National Renewable Energy Laboratory
Innovation for Our Energy Future

Comparison of PV and Wind Variability

Utility-Scale PV Variability Shop

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Presentation Outline

- Inroduction
- Data Sources
- Average Profiles of PV and Wind Power
- Ramping Statistics on Different Time Scales
- Comparison of PV and Wind Ramp Distribution
- Correlation among Plants
- Summary

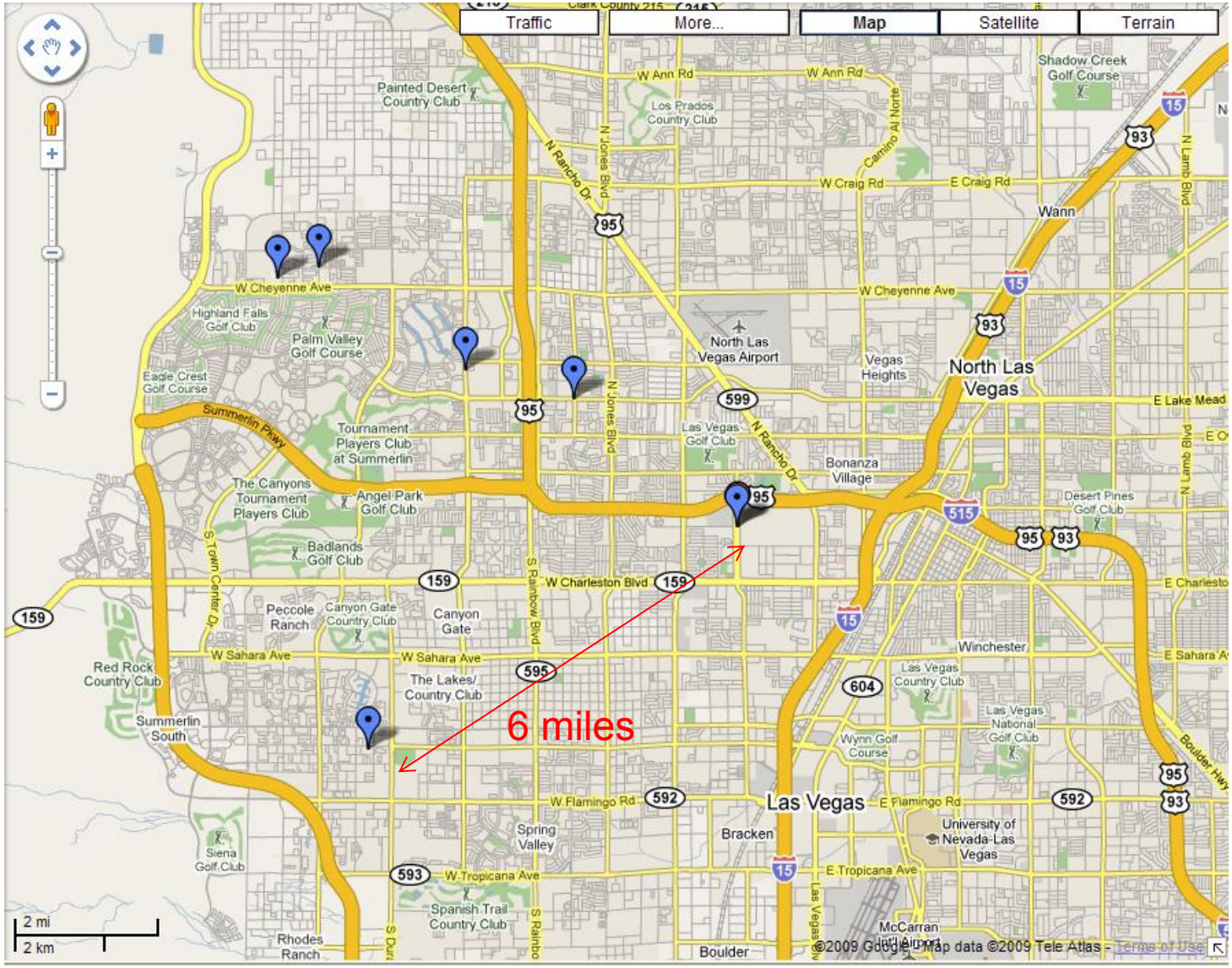
Introduction

- Both PV and wind power are variable in nature
- The outline of PV production is well-known because the position of sun is fixed at any given time
- Outputs from PV facilities within the same time zone could be highly correlated
- Although wind can change quickly, its short-time frame (1-second and 1-minute) changes are limited. Coupled with turbine inertial, the short-time frame wind power changes are small and not totally random.
- There is no inertial in PV panel and the associated inverter.

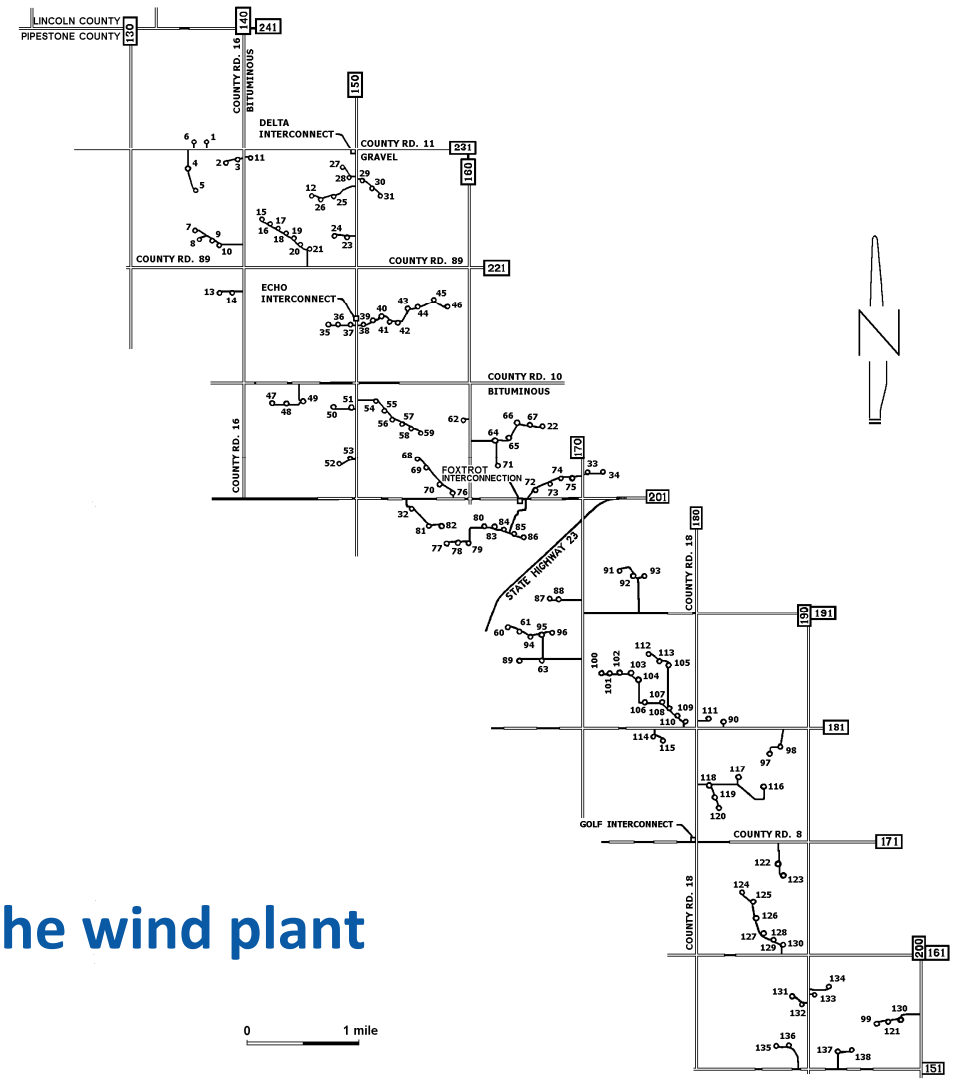
Data Sources

- PV Data – 1-minute PV output data from 6 LVWD facilities (2007 through April 2009)
    1. Ronzone (675 kW, single-axis tracking)
    2. Ft Apache (325 kW, single-axis tracking)
    3. Gd Canyon (325 kW, single-axis tracking)
    4. Spg Mtn (450 kW, single-axis tracking)
    5. Luce (450 kW, single-axis tracking)
    6. LVSP (450 kW, fixed-tilt)
- Wind Data – 1-minute plant output data from plants in Buffalo Ridge area (Minnesota) during the same period; mostly 750-kW turbines

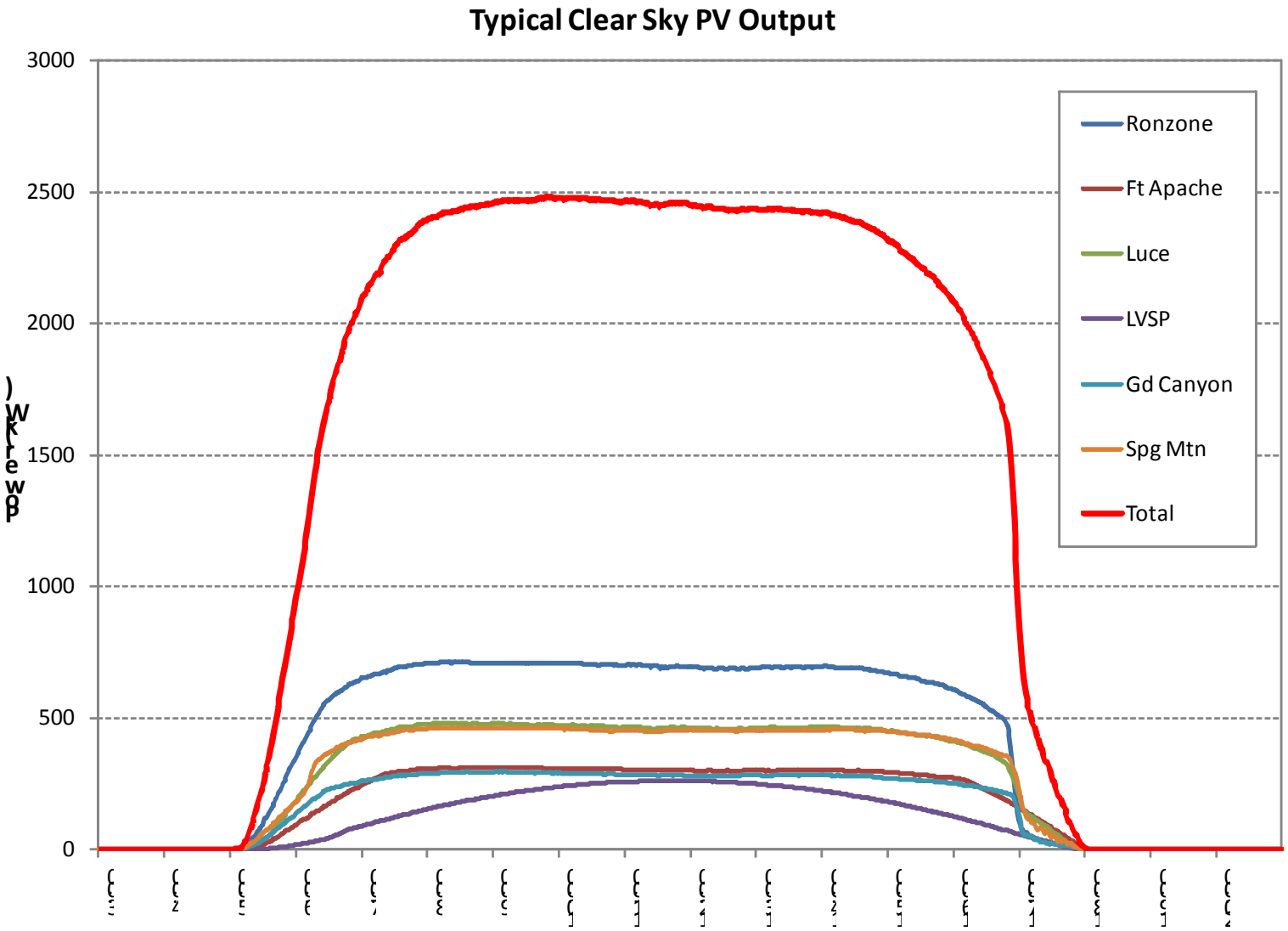
Locations of PV Facilities



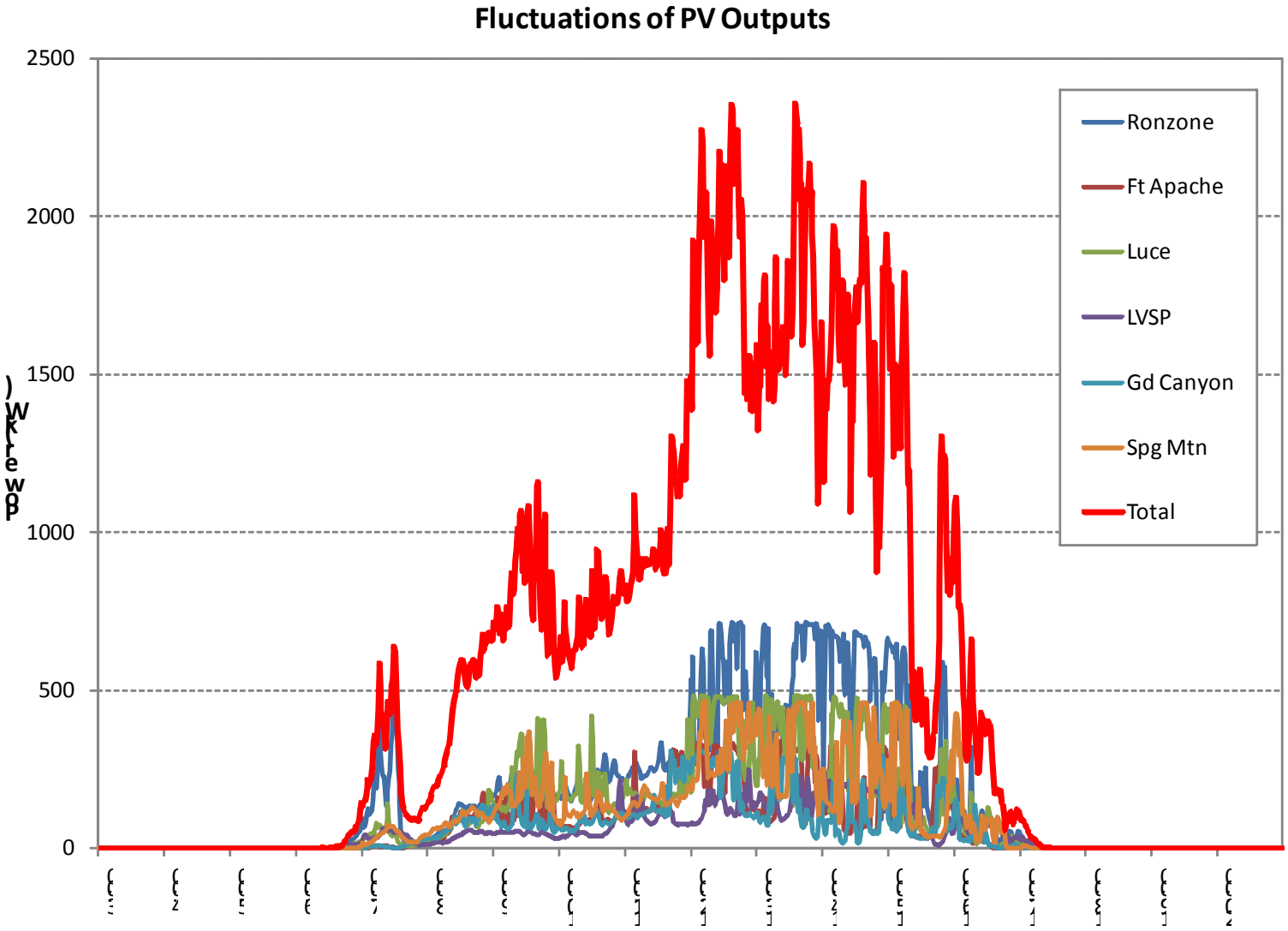
Locations of turbines at the wind plant



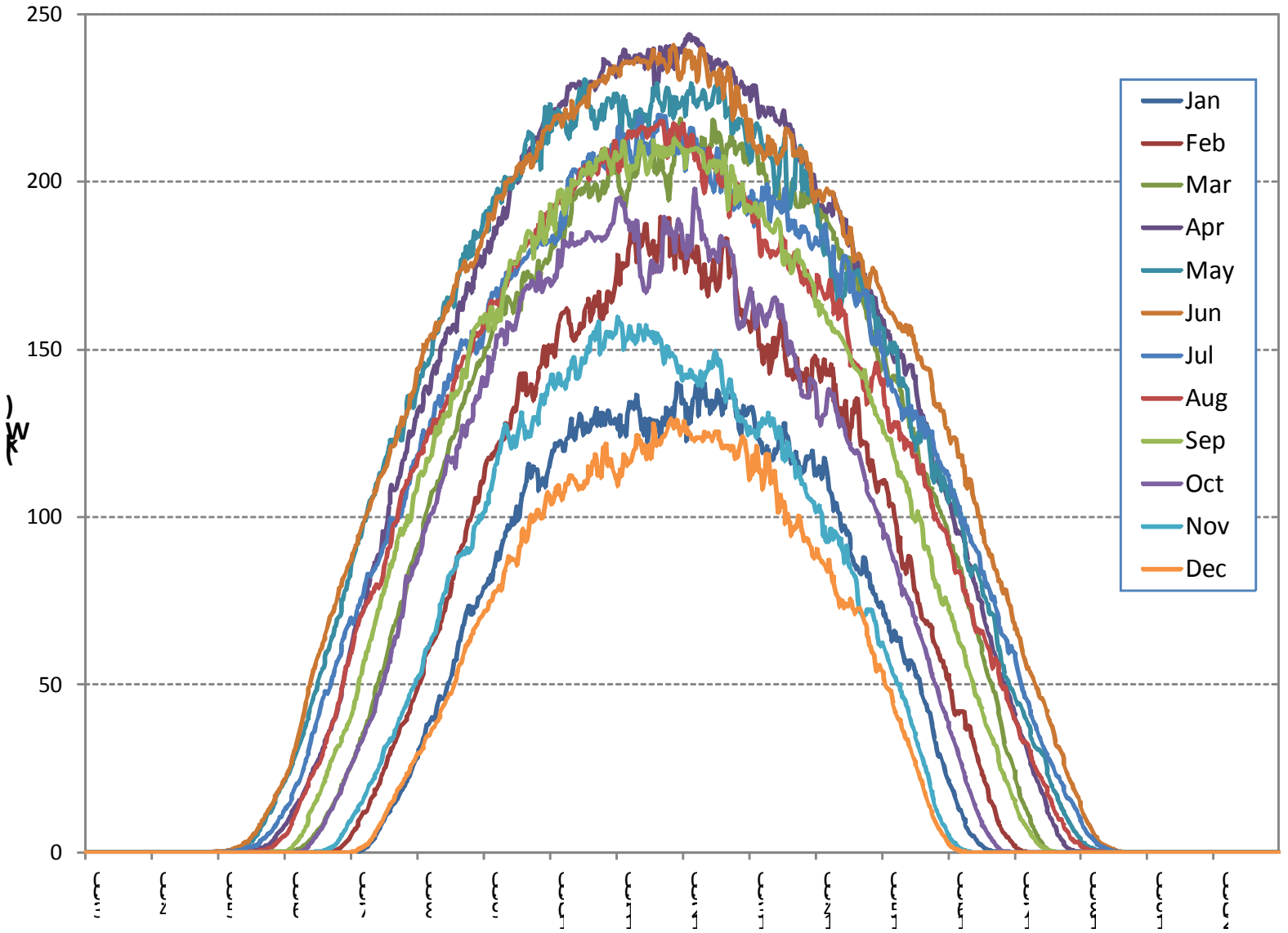
PV Profiles (clear sky)



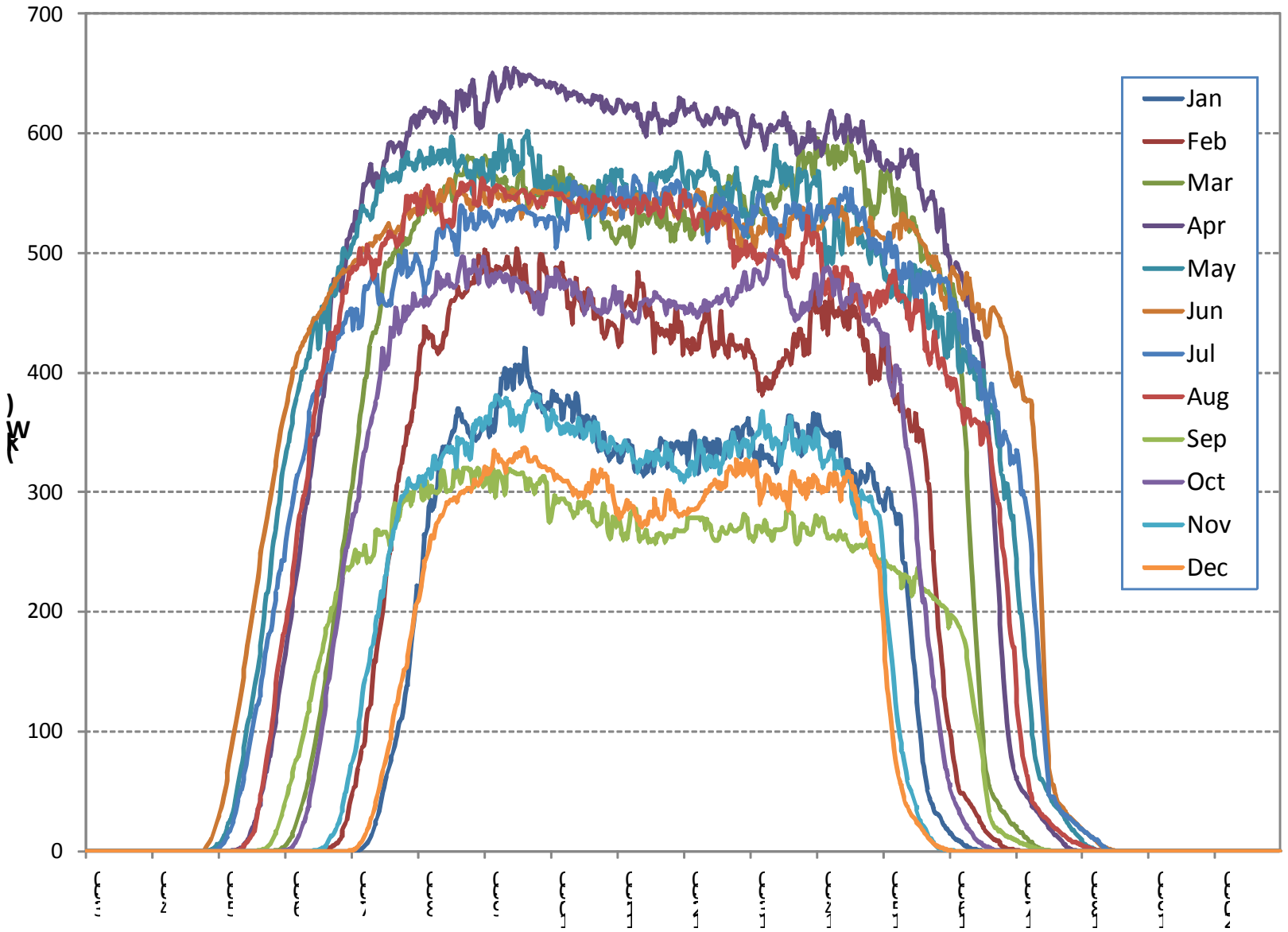
PV Profiles (cloudy day example)



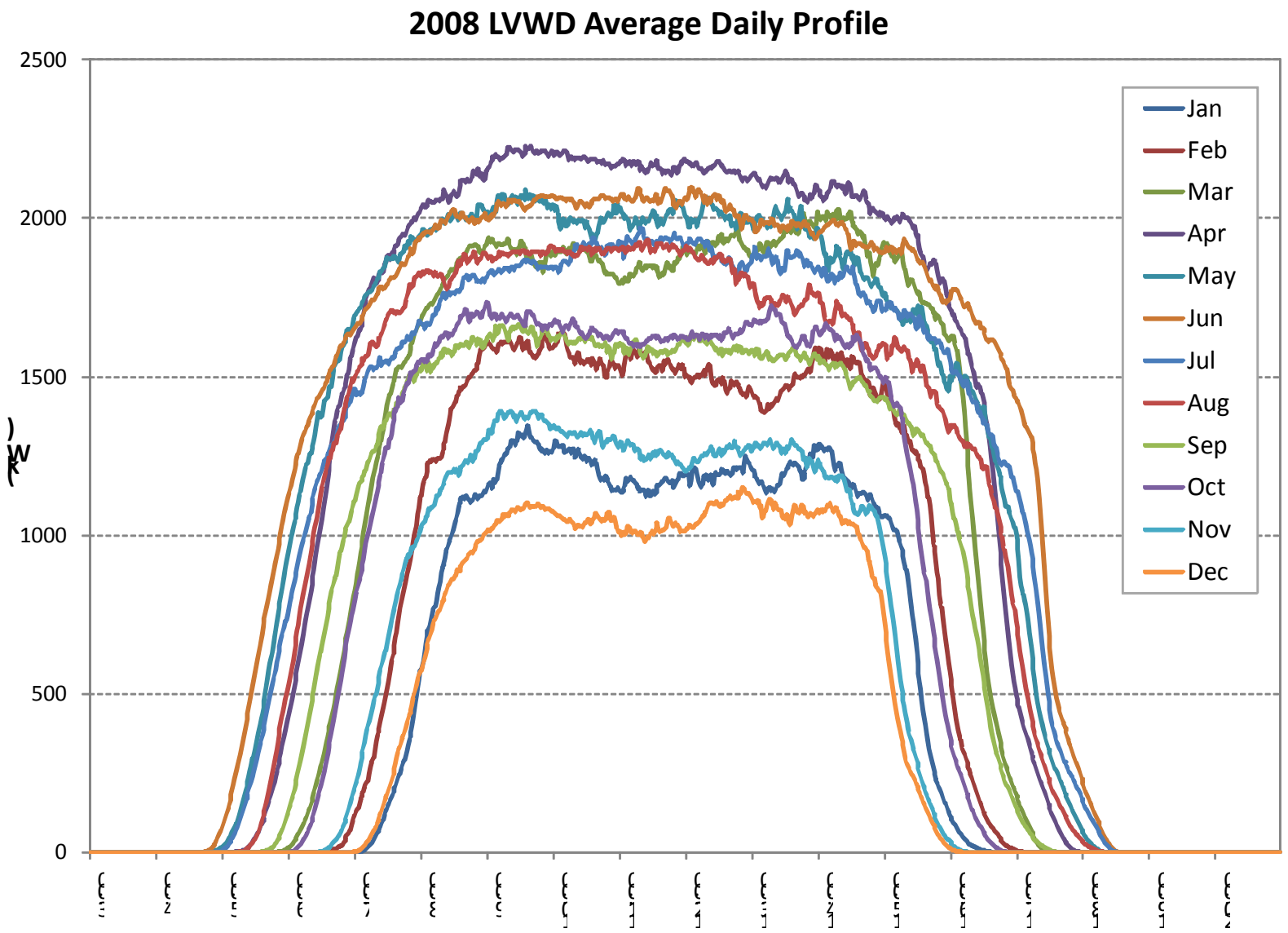
Fixed-tilt PV Monthly Average Profiles



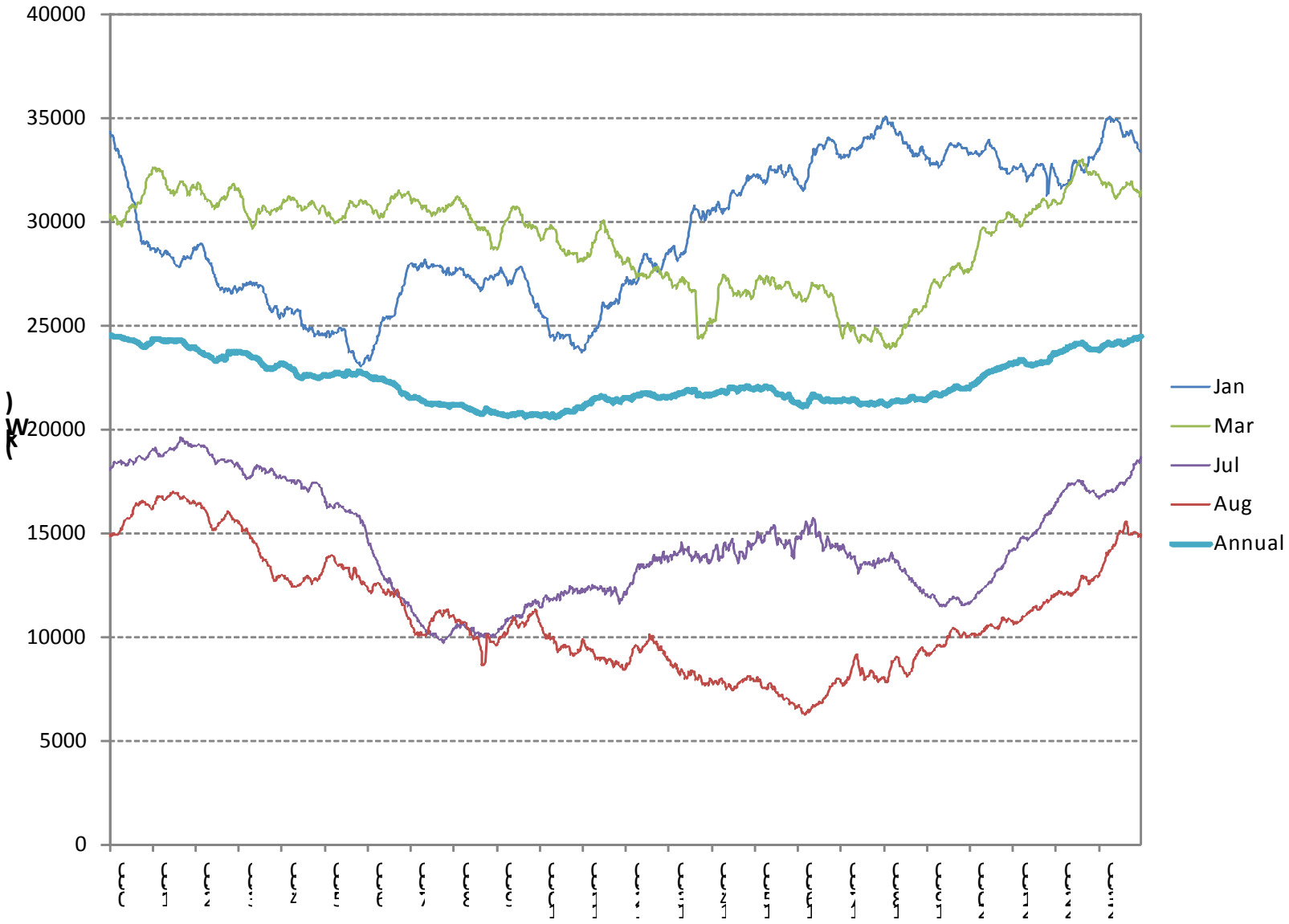
Single-axis Tracking PV Monthly Average Profiles



PV Monthly Average Profiles



Wind Power Monthly Average Profiles



Wind Ramp Statistics

	Delta (22.5 MW)			Golf (41.3 MW)			LB (63.8 MW)			BR (240 MW)		
1-minute												
	Stdev	Max (+)	Max (−)	Stdev	Max (+)	Max (−)	Stdev	Max (+)	Max (−)	Stdev	Max (+)	Max (−)
2007	1.6%	71%	94%	1.2%	75%	92%	1.0%	50%	53%	0.5%	30%	57%
2008	1.5%	73%	86%	1.2%	68%	93%	0.9%	58%	53%	0.5%	20%	79%
2009	1.6%	71%	82%	1.2%	67%	60%	1.0%	54%	81%	0.5%	12%	28%
10-minute												
2007	5.0%	78%	85%	4.3%	88%	90%	3.7%	79%	86%	2.5%	44%	92%
2008	4.5%	87%	90%	4.2%	66%	86%	3.5%	56%	57%	2.4%	39%	82%
2009	4.5%	68%	77%	4.1%	73%	73%	3.4%	63%	63%	2.6%	23%	36%
1-hour												
2007	10.7%	74%	84%	10.1%	85%	68%	9.6%	76%	65%	8.1%	57%	48%
2008	9.8%	76%	65%	9.9%	75%	79%	9.4%	74%	55%	8.0%	51%	56%
2009	9.7%	83%	75%	9.6%	77%	65%	9.3%	75%	69%	8.6%	49%	38%

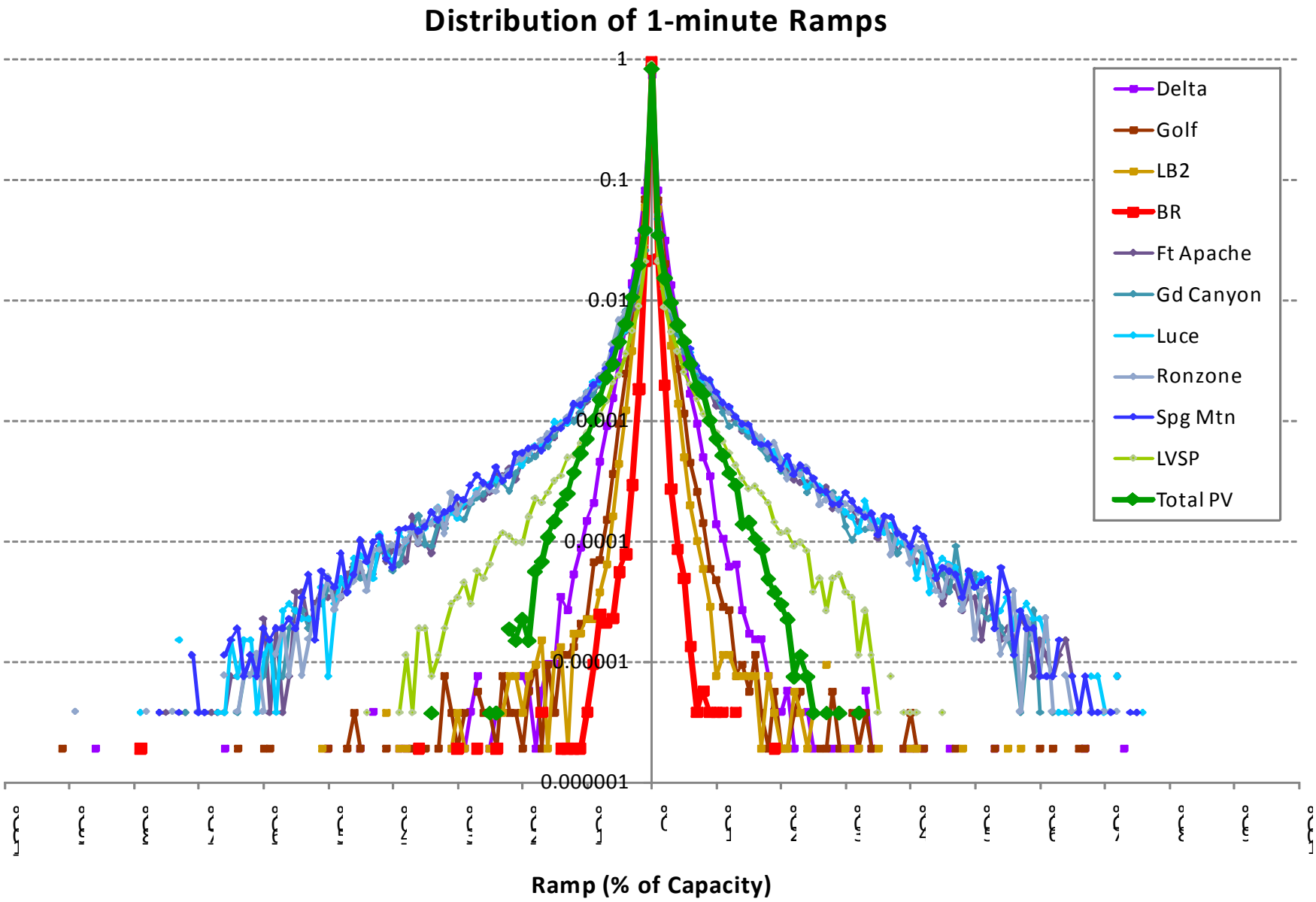
- Outputs from bigger the wind plants (or more turbines) are less variable than smaller plants
- Detailed analysis shows that the severe down ramps in shorter time frame are invariably caused by outages or curtailment; severe up ramps are the results of starting under high wind

PV Ramp Statistics

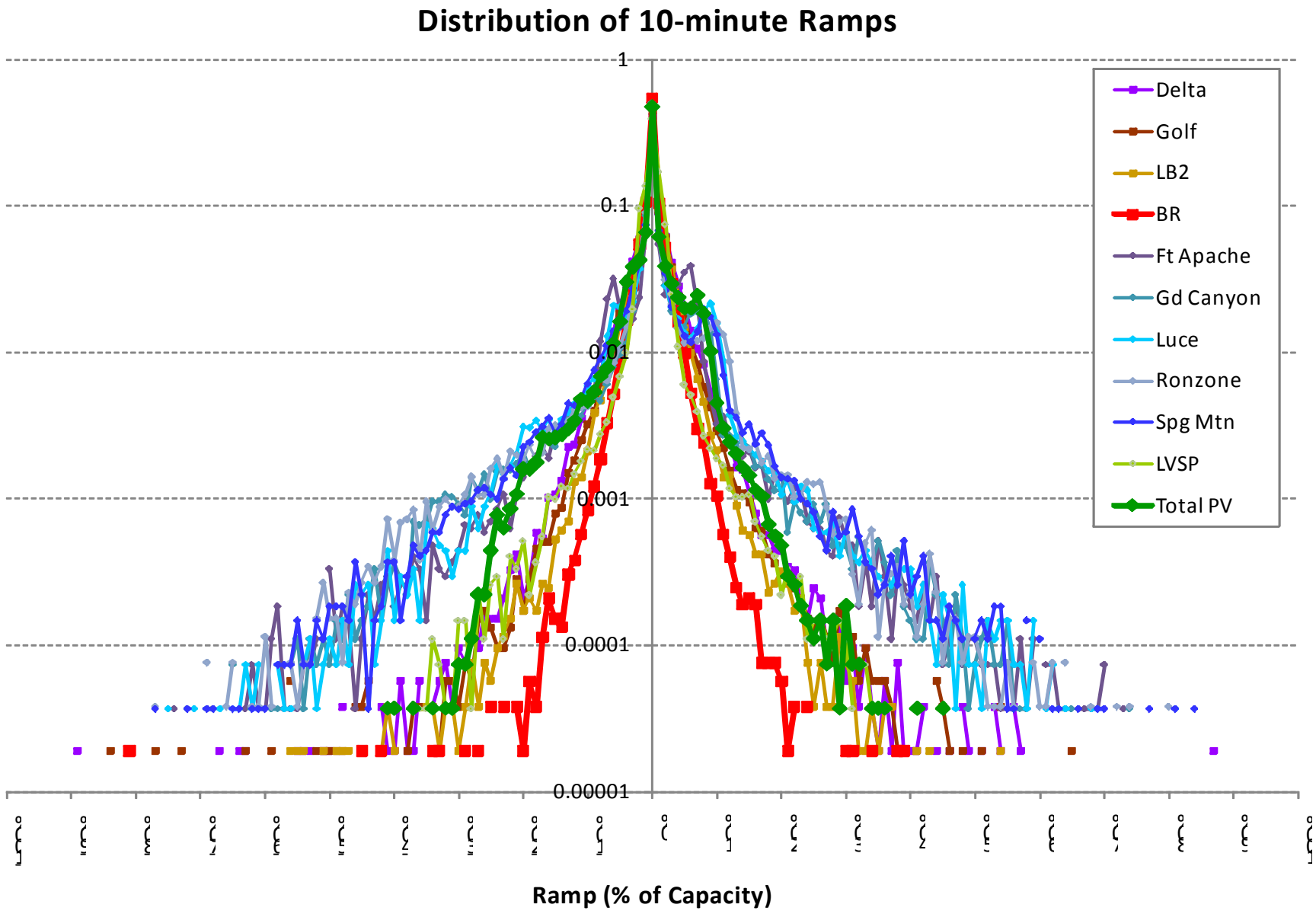
	LVSP (450 kW)			Spring Mtn (450 kW)			Ronzone (675 kW)			Total (2675 kW)		
1-minute												
	Stdev	Max (+)	Max (−)	Stdev	Max (+)	Max (−)	Stdev	Max (+)	Max (−)	Stdev	Max (+)	Max (−)
2007	1.8%	42%	38%	4.3%	76%	83%	4.0%	72%	87%	1.7%	27%	24%
2008	2.0%	46%	45%	4.4%	75%	77%	4.2%	73%	89%	1.7%	32%	35%
2009	2.1%	47%	40%	4.7%	79%	72%	4.5%	77%	78%	1.9%	32%	28%
10-minute												
2007	3.2%	29%	33%	8.7%	79%	84%	8.3%	77%	70%	4.9%	31%	38%
2008	3.6%	35%	36%	8.2%	85%	77%	8.3%	81%	78%	5.0%	46%	42%
2009	3.5%	35%	39%	8.3%	76%	73%	8.5%	71%	69%	5.4%	41%	37%
1-hour												
2007	8.4%	34%	30%	20.0%	75%	76%	21.2%	76%	79%	16.8%	46%	54%
2008	8.7%	35%	35%	20.6%	89%	70%	20.8%	71%	74%	16.9%	50%	62%
2009	8.9%	34%	38%	21.4%	64%	82%	22.3%	62%	74%	17.9%	54%	51%

- Outputs from single-axis PV appears to be more variable than fixed-tilt PV. It's not clear this is true in other areas.
- No clear conclusion about PV and wind variability can be drawn because the size differences between PV and wind (more PV data needed)

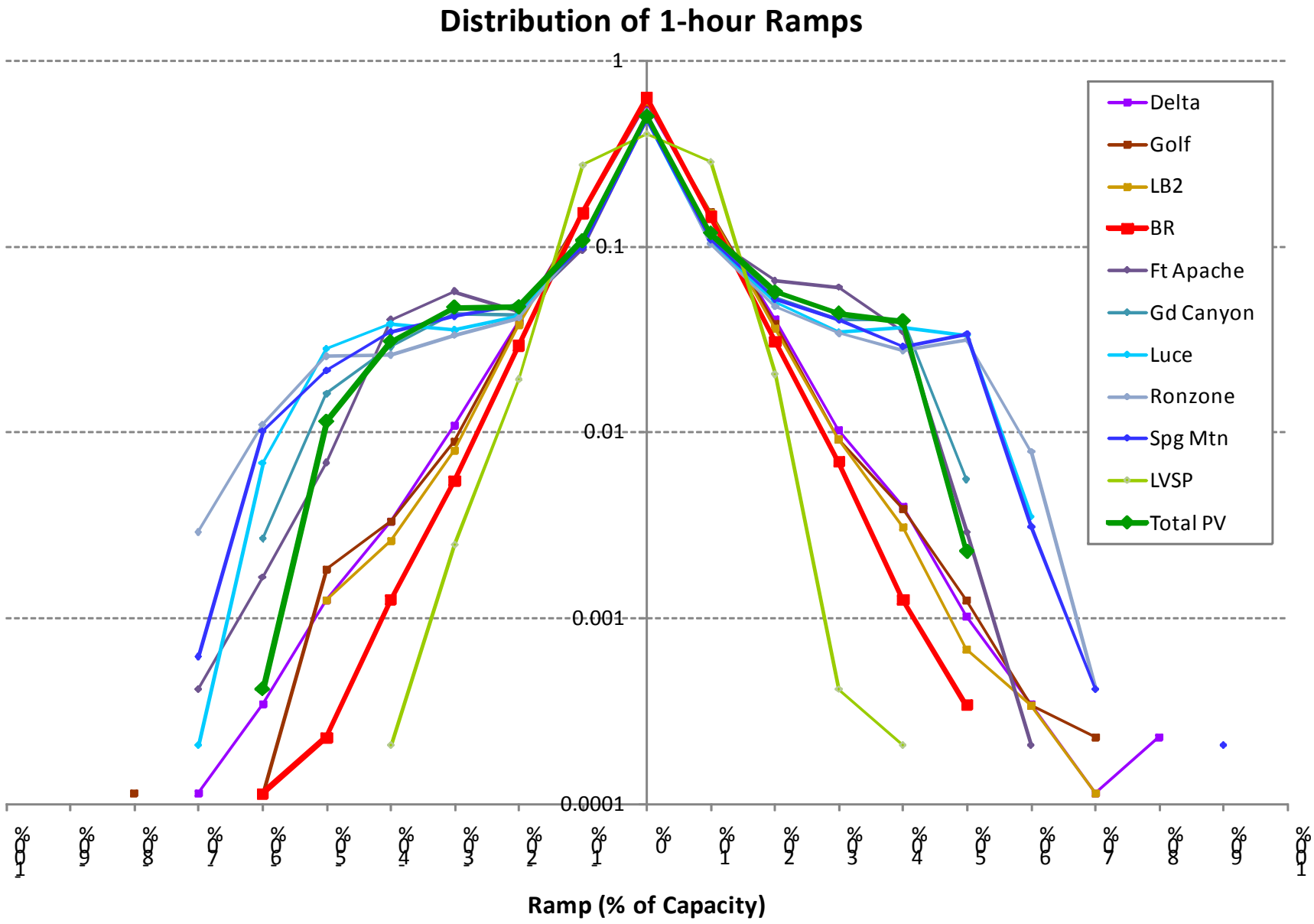
1-minute Ramp Distribution of PV and Wind



10-minute Ramp Distribution of PV and Wind



1-hour Ramp Distribution of PV and Wind



Correlation among Plants

- Correlation between adjacent PV facilities is higher than further away PV facilities (avg. 0.93 vs 0.78)
- PV facilities have slightly higher correlation coefficients than adjacent wind plants (avg. 0.84)
- Further analysis will look into 1-second PV time series

Summary

- PV have relatively large up ramp in the morning and down ramps in the afternoon, but their magnitudes is bounded by clear sky values.
- Even for relatively short distance and small installations, PV facilities still benefit from spatial diversity.
- More high resolution data from larger PV installations are needed to have a better understanding of the variability issue.