Statistical Analysis

Part II – Hourly variability and Day-ahead predictability

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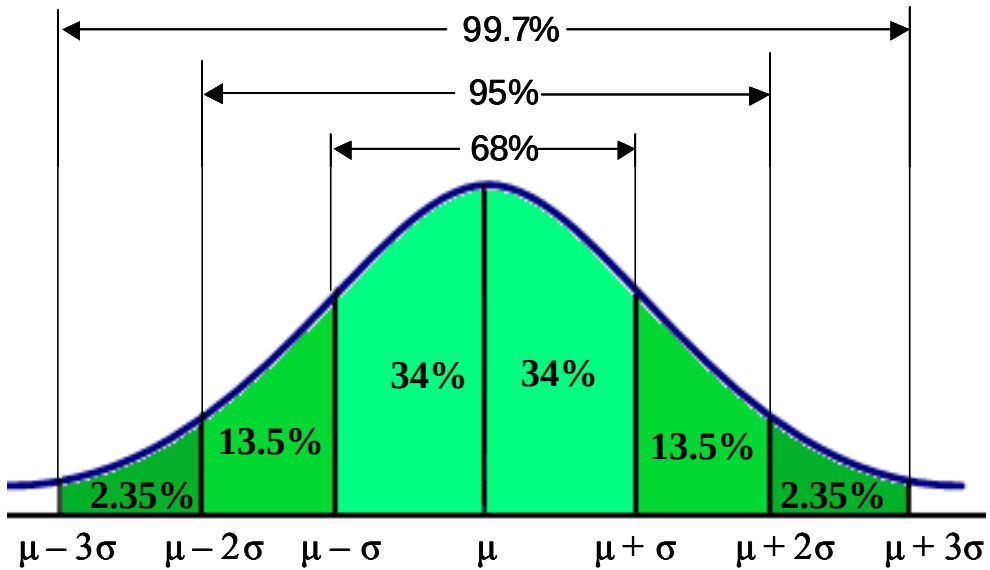
Hour-to-Hour Variability

Variability Analysis - Deltas

Statistics used to characterize variability:

- Delta (Δ) – The difference between successive data points in a series, or period-to-period ramp rate.
  - Positive delta is a rise or up-ramp
  - Negative delta is a drop or down-ramp
- Mean (μ) – The average of the deltas (typically zero within a diurnal cycle)
- Sigma (σ) – The standard deviation of the deltas; measures spread about the mean

For a normal distribution of deltas, σ is related to the percentage of deltas within a certain distance of the mean



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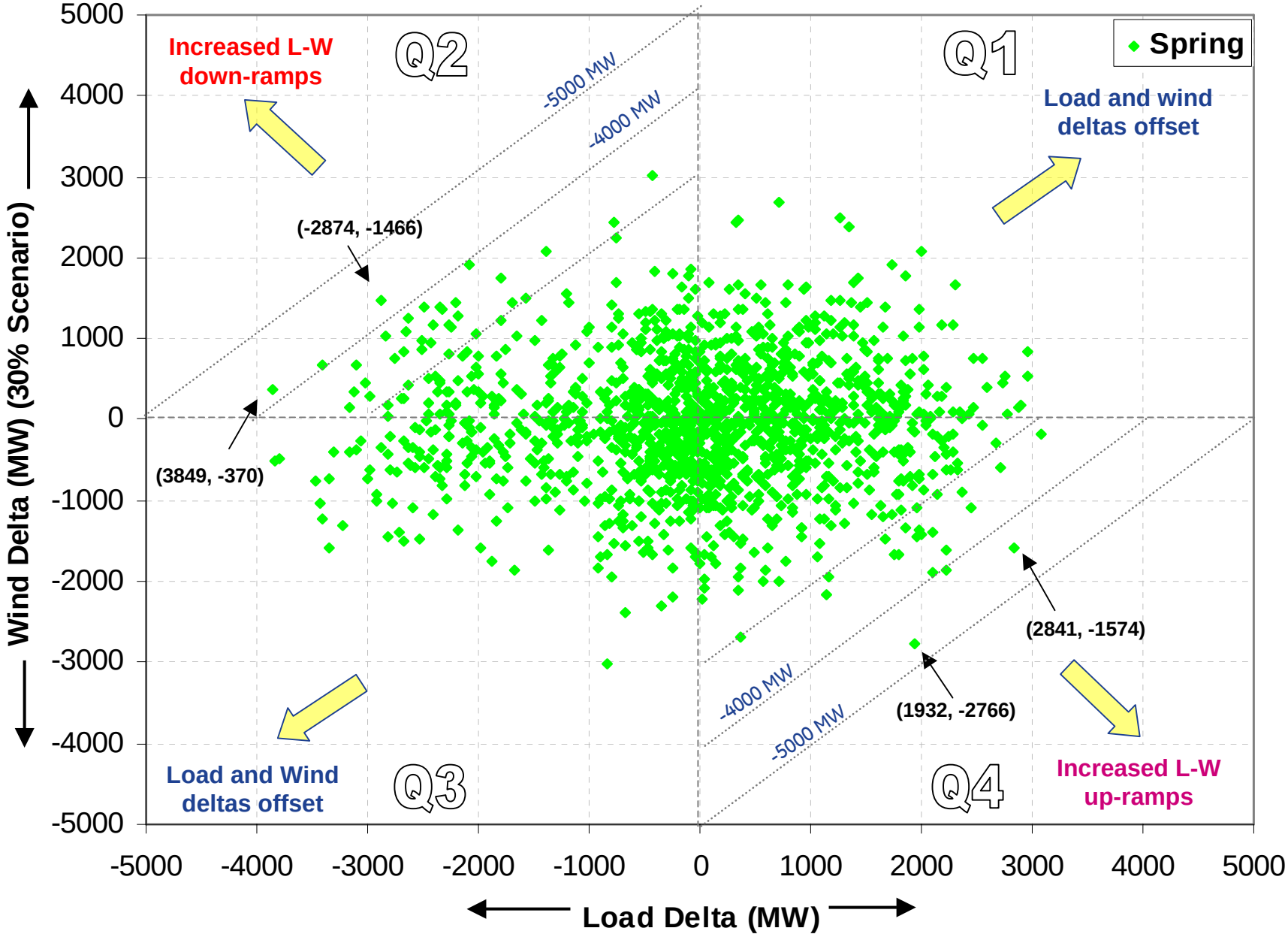
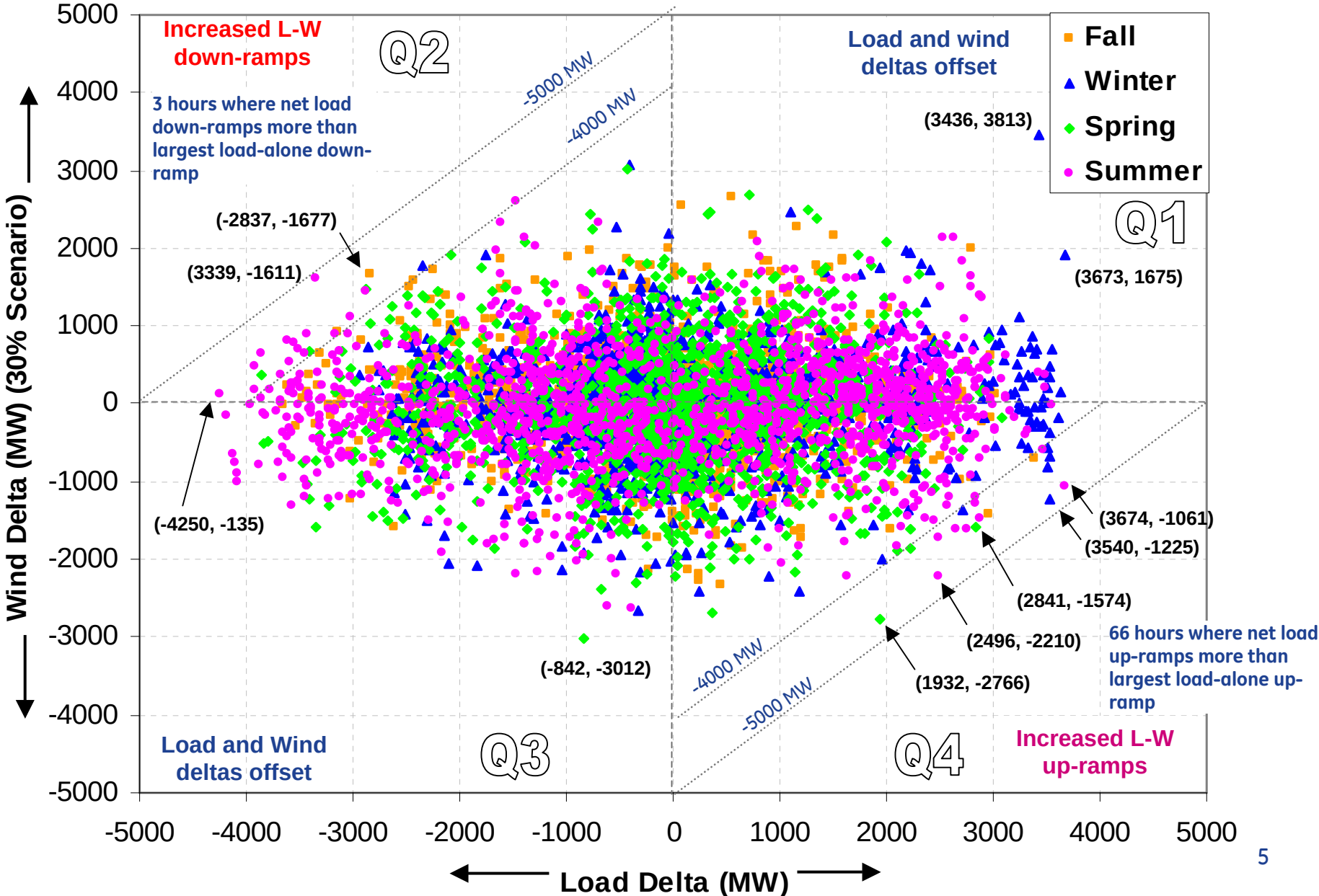
Study Footprint Wind Deltas vs. Load Deltas for Spring 2006

(30% Wind Energy in Footprint – LP Scenario)



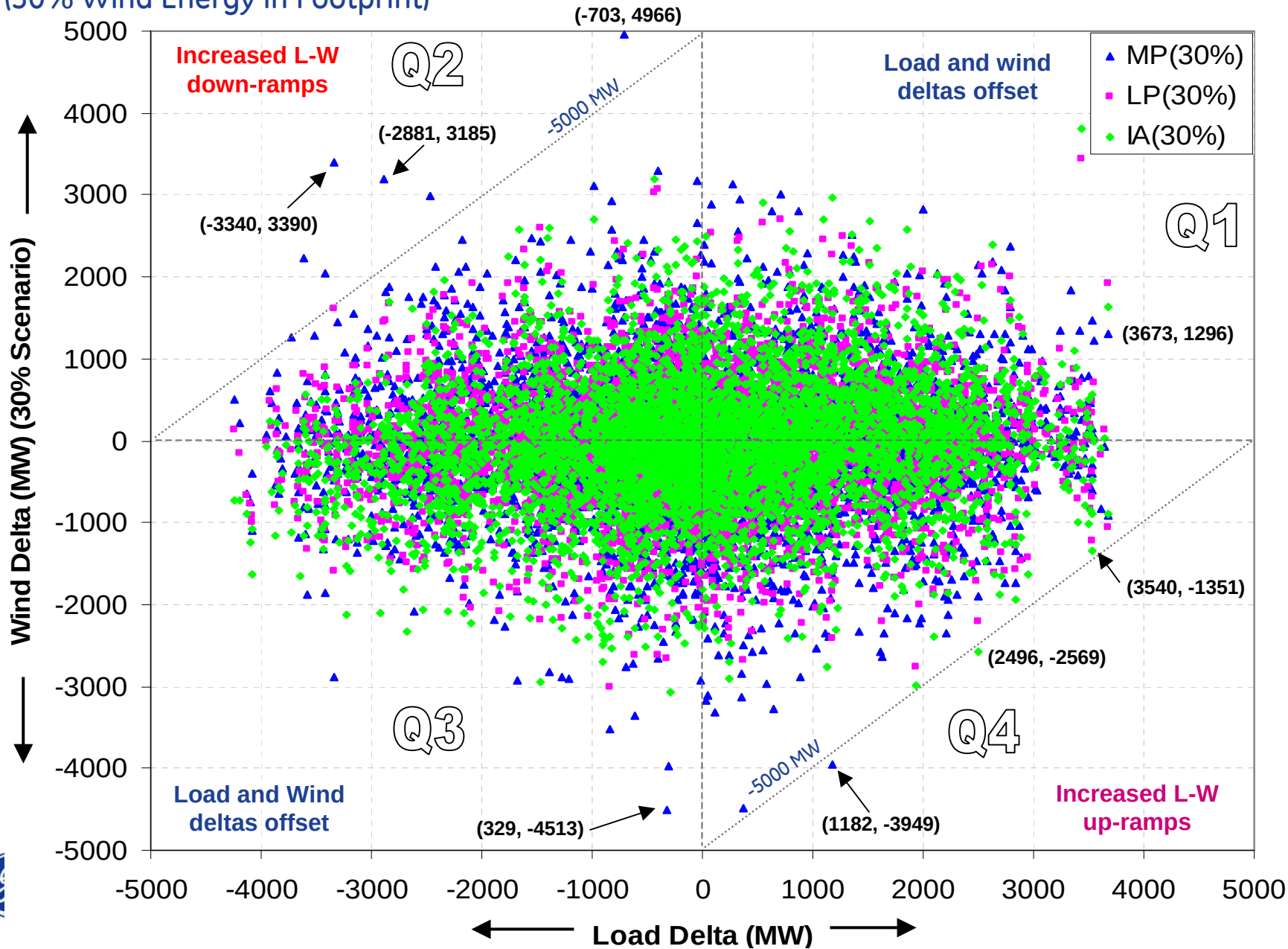
Study Footprint Wind Deltas vs Load Deltas by season for 2006

(30% Wind Energy in Footprint – LP Scenario)



Study Footprint Wind Deltas vs Load Deltas by Scenario for 2006

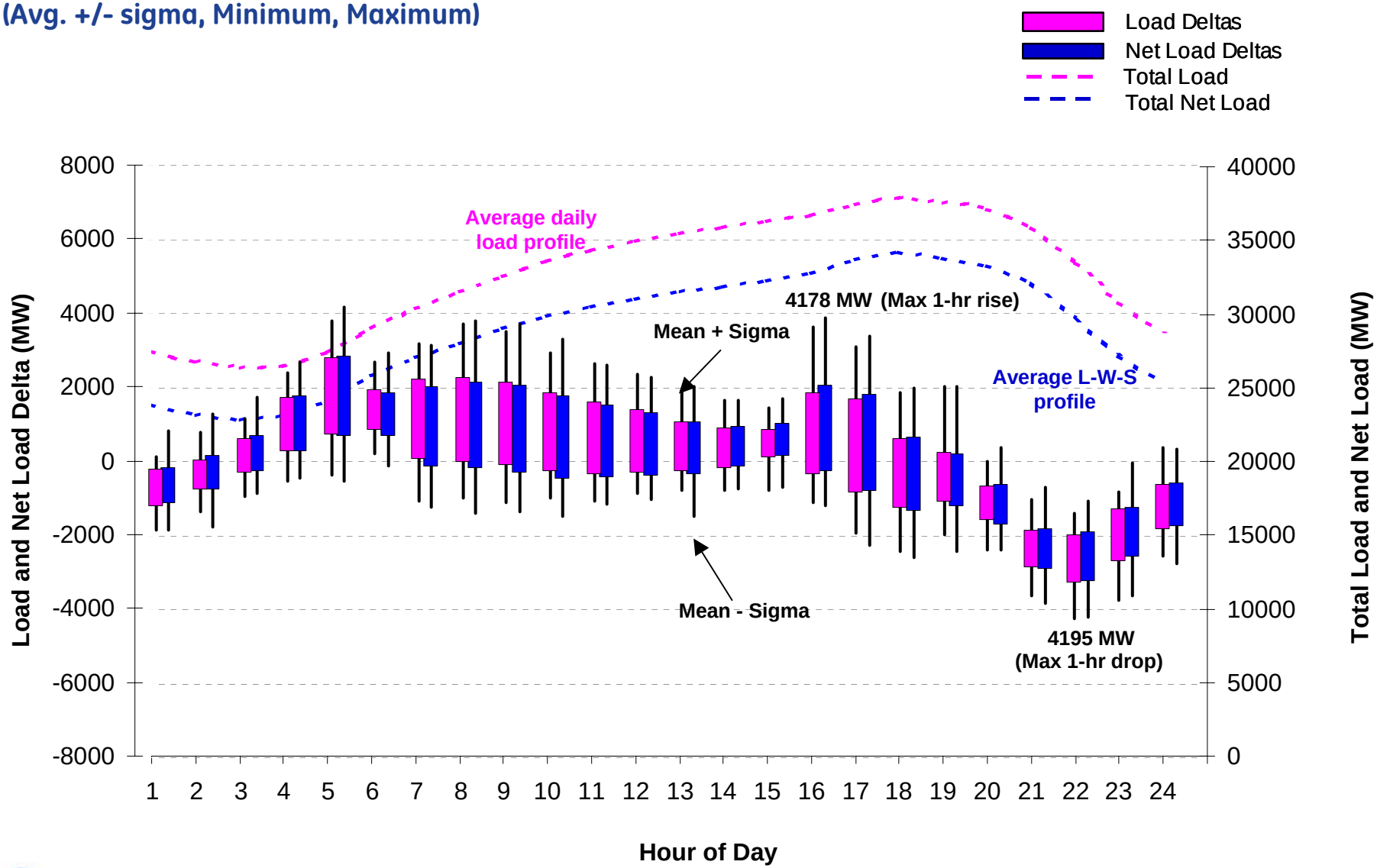
(30% Wind Energy in Footprint)



Study Footprint Average Daily Profile of Deltas Over Year 2006

(**10%** Wind Energy in Footprint – **LP Scenario**)

(Avg. +/- sigma, Minimum, Maximum)



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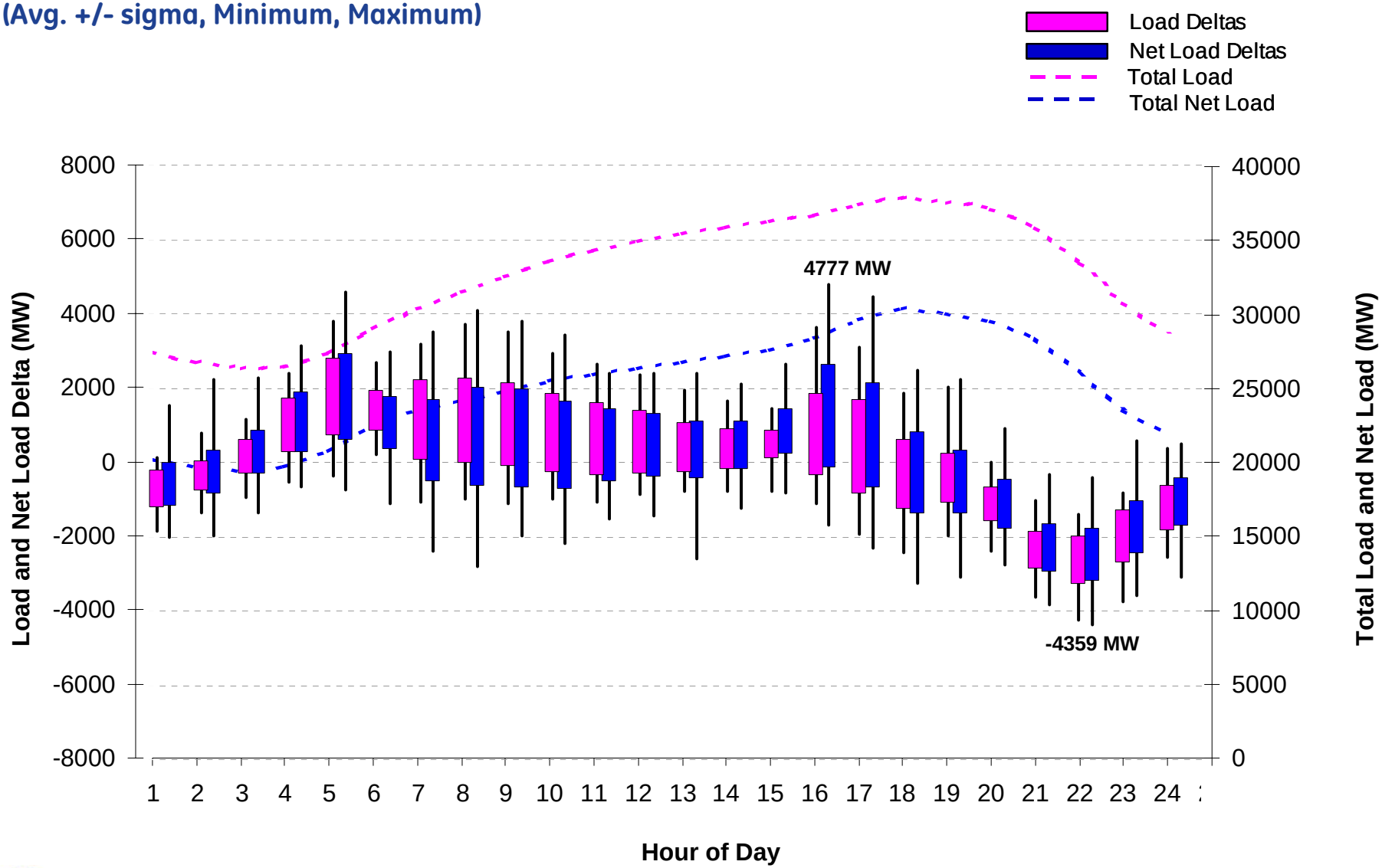
Study Footprint Average Daily Profile of Deltas Over Year 2006

(20% Wind Energy in Footprint – LP Scenario)

(Avg. +/- sigma, Minimum, Maximum)



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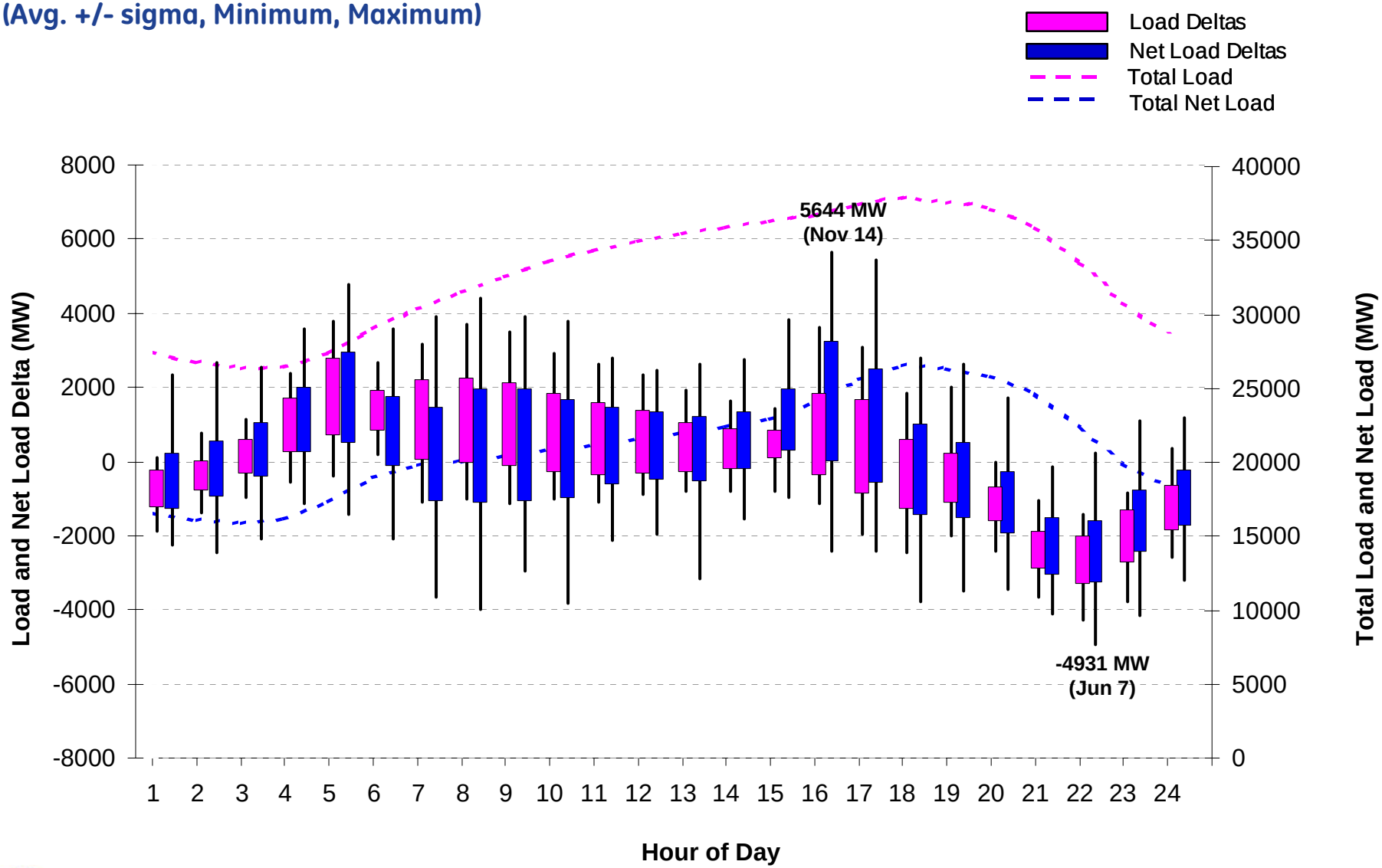
Study Footprint Average Daily Profile of Deltas Over Year 2006

(**30%** Wind Energy in Footprint – **LP Scenario**)

(Avg. +/- sigma, Minimum, Maximum)



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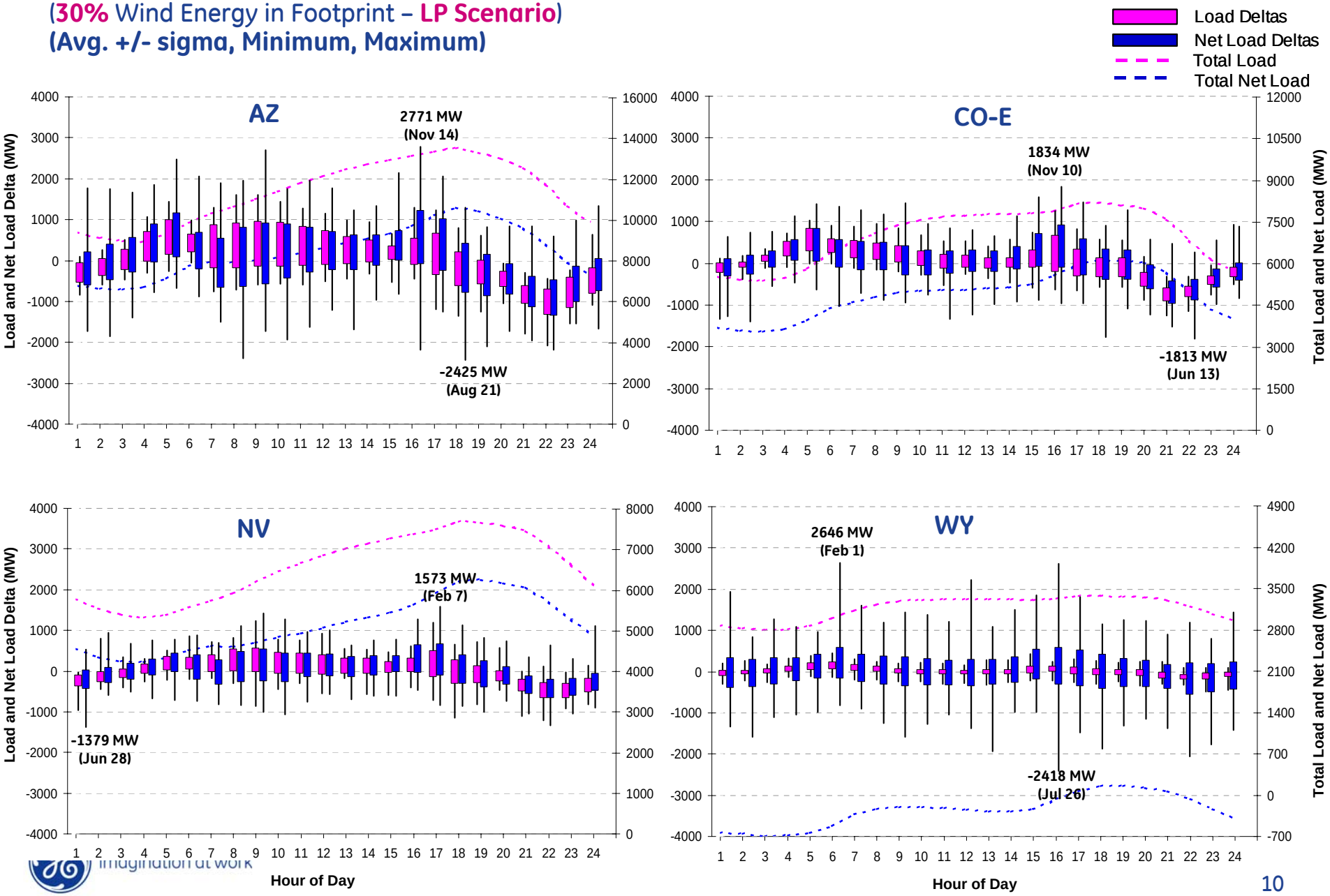
Average Daily Profile of Deltas Over 2006 for Selected Areas

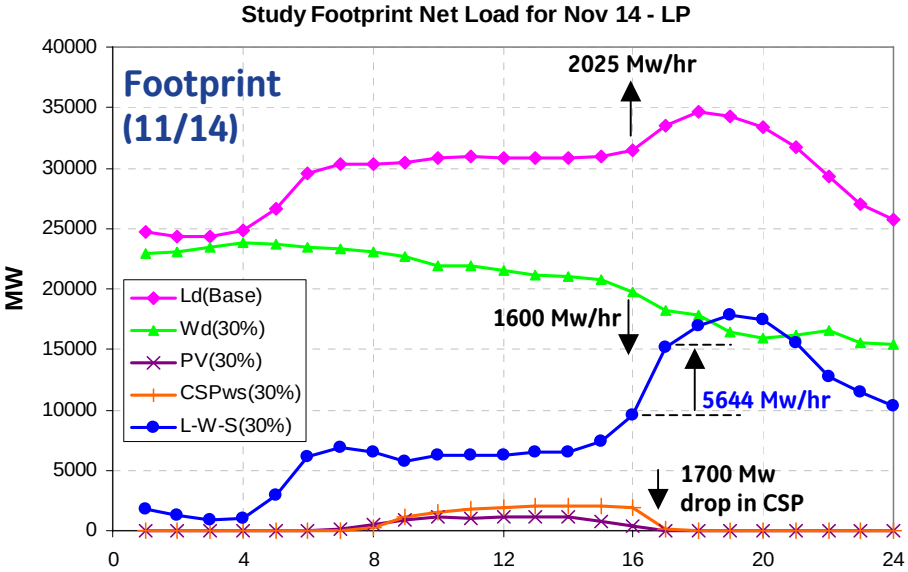
(**30%** Wind Energy in Footprint – **LP Scenario**)

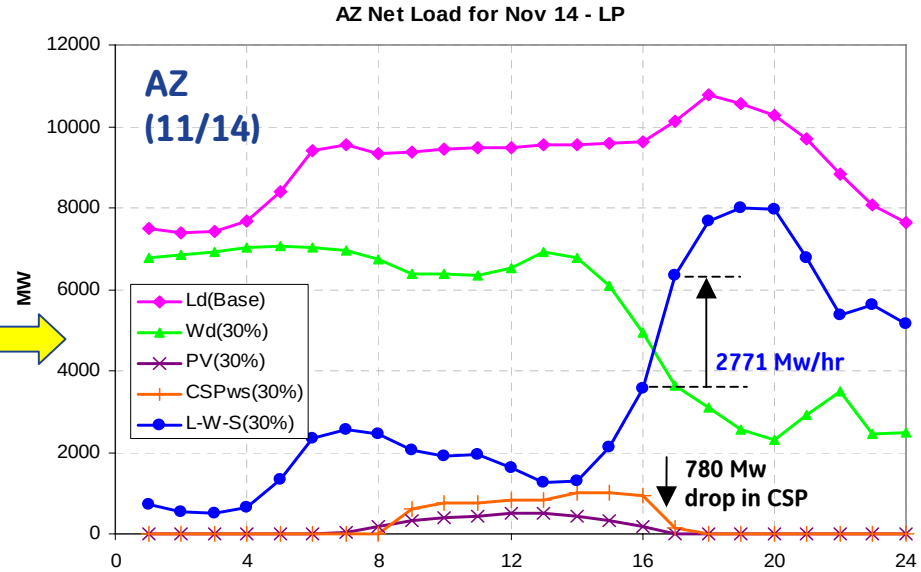
(Avg. +/- sigma, Minimum, Maximum)

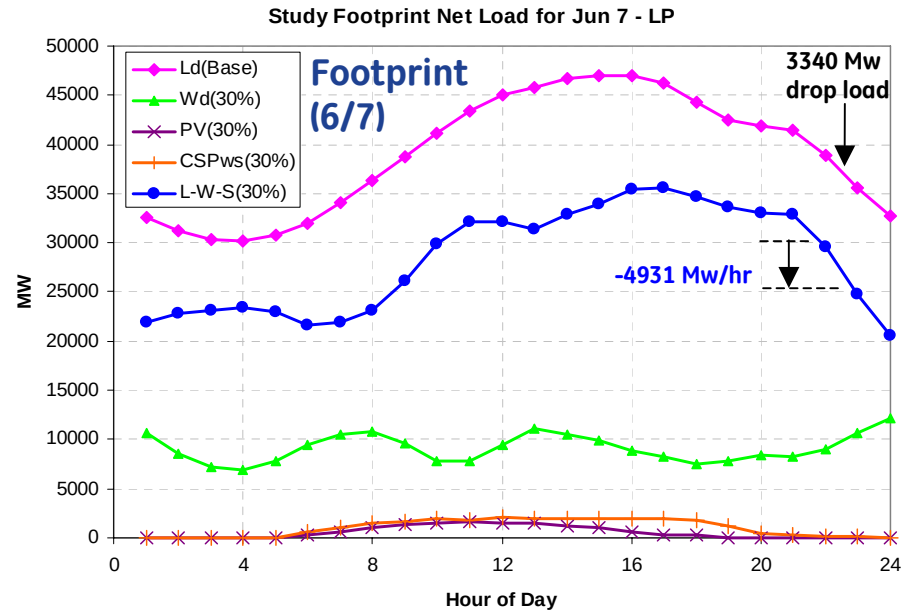


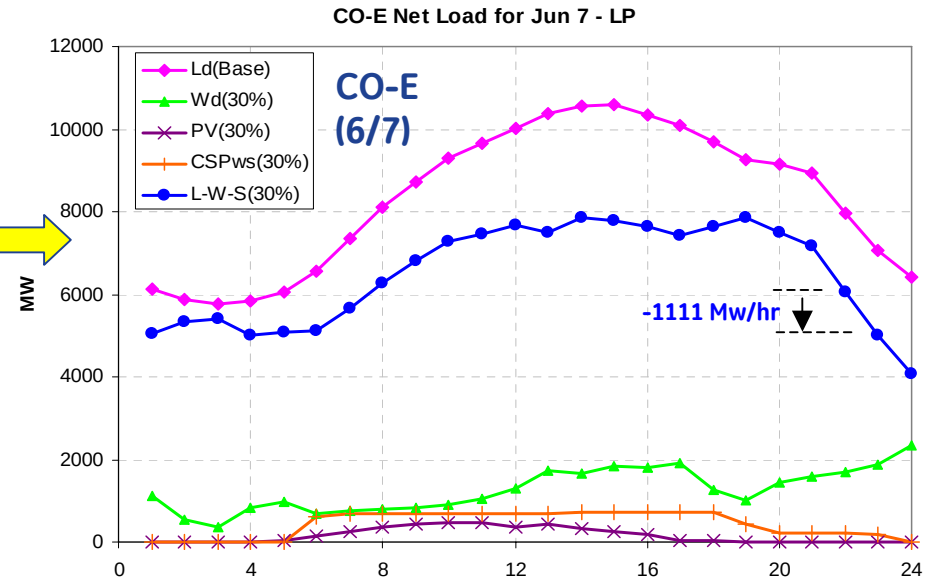
Selected Days with Extreme 1-Hour Up-Ramps and Down-Ramps

(30% Wind Energy in Footprint – LP Scenario)



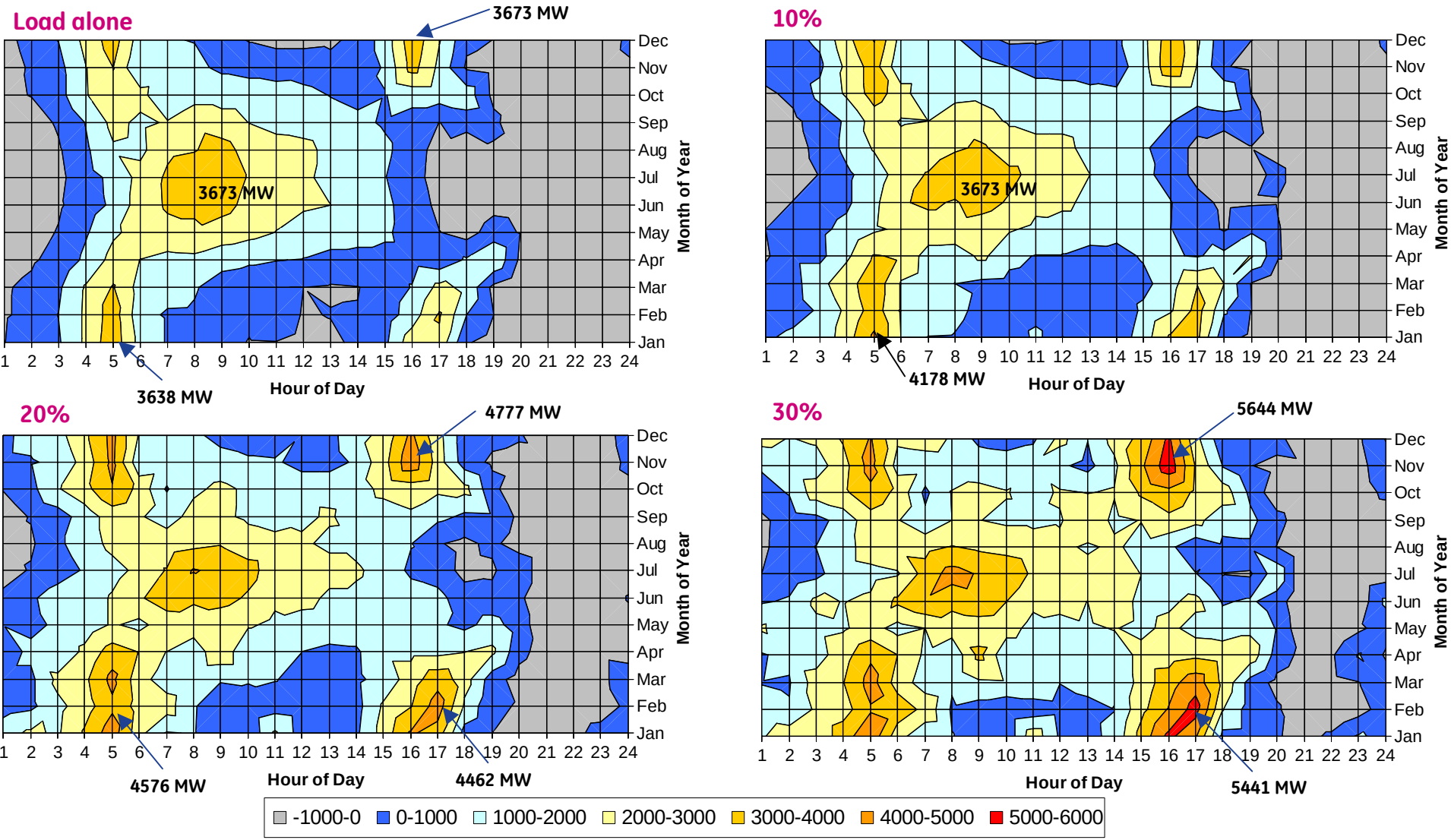






Study Footprint - Timing of Extreme Net Load Up-Ramps

(Local Priority Scenario)



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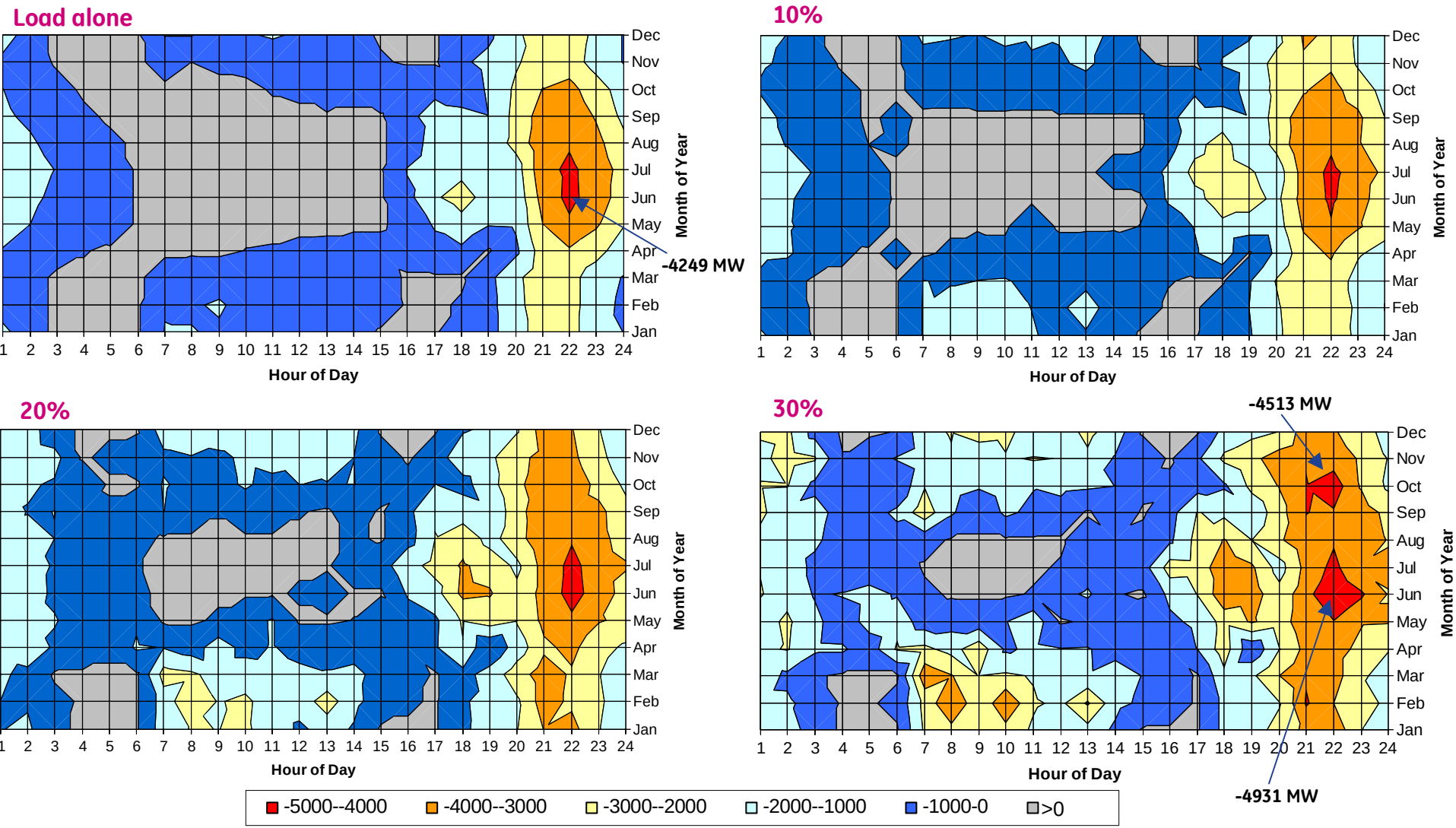
Wind/solar drops drive extreme up-ramps in late afternoons during late fall and winter

Study Footprint - Timing of Extreme Net Load Down-Ramps

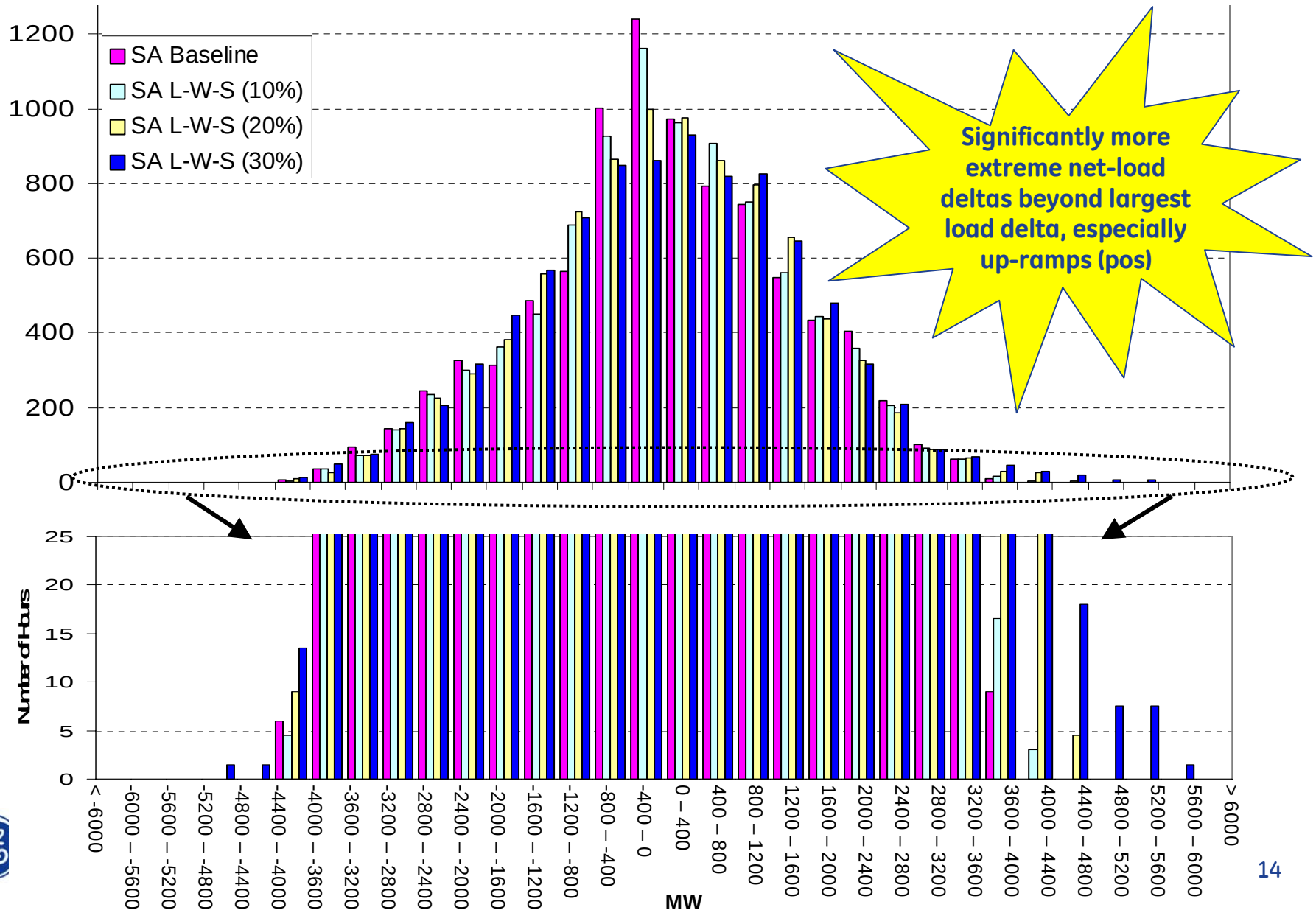
(Local Priority Scenario)



Extreme down-ramps driven by summer/early fall evening load roll-off

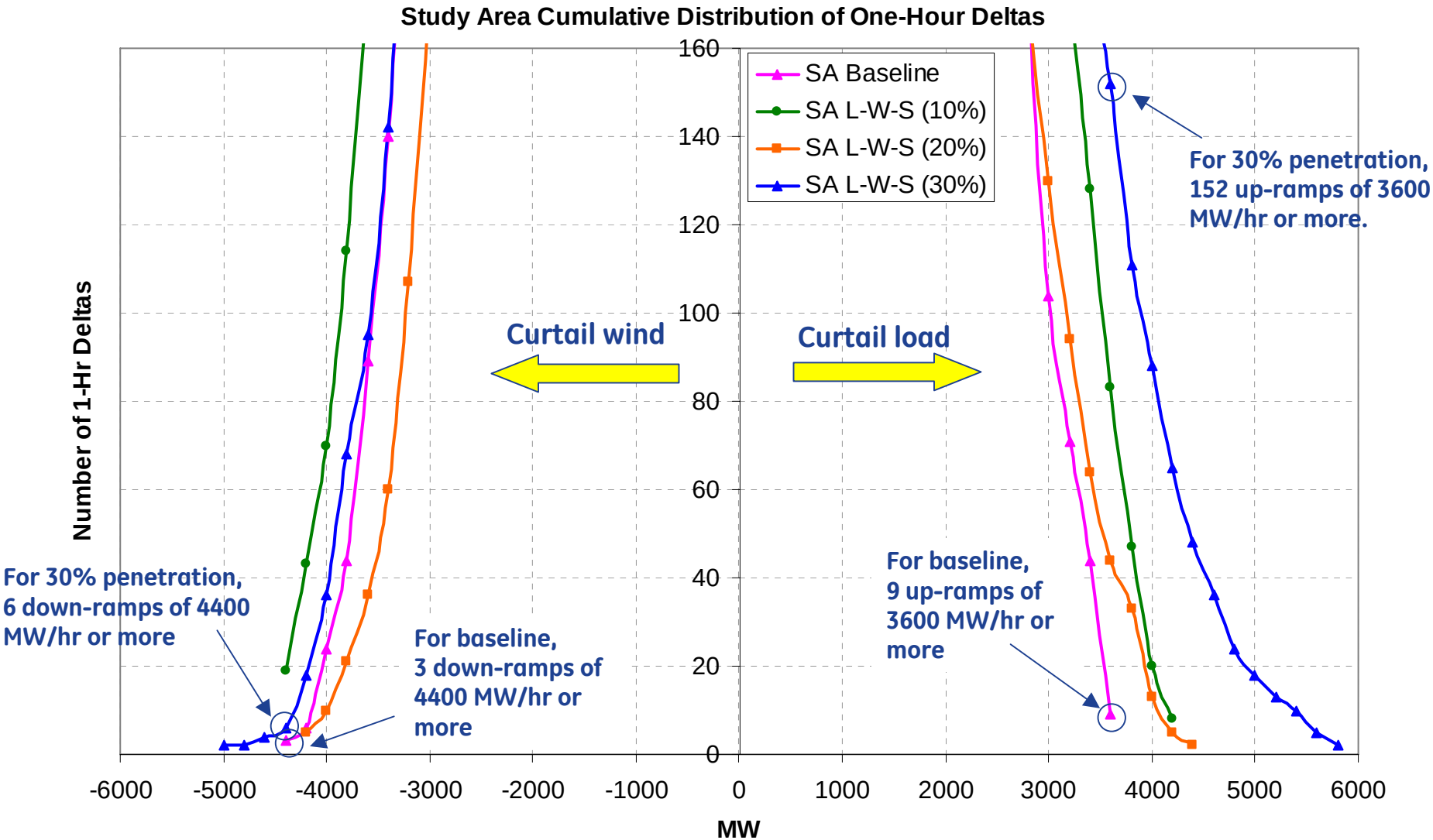
Study Footprint Distribution of Net Load Deltas

(**30%** Wind Energy in Footprint – **LP Scenario**)



Distribution of Extreme Hourly Net Load Deltas 2006

(Local Priority Scenario)



There is a case to be made for load participation

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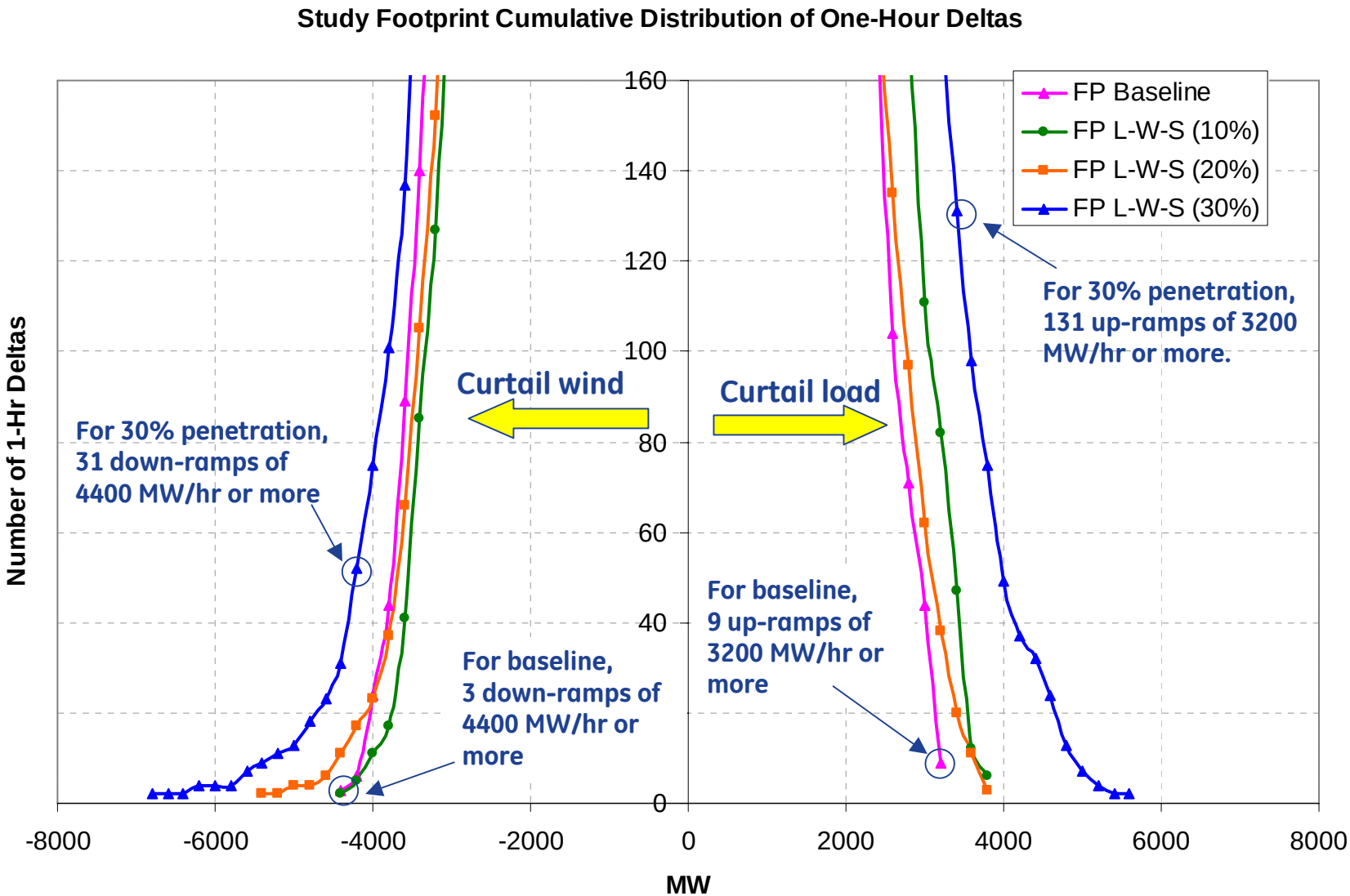
Distribution of Extreme Hourly Net Load Deltas 2006

(Mega project Scenario)



More and larger extreme down-ramps with concentration of wind in WY

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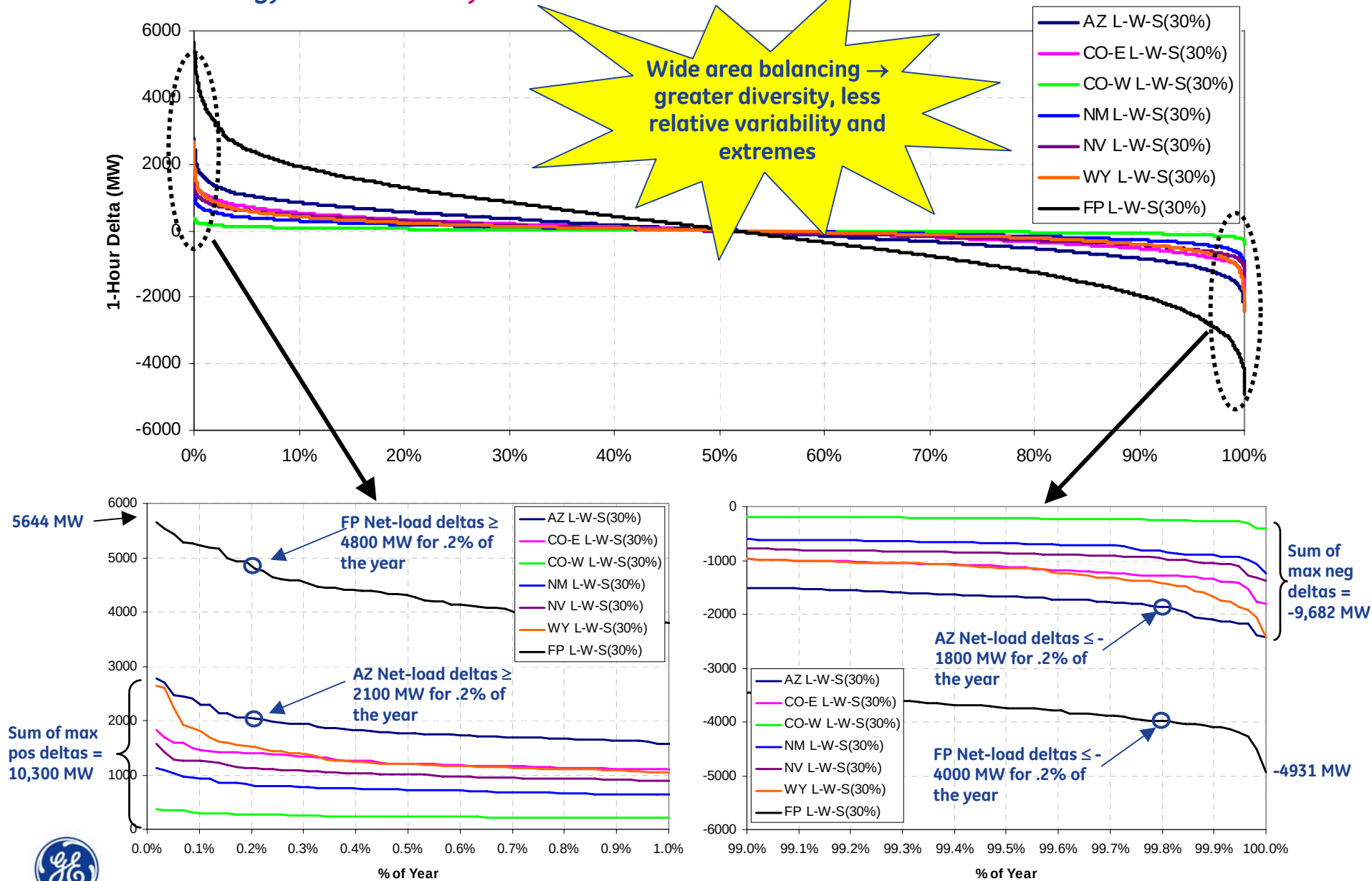
Duration of Extreme Hourly Net Load Deltas 2006

30% Wind Energy - Local Priority Scenario



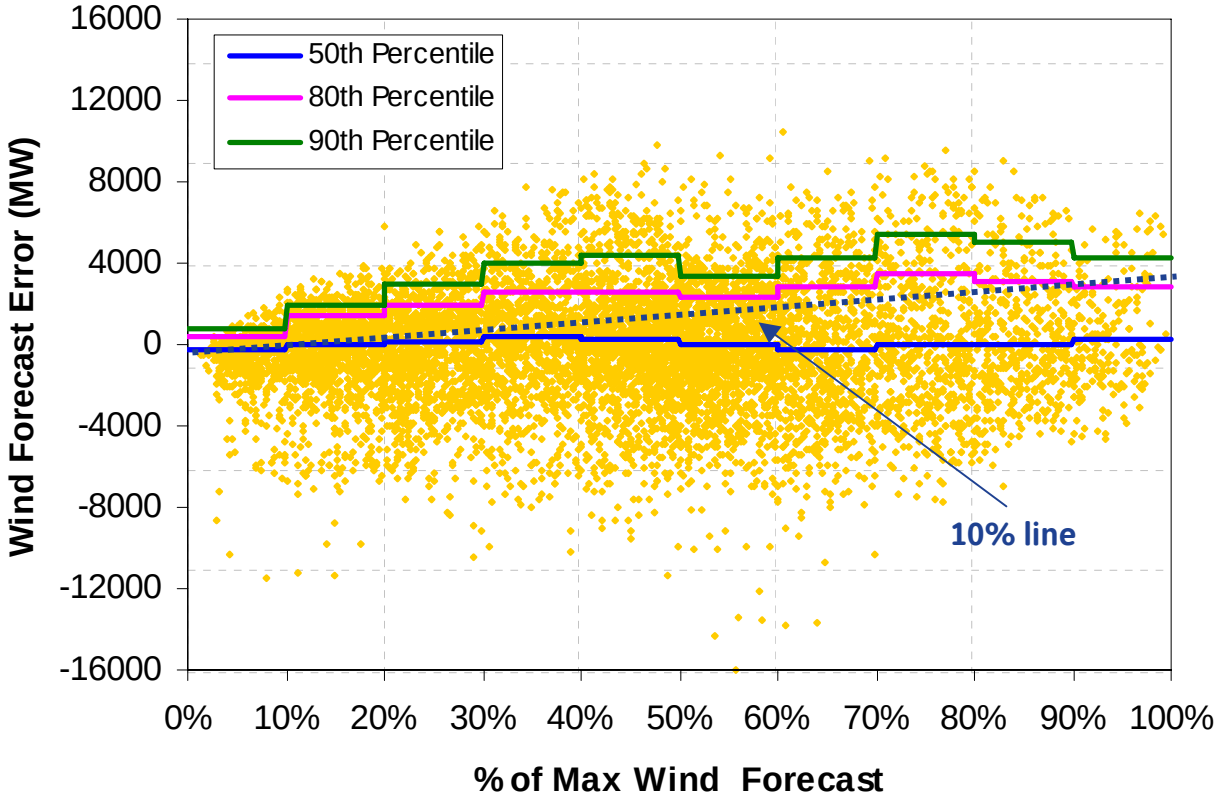
Summary Statistics

Area:	Ariz			CO-E			CO-W			NM			NV			WYCE			In Foot Print			WECC		
Scenario	**IA**	**LP**	**MP**	**IA**	**LP**	**MP**	**IA**	**LP**	**MP**	**IA**	**LP**	**MP**	**IA**	**LP**	**MP**	**IA**	**LP**	**MP**	**IA**	**LP**	**MP**	**IA**	**LP**	**MP**
Sigma (MW)																								
Load-alone	584	584	584	368	367	367	37	37	37	152	152	152	312	312	312	87	87	87	1433	1433	1433	4387	4384	4384
Baseline (Existing)	583	583	583	375	374	374	37	37	37	158	158	158	311	311	311	101	101	101	1429	1429	1429	4392	4392	4392
10% In FP Scenario	591	587	573	376	377	376	44	41	38	162	170	192	311	315	311	101	118	188	1401	1414	1426	4229	4240	4248
20% In FP Scenario	647	613	587	399	401	379	64	57	38	194	203	228	333	331	313	124	212	434	1417	1437	1480	4190	4209	4230
30% In FP Scenario	719	657	616	453	427	380	86	73	40	230	240	288	370	352	317	164	366	658	1491	1523	1594	4137	4153	4182
	Ariz			CO-E			CO-W			NM			NV			WYCE			In Foot Print			WECC		
Max Neg Delta (MW)	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP
Load-alone	-2088	-2088	-2088	-1340	-1340	-1340	-120	-120	-120	-515	-515	-515	-1201	-1201	-1201	-316	-316	-316	-4250	-4250	-4250	-13448	-13435	-13435
Baseline (Existing)	-2087	-2087	-2087	-1337	-1337	-1337	-120	-120	-120	-522	-522	-522	-1201	-1201	-1201	-529	-492	-492	-4282	-4282	-4282	-13385	-13385	-13385
10% In FP Scenario	-2184	-1886	-1941	-1321	-1317	-1323	-199	-151	-128	-514	-571	-874	-1660	-1342	-1156	-508	-547	-1359	-4053	-4195	-4434	-12724	-12861	-13157
20% In FP Scenario	-2492	-2115	-1867	-1624	-1627	-1306	-312	-255	-135	-869	-982	-1186	-1252	-1368	-1260	-650	-1412	-3204	-4168	-4359	-5511	-12401	-12396	-12840
30% In FP Scenario	-3043	-2425	-2354	-1913	-1813	-1298	-460	-404	-135	-1146	-1242	-1427	-1407	-1379	-1327	-1086	-2418	-4798	-4534	-4931	-6729	-12274	-12532	-12552
	Ariz			CO-E			CO-W			NM			NV			WYCE			In Foot Print			WECC		
Max Pos Delta (MW)	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP
Load-alone	1601	1601	1601	1172	1172	1172	130	130	130	636	636	636	1234	1234	1234	505	505	505	3674	3674	3674	10722	10715	10715
Baseline (Existing)	1600	1600	1600	1692	1257	1257	130	130	130	605	605	605	1229	1229	1229	435	435	435	3793	3793	3793	10896	10896	10896
10% In FP Scenario	1858	1852	1642	1479	1280	1266	202	157	131	616	626	887	1185	1170	1200	429	539	1290	4178	4178	3898	10967	10959	10983
20% In FP Scenario	2732	2295	2165	1416	1445	1281	351	281	131	875	957	1120	1492	1394	1176	506	1537	3085	4853	4777	4499	11676	11366	12202
30% In FP Scenario	3483	2771	2564	2097	1834	1364	512	373	152	1047	1129	1355	1711	1573	1383	809	2646	4487	5820	5644	5864	15271	14383	14318
	Ariz			CO-E			CO-W			NM			NV			WYCE			In Foot Print			WECC		
No. Drops > 3* Ld Sigma	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP
Load-alone	2	2	2	4	4	4	10	10	10	5	5	5	6	6	6	5	5	5	0	0	0	0	0	1
Baseline (Existing)	2	2	2	5	5	5	10	10	10	5	5	5	6	6	6	39	38	38	0	0	0	0	0	1
10% In FP Scenario	3	2	1	11	13	13	38	24	10	15	27	73	8	8	6	35	98	367	0	0	1	0	0	0
20% In FP Scenario	23	7	3	24	25	14	218	133	11	72	90	143	17	12	6	112	469	1164	0	1	9	0	0	0
30% In FP Scenario	52	20	13	45	31	13	485	310	11	144	176	300	34	16	6	278	1009	1492	2	3	15	4	3	0
	Ariz			CO-E			CO-W			NM			NV			WYCE			In Foot Print			WECC		
No. Rises > 3* Ld Sigma	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP
Load-alone	0	0	0	4	4	4	8	8	8	12	11	11	3	3	3	45	45	45	0	0	0	1	1	0
Baseline (Existing)	0	0	0	3	2	2	8	8	8	13	13	13	3	3	3	65	65	65	0	0	0	1	1	0
10% In FP Scenario	3	3	0	2	3	2	38	26	10	26	37	83	7	8	6	69	118	417	0	0	0	0	0	0
20% In FP Scenario	30	12	7	22	21	7	249	178	11	84	100	162	22	22	7	140	530	1198	10	2	5	0	0	0
30% In FP Scenario	63	32	32	81	56	12	491	340	35	168	187	328	67	43	10	326	1061	1555	29	28	26	0	0	3

Day-Ahead Predictability

Study Footprint Next Day Wind Forecast Errors vs. Forecast

30% Wind Energy - Local Priority Scenario



Forecast error is not a linear function of the wind forecast

Discounting forecast to increase spin does not appear to be a good option

	30% Scenario				20% Scenario				10% Scenario			
% of Max MW	Freq	50th	80th	90th	Freq	50th	80th	90th	Freq	50th	80th	90th
10%	531	-310	449	787	554	-190	303	558	588	-94	163	306
20%	1113	-43	1359	1969	1108	-62	879	1299	1126	-32	459	676
30%	1054	183	1989	2945	1084	13	1291	1960	1190	18	669	1014
40%	967	376	2640	3941	1035	233	1782	2778	1441	14	771	1273
50%	1448	236	2526	4388	1584	81	1616	2898	1511	-32	790	1342
60%	1474	-60	2311	3319	1329	-3	1648	2438	1145	-39	1069	1539
70%	879	-284	2839	4251	830	-67	2052	3130	752	-46	1072	1794
80%	606	-50	3453	5417	617	-109	2228	4040	584	14	1261	1822
90%	466	-46	3131	5037	432	-19	2040	3297	331	109	968	1515
100%	222	209	2840	4270	187	371	2283	3280	92	40	915	1579

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Key Take-Aways

- Significant monthly/seasonal variation of wind and solar energy within footprint and across areas
- Relatively small observable difference among scenarios, but more pronounced at area level
- Load coincidence with wind and solar a large driver of diurnal variability
- At footprint and area level, net load variability tends to be high during fall/winter late afternoons due to simultaneous load rise, and wind/solar roll-off
- Extreme net load down-ramps in summer/early fall driven by evening load roll-off
- There is a good case to be made for load participation in reducing ramping requirements
- Wide area balancing → greater diversity, less relative variability and extreme ramps
- Forecast error is not a linear function of the wind forecast → discounting forecast to increase spin may not to be a good option