Consortium for
Electric
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NERC Interconnections Frequency Response Performance

NERC Interconnections 2009–2012 Frequency Response Statistics, Typical Frequency Events Profiles, and Observations on NERC-FRI Report Statistics

For: NERC Resources Subcommittee, NERC Technical Staff

By: Carlos Martinez, Rafael Campo – CERTS/ASR

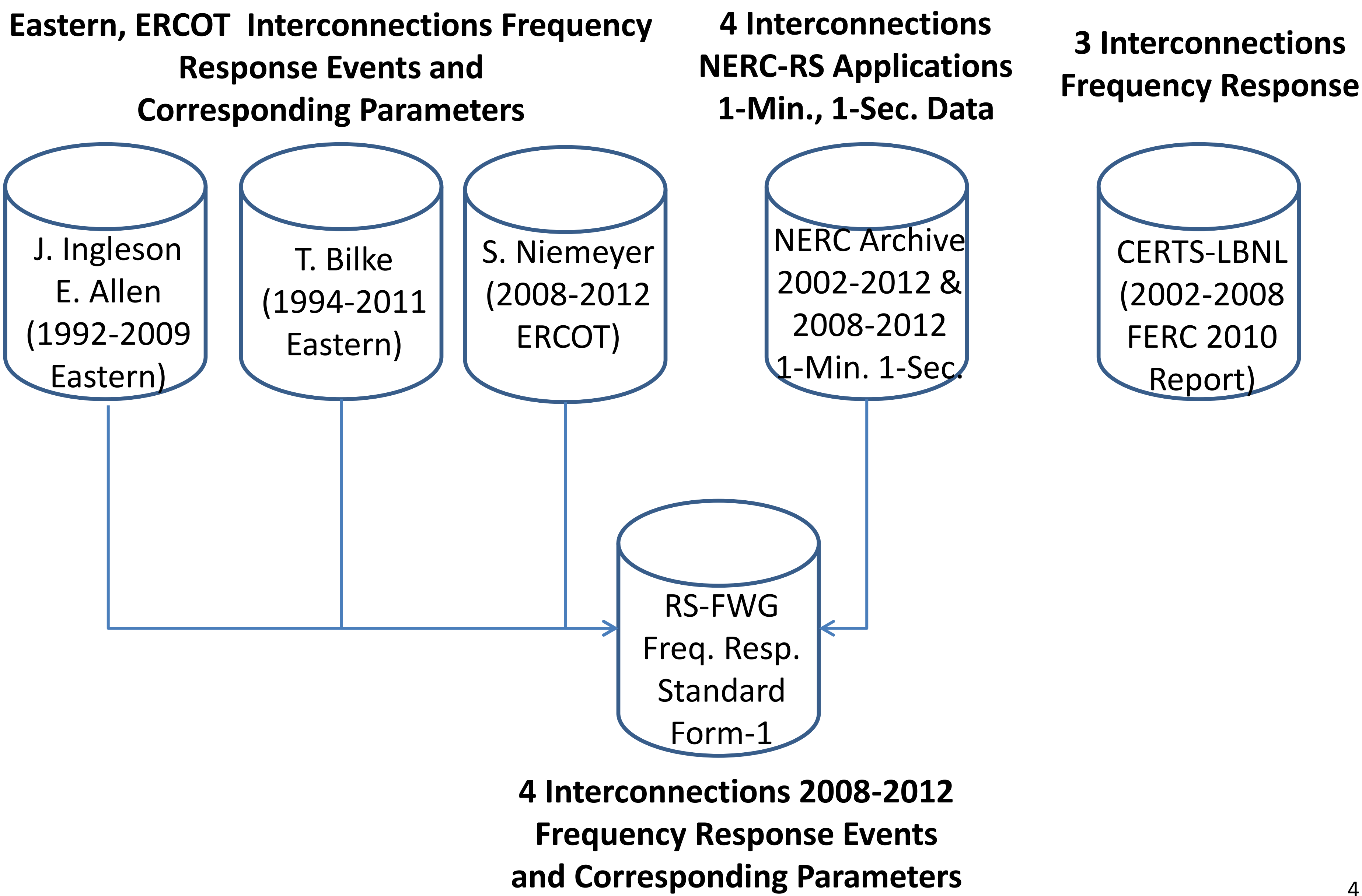
Atlanta, Georgia, October 24-25, 2012

Presentation Outline

- Review NERC Interconnections 2008-2012 Frequency Events Datasets Available for Frequency Response Analysis
- NERC Interconnections 2009-2012 Events Frequency Response Statistical Summaries and Trends
- NERC Interconnections 2009-2012 Statistics and Trends for Events Loss MW and Frequency-C
- NERC Interconnections Typical Events Frequency Profiles
- Review CERTS Observations and Recommendations on NERC Frequency Response Initiative (FRI) Report statistics – Version 09/16/2012

NERC Interconnections 2008-2012
Candidate Frequency Events Datasets

NERC Interconnections Known Historical Events Datasets



NERC Interconnections 2008-2012 Candidate Frequency Events Dataset - PMU 1-Sec. Data

Year	Interconnections Candidate Frequency Events			
	Eastern	Western	ERCOT	Hydro Quebec
2008	45	60	46	0
2009	76	64	93	0
2010	103	82	129	0
2011	120	63	106	55
2012	47	58	64	46
TOTAL	391	327	438	101

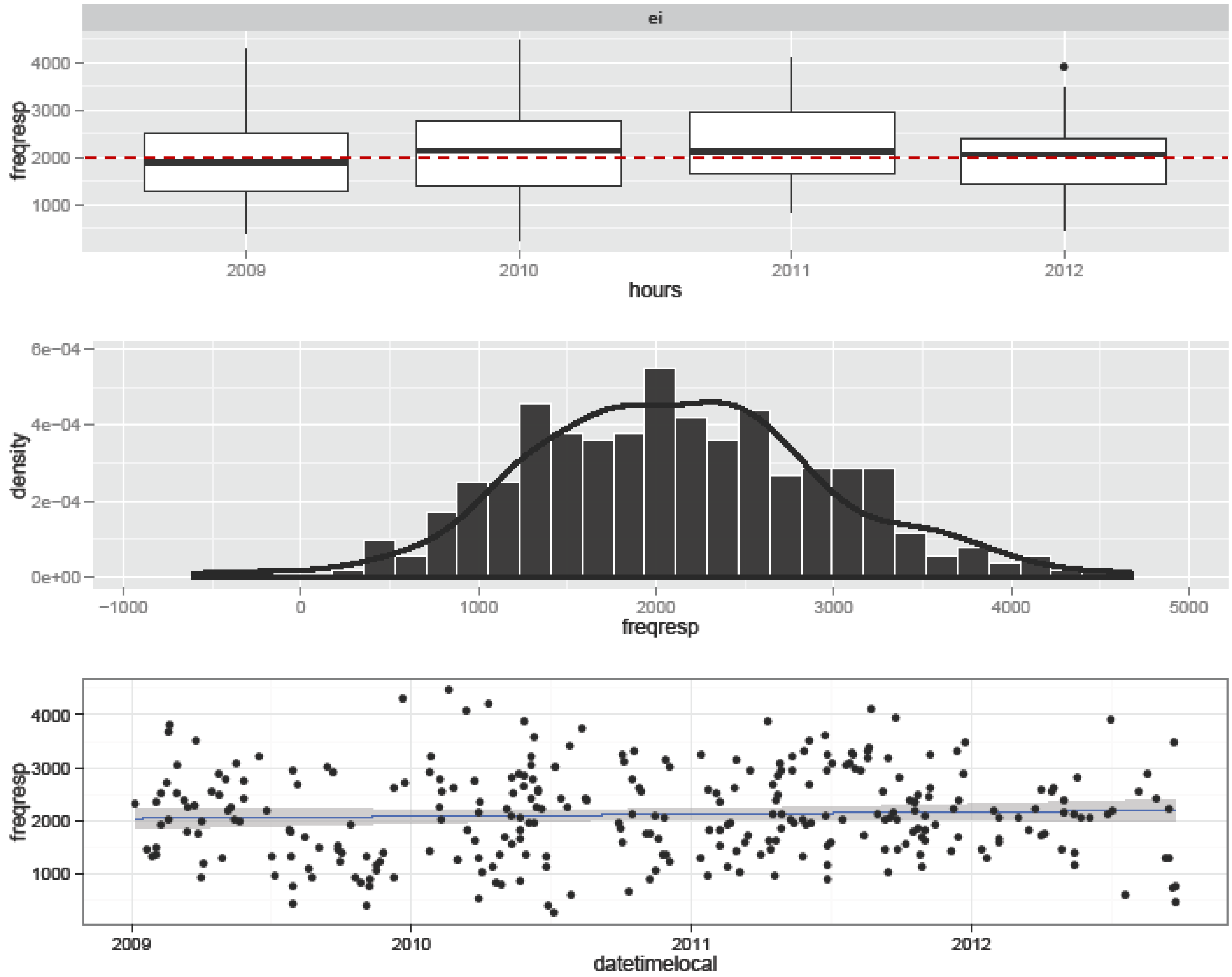
Frequency Events Dataset including identification flags for:

a. RS-FWG Selected Events, Form1 for: Eastern, Western, ERCOT, Hydro Quebec
b. Eastern Events – T. Bilke Dataset
c. ERCOT Events – S. Niemeyer Dataset

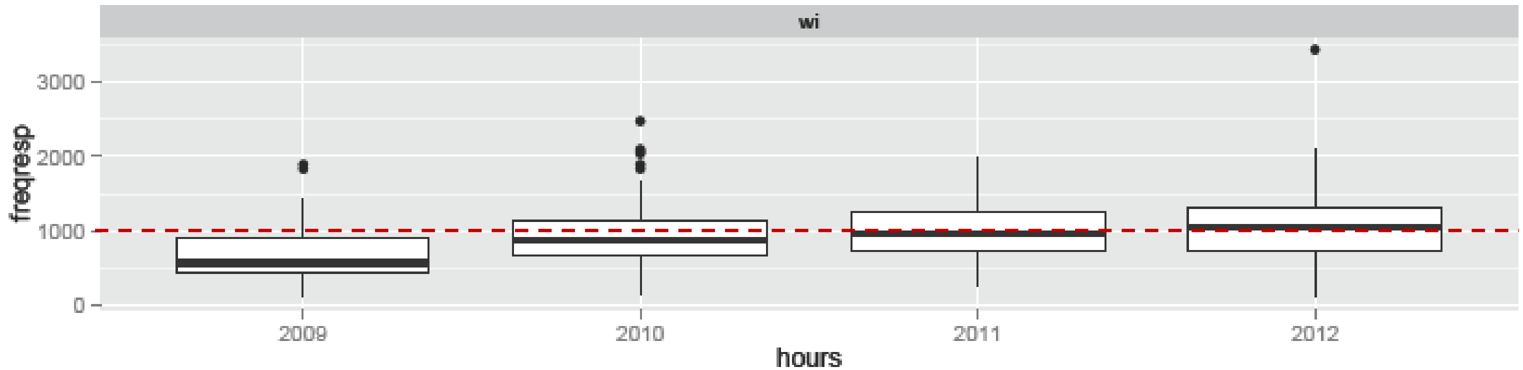
CERTS RECOMMENDATION: Use the RS-FWG 2008-2012 dataset as the Master Dataset for Interconnections Frequency Analysis, replication and validation of statistical analysis, and ALR events for each interconnection

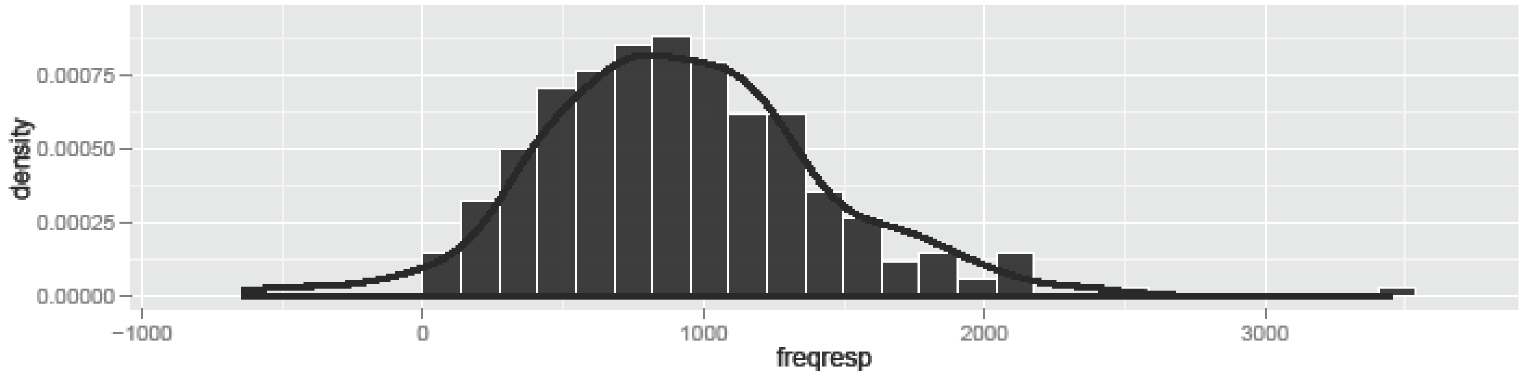
NERC Interconnections 2009 to 2012 Events Frequency Response Statistics

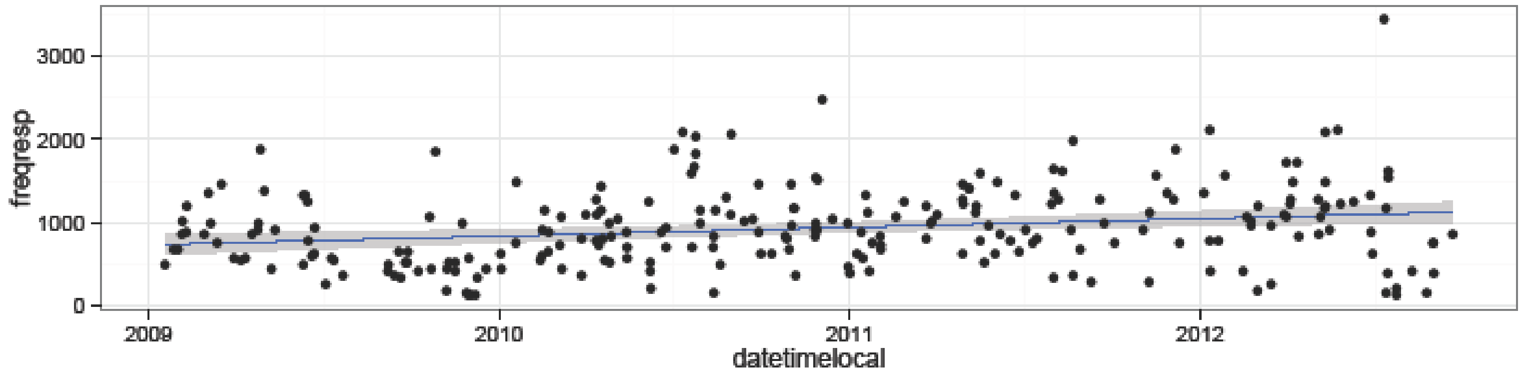
Eastern 2009-2012 Frequency Response Statistics



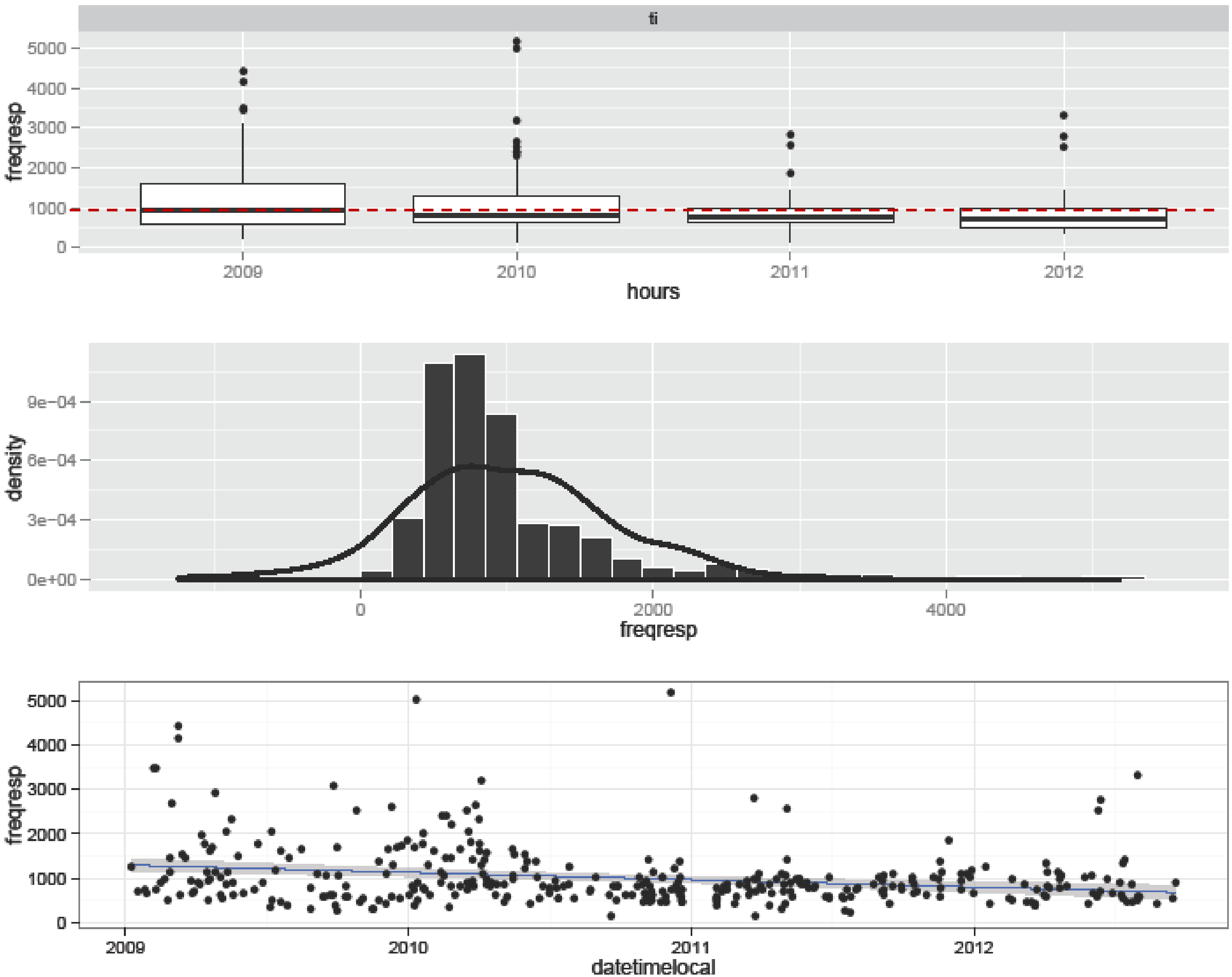
Western 2009-2012 Frequency Response Statistics





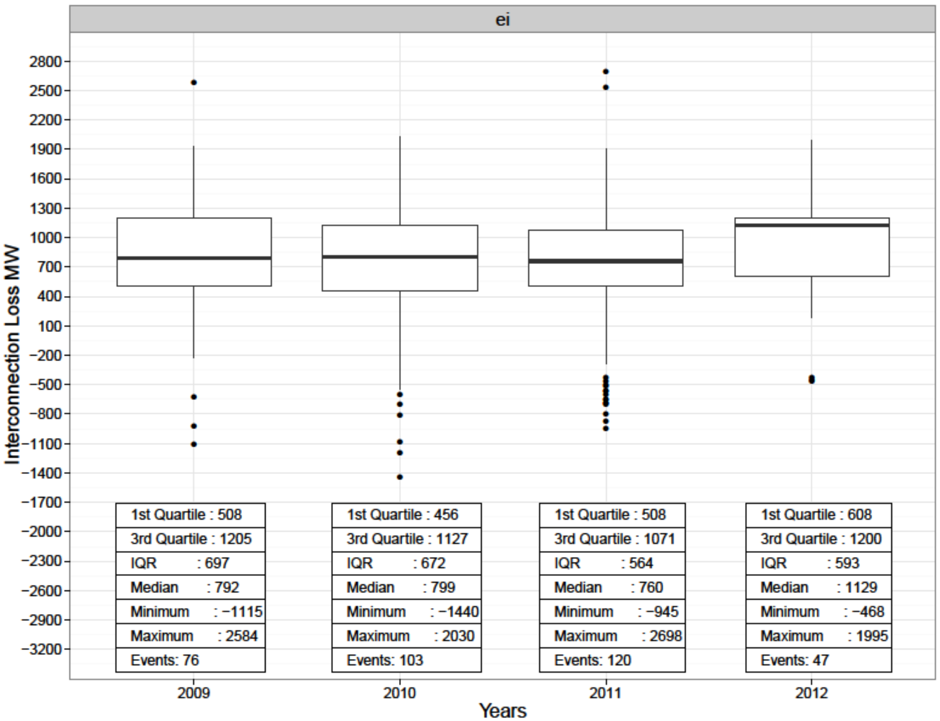


ERCOT 2009-2012 Frequency Response Statistics

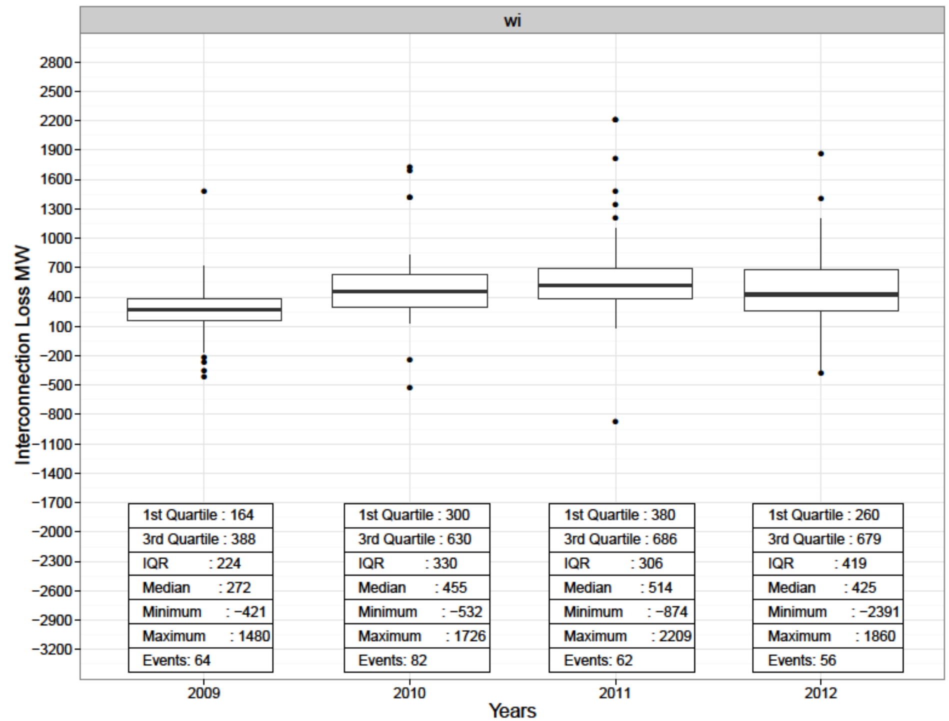


NERC Interconnections 2009-2012 Statistics for Events Loss MW and Events Frequency-C

Eastern, Western 2009-2012 Frequency Events Loss MW Statistics

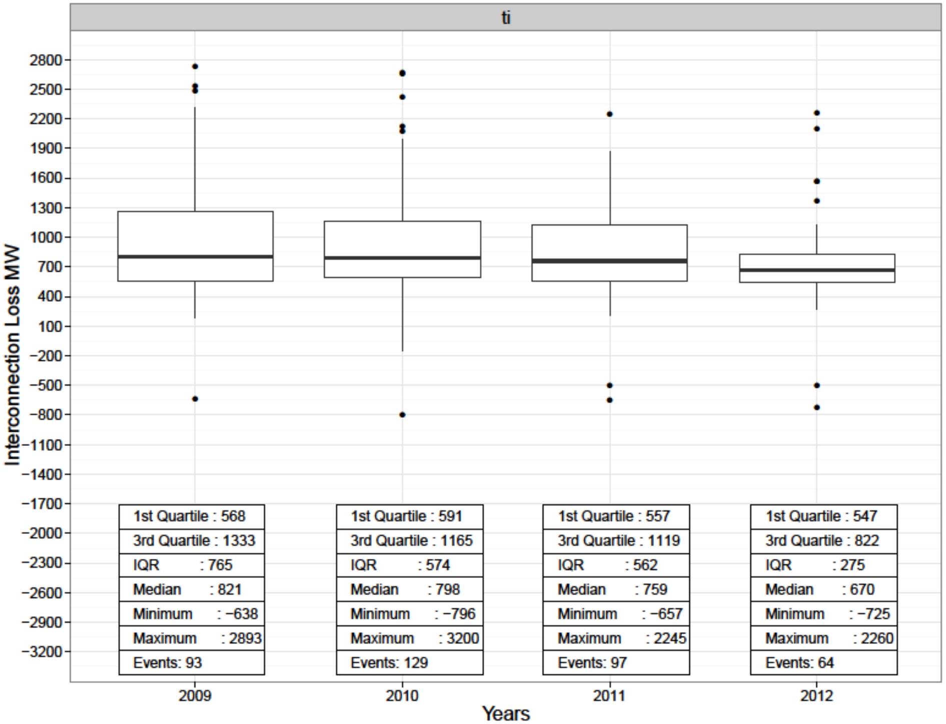


Eastern Interconnection

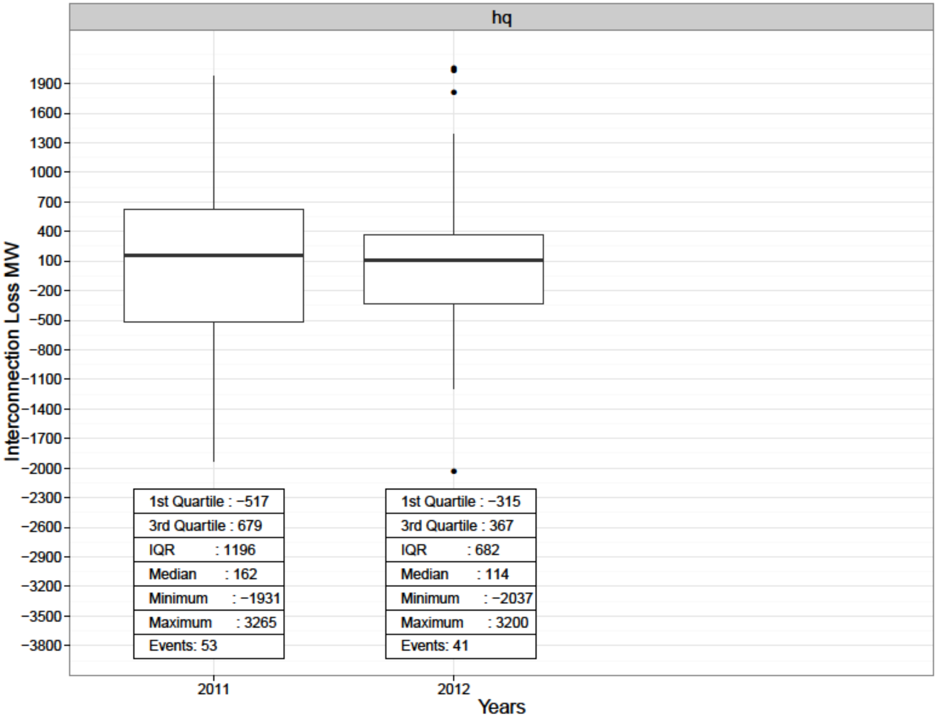


Western Interconnection

ERCOT, Hydro-Quebec 2009-2012 Frequency Events Loss MW Statistics

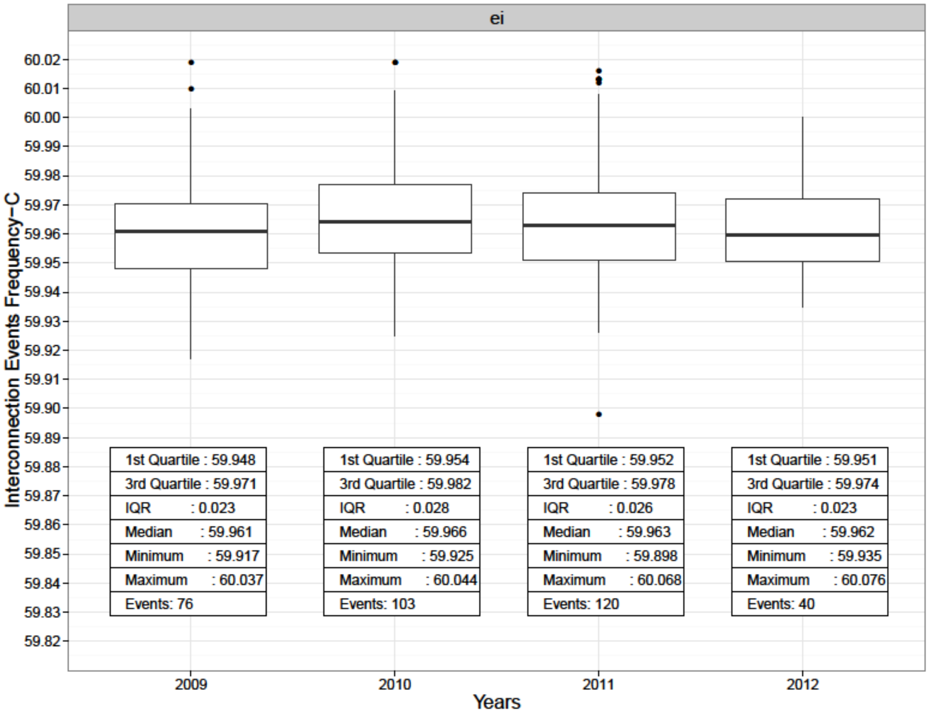


ERCOT Interconnection

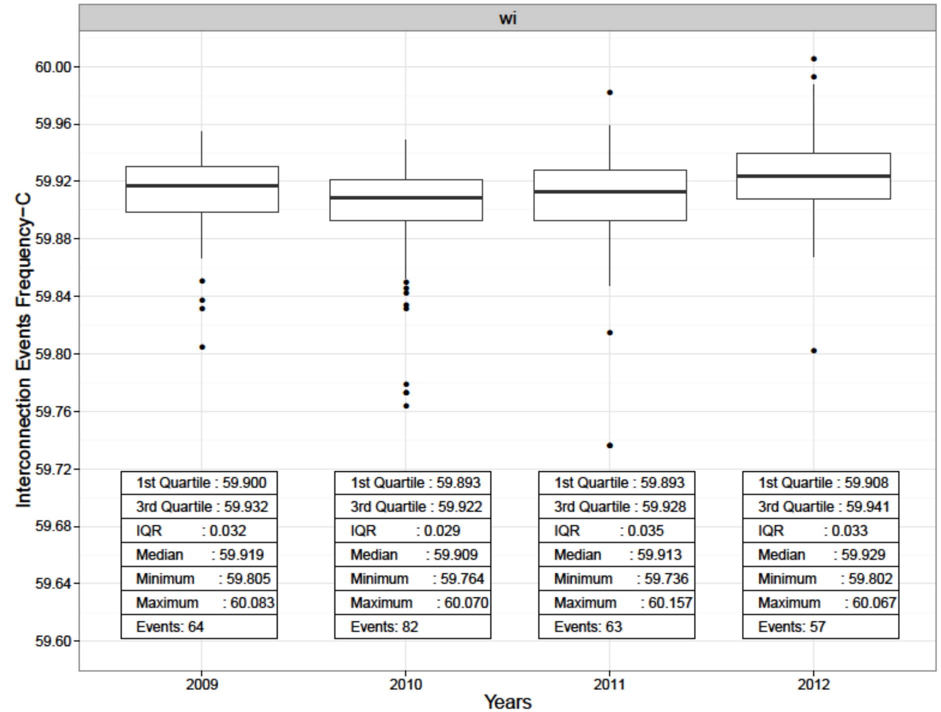


Hydro Q. Interconnection

Eastern, Western 2009-2012 Frequency Events Frequency-C Statistics

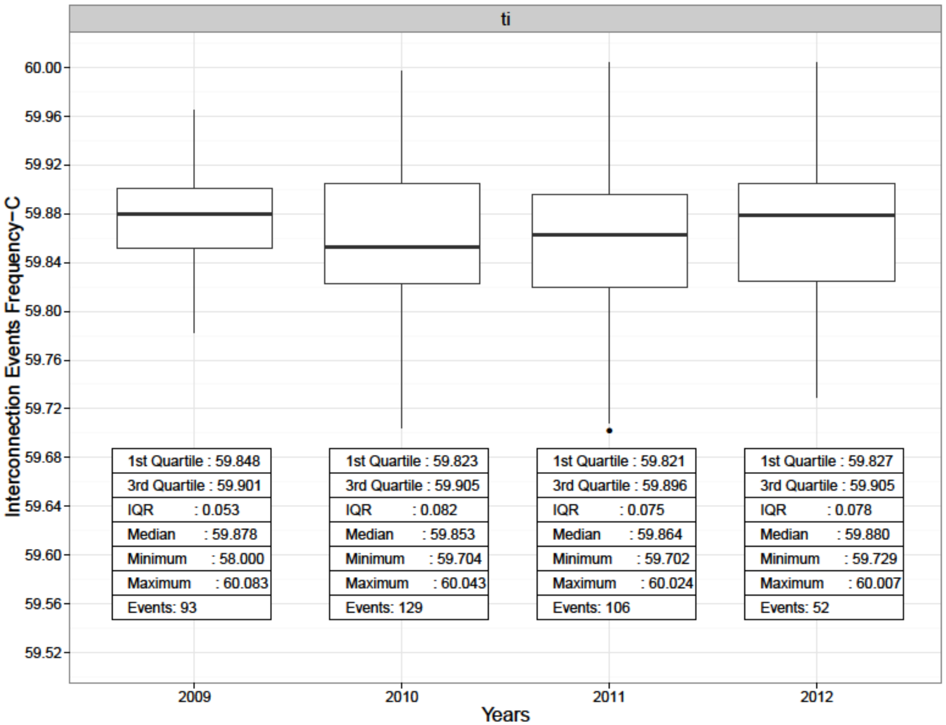


Eastern Interconnection

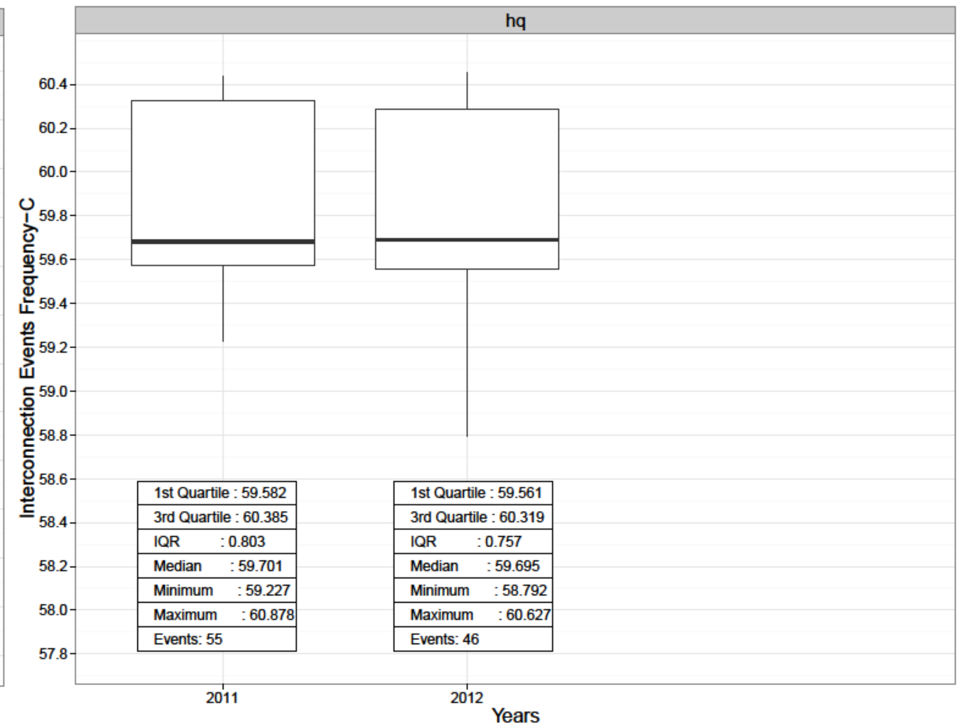


Western Interconnection

ERCOT, Hydro-Quebec 2009-2012
Frequency Events Frequency-C Statistics

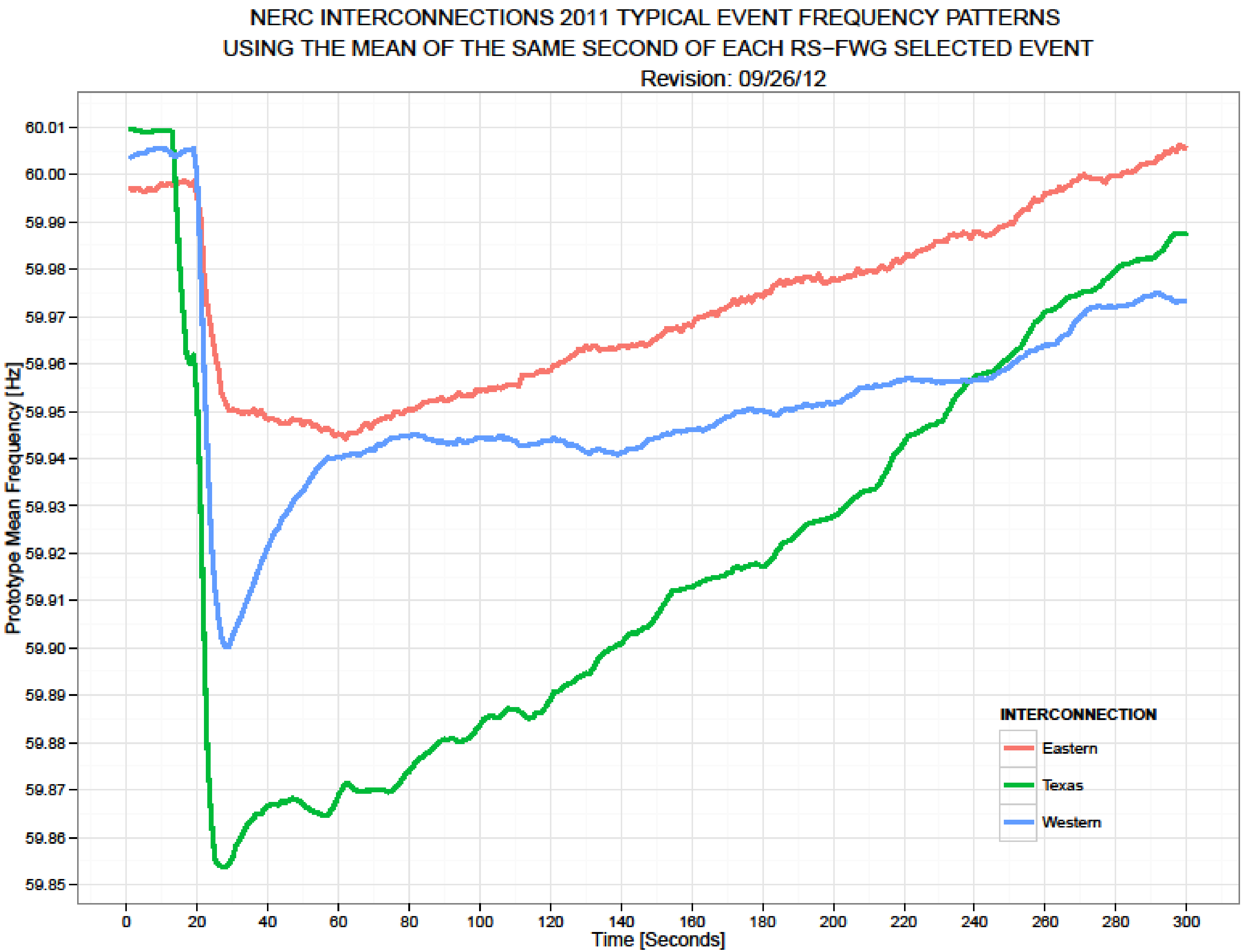


ERCOT Interconnection



Hydro Q. Interconnection

NERC Interconnections Typical Events Frequency Profiles


NERC INTERCONNECTIONS 2011 TYPICAL EVENT FREQUENCY PATTERNS
USING THE MEAN OF THE SAME SECOND OF EACH RS-FWG SELECTED EVENT
Revision: 09/26/12
Prototype Mean Frequency [Hz]
60.01
60.00
59.99
59.98
59.97
59.96
59.95
59.94
59.93
59.92
59.91
59.90
59.89
59.88
59.87
59.86
59.85
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Time [Seconds]
INTERCONNECTION
Eastern
Texas
Western

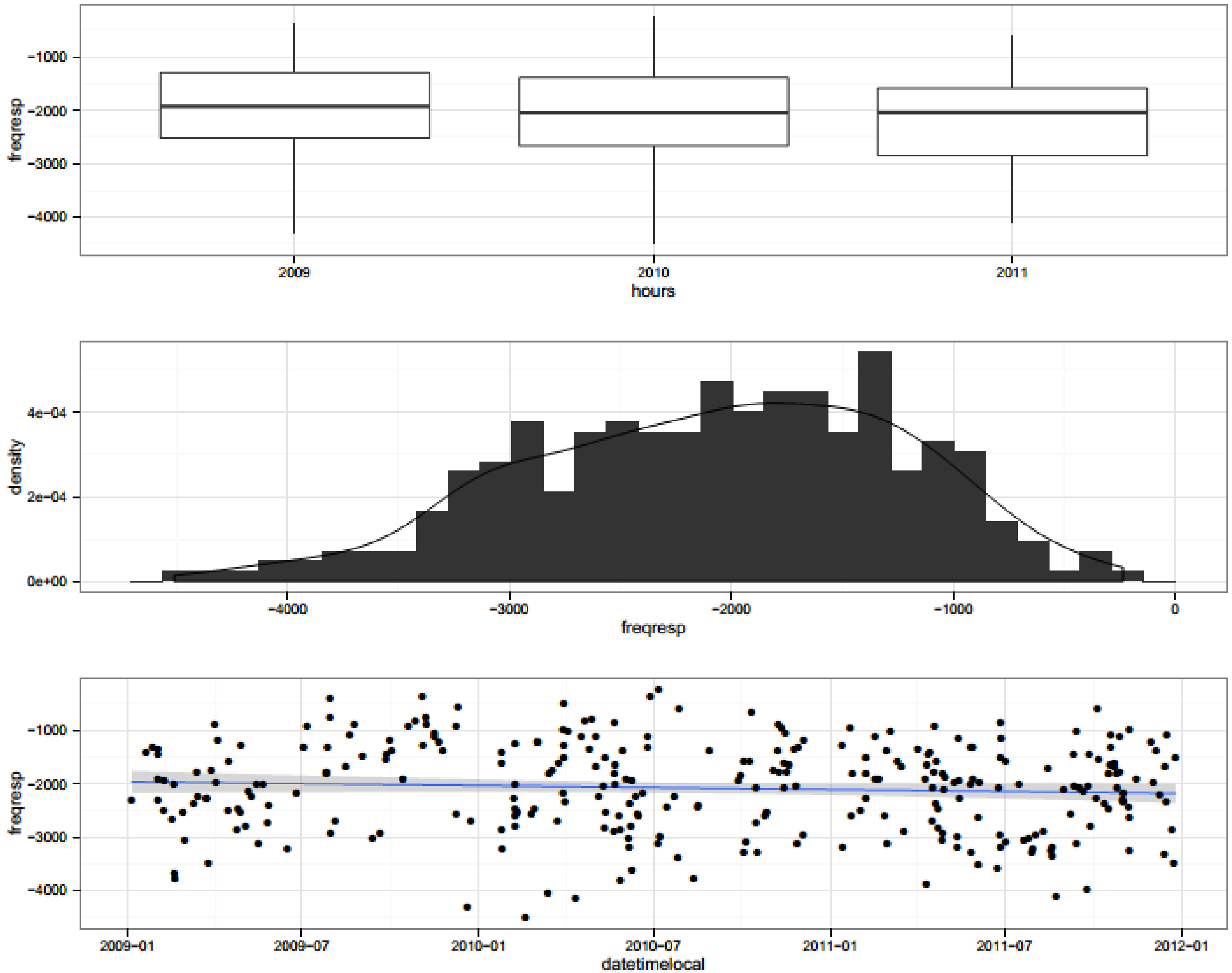
CERTS Replication Analysis and Observations on NERC FRI Report Version 09/16/12

Rafael Campo Ph.D.

- Electrical Engineer; MSc and PhD in IEOR (Industrial Engineering and Operations Research). University of California, Berkeley;
- University Visiting Professor:
  - University of Michigan (Ann Arbor), graduate course in Time Series Analysis and Forecast;
  - South America and Caribbean Universities (Brazil, Colombia, Venezuela, Puerto Rico) - Courses in Operations Research;
- Consulting and Development Work for Electric Power Industry:
  - Probability analysis of Frequency Response data, as collected by PMUs (CERTS);
  - Grid Performance Monitoring Metrics using Phasors (CERTS);
  - Hydro-thermal dispatch;
  - Advanced applications in control centers (AEP and Systems Control Inc.);
  - Time Series and Risk studies in electric power markets;
  - Member of Market Surveillance Committees;
- Consulting work for: World Bank, IDB, IAEA, IEA, etc.

CERTS FR Performance Replication - FRI Report

CERTS REPLICATION DESCRIPTIVE STATISTICS AND TRENDS - DIFFERENCES WITH FRI REPORT

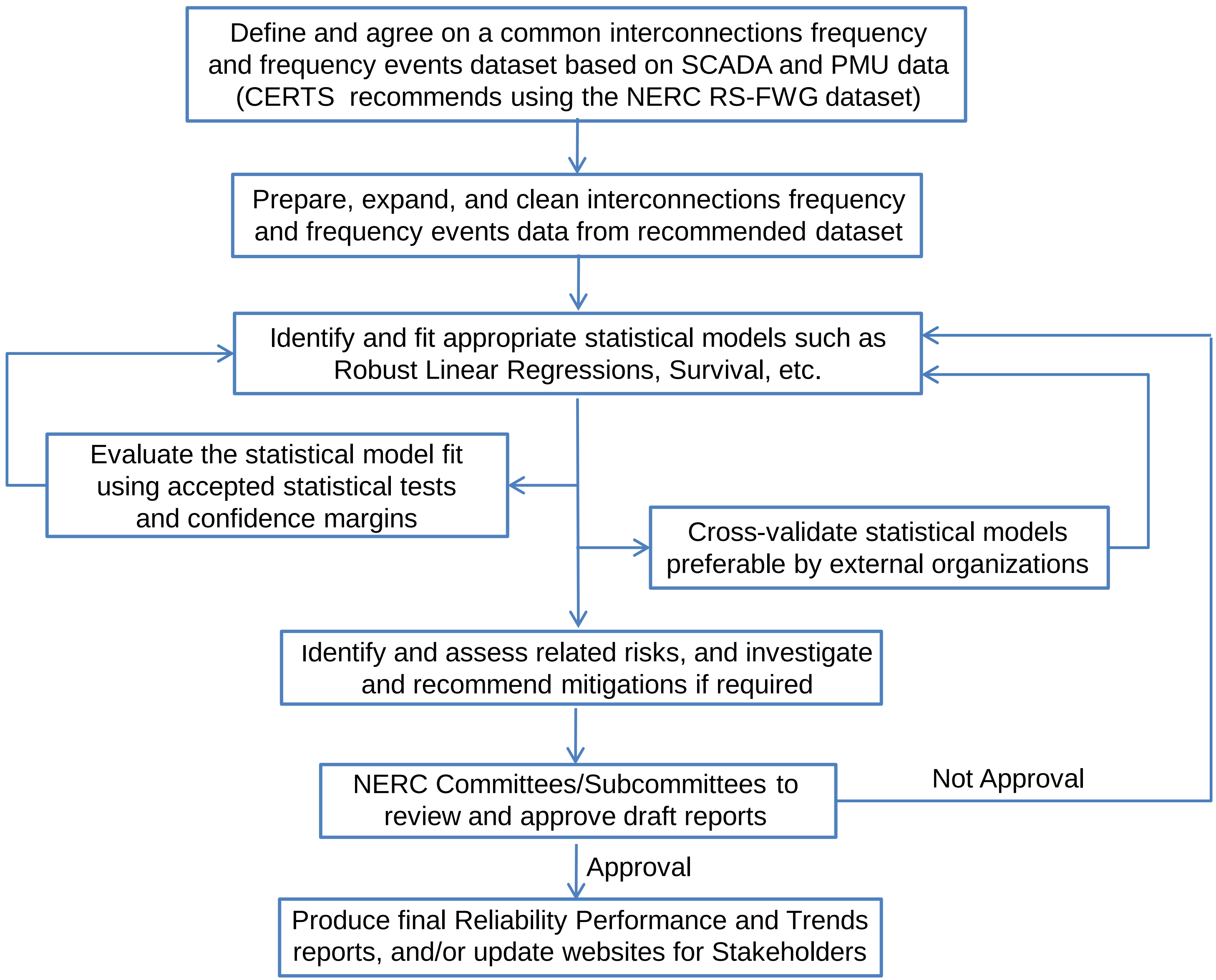


Eastern Frequency Response Performance From 2009 to 2011

Use of Statistics for Reliability Performance Analysis

- Additional variables introduced by electricity markets, integration of renewable generation and Smart Grids make necessary the use of statistical and risk analysis for reliability performance analysis and for defining adequate performance metrics for reliability standards;
- The statistical and risk analysis process described in the next slide is recommended for reliability analysis, including cross-validation and replication;
- In our view, the statistical processes used in the NERC FRI Report are sound;
- We have reservations on the FRI conclusion of Eastern FR upward trend during the 2009-2011 period (Slide 24). Replication (Slide 19) does not confirm this trend;
- We make recommendations to complement the FRI analysis and improve robustness of the performance results;

Recommended Statistical and Risk Processes for Interconnections Reliability Performance Analysis



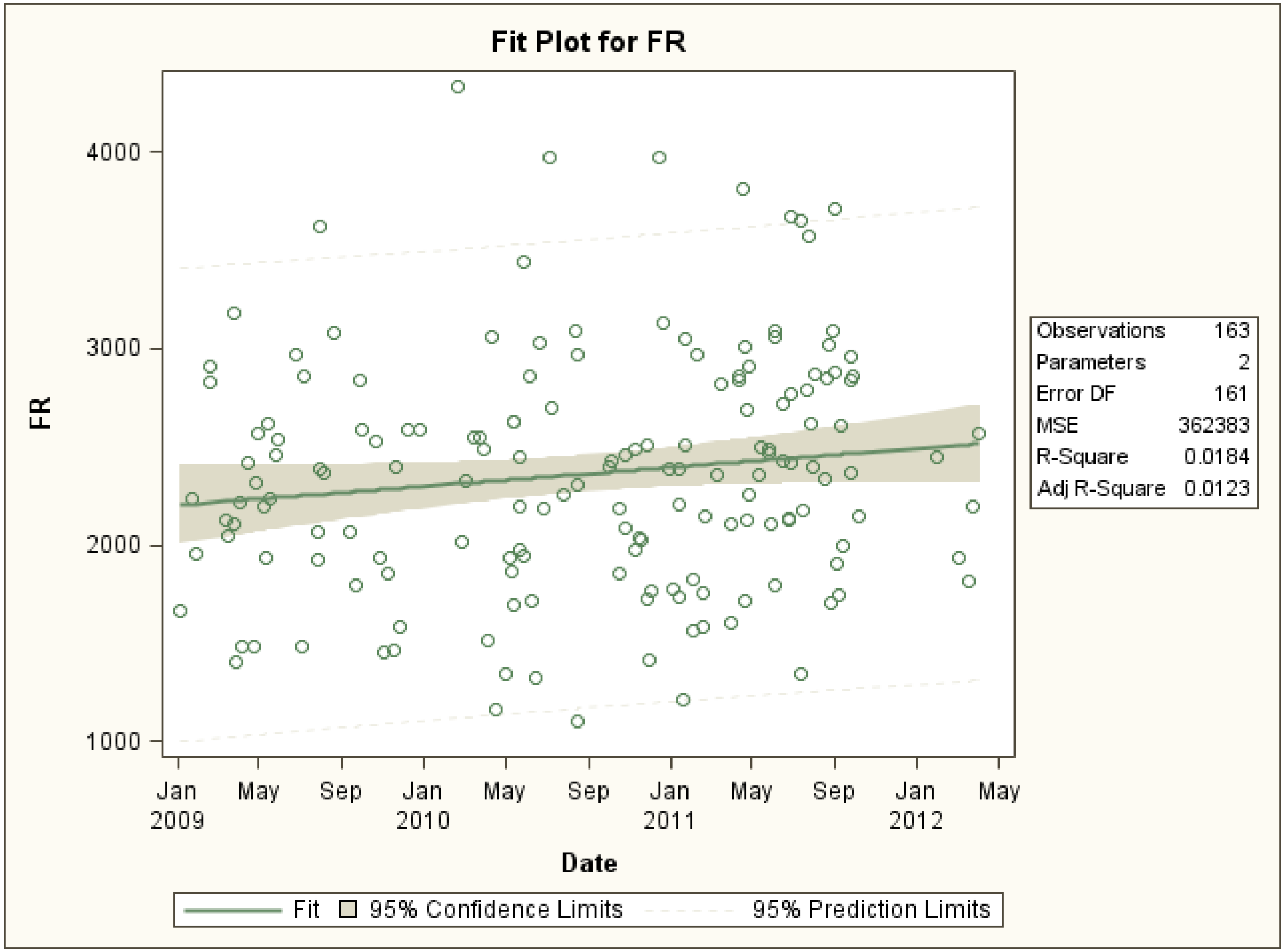
CERTS Observations on FRI Report – Summary

- CERTS replication boxplots and regression show that Frequency Responses in 2010 and in 2011 were lower than in 2009. Frequency response in 2011 appears slightly lower than in 2010.
- The scatter plot from the FRI report and CERTS replication reveal large variability and consequently large uncertainty in the data, suggesting difficulties in fitting appropriate linear regression models.
- The R- square obtained in the FRI analysis (0.0184) is too low. The FRI report specifically points this characteristic: "..Changes in time explain only 1.8% of variability of Frequency Response .."
- The FRI report postulates that the distribution of the 2009-2011 FR is (truncated) normal. However, the histogram-density of the 2009-2011 FR distribution from CERTS replication, does not support this assertion. In addition, CERTS recent reports on FR performance provide rather strong evidence of the presence of "fat tails" in the distributions of MW and frequency events for the Eastern Interconnection.
- The FRI correlations report of the linear regression explanatory variables (date, season, and pre-disturbance frequency) with the FR, as well as their coefficients of determination, are rather low to draw definitive conclusions.

Detailed Observations on FRI Report Version 09/16/12

- Data used in FRI Report has very large variance;
- The more complete available events data set was not used (Eastern = 391 events available vs. 158 used observations);
- No accounting was made for measurement errors and measurement uncertainties;
  - Note: CERTS has made analysis of PMU measurement uncertainties;
- Additional explanatory variables might be more relevant than the ones used;
- Results using RS-FWG data set fail to confirm FRI Report Eastern FR uptrend

FRI Report Scatter Plot of Eastern FR (Using 2009, 2010 and 2011 data)



FRI Report - FR vs. Time Model

Mathematical regression model fit to the data, with time as the only explanatory variable:

$FR(t) = k + a*t + \varepsilon (t)$

(“k” is the intercept and “a” the slope); $\varepsilon (t)$ iid Normal random variables;

Standard deviation of $\varepsilon (t) = 602$; therefore, with 95% probability actual values are

(Linear regression) fitted values ± 1,204 MW/.1Hz

(Mean value about 2,400 MW/.1Hz)

Observations on FRI Model: FR vs. Time

- Statistical tests confirm that residuals have normal distribution, with zero mean.
  - The regression hypothesis are then satisfied;
- P-value used for testing flat versus positive slope (0.083) is larger than commonly used significance level (0.05)
  - At 5% significance level, therefore, the slope is flat;
- Model coefficient of determination (R^2) too low (1.8%)
  - Very low dependence of FR on time, as the paper indicates;
- F tests at 5% significance level
  - No variation in time of FR from 2009 to 2010 to 2011;
- We advice caution in concluding FR dependence on time;

FRI Report - Multiple Linear Regression

- Time as an explanatory variable has very low coefficient of determination and does not seem to pass the t-test;
- Season and pre-disturbance frequency have larger explanatory value and pass the t-test;
- Overall coefficient of determination (15%) low; standard deviation of residuals (565 MW/.1Hz) high;
- As indicated above, need additional data and/or further explanatory variables, for more robust results;

FRI Report - Notes on Normality Assumption for FR

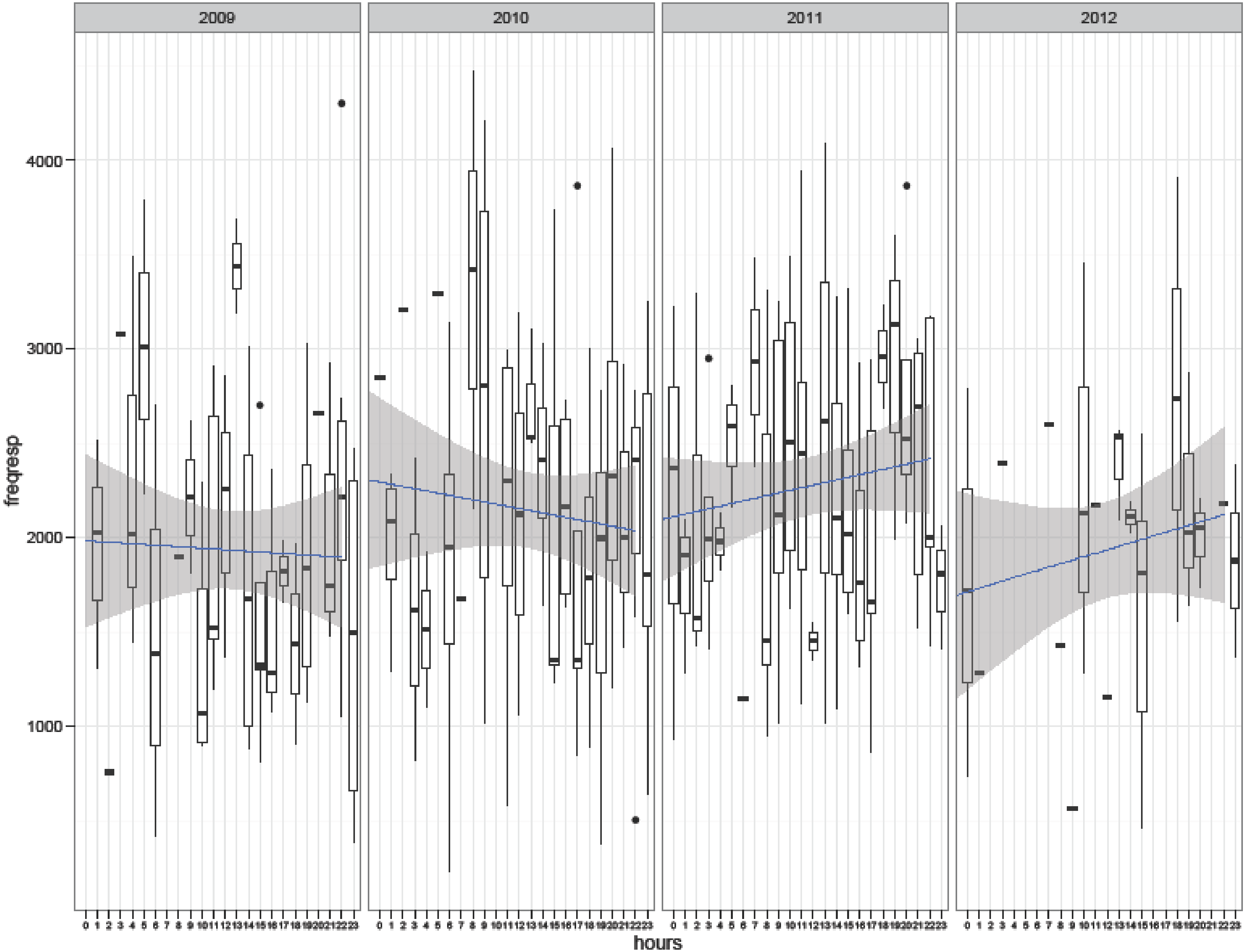
- CERTS fit and tested Power Law distributions to extreme (MW and delta frequency) events;
- The results prove the presence of "fat tails" in the statistical distribution of these events;
- Extreme events are the most important from a reliability point of view;
- They would not be captured with the usual regression analysis;

CERTS Suggestions and Recommendations

Suggestions and Recommendations - Summary

- Use the available RS – FWG Frequency Events dataset for uniformity, for increasing event sample size and for improving statistical confidences;
- Use Statistical Analysis for Interconnections Frequency Analysis, but be certain the analysis can be replicated;
- To add robustness to the performance results we suggest:
  - Accounting for measurement errors and measurement uncertainty;
  - Trying additional explanatory variables, example:
    - Time-of-day (see next slide);
    - MISO tried Top-of-the-Hour; Sundays/No Sundays and Average Temperatures, for a Δfreq analysis using 2011 and 2012 data (first 6 months); they obtained $R^2 = 0.58$;
- Research practicality and utilization of the Survival Probability models as an alternative for Linear Regression models

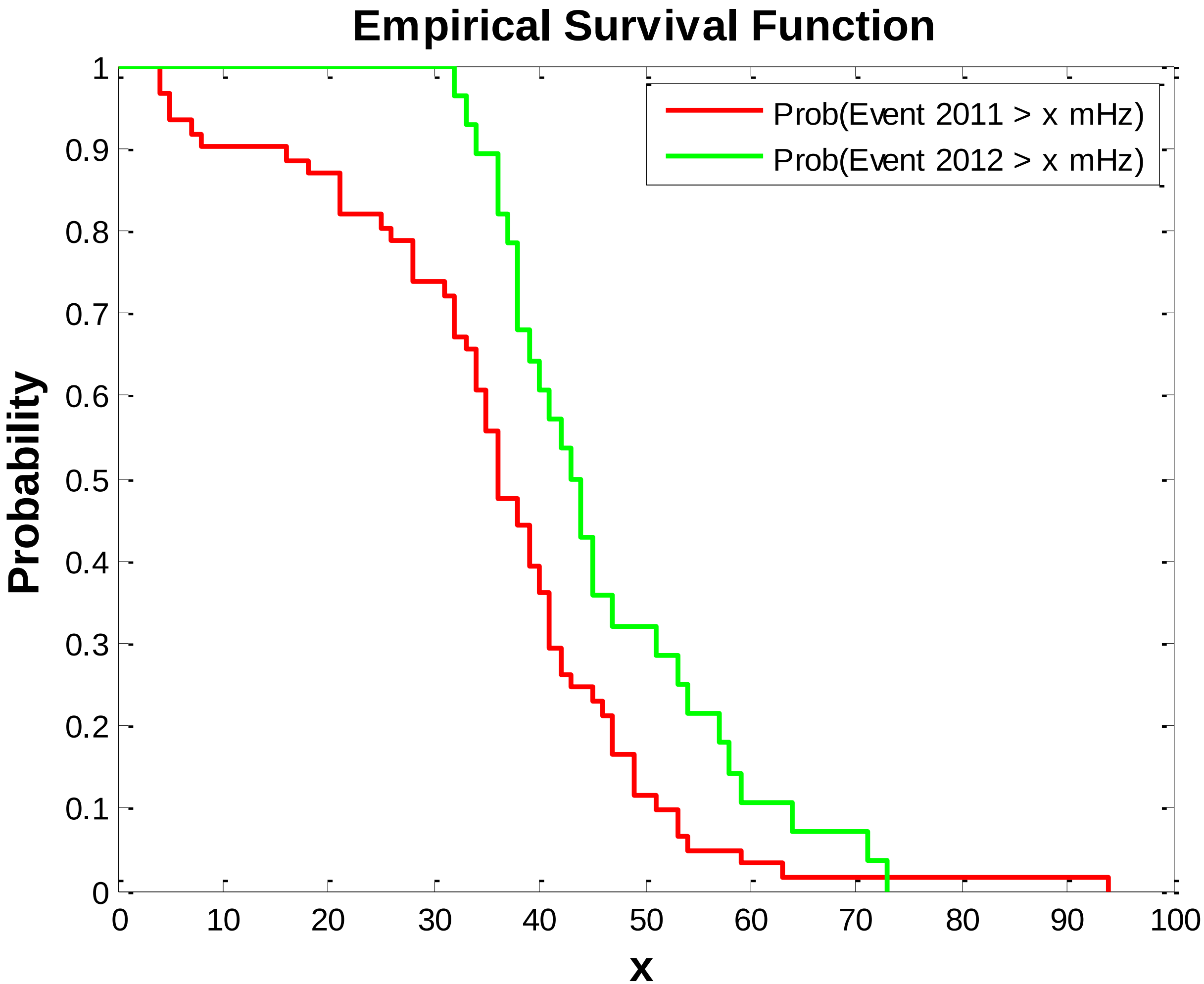
Eastern 2009-2012 FR vs. Hour of Day



Alternative: Survival Probability Plots for Comparisons

- Method widely used in reliability analysis;
- Empirical survival functions are compared for (non negative) data sets involved (2 at a time): X and Y;
- $Y \geq X$ (stoch.); iff $Pr(Y \geq a) \geq Pr(Y \geq a)$ for all a; In this case, mean of Y is above mean of X;
- Compare plots of $(1 - F)$ for Y and X;
- Different from regression, method does not require equal number of observations for X and Y and is less influenced by outliers;
- Additional comparisons can be made visually;
- Statistical tests can be performed;
- Next slide compares Δ freq (C – A) of 2011 and 2012

Use of Survival Plots for Comparing Eastern Events Frequency-C for 2011 and 2012



2012 Frequency-C below 2011 Frequency-C

Except for Large Values; K-S Test Passed at 5% Significance Level