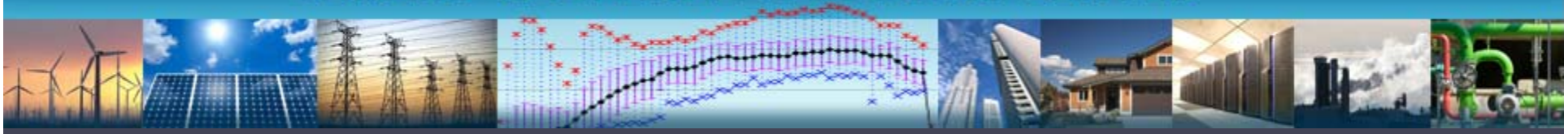
DEMAND RESPONSE RESEARCH CENTER



Demand Response Shed Variability

October, 2012

Sila Kiliccote, Johanna Mathieu, Duncan Callaway, Livio Fenga, Nathan Addy,

Deputy, Demand Response Research Center

skiliccote@lbl.gov

http://drrc.lbl.gov

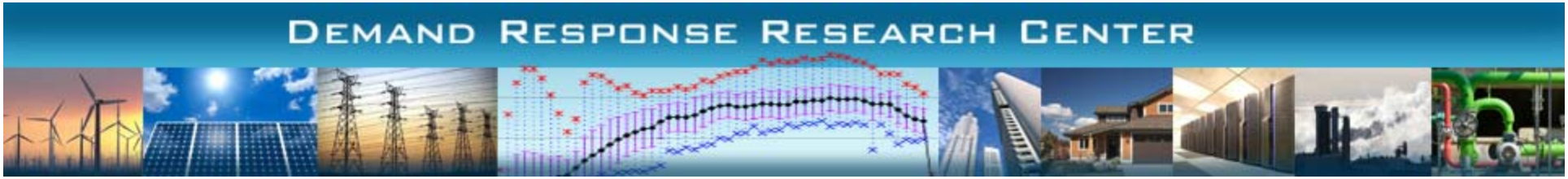
pier

PUBLIC INTEREST ENERGY RESEARCH

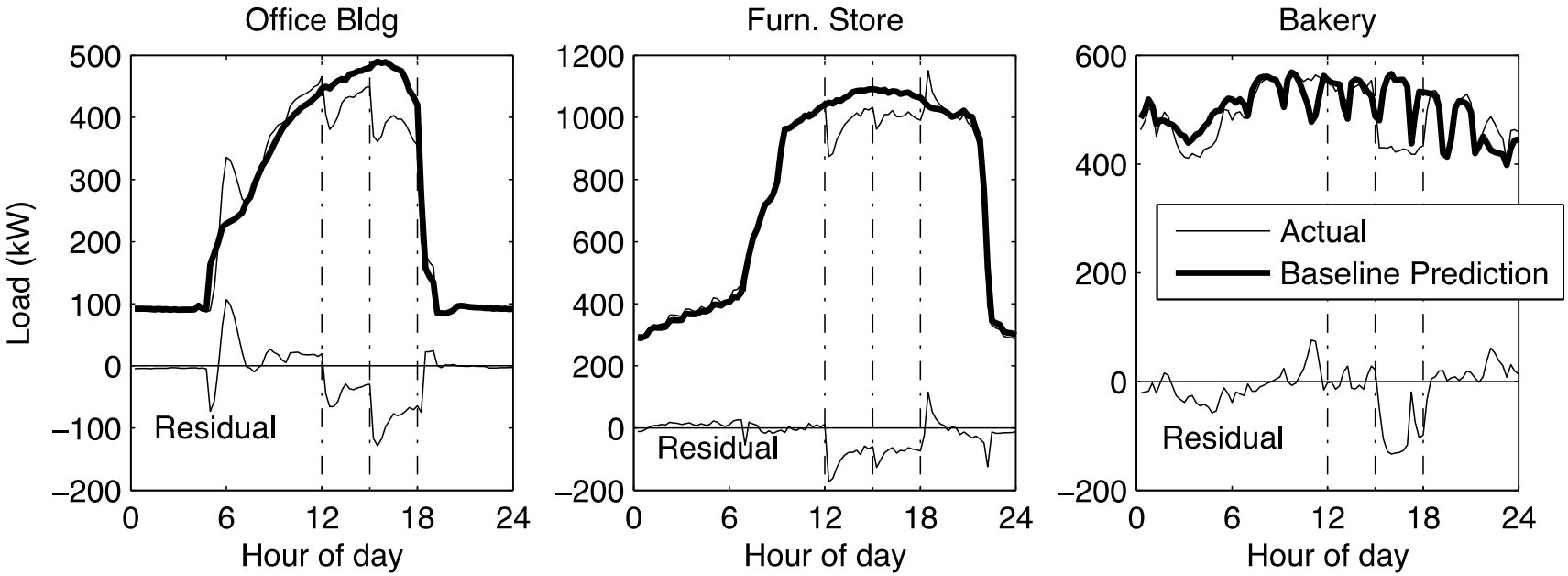
BERKELEY LAB

Outline

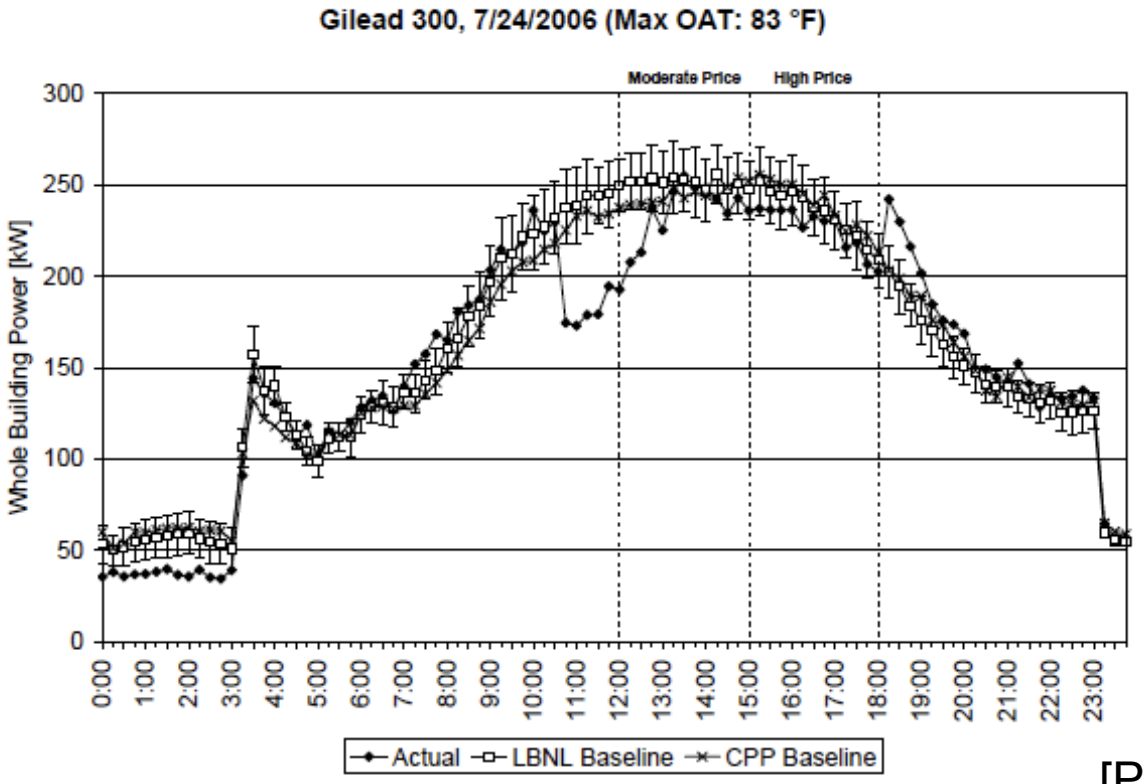
- Introduction
  - Research Question
- Methodology
  - Determine Errors on Sheds
  - Define Shed Variability Metric (SVM)
- Results
  - Characterize Facilities with SVM
- Future Work



DR sheds are usually estimated by subtracting actual measured load (kW) from load predicted by a baseline model



Sheds are generally reported without uncertainty bounds, even if some sort of error analysis has been done.



[Piette et al. 2007]

Date	Price Level	kW		W/ft²		WBP%	
		Max	Ave	Max	Ave	Max	Ave
Jul-24	Moderate Price	49	20	0.59	0.24	19%	8%
	High Price	22	14	0.27	0.16	9%	6%

Figure ES.4 Average Hourly CPP Load Impacts by Event – *PG&E*

[Braithwait et al. 2010]

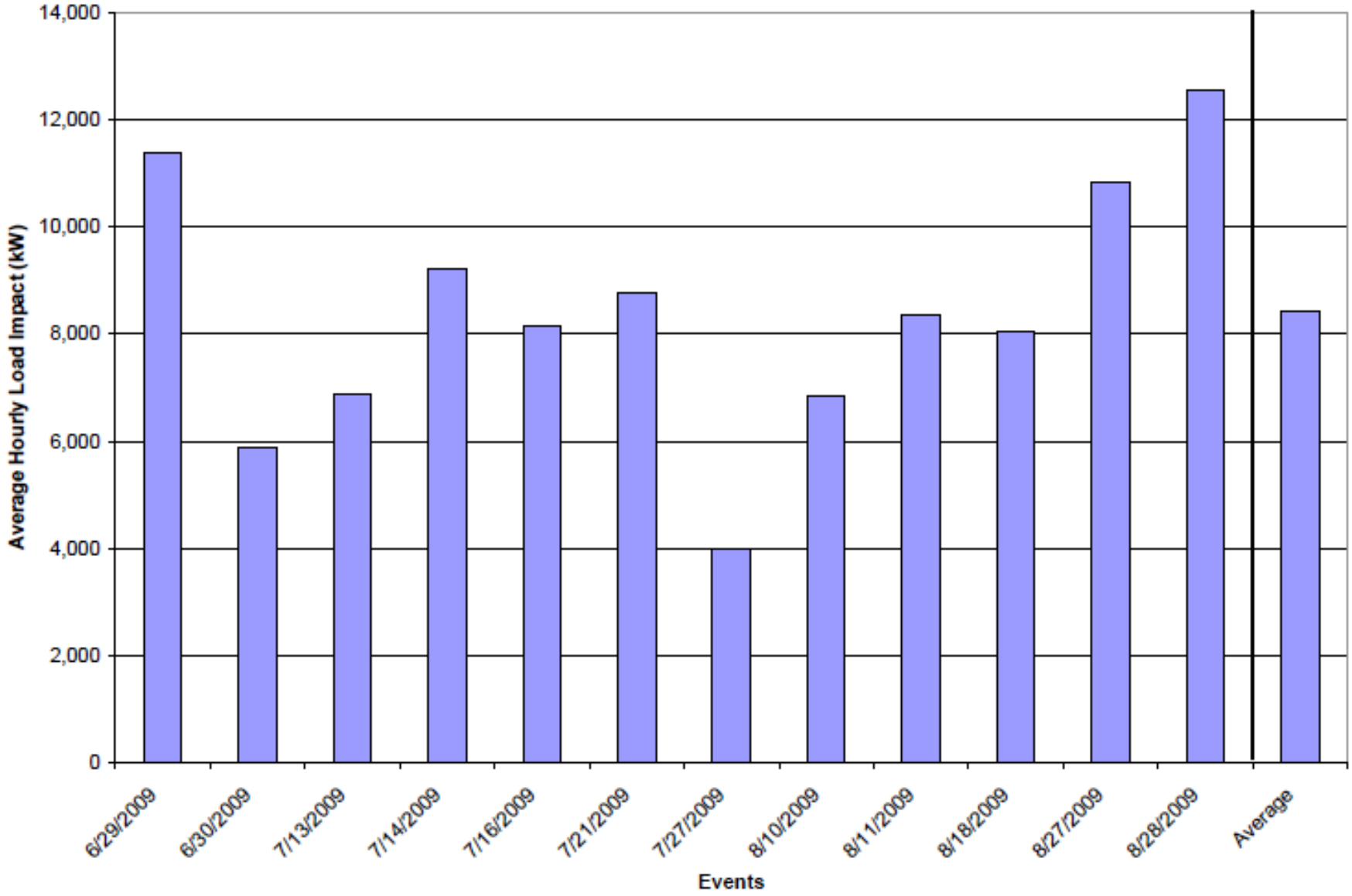


Figure ES.4 Average Hourly CPP Load Impacts by Event – *PG&E*

[Braithwait et al. 2010]

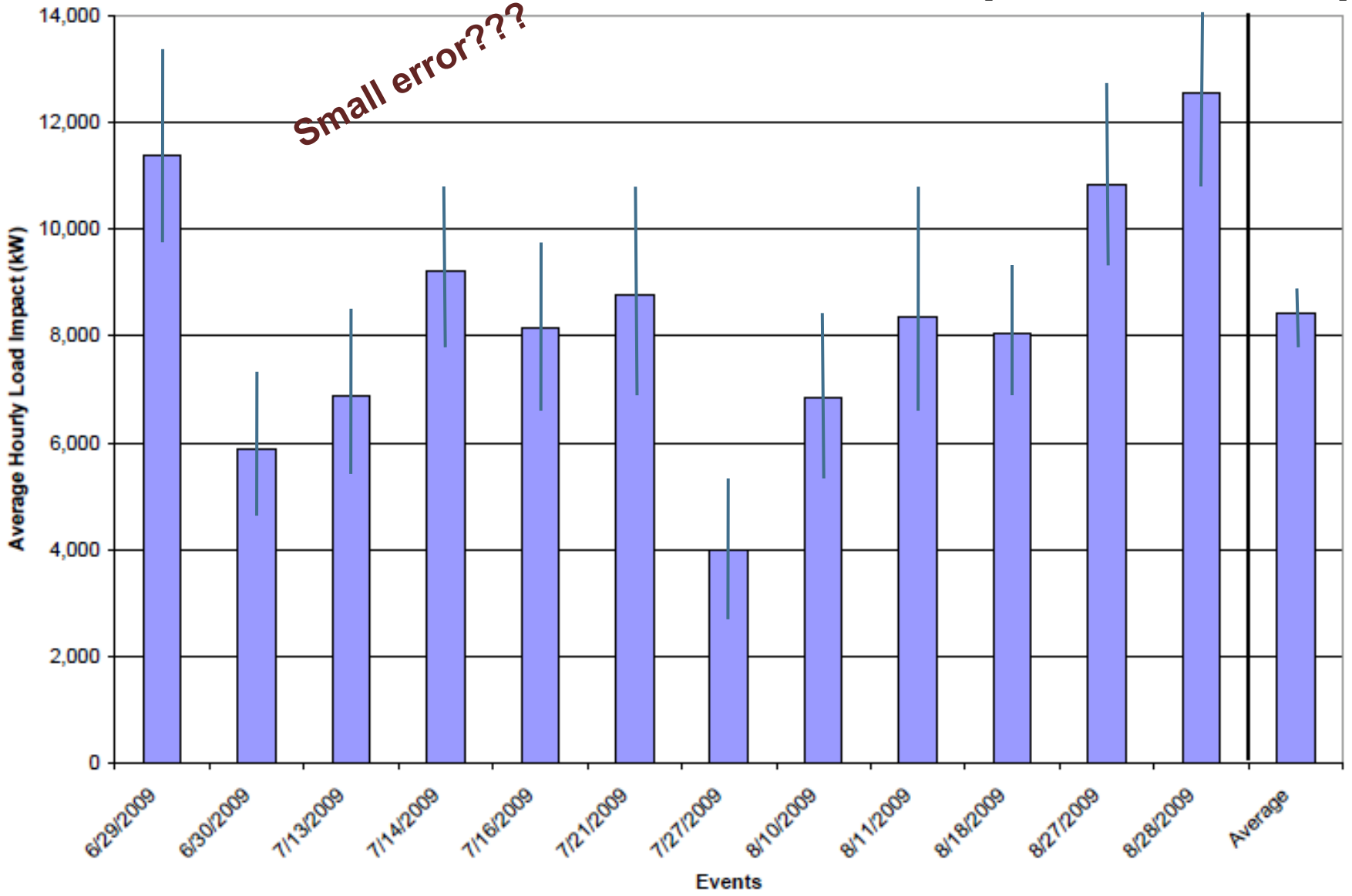
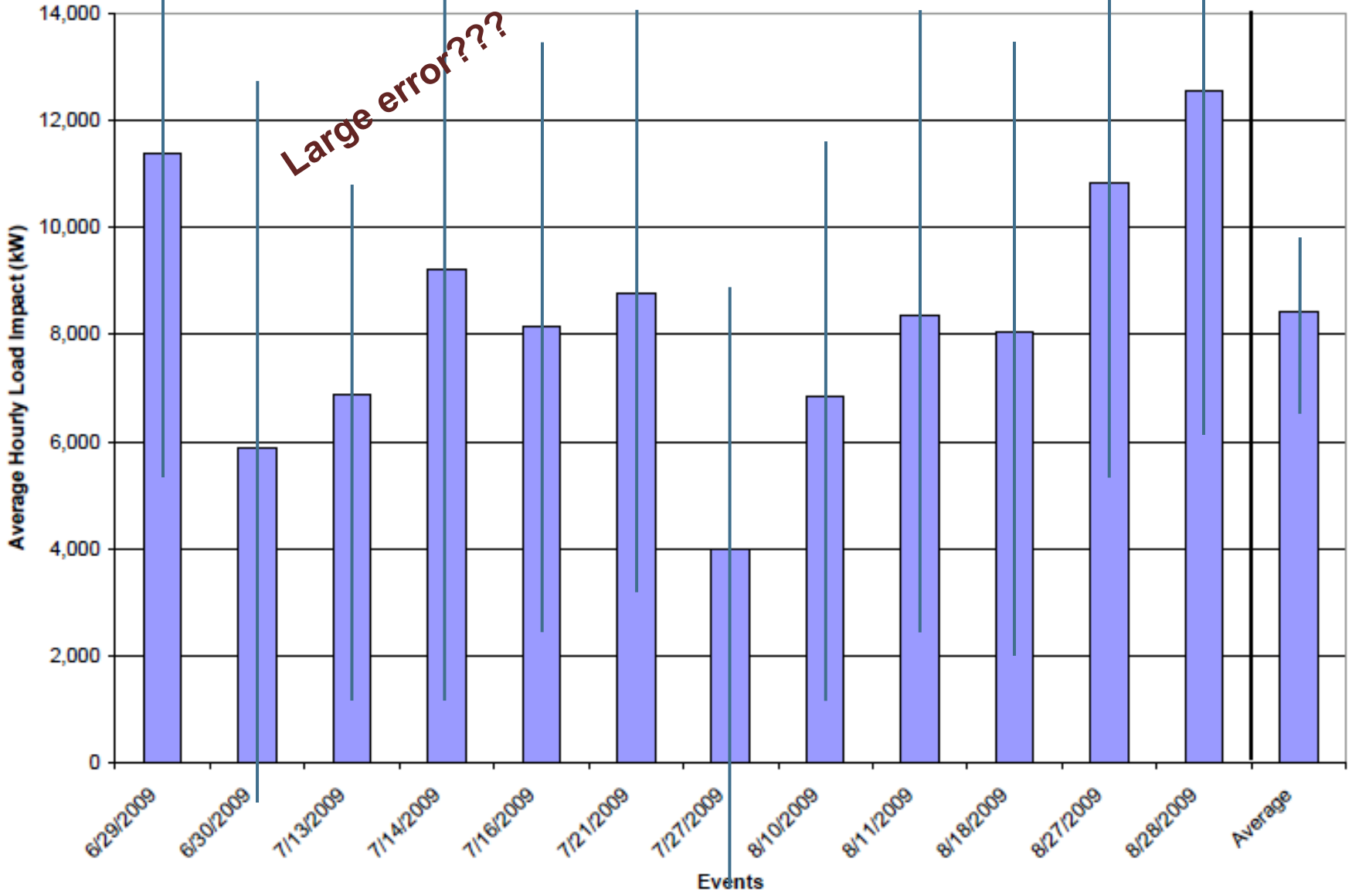


Figure ES.4 Average Hourly CPP Load Impacts by Event – *PG&E*

[Braithwait et al. 2010]



Why does understanding 'real' versus 'observed' variability matter?

- At the aggregate level
  - Real variability could cause frequency/resource adequacy issues
  - Observed variability can affect policy
  - Variability affects Measurement & Verification
  - Participation in DR bidding programs & ancillary services markets
- At the individual facility level
  - DR performance feedback
  - Variability affects Measurement & Verification
  - Participation in DR bidding programs and ancillary services markets

Research Questions:

- How big is baseline model error?
- Is observed shed variability the result of real variability or simply model error?

Methodology:

- Determine errors on sheds
- Define shed variability metric
- Characterize facilities and aggregate populations by shed variability metric

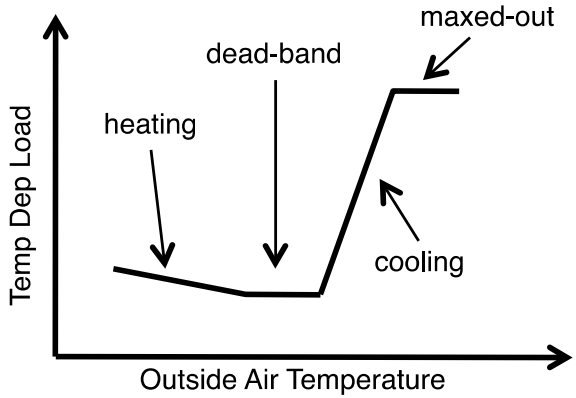
Baseline Models

Common Models

- Averaging
  - 3/10, Average of the 3 non-DR days with the highest energy use out of the last 10 non-DR days
  - 10/10, Average of the last 10 non-DR days
- Regression, built with non-DR days
  - Time-of-day, day-of-week indicator variables
  - Linear temperature dependence

Our Model

- Regression, built with non-DR days
  - Time-of-week indicator variables
  - Piecewise linear temperature dependence



Occupied: $$\hat{L}_o(t_i, T(t_i)) = \alpha_i + \sum_{j=1}^{6} \beta_j T_{c,j}(t_i)$$

Unoccupied: $$\hat{L}_u(t_i, T(t_i)) = \alpha_i + \beta_u T(t_i)$$

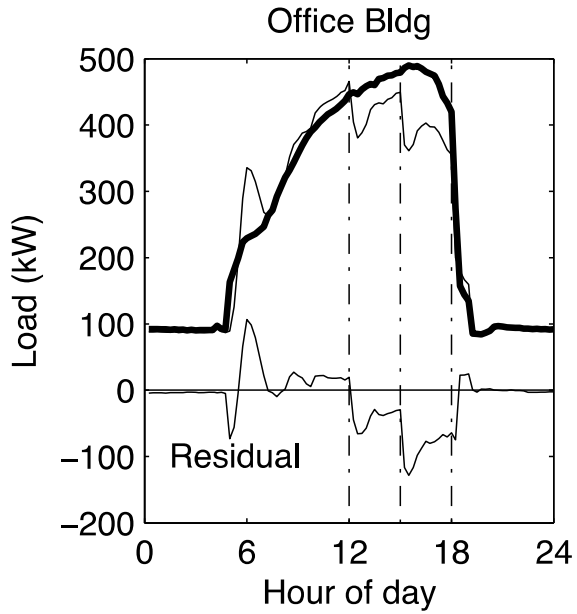
[Mathieu et al. 2011, *IEEE Trans on Smart Grid*]

DR Parameters

1. Average Demand Shed 1 (kW)
Baseline minus actual average demand 12-3pm

2. Average Demand Shed 2 (kW) Baseline minus actual average demand 3-6pm

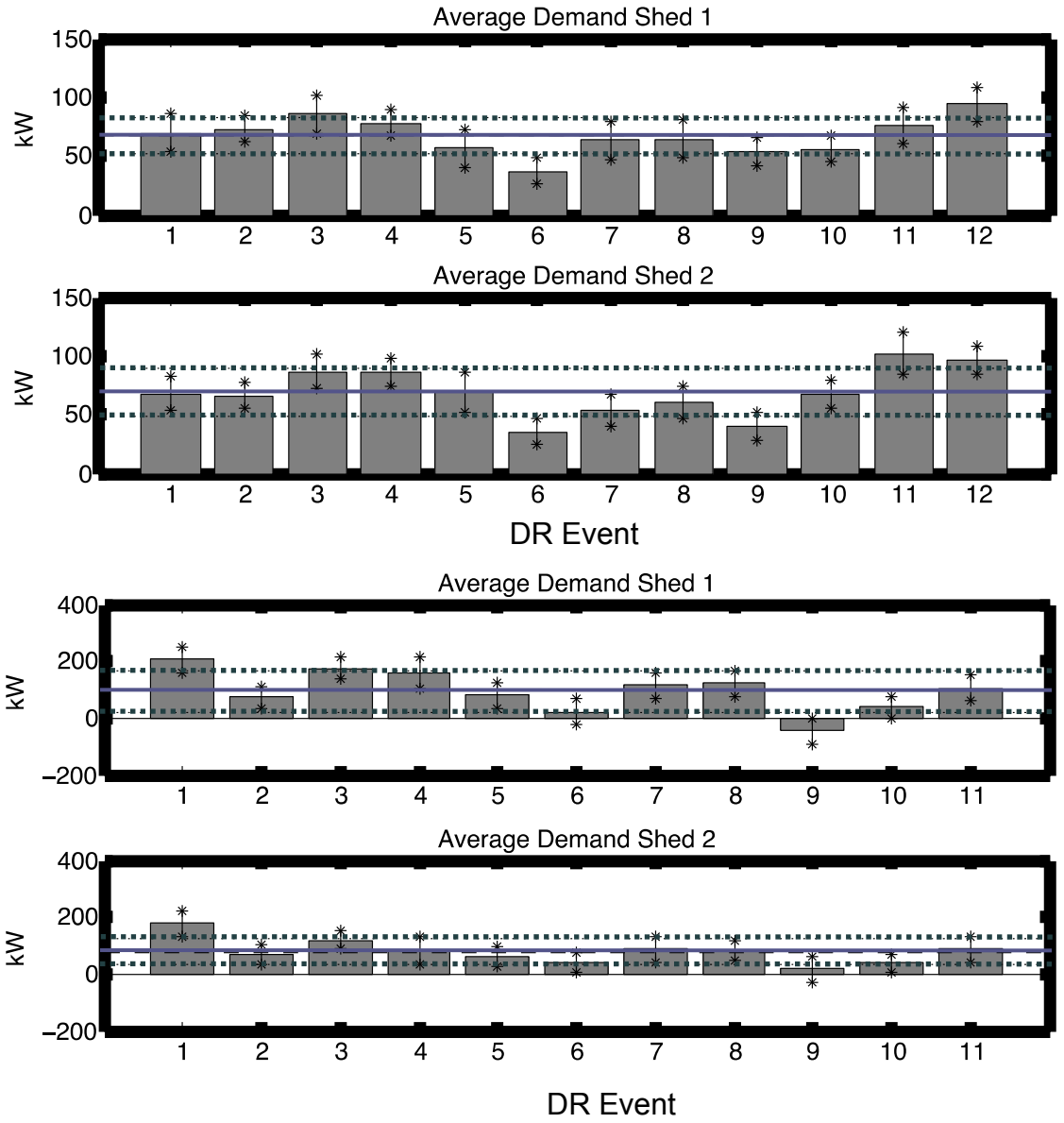
Others we identified in the paper:
- Daily Peak Demand
- Rebound
- Daily Energy



Errors on DR Sheds

$Y=\alpha x+\beta+\varepsilon$

- Standard practice:
  - use the standard error on the regression coefficients, α and β
    (e.g., Fels 1986, Braithwait et al. 2010, Kissock and Eger 2008)
    BUT… *the standard errors underestimate the true error due to autocorrelation and heteroscedasticity of the regression residuals.*
  - Compute the standard deviation of the regression residuals, ε
    (e.g., Piette et al. 2007)
    BUT… *the regression residuals are self-influenced.*
- We use 'Leave One Out Cross Validation' (LOOCV).



County Bldg 2009

Retail Store 2008

Error bars (1 Std Dev)

Mean of all events

Std Dev (1) of all events

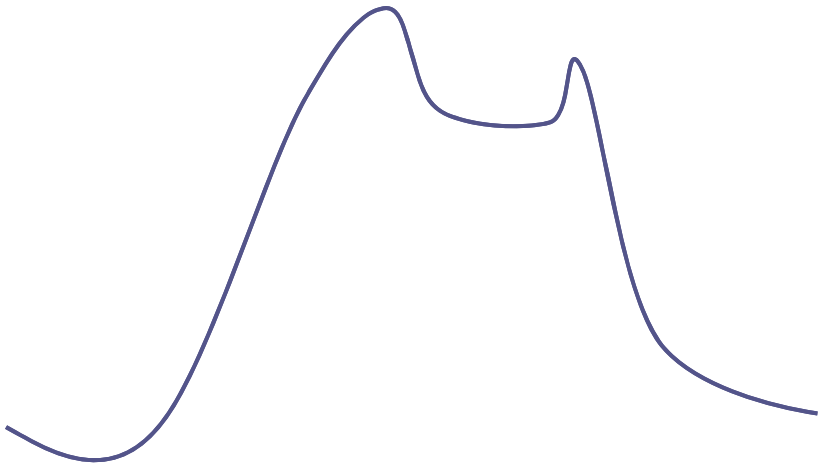
Shed Variability Metric (SVM) Derivation

What is the variance of the real shed, Var(RS)?

Shed Variability Metric (SVM) Derivation

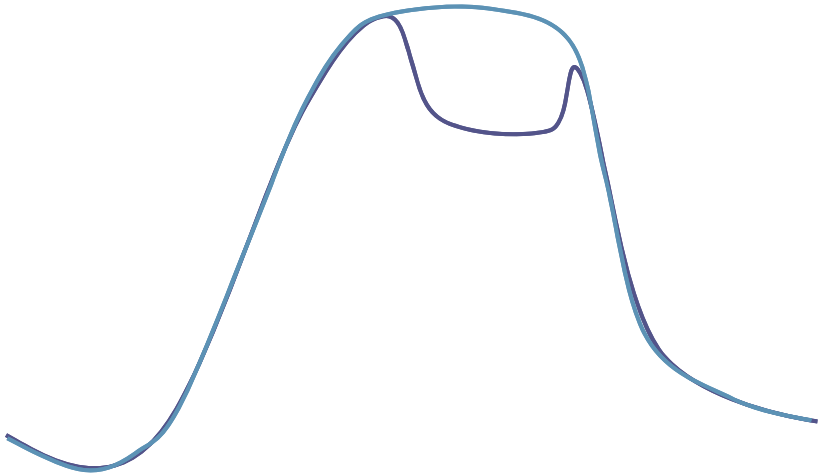
What is the variance of the real shed, Var(RS)?

Observed Load (OL)



Shed Variability Metric (SVM) Derivation

What is the variance of the real shed, Var(RS)?

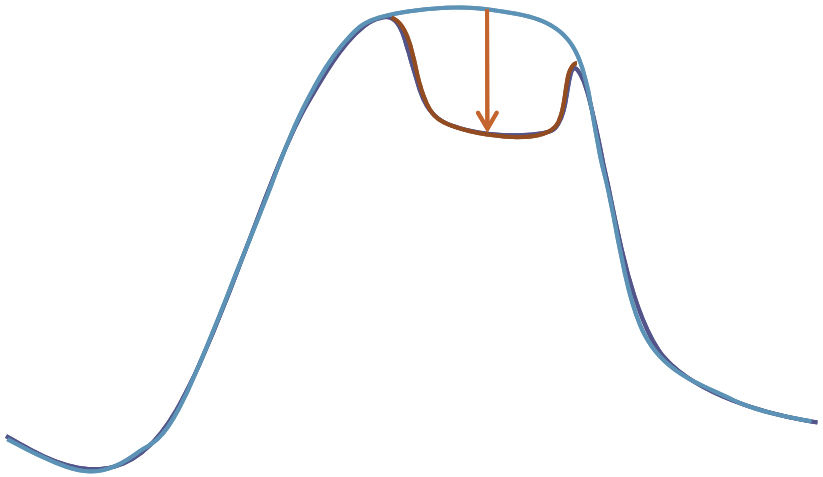


Observed Load (OL)

Real Baseline Load (RBL)

Shed Variability Metric (SVM) Derivation

What is the variance of the real shed, Var(RS)?

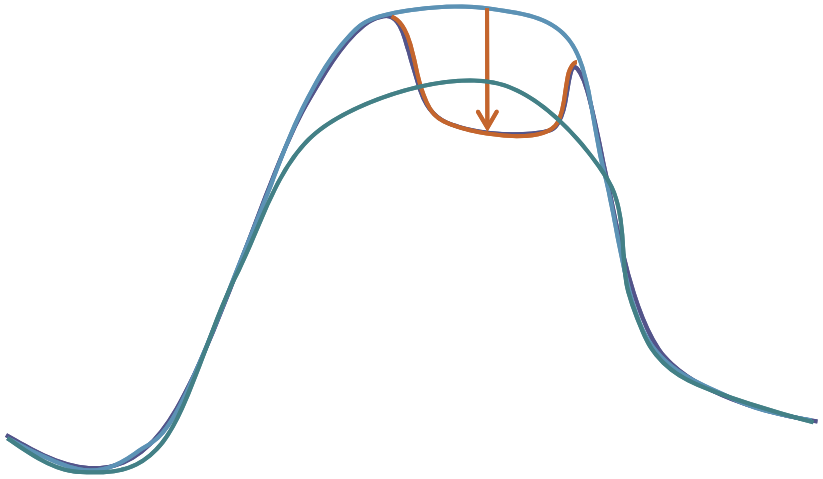


Observed Load (OL)
Real Baseline Load (RBL)
Real Shed (RS)

$$OL = RBL - RS$$

Shed Variability Metric (SVM) Derivation

What is the variance of the real shed, Var(RS)?

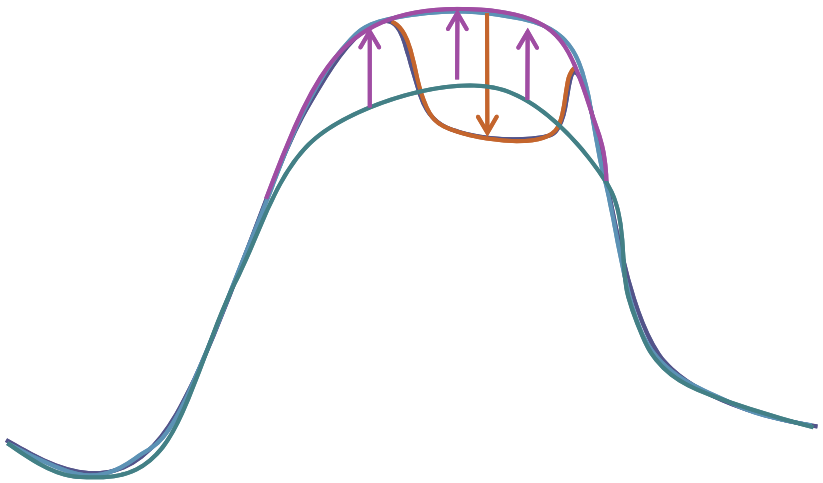


Observed Load (OL)
Real Baseline Load (RBL)
Real Shed (RS)
Predicted Baseline Load (PBL)

$$OL = RBL - RS$$

Shed Variability Metric (SVM) Derivation

What is the variance of the real shed, Var(RS)?

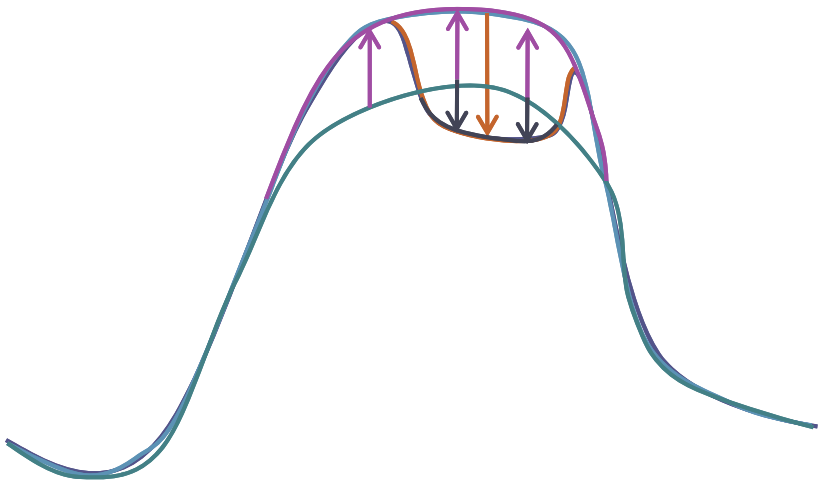


Observed Load (OL)
Real Baseline Load (RBL)
Real Shed (RS)
Predicted Baseline Load (PBL)
Unmodeled Load (UL)

$$OL = RBL - RS \qquad RBL = PBL + UL$$

Shed Variability Metric (SVM) Derivation

What is the variance of the real shed, Var(RS)?



Observed Load (OL)
Real Baseline Load (RBL)
Real Shed (RS)
Predicted Baseline Load (PBL)
Unmodeled Load (UL)
Observed Shed (OS)

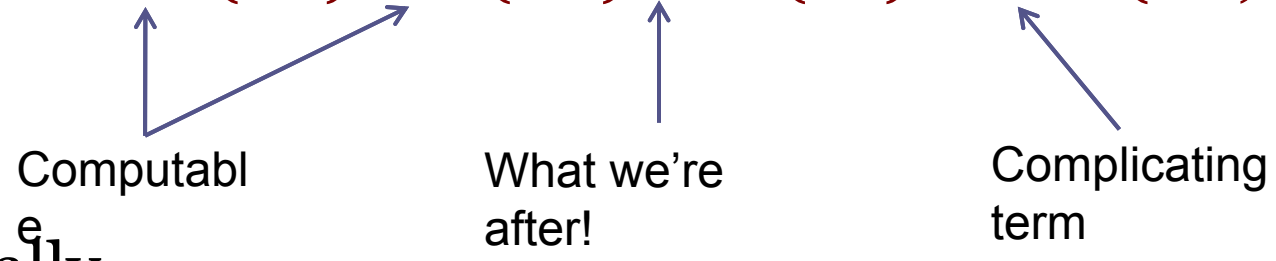
$$OL = RBL - RS \qquad RBL = PBL + UL$$

$$OS = OL - PBL$$

- Rearranging and cancelling terms…
  Observed Shed (*OS*) = Unmodeled Load (*UL*) – Real Shed (*RS*)

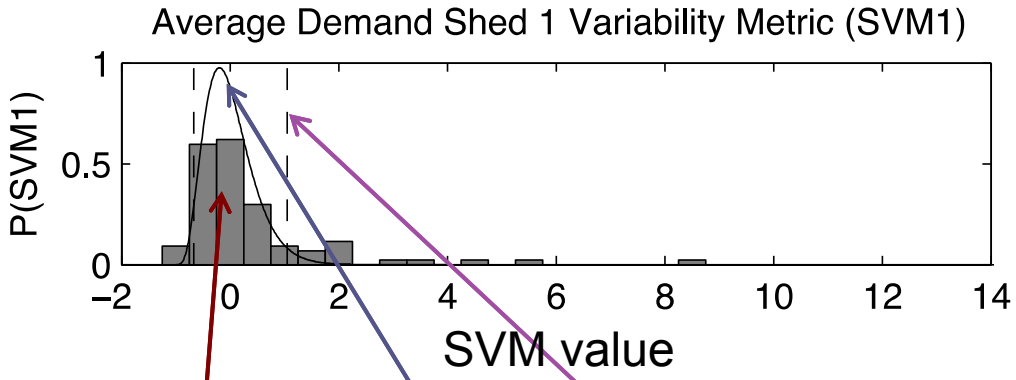
- Taking the variance of both sides…
  $Var(OS)=Var(UL)+Var(RS)-2*Cov(UL,RS)$

- Defining the SVM…
  $SVM:=Var(OS)-Var(UL)=Var(RS)-2*Cov(UL, RS)$



- Finally…
  normalize raw power measurements so that $Var(UL)=1$

SVMs for 87 individual facility-years

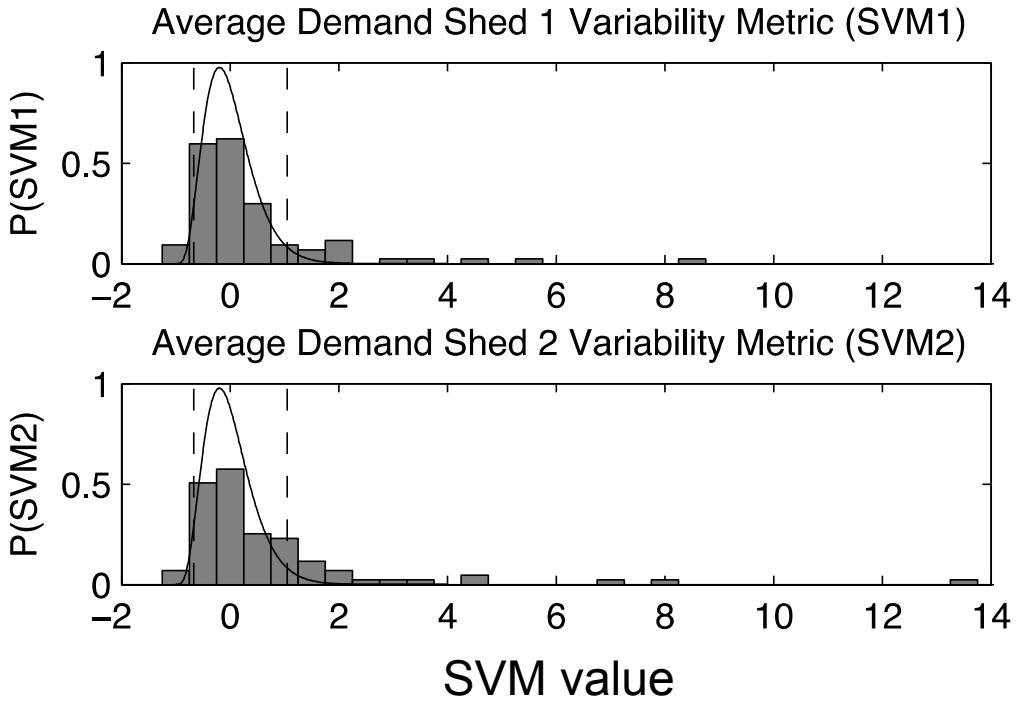


Dashed: 95% confidence interval assuming Var(RS)=0

Solid: χ^2 distribution assuming Var(RS)=0

Histogram: data

SVMs for 87 individual facility-years

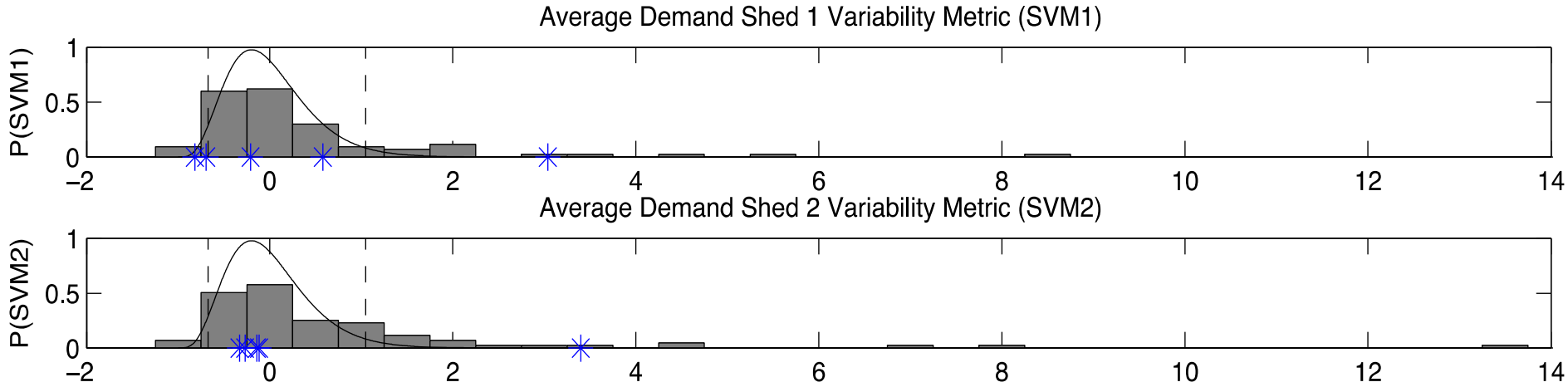


Number (percent) of facility-years with SVMs inside and outside the 95% confidence interval bounds

Metric	Inside Bounds	Outside Bounds
SVM1	65 (75%)	22 (25%)
SVM2	62 (71%)	25 (29%)

Variability Metrics for the Aggregate Populations

* aggregate system results



Bold values indicated p-values ≤ 0.05

Year	Facilities (Peak[a])	Shed 1		Shed 2	
		SVM1	p-value	SVM2	p-value
2006 (Zone 1)	4 (2.7 MW)	**-0.819**	**(0.01)**	-0.269	(0.67)
2006 (Zone 2)	8 (8.4 MW)	**3.039**	**(<0.01)**	**3.399**	**(<0.01)**
2007	13 (11.7 MW)	0.579	(0.21)	-0.117	(0.90)
2008	21 (14.6 MW)	-0.210	(0.72)	-0.142	(0.86)
2009	32 (26.9 MW)	**-0.696**	**(0.03)**	-0.331	(0.46)

Findings

- DR parameter results reported without uncertainty estimates can be misleading.
- Observed variability is driven, in large part, by model error.
- Some facilities exhibit real variability.
- In some cases, the aggregate population exhibits real variability, resulting in implications for the system operator with respect to resource planning and system frequency.

Extended and Future Work

- Implementation of the same methodology to SDG&E and SCE's AutoDR program participants – more and diverse data sets
- Better models
  - Reg-SARIMA-X + 4 others

Thank you!

Sila Kiliccote
skiliccote@lbl.gov
http://drrc.lbl.gov