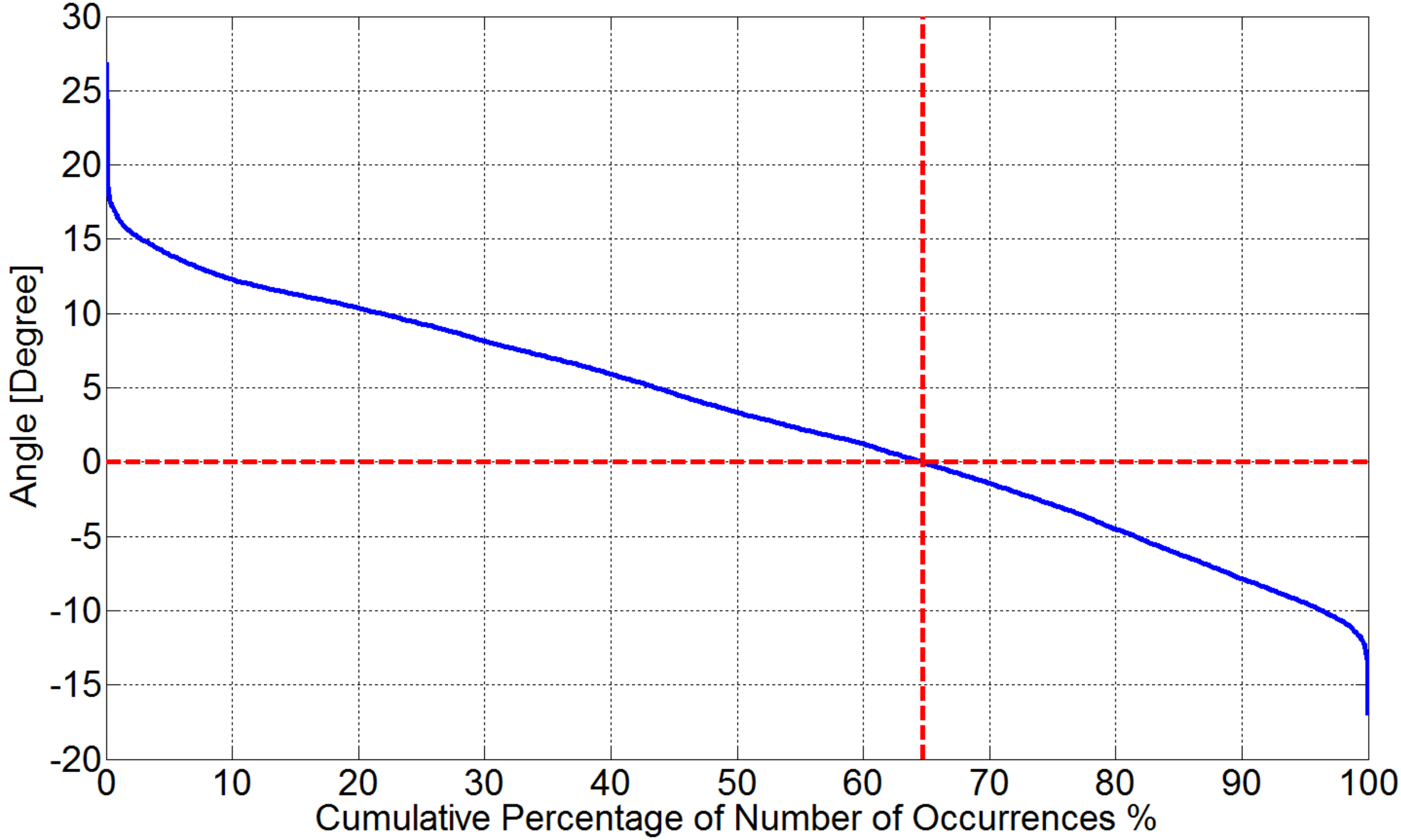

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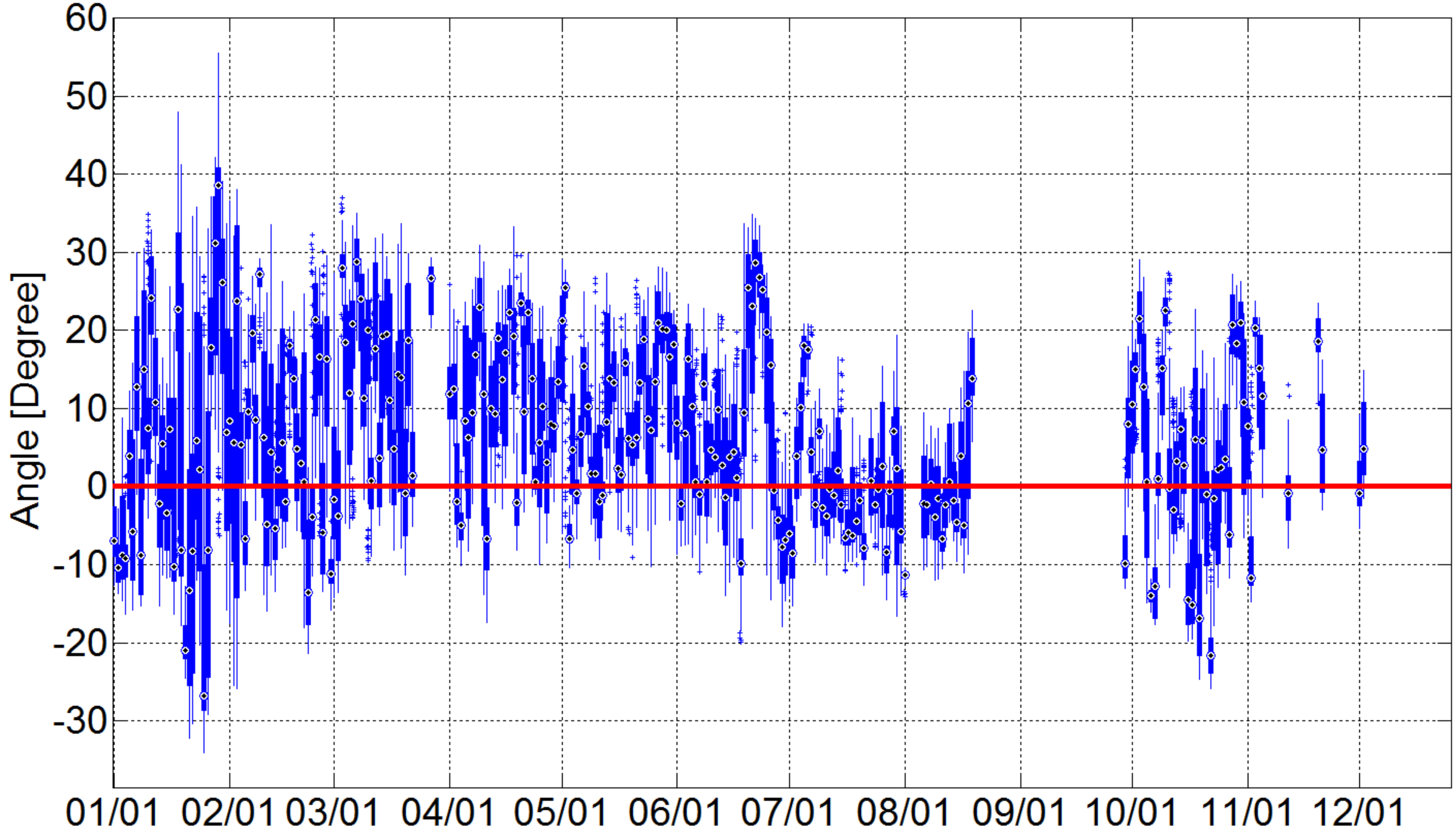

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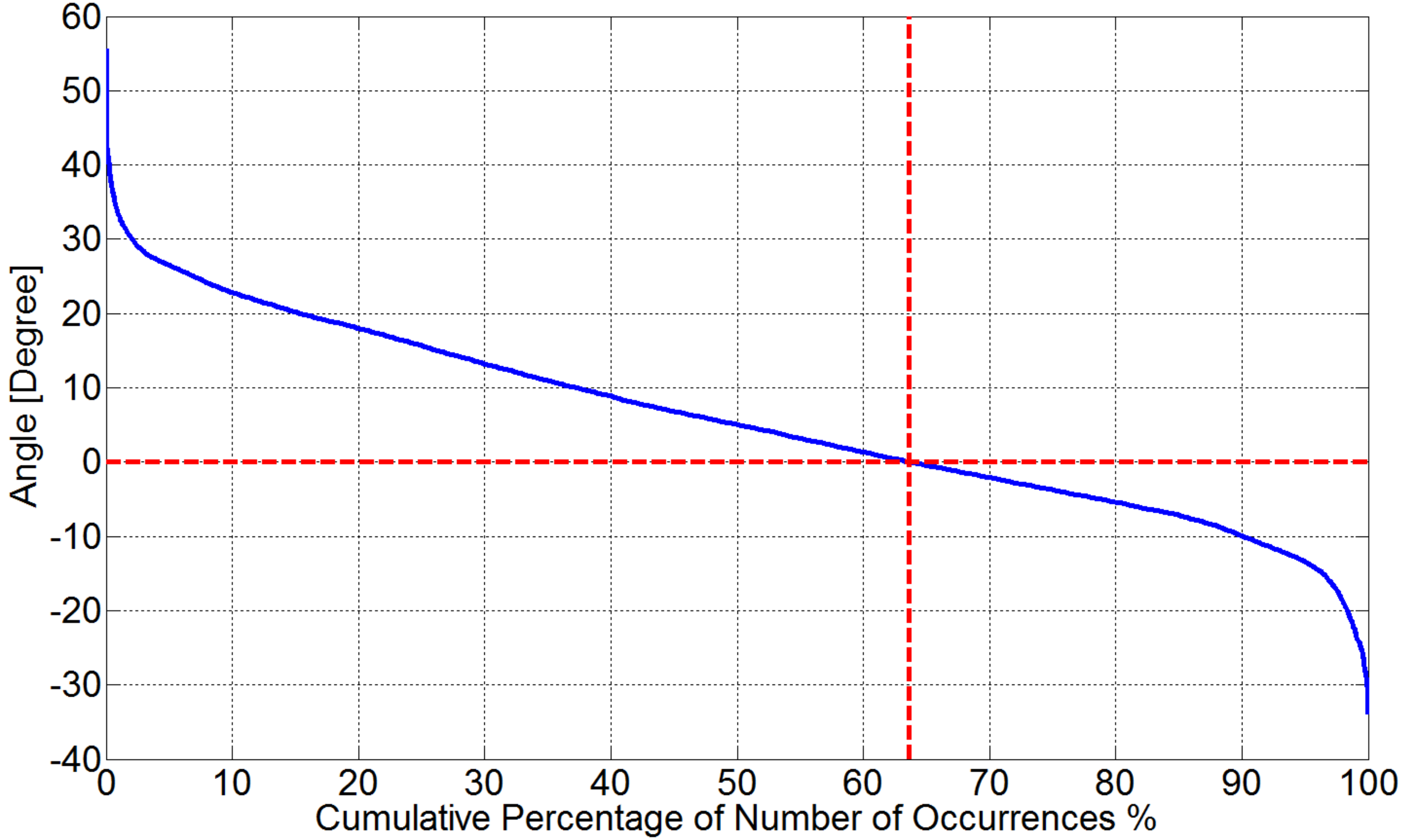
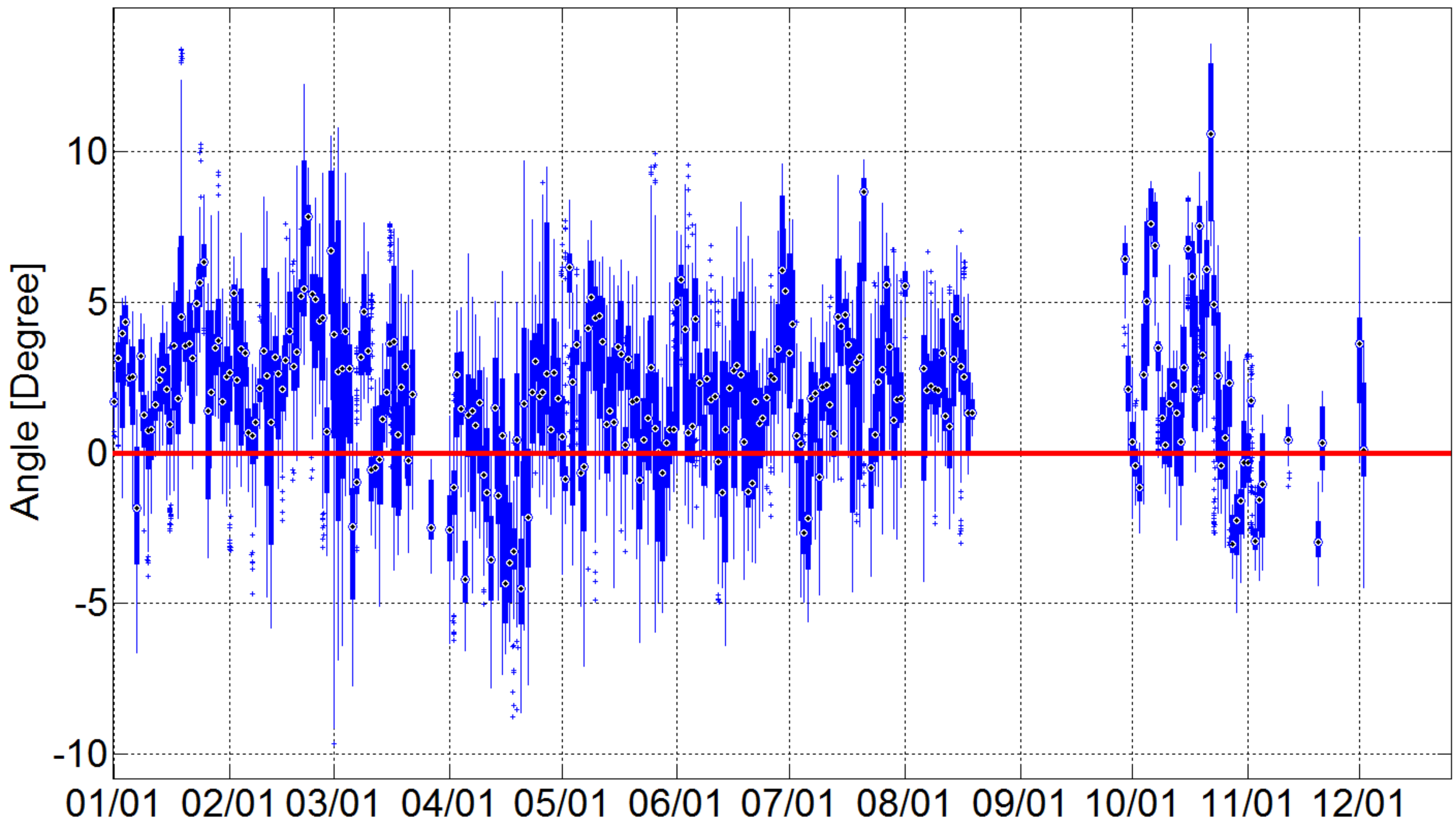


West 12-FarWest 7



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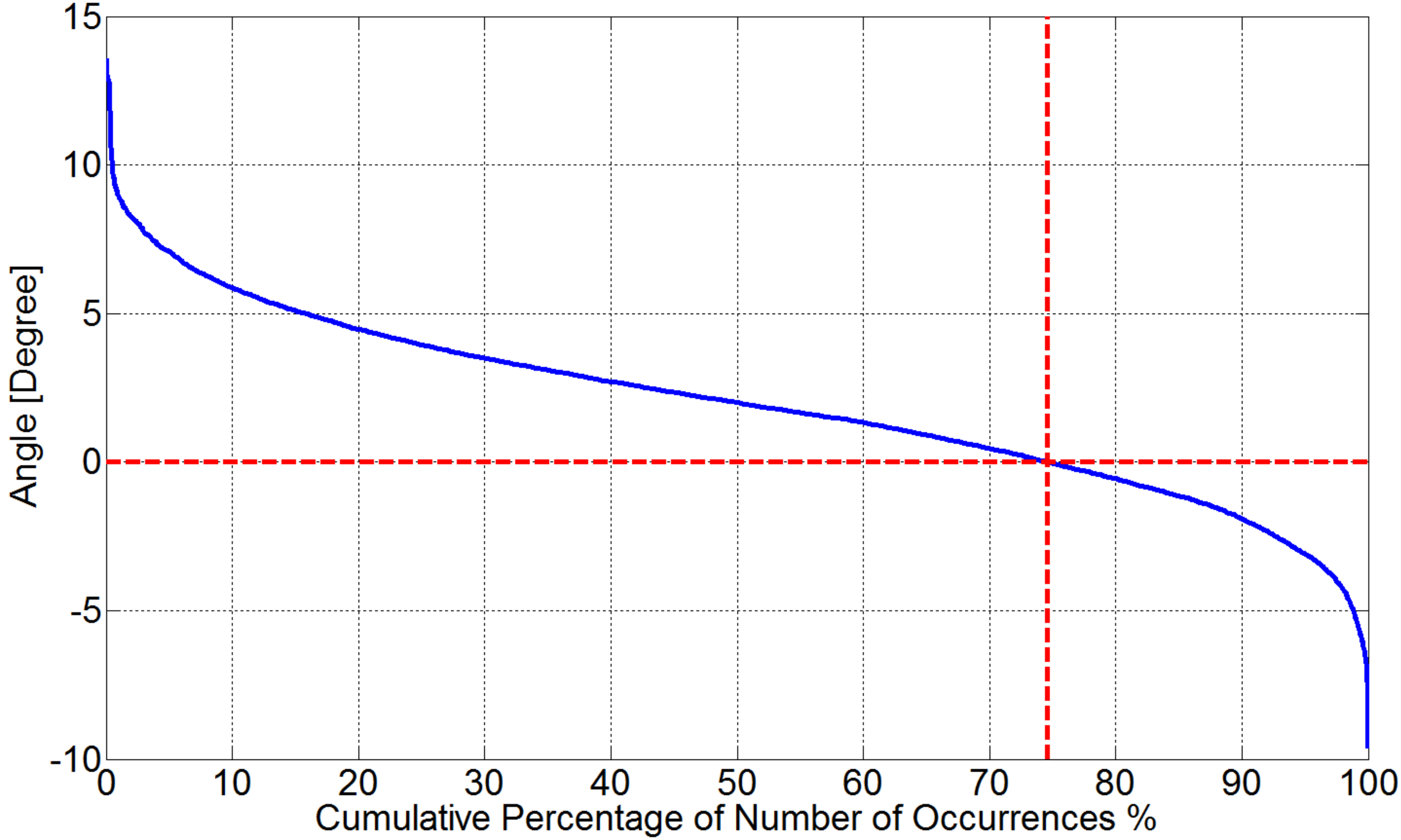

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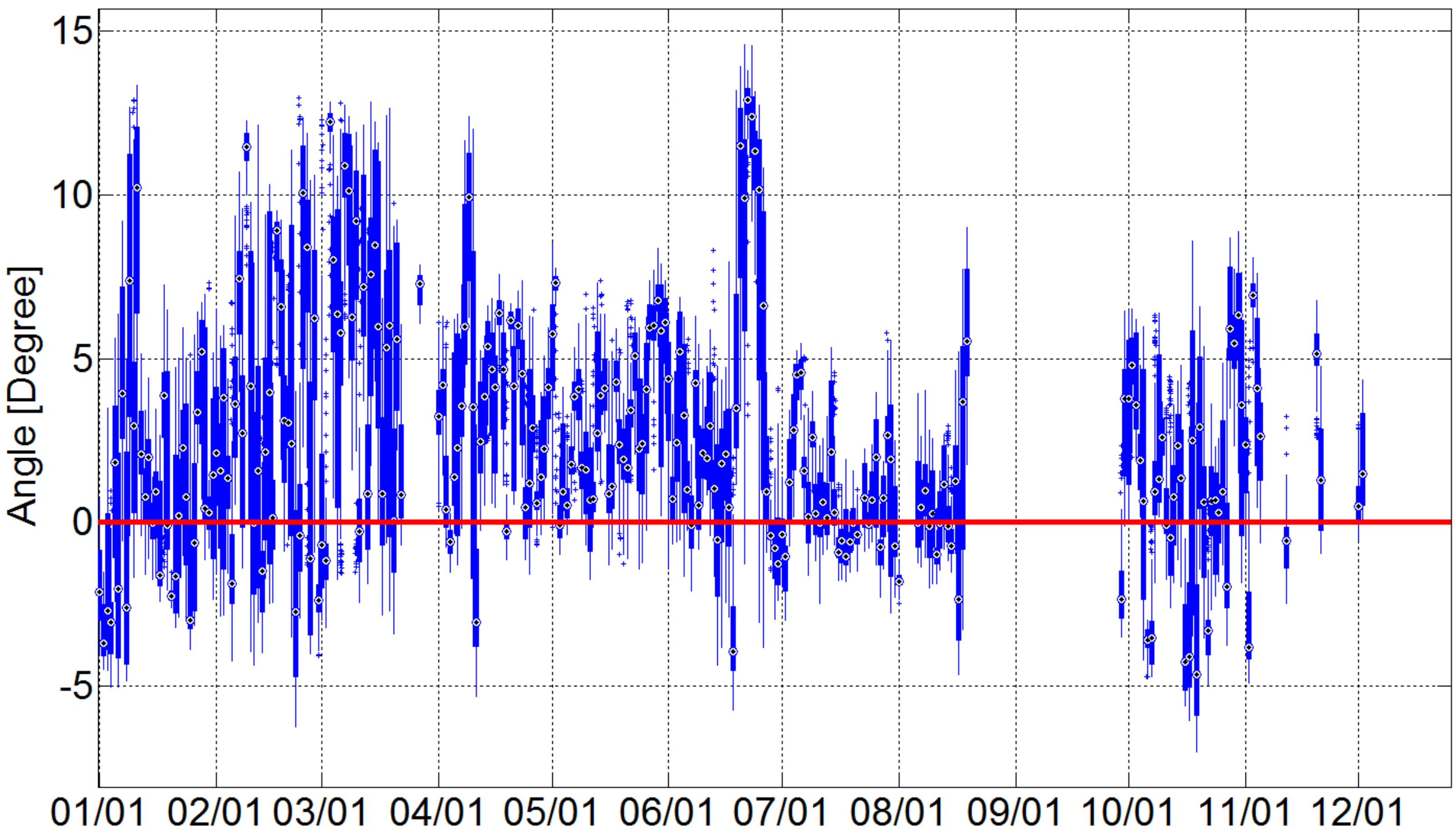

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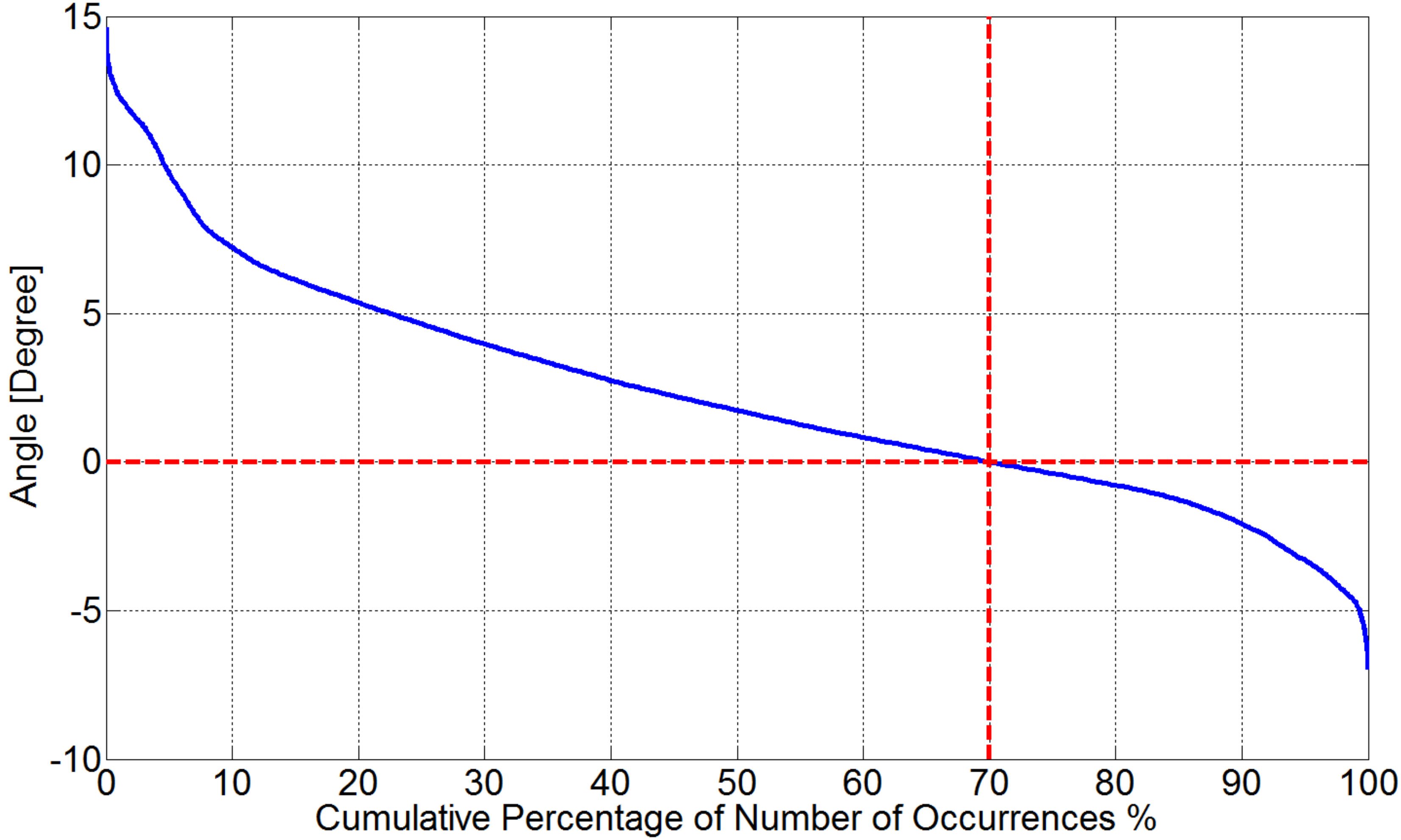

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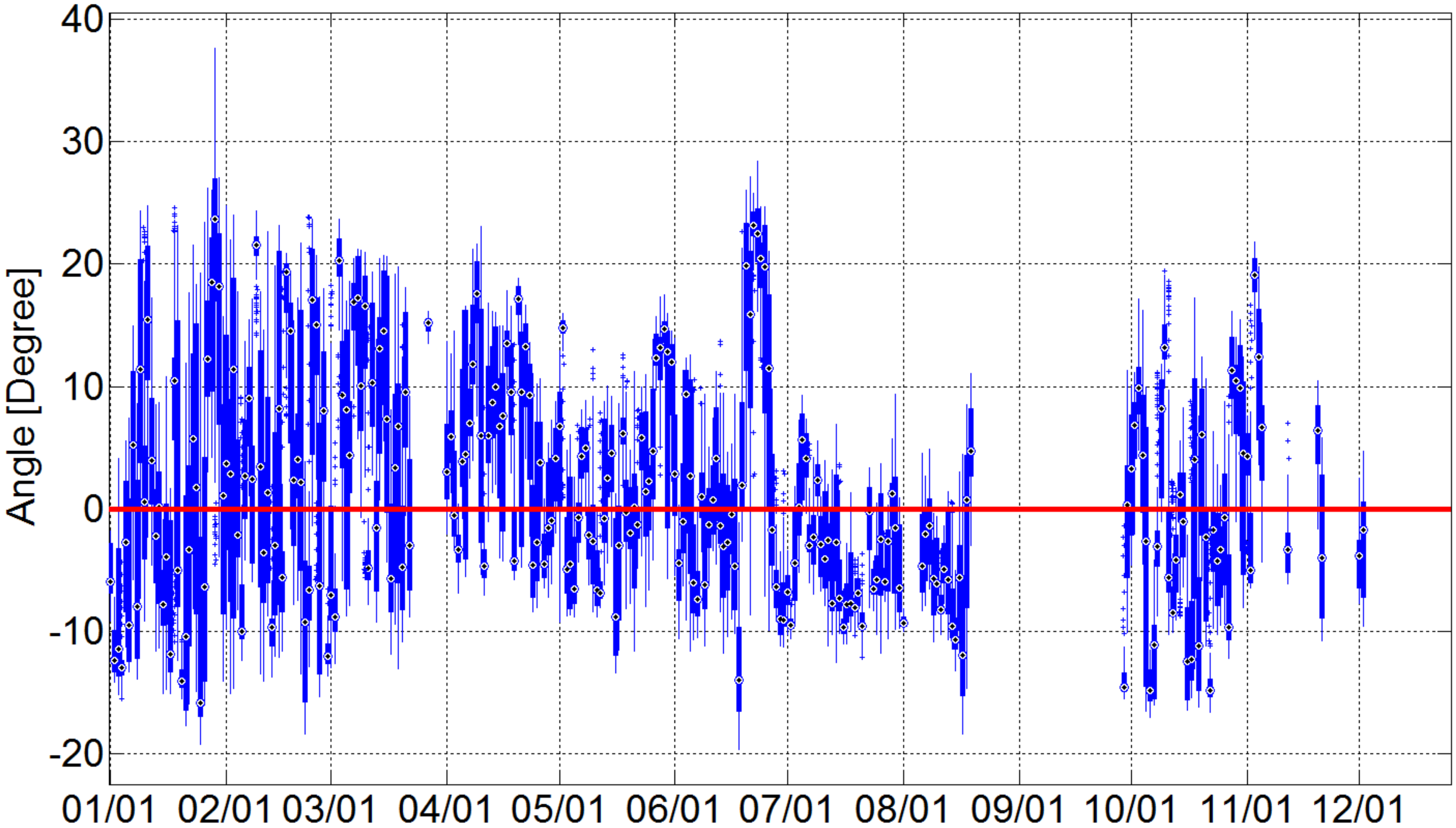

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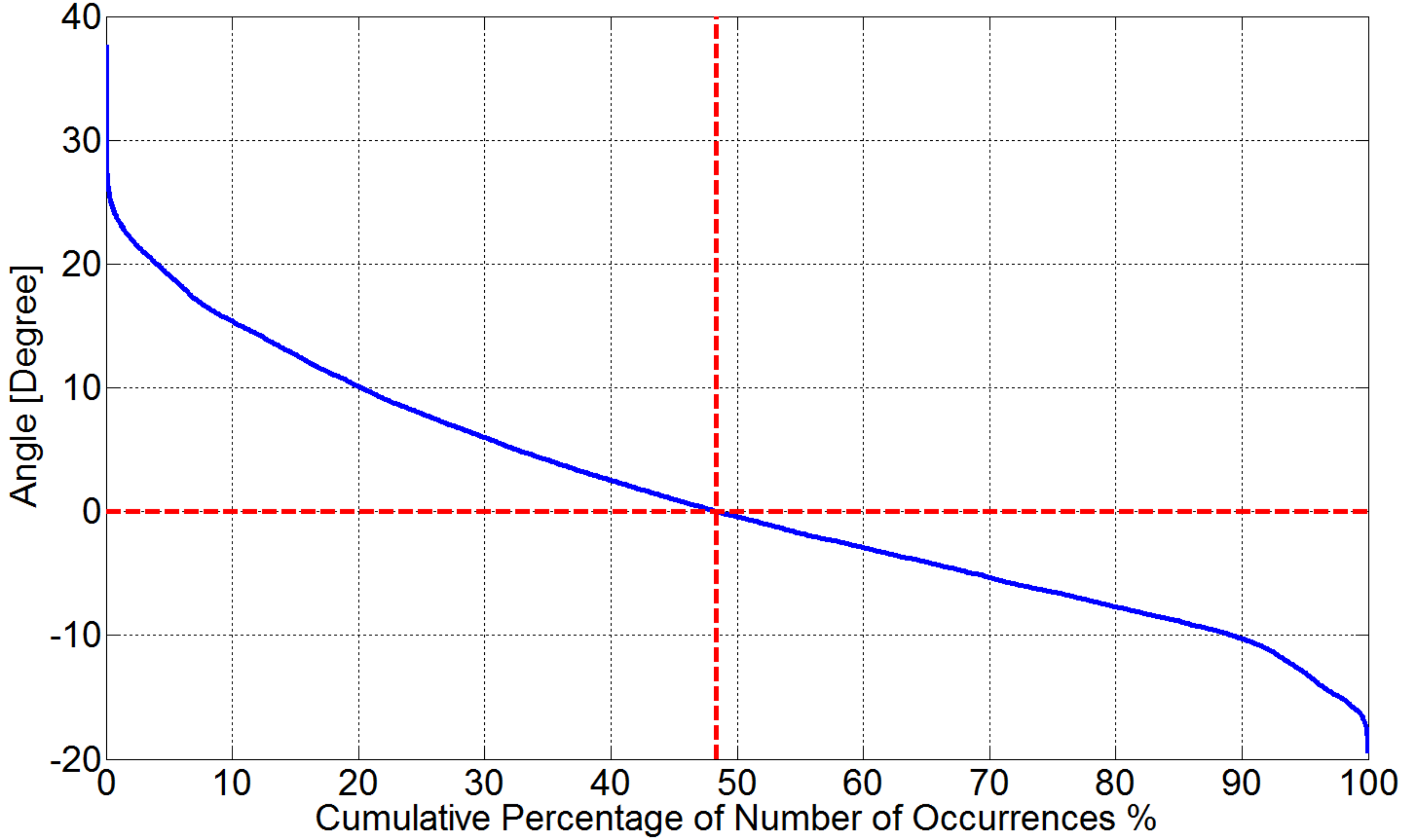

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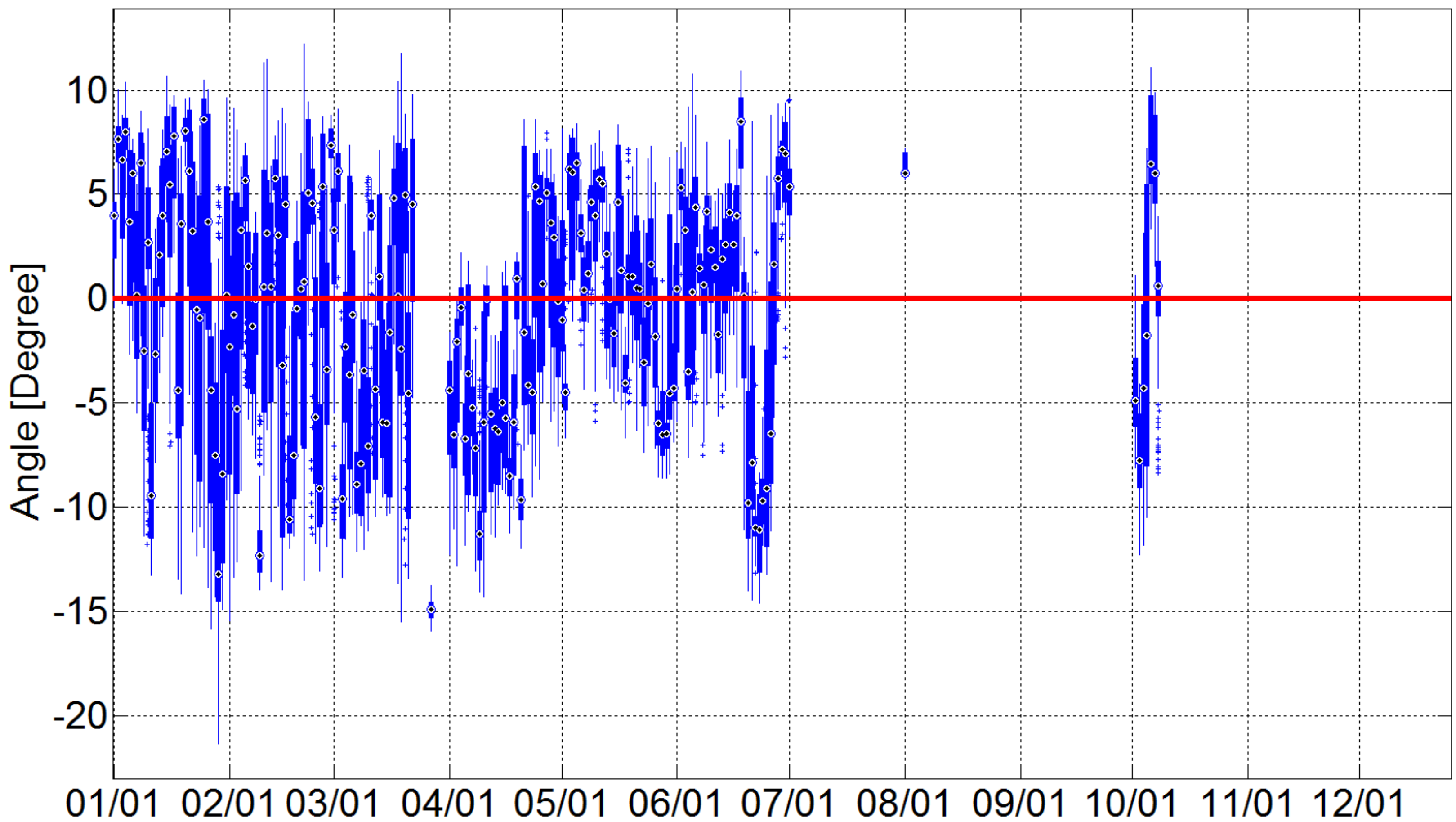

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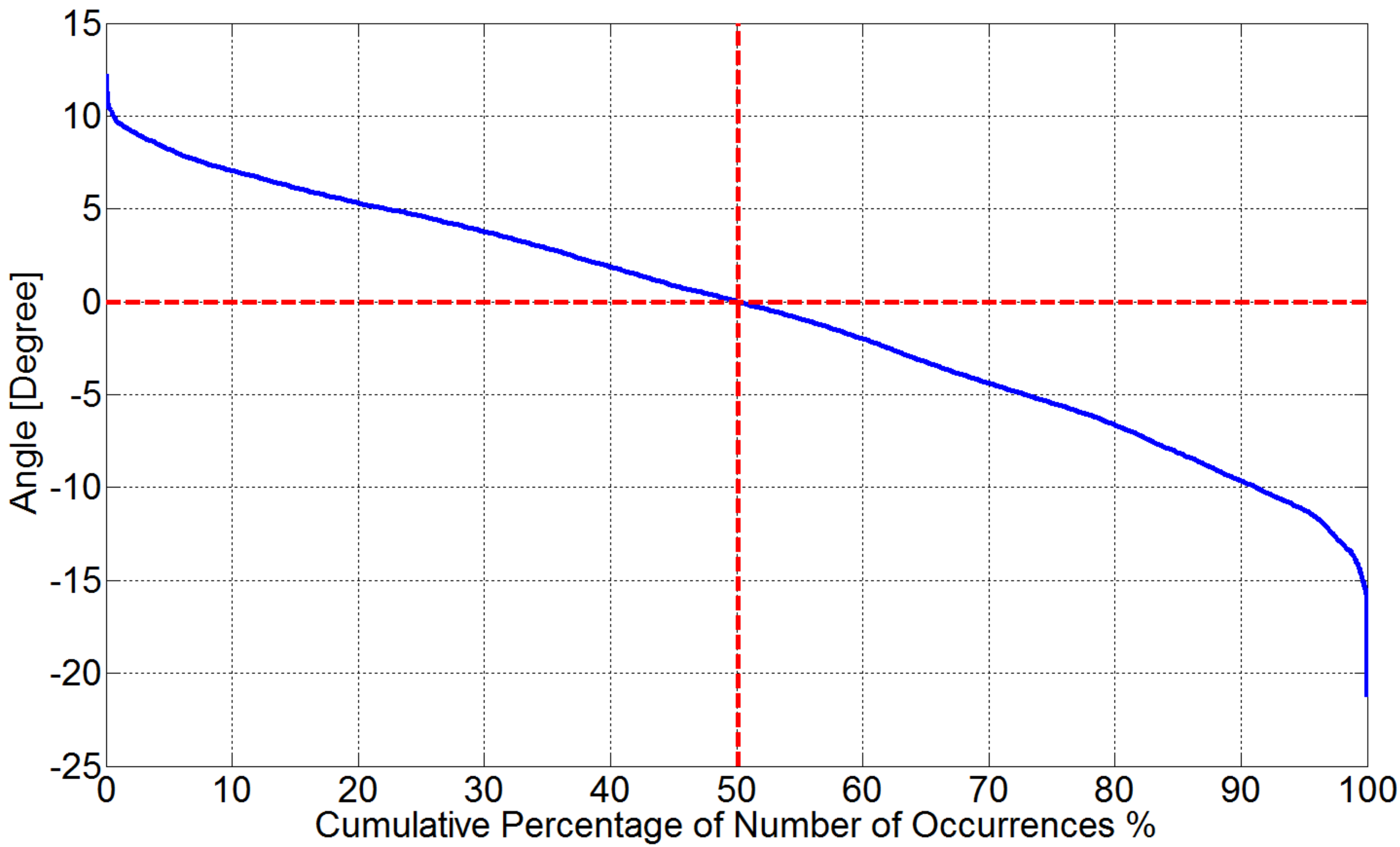

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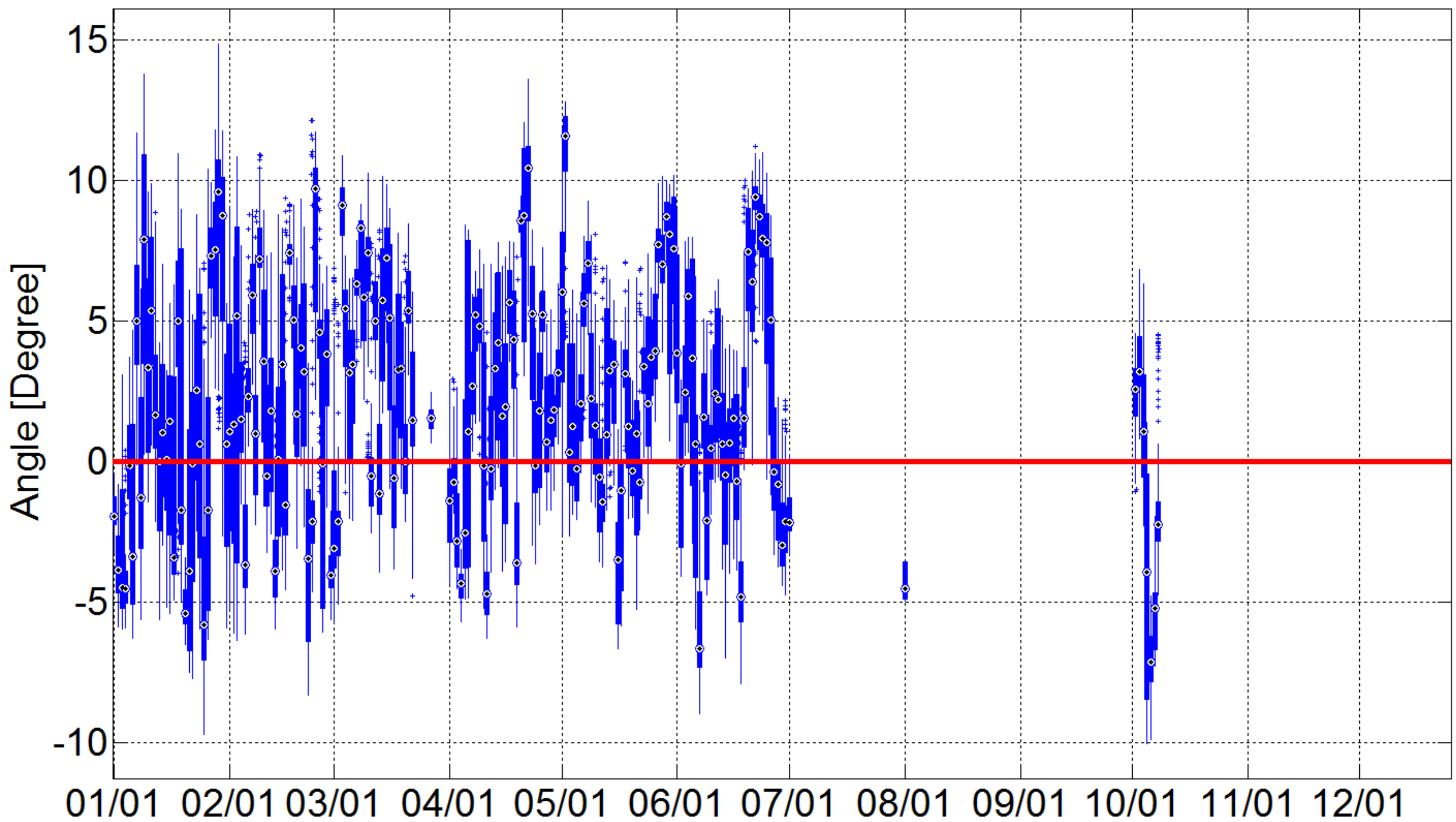

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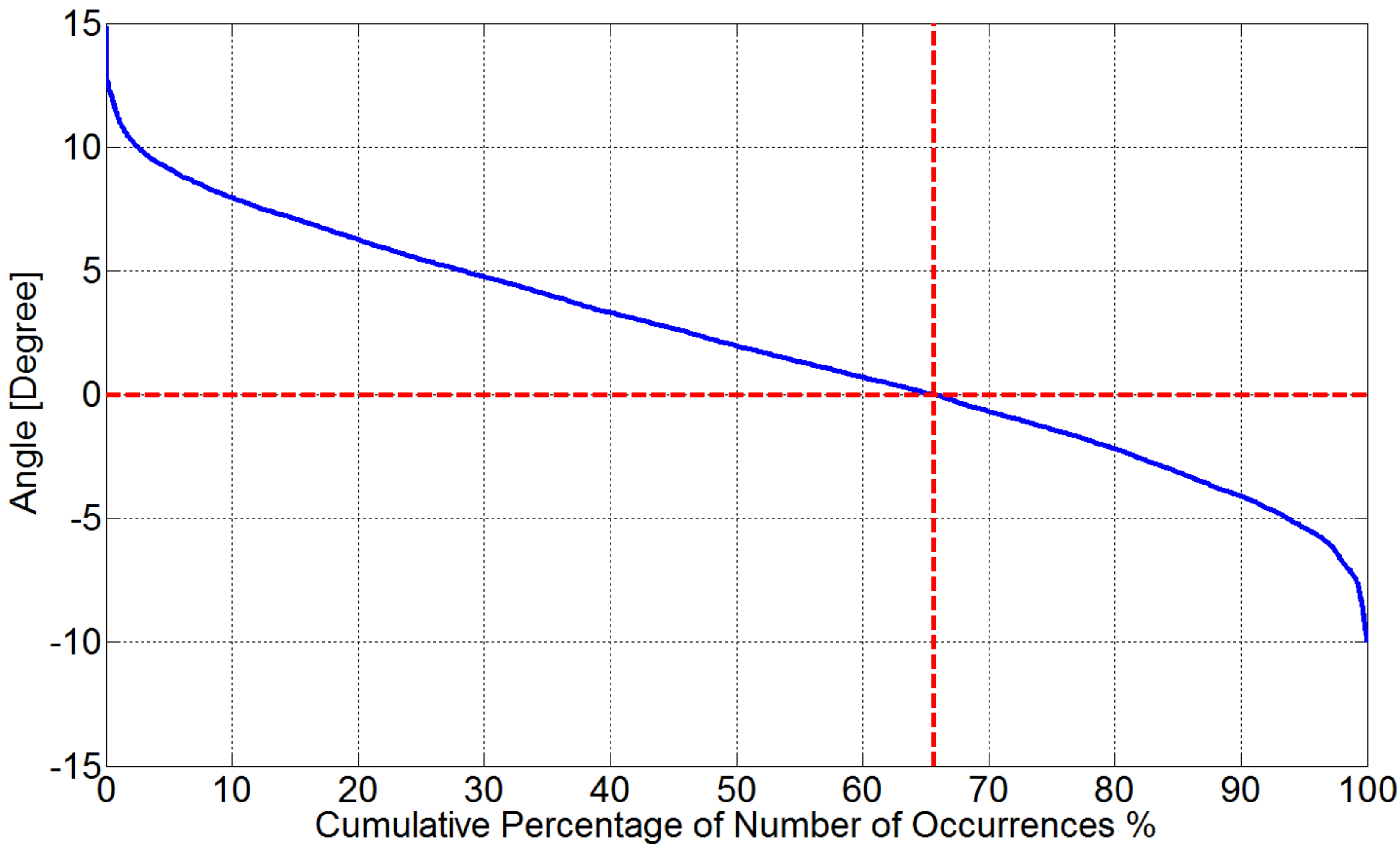
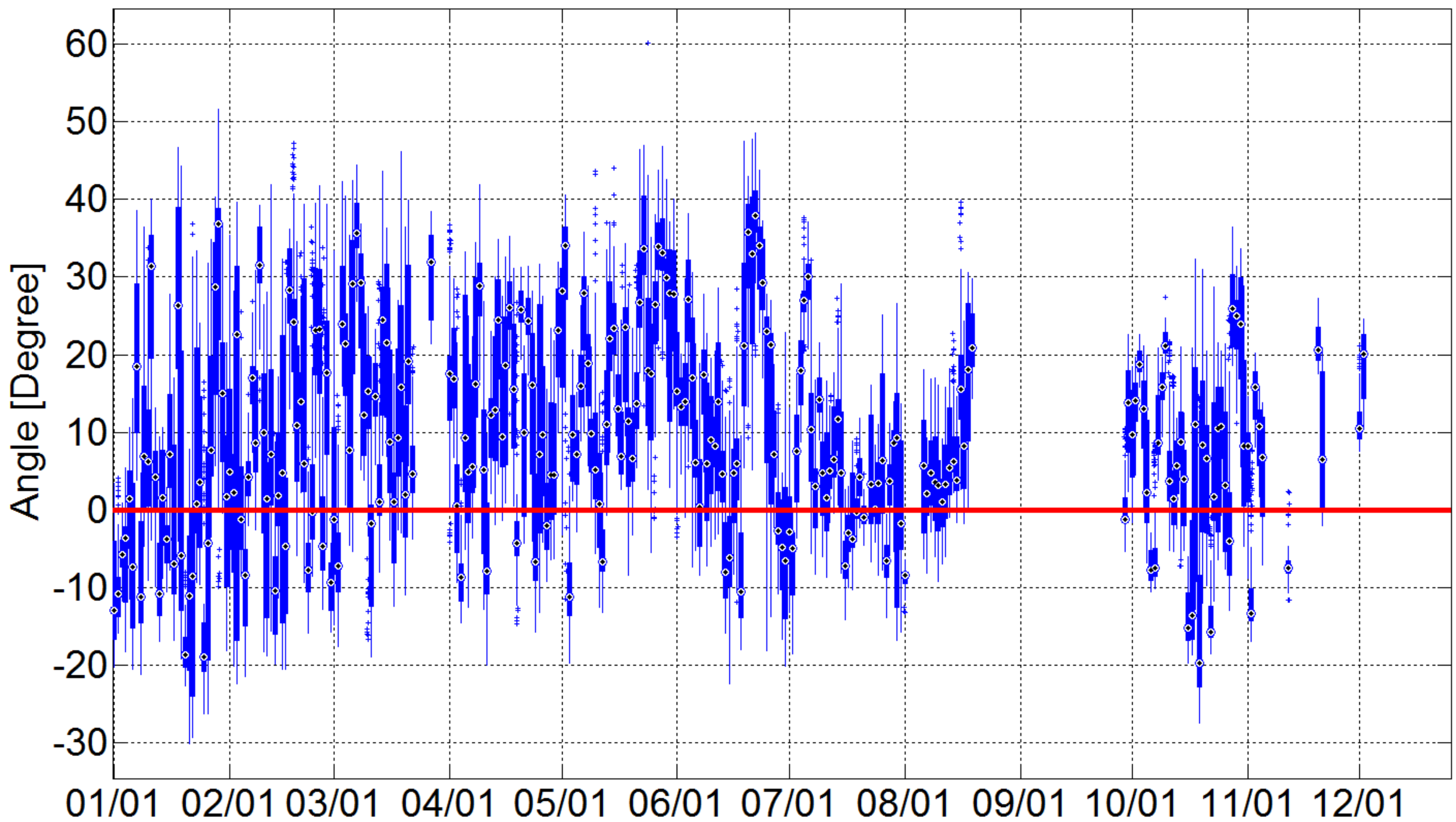


FarWest 9-West 4



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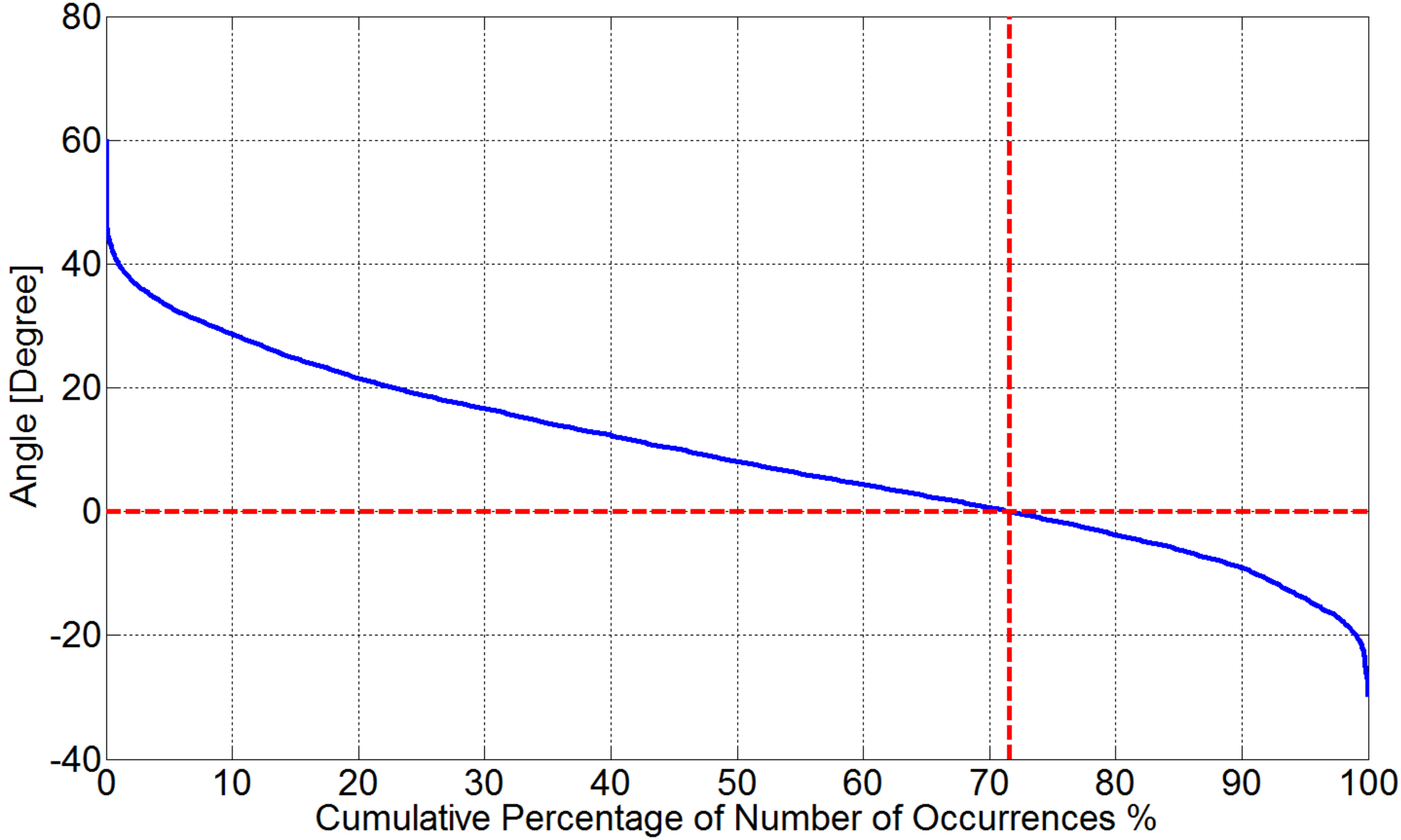
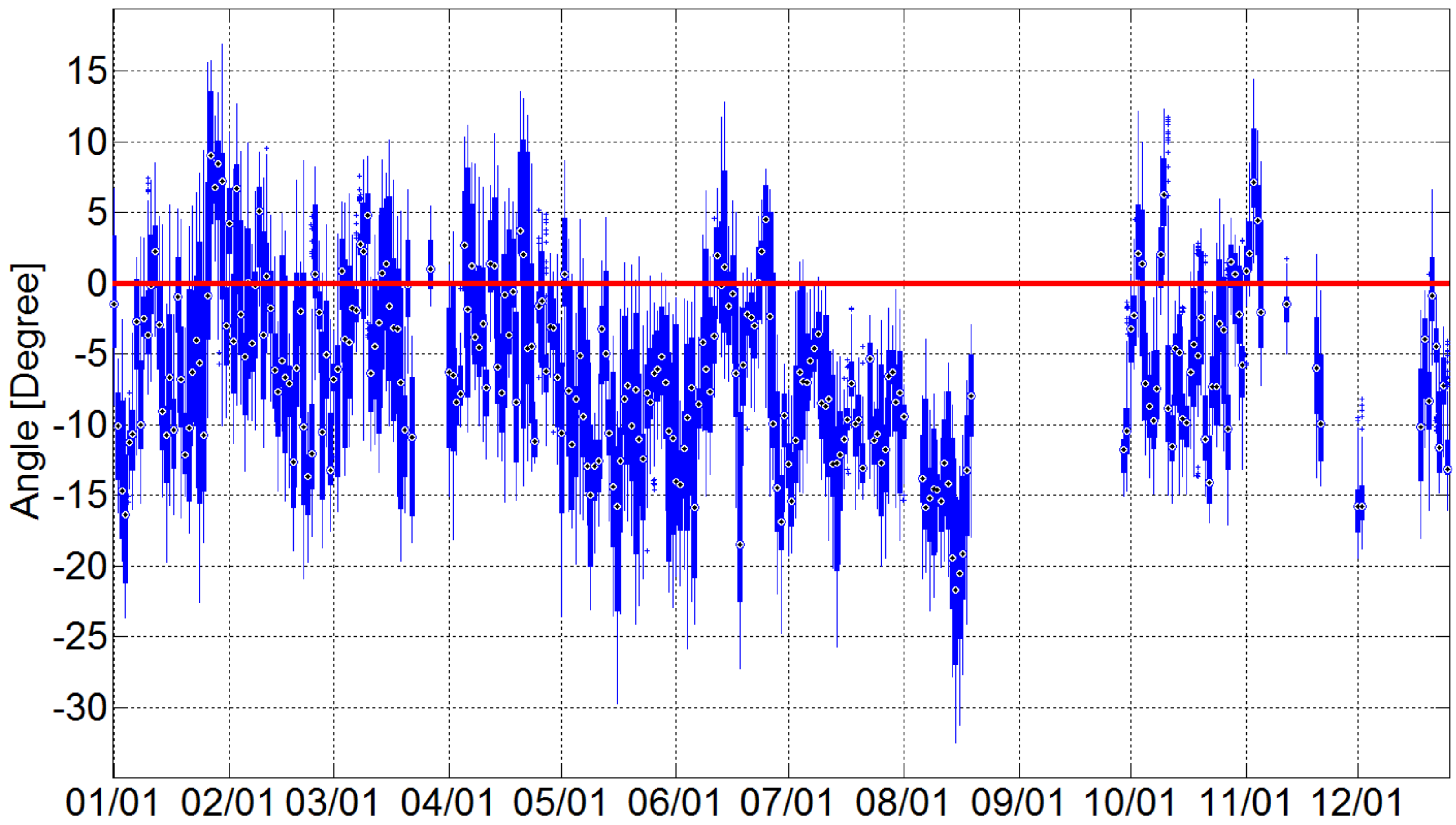


West 4-North 7



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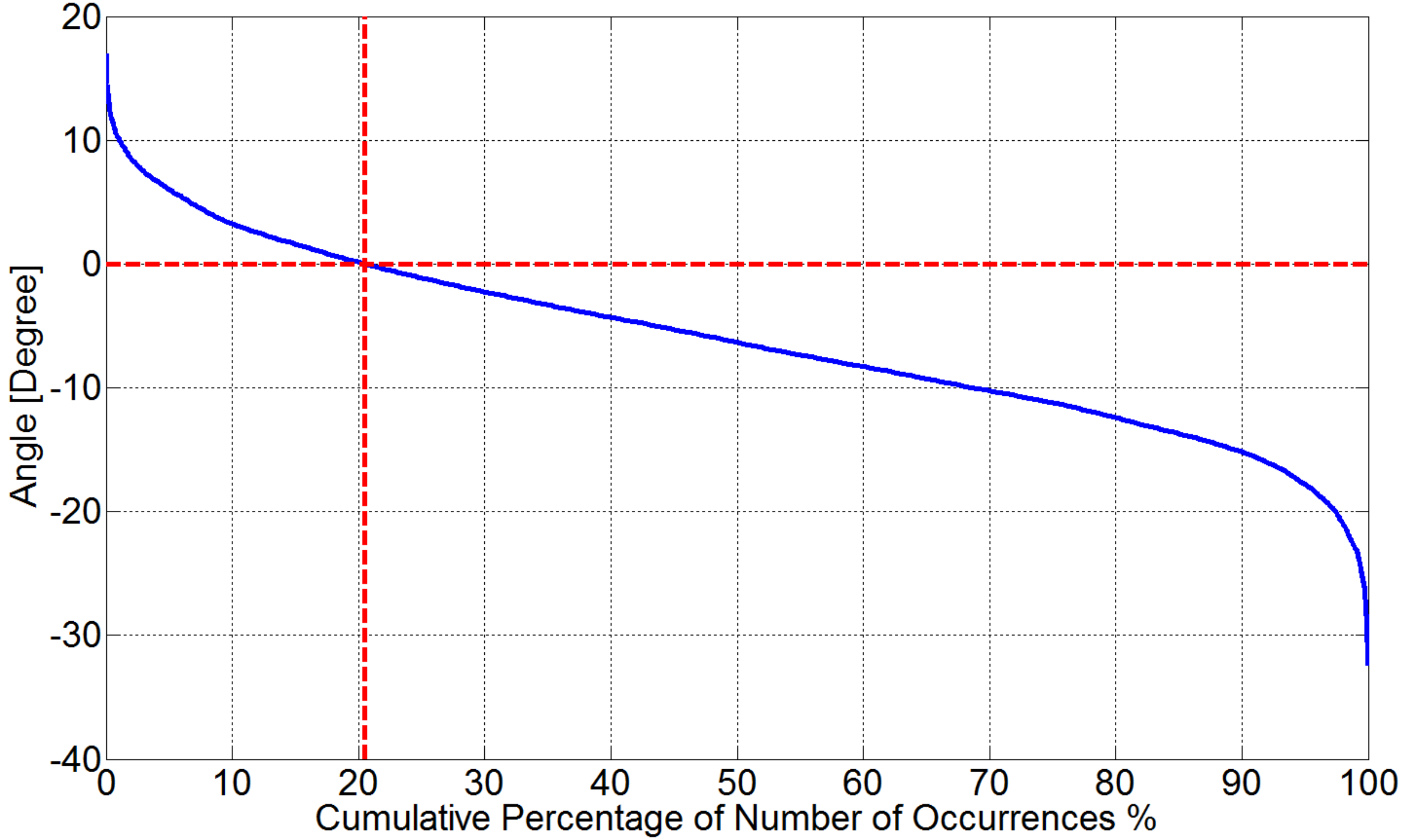
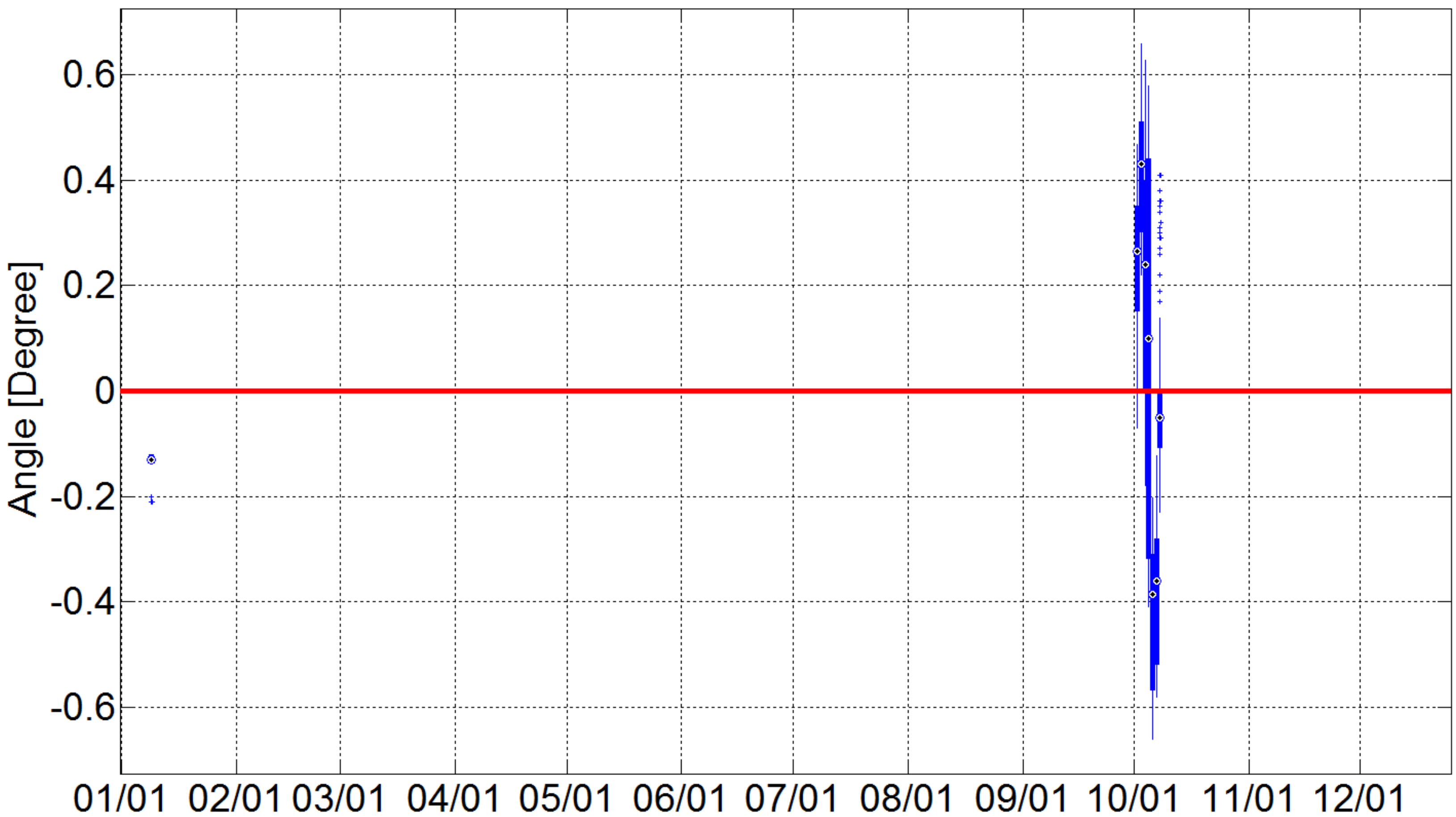
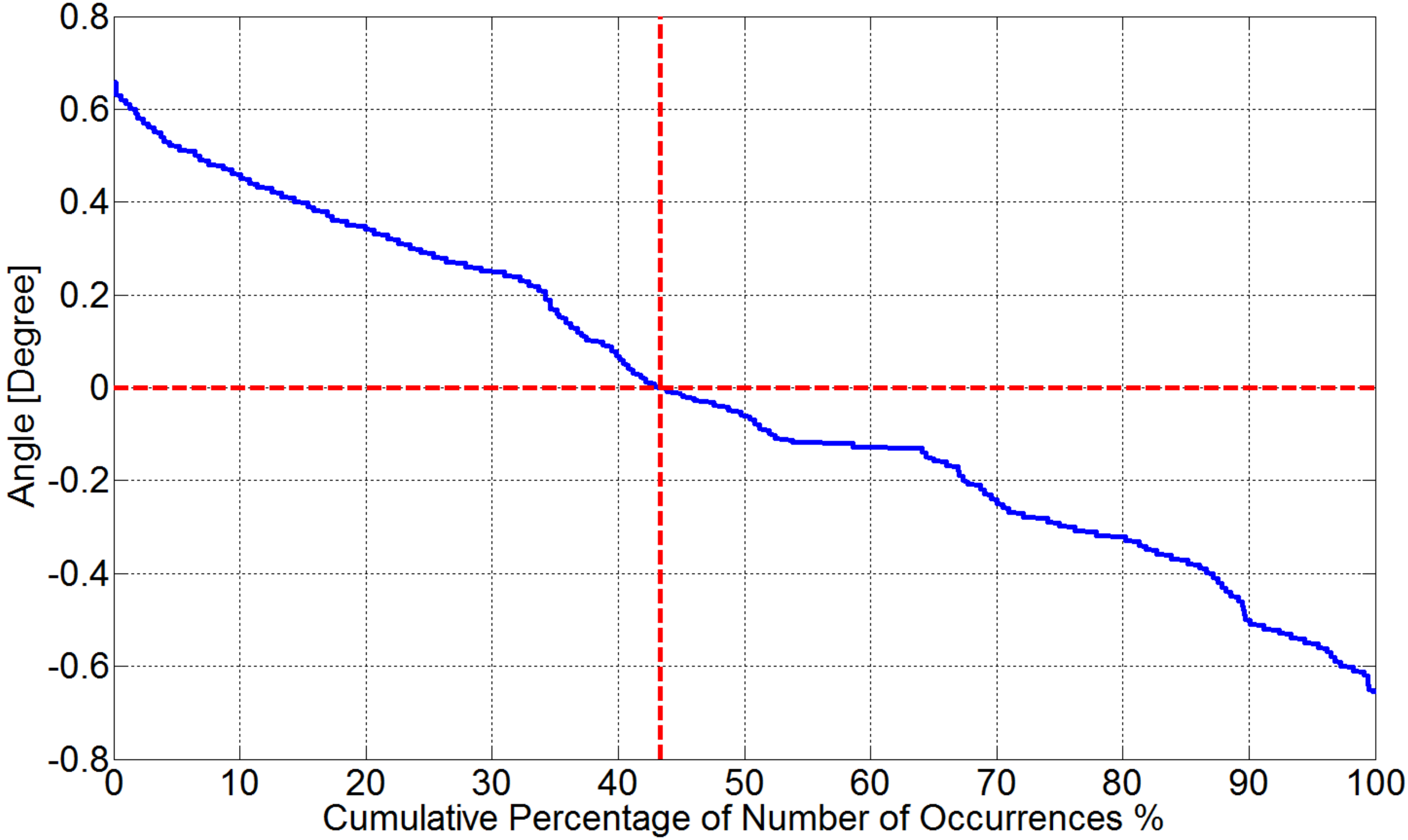


West 16-West 14



West 16-West 14



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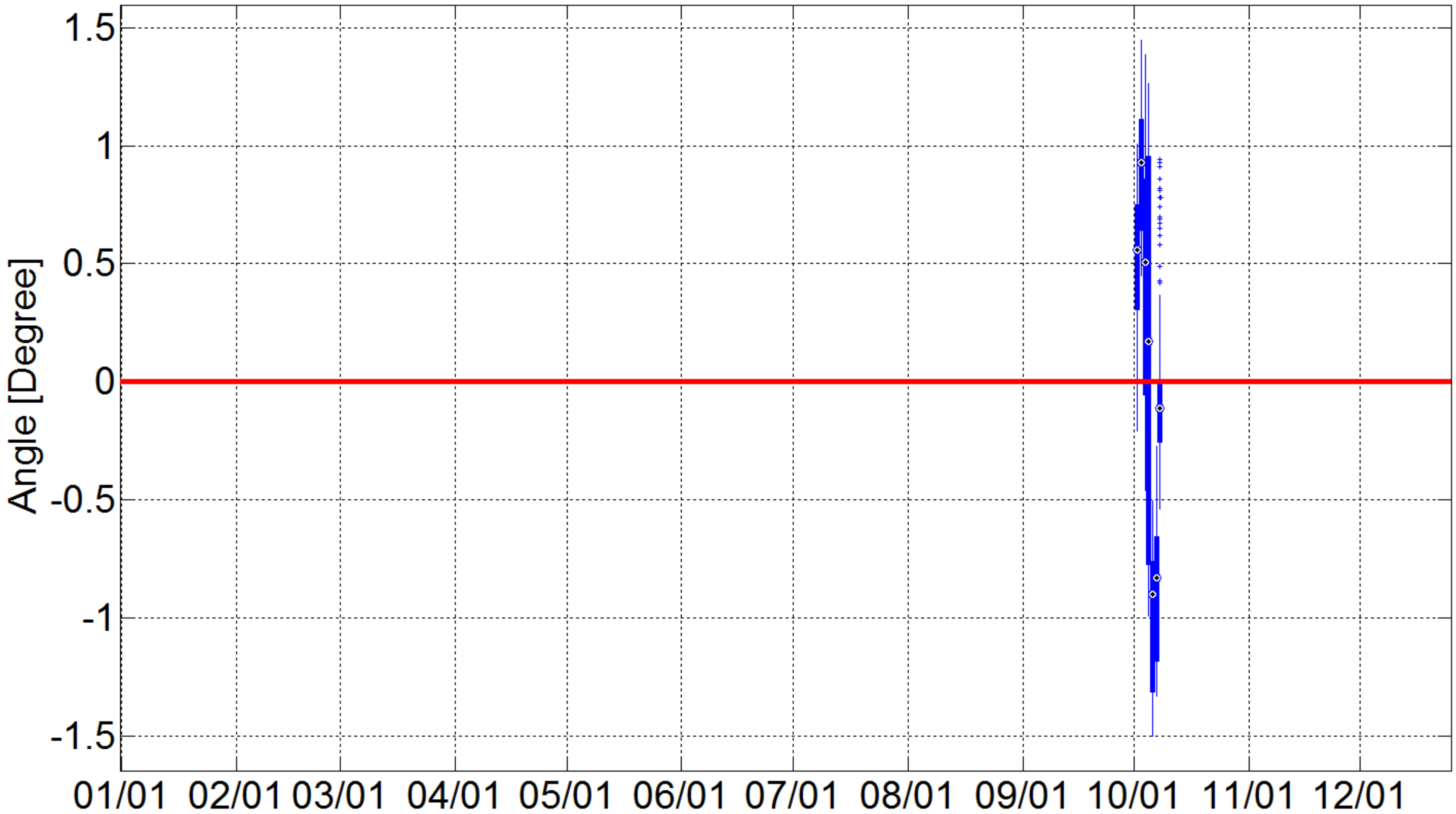

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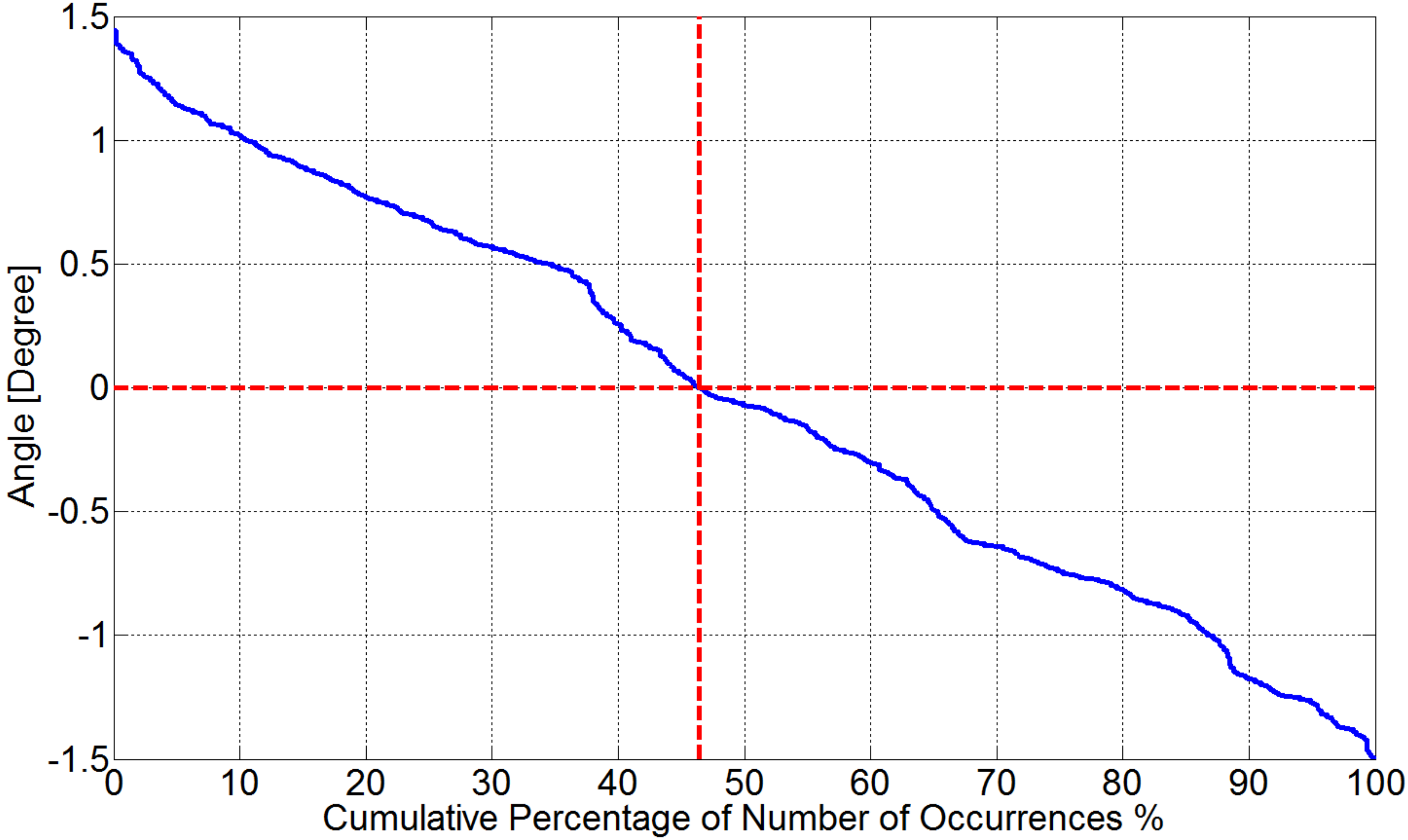
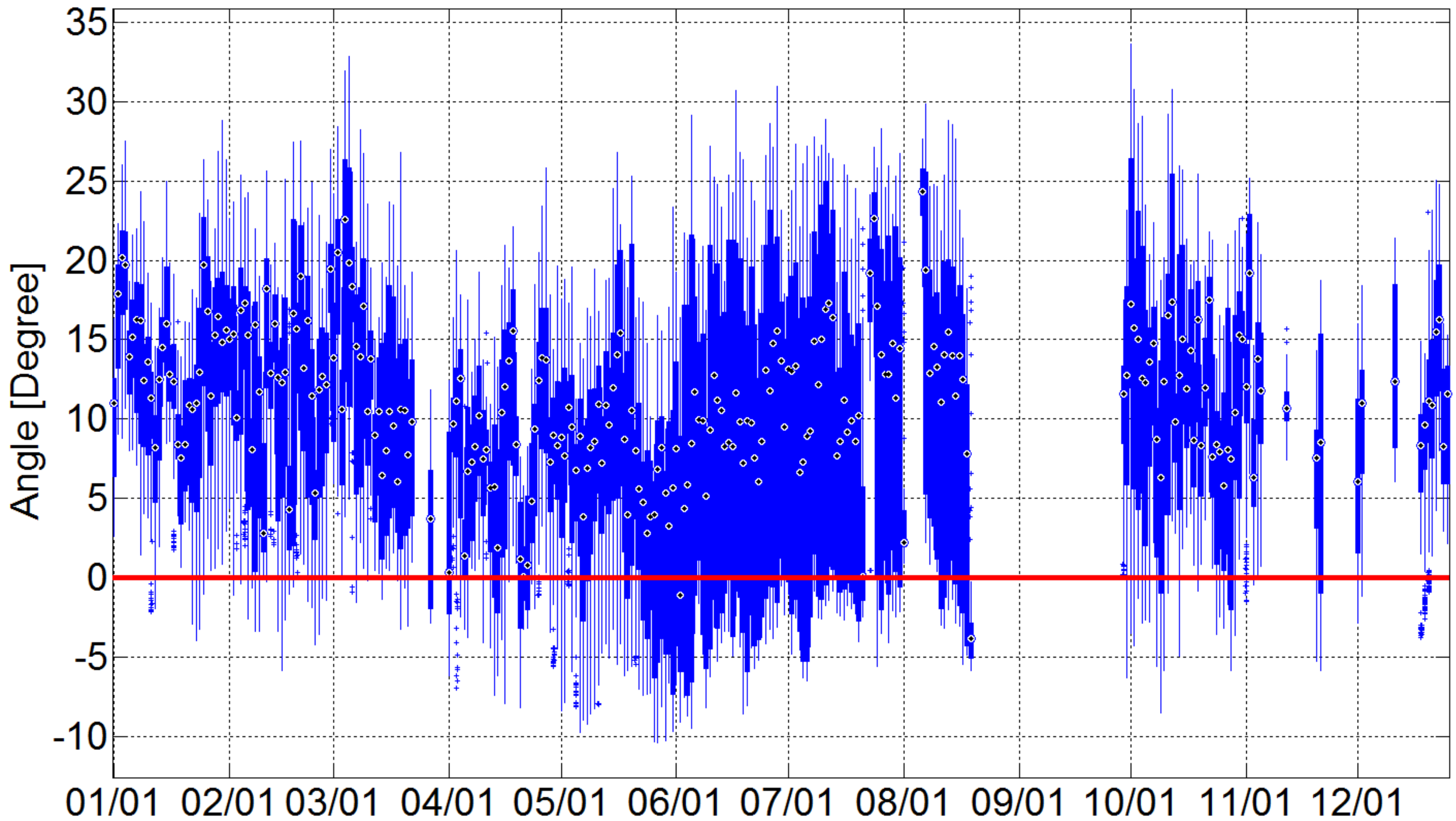


Coast 1-South 10*



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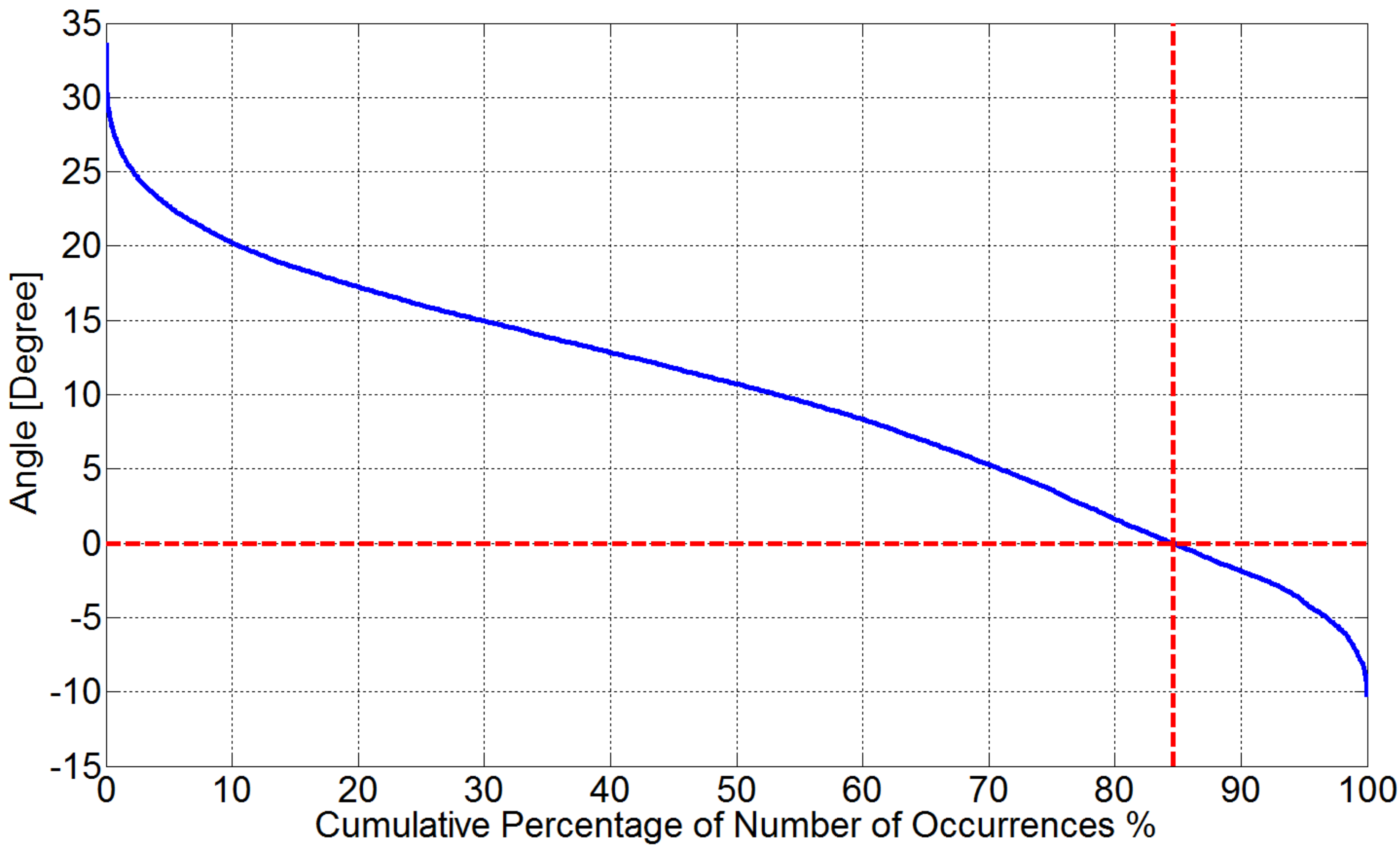
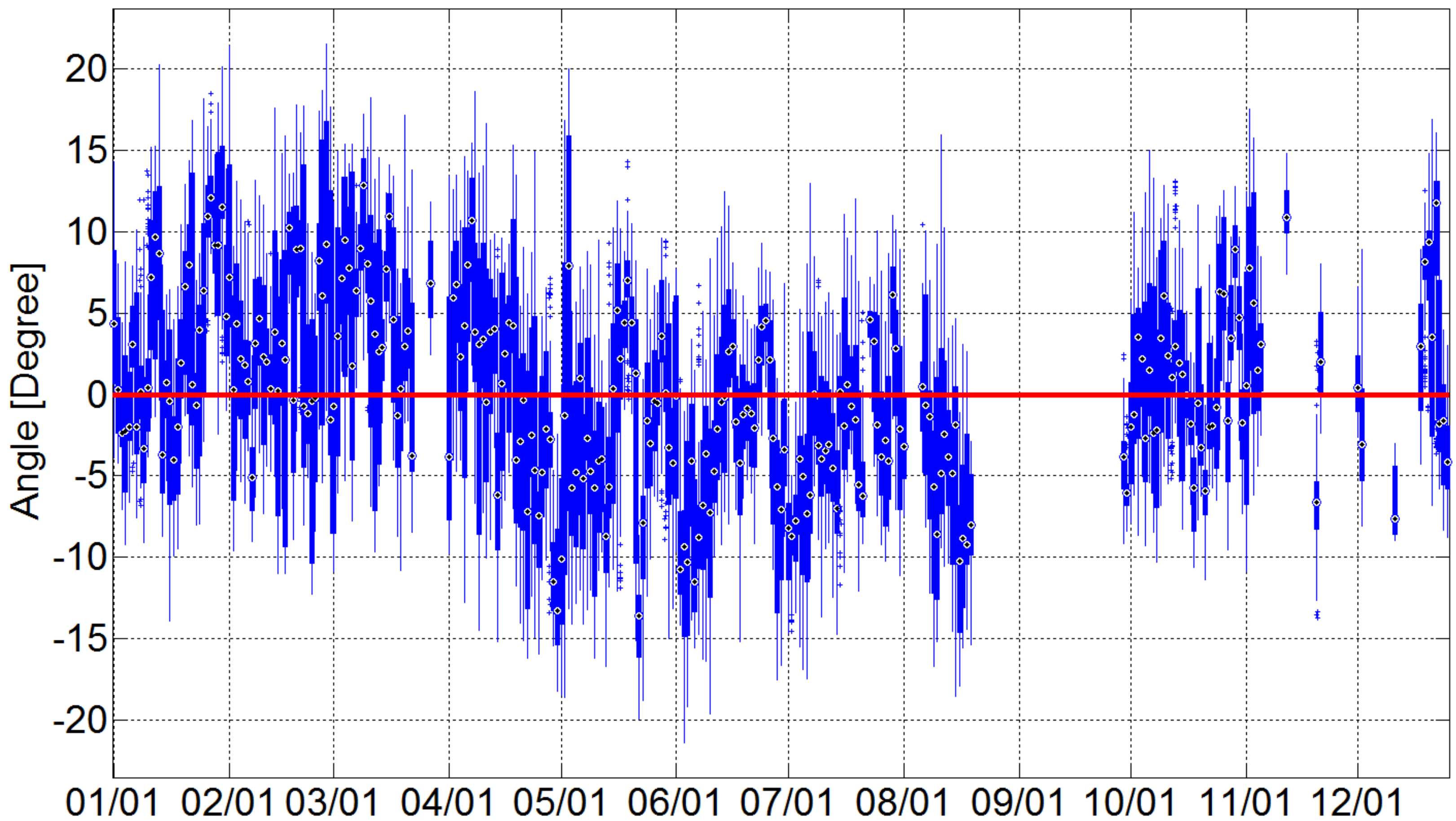
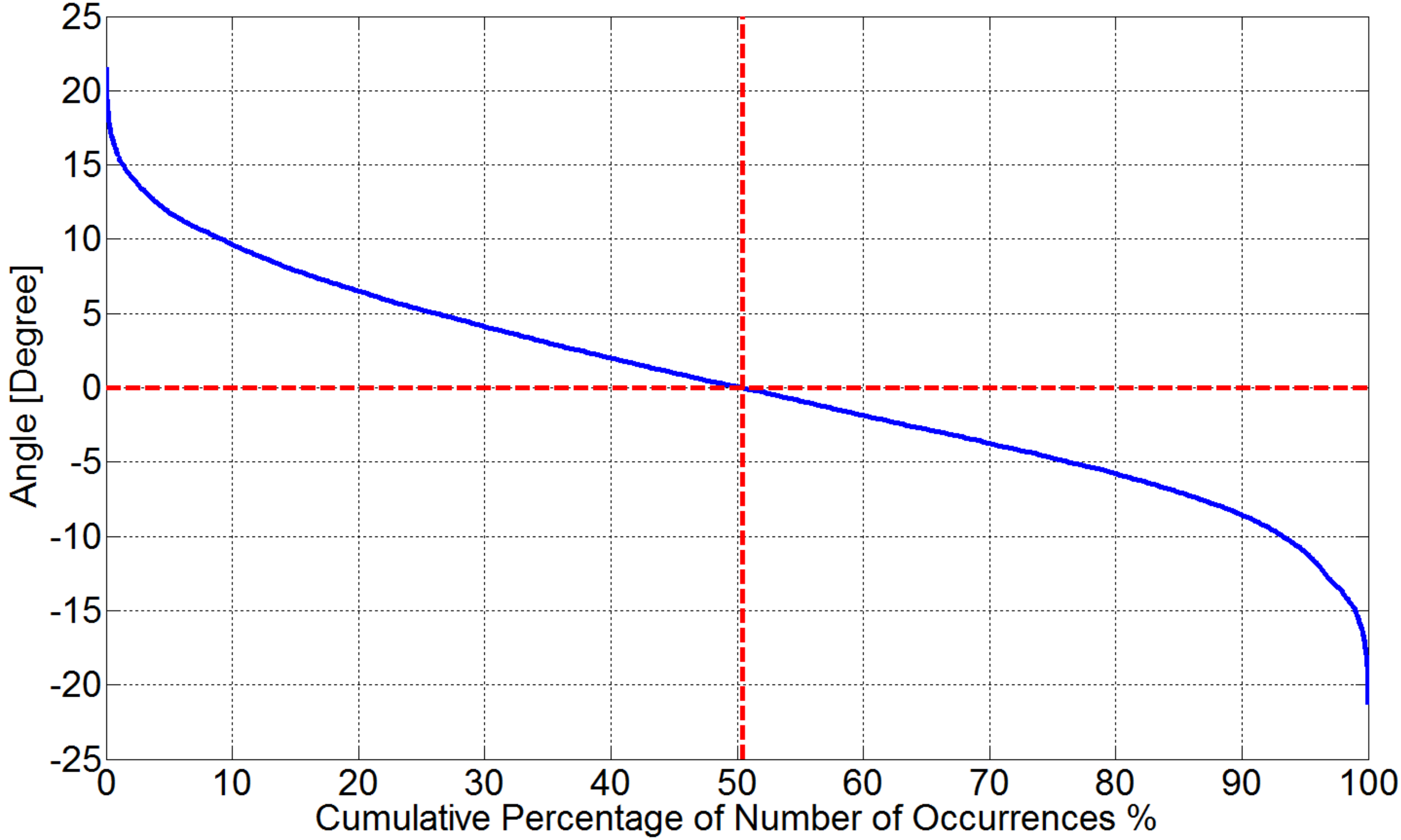


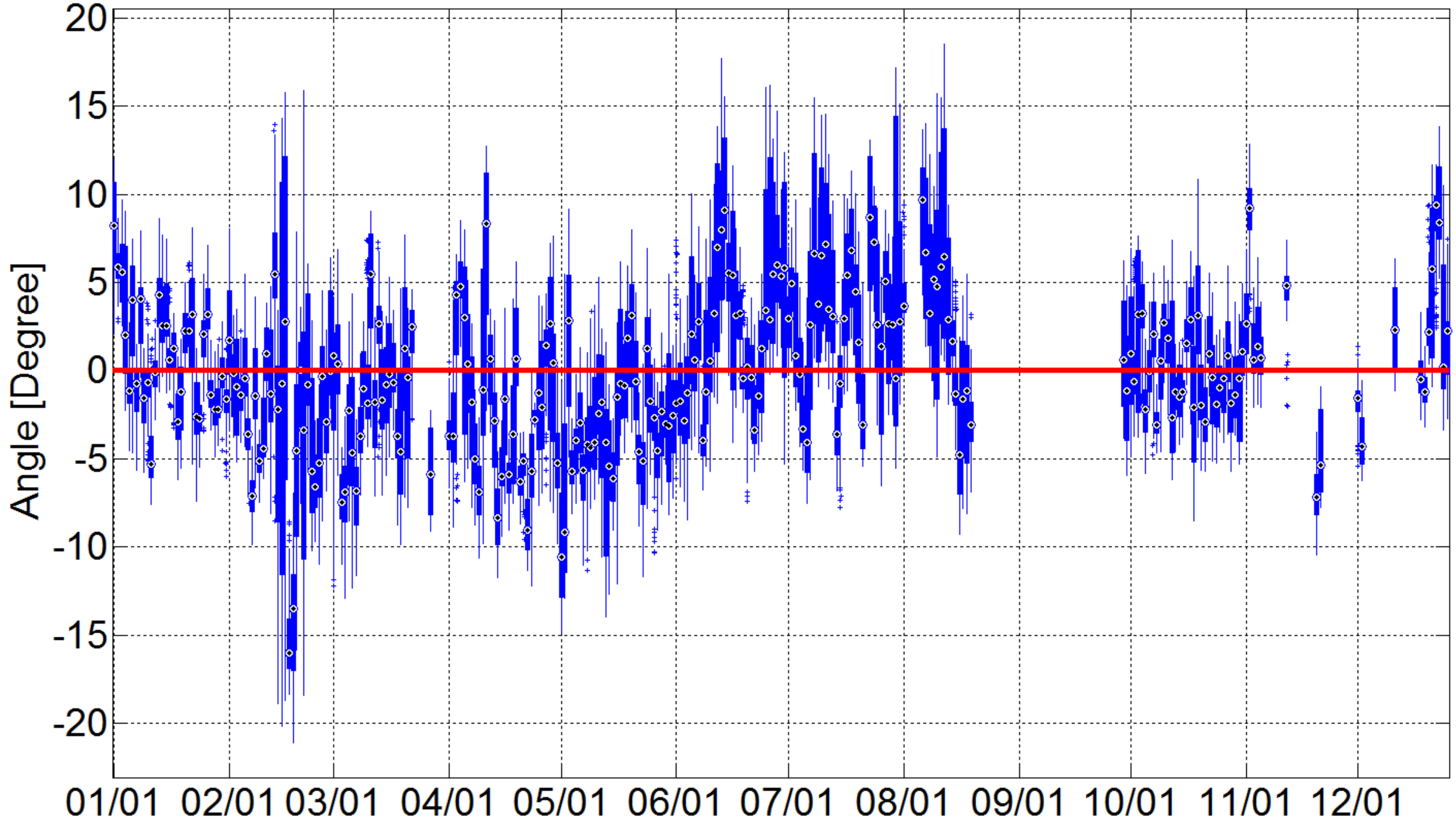
South 3*-South 11*



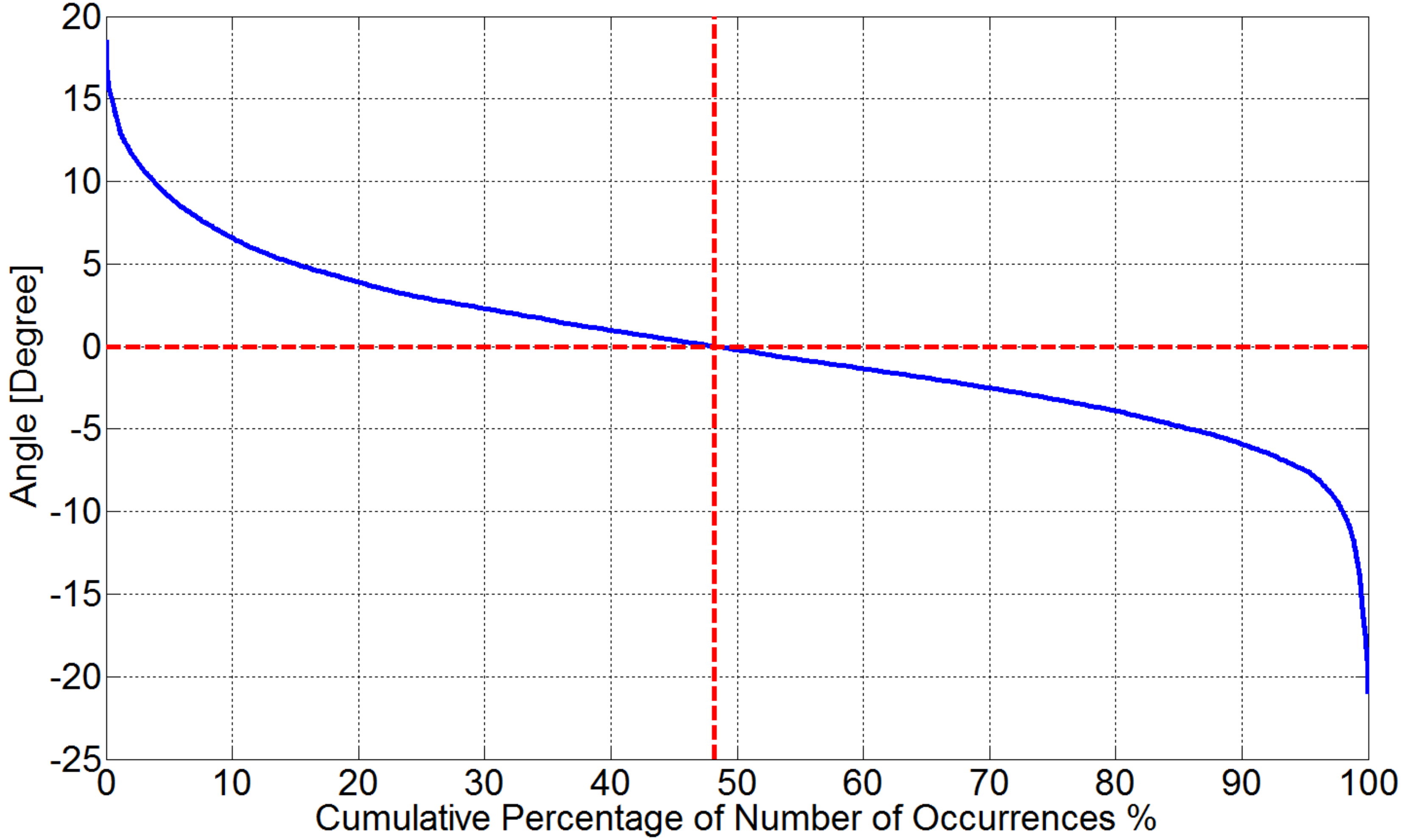
South 3*-South 11*



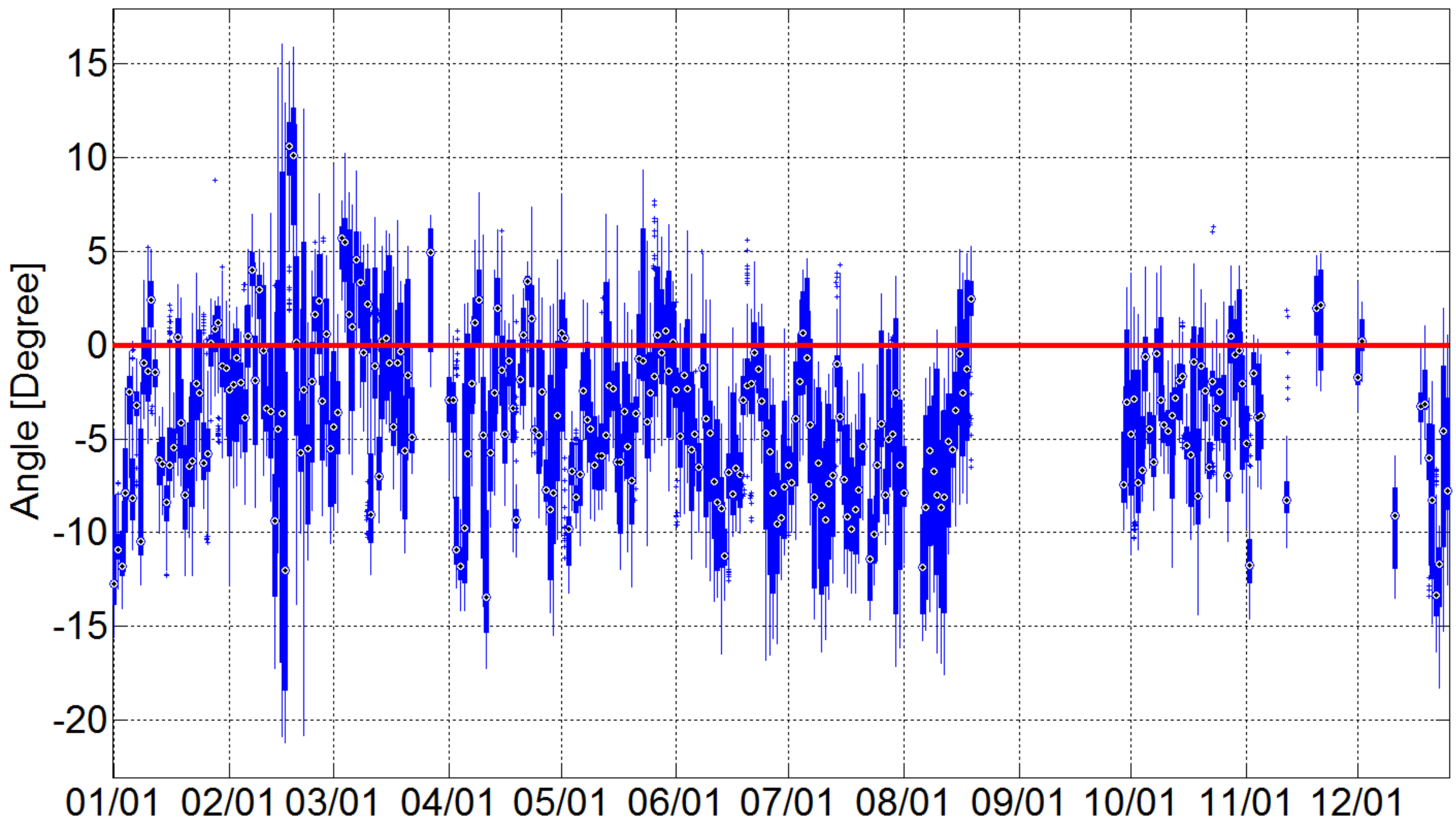
South 11*-North 7



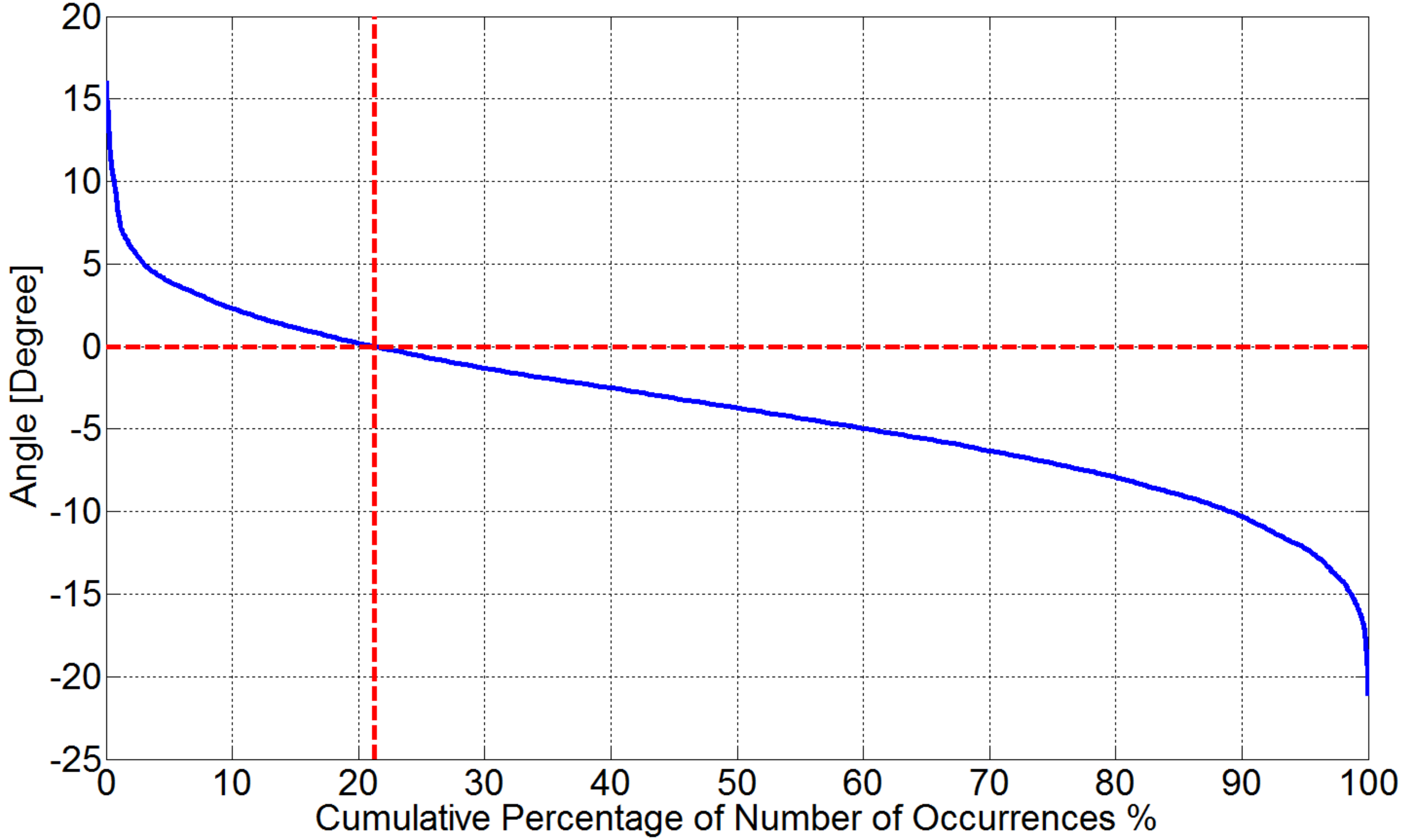
South 11*-North 7



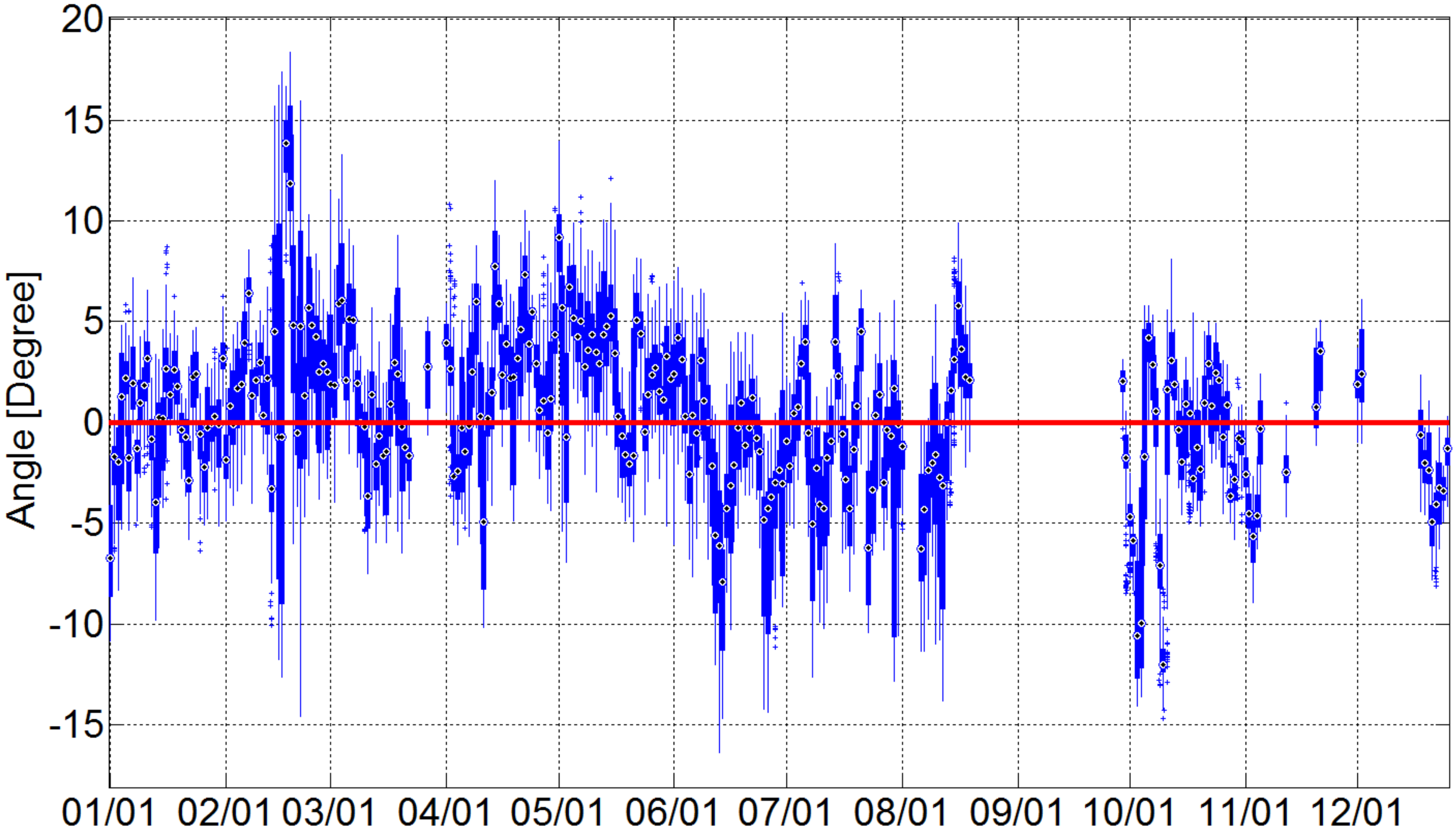
North 7-South 7*



North 7-South 7*



North 7-South 9*



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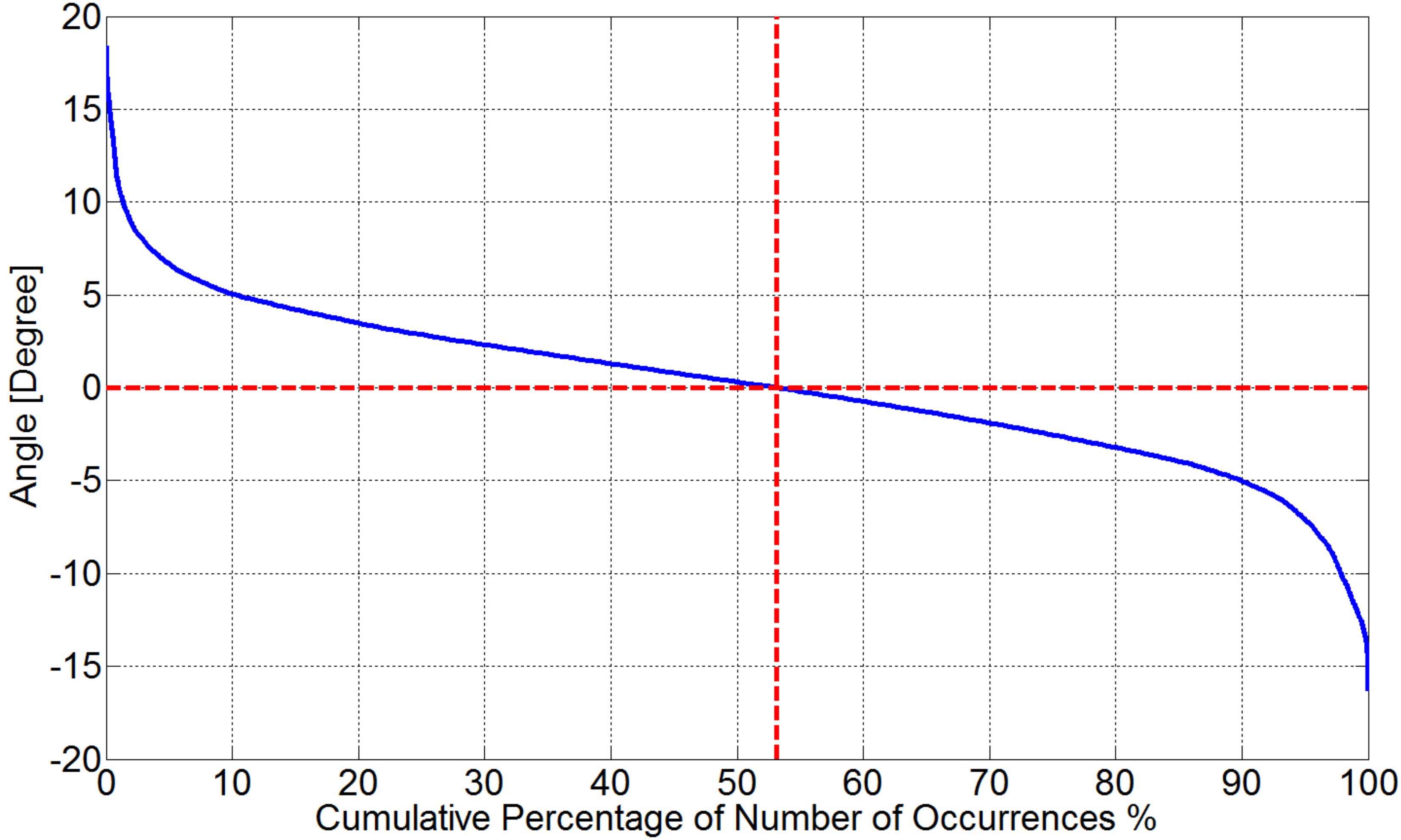
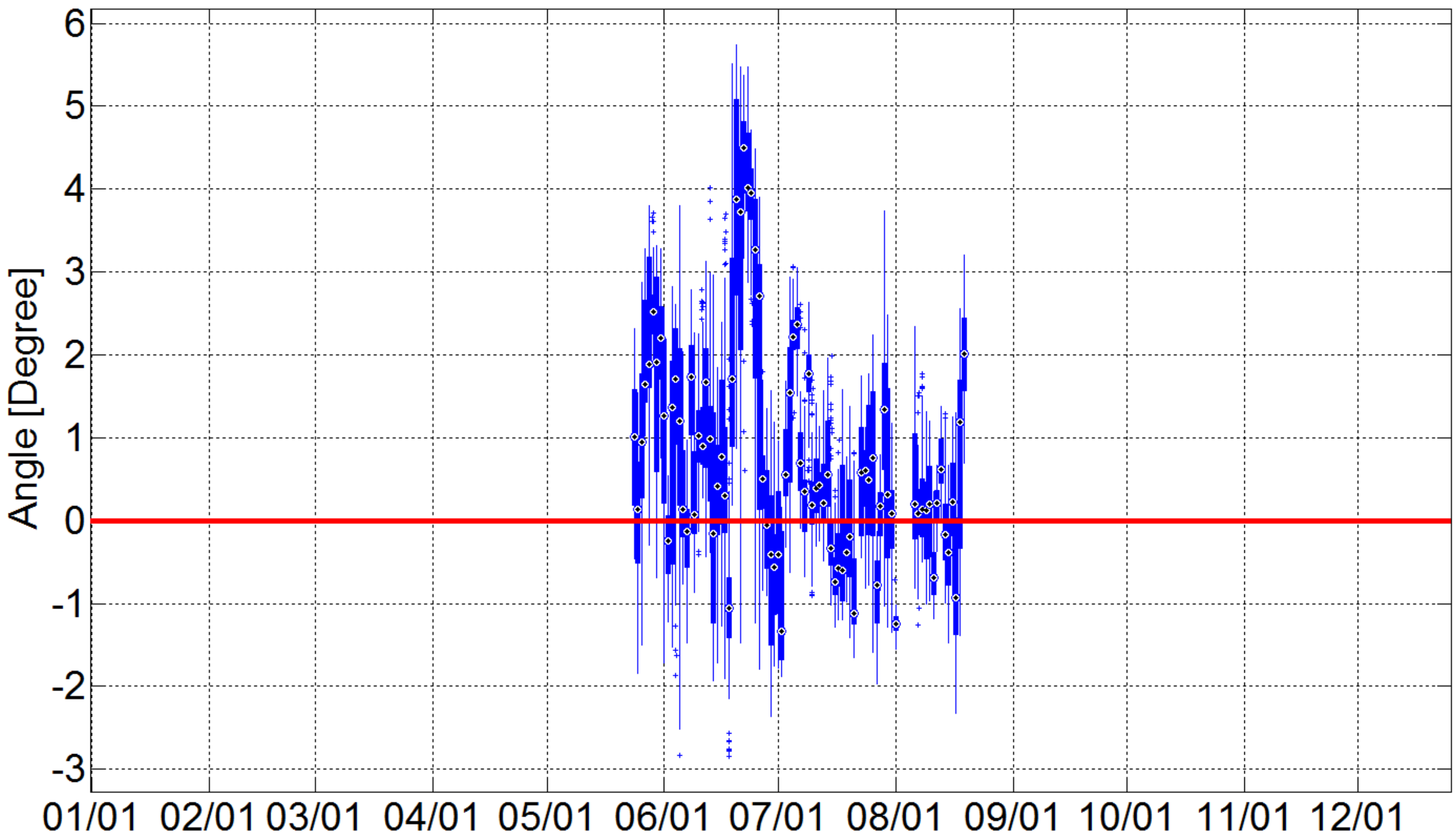
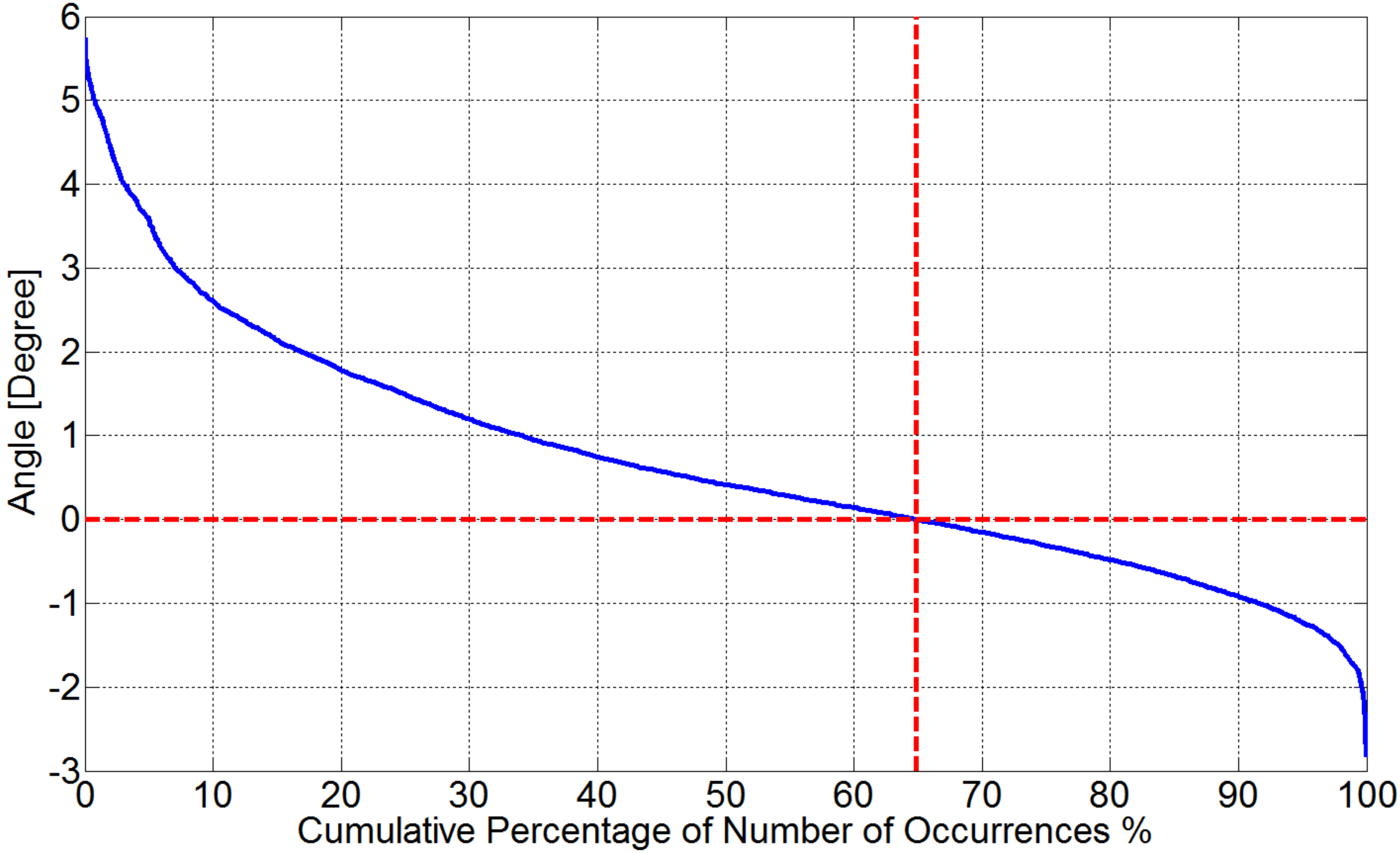


West 11-West 8*



West 11-West 8*



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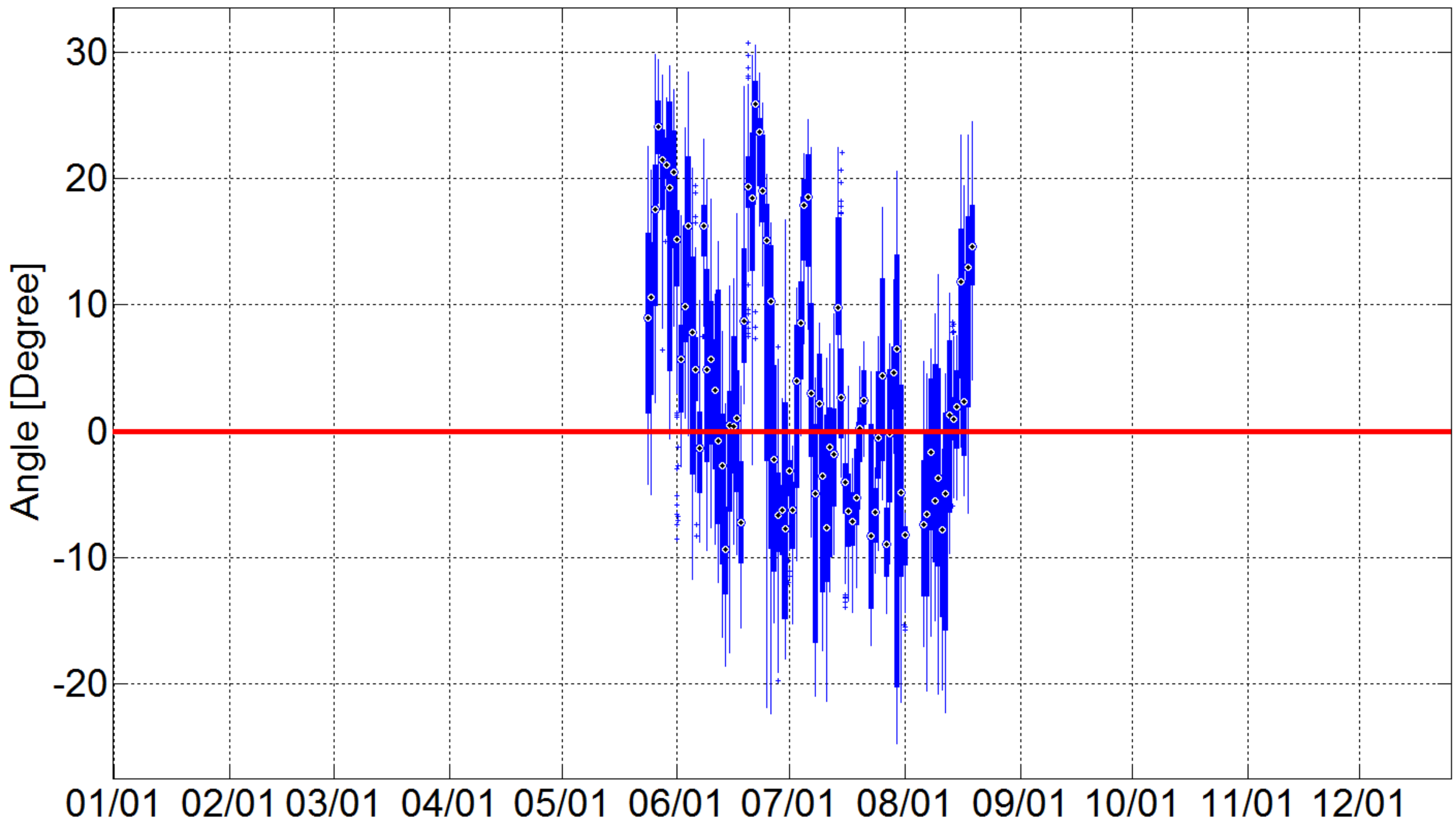

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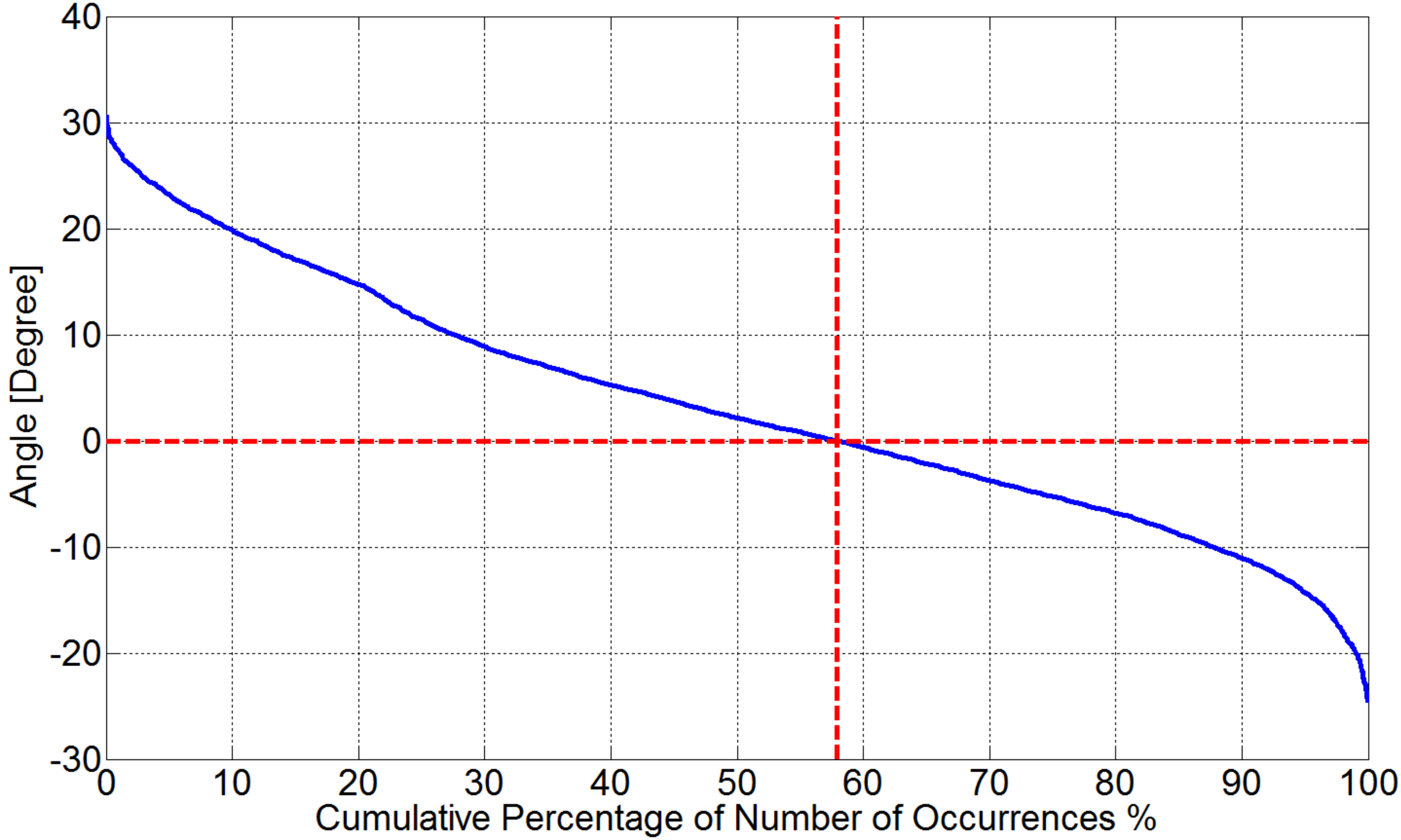

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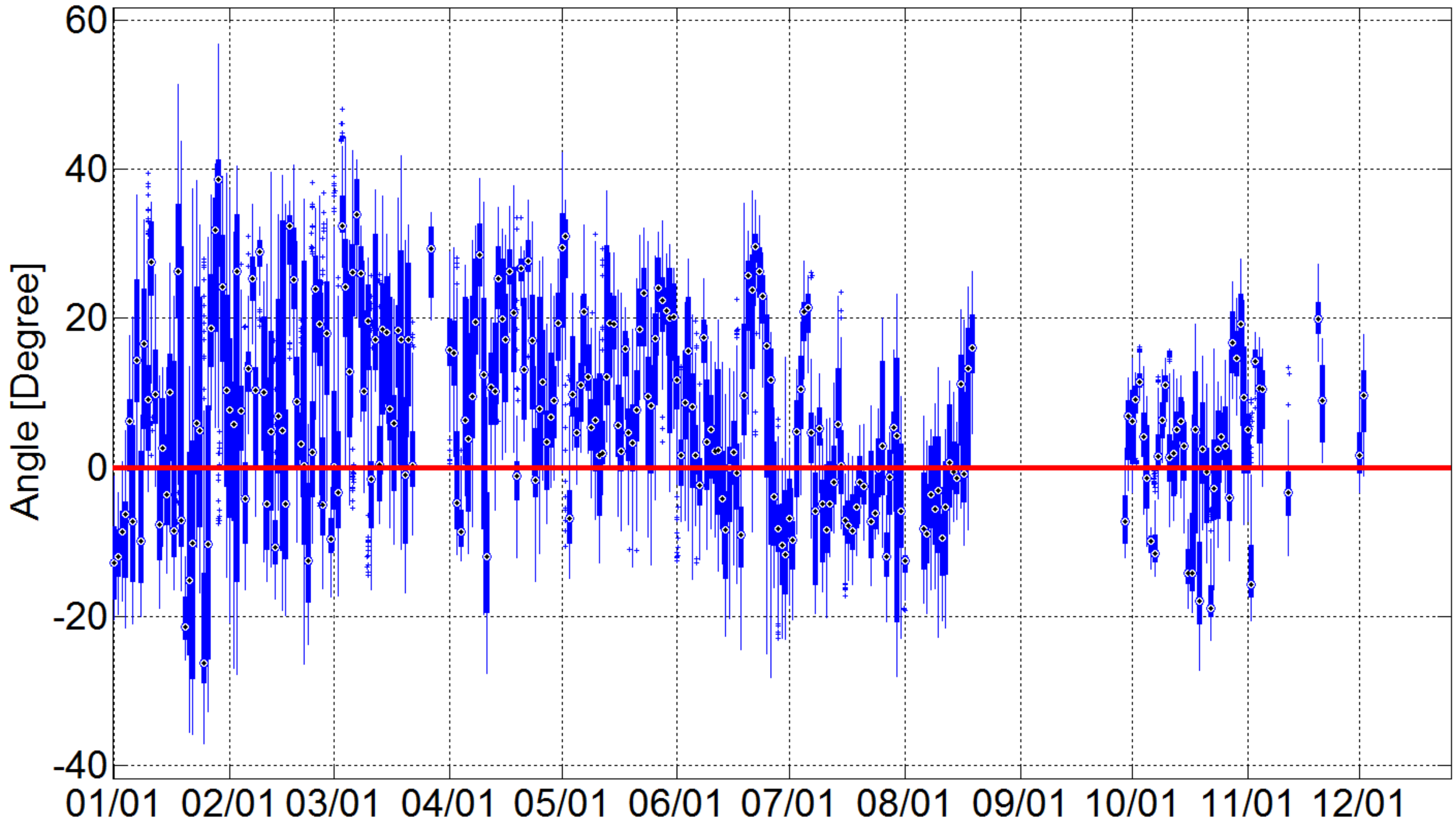

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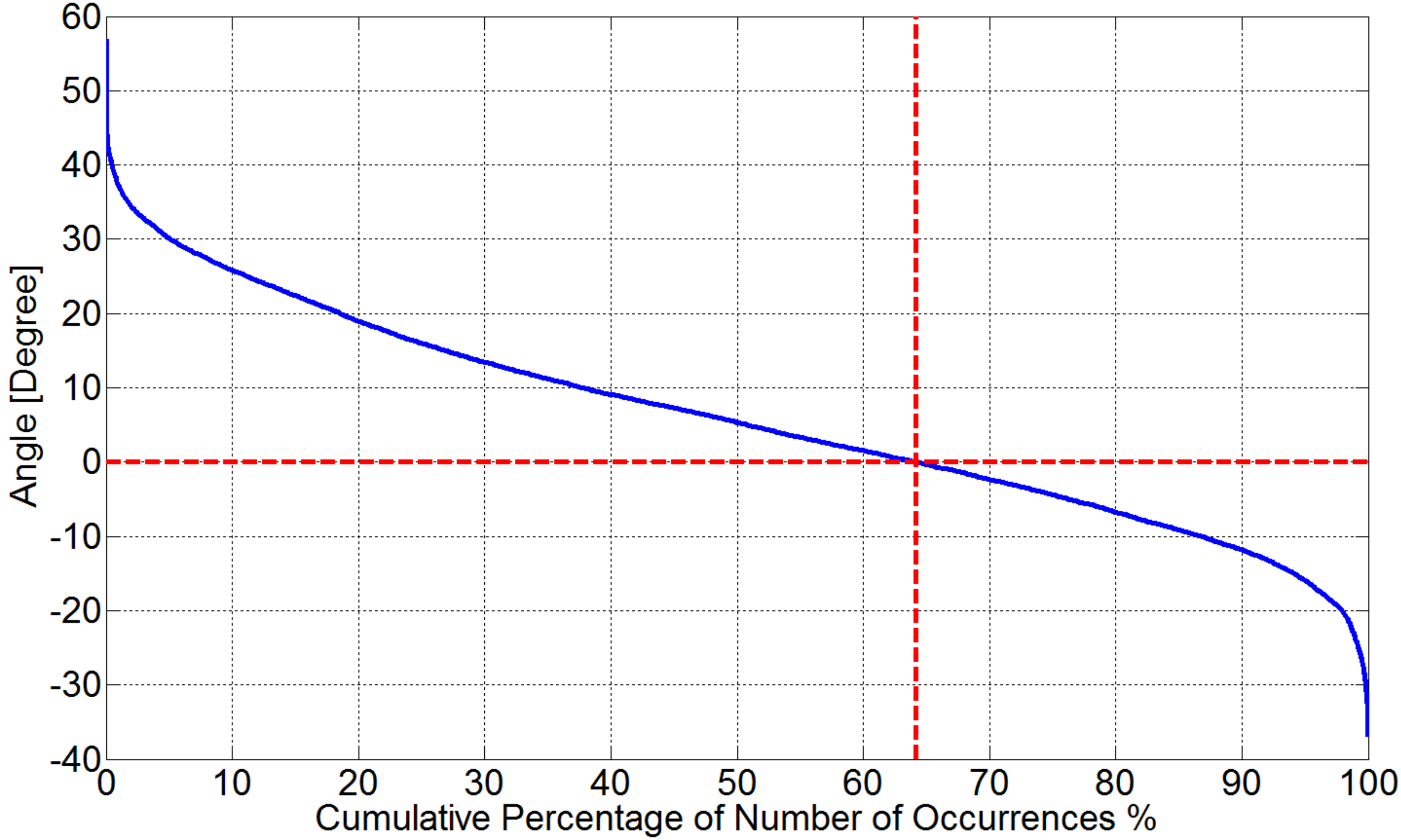

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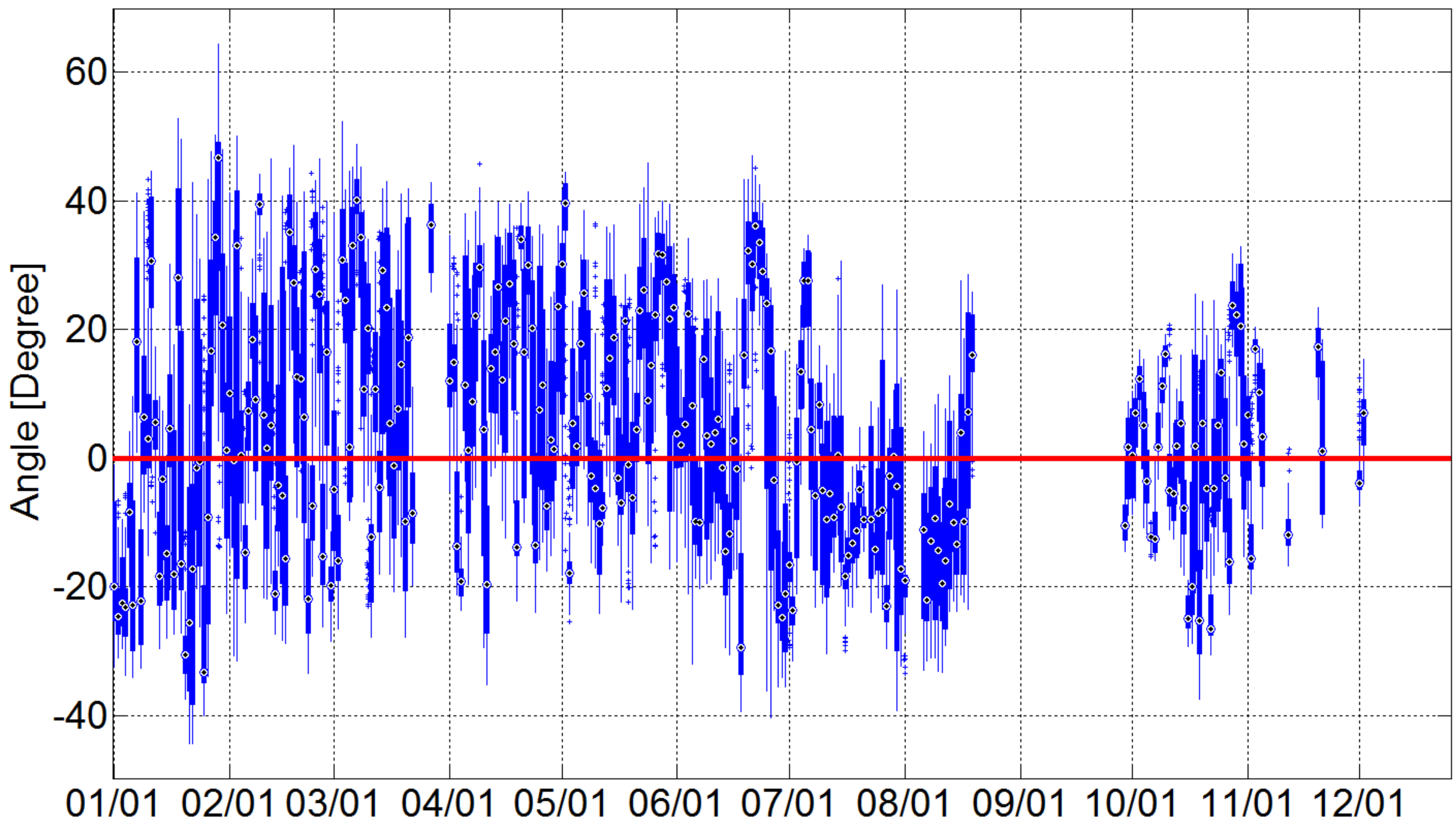

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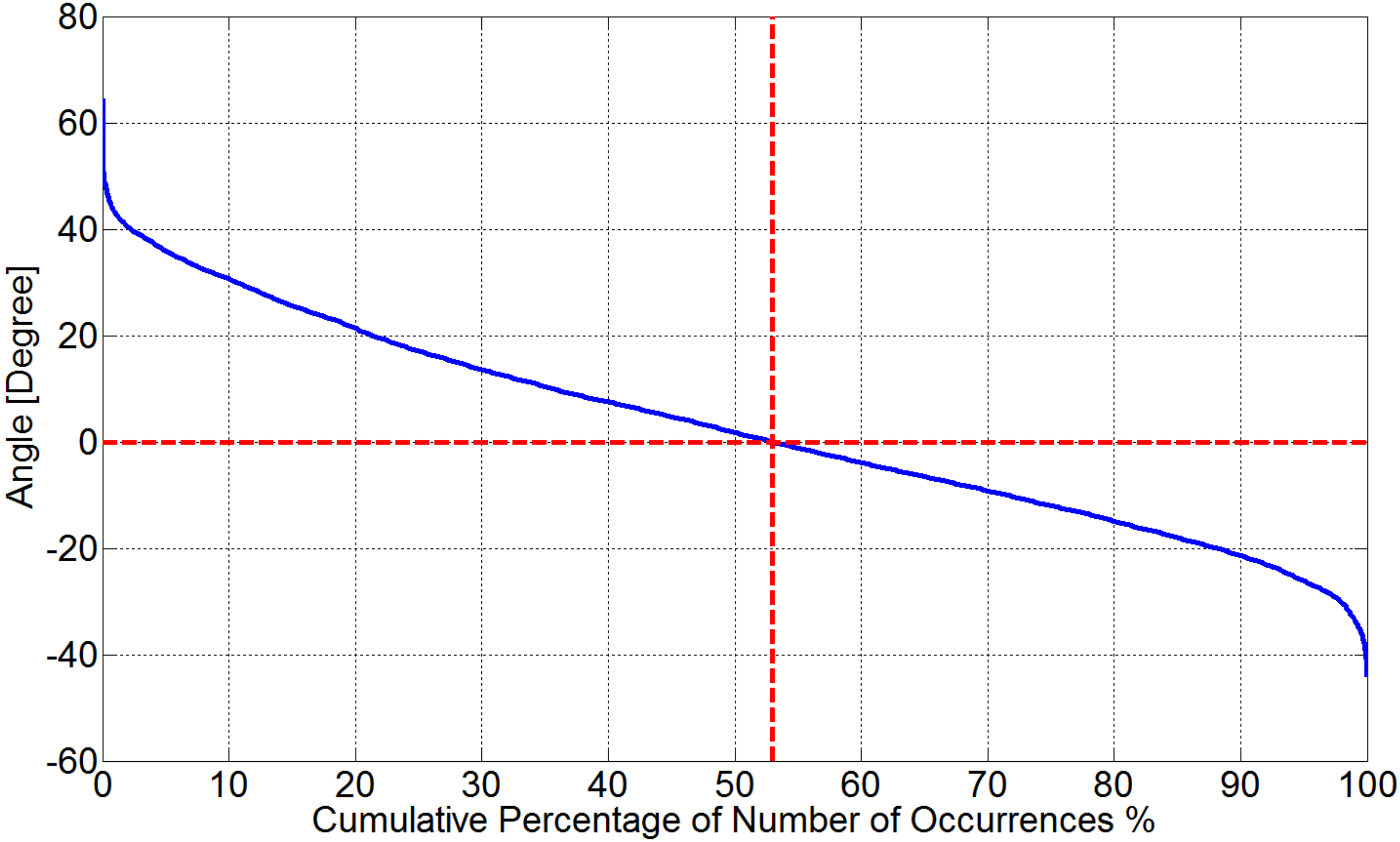


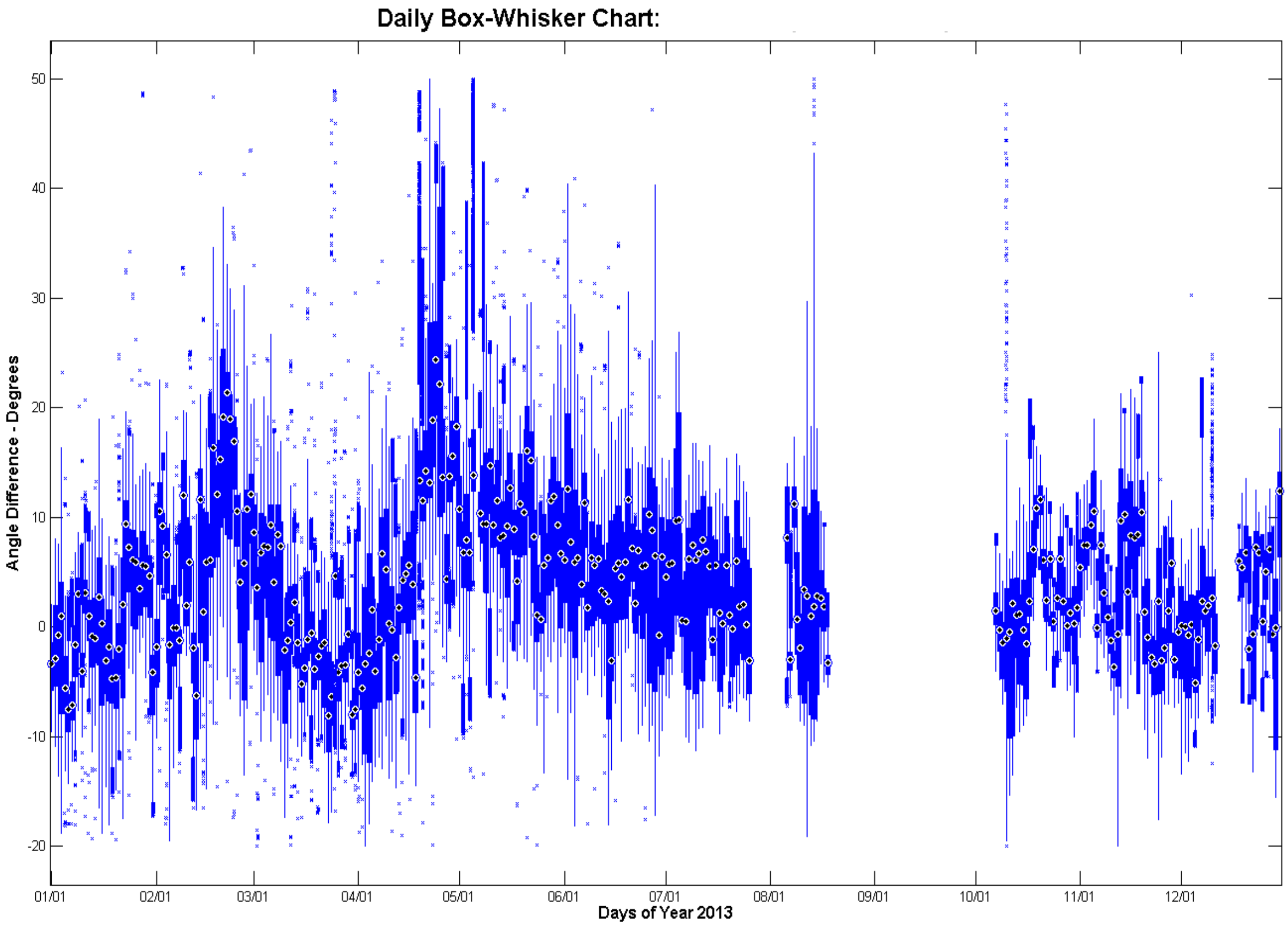
Appendix C – Part 2
CCET Discovery Across Texas project

Baseline Analysis Update – Angle Differences

Phasor Data: January to December 2013
Box-Whisker Plots and Time Duration Curves

Electric Power Group CCET ERCOT

Coast 1-South 13



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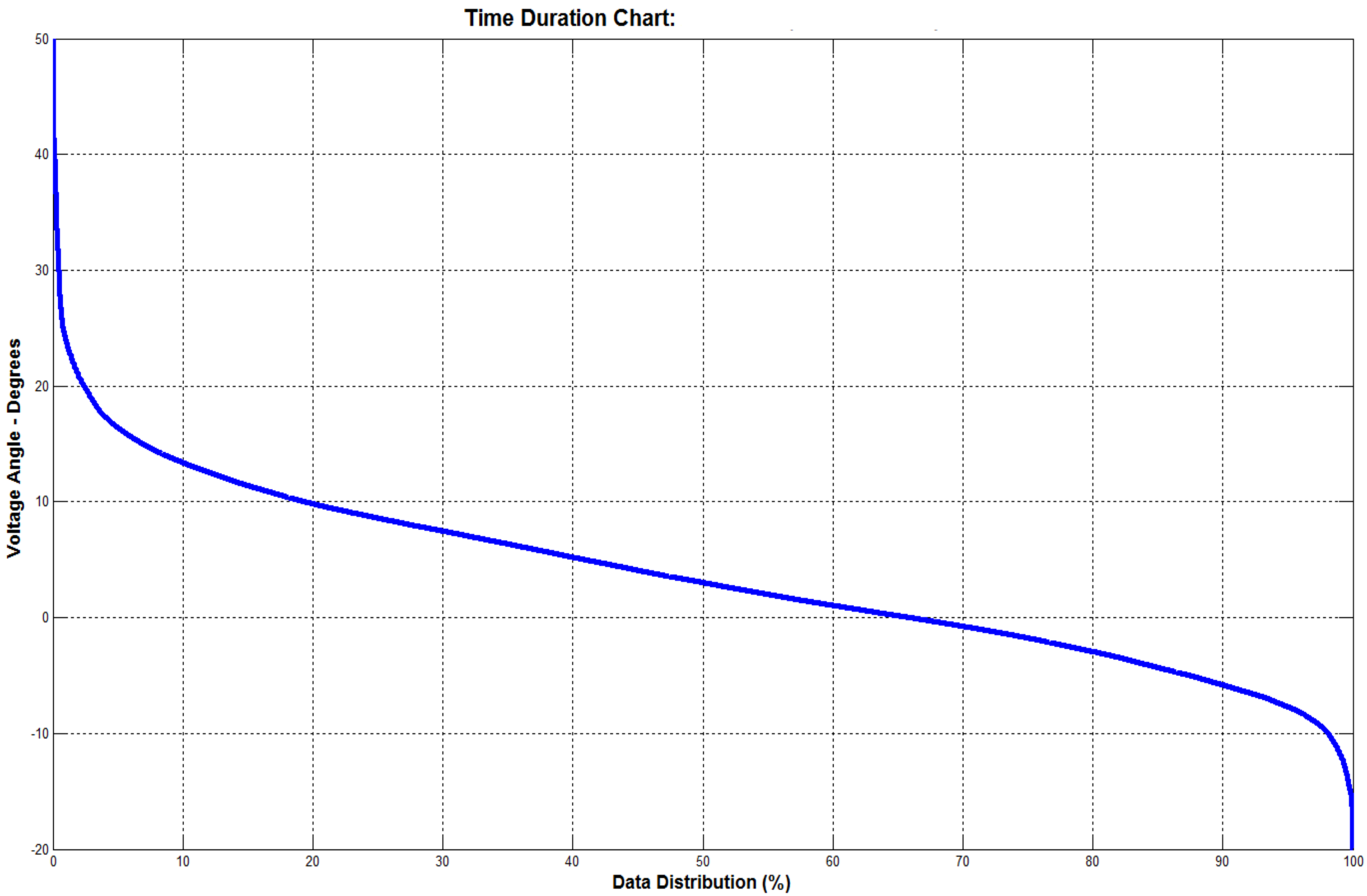

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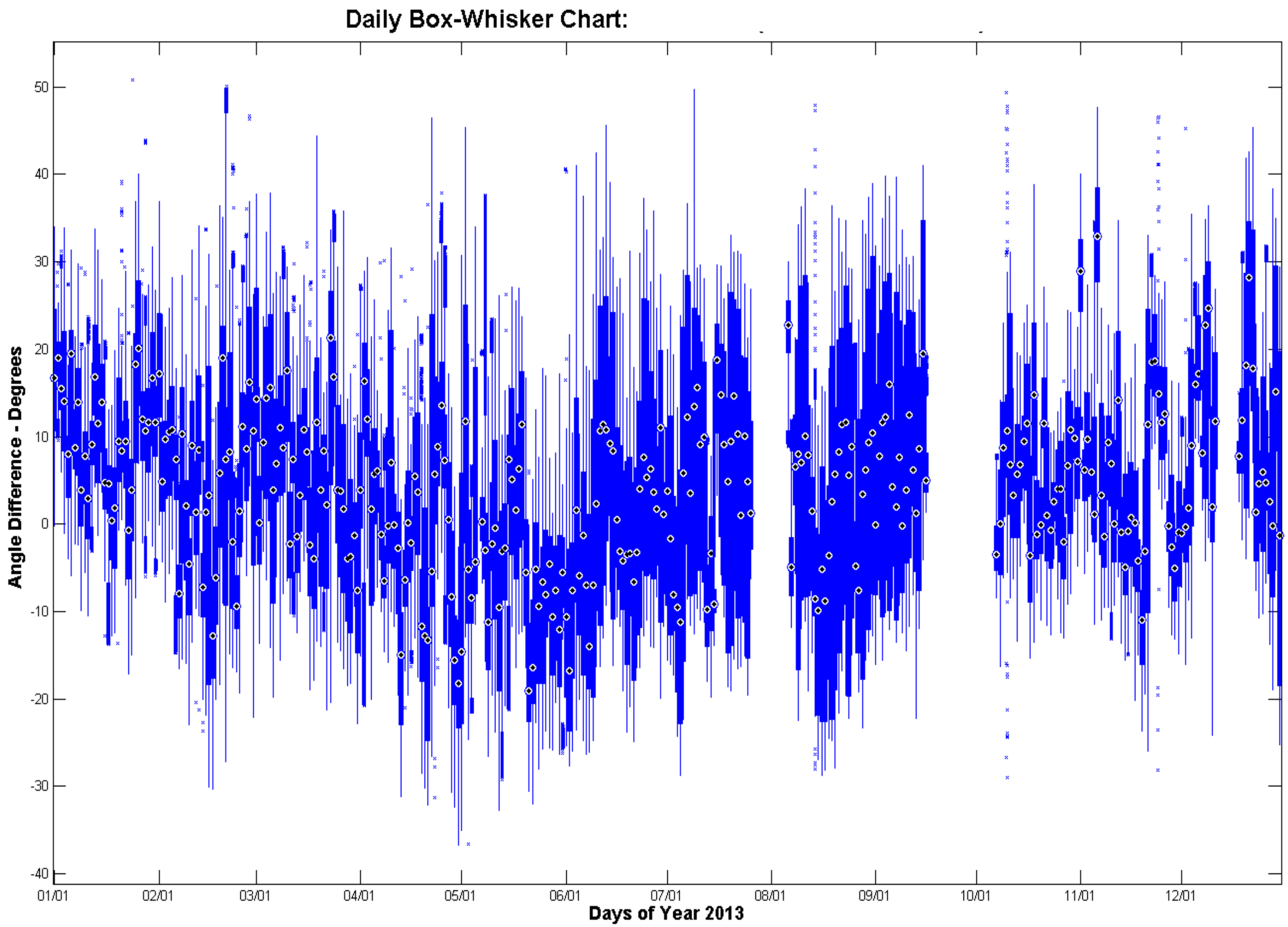

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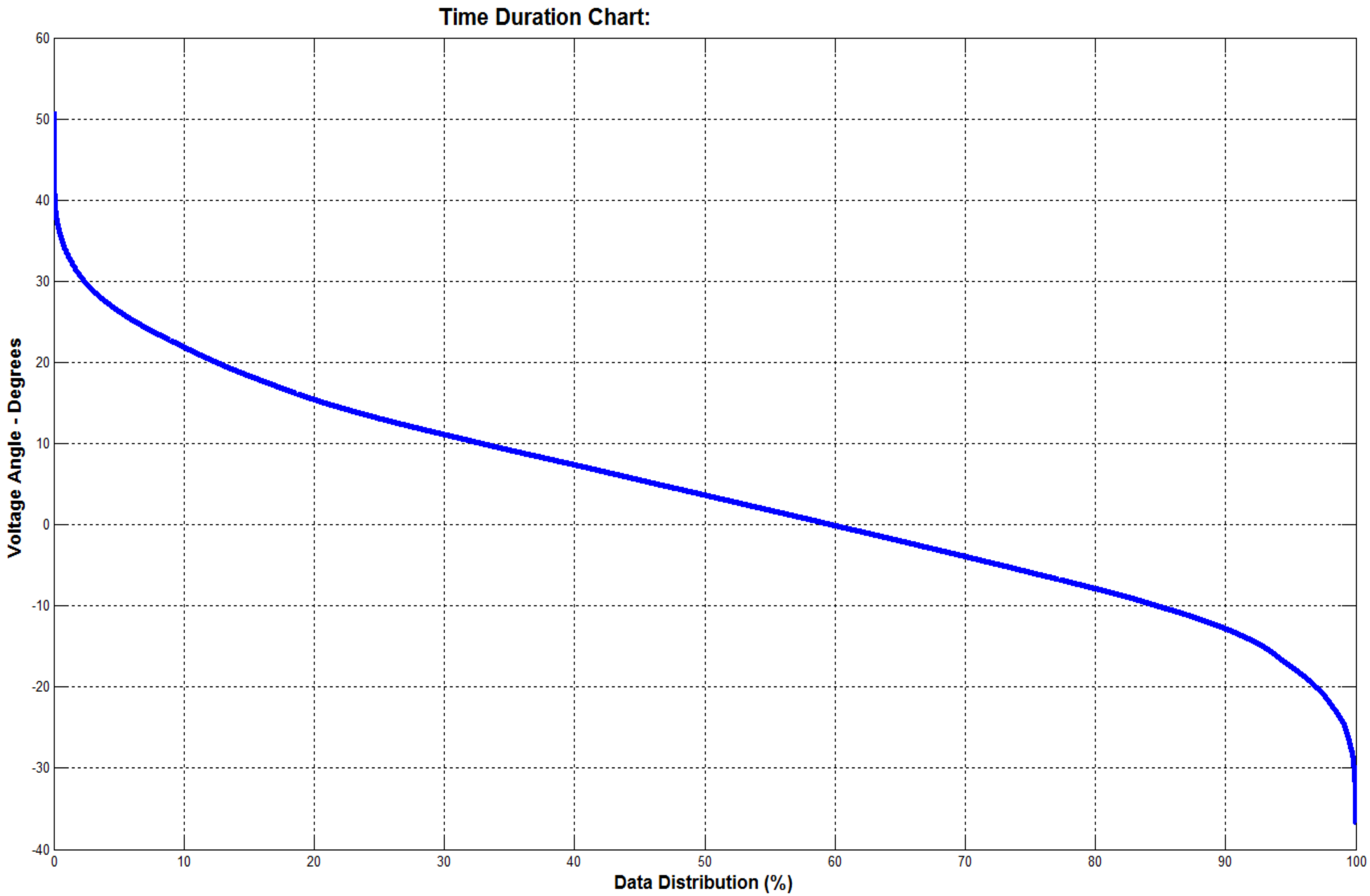

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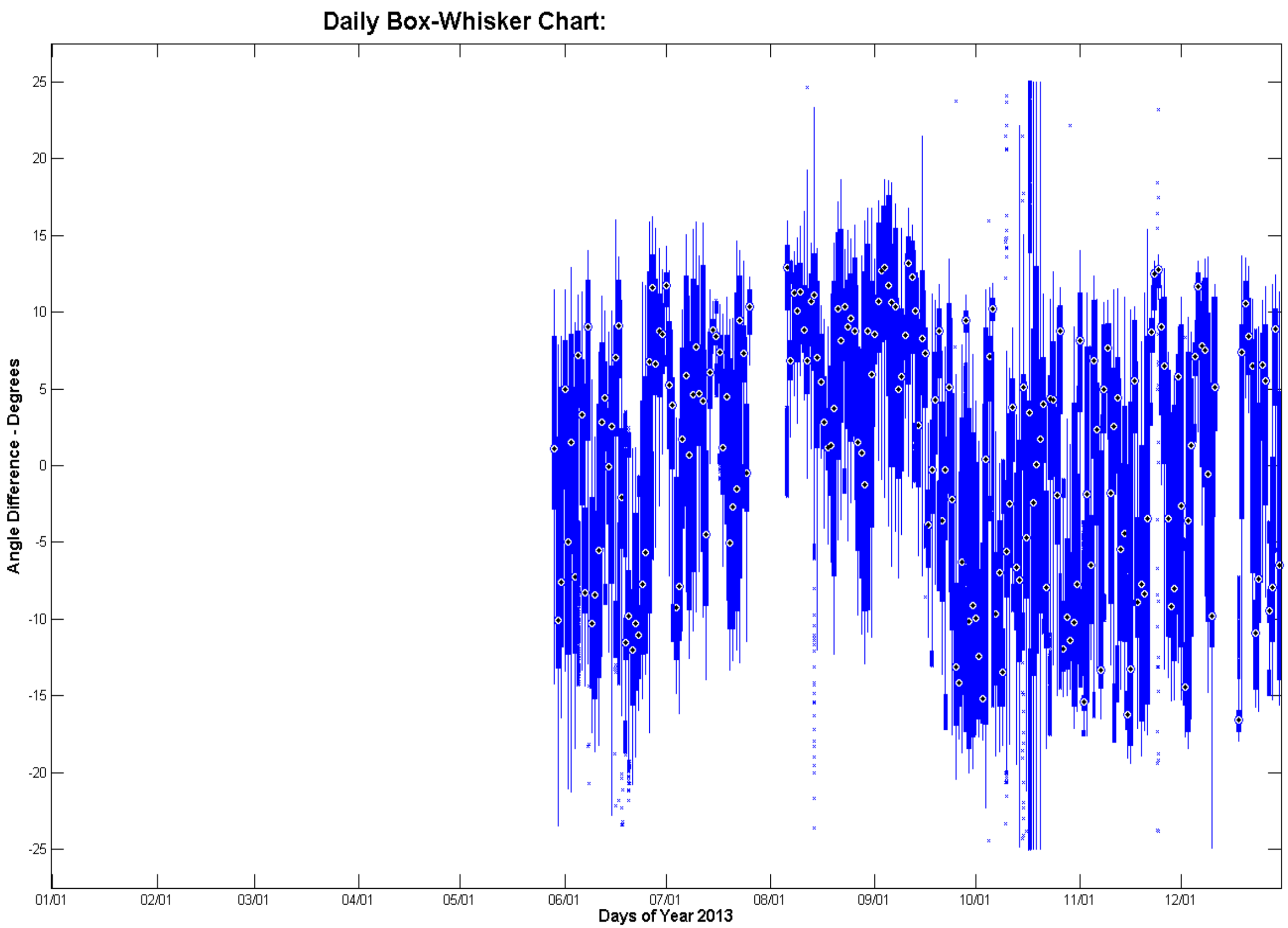

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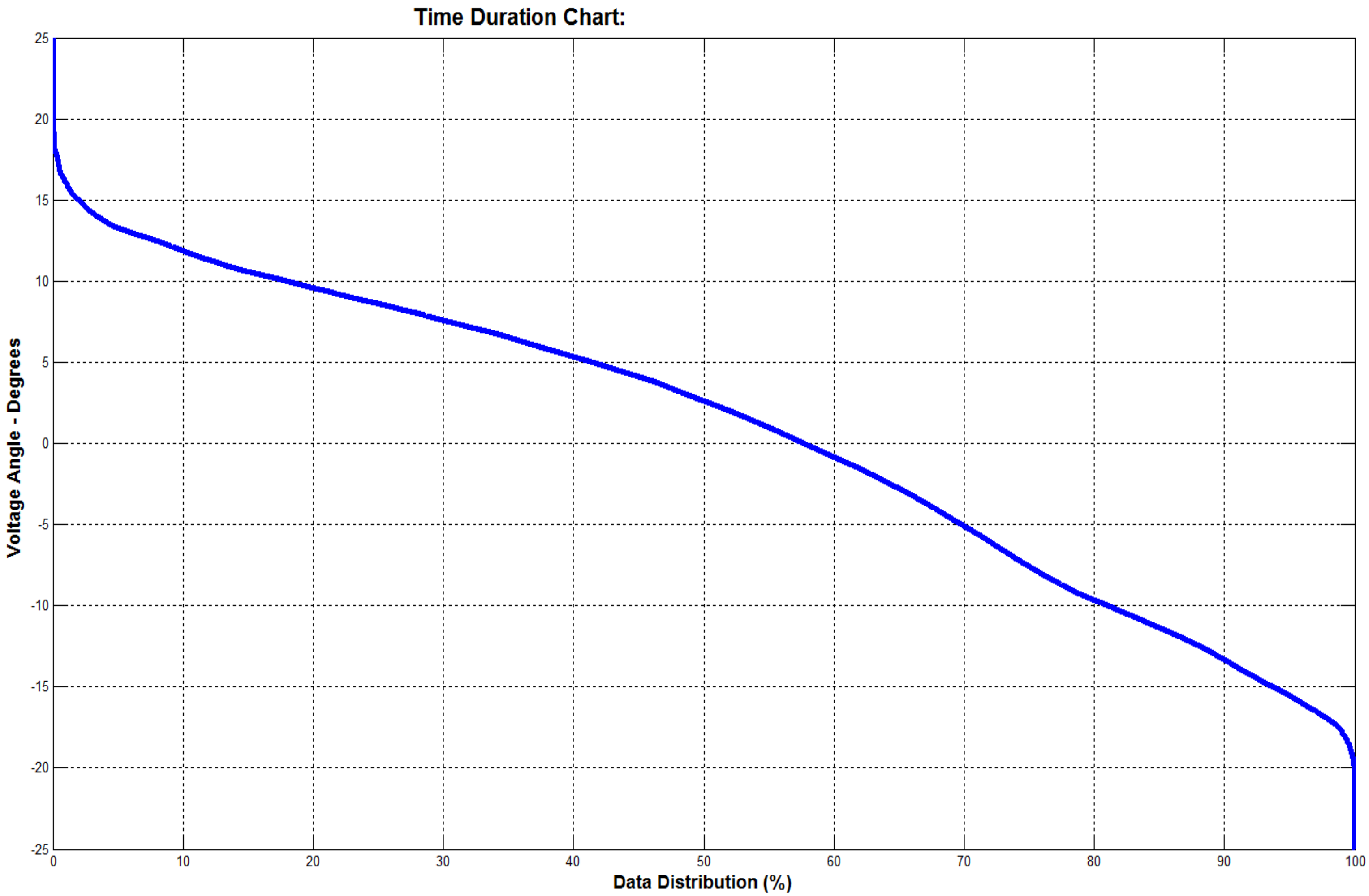

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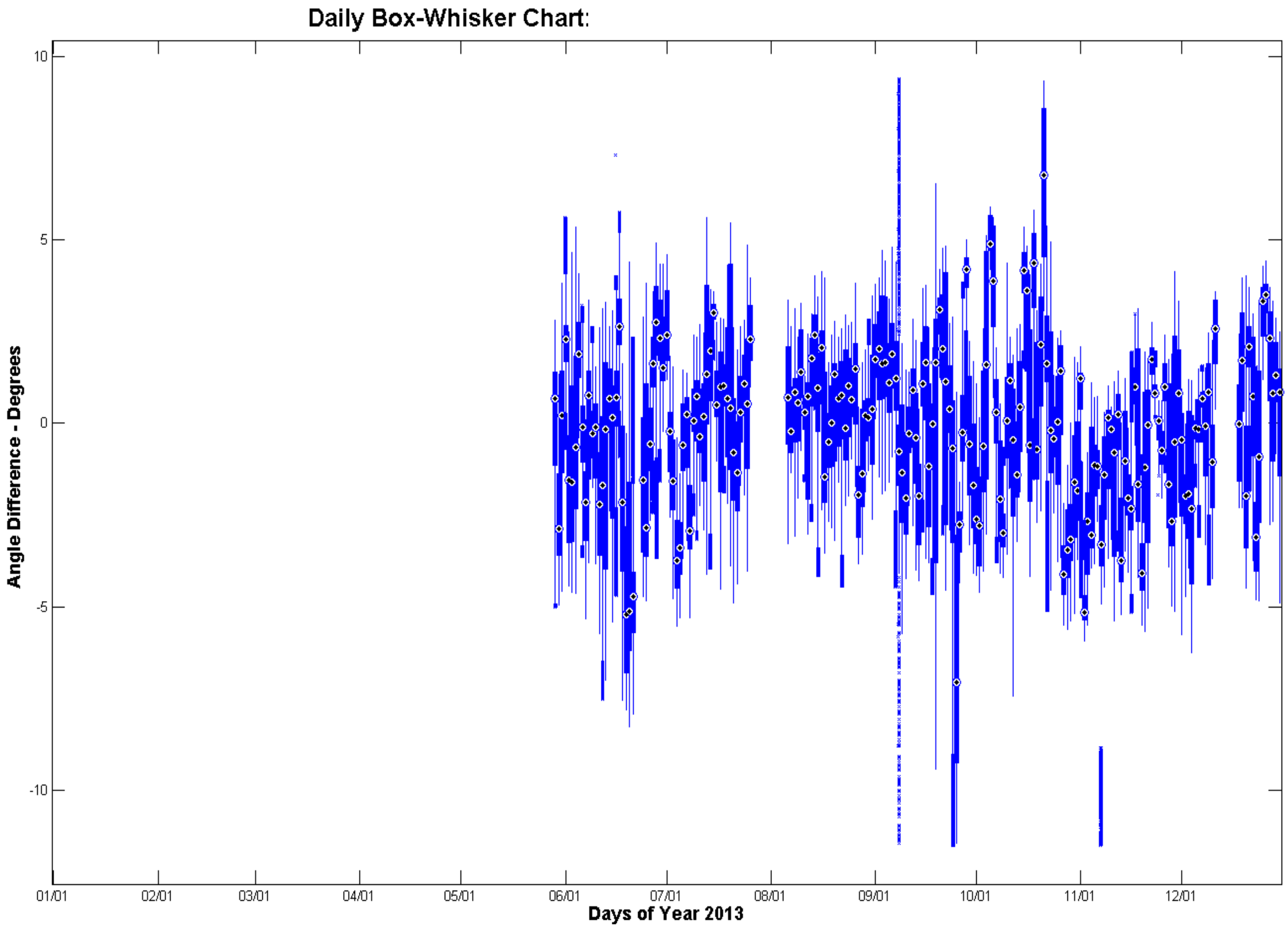

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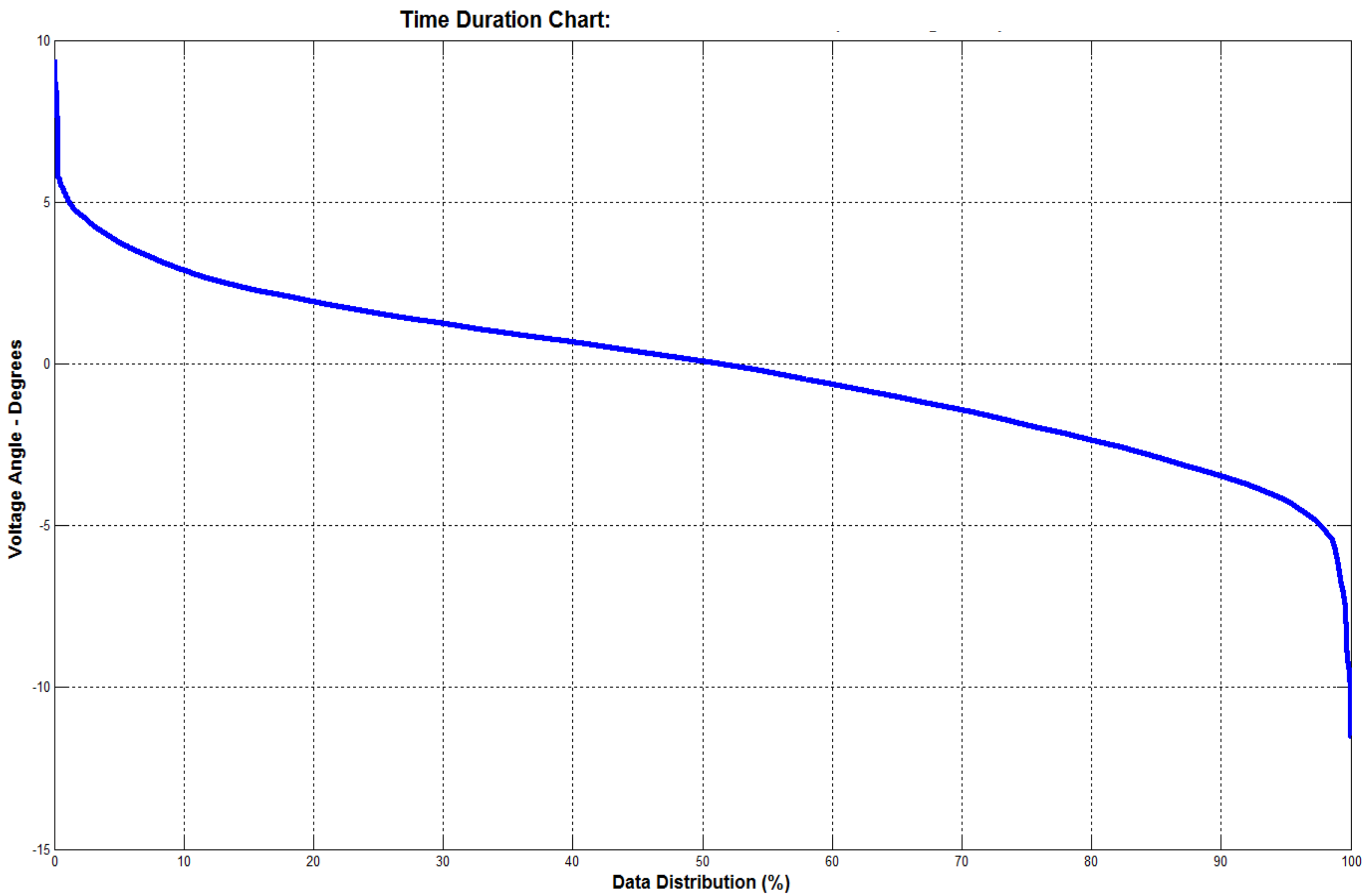

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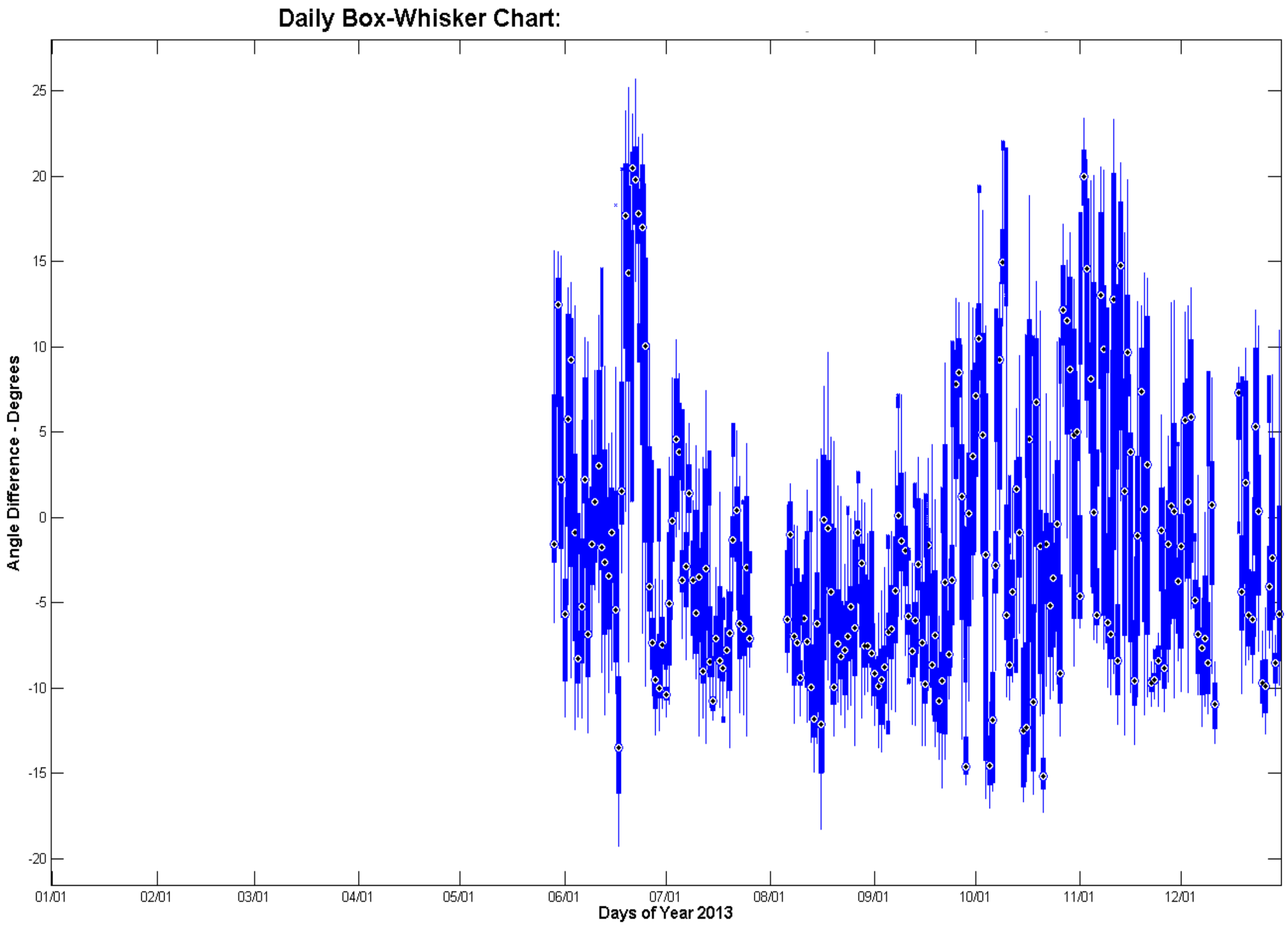

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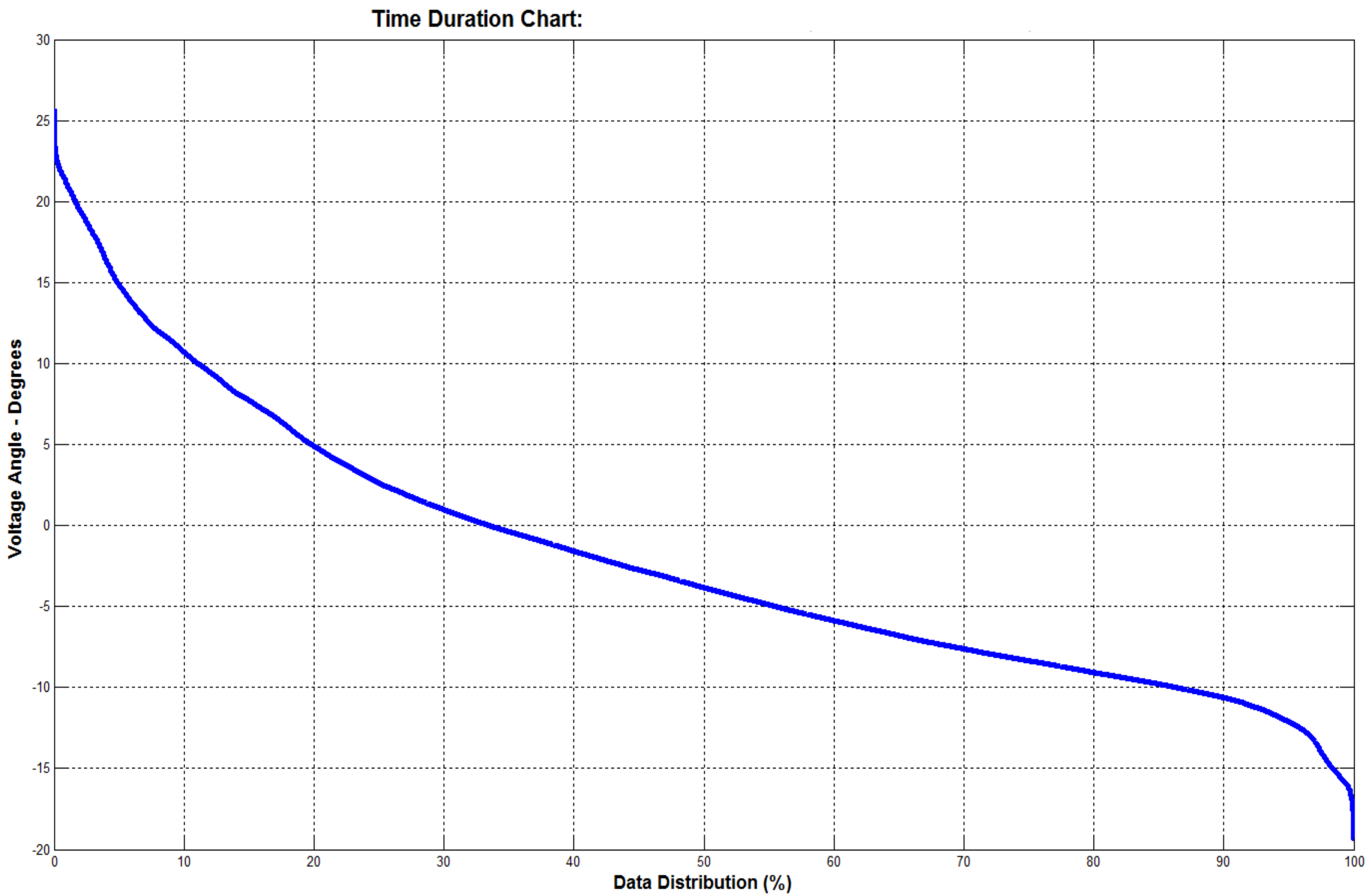

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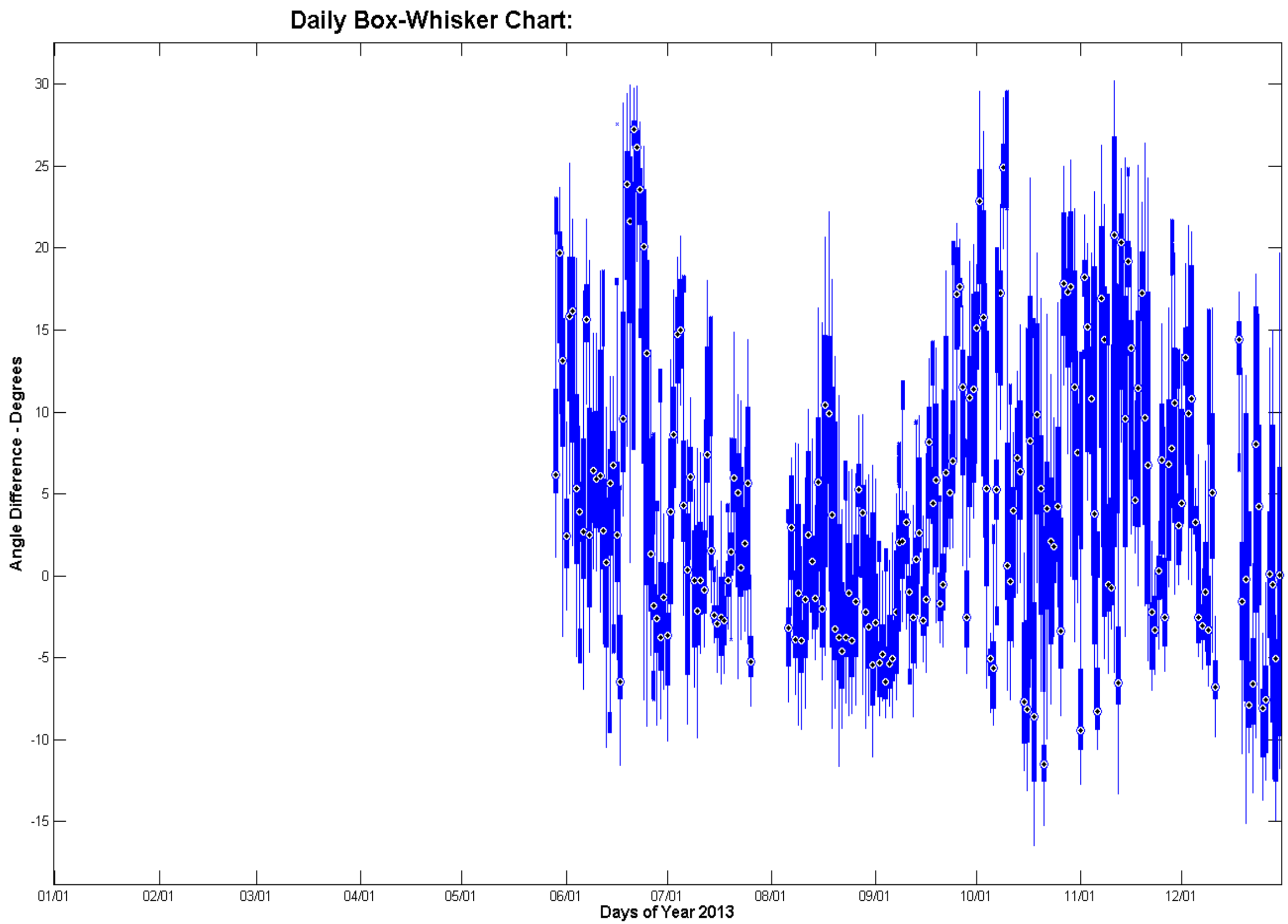

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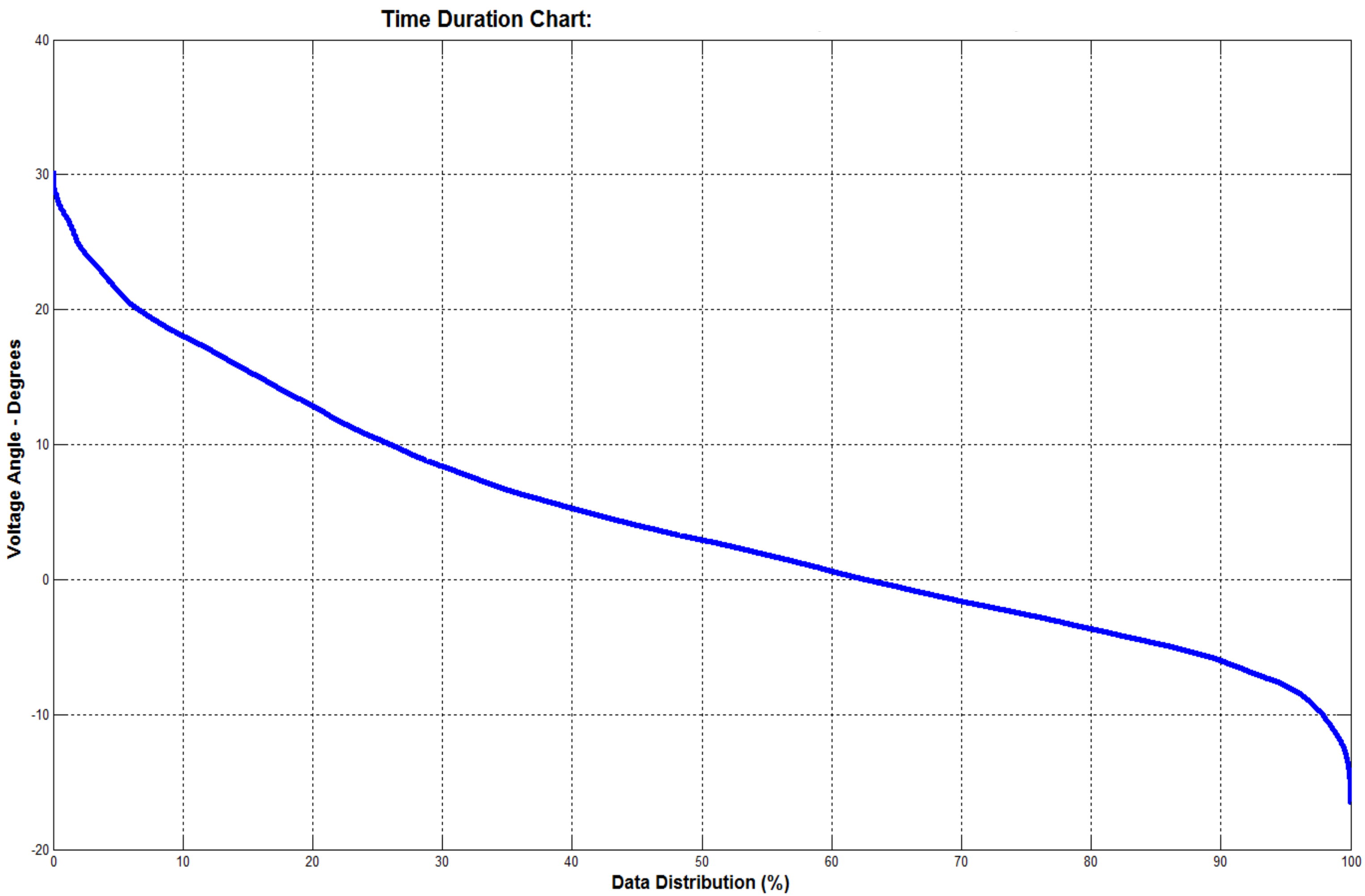

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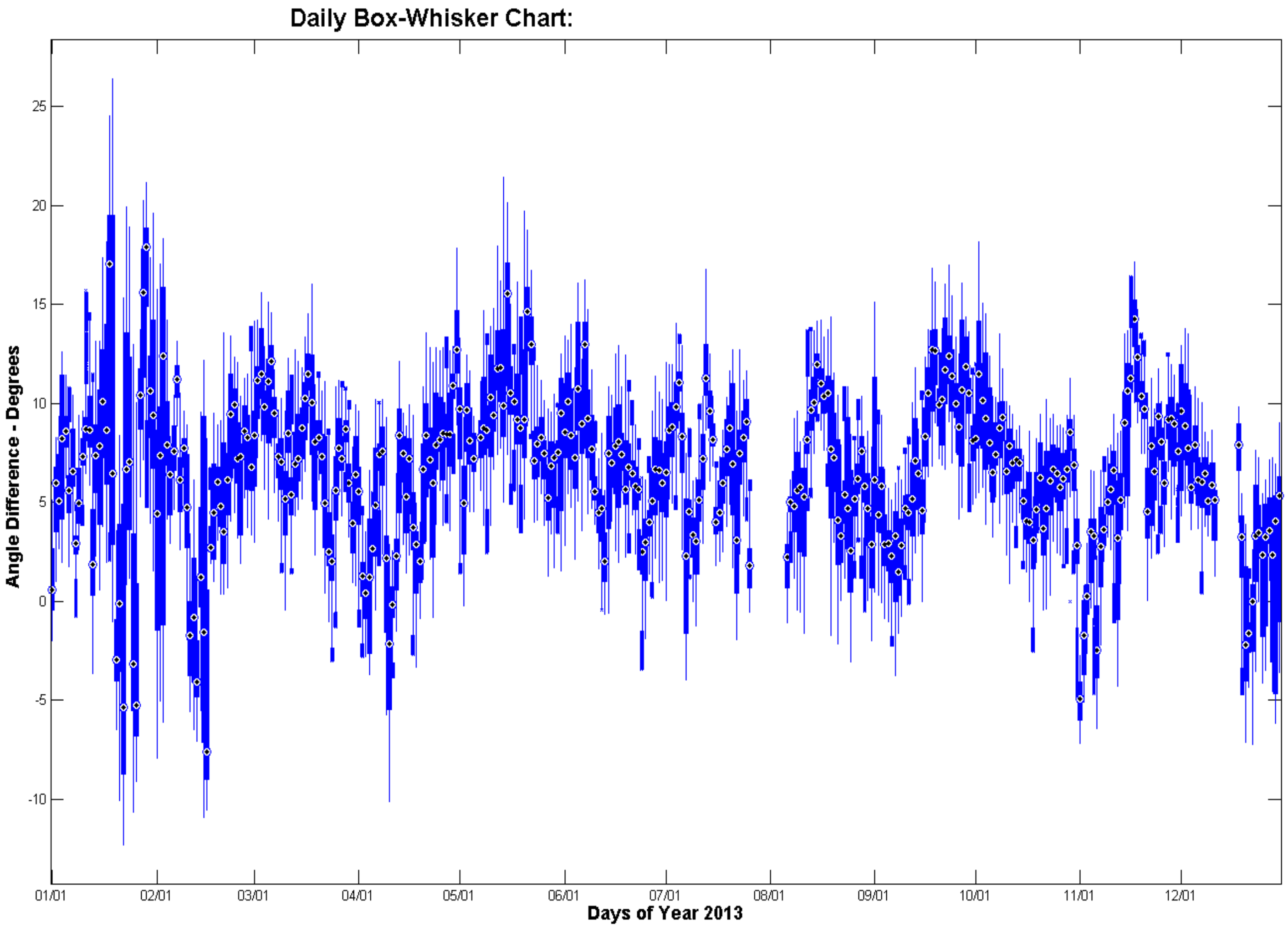

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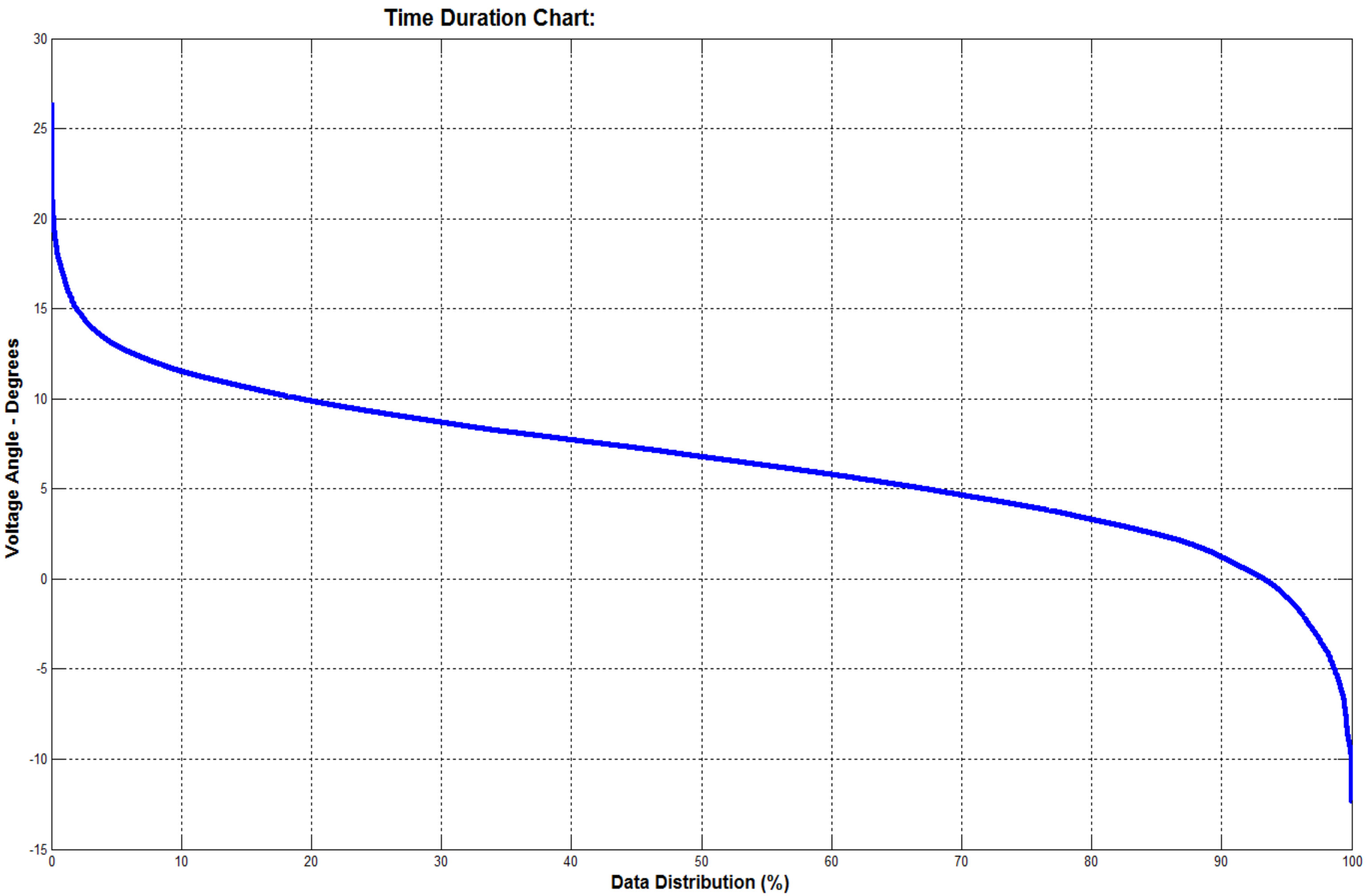

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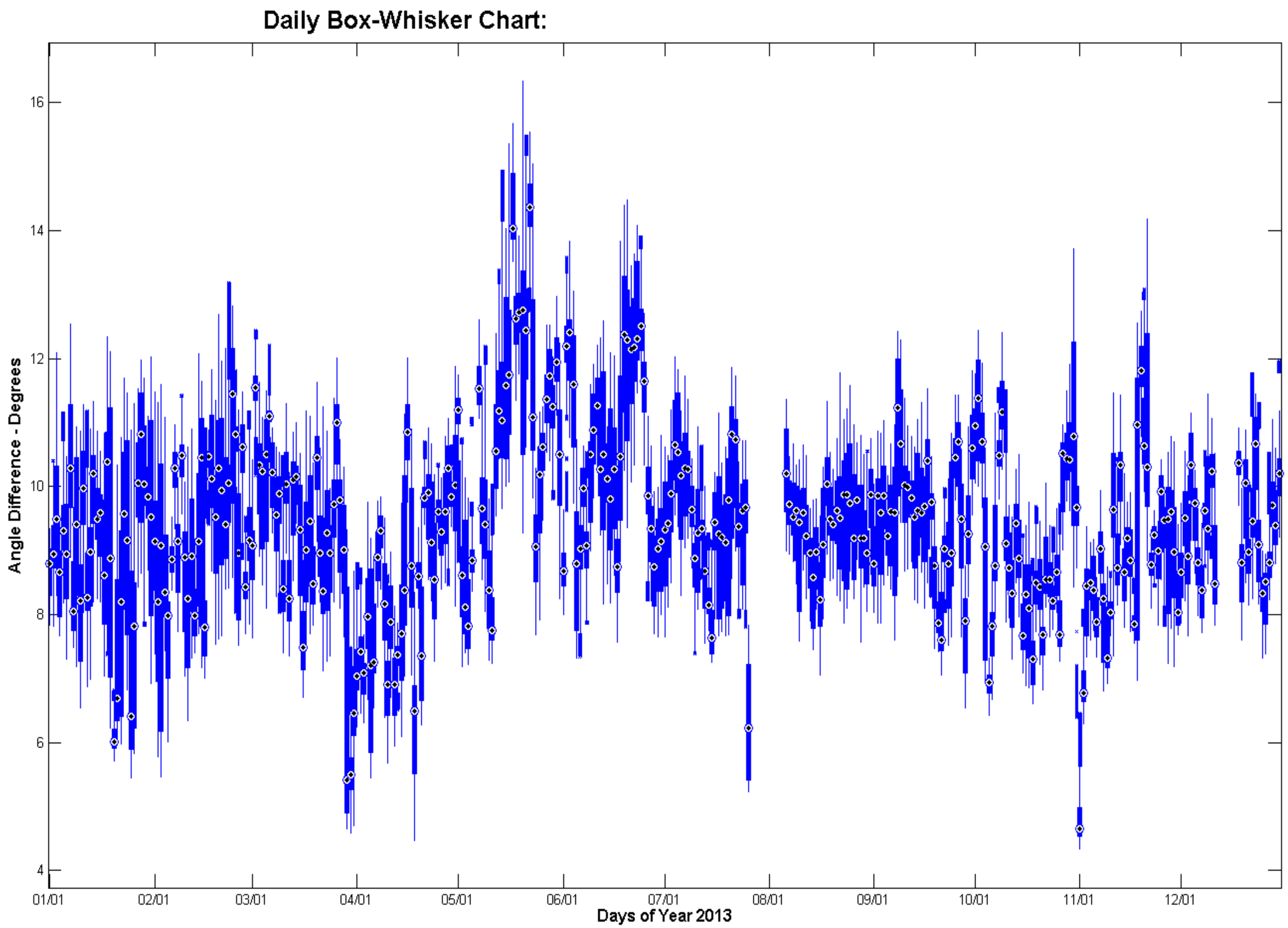

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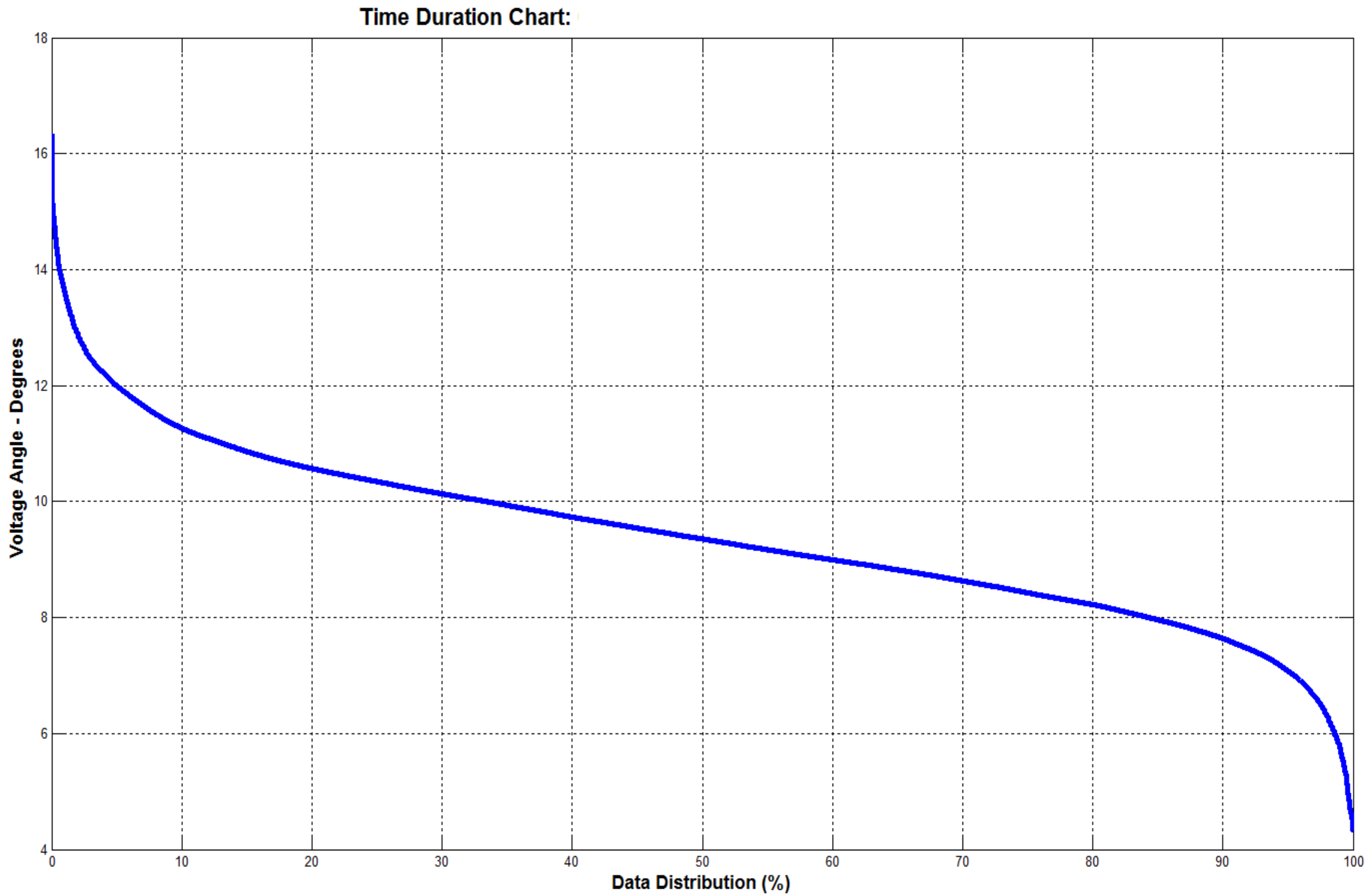

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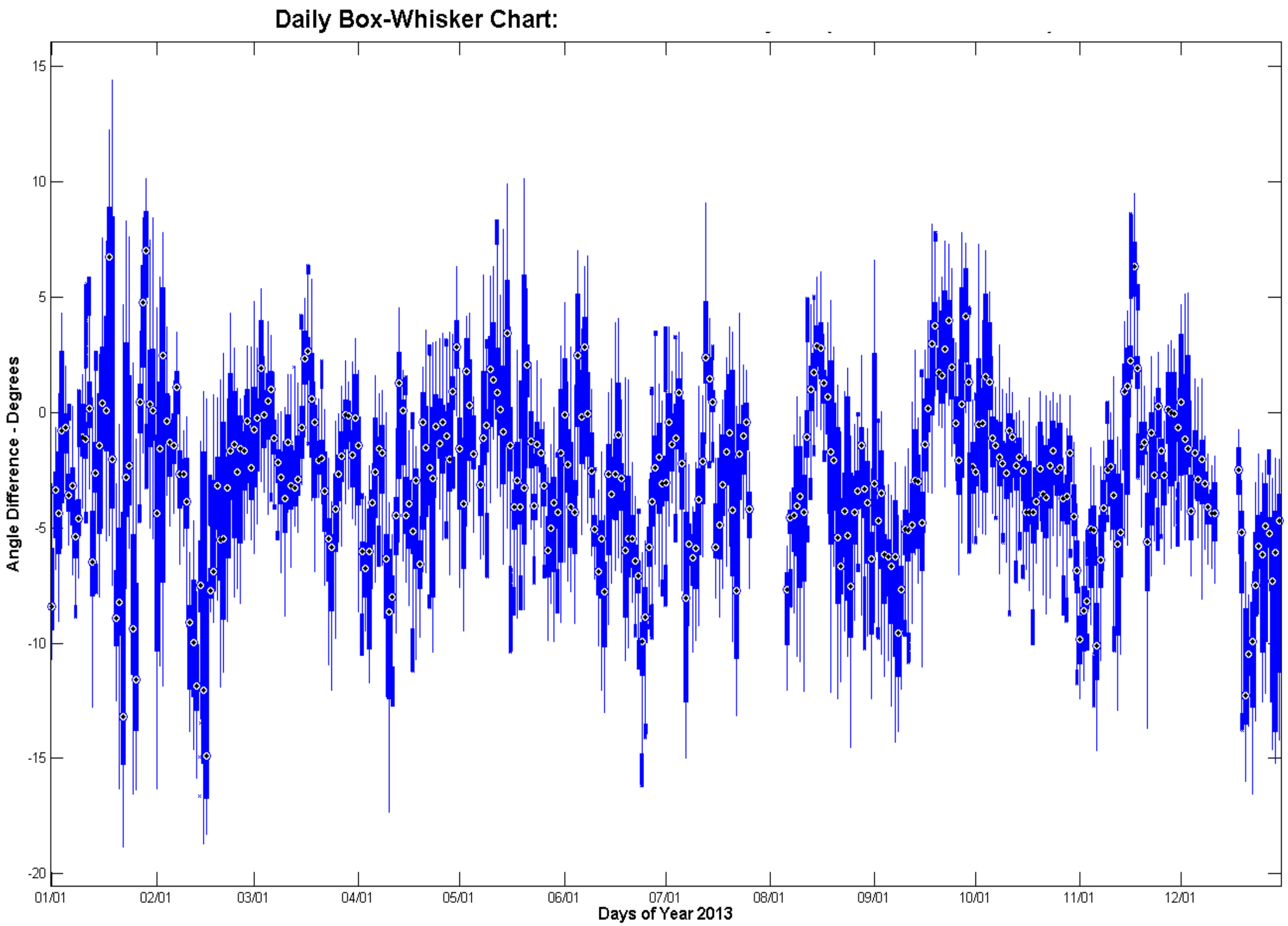

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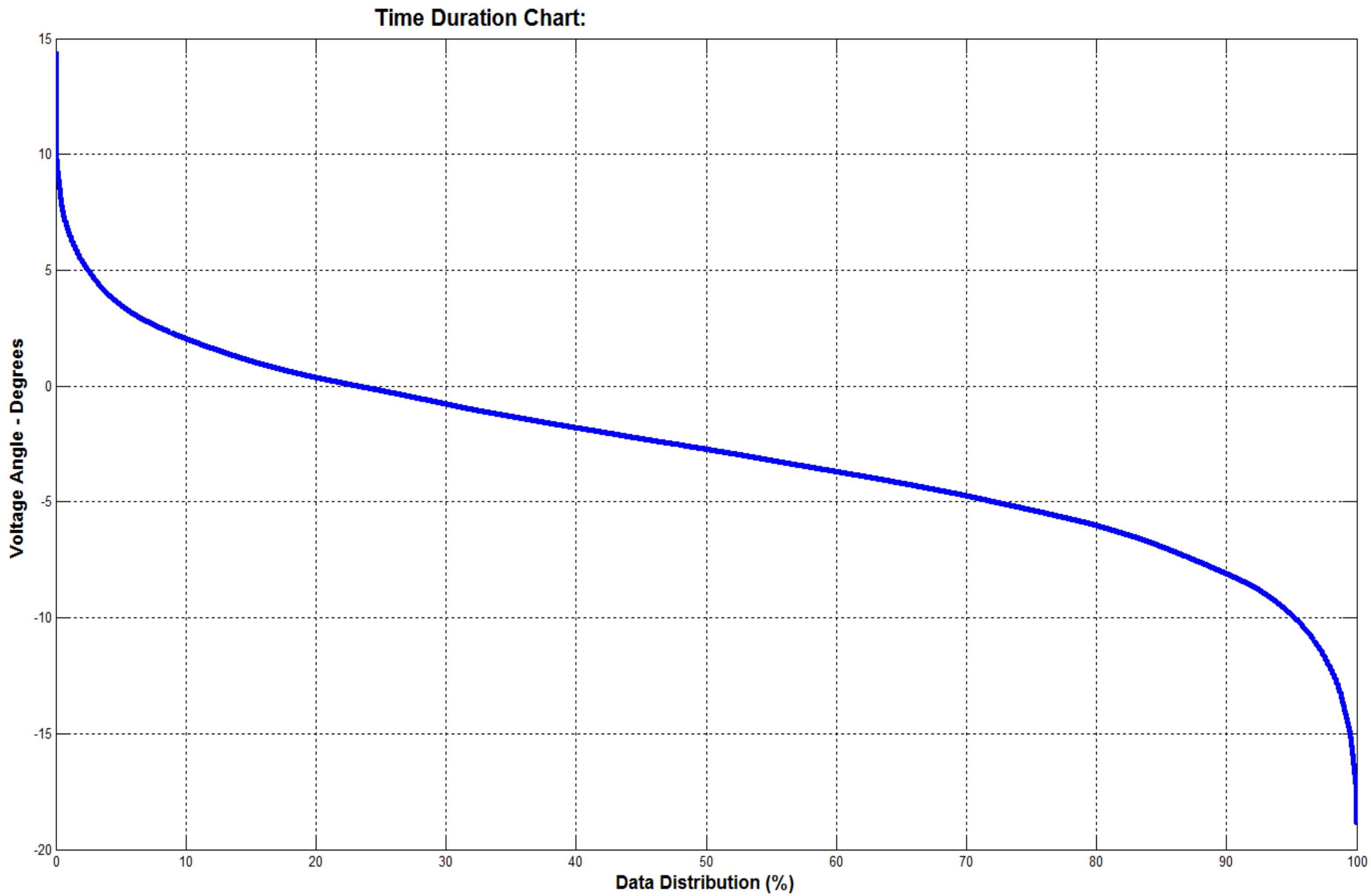

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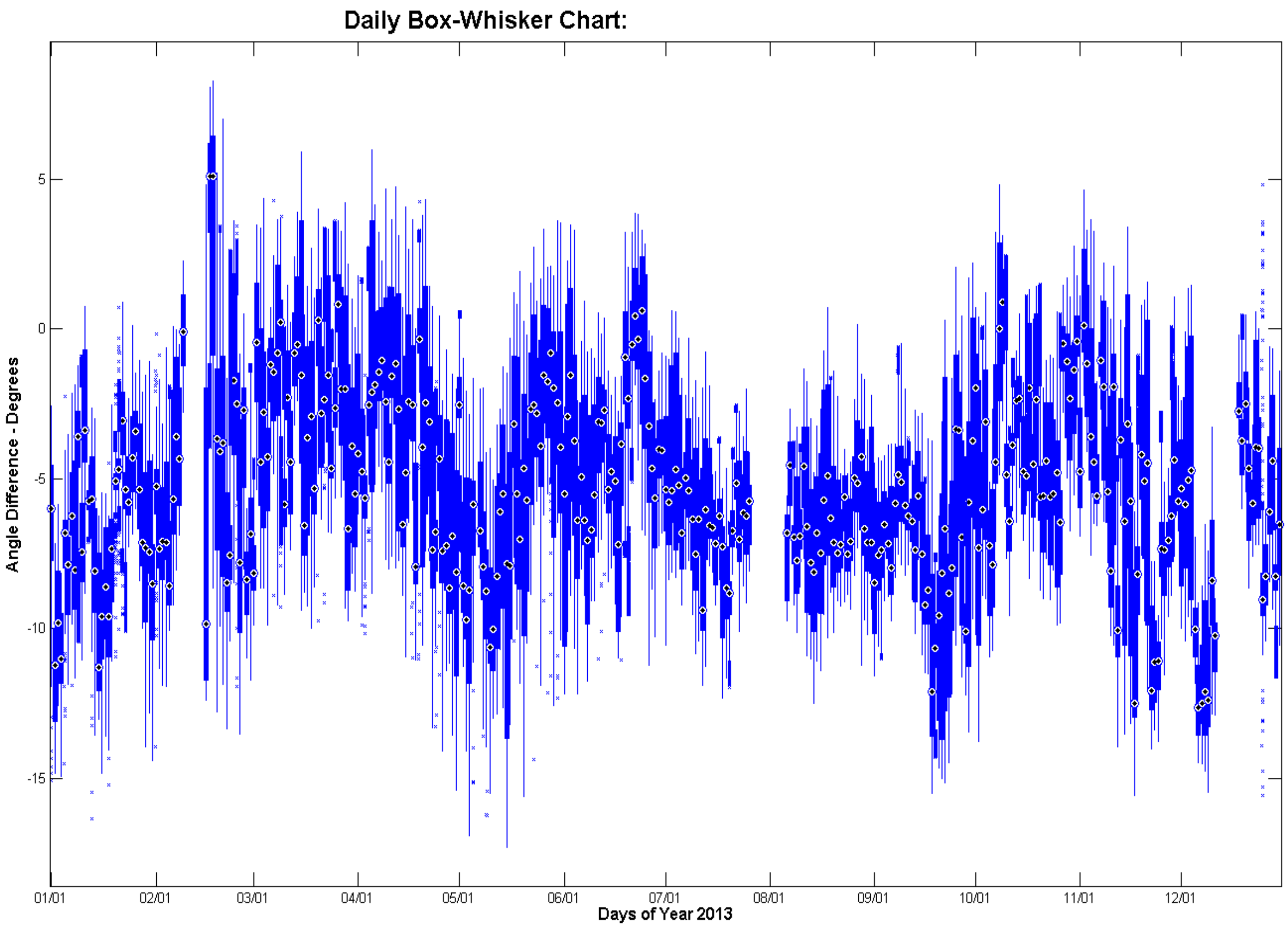

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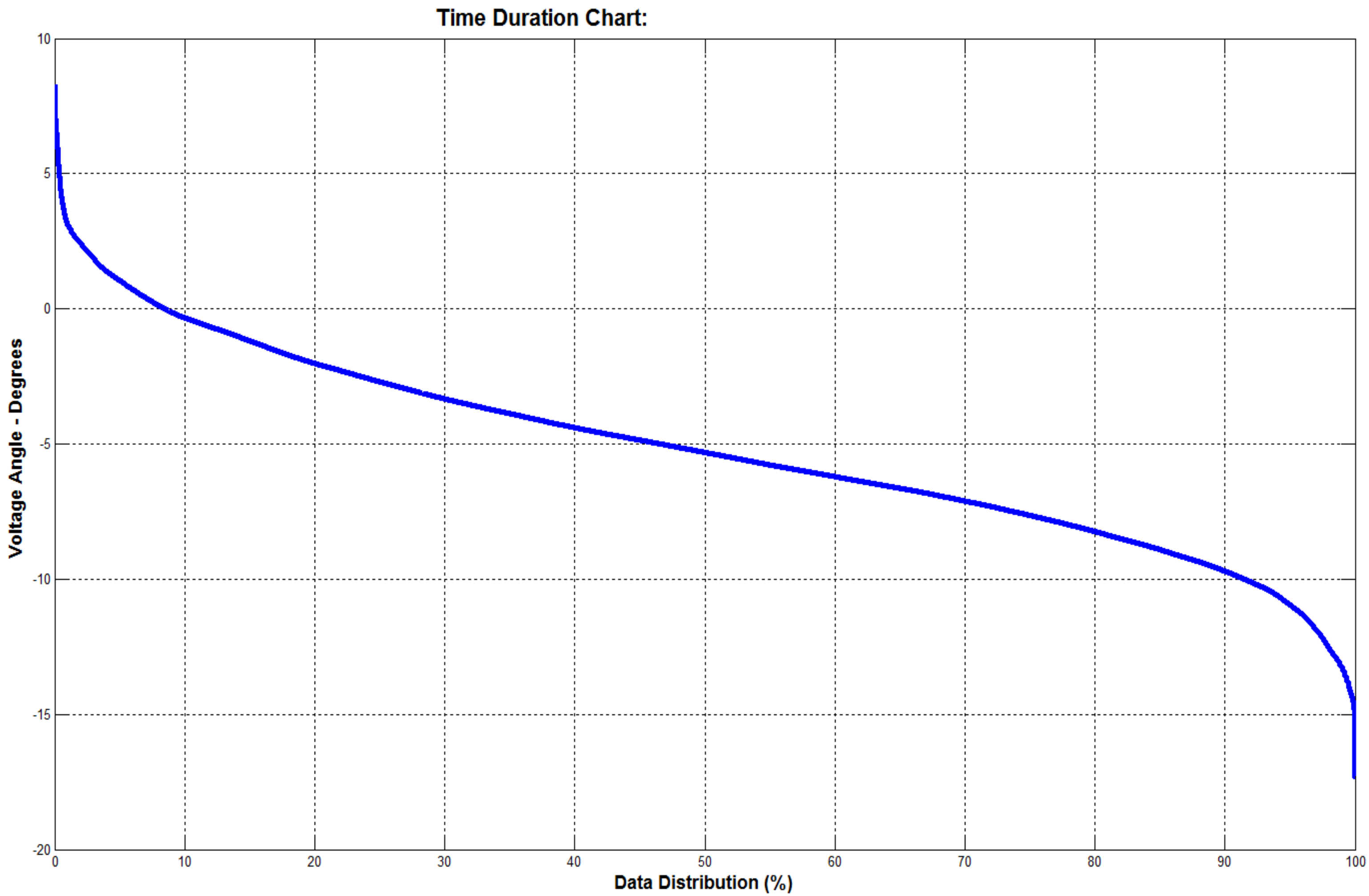

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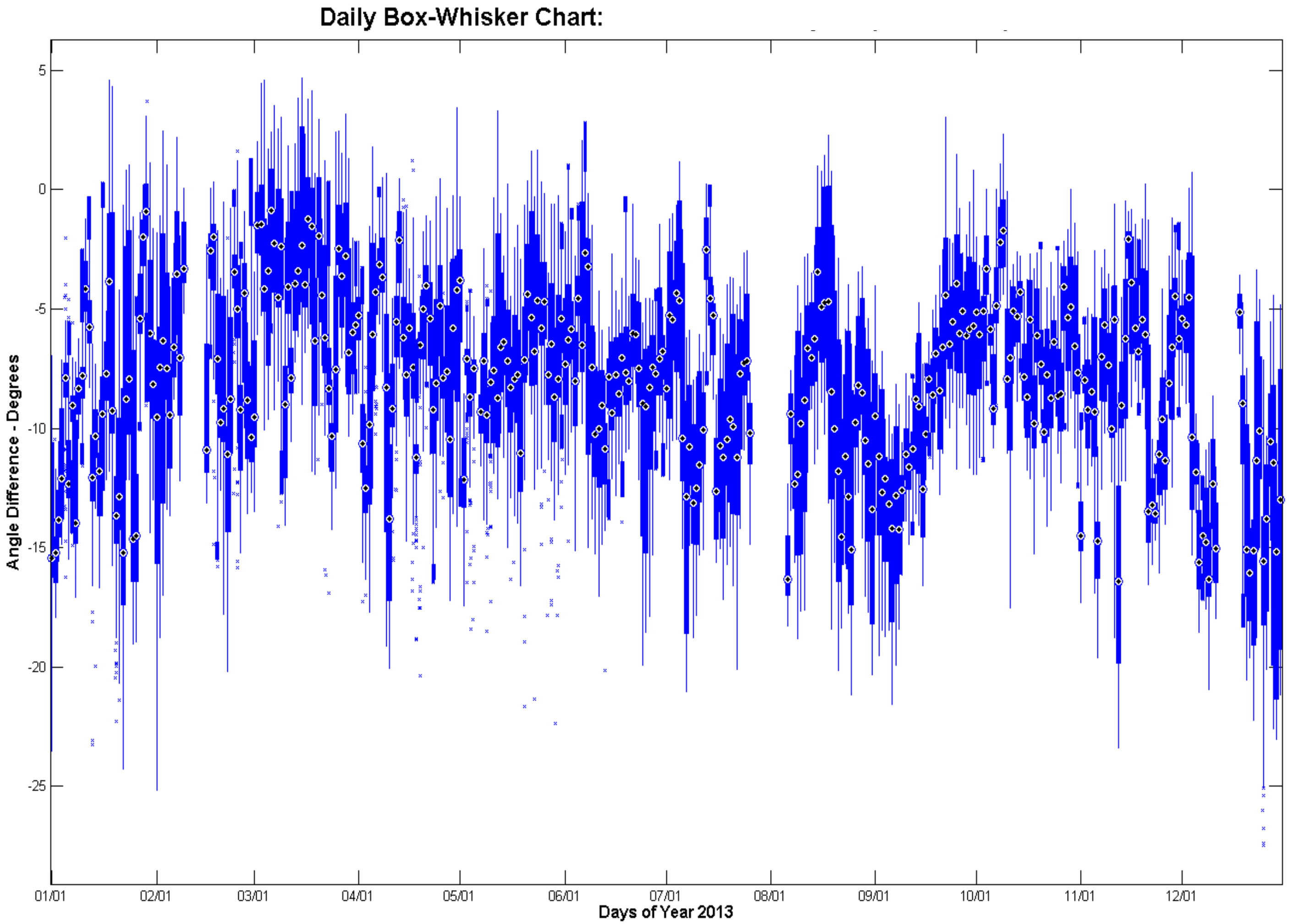

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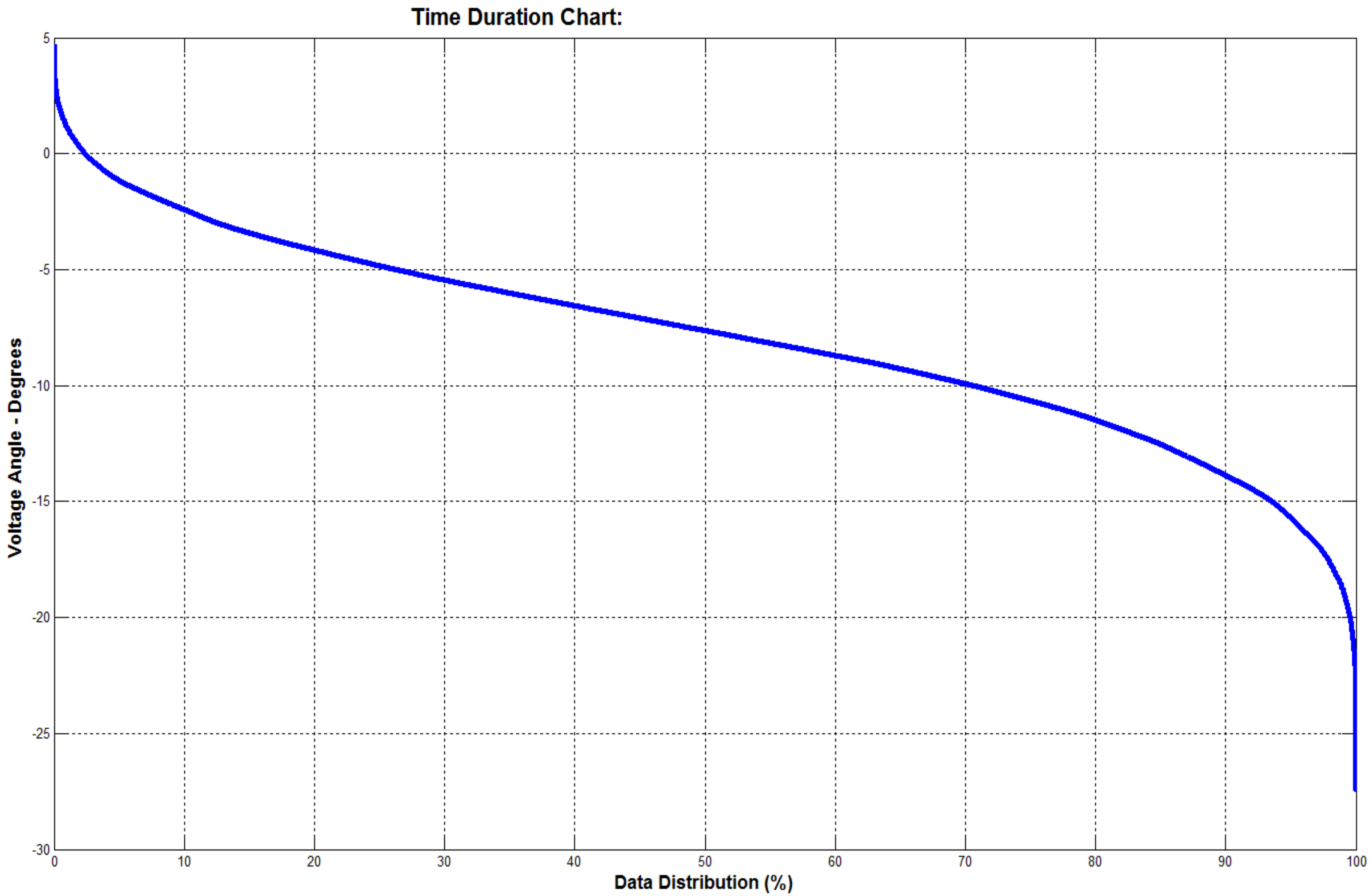

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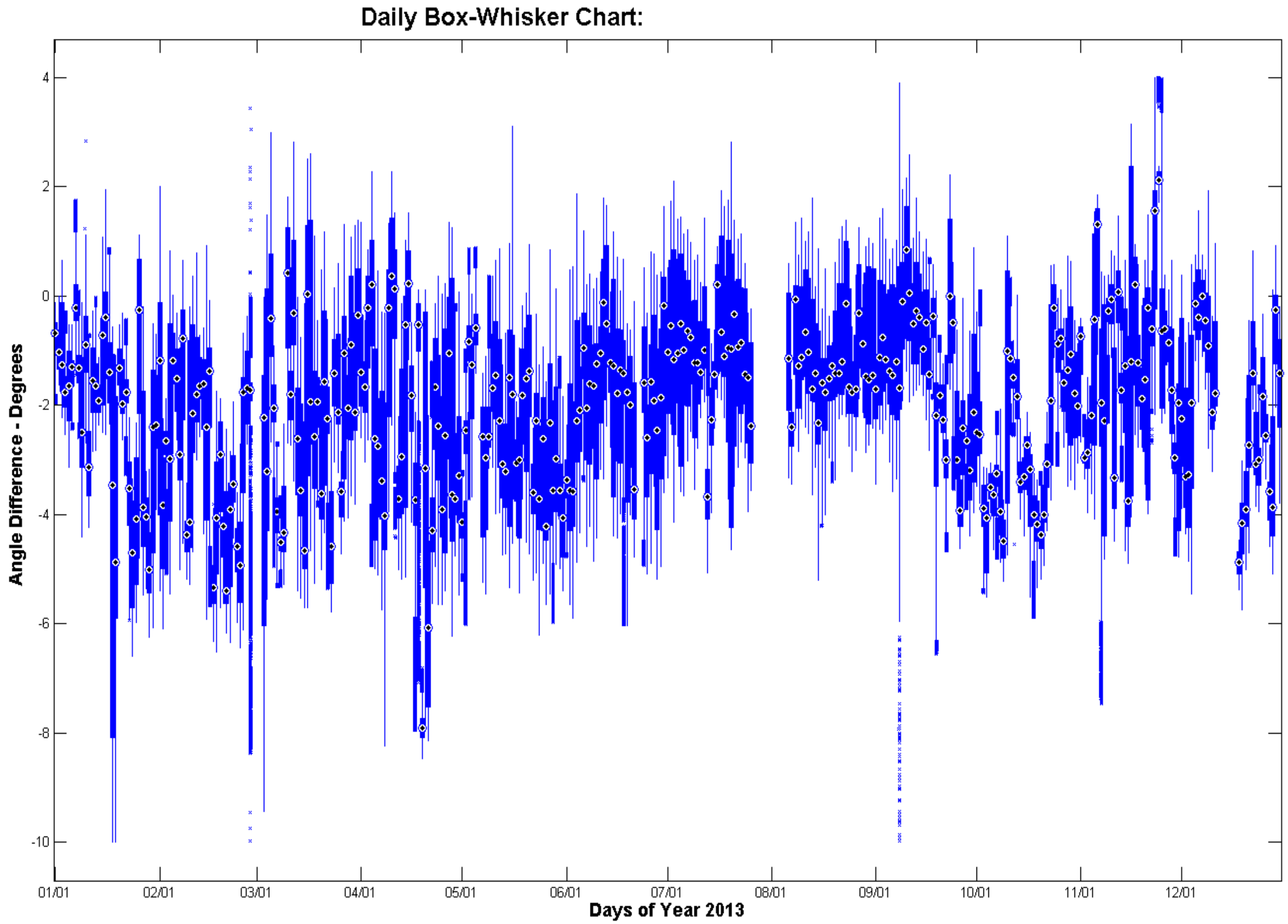

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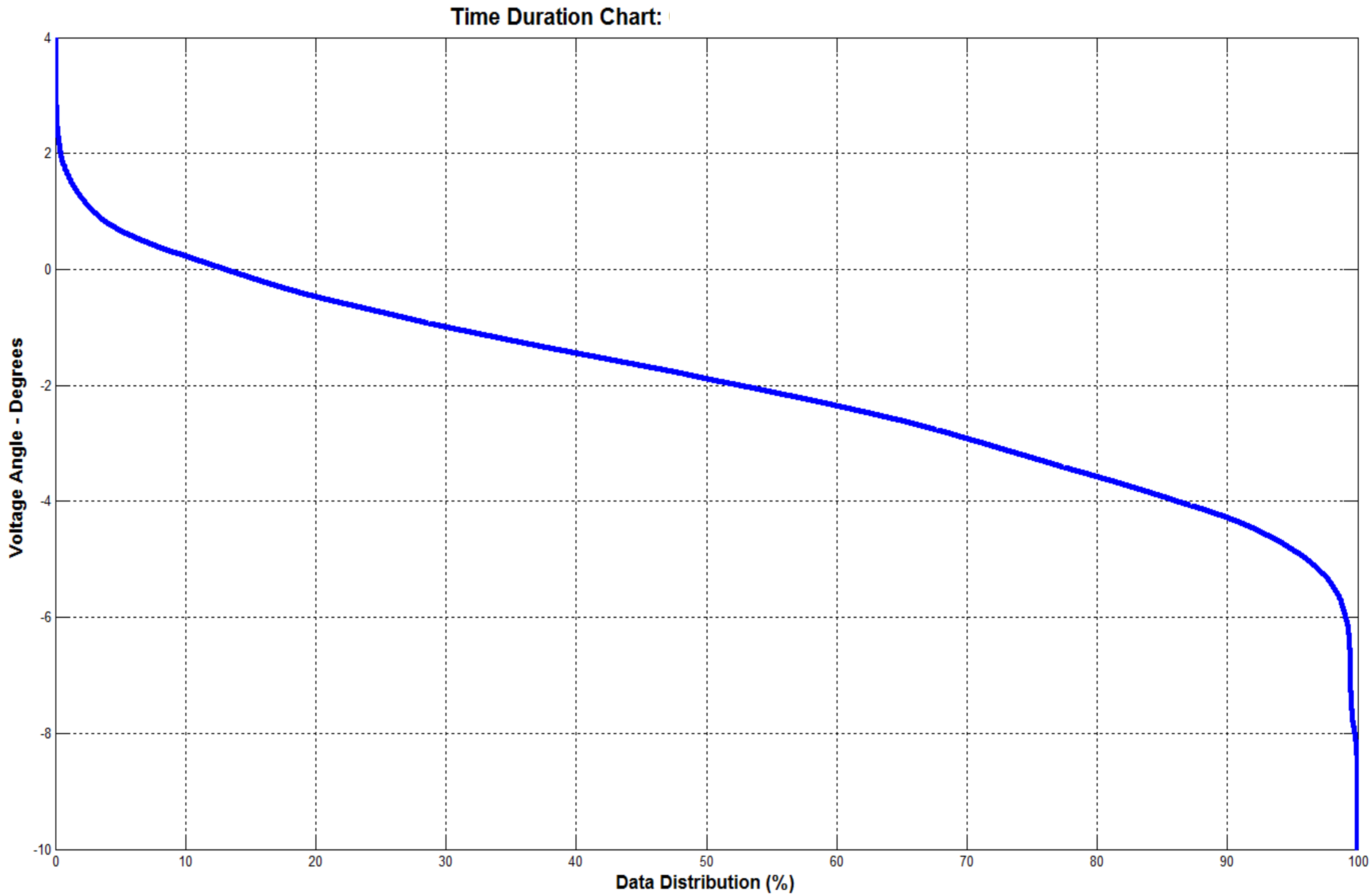

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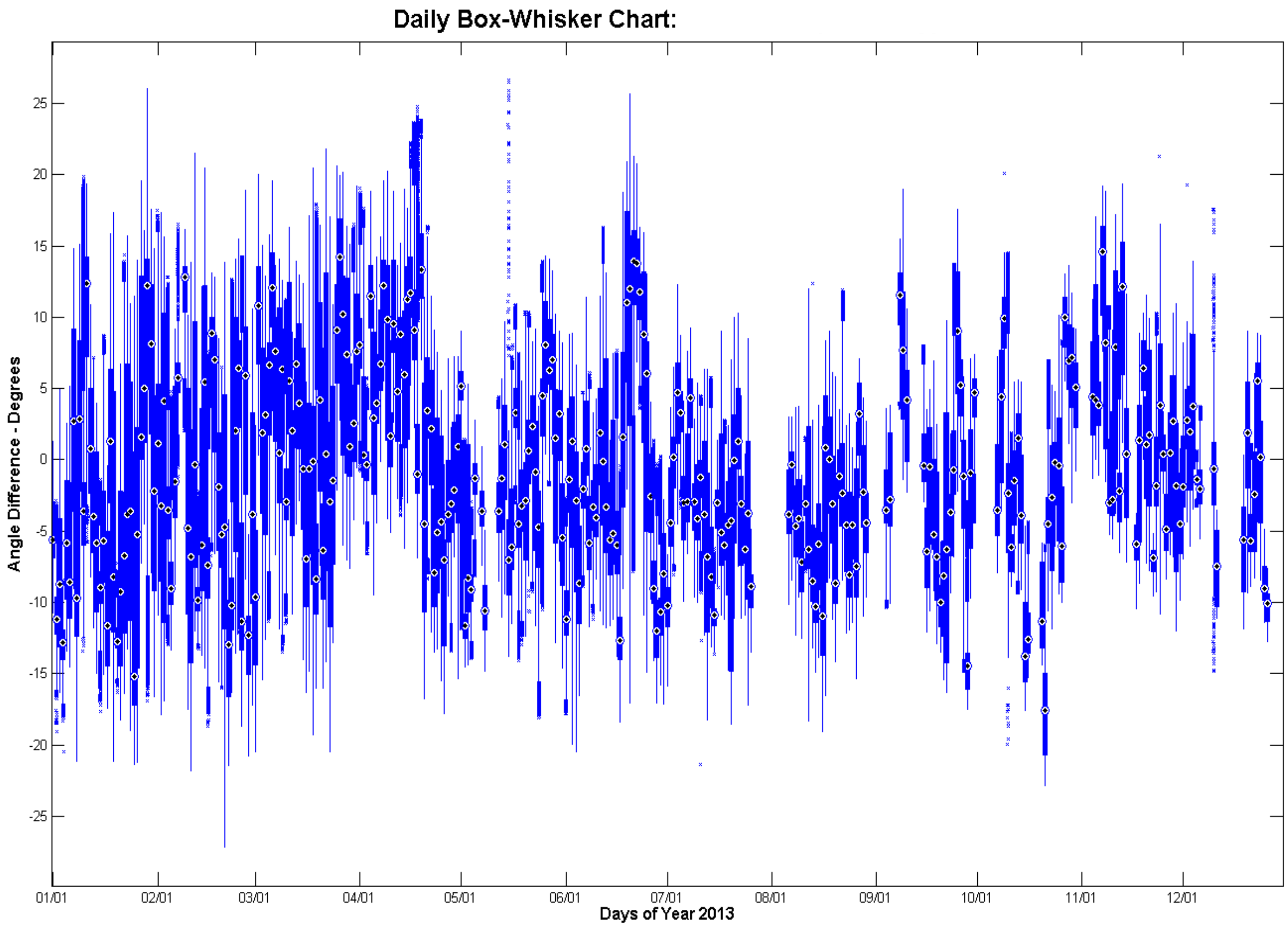

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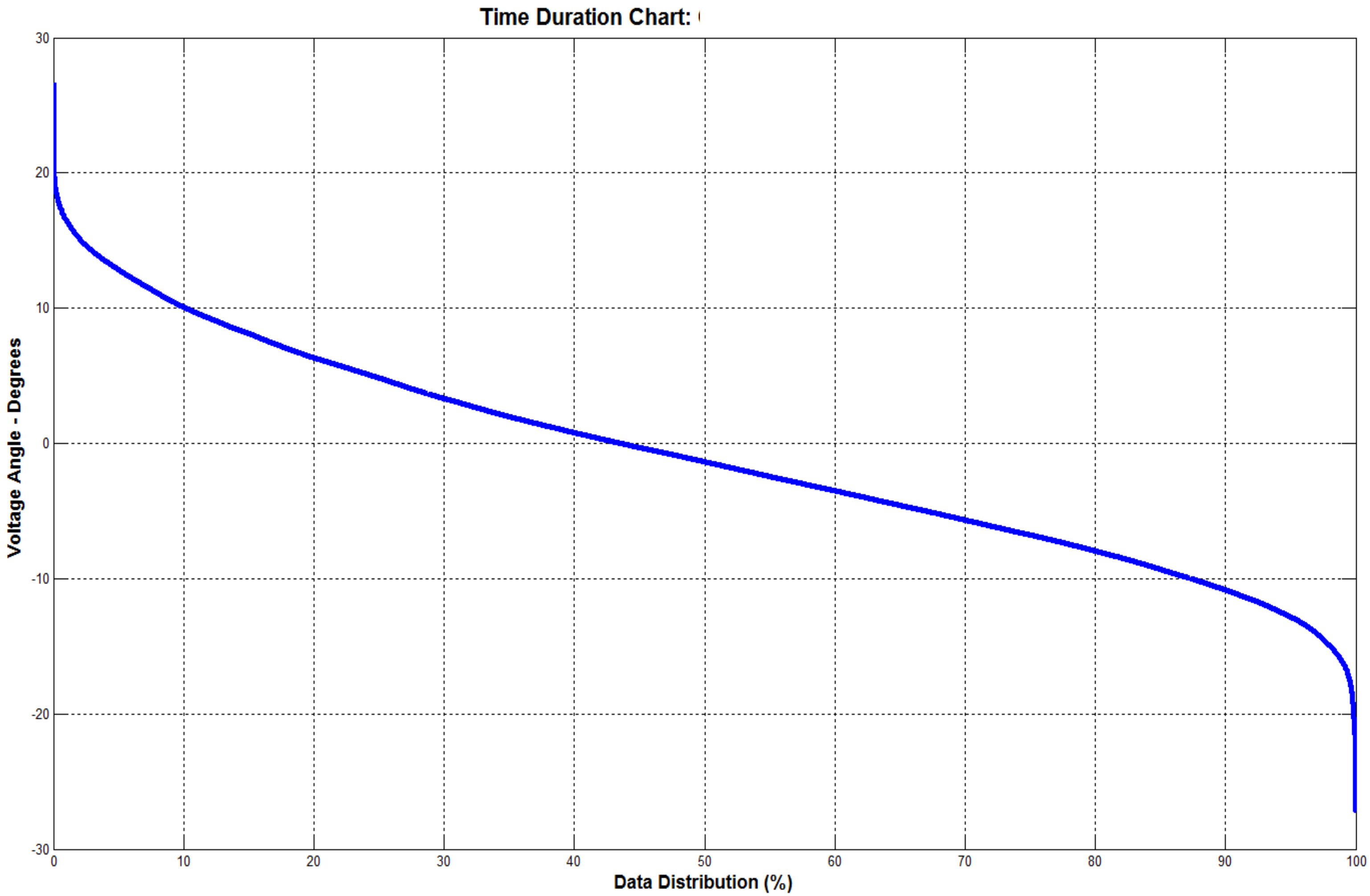

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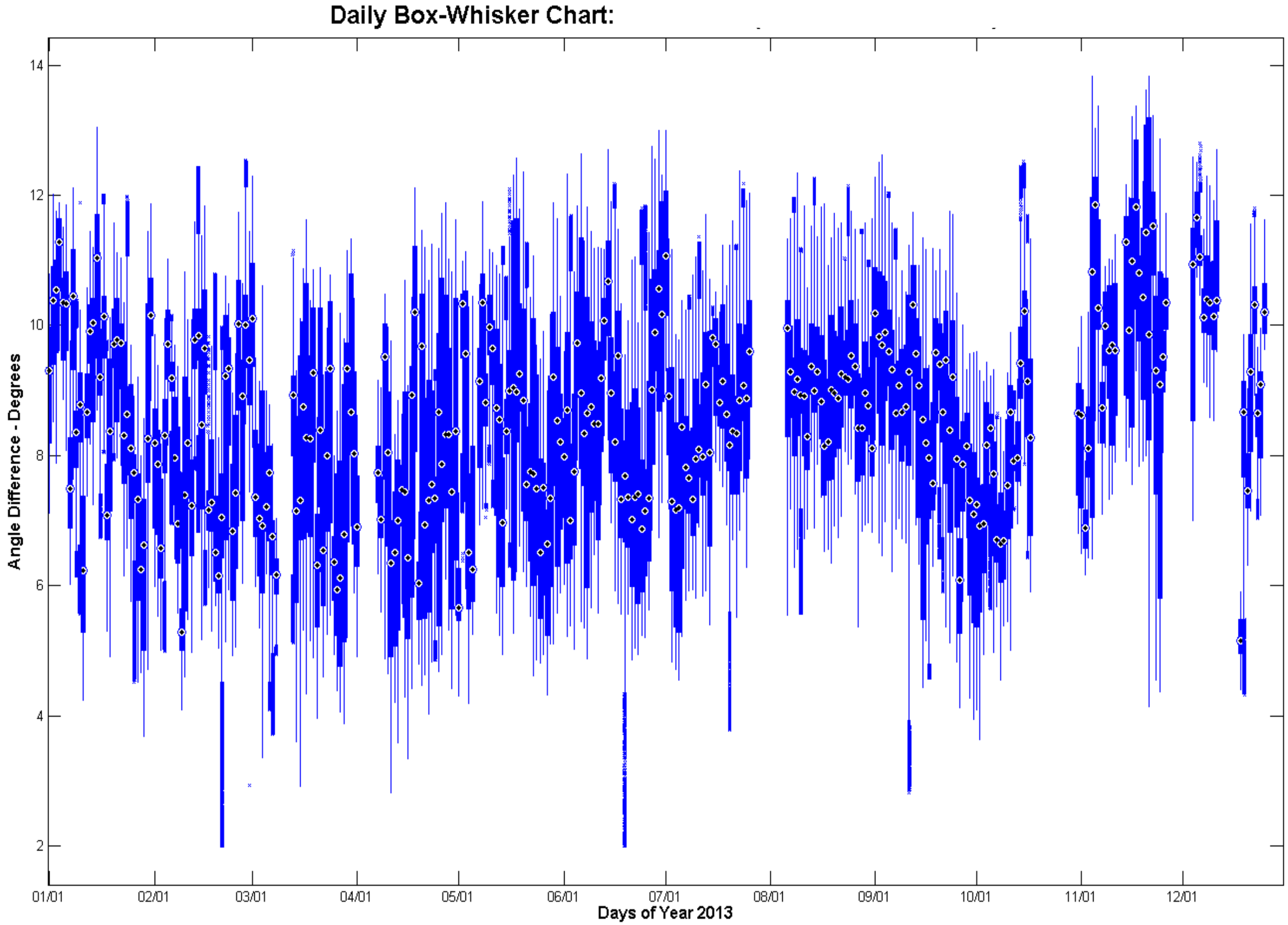

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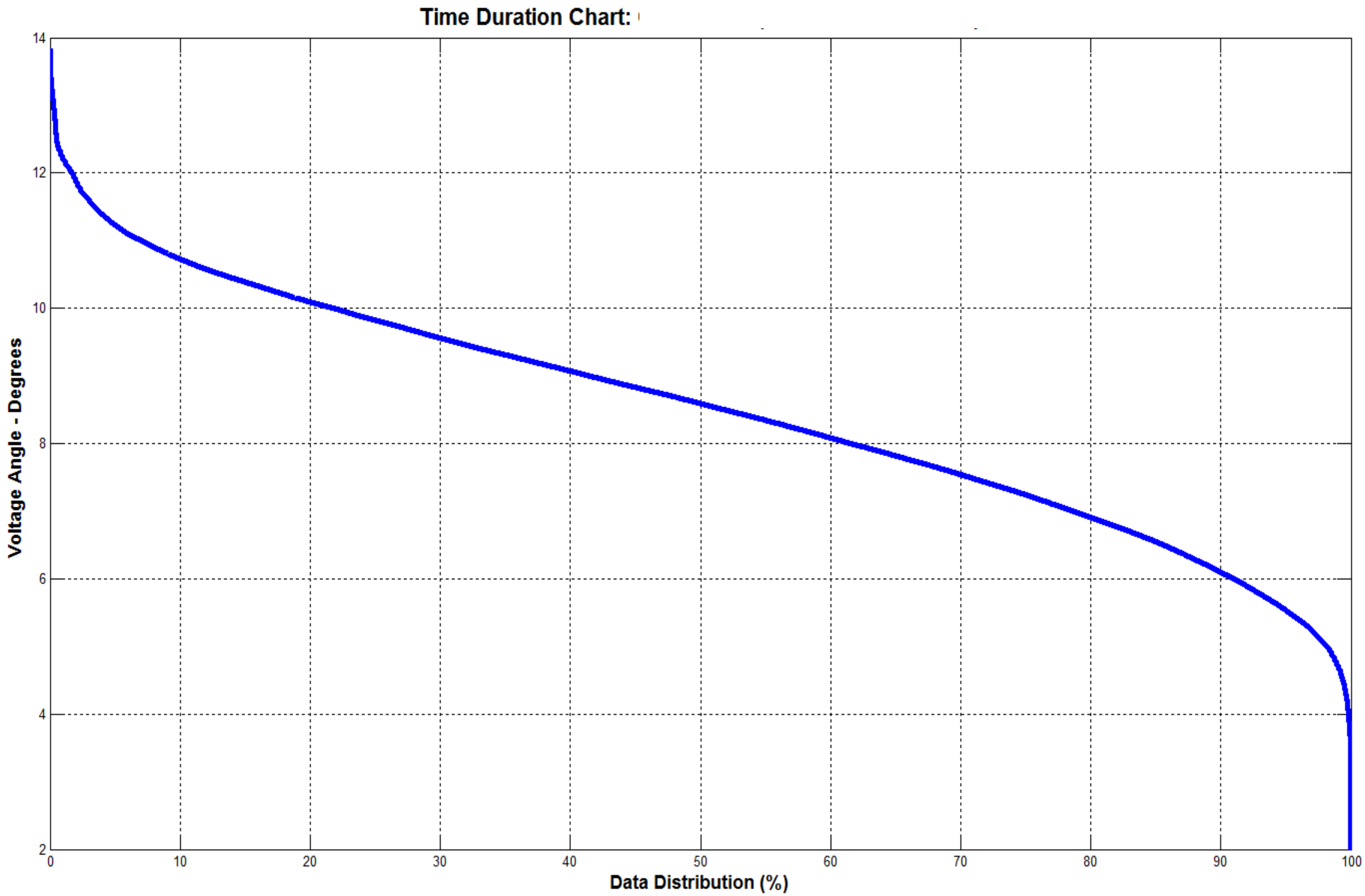

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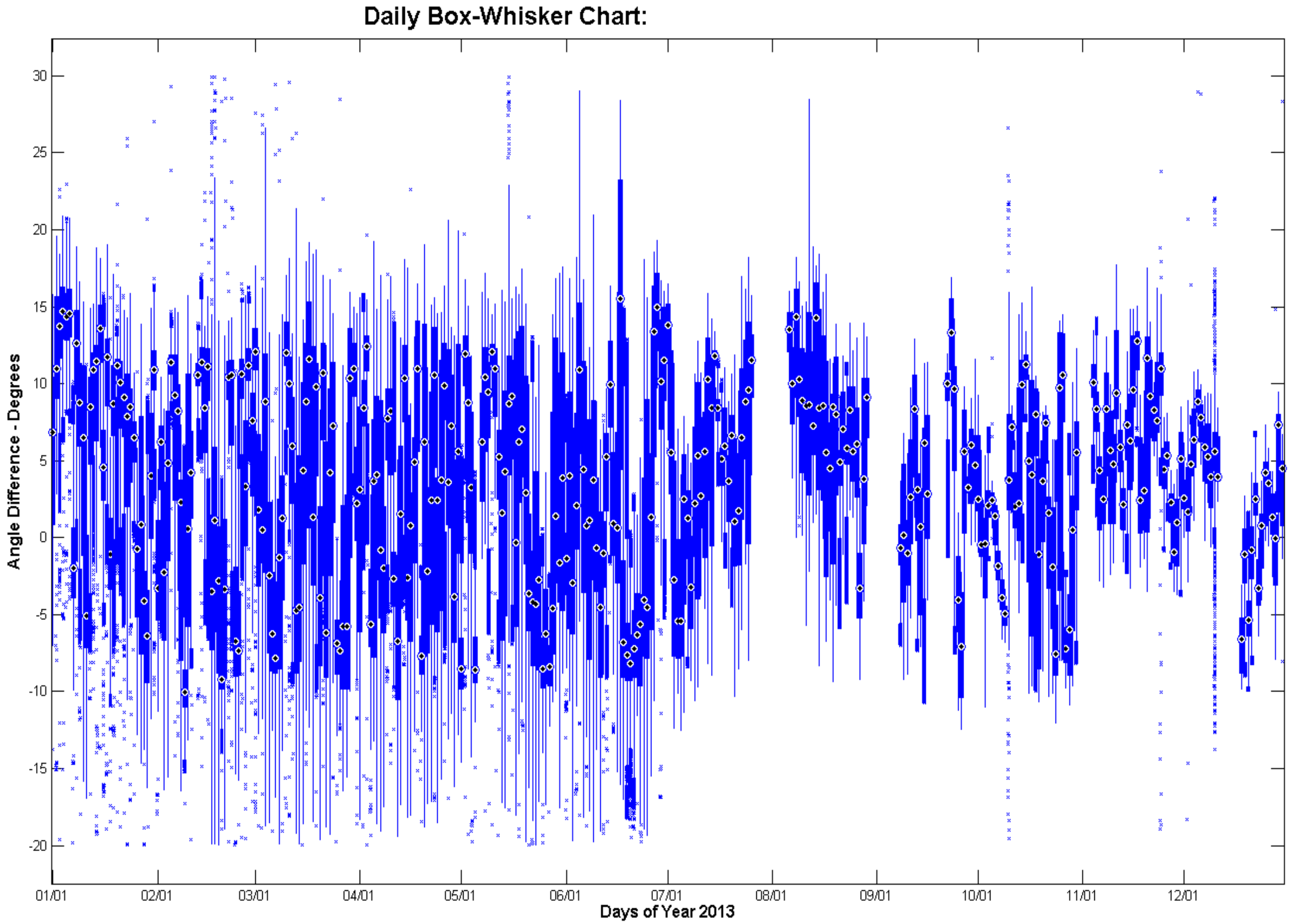

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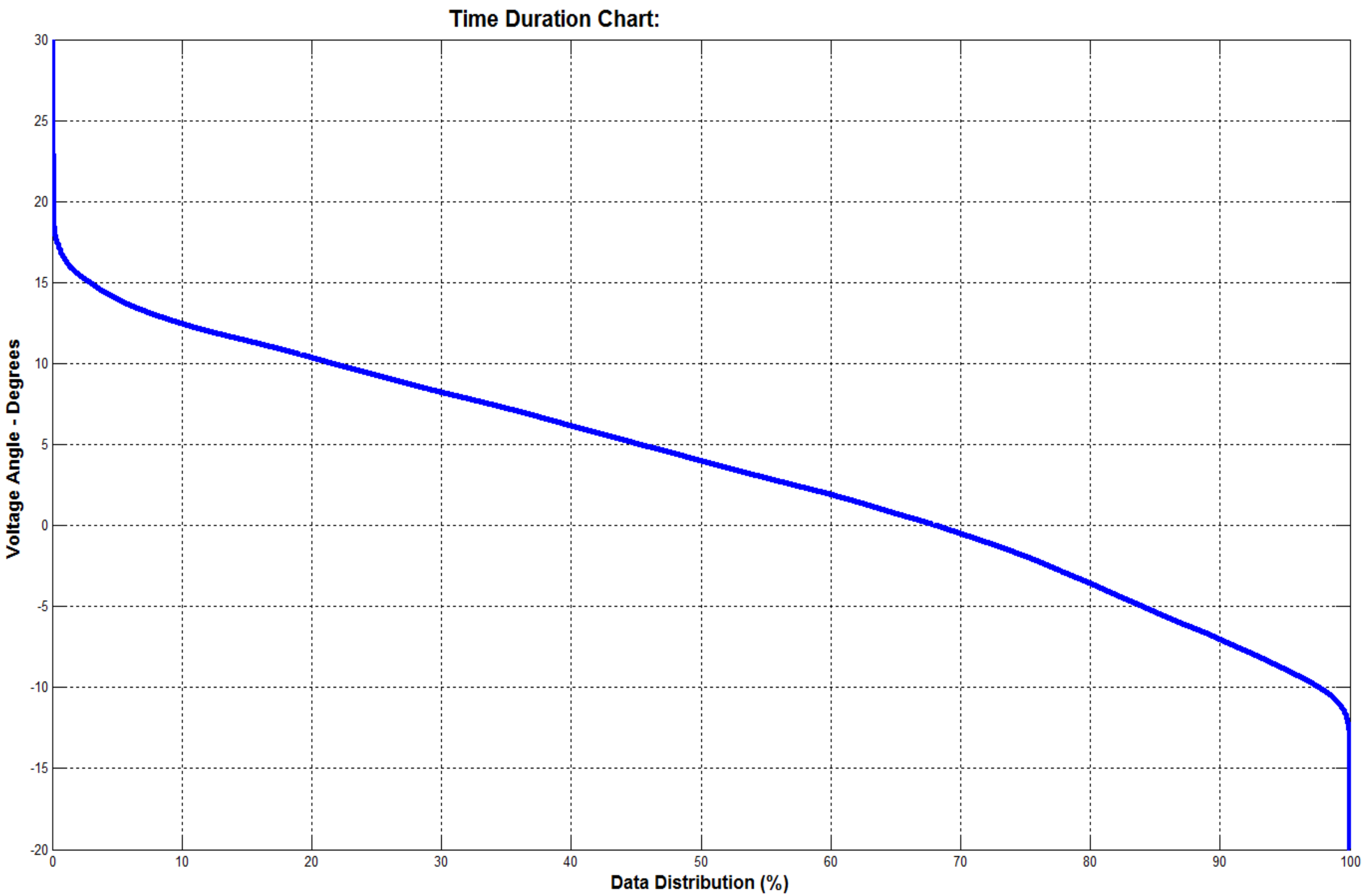

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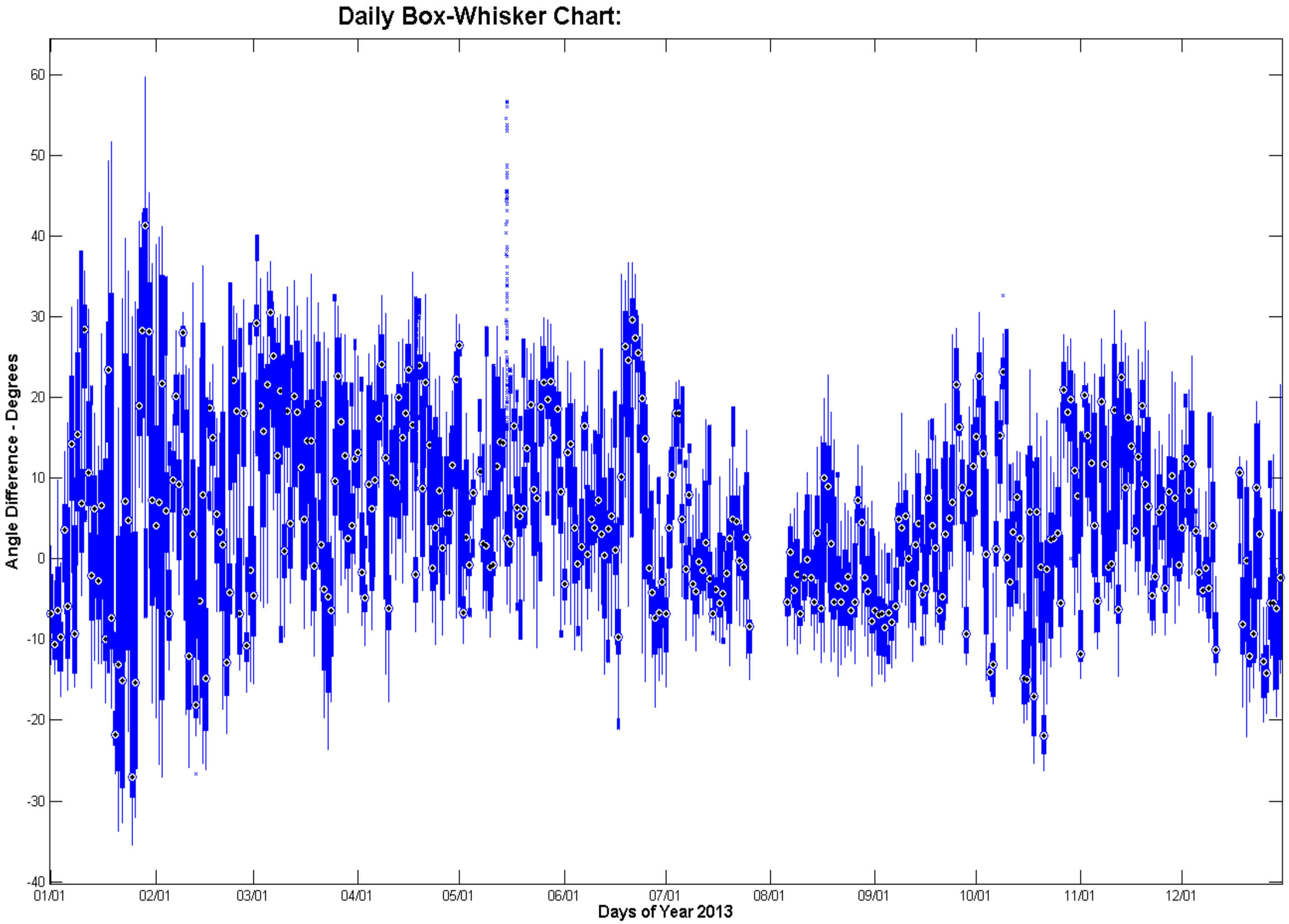

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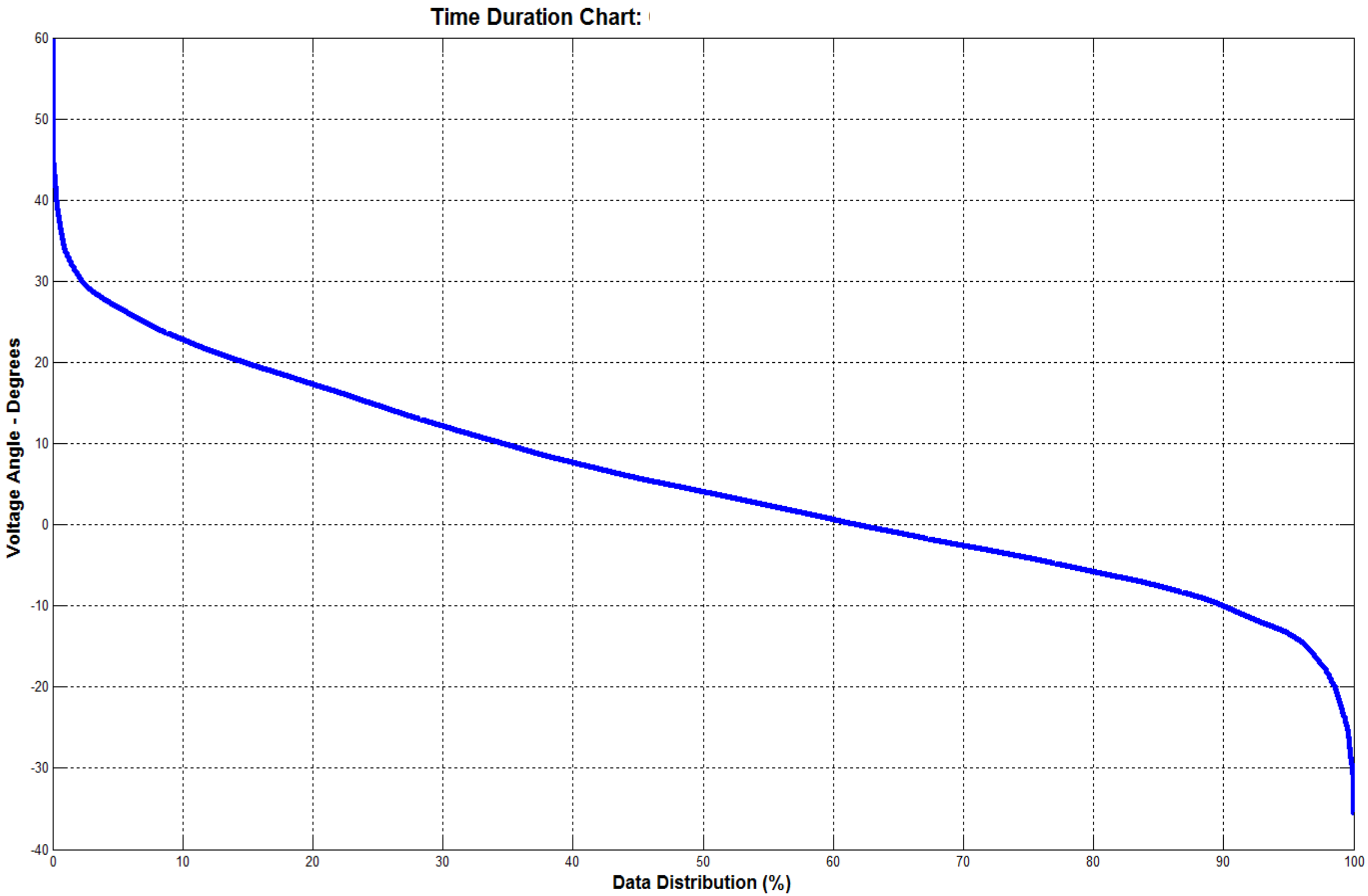

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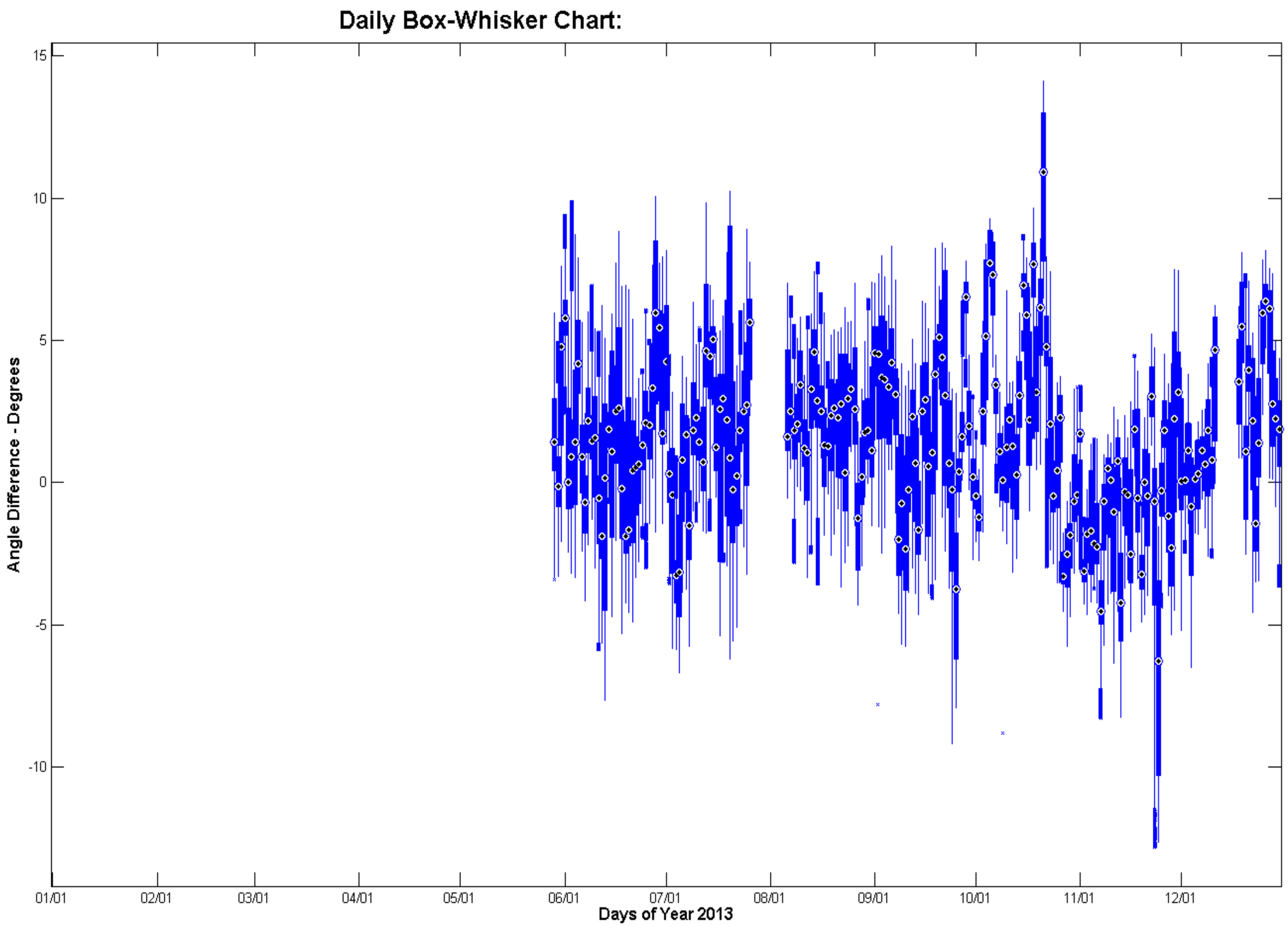

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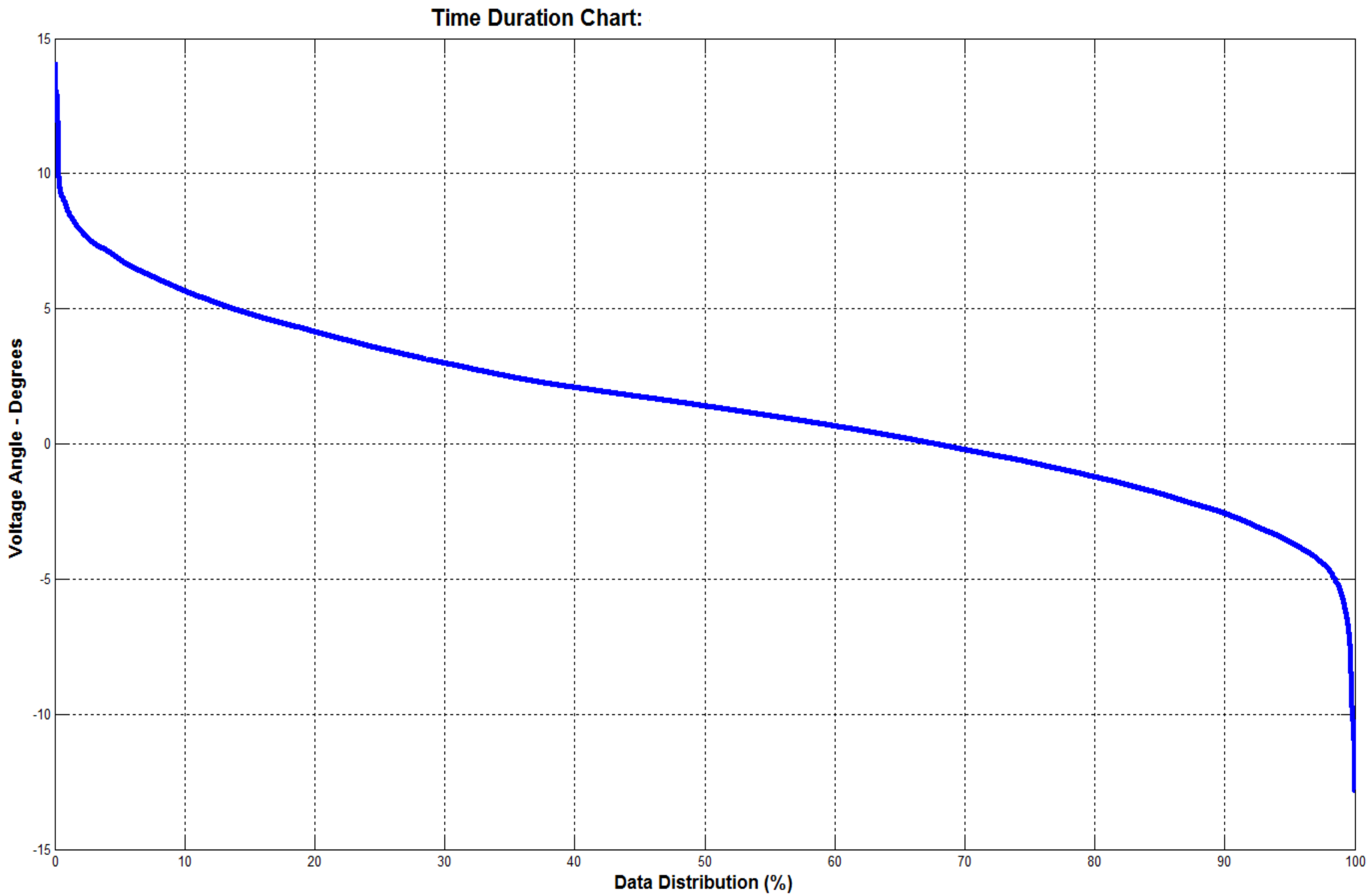

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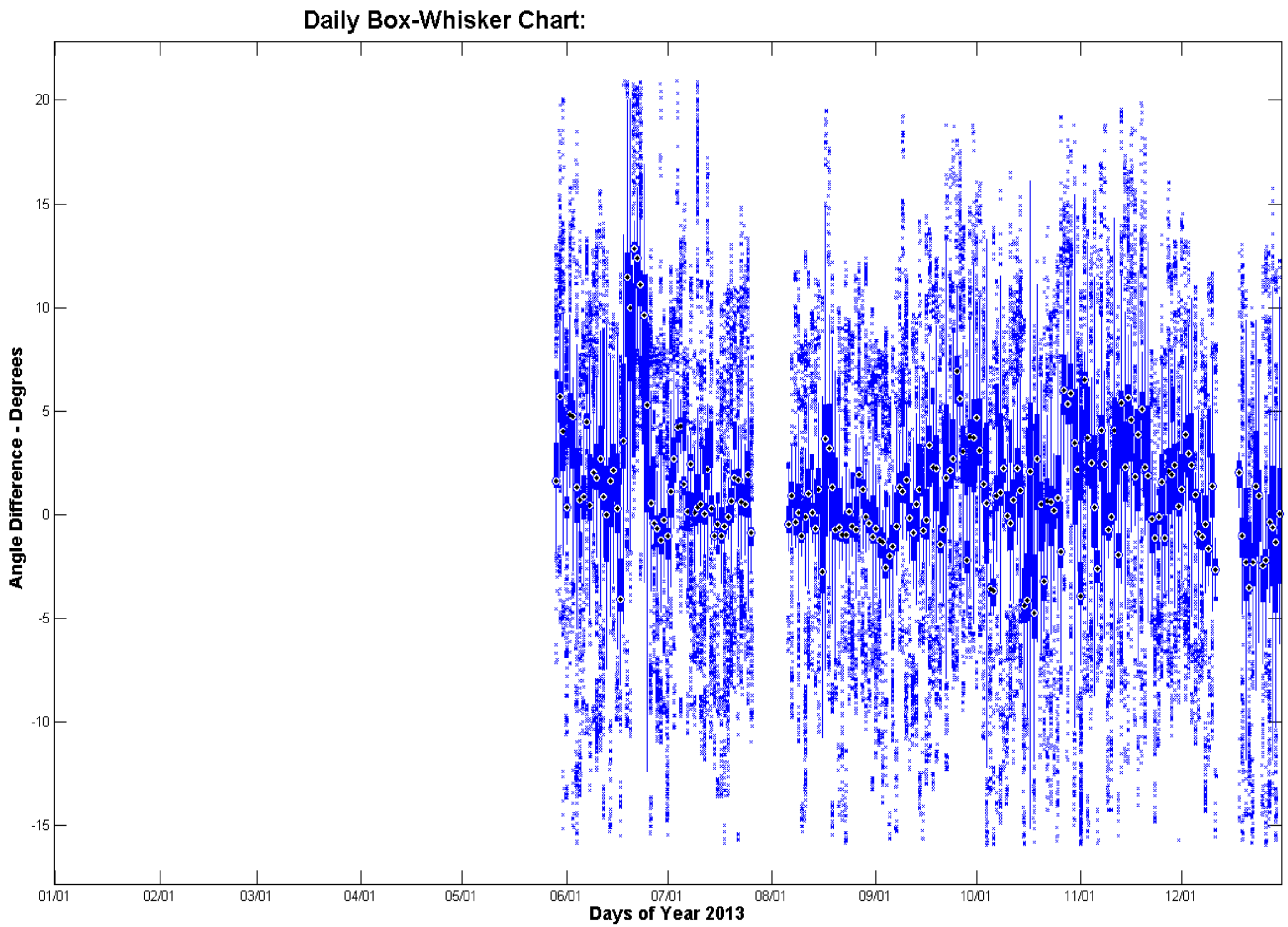

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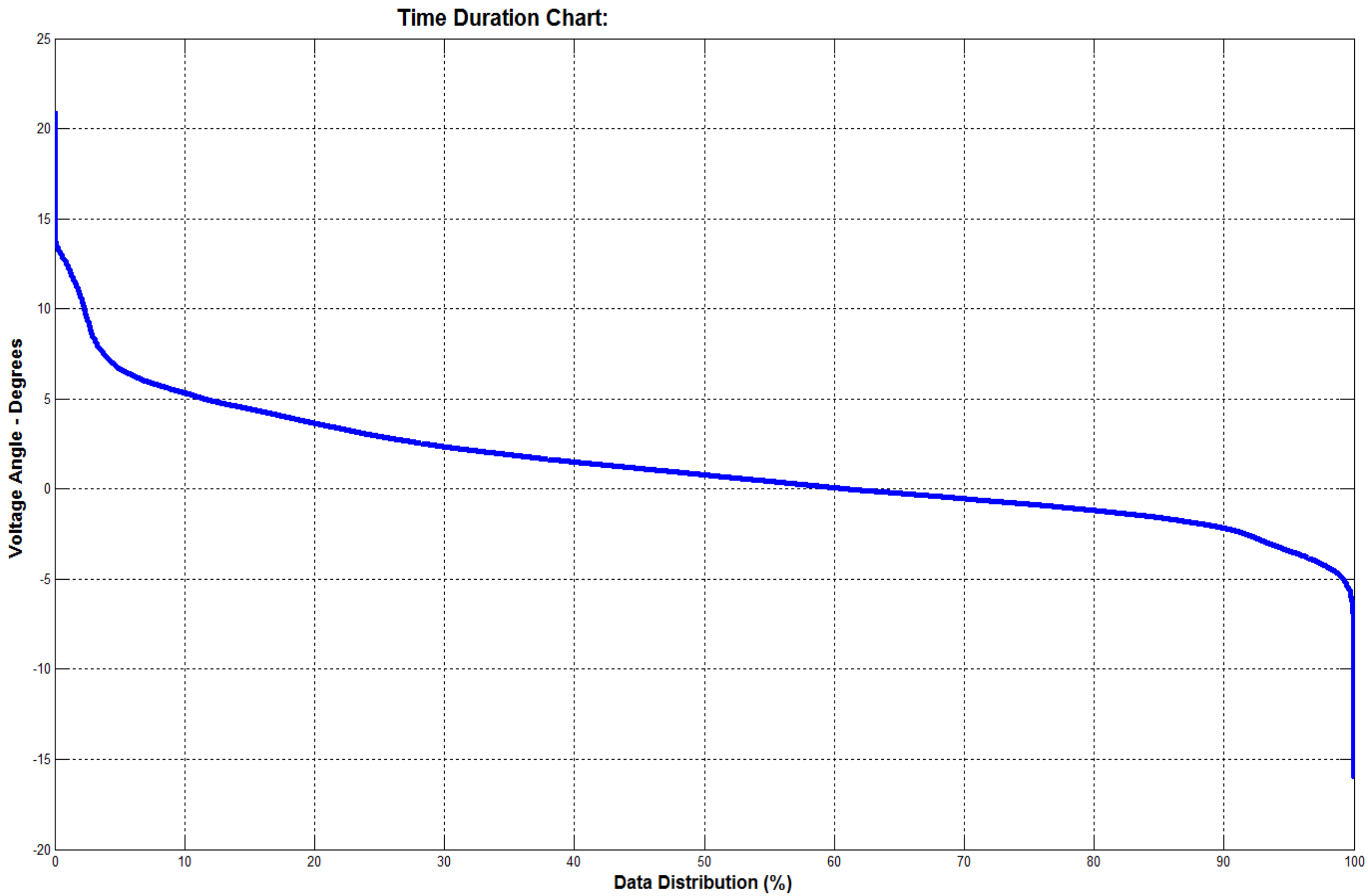

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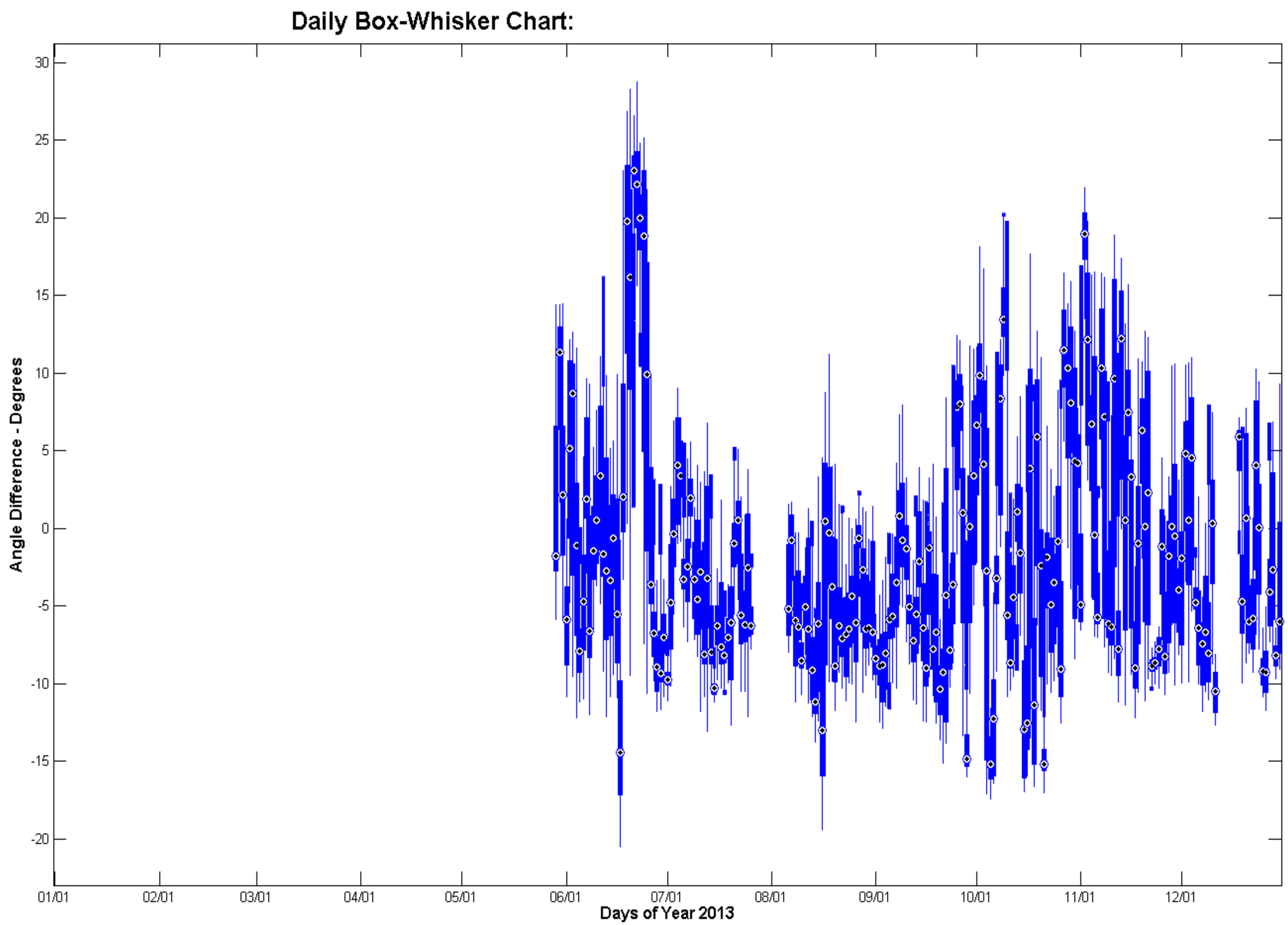

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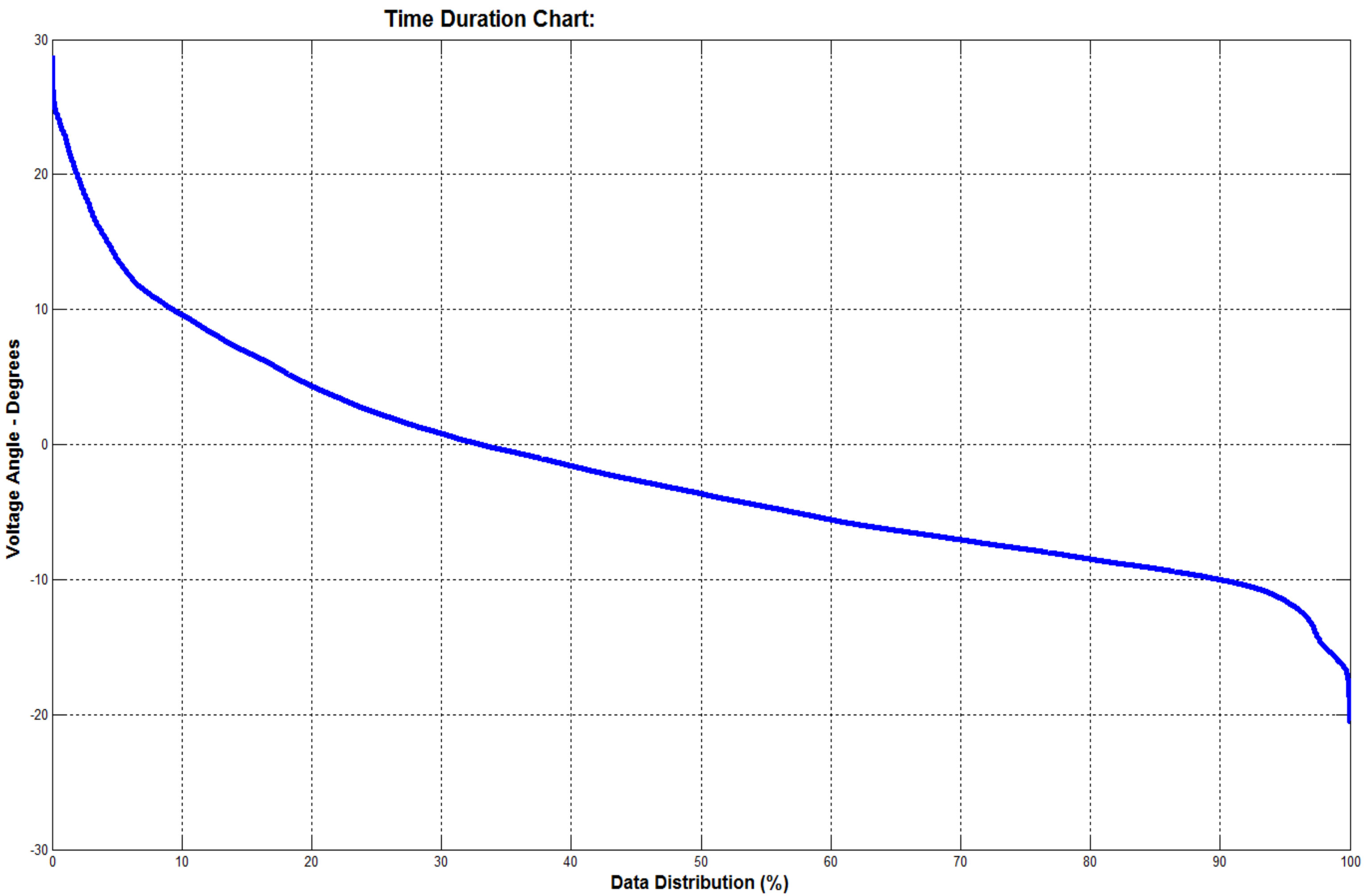

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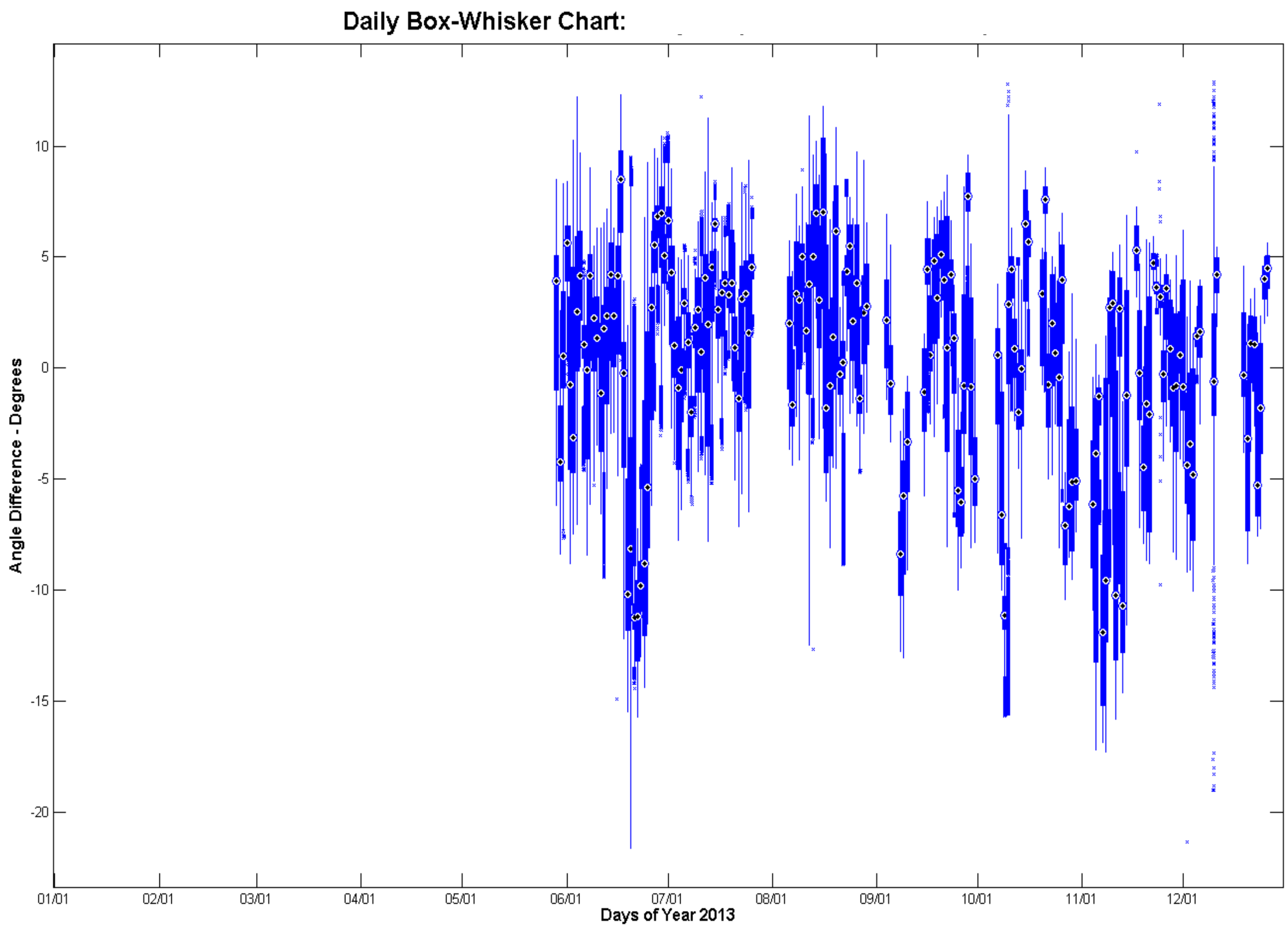

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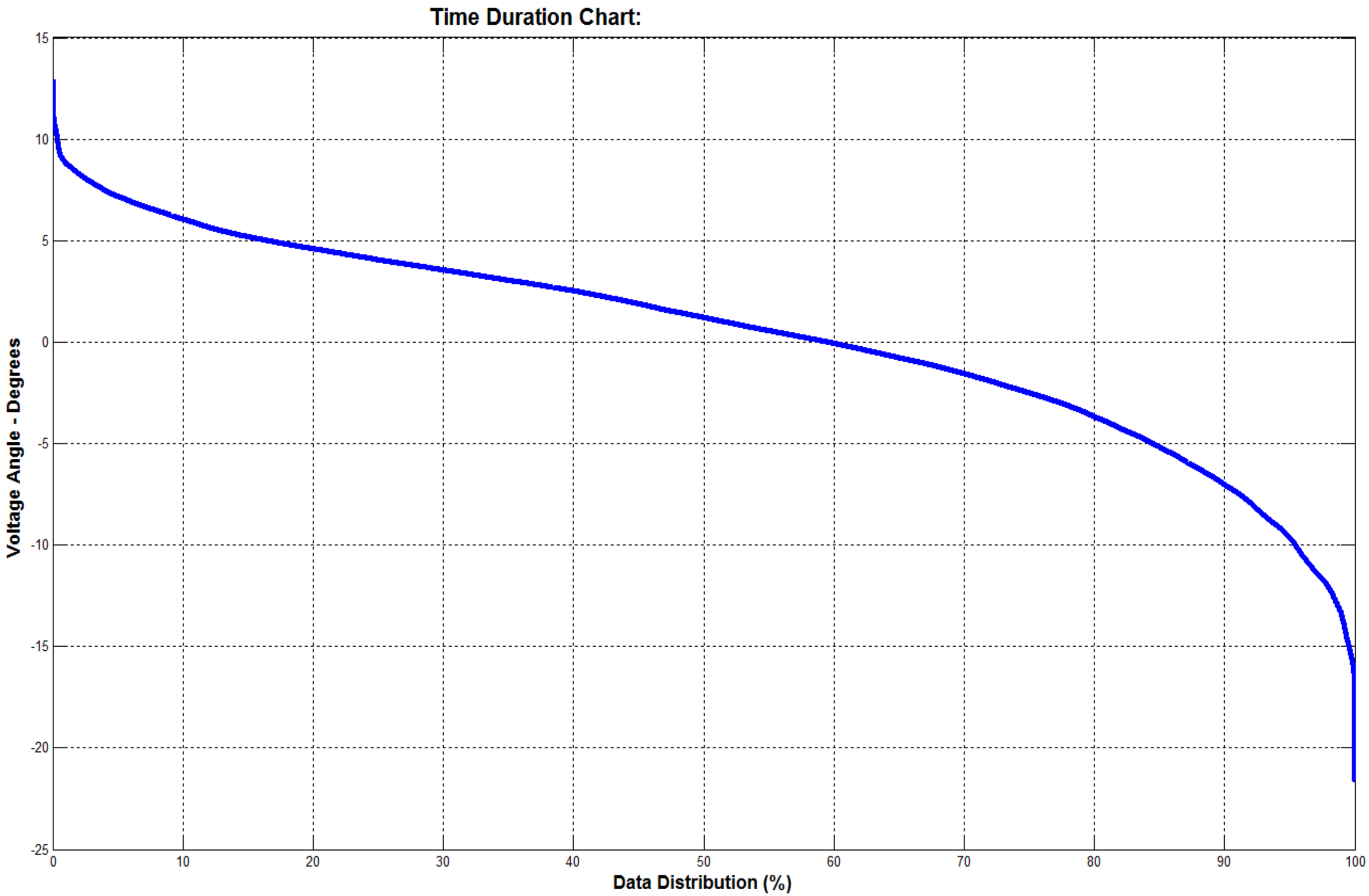

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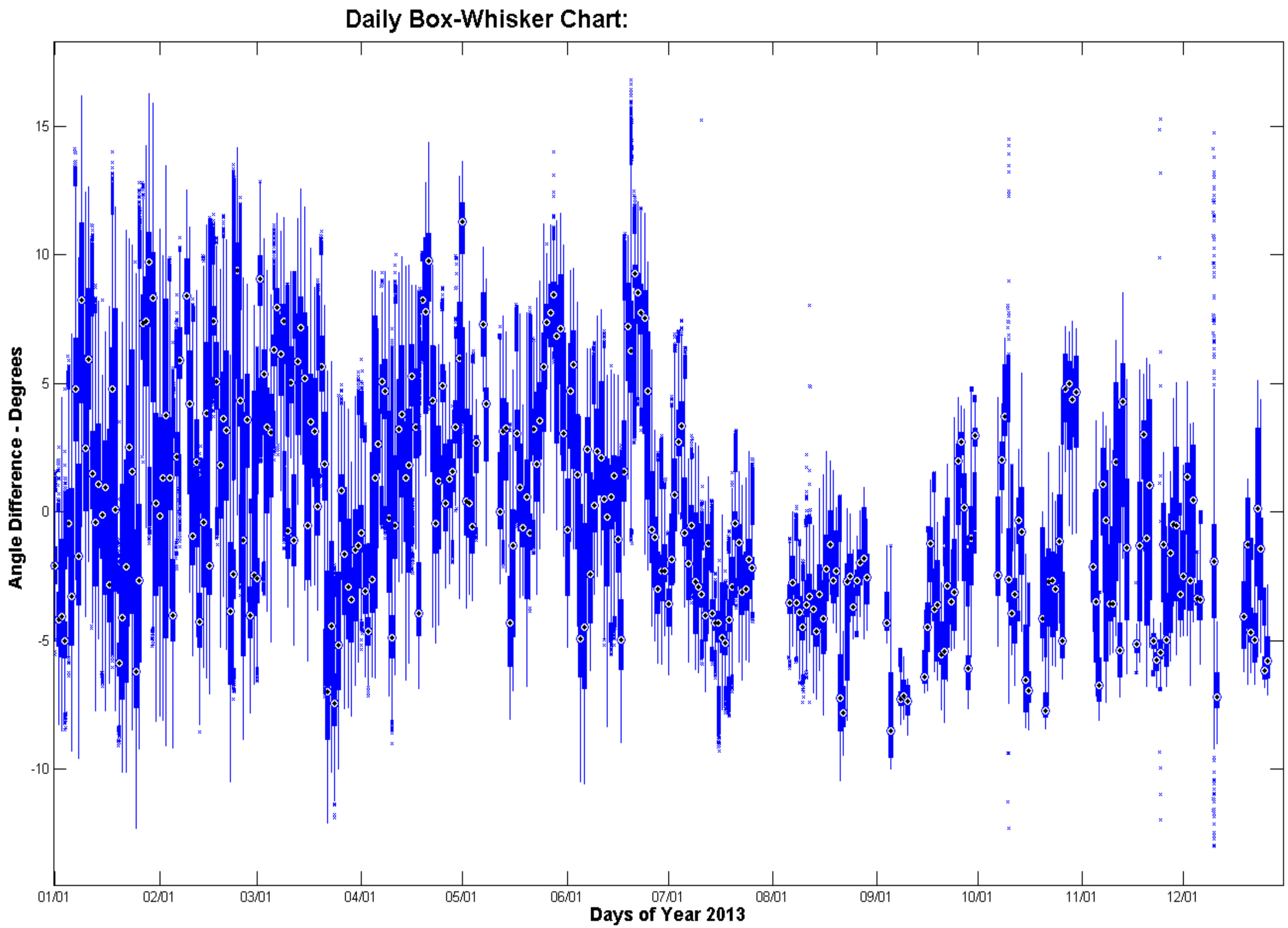

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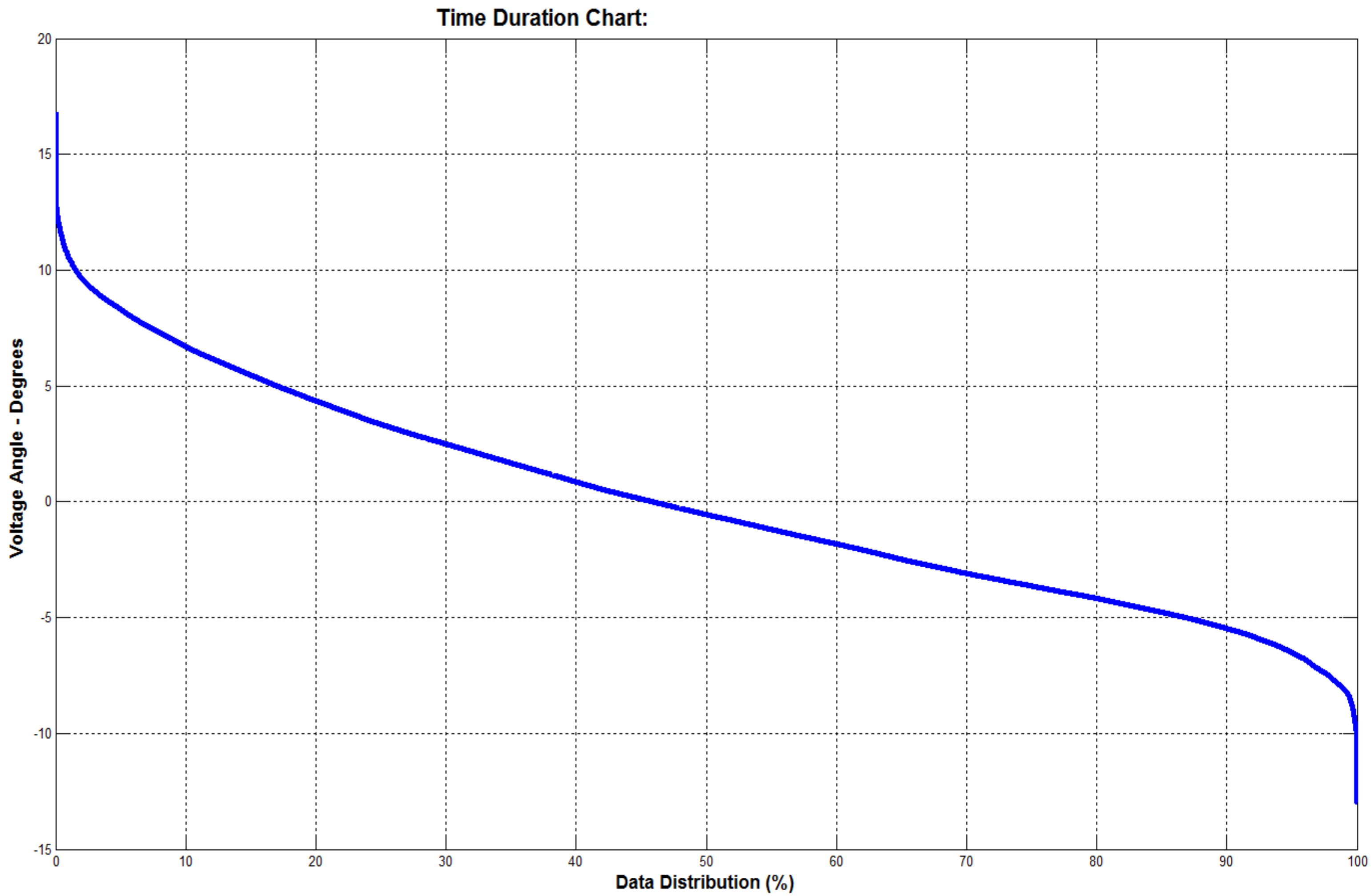

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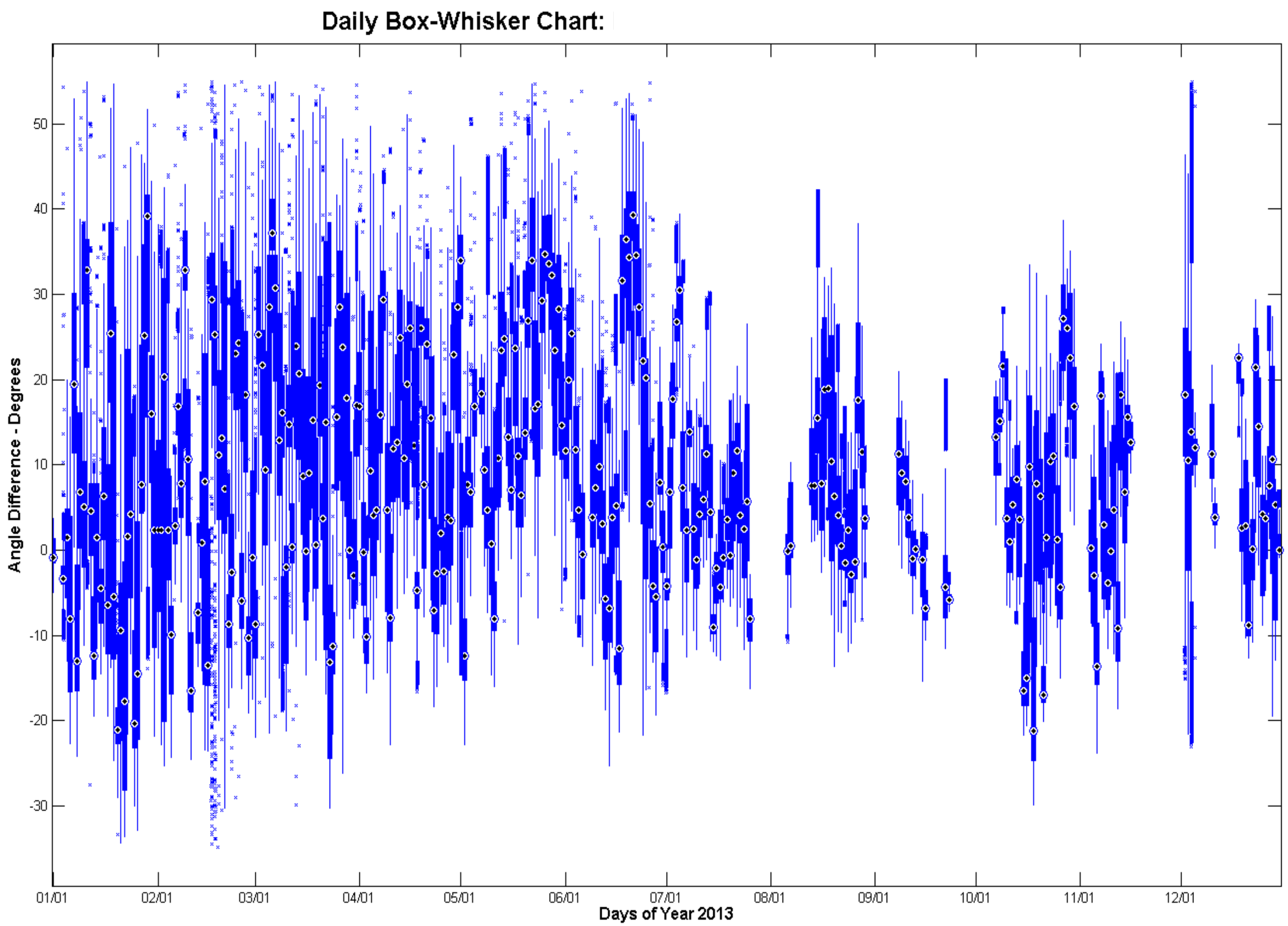

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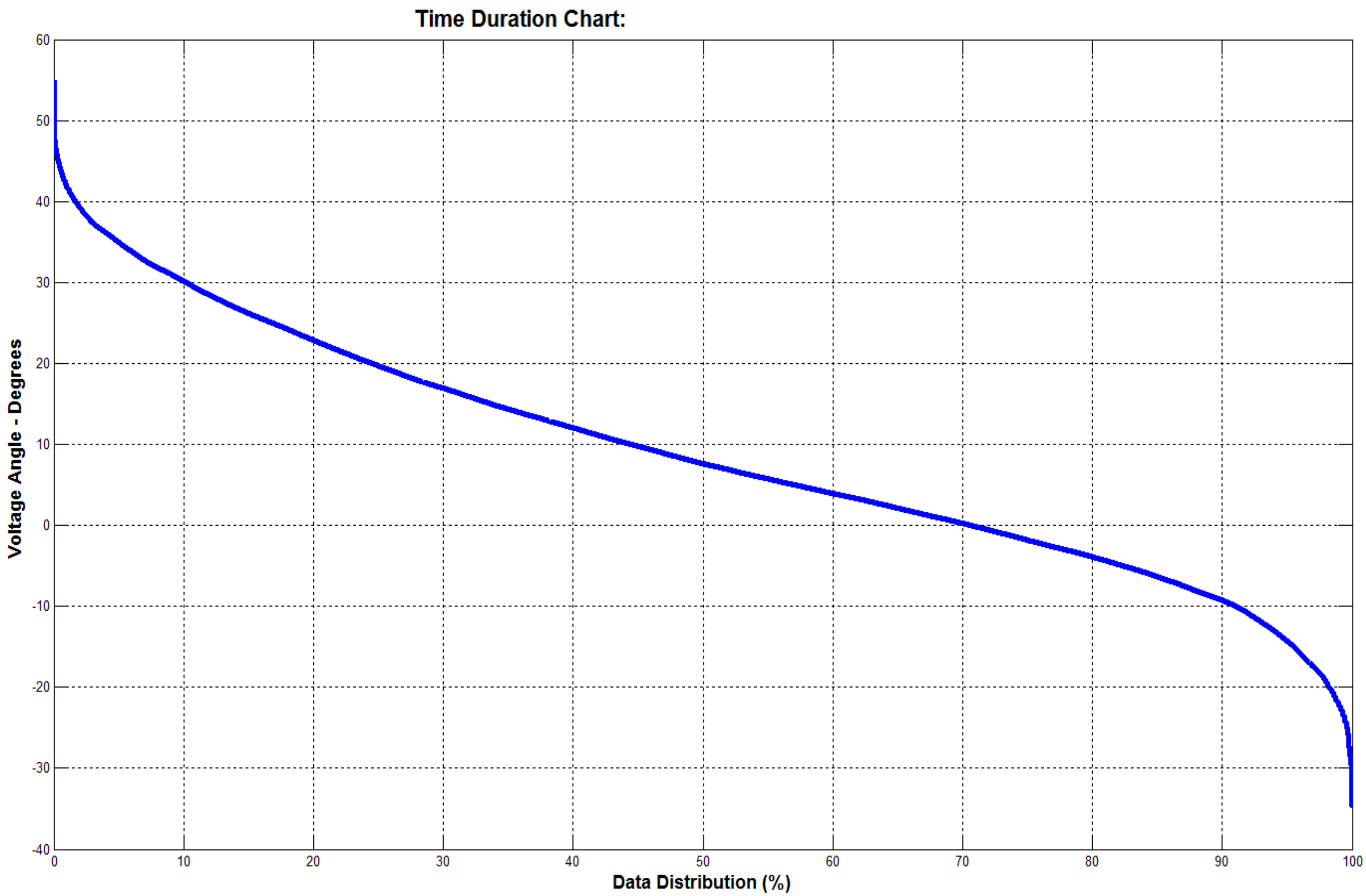

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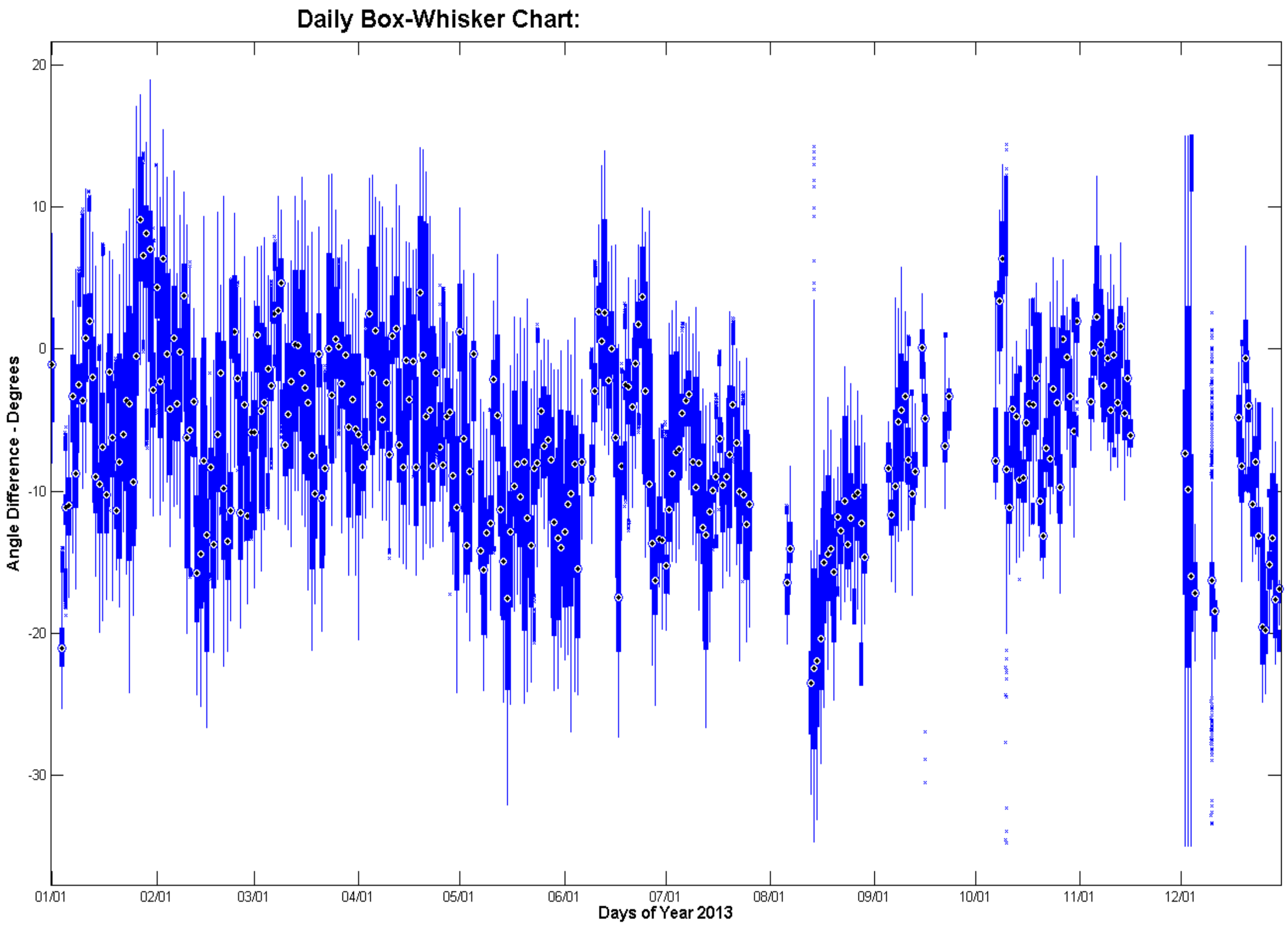

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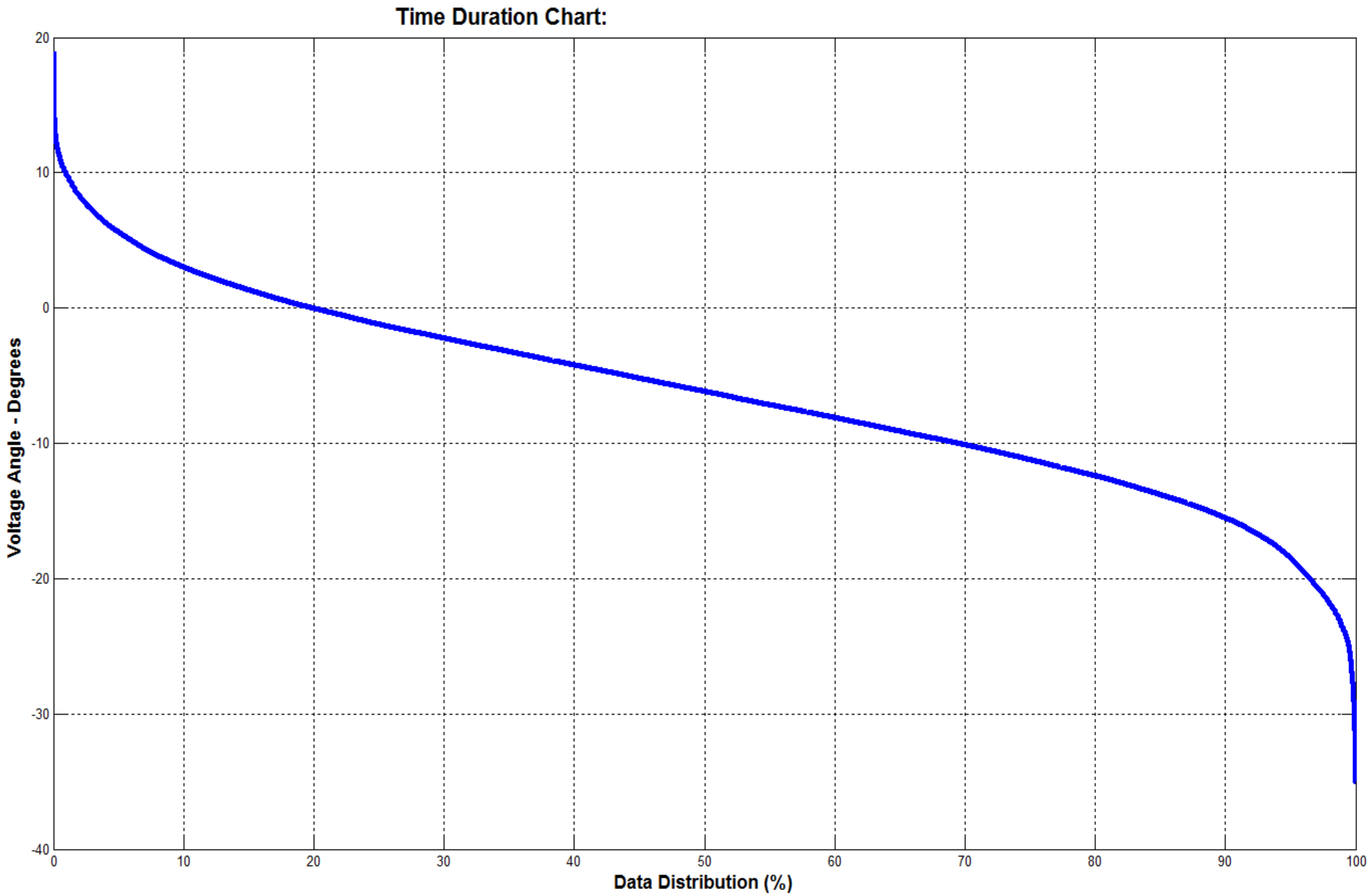

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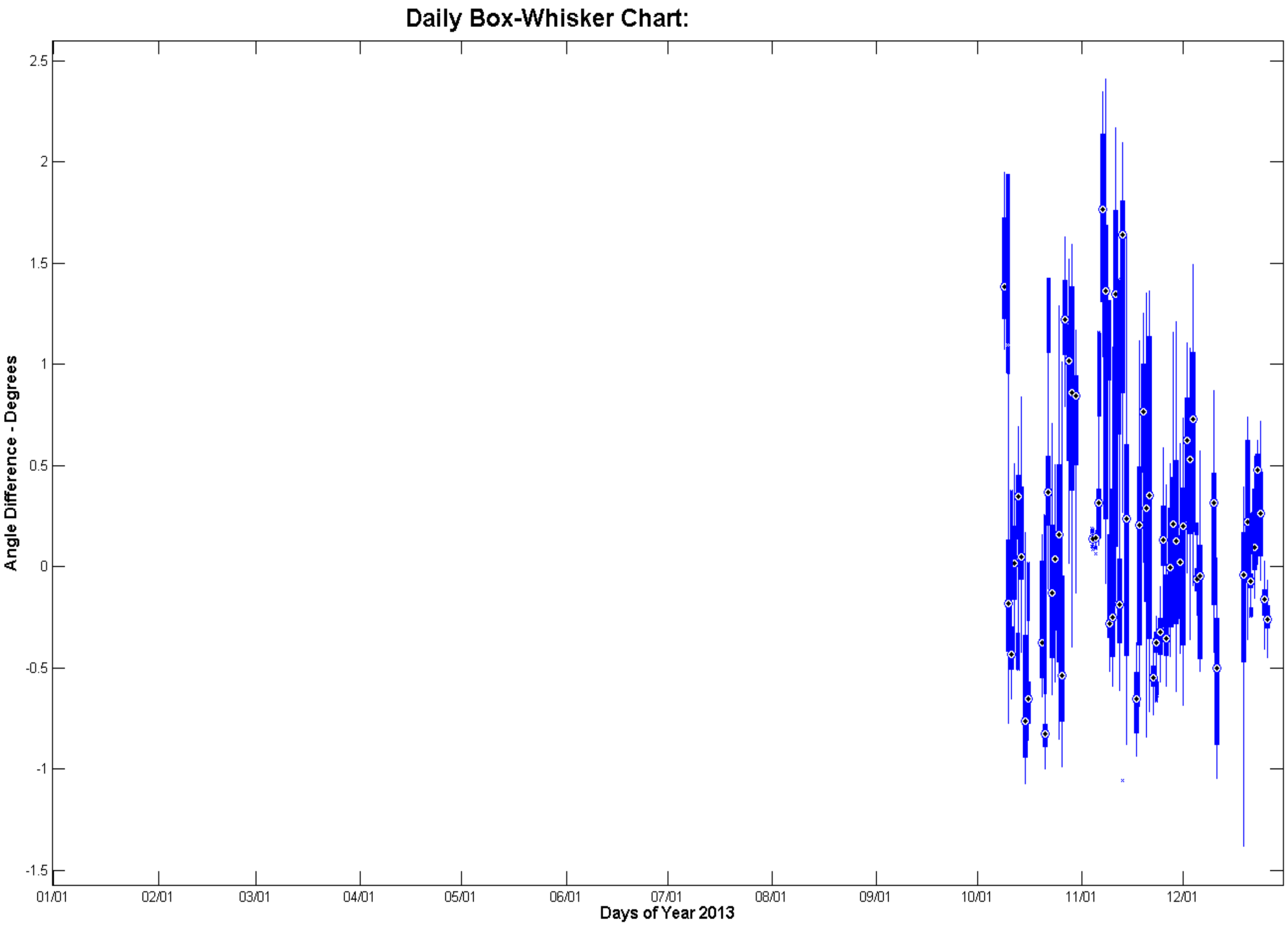

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