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Photo from Tom Hall, NREL/PIX 06588

Solar Ramping Distributions over Multiple Timescales and Weather Patterns

Photo by Warren Gretz, NREL/PIX 10926

1st International Workshop on the Integration of Solar Power into Power Systems
October 24, 2011

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NREL/PR-5500-53409

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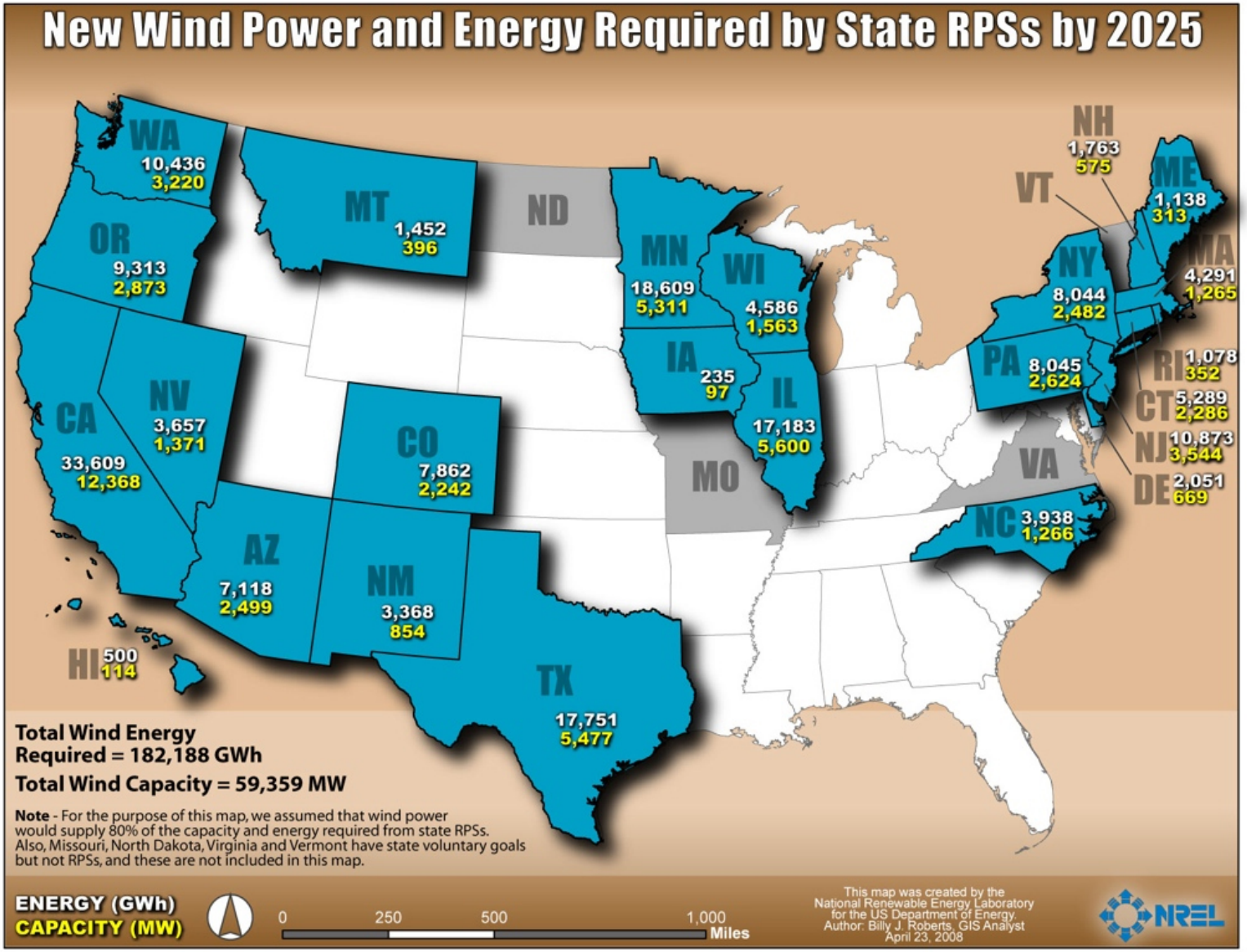
Topics

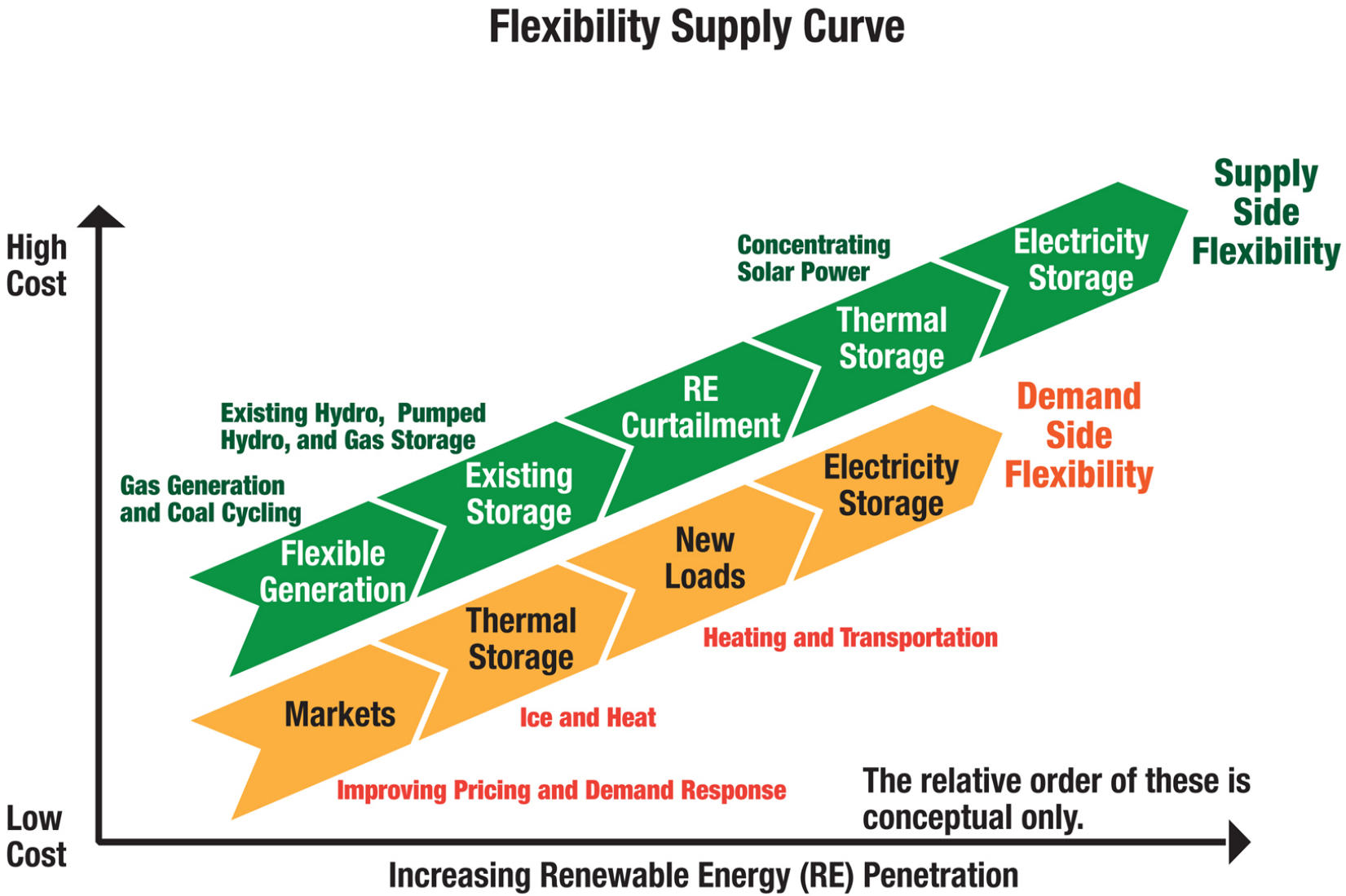
- Introduction
- Statistical Background
- Datasets Utilized
- Ramp Distributions by Timescale
- Ramp Distributions by Weather Pattern
- Conclusions

Photo from Native Energy, Inc., NREL/PIX 17593

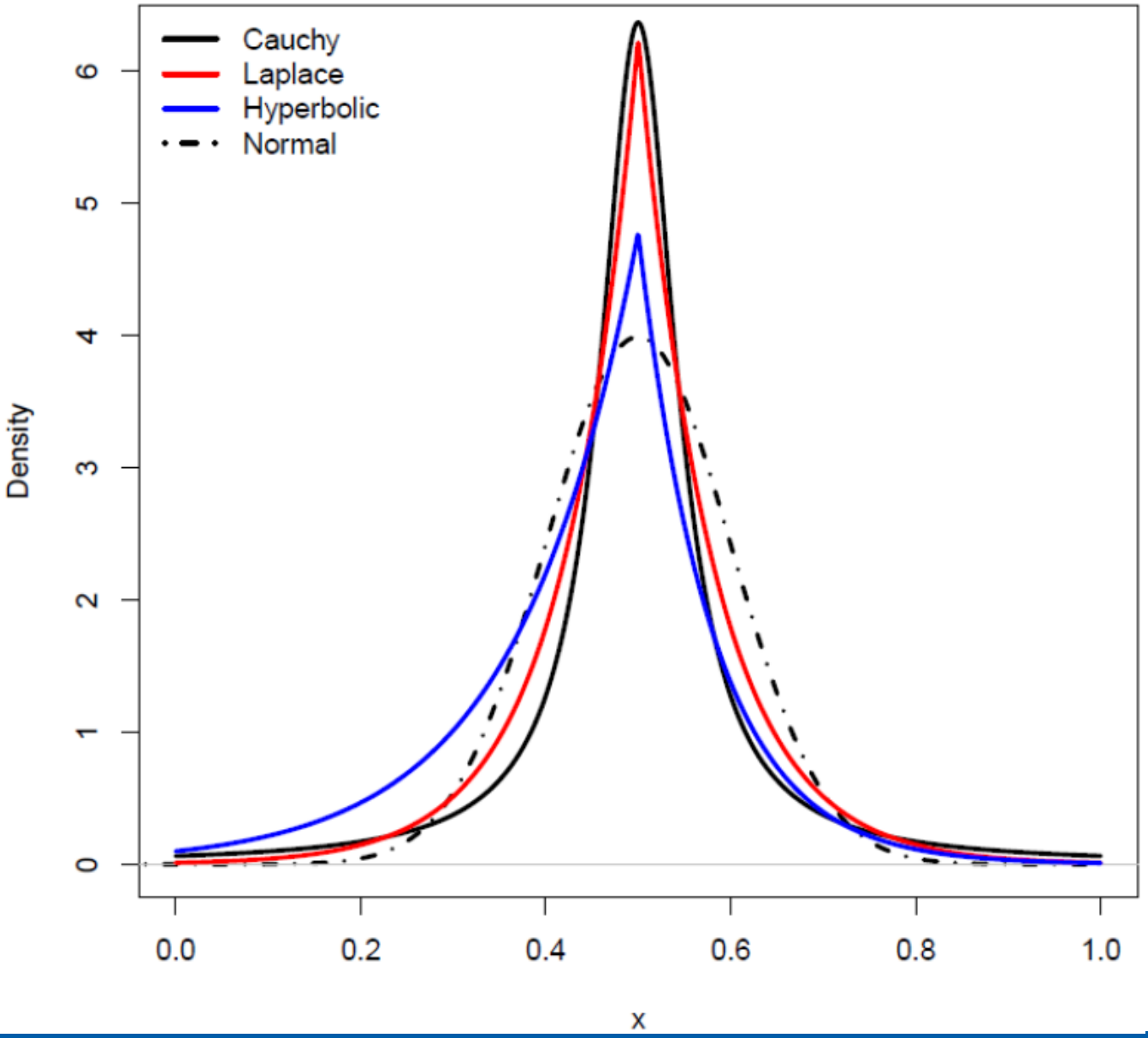
Renewable Energy Portfolio Standards



Renewable Generation Integration Background



Statistical Background



- Skewness – 3rd Statistical Moment

$$\gamma = E\left[\left(\frac{X-\mu}{\sigma}\right)^3\right]$$

- Kurtosis – 4th Statistical Moment

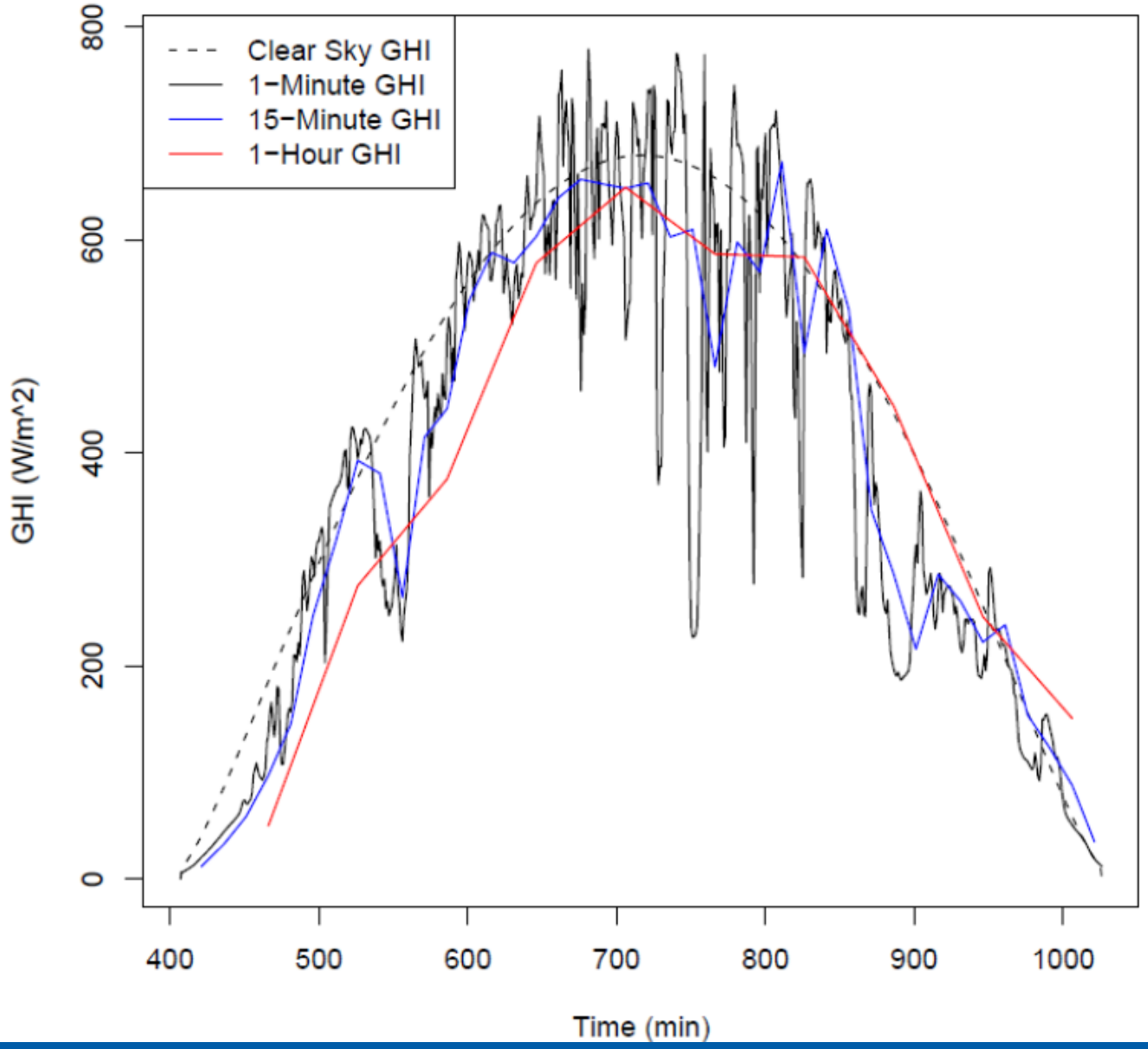
$$\kappa = \frac{E(\varepsilon^4)}{\sigma^4}$$

Datasets Utilized

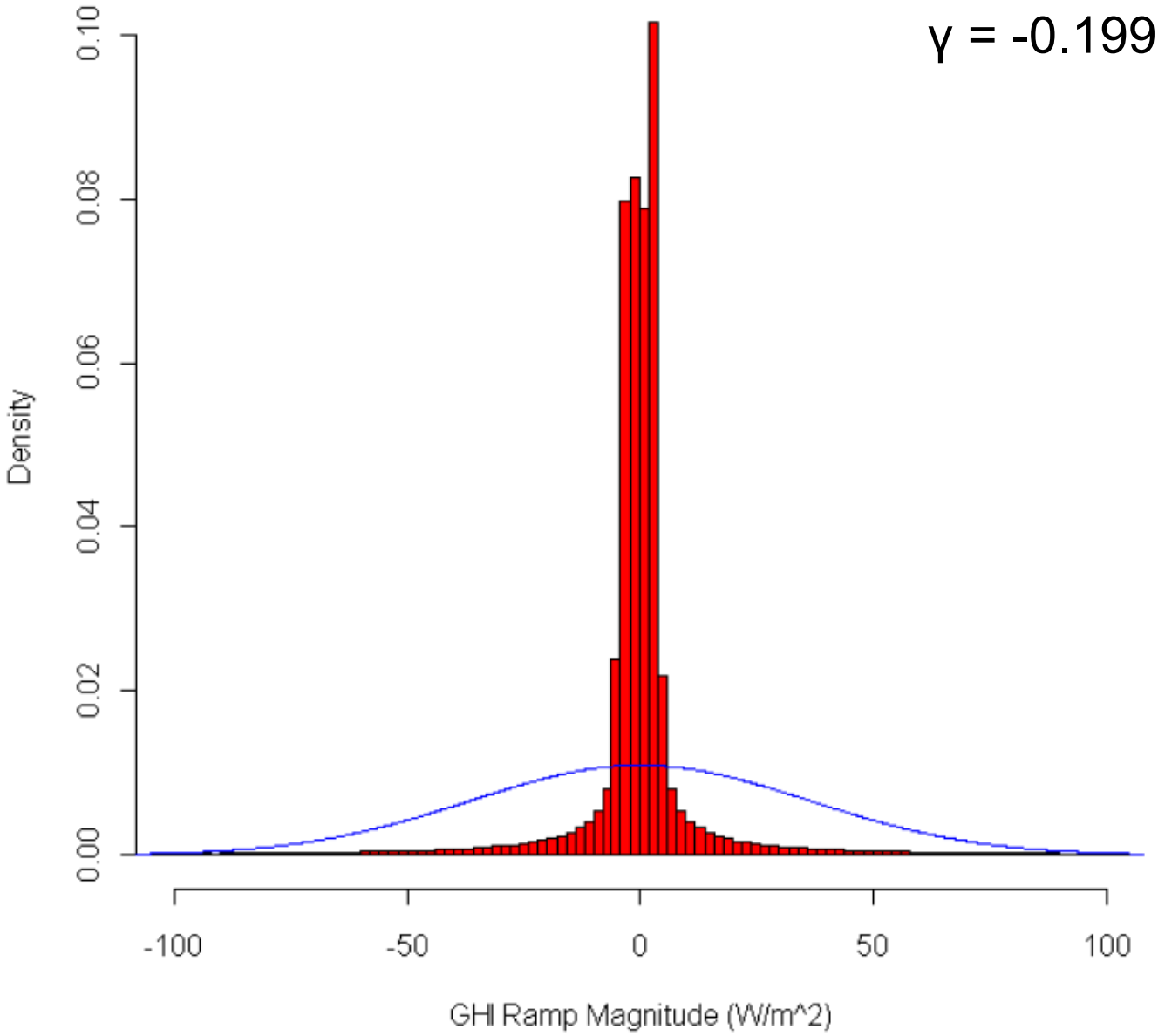
- 26 Datasets – one minute data for one year
  - 7 different sites throughout the western United States
  - 6 different years

Site	Location	'05	'06	'07	'08	'09	'10
SRRL	Golden, CO	X	X	X	X	X	X
NWTC	Boulder, CO	X	X	X	X	X	X
NPCS	Las Vegas, NV		X	X	X	X	
UNLV	Las Vegas, NV		X	X	X	X	X
HSU	Arcata, CA				X	X	
LMU	Los Angeles, CA					X	X
SSO	Monte Vista, CO					X	

Solar Variability

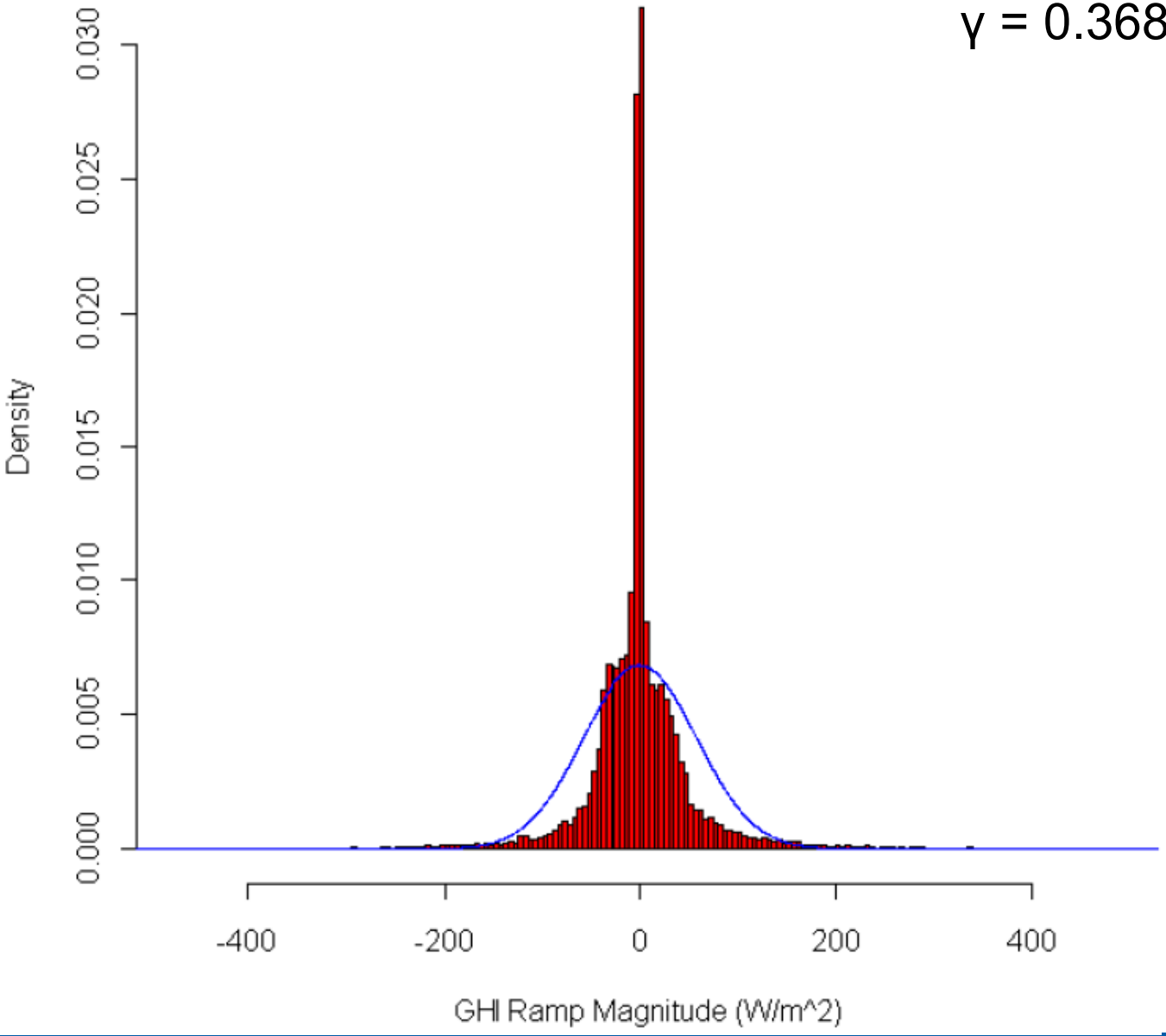


One-Minute GHI Ramps – Site #20

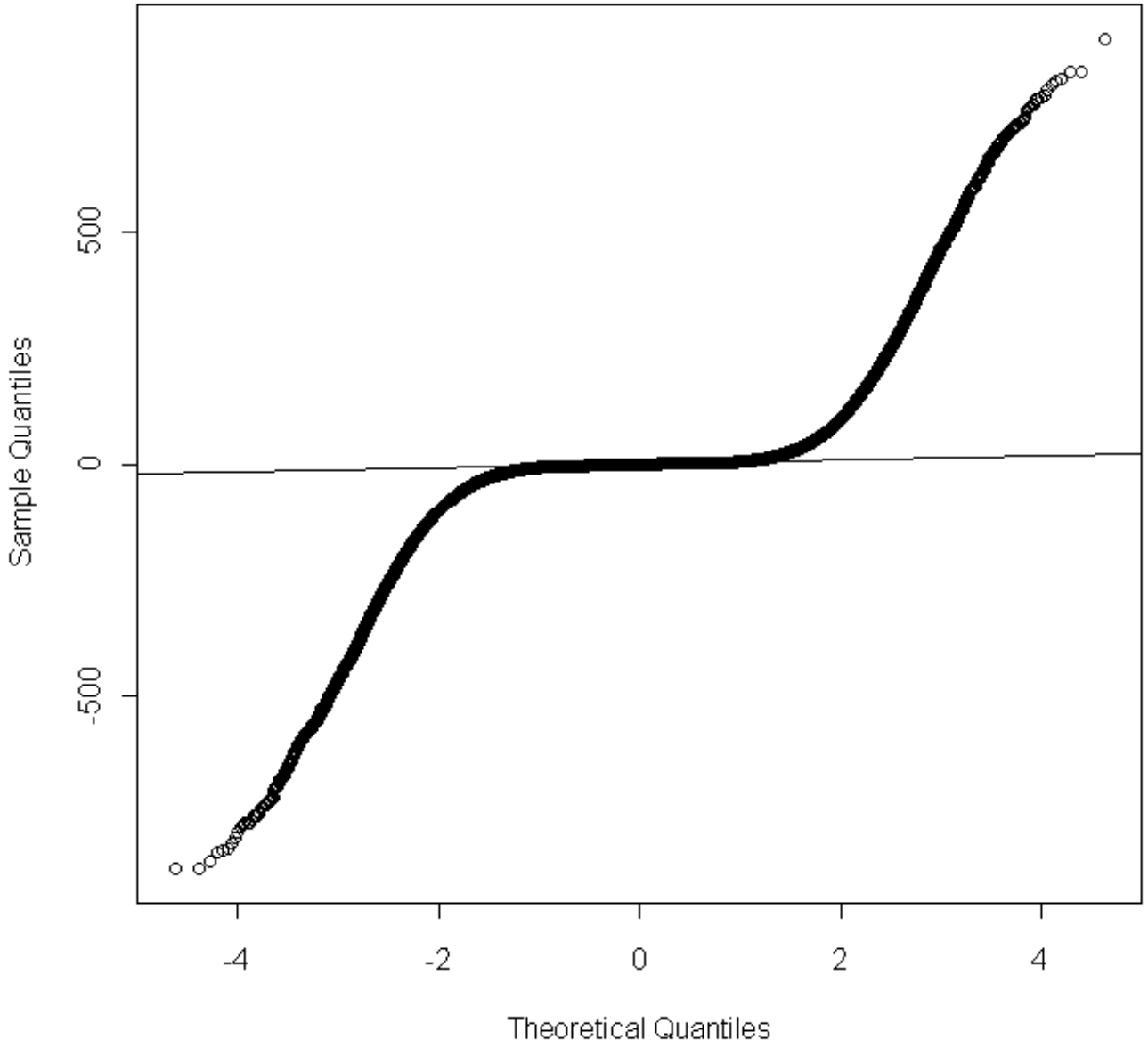


15-Minute GHI Ramps – Site # 19

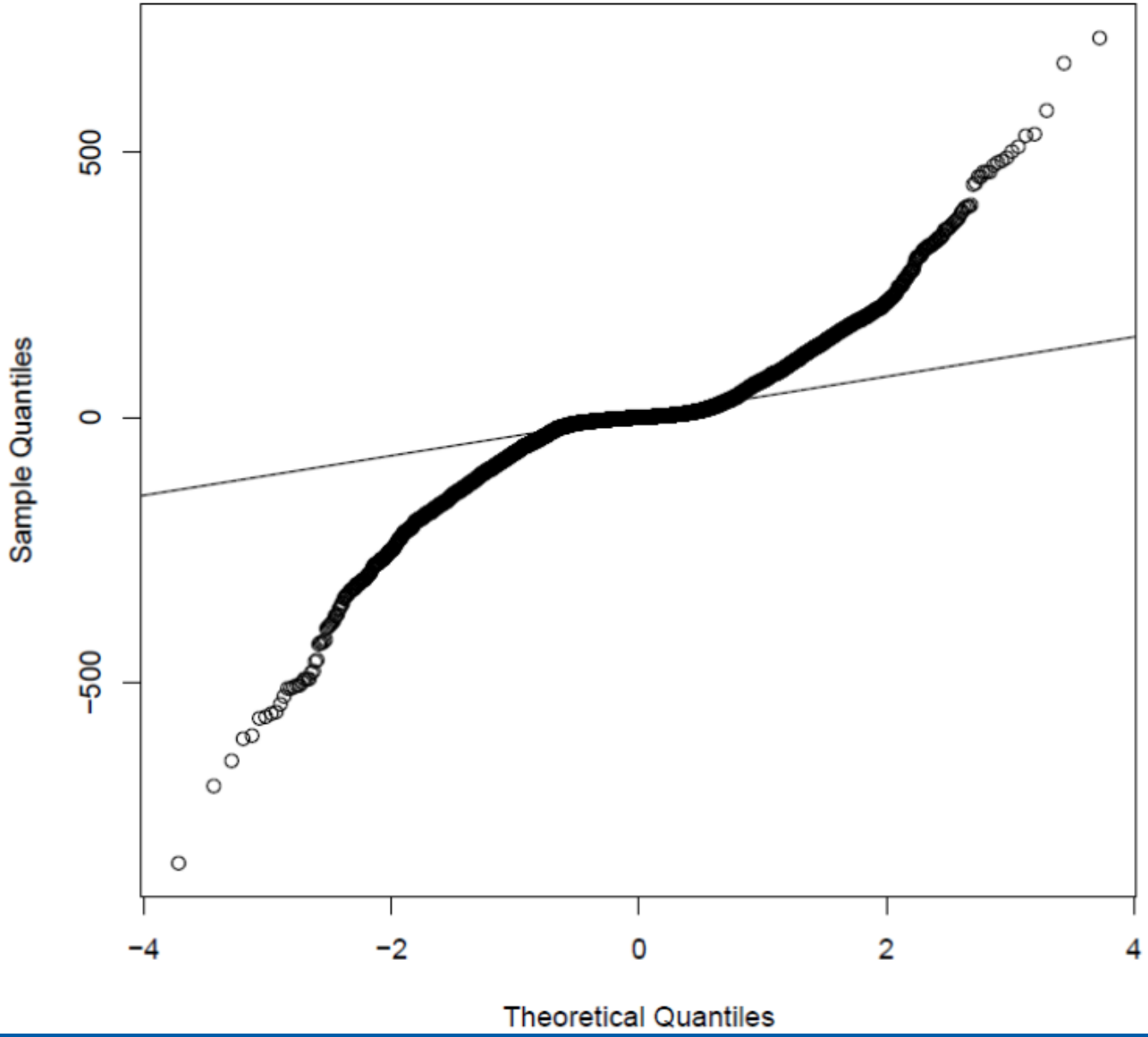
γ = 0.368; κ = 11.42



Normal Q-Q Plot – Site # 5 1-Min Ramps



Normal Q-Q Plot – Site # 23 60-Min Ramps



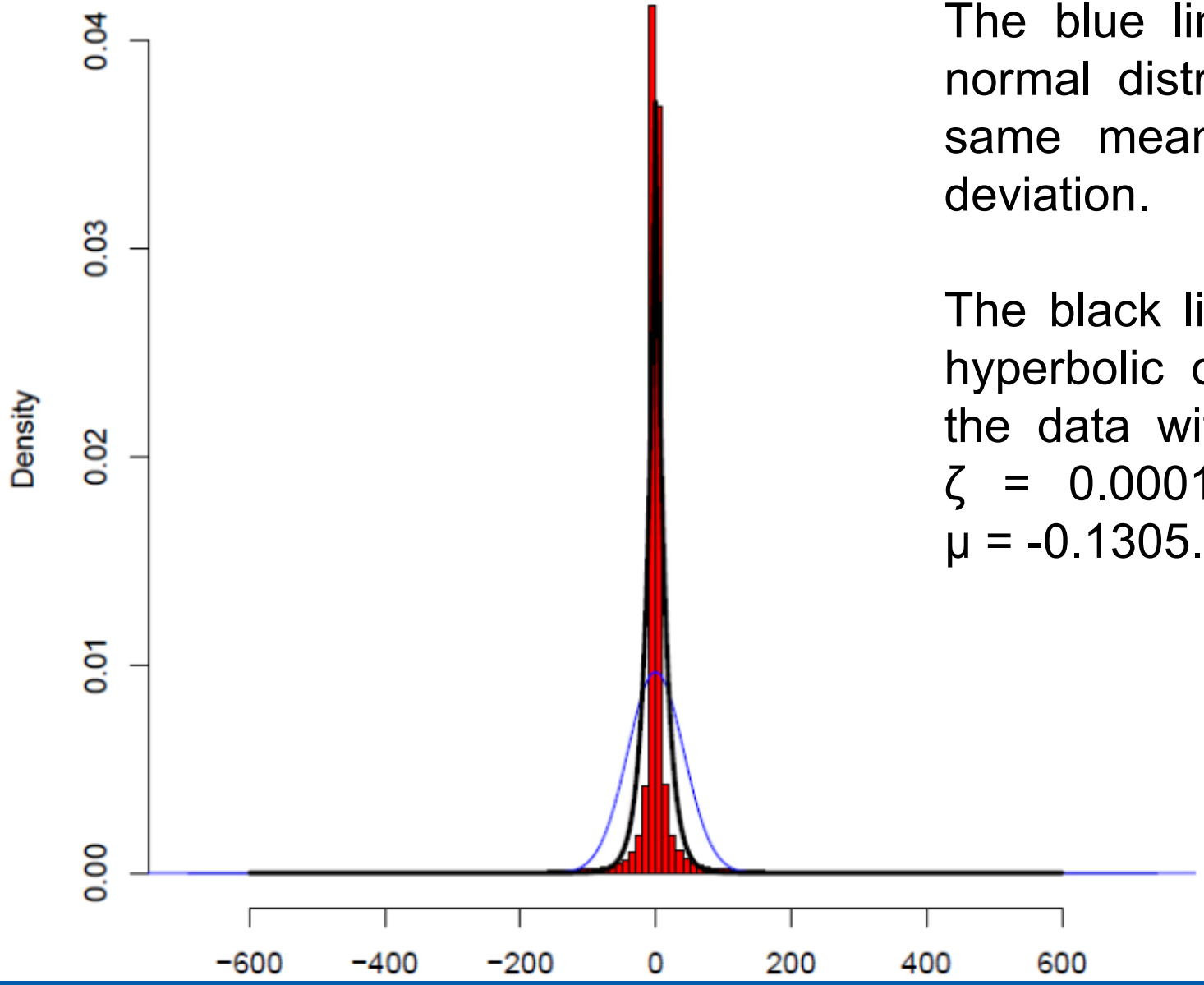
Skewness Values – Multiple Timescales

Site	1-Min	5-Min	15-Min	30-Min	60-Min
1	-0.064	-0.228	-0.323	-0.331	-0.234
2	-0.907	-0.150	-0.453	-0.384	-0.331
3	-0.328	-0.013	-0.109	-0.251	-0.175
4	-0.166	-0.022	0.143	-0.195	-0.333
5	-0.069	-0.063	-0.262	-0.586	-0.584
6	-1.517	-0.105	-0.264	-0.188	-0.190
7	0.039	0.053	-0.071	0.071	-0.198
8	0.068	-0.188	-0.072	0.097	-0.057
9	-0.158	-0.312	-0.417	-0.712	-0.635
10	-0.394	-0.284	-0.408	-0.513	-0.382
11	-0.098	-0.137	-0.472	-0.523	-0.193
12	0.164	0.305	0.378	0.578	0.451
13	0.001	-0.1117	-0.474	-0.411	-0.379
14	-0.065	-0.261	-0.444	-0.408	-0.262
15	-1.373	-0.299	-0.192	-0.351	-0.643
16	-0.118	-0.145	-0.280	-0.304	-0.316
17	0.050	-0.264	-0.462	-0.624	-0.725
18	-0.161	0.156	0.074	0.330	0.308
19	0.034	-0.035	0.368	0.447	0.427
20	-0.167	-0.180	-0.617	-0.746	-0.859
21	-0.149	-0.118	-0.532	-0.868	-0.948
22	-2.248	-0.073	-0.221	-0.131	-0.172
23	-0.115	-0.145	-0.369	-0.442	-0.345
24	0.231	0.399	0.868	0.311	0.180
25	-0.046	-0.120	0.054	-0.145	0.003
26	-0.004	-0.124	-0.068	-0.270	-0.365

Kurtosis Values – Multiple Timescales

Site	1-Min	5-Min	15-Min	30-Min	60-Min
1	50.11	22.53	13.54	11.02	7.46
2	146.38	22.86	13.46	9.96	6.18
3	101.99	42.56	24.59	13.15	5.30
4	108.44	40.38	24.69	14.64	6.85
5	47.04	21.49	12.89	9.41	7.24
6	246.96	22.27	13.45	9.46	6.73
7	105.14	40.16	26.79	22.58	18.48
8	87.49	39.77	23.19	19.41	17.02
9	51.18	23.87	15.75	15.49	8.96
10	75.88	20.74	13.66	10.12	7.80
11	89.74	43.33	26.89	14.36	9.32
12	51.87	22.82	11.87	7.21	2.48
13	78.95	39.81	24.35	21.64	20.30
14	59.83	26.74	16.12	9.75	3.97
15	217.24	22.53	12.82	9.93	6.50
16	48.77	19.52	12.92	9.47	6.93
17	69.67	30.45	19.88	14.90	12.11
18	94.74	40.28	22.28	13.10	6.77
19	49.33	24.82	11.42	5.85	2.53
20	70.64	30.602	20.41	16.97	13.52
21	50.15	22.50	16.52	14.90	11.72
22	336.15	22.68	13.12	10.11	6.94
23	43.20	20.21	12.50	8.99	7.05
24	60.27	42.91	21.87	4.20	0.22
25	79.89	34.88	21.87	11.75	5.53
26	45.32	21.76	13.36	9.98	6.97

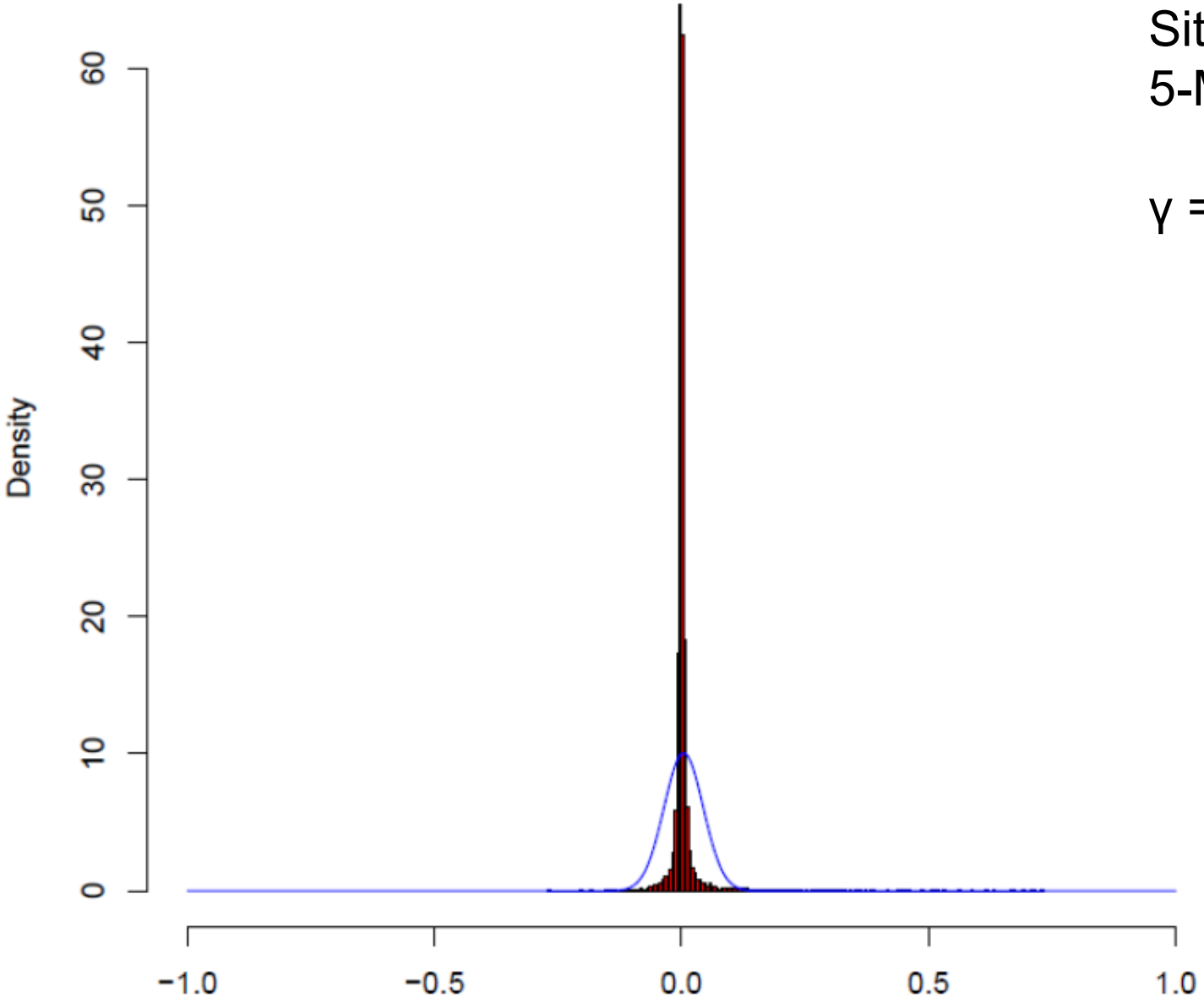
Distribution Fitting – Site #12 1-Minute



The blue line represents a normal distribution with the same mean and standard deviation.

The black line represents a hyperbolic distribution fit to the data with: $\pi = 0.0050$, $\zeta = 0.0001$, $\delta = 0.0015$, $\mu = -0.1305$.

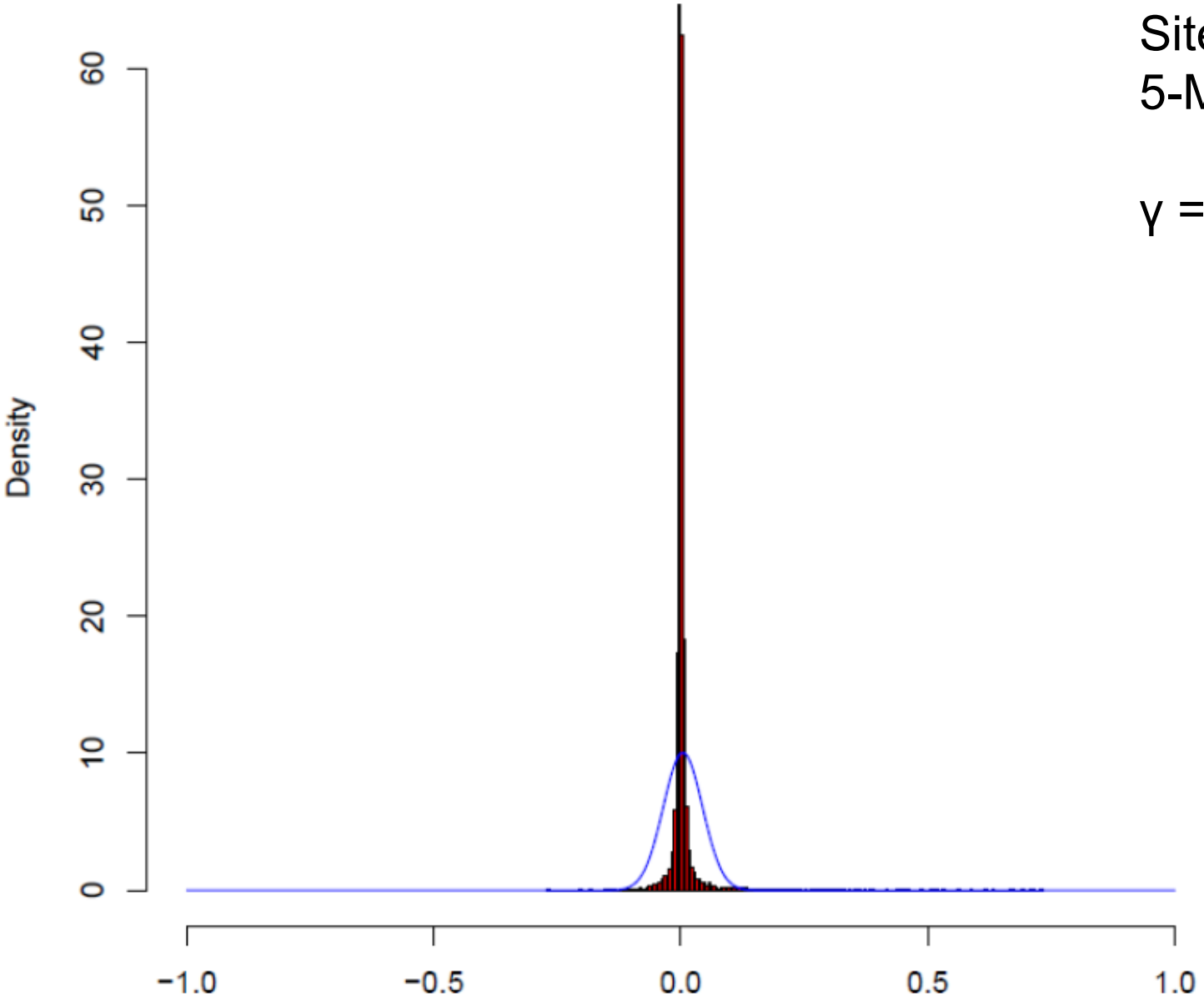
Distributions by Weather Patterns – Clear Sky



Site # 26
5-Minute GHI ramps

$\gamma = 9.17$; $\kappa = 119.89$

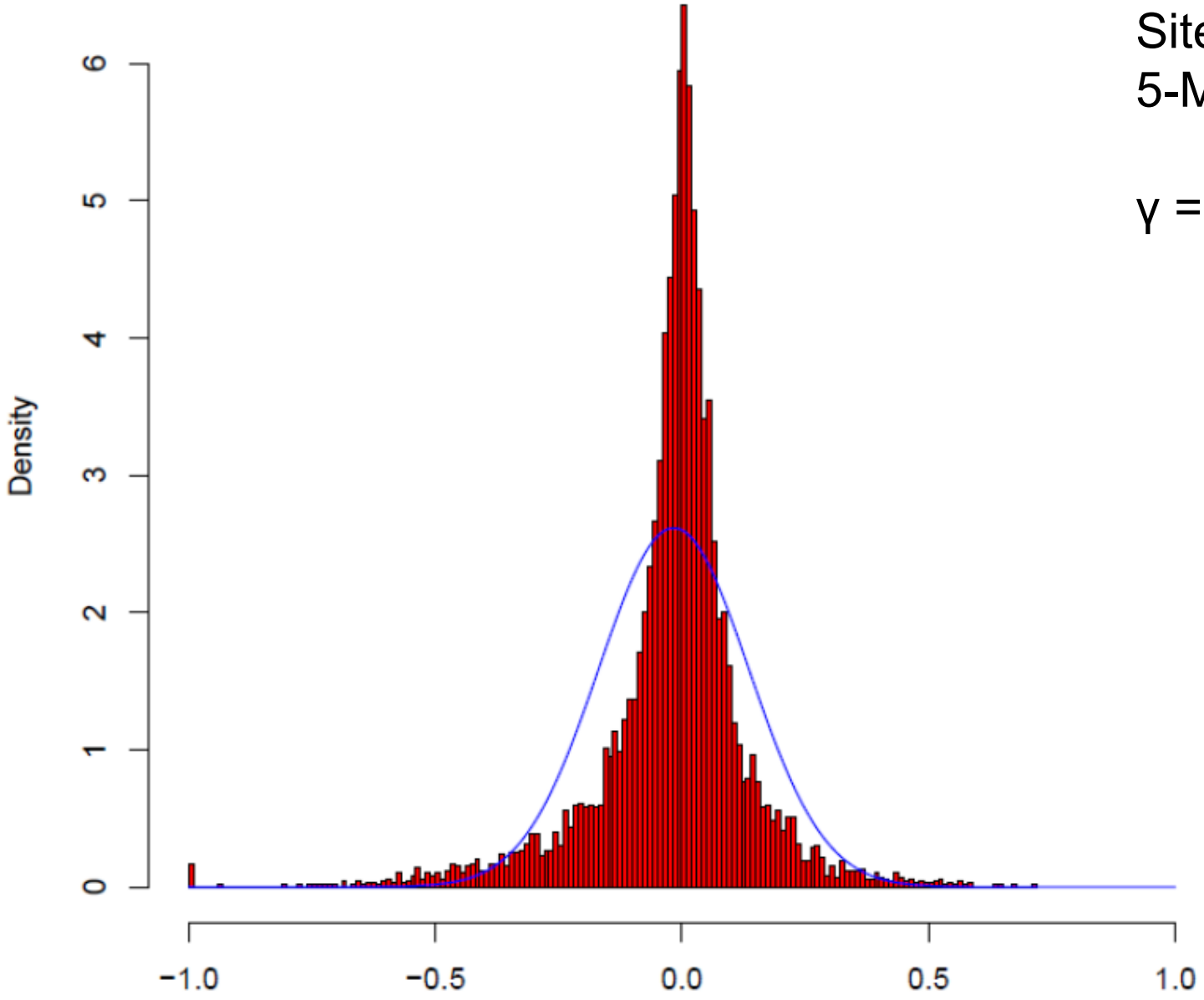
Overcast Conditions



Site # 26
5-Minute GHI ramps

γ = -5.74; κ = 36.64

Intermittent Cloud Activity



Site # 26
5-Minute GHI ramps

$\gamma = -1.05$; $\kappa = 5.99$

Acknowledgements

- Dr. Debra Lew and Yih-huei Wan– NREL
- U.S. DOE – Solar program

Photo by Warren Gretz, NREL/PIX 11188

Photo by Todd Spink, NREL/PIX 14961

Questions?

Photo by Patrick Corkery, NREL/PIX 17731

Photo from Iberdrola Renewables, NREL/PIX 16105